Dissipation of [^{14}C]Glufosinate Ammonium in Two Ontario Soils

Marco A. Gallina and Gerald R. Stephenson*

Department of Environmental Biology, University of Guelph, Guelph, Ontario, Canada N1G 2W1

Soil thin-layer chromatographic analysis revealed that [^{14}C]glufosinate ammonium was slightly more mobile than amitrole less mobile than picloram in Fox sandy loam and Guelph loam soils. Two glufosinate ammonium metabolites, 3-(methylphosphinyl)propionic acid (MPPA-3) and 2-(methylphosphinyl)acetic acid (MPAA-2), were more mobile than the parent herbicide in the Fox sandy loam. In the Guelph loam, the MPAA-3 metabolite was again more mobile than the parent herbicide. However, the MPAA-2 metabolite was significantly less mobile than the parent herbicide. The adsorption coefficients for [^{14}C]glufosinate ammonium in the Guelph loam and Fox sandy loam soils were 0.37 and 0.21, respectively. Laboratory degradation studies indicated that [^{14}C]glufosinate ammonium was rapidly degraded to its metabolites, MPPA-3 and MPAA-2, and eventually to $^{14}CO_2$. In all studies conducted, the half-life of glufosinate was between 3 and 7 days.

INTRODUCTION

Glufosinate ammonium (the ammonium salt of DL-homoalanin-4-ylmethylphosphinic acid) (Figure 1) is a nonselective, contact herbicide used to control emerged annual and perennial grasses and broadleaf weeds at rates up to 1 kg/ha (Mersey et al., 1990; Smith, 1988, 1989). It has potential for use in minimum tillage systems, chemical fallow, orchards, and vineyards and as a stale seedbed treatment for vegetables and other crops. It also has potential for use as a preharvest crop desiccant (Mersey et al., 1990). The free acid form of glufosinate ammonium is a metabolite that is produced naturally by the bacterium *Streptomyces viridochromogenes* L. It is called "phosphinothricin" and was first discovered in 1972 (Duke and Lydon, 1987).

In plants, glufosinate irreversibly inhibits the enzyme glutamine synthetase, thereby blocking the synthesis of glutamine from glutamate and ammonia (Mandershield and Wild, 1986). The subsequent accumulation of toxic levels of ammonia within the cell causes tissue necrosis and eventual death of the plant shoot. Glufosinate ammonium degrades rapidly in a nonsterile environment such as soil (Behrendt et al., 1990; Smith, 1988, 1989), which may explain why it has little herbicidal activity in soil. Field studies have indicated that in most soils glufosinate does not leach more than 15 cm (Behrendt et al., 1990; Smith, 1988, 1989). Recent research by Smith (1988, 1989) indicates that glufosinate ammonium adsorption and desorption are readily influenced by available soil moisture. Degradation studies have indicated that two major metabolites are formed (Figure 1), with glufosinate degrading to 3-(methylphosphinyl)propionic acid (MPPA-3) which in turn degrades to 2-(methylphosphinyl)acetic acid (MPAA-2) (Behrendt, 1990; Hoechst AG, 1989). In dissipation studies carried out in crops where the commercial formulation could eventually be registered for weed control, the active ingredient has never been detected as a residue in the harvested crop (Hoechst AG, 1989). Furthermore, only trace residues of the first metabolite, MPPA-3, were detectable in a few of the studies.

The studies reported here were conducted to examine the degradation of glufosinate ammonium to volatile as well as nonvolatile metabolites in soil and to compare the mobility of glufosinate ammonium and any nonvolatile metabolites with other, better understood pesticides.

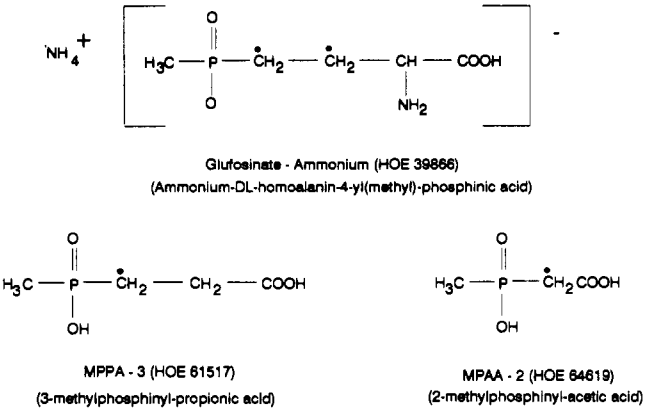

Figure 1. Glufosinate ammonium and two degradation products recovered from soil. (A dot indicates ^{14}C in radiolabeled standards.)

