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Sharon A. Clay
South Dakota State University, sharon.clay@sdstate.edu

William C. Koskinen
USDA, Agricultural Research Service

Paul Carlson
USDA, Agricultural Research Service

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Alachlor Movement Through Intact Soil Columns Taken From Two Tillage Systems[1]

SHARON A. CLAY, WILLIAM C. KOSKINEN, and PAUL CARLSON[2]

Abstract. Intact soil columns were evaluated as a screening technique to determine the effect of tillage on herbicide movement through soil. Alachlor was applied at 3.3 kg ai ha^{-1} to intact surface 0- to 10-cm and subsurface 10- to 20-cm soil columns (15-cm diam) taken from long-term no-till and conventional tillage plots and leached with 11.6 pore volumes (7 L; 39 cm) of water at a rate that did not create ponding. Leachate was collected in 0.07 pore volume fractions. Twice as much alachlor leached from surface no-till than from surface conventional tillage columns. The differences in leaching patterns from the surface soil can be attributed to the effect of tillage on soil physical and chemical properties. Using intact soil columns in the laboratory can be a useful rapid screening technique to evaluate tillage impacts on herbicide movement. **Nomenclature:** Alachlor, 2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide.

Additional index words: Herbicide movement screening technique.

INTRODUCTION

Tillage management influences many soil factors including organic carbon distribution, soil pH, microbial populations, porosity, and water movement (9). A change in tillage management may change herbicide movement and distribution within and between soil series. For instance, in several field studies, greater herbicide movement was reported in no-till management systems compared with conventional tillage (7, 8). However, large scale field experiments to evaluate herbicide movement in various soil types treated with different tillage management practices are impractical due to cost and time involved.

As alternatives to field studies, different techniques have been used to characterize herbicide movement through soil. For example, column studies have been used to demonstrate pesticide movement and distribution in several soil types under various treatments. Often the columns are packed in the laboratory using field moist or air-dried sieved soil (3, 4, 5, 10, 11, 13, 15). Zins et al. (16) packed soil columns, grew alfalfa in the columns, and then determined the influence of alfalfa roots on movement of herbicide through soil. Dekkers and Barbera (5) and Gertsl and Yaron (6) showed that soil structure greatly influences herbicide movement. In contrast with packed columns, White et al. (14) used undisturbed soil columns taken from the field to study bromacil [5-bromo-6-methyl-3-U-methylpropyl)-2,4(1*H*,3*H*)pyrimidinedione] and napropamide [*N*,*N*-diethyl-2-(1-naphthalenyloxy)propanamide] movement under continuous and discontinuous watering regimes.

A need exists to develop a simple and reliable laboratory/greenhouse screening system that can rapidly and accurately determine the most promising pesticide management practices for reducing potential groundwater contamination. Once these management practices have been identified by the soil screening system, they can then be field-tested. The objective of this study was to evaluate the use of small (15 cm diam by 10 cm) intact field moist soil columns as a screening method to determine the influence of tillage practice on herbicide movement through soil.

MATERIALS AND METHODS

Field. Intact soil columns were removed in early June from conventional tillage (fall moldboard plowed to a depth of 15 cm) and no-till plots (8 yr of continuous no-till management) located at the University of Minnesota Rosemont Agricultural Experiment Station just before herbicides were to be applied. The soil was a Waukegan silt loam (fine-silty over sandy or sandy-skeletal, mixed, mesic Typic Hapludoll). Soil properties are listed in Table 1. Field bulk densities of both tillage treatments were approximately 1.17 in the 0- to 10-cm depth and 1.25 in the 10- to 20-cm depth.

Cores were obtained by pushing a 15 cm (inside diam) by 15 cm (depth) PVC pipe (0.8 cm wall thick-

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[2] Asst. Prof., Plant Sci. Dep., S. Dak. State Univ., Brookings, SD 57006 and Soil Sci. and Res. Asst. Trainee, Soil and Water Res. Unit, USDA-Agric. Res. Serv., St. Paul, MN 55108.

Table 1. Soil pH and organic carbon content by depth of a Waukegan silt loam managed with no-till and conventional tillage techniques.

