JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Determination of the 1′*S* and 1′*R* Diastereomers of Metolachlor and *S*-Metolachlor in Water by Chiral Liquid Chromatography−Mass Spectrometry/Mass Spectrometry (LC/MS/MS)

A. KENT KABLER* AND SUNMAO CHEN

Environmental Fate Department, Syngenta Crop Protection, Inc., Post Office Box 18300, Greensboro, North Carolina 27419

An enantioselective method for the separation and quantification of the diastereomer pairs of metolachlor and *S*-metolachlor in surface and ground waters is presented. Samples are purified and concentrated using a C_{18} (octadecyl silica) solid-phase extraction (SPE) procedure and analyzed by chiral column liquid chromatography−mass spectrometry/mass spectrometry (LC/MS/MS) interfaced with either atmospheric pressure chemical ionization (APcI) or atmospheric pressure photoionization (APPI) sources. The overall mean percent procedural recoveries (percent relative standard deviations) are 89% (10.6%) for surface water and 80% (9.1%) for ground water. The method limit of quantitation (LOQ) is 0.10 ppb. The method validation was conducted under U.S. EPA FIFRA Good Laboratory Practice Guidelines 40 CFR 160.

KEYWORDS: Chiral; metolachlor; LC/MS/MS; photoionization; chemical ionization; diastereomer

INTRODUCTION

Metolachlor [acetamide, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)-] is a chloroacetanilide herbicide used primarily for the control of annual grasses and broadleaf weeds in corn and soybeans. It was introduced to the marketplace in 1976 as a racemic mixture of two pairs of diastereomers, 1′*S* (*aS*,1′*S* + *aR*,1′*S*) and 1′*R* (*aR*,1′*R* + *aS*,1′*R*), with an isomeric ratio close to 50:50. The diastereomer pairs are also atropisomeric because of the hindered rotation about the phenyl−nitrogen bond, and their stereochemical structures are presented in **Figure 1**. Later studies showed that the majority of the herbicidal activity of metolachlor was associated with the *aR*,1′*S* and *aS*,1′*S* isomers; thus, *S*-metolachlor (*S*-MOC), consisting of an 88:12 ratio of 1′*S*/1′*R* isomers, was registered in 1997 as a reduced risk pesticide under the Reduced Risk Initiative of the EPA (*1*). The replacement of the racemate with the isomerically enriched product allows for a 35% reduction in the application rate while still maintaining equivalent weed control (*2*).

Sensitive, multiresidue methodology is reported for the achiral analysis of many chloroacetamides and their degradation products (*3*−*4*). However, because of the widespread use of enriched *S*-MOC, a change in the isomeric composition of metolachlor residues found in environmental matrices is expected (*5*−*9*). To monitor the magnitude of this isomeric shift, a sensitive enantioselective analytical method is required. Current enantioselective methods for the analysis of chloroacetamide pesticides include chiral column high-performance liquid chromatography (HPLC) with UV, polarimetric, and circular dichroism (CD) detection (*10*−*11*). While these methods have been used for detecting and characterizing metolachlor at high concentrations, they do not provide the sensitivity required for residue monitoring at the parts per billion concentration level. Goss et al. have reported that "high sensitivity" polarimeters capable of optical rotation measurements of 1−10 μdeg still

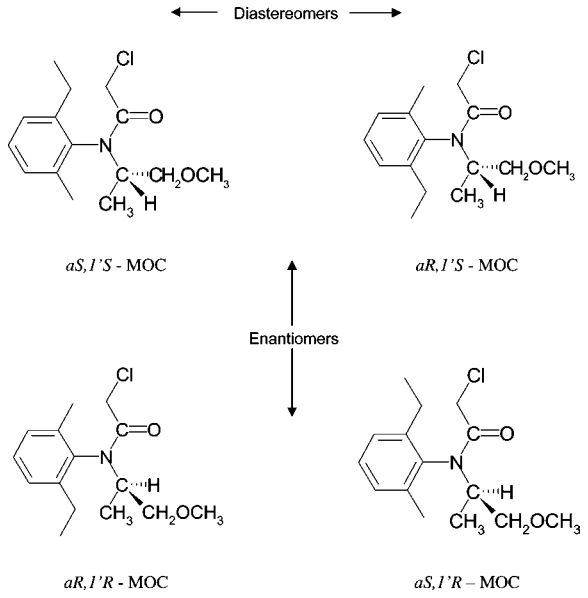

Figure 1. Metolachlor stereoisomers and nomenclature.

* To whom correspondence should be addressed. Telephone: 336-632-6014. Fax: 336-632-7581. E-mail: kent.kabler@syngenta.com.