MATERIALS AND METHODS

Soils. The two soils used in these studies were a Fox sandy loam (FSL) (arenic Halpudalf) and a Guelph loam (GL) (typic Halpudalf); the composition and physical characteristics of these soils are presented in Table I. In all studies, a composite sample of each soil was obtained from the 0–10-cm soil horizon, mixed thoroughly, passed through a 2-mm screen, and then stored at room temperature in cardboard boxes until needed.

Chemicals. [^{14}C]Glufosinate, labeled in the two CH_2 carbon atoms, with a specific activity of 464.7 MBq/mmol was provided by Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, as were the samples of analytically pure glufosinate ammonium and MPPA-3. Also supplied was [^{14}C]MPPA-3 labeled in the third carbon position with a specific activity of 134.3 MBq/mmol and [^{14}C]MPAA-2 labeled in the second carbon position with a specific activity of 127.9 MBq/mmol (Figure 1).

Radiolabeled glufosinate ammonium was prepared by incubating [^{14}C]glufosinate or DL-homoalanin-4-yl-methylphosphinic acid (as its hydrochloride) in an excess of 14% NH_4OH for 20 min. The water and free NH_3 were removed by evaporation under a stream of N_2. All radiolabeled compounds had a chemical purity of greater than 98% as determined by thin-layer chromatography and were dissolved in pure methanol until diluted for use.

Soil Thin-Layer Chromatography (STLC). The herbicides and glufosinate metabolites included in mobility experiments were all radiolabeled. Reference herbicides were selected to provide estimates of the five mobility classes as described by Helling (1971b) and included pyrazon [5-amino-4-chloro-2-phenyl-3(2*H*)-pyridazinone] from mobility class 2, atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine from mo-

0021-8561/92/1440-0165$03.00/0

Table I. Some Characteristics of the Two Soils Used in This Study

soil	% sand	% silt	% clay	% OM	pH	CEC
Guelph loam	24.0	53.0	23.0	5.7	7.2	19.9
Fox sandy loam	76.9	17.0	6.1	1.7	5.2	12.5

bility class 3, and picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) from mobility class 4. Once the mobility classes of glufosinate and its metabolites were determined, other herbicides within their mobility class, namely 2,4-D (2,4-dichlorophenoxyacetic acid), amitrole (1*H*-1,2,4-triazol-3-amine), and picloram (class 4), were used to further define the mobility of glufosinate ammonium or its metabolites.

The STLC plates were prepared according to the methods of Helling (1971a) and Jotcham et al. (1989) with only slight modifications. A glass plate, 20 cm by 20 cm, was used as the soil backing. Five strips of masking tape, 1 cm wide, were applied to a thickness of 1 mm along the edge of the glass and on the surface of the plate so that the four soil columns could be isolated from each other. Distilled water was added to both soils to form a slurry. The Guelph loam slurry was formed by adding 1 mL of water/2 g of soil, while the Fox sandy loam slurry was formed by adding 1 mL of water/3 g of soil. This slurry was then applied evenly on the exposed glass surface. A glass rod was rolled over the masking tape strips to obtain a uniform and smooth soil surface. The plates were then allowed to air-dry at room temperature for approximately 2 h or until no surface moisture was visible before the strips of masking tape were removed. A 2-cm strip of soil was then scraped off the glass from the bottom and top of the plate, and the plates were allowed to air-dry overnight. To prevent the soil from sloughing off when placed in the developing solvent, a strip of chromatography paper was wrapped around the lower portion of the plate to act as a wick. The wick was affixed by using tape on the back of the glass and an elastic band was placed around the paper and glass to ensure even contact with the soil.