Depth	pH[a] No-till	pH[a] Conventional	Organic carbon[b] No-till	Organic carbon[b] Conventional
cm			%	
0– 2.5	5.1	5.7	10.1	2.9
2.5– 5.0	4.3	5.3	4.4	3.1
5.0– 7.5	4.5	6.0	2.9	2.5
7.5–10.0	5.5	6.0	2.9	2.7
10.0–12.5	6.1	5.1	2.9	2.9
12.5–15.0	6.4	5.3	3.0	2.9
15.0–17.5	6.4	5.6	3.0	2.8
17.5–20.0	6.4	5.9	3.5	2.8

[a] pH determined in soil:0.01 M $CaCl_2$ (1:1 w/v).

[b] Organic matter determined by combustion.

ness) with a beveled edge into the soil and removing an intact soil column from the 0- to 10-cm depth. Corn residue remained on the soil surface of the no-till columns. A similar column was obtained from the 10- to 20-cm soil depth. Bulk densities of the cores were similar to the field bulk density. Each sample was duplicated. Soil columns were stored at 4 C until the leaching experiments were conducted. Bulk soil samples were also taken from the plots in 5-cm increments to a depth of 20 cm for adsorption-desorption studies.

Leaching study. Each field moist soil column in the polyvinyl chloride (PVC)[3] pipe was placed into a 15-cm PVC cap that contained a small water outlet and 2.5 kg of acid-washed sand as a physical support for the soil column. A 10-ml water aliquot containing 12.5 µmol Br ml^{-1}, and a 1-ml aliquot containing 0.22 µmol (equivalent of 3.3 kg ai ha^{-1}) of alachlor were added dropwise to the soil surface in the center 8 cm. The alachlor solution contained 12.95 kBq of uniformly-ring labeled ^{14}C-alachlor. The final specific activity of the alachlor solution was 50 kBq μmol^{-1}. Preliminary studies indicated that alachlor did not adsorb to the PVC pipe (authors unpublished data).

Twenty-four hours after chemical application, a 0.1 cm layer of glass wool was placed on the soil surface and water was applied dropwise over the soil surface at an approximate rate of 0.5 cm h^{-1} (90 ml h^{-1}). Water did not pond on the soil surface at this application rate. Each column was leached with 11.6 pore volumes (7 L; 39 cm) of water. The pore volume of each column was approximately 600 ml. Leachate from the columns was collected for 4 d in approximately 0.07 pore volumes (40-ml) fractions using a fraction collector. The leachate was refrigerated at 5 C until analyzed.

Leachate fractions were analyzed for bromide using a bromide specific ion electrode. Radiolabeled alachlor in each fraction was determined by adding a 1-ml aliquot of leachate to liquid scintillation cocktail and quantifying the radioactivity by liquid scintillation counting (LSC)[3] techniques. The total amount of alachlor in each fraction was calculated from the specific activity.

Five 2.5-cm diam soil cores were removed from each soil column from the area of alachlor application after leaching. Two soil cores were also removed outside the application area. The soil cores were divided into 2.5-cm depth increments and frozen until analyzed. The amount of radiolabeled alachlor in each increment was quantified by combustion to $^{14}CO_2$. Approximately 0.5 g of moist soil was mixed with an equal volume of cellulose and burned in a Packard 306 oxidizer[4]. The evolved $^{14}CO_2$ was trapped in Carbosorb[4] and collected in a liquid scintillation vial. Permafluor V[4] was then added and the radioactivity determined by LSC techniques. Percent moisture (air-dry basis) was determined on a soil subsample of each increment.

Adsorption-desorption isotherms. Adsorption and desorption isotherms of alachlor were determined on soil for each tillage management by 5-cm depth increment using the batch equilibration technique described by Clay and Koskinen (2). Desorption studies were conducted on soil used initially in the adsorption of alachlor to the soil from 0.01 M $CaCl_2$ solutions containing 13.7 µmol alachlor L^{-1}.

Statistical analysis. Pooled estimates of standard error were calculated for 1) cumulative amounts of alachlor in 3.3 and 11.6 pore volumes of leachate and 2) herbicide distribution by depth within and between tillage treatments calibrated from the average alachlor content of five cores taken within the application area after leaching. The 95% confidence intervals were calculated for paired t-tests using the pooled estimates of standard error.

Freundlich adsorption and desorption coefficients were calculated by least squares technique on the mean of replicates of the log-transformed equilibrium solu-

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[3] Abbreviations: LSC, liquid scintillation counting; PVC, polyvinyl chloride.