10.1021/jf061186+ CCC: $33.50
Published on Web 08/02/2006

require large sample amounts in the range of 1−25 μg (*12*). Klein et al. have used capillary zone electrophoresis (CZE) and chiral column HPLC coupled with mass spectrometric (MS) detection for the separation and analysis of the isomers of metolachlor, and two of its metabolites spiked in ground water at 5 μg L^{-1} (ppb); however, the method did not fully resolve the *R′* atropisomers of metolachlor (*13*). Chiral high-resolution gas chromatography with mass spectrometric detection (HRGC/MSD) has also been used for the analysis of the isomers of metolachlor. However, Buser et al. (*14*) reported that elevated temperatures (>200 °C), typically encountered in a GC injector port or column oven during chiral GC analysis, can cause thermal interconversion of the metolachlor atropisomers because the phenyl−nitrogen rotational bond energy barrier (154 kJ/mol) may be exceeded at typical GC operating temperatures.

In this paper, an analytical method is presented for the analysis of *S*-metolachlor and racemic (rac) metolachlor in water. Surface and ground water samples were fortified at 0.10 ppb [method limit of quantitation (LOQ)] and 1.0 ppb (10× the LOQ) and analyzed for total metolachlor residues and isomeric composition. The analyses were accomplished using chiral column high-performance liquid chromatography/tandem mass spectrometry (LC/MS/MS), employing two separate ionization sources, atmospheric pressure photoionization (APPI) and atmospheric pressure chemical ionization (APCI).

EXPERIMENTAL PROCEDURES

Standards and Reagents. Analytical standards (chemical purity > 99%) of rac-metolachlor (Syngenta ID number CGA-24705, CAS 51218-45-2), *S*-metolachlor (CGA-77102, CAS 87392-12-9), and *R*-metolachlor (CGA-77101, CAS 178961-20-1) were obtained from the Analytical and Product Chemistry Department of Syngenta Crop Protection, Inc. (Greensboro, NC). Individual 200 ng/μL stock solutions were prepared by dissolving 20.0 mg (corrected for purity) of each standard into 100 mL of acetonitrile. Fortification standards were prepared by diluting each stock solution in acetonitrile/water (20:80, v/v). A calibration stock solution of rac-metolachlor was prepared by aliquoting 2.5 mL of the 200 ng/μL stock solution into a 50.0 mL volumetric flask and evaporating the solvent, acetonitrile, to dryness using an N-Evap nitrogen evaporator (Organomation Associates, Berlin, MA). After the solvent was completely evaporated, the standard was reconstituted by adding *n*-hexane/2-propanol (90:10, v/v) to the mark. External calibration standards were prepared by serial dilution of this stock standard to concentrations ranging from 0.005−0.100 ng/μL. The organic solvents used were of high purity (HPLC grade) and were obtained from Fisher Scientific (Pittsburgh, PA) and EM Science (Gibbstown, NJ). Water used in the preparation of the standards was obtained from a Hydro Picopure (Research Triangle Park, NC) laboratory purification system.

Water Sample Sources. A bulk surface water sample was obtained from City Lake Reservoir, High Point (Guilford County), NC. Ground water samples were obtained from control-monitoring well at a site located in Macon County, GA. These samples were analyzed by Agvise Laboratories (Northwood, ND), and a summary of the characterization data are presented in **Table 1**.

Sample Storage. Water samples to be analyzed for residues of metolachlor and *S*-metolachlor should be stored in the dark at refrigerator temperatures (4 °C). Previous work in this laboratory has shown that metolachlor is stable in water for at least 2 years when stored under these conditions (*15*) and stable for 14 months at room temperature when stored in the dark (*16*).

Sample Preparation. A 50 mL aliquot portion of the water sample was added to a graduated polypropylene centrifuge tube and fortified with either rac-metolachlor or *S*-metolachlor at the LOQ or at 10× the LOQ depending upon the recovery sample to be evaluated. The fortified sample was acidified with 0.25 mL of concentrated phosphoric acid and transferred to a polypropylene reservoir (60 mL capacity). The reservoir was connected to a preconditioned C_{18} solid-phase extraction cartridge (Varian, Inc., Walnut Creek, CA., Part 12256001) containing 1 g packing/6 mL volume, preconditioned with 2 × 5 mL of methanol and 2 × 5 mL of 0.5% phosphoric acid. Metolachlor was eluted from the SPE cartridge with 15 mL of methanol and collected in a 50 mL concentration tube. The drop rate during SPE using a vacuum aspirator was controlled to about 1 drop/s; thus, the load and elution steps required about 17 and 5 min, respectively. The eluate was evaporated to dryness using a rotary evaporator with a water bath temperature of 30−40 °C, followed by reconstitution to the desired volume (1 mL for the LOQ samples) in *n*-hexane/2-propanol (90:10, v/v). Typically, 12 samples can be prepared as one set (or batch) and analyzed overnight.