After overnight air-drying, the plates were spotted dropwise with approximately 40 000 dpm of radiolabeled herbicide (or metabolite) per spot at a point 2 cm above the bottom edge of the soil column. Each spot was approximately 1.0 cm in diameter or less, and the lower edge was at least 0.5 cm above the paper strip at the base of the plate. The plates were then placed in a sealed, glass chromatography chamber (30 × 10 × 25 cm) filled with water to a height of 1 cm. The plates were removed when the solvent front (water) had reached a height of 10 cm above the origin or application spots for the herbicides. After overnight drying at room temperature, 10 1-cm increments of soil were scraped from each soil column with a razor blade, wrapped in tissue paper (7 cm × 7 cm), pelleted (Parr pellet press), and combusted using a Model OX 300 biological oxidizer (R. J. Harvey Instrument Corp., Hillsdale, NJ). The resulting $^{14}CO_2$ was trapped in carbon-14 scintillation cocktail (Harvey Instrument) and quantified by liquid scintillation counting (LSC) methods. Combustion of [^{14}C]methyl methacrylate calibration standards (New England Nuclear, 6.6 Bq/mg) indicated a recovery of 93% for combustion and trapping.

Each STLC plate with four soil columns permitted mobility comparisons between glufosinate (or metabolite) and three reference pesticides in a particular soil. Four replicate chromatograms were run for each comparison in the study. Weighted R_f values (or average distances moved) as calculated according to the method of Sharom and Stephenson (1976) were employed in all mathematical comparisons of STLC mobility and significant differences were determined by Duncan's multiple range test.

Soil Adsorption Studies. All adsorption studies were conducted at room temperature (24 ± 1 °C) and were replicated three times. Using the methods of Sharom and Stephenson (1976), 1-g (oven-dry weight: 105 °C for 24 h) samples of the two Ontario soils were placed in 15-mL glass tubes containing desired concentrations of technical glufosinate and radiolabeled glufosinate in 5 mL of water. In a study to determine the equilibration time, the tubes were agitated on a vortex shaker at regular time intervals between 0 and 6 h. Triplicate samples of each soil were removed after 0, 1, 2, 3, 4, 5, and 6 h and centrifuged at 1000*g* for 10 min. A 1-mL aliquot was removed from the supernatant of each tube and added to a 20-mL scintillation vial containing 12 mL of Aquasol II, and the radioactivity was determined by LSC. Comparison of the herbicide concentrations in the supernatant solutions before and after the various agitation times permitted calculations of glufosinate adsorption.

Table II. Soil Thin-Layer Chromatographic Mobility of Glufosinate and Two of Its Metabolites in Comparison with Other Pesticides of Known Mobilities in Two Different Soils

		R_f values[b,c]	
treatment	soil mobility class[a]	Fox sandy loam	Guelph loam
pyrazon	2	0.20 h	
atrazine	3	0.25 g	
amitrole	4	0.45 e	0.40 e
2,4-D	4	0.50 d	0.48 d
picloram	4	0.61 c	0.59 b
glufosinate		0.56 cd	0.52 c
MPAA-2		0.67 b	0.36 f
MPPA-3		0.85 a	0.68 a

[a] As determined by Helling (1971). [b] R_f values, or average distances moved, were calculated by multiplying the radioactivity (dpm) in each segment times the number of cm for that segment from the origin. These 10 values were then summed and divided by the total dpm on the chromatogram. [c] Within each column, values followed by the same letter did not differ significantly at the 5% level using ANOVA and Duncan's multiple range test.

In a study to develop adsorption isotherms for glufosinate ammonium in the two Ontario soils, triplicate 1.0-g samples of the two soils were weighed for each concentration of glufosinate ammonium to be examined. Four concentrations of 0, 2.5, 5, 10, and 20 μg/mL were prepared using a mixture of ^{14}C-labeled and unlabeled glufosinate ammonium. The concentration of radioactivity in the solutions was 13 500 dpm/mL. A 5-mL aliquot of the solution of appropriate concentrations was added to the soil in a 15-mL glass tube and covered with a snap-on cap. Blanks containing only the glufosinate ammonium solution were included in each determination. The tubes were then agitated periodically on a vortex shaker. After the 4-h equilibration period, the tubes were centrifuged and the percent adsorption was determined.