[4] Packard Instrument Co., 2200 Warrenville Rd., Downers Grove, IL 60515. Mention of a trade name does not imply an endorsement or recommendation by S. Dak. State Univ. or USDA-Agric. Res. Serv.

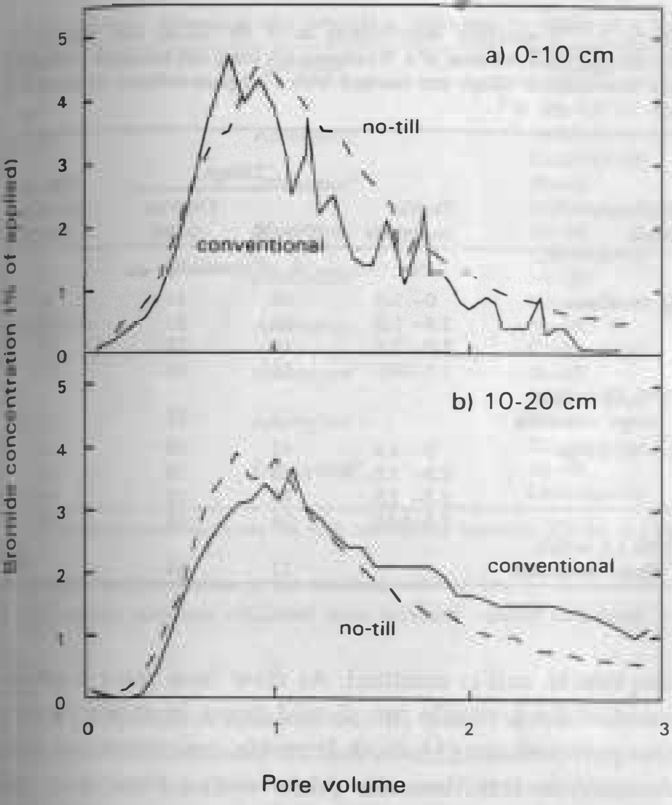

Figure 1. Bromide movement through a) 0- to 10-cm and b) 10- to 20-cm no-till (- - - -) and conventional tillage (——) soil columns.

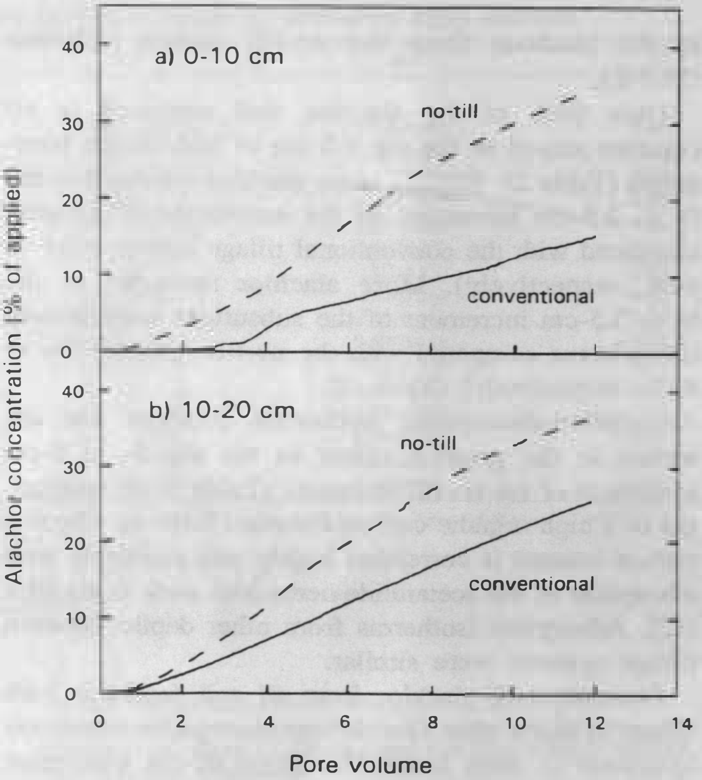

Figure 2. Cumulative amounts of alachlor leached from a) 0- to 10-cm and b) 10- to 20-cm no-till (- - - -) and conventional tillage (——) soil columns.

tion data. Statistical evaluation included Bartlett's test for homogeneity of variances, and comparison of slopes and elevations of regression lines. The 95% confidence intervals for the intercept (log K_f) and slope (l/n) were calculated.