Table 1. Characterization Data for the Water Samples Used in the Method Validation

	surface water	ground water
location	High Point City Lake	Macon County, GA
pH	7.3	7.0
calcium (ppm)	7.2	15
magnesium (ppm)	2.8	1.0
potassium (ppm)		2.0
sodium (ppm)	7.2	2.0
sulfate sulfur (ppm)		9.0
nitrate nitrogen (ppm)		<0.10
carbonate (mequiv/L)		0
bicarbonate (mequiv/L)		0.69
chloride (ppm)		2
alkalinity (mg of $CaCO_3$/L)		36
hardness (mg of $CACO_3$/L)	30	43
conductivity (mmhos/cm)	0.12	0.16
sodium adsorption ratio (SAR)	0.58	0.1
total dissolved solids (ppm)	114	110
turbidity (NTU)	3.11	106

Instrumentation. Analyses were performed using a Perkin-Elmer Series 200 liquid chromatograph interfaced via APPI or APcI sources to an Applied Biosystems/MDS Sciex API-365 tandem mass spectrometer. A ChiralPak AS-H, 0.46 cm i.d. × 25 cm column (Chiral Technologies, Exton, PA) maintained at 25 °C was used for separation of the metolachlor diastereomers. The chiral stationary phase (CSP) was amylase tris [(*S*)-1-phenylethylcarbamate] coated on silica gel support (*17*). The mobile phase consisted of *n*-hexane/2-propanol (90:10, v/v) at an isocratic flow rate of 1.0 mL/min with a 1:5 split, 1 part to the mass spectrometer and the rest to waste. The sample injection volume was 50 μL, and the total analysis time was 12.0 min.

A Macintosh 8500 Power PC running MassChrom 1.6 was used to control the instrumentation. Metolachlor has an exact mass of 283.1 amu and was analyzed in the multiple reaction monitoring (MRM) mode using positive polarity with *m*/*z* 284.1 as the protonated precursor molecular ion $(M + H)^+$ and *m*/*z* 252.1 as the product ion. The scan rate was 0.2 s/scan with a dwell time of 200 ms. Toluene was used as a dopant during the APPI analysis to enhance photoionizaion and infused at 0.6 mL/h using a Harvard syringe pump. Typical source operating conditions for APPI were as follows: ionspray voltage, 1300 V; orifice potential, 24 V; ring voltage, 110 V; and source temperature, 400 °C. Because of the risk of explosion when using flammable solvents with a high voltage ion source, nitrogen was used as a nebulizing and curtain gas and the flow was set to 10 (1.2 L/min) for both. Ions were fragmented in a collision cell using nitrogen as a collision-activated dissociation (CAD) gas with collision energy of −20 eV. Operating conditions for APcI were essentially the same, except ionization was by corona discharge using a needle current of 2 μA. The source temperature was lowered to 350 °C, and the nebulizing and curtain gas flow rates were set to 9 (1.18 and 1.08 L/min, respectively).

Sample Analysis. This method was validated as per U.S. EPA-FIFRA Good Laboratory Practices (GLP) guidelines (*18*) at fortification levels of 0.10 and 1.0 ppb in surface and ground waters using five sample replicates at each fortification level. Two additional nonfortified