Glufosinate Degradation to Nonvolatile Metabolites. Large samples of the two soil types were thoroughly mixed and placed in 25-cm pots. Sufficient moisture was added to bring the soils to field capacity. The pots were then placed in a controlled environment room (25 °C day and 16 °C night temperatures, 16-h photoperiod, relative humidity of 65%, and light intensity of 450 μE m^{-2} s^{-1}) and allowed to stand for 2 weeks to restore "normal" microbial activity. During this period, soil moisture was restored to field capacity every 3 days by watering to a predetermined weight. Fifteen sieved, 50-g samples (2-mm brass sieve) of each soil were then transferred to 250-mL glass Erlenmeyer flasks. The flasks were stoppered with cotton plugs and placed in a dark cupboard (22 ± 2 °C) for another 2-week period to further ensure that the soil microbial activity was restored to normal levels.

The soils (50 g) in the flasks were each treated with 82.0 μg of formulated glufosinate ammonium plus 7.2 μg of [^{14}C]glufosinate ammonium in a volume of 200 μL of water applied in a dropwise manner. After mixing, the resulting concentration approximated a field application rate of 0.5 kg/ha. The flasks were capped with cotton plugs and incubated in the dark at 22 ± 2 °C. Distilled water was added at 3-day intervals to restore moisture levels to field capacity (measured at one-third bar tension, w/w basis).

The soils in three randomly sampled flasks were extracted on days 1–4 and 7. Using procedures described by Smith (1988, 1989), calcium hydroxide (500 and 750 mg for FSL and GL soils, respectively) was added with 100 mL of water prior to shaking the soils in the flasks for 1 h immediately and again after 20 h. After transfer and centrifugation in 200-mL tubes, the extractable radioactivity in 2-mL aliquots of the alkaline supernatant was determined by LSC (in 10 mL of Aquasol II cocktail, NEN, Boston, MA). The extracts were acidified (0.5 mL, 12 N HCl), and 35-mL aliquots were concentrated to 1-mL volumes on a

Table III. Radioactivity Recovered from Guelph Loam and Fox Sandy Loam Soils Treated with [14C]Glufosinate under Laboratory Conditions[a] and Analyzed for 14C-Labeled Nonvolatile Compounds by Thin-Layer[b] Chromatography after 7 Days

		% of applied radioactivity[c]				
soil	days	glufosinate	MPPA-3	MPAA-2	nonextracted residue[d]	total recovered
Fox sandy loam	0	95 (0.1)	0 (0)	0 (0)	5 (0.2)	100 (0.1)
	1	68 (0.6)	10 (0.7)	7 (0.3)	5 (1.8)	91 (6.4)
	2	67 (1.5)	16 (2.6)	9 (1.7)	4 (1.7)	96 (3.6)
	3	54 (2.1)	21 (2.7)	9 (0.8)	5 (2.1)	90 (1.3)
	4	45 (0.6)	20 (0.2)	9 (0.4)	6 (0.6)	77 (1.0)
	7	33 (2.4)	31 (4.5)	14 (2.2)	4 (1.4)	79 (1.0)
Guelph loam	0	90 (0.1)	0 (0)	0 (0)	10 (0.2)	99 (0.9)
	1	66 (0.4)	17 (0.3)	7 (0.7)	5 (2.8)	96 (2.7)
	2	60 (0.9)	21 (1.8)	8 (1.1)	4 (2.1)	93 (1.6)
	3	53 (1.6)	26 (1.5)	9 (0.2)	5 (2.5)	93 (1.4)
	4	54 (0.7)	24 (1.1)	7 (0.4)	4 (0.4)	89 (2.1)
	7	22 (1.5)	40 (1.4)	10 (0.5)	5 (3.1)	78 (2.6)

[a] Soil flasks were kept in darkness at a temperature of 22 ± 2 °C, and water was added to the soils at 3-day intervals to maintain the soils at field capacity. [b] Thin-layer chromatography was on 0.25-mm silica gel plates with 2-propanol/acetic acid/water (2:1:1 v/v/v) as the solvent system. The R_f values were 0.16, 0.47, and 0.23 for glufosinate, MPPA-3, and MPAA-2, respectively. [c] Average of triplicate samples. Numbers in parentheses represent standard error. [d] As determined by oxygen combustion of extracted soil samples.