RESULTS

Leaching studies. Bromide concentrations reached a peak when approximately 0.83 pore volumes of leachate percolated through the columns (Figure 1). After 2.9 pore volumes of leachate had been collected, significant bromide concentrations were not detected. Tillage and core depth influenced bromide leaching patterns. The peak bromide concentration in the leachate from the surface conventional till columns was measured after approximately 0.73 pore volumes compared with 0.92 pore volumes from the no-till treatment. Bromide in the leachate from the subsurface no-till columns reached peak concentrations at 0.80 pore volumes while the bromide peak from subsurface conventional tillage columns occurred at approximately one pore volume.

Leaching patterns of alachlor differed between tillage and depth (Figure 2). For the surface columns, alachlor was not observed in the first 0.83 pore volumes of leachate from the conventional tillage, whereas 0.6% of the applied alachlor leached from the no-till columns. The amount of alachlor collected in the first 3.3 pore volumes of leachate from surface no-till columns was four-fold greater than the amount leached from the conventional tillage columns (6.3 vs 1.5%, respectively). The total amount of alachlor leached from the surface no-till columns in 11.6 pore volumes of leachate was double the amount leached from conventional tillage columns (29.7 vs 14.4%, respectively).

The amount of alachlor leached in the first 3.3 pore volumes from the subsurface columns from no-till treatment was double the amount leached from subsurface conventional tillage columns (11.4 vs 5.3%, respectively). The total amount of alachlor contained in 11.6 pore volumes of leachate from the subsurface columns of both tillages (37.5% from no-till and 26.6% from conventional tillage) was similar to the amount contained in the leachate from the no-till surface columns (29.7%).

Over 60% of the alachlor that remained in all columns stayed in the top 5.0 cm of both tillage treatments (Table 2). Slightly more alachlor remained in the 0- to 2.5-cm increment of the surface no-till column compared with the conventional tillage columns (54 vs 44%, respectively). More alachlor remained in the 0- to 2.5-cm increment of the subsurface conventional till columns compared with the no-till columns (56 vs 43%, respectively) (Table 2).

Adsorption-desorption isotherms. Alachlor was adsorbed to the greatest extent in the top 0- to 5-cm increment of the no-till treatment (Table 3) corresponding to a high organic carbon content (Table 1). Organic carbon content is correlated highly and positively with adsorption of the acetanilide herbicides such as alachlor (12). Adsorption isotherms from other depths between tillage systems were similar.

Desorption of alachlor from all soil depths in both tillage systems after five desorption equilibrations was hysteretic in most cases (the slope of the desorption isotherm was less than the slope of the adsorption isotherm). Desorption isotherms from the same depths were similar except for the 0- to 5-cm depth of the no-till compared with conventional till soil.

DISCUSSION

The data from this study show that small intact field-moist soil columns can be used with minimal problems as a screening method to determine the influence of tillage practices on herbicide movement through soil. A frequently cited problem when using soil columns to assess chemical movement is edge flow. In this study, edge flow of the chemicals was minimized by first, applying the chemicals to the center of the column and second, applying water at a rate that did not create ponding. Soil samples taken along the column edge after leaching events contained less than 2% of the ^{14}C compared with the amount detected below the area of application. These data suggest that most of the chemical moved through the center of the column and not along the column edge.

Another common problem with using soil columns is possible soil compaction and subsequent loss of structure and macropores that could cause preferential flow. Bromide was used as a conservative tracer for water in this experiment. Bromide is an anion and therefore sorption to soil is minimal. At slow flow rates, displacement of the bromide ion should occur in approximately one pore volume (1). Peak bromide concentrations were detected in less than one pore volume from most soil columns. These data indicated that preferential flow occurred in columns.

Table 2. ^{14}C-alachlor distribution in 0- to 10-cm and the 10- to 20-cm intact soil columns of a Waukegan silt loam soil managed with no-till and conventional tillage and leached with 11.6 pore volumes of water at a rate of 0.5 cm h^{-1}.