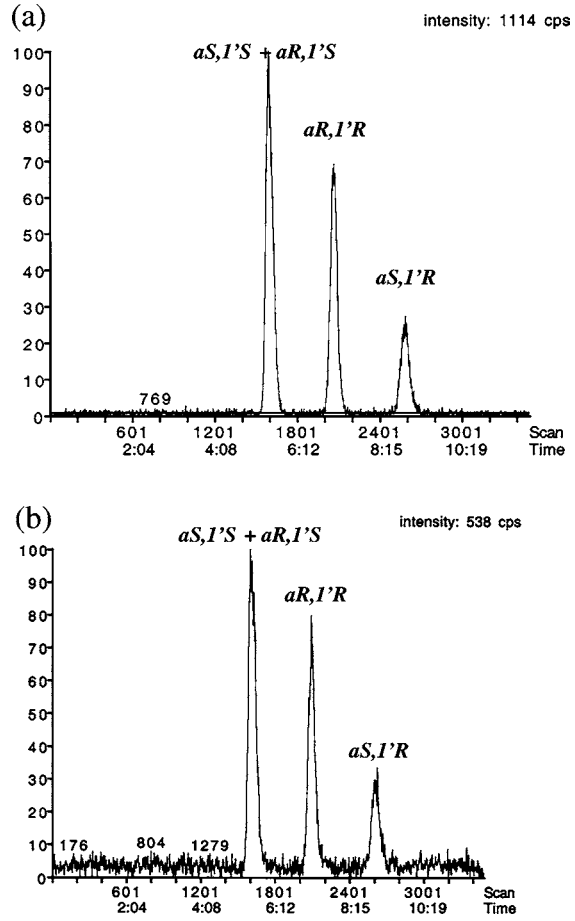

Figure 2. Representative MRM chromatograms of rac-metolachlor calibration standard (0.25 ng on-column) using (a) LC/MS/MS/APPI+ and (b) LC/MS/MS/APcI+.

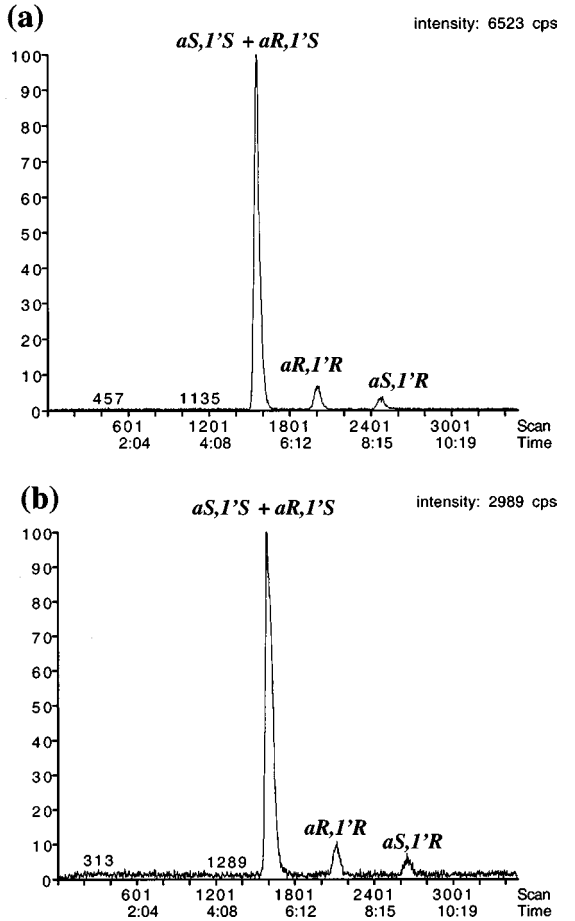

Figure 3. Representative MRM chromatograms of a *S*-metolachlor calibration standard (0.25 ng on-column) using (a) LC/MS/MS/APPI+ and (b) LC/MS/MS/APcI+.

samples served as controls and were analyzed with each sample set. Calibration standards were interspersed throughout each analytical set as a means of checking the system stability and linearity.

Calculations. Metolachlor has two chiral elements that form two pairs of enantiomers as shown in **Figure 1**. The *aS*,1′*S* and *aR*,1′*R* isomers form one pair, while the *aR*,1′*S* and *aS*,1′*R* isomers form the other pair. The 1′*S* and 1′*R* isomer pairs are both diastereomeric and atropisomeric, and for racemic metolachlor, the ratio of the 1′*S* diastereomers ([*aS*,1′*S*] + [*aR*,1′*S*]) to the 1′*R* diastereomers ([*aR*,1′*R*] + [*aS*,1′*R*]) is close to 1 (or 50:50). For *S*-metolachlor, the ratio of the 1′*S* to the 1′*R* diastereomers is approximately 88:12. The chiral separation employed in this method does not resolve the 1′*S* diastereomers; however it does resolve the 1′*R* diastereomers into its atropisomers.

The total metolachlor residue is calculated as per eq 1. The peak areas of the individual isomers are summed, and the total metolachlor residue (in nanograms) is extrapolated from an external standard linear least-squares calibration curve. This total metolachlor residue is used to calculate the individual procedural recoveries for each fortified sample

$$[\text{metolachlor}] = [1'S] + [aR,1'R] + [aS,1'R] \quad (1)$$

where [ ] = peak area.

RESULTS AND DISCUSSION

Chromatography. Representative MRM chromatograms of a 0.005 ng/μL calibration standard (0.250 ng injected on-column), the lowest concentration of standard injected and used to construct the calibration curve [equivalent to the limit of detection (LOD)], are shown in **Figures 2** and **3** for rac- and *S*-metolachlor, respectively, when using APPI and APcI. As can be seen, baseline separation is exceeded ($R_S > 1.5$) for all of the diastereomers, except for the two that comprise *S*-metolachlor. On the basis of the high degree of peak symmetry for *S*-metolachlor, it is apparent that very little or no separation takes place between its diastereomers when using a ChiralPak AS-H CSP column. The difference in enantiomeric composition between rac- and *S*-metolachlor is quite evident when comparing **Figure 2** to **Figure 3** as denoted by the large difference in peak areas for the same diastereomers.