rotary evaporator. Coextractants were then removed using C_{18} Sep-Pak cartridges (Waters Associates, Milford, MA) which had been activated by methanol (2 mL) and rinsed with distilled water (5 mL). Each 1-mL extract and a subsequent 2-mL volume of water were pushed through the C_{18} Sep-Pak cartridges and into test tubes. The extracts were further concentrated to 200-μL volumes on a nitrogen evaporator equipped with a water bath set at 40 °C. Alkaline extractable, radiolabeled metabolites were separated and quantified by thin-layer chromatographic methods employing 0.25-mm silica gel plates (Whatman PLK5F, Maidstone, England) developed to a height of 15.0 cm with 2-propanol/acetic acid/water (2:1:1 v/v/v). We also considered the use of 2-propanol/acetone/HCl (30:7.5:12.5) or butanol/acetone/HCl (20:10:15) (Smith, 1988) as additional solvent systems. However, while they did separate the parent glufosinate peak, they did not separate the two metabolites from each other. After drying, R_f values and quantities of metabolites were determined by scraping 30 0.5-cm sections of the gel (above each origin) into vials and then measuring the radioactivity in each by LSC with Aquasol II (NEN) as the cocktail.

Any nonextractable radioactivity remaining with the soil was estimated by combustion and LSC methods as described earlier.

Degradation to Volatile Metabolites. Weighed portions of soil (equivalent to 100 g of dry weight) were added to black painted, 500-mL glass Erlenmeyer flasks. Sufficient moisture was added to bring the soils to field capacity (on day 1 and at 3-day intervals thereafter). After a further 2-week preincubation period, the soils were treated with sufficient formulated and radiolabeled glufosinate ammonium (as described earlier) to approximate a field application rate of 0.5 kg/ha (14.4 μg of radiolabeled plus 164.0 μg of formulated compound/100 g of soil) and then incubated at 22 ± 2 °C in the dark. Each of the three replicate flasks was sampled for volatile 14C-labeled metabolites on days 1–10 and on days 12, 15, 18, and 22. In this procedure, each flask was connected to a flow-through-vapor-trapping device designed according to one described by Guildemeister (1985) and equipped with a vacuum pump, flow gauge, and release values to adjust flow rates to approximately 100 mL/min. Filtered, incoming air first passed through the flow meter and then through water before passing through the flask containing the soil plus [14C]glufosinate. Subsequently the air passed through the sulfuric acid and ethylene glycol traps for volatile radiolabeled metabolites other than CO_2. Finally the air passed through two CO_2 traps in succession containing carbon-14 scintillation cocktail and then through the vacuum pump. After 20 min, each flask was disconnected from the flow-through device, adjusted for soil moisture content, restoppered, and reincubated at 22 ± 2 °C. Radioactivity in each of the traps was then estimated by subjecting 2-mL aliquots of the acid and glycol traps and the entire contents of the $^{14}CO_2$ traps to LSC. On day 22, the remaining soils were analyzed for percent moisture and 50-g (equivalent dry weight) portions of the soils were analyzed for alkaline extractable, radiolabeled metabolites by TLC methods as described earlier.

RESULTS AND DISCUSSION

Soil Thin-Layer Chromatography Studies. A preliminary study in the FSL soil indicated that glufosinate and its metabolites were considerably more mobile than pyrazon and atrazine but similar in mobility to picloram (Table II). In a subsequent test, amitrole and 2,4-D were included since they are reported to be within the same mobility class as picloram (Jotcham et al., 1989). The second study confirmed that glufosinate belongs in mobility class 4 since its mobility was not significantly less than that of amitrole nor greater than that of picloram, both of which are mobility class 4 pesticides (Table II). 2,4-D is also a moderately to highly mobile, class 4 pesticide, and glufosinate mobility was very similar to that of 2,4-D in the two soils examined (Table II). In the Fox sandy loam, the two metabolites, MPPA-3 and MPAA-2, were significantly more mobile than glufosinate (Table II). In the Guelph loam, MPPA-3 was again the most mobile compound examined. MPAA-2 mobility was markedly different in these two soils. In the Fox sandy loam, it was one of the two most mobile compounds but in the Guelph loam it was one of the least mobile compounds examined (Table II). When glufosinate or its metabolites were extracted from developed STLC plates, reconcentrated, and reanalyzed by TLC on silica gel plates, more than 95% of the extracted radioactivity cochromatogrammed with appropriate radiolabeled standards. Thus, there was little if any evidence that glufosinate, MPPA-3, or MPAA-2 was degraded during the STLC procedure in either of the soils examined.