Soil core depth	Depth increment	Tillage: No-till	Tillage: Conventional	95% CI between tillage
	cm	— % of remaining		
0- to 10-cm	0– 2.5	54	44	9
	2.5– 5.0	20	27	NS
	5.0– 7.5	14	18	NS
	7.5–10.0	13	12	NS
95% CI within tillage treatment		3	12	
10- to 20-cm	0– 2.5	43	56	3
	2.5– 5.0	20	13	NS
	5.0– 7.5	19	12	NS
	7.5–10.0	18	18	NS
95% CI within tillage treatment		11	12	

Preferential movement of bromide and dyes through no-till and conventional tillage systems have been reported (1). Zins et al. (16) reported preferential flow of atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and alachlor in soil columns containing roots compared with columns without roots. Preferential flow measured in no-till columns used in the present study may have been due to pore structure created by root or animal activity. Pore structure that had developed the previous year in the surface conventional tillage columns was disrupted by fall plowing.

Small intact field-moist soil columns can detect differences in leaching patterns due to tillage. Alachlor movement in the columns lagged behind bromide movement. The retardation in movement was expected because alachlor, unlike bromide, does not move with water but is adsorbed to soil and organic matter. Adsorption of alachlor on soil also resulted in tailing of alachlor in leachate with no peaks in concentration measured over the time of the experiment. Although alachlor was adsorbed more on the surface no-till soil compared with conventional till, more alachlor was leached from the no-till surface column. More continuous pores or channels probably were present in the no-

Table 3. Alachlor adsorption and desorption isotherms by depth of a Waukegan silt loam with no-till and conventional tillage techniques.

Depth	Isotherm	Tillage	K_f[a]	1/n[b]	r^2
cm					
0– 5.0	Adsorption	No-till	6.0(4.1–8.7)	1.06(0.10)	0.96
		Conventional	3.6(2.7–4.1)	0.86(0.06)	0.98
	Desorption[c]	No-till	4.6(4.1–5.3)	0.62(0.10)	0.78
		Conventional	3.2(2.9–3.6)	0.44(0.04)	0.90
5.0–10.0	Adsorption	No-till	3.6(1.3–10.3)	0.60(0.20)	0.69
		Conventional	4.0(2.4–6.7)	0.89(0.12)	0.93
	Desorption[c]	No-till	3.9(3.2–4.8)	0.60(0.13)	0.69
		Conventional	3.8(3.4–4.2)	0.62(0.06)	0.92
10.0–15.0	Adsorption	No-till	4.0(1.9–8.5)	0.88(0.19)	0.85
		Conventional	3.9(2.5–5.8)	0.92(0.10)	0.96
	Desorption[c]	No-till	3.4(2.6–4.4)	0.51(0.15)	0.54
		Conventional	3.4(3.0–3.9)	0.42(0.06)	0.82
15.0–20.0	Adsorption	No-till	3.7(2.8–4.9)	0.80(0.06)	0.98
		Conventional	4.0(3.2–4.9)	0.91(0.05)	0.99
	Desorption[c]	No-till	3.4(3.1–3.7)	0.54(0.05)	0.93
		Conventional	3.5(2.9–4.1)	0.47(0.09)	0.75

[a] Numbers in parentheses are the 95% confidence intervals (CI) for K_f, antilogs of log K_f-CI log K_f and log K_f + CI log K_f. Units for K_f are μmol$^{1-1/n}$ L 1/n kg^{-1}.

[b] Number in parentheses is the standard error of 1/n.

[c] Desorption isotherms calculated from solutions initially containing 3.71 μmol L^{-1}.

till columns which allowed for by-pass flow to occur. In surface conventional tillage, alachlor passed through a more mixed medium which allowed for more contact with soil particle surfaces resulting in less alachlor leached from the columns.

Alachlor breakthrough occurred at the same time from subsurface columns and total amounts of alachlor leached from the subsurface columns were similar. Adsorption and desorption isotherms were similar for the subsurface depths. Over 60% of the retained alachlor remained in the surface 5 cm of all columns. Alachlor distribution patterns could be attributed to the tillage effect on both soil physical and chemical properties.

Small intact soil columns in this study detected differences in bromide and alachlor leaching patterns between no-till and conventional tillage systems. The results that more alachlor leached from no-till columns compared with conventional tillage agree with field results (7, 8). The technique of leaching intact soil columns in the laboratory appears to be a useful tool for observing gross differences in herbicide movement between tillage systems or soil types or both. This technique may point out possible field problems and solutions to pesticide movement in an efficient and cost effective manner.

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