The standard calibration curves extended from 0.250−5.0 ng on-column and the linear regression correlation coefficients (R^2) were 0.99 or higher for all of the calibration curves generated in this study. Each rac- or *S*-metolachlor calibration curve was obtained by summing the areas of the three separated peaks and plotting this value against the total concentration of each standard. Thus, one calibration curve represents the sum of all three peaks (or all four stereoisomers). Note the higher signal-to-noise ratio (S/N) in **Figures 2** and **3** for the chromatograms obtained when using APPI (~10×) compared to those obtained using APcI. Thus, APPI may be the interface/source of choice when sensitivity is an issue for analyzing these compounds. In APPI, a dopant (e.g., toluene) is infused into the system after the analytical column but prior to entrance into the interface/source. Dopants are selected that are easily ionized by the photons generated by the krypton discharge lamp because this charge is quickly and efficiently transferred via ion−molecule reactions with the analyte molecules to create analyte ions. In APcI, primary ions (N2*+ or O2*+) are produced via electron

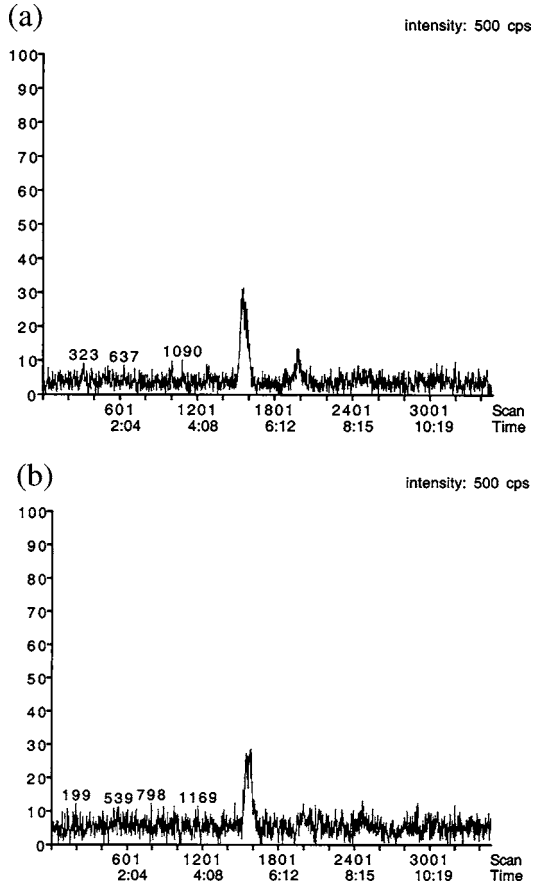

Figure 4. Representative MRM chromatograms of a surface water control sample using (a) LC/MS/MS/APPI+ and (b) LC/MS/MS/APcI+.