Soil Adsorption. Adsorption equilibrium was established after 2 h of shaking for [14C]glufosinate in both soils. Adsorption isotherms for glufosinate in both soils, plotted in Figure 2, indicated that there was a linearly proportional relationship between the amount of herbicide adsorbed and the concentration of the herbicide in solution at equilibrium. The distribution coefficients (K values) were used to compare the adsorptive capacity of both soils and established that the adsorption of glufosinate was almost 2-fold higher (0.37 vs 0.21) in the Guelph loam as compared to the Fox sandy loam. The higher organic matter and clay contents are likely explanations for the higher adsorption in the Guelph loam soil (Table I).

Degradation to Nonvolatile Metabolites. At zero time in the laboratory degradation study, aqueous calcium hydroxide extraction yielded recoveries of 95% and 90% of total radioactivity (applied as [14C]glufosinate) from the FSL and GL soils, respectively (Table III). Total

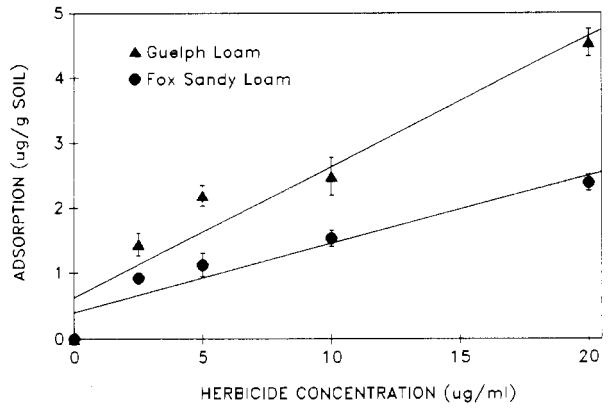

Figure 2. Adsorption isotherms for glufosinate in two Ontario soils. The regression equations are $y = 0.624 + 0.201x$, $r^2 = 0.92$, and $y = 0.399 + 0.105x$, $r^2 = 0.91$, for the GL and FSL soils, respectively. Standard error at each point was less than 0.05 μg/g unless otherwise indicated by standard error bars.

Table IV. Radioactivity Recovered in a Fox Sandy Loam or a Guelph Loam Soil, 22 Days after Treatment with [^{14}C]Glufosinate and Aeration in a Flow-through-Vapor-Trapping Apparatus

	% of applied ^{14}C[a]	
	Fox sandy loam	Guelph loam
^{14}C released as CO_2	10 (0.6)	12 (0.8)
nonextractable ^{14}C[b]	6 (0.6)	10 (1.9)
total ^{14}C in aqueous extract	85 (2.1)	77 (1.0)
glufosinate	8 (0.5)	11 (0.3)
MPPA-3	61 (0.6)	53 (0.3)
MPAA-2	16 (0.1)	13 (0.4)
total ^{14}C recovered	101 (0.3)	99 (0.4)

[a] Average of triplicate samples with numbers in parentheses representing standard error. [b] Obtained by combusting soils after the solvent extraction and correcting for the amount of radioactivity in the water remaining in the soil. [c] Thin-layer chromatography was on 0.25-mm silica gel plates. R_f values were 0.16, 0.47, and 0.23 for glufosinate, MPPA-3, and MPAA-2 in 2-propanol/acetic acid/water (2:1:1 v/v/v), respectively.

recoverable radioactivity decreased with time as determined by oxygen combustion of the extracted soils. By the end of the 7-day incubation, only 80% of the applied radioactivity could be accounted for in the form of glufosinate or nonvolatile metabolites (Table III). Thus, up to 20% could have been lost as $^{14}CO_2$ or other volatile ^{14}C-labeled products. Thin-layer chromatographic analysis of the authentic standards as well as the aqueous extracts of [^{14}C]glufosinate-treated soils revealed that glufosinate, MPPA-3, and MPAA-2 had R_f values of 0.16, 0.47, and 0.23, respectively, in the 2-propanol/acetic acid/water (2:1:1 v/v/v) solvent system. By day 4, only half of the recoverable radioactivity remained in the form of unaltered [^{14}C]glufosinate, indicating an approximately 50% conversion to [^{14}C]MPPA-3, [^{14}C]MPAA-2, or volatile ^{14}C-labeled products (Table III).