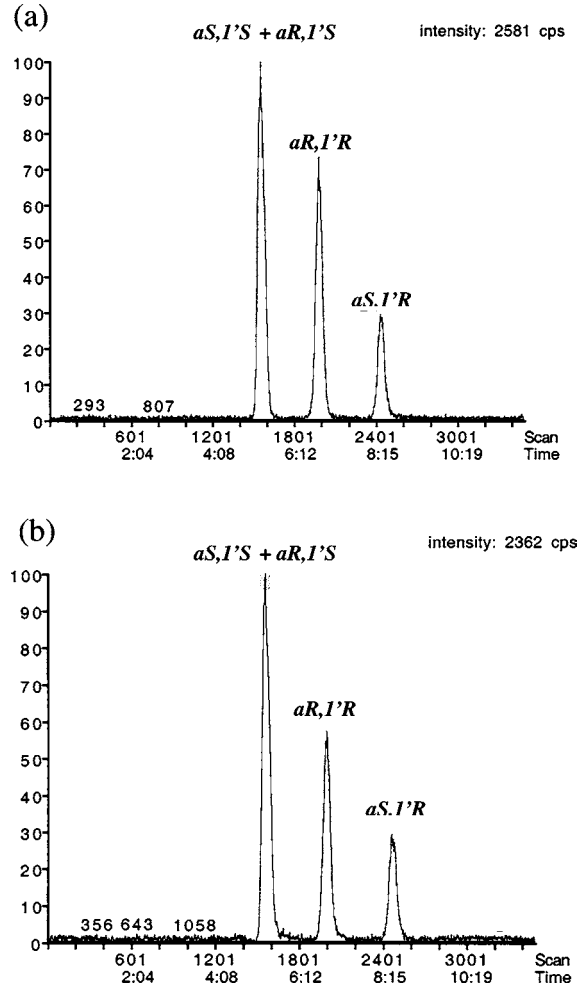

Figure 5. Representative MRM chromatograms of a surface water procedural recovery sample fortified at 0.10 ppb with rac-metolachlor (0.50 ng on-column) using (a) LC/MS/MS/APPI+ (87.3% recovery) and (b) LC/MS/MS/APcI+ (97.1% recovery).

ionization from a corona discharge. These ions collide with vaporized solvent molecules (IPA in this case) to form secondary reactant gas ions. In the positive-ion mode, proton transfer [$(M + H)^+$] or adduction of the reactant gas ion can occur to produce the ions of molecular species, depending upon the relative proton affinities of the reactant ions and the gaseous analyte molecules. For the analysis of metolachlor using the operating parameters described in this work, the dopant-mediated ion transfer process in APPI appears to be more efficient than the chemical ionization process in APcI. In addition, other variables such as the dopant infusion rate (APPI only) and ionization temperature (both APPI and APcI) were adjusted but did not significantly impact the sensitivity of the analyses. The ratio of the diastereomer pairs varied slightly for the two ionization techniques, but differences in peak integration because of the chromatographic baseline noise observed in the APcI MRM chromatograms may have partially contributed to this observation. There was no apparent difference in the detector response between the 1′*S* and 1′*R* diastereomers when analyzed using the same ion source. For normal-phase chiral separations requiring the use of nonpolar solvents, APPI and APcI provide alternative ionization techniques to electrospray, which typically requires mobile-phase modifiers to enhance ionization. Both APPI and APcI offer high sensitivity for LC/MS/MS analysis, most notably in the positive polarity mode (*19*−*20*). Thurman et al. noted that APcI+ is particularly effective for those stable, neutral pesticides that are weakly basic and easily volatilized (*21*).

Representative MRM chromatograms for surface water control samples are shown in **Figure 4**. A small peak (S/N ∼ 3) is obtained by both APPI and APcI; however, its t_R does not match any of the diastereomers of metolachlor, and if it was metolachlor, its concentration would be ≪0.10 ppb and thus insignificant as far as monitoring water at the 0.10 ppb concentration level. The authors chose to show a figure for control surface water because the ground water control sample chromatograms were flat baselines and devoid of extraneous peaks.

Representative MRM chromatograms of control surface water fortified with 0.10 ppb of either rac- or *S*-metolachlor are shown in **Figures 5** and **6**, respectively. The specific recoveries obtained during these analyses are 87.3% (**Figure 5a**), 97.1% (**Figure 5b**), 102% (**Figure 6a**), and 106% (**Figure 6b**), and these numbers are included in the averages shown in **Tables 2** and **3**. The peak areas shown here are twice those shown in **Figure 2** for the 0.25 ng injected standard; thus, there is more than sufficient S/N for unambiguous peak integration and identification of the analytes.

Method Performance. The total metolachlor residue recovered from each fortified sample was calculated by summing the area of the three separated peaks, placing this value into the calibration equation, and extrapolating the metolachlor equivalent mass from the calibration curve. The metolachlor equivalent mass was then divided by the theoretical mass of metolachlor fortified in each sample (0.1 or 1.0 ppb) to calculate the percent recovery. The mean procedural recoveries and relative standard deviations for rac- and *S*-metolachlor obtained using APPI and APcI are listed in **Tables 2** and **3**, respectively. All average recoveries were between 70 and 104%, except for