Degradation to Volatile Metabolites. In the laboratory study of degradation to volatile metabolites, there was a gradual release of $^{14}CO_2$ over the 22 days of the study. At the end of the study, approximately 10% and 12% of the total applied radioactivity was released as $^{14}CO_2$ from the Fox sandy loam and Guelph loam soils, respectively (Table IV). However, no radioactivity was detected in the sulfuric acid or ethylene glycol traps, indicating that $^{14}CO_2$ was the only volatile ^{14}C-labeled product released during the degradation of glufosinate ammonium. At the end of the study, approximately 85% and 77% of the applied radioactivity was extractable with aqueous calcium hydroxide solvents from Fox sandy loam and Guelph loam soils, respectively, and most of the radioactivity was identifiable as the metabolites MPPA-3 or MPAA-2 (Table IV).

These studies indicate that glufosinate is very readily degraded in soil. Half-lives of between 4 and 7 days were observed in two different nonsterile soils under laboratory conditions. It is apparent from these studies that glufosinate degrades by deamination to MPPA-3 and subsequent decarboxylation to MPAA-2. In our studies, no volatile radiolabeled metabolites other than $^{14}CO_2$ were observed. On the basis of comparative soil thin-layer chromatography, with other well-characterized pesticides, glufosinate should be regarded as a moderately to highly mobile pesticide [class 4 (Helling, 1971)] or very similar to 2,4-D. The metabolites, MPPA-3 and MPAA-2, were both more mobile than glufosinate in the Fox sandy loam, but MPAA-2 was significantly less mobile in the Guelph loam soil.

ACKNOWLEDGMENT

Funding for this project was provided by Hoechst Canada, Ltd., Regina, Saskatchewan. Thanks are due to Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, for supplying the analytical and radiolabeled glufosinate and metabolites.

LITERATURE CITED

Behrendt, H.; Matthies, M.; Gildemeister, H.; Gorlitz, G. Leaching and transformation of glufosinate-ammonium and its main metabolite in a layered soil column. *Environ. Toxicol. Chem.* **1990**, *9*, 541–549.

Duke, S. O.; Lydon, J. Herbicides from natural compounds. *Weed Technol.* **1987**, *1*, 122.

Guildemeister, H. "Proposed protocol for HOE 039866 ^{14}C aerobic soil metabolism study"; Report CB066/85V; Hoechst A.G., Frankfurt, 1985.

Helling, C. S. Pesticide mobility in soils I; parameters of thin-layer chromatography. *Soil Sci. Soc. Am. Proc.* **1971a**, *35*, 732–737.

Helling, C. S. Pesticide mobility in soils II; applications of soil thin-layer chromatography. *Soil Sci. Soc. Am. Proc.* **1971b**, *35*, 737–743.

Hoechst, AG. "Product information HOE 39866"; Hoechst Aktiengesellschaft, Frankfurt, FRG, 1989.

Jotcham, J. R.; Smith, D. W.; Stephenson, G. R. Comparative persistence and mobility of pyridine and phenoxy herbicides in soil. *Weed Technol.* **1989**, *3*, 155–161.

Mandersheild, R.; Wild, A. Studies on the mechanism of inhibition by phosphinothricin of glutamine synthetase isolated from *Triticum aestivum* L. *J. Plant Physiol.* **1986**, *123*, 135.

Mersey, B. G.; Hall, J. C.; Anderson, D. M.; Swanton, C. J. Factors affecting the herbicidal activity of glufosinate–ammonium: absorption, translocation, and metabolism in barley and green foxtail. *Pestic. Biochem. Physiol.* **1990**, *37*, 90–98.

Sharom, M. S.; Stephenson, G. R. Behaviour and fate of metribuzin in eight Ontario soils. *Weed Sci.* **1976**, *24*, 153–160.

Smith, A. E. Persistence and transformation of the herbicide [^{14}C]glufosinate-ammonium in prairie soils under laboratory conditions. *J. Agric. Food Chem.* **1988**, *36*, 393–397.

Smith, A. E. Transformation of the herbicide ^{14}C-glufosinate in soils. *J. Agric. Food Chem.* **1989**, *37*, 267–271.

Received for review April 17, 1991. Revised manuscript received October 1, 1991. Accepted October 14, 1991.

Registry No. MPPA-3, 15090-23-0; MPAA-2, 72651-25-3; glufosinate ammonium, 77182-82-2.