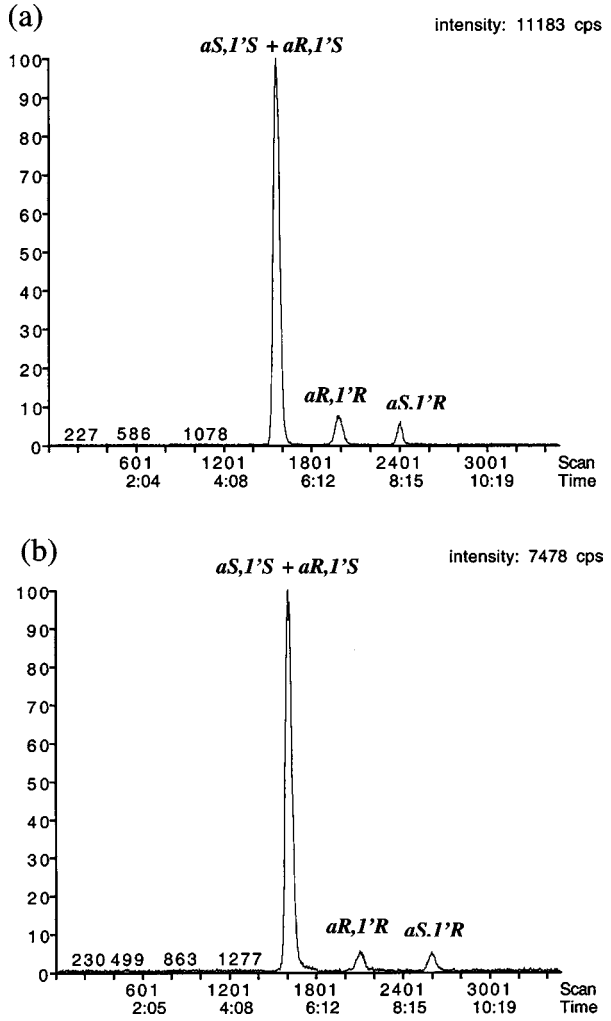

Figure 6. Representative MRM chromatograms of a surface water procedural recovery sample fortified at 0.10 ppb with *S*-metolachlor (0.50 ng on-column) using (a) LC/MS/MS/APPI+ (102% recovery) and (b) LC/MS/MS/APcI+ (106% recovery).

Table 2. Summary of Diastereomeric Ratio and Procedural Recovery (Percent Relative Standard Deviation) for rac-Metolachlor Using LC/MS/MS with Either APPI+ or APcI+

fortification level (ppb)	diastereomeric ratio 1′***S***/1′***R*** (percent relative standard deviation)	procedural percent recovery	
		mean	range
	ground water (APPI)		
0.1 ($n = 4$)	49:51 (4.2)	79.5 (18.8)	62–97
1.0 ($n = 5$)	48:52 (2.8)	76.8 (7.0)	73–86
	ground water (APcI)		
0.1 ($n = 4$)	54:46 (2.8)	87.3 (12.3)	78–95
1.0 ($n = 5$)	50:50 (1.7)	67.0 (1.1)	66–68
	surface water (APPI)		
0.1 ($n = 5$)	48:52 (1.5)	82.4 (8.5)	75–90
1.0 ($n = 5$)	48:52 (2.4)	84.2 (6.4)	79–90
	surface water (APcI)		
0.1 ($n = 5$)	52:48 (0.9)	86.8 (7.8)	79–93
1.0 ($n = 5$)	52:48 (1.1)	83.4 (1.4)	82–85

the 1.0 ppb fortification level (67%) in ground water using APcI. All relative standard deviations were <20% (the highest was 19.0% for surface water using APPI). Overall, the mean percent recoveries (relative standard deviations) for rac- and *S*-metolachlor in the surface and ground water samples were 84 (6.0), 93 (15.1), 78 (9.8), and 83% (8.5%), respectively.

Table 3. Summary of Diastereomeric Ratio and Procedural Recovery (Percent Relative Standard Deviation) for *S*-Metolachlor Using LC/MS/MS with Either APPI+ or APcI+

fortification level (ppb)	diastereomeric ratio 1′***S***/1′***R*** (percent relative standard deviation)	procedural percent recovery	
		mean	range
	ground water (APPI)		
0.1 ($n = 4$)	90:10 (0.9)	78.6 (10.9)	70–90
1.0 ($n = 5$)	90:10 (0.6)	73.0 (6.9)	67–78
	ground water (APcI)		
0.1 ($n = 4$)	89:11 (2.2)	90.6 (12.3)	79–103
1.0 ($n = 5$)	92:8 (0)	89.8 (3.7)	86–94
	surface water (APPI)		
0.1 ($n = 5$)	86:14 (1.9)	98.0 (19.0)	69–121
1.0 ($n = 5$)	89:11 (5.1)	94.8 (11.3)	82–105
	surface water (APcI)		
0.1 ($n = 5$)	89:11 (1.6)	103.8 (11.3)	86–119
1.0 ($n = 5$)	91:9 (0.5)	75.8 (18.7)	54–87

The diastereoisomeric composition of metolachlor in each fortified sample was determined by dividing the area in the 1′*S* peak by the total area of the (1′*S* + 1′*R*) peaks found in the MRM chromatograms. For the ground water samples fortified with rac-metolachlor, the mean ratios of the metolachlor 1′*S* diastereomers to the total (1′*S* + 1′*R*) were 49:51 using APPI and 52:48 using APCI, and for the surface water samples fortified with rac-metolachlor, the mean diastereomeric ratios were 48:52 using APPI and 52:48 using APcI (**Table 2**). Therefore, the 1′*S* to 1′*R* isomer ratio of rac-metolachlor determined by this method is approximately (50:50) ± 2% and close to the expected value for this standard [i.e., enantiomeric excess (ee) is approximately 0]. The mean diastereomer ratios for the *S*-metolachlor fortified ground water samples were 90:10 using APPI and 91:9 using APcI, and for *S*-metolachlor fortified surface water samples, the ratios were 88:12 using APPI and 90:10 using APcI (**Table 3**). Therefore, the 1′*S*/1′*R* isomer ratio of *S*-metolachlor determined by this method is approximately (89:11) ± 2%, and the ee is approximately 78%. This is also well within the expected ratios for the standard used in this study. In formulations incorporating *S*-metolachlor, the ratio of *S*/*R* isomers can vary from 80 to 100% *S* and 20 to 0% *R*. Thus, the method appears to be a useful means of accurately measuring and evaluating the enantiomeric ratio or ee in samples collected in the field.

In this work, the LOD is simply defined as the lowest concentration of standard injected that was used to construct the calibration curve, and the lower limit of method validation (LLMV) is defined as the lowest fortification level studied for procedural recovery purposes (in this case, equivalent to the LOQ). These definitions are conservative when compared to the 3σ and 10σ (standard deviations) for LOD and LOQ of the U.S. EPA. For this method, the LC/MS/MS signal for the samples fortified at the LOQ was significantly higher than 10σ, but further studies and validation would be required to determine just how much lower the LOQ and LOD could be adjusted. It may also be possible to extract a larger sample volume (i.e., >50 mL) to decrease detection limits.

CONCLUSIONS

This GLP-validated enantioselective method can be used to determine the exact diastereomer composition of metolachlor in water-monitoring samples, and this information will be useful in determining whether or not the source of the metolachlor is

from rac- or *S*-metolachlor and the relative combination of each. The method performance fully meets the U.S. EPA FIFRA and OECD requirements that environmental methods demonstrate average recoveries of 70−110% and relative standard deviations of 20% or less at all fortification levels. APPI/APcI−LC/MS/MS, with a chiral column, provides better sensitivity and peak resolution for the analysis of water samples than previously reported methods and is not subject to thermal interconversion of atropisomers as observed with current GC/MS methods. APPI is generally preferred to APcI based solely on sensitivity considerations. This method successfully passed an independent laboratory validation (ILV) study at an outside contract laboratory at the fortification levels described in this paper. Future method development will focus on the chiral analysis of the major degradates of metolachlor, ethanesulfonic acid (ESA) and oxanilic acid (OA).

ACKNOWLEDGMENT

The authors thank Dr. Robert A. Yokley of Syngenta Crop Protection, Inc. for assistance with the preparation of this manuscript.

LITERATURE CITED

(1) U.S. Environmental Protection Agency. Office of Pesticide Programs; Pesticide Registration (PR) Notice 98-7, 1997.
(2) Moser, H.; Rihs, G.; Sauter, H. Der einfluss von atropisomerie and chiralem zentrum auf die biologische aktivitat des metolachlor (in German). *Z. Naturforsch., B: Chem. Sci.* **1982**, *87*, 451−462.
(3) Yokley, R. A.; Mayer, L. C.; Huang, B.; Vargo, J. D. Analytical method for the determination of metolachlor, acetochlor, alachlor, dimethenamid, and their corresponding ethanesulfonic and oxanillic acid degradates in water using SPE and LC/ESI−MS/MS. *Anal. Chem.* **2002**, *74*, 3754−3759.
(4) Vargo, J. D. Determination of sulfonic acid degradates of chloroacetanilide and chloroacetamide herbicides in groundwater by LC/MS/MS. *Anal. Chem.* **1998**, *70*, 2699−2703.
(5) Buser, H. R.; Poiger, T.; Muller, M. D. Changed enantiomer composition of metolachlor in surface water following the introduction of the enantiomerically enriched product to the market. *Environ. Sci. Technol.* **2000**, *34*, 2690−2696.
(6) Jayasundera, S.; Schmidt, W. F.; Hapeman, C. J.; Torrents, A. Influence of the chemical environment on metolachlor conformations. *J. Agric. Food Chem.* **1999**, *47*, 4435−4442.
(7) Garrison, A. W. Probing the enantioselectivity of chiral pesticides. *Environ. Sci. Technol.* **2006**, *40*, 16−23.
(8) Buser, H. R.; Muller, M. D. Environmental behavior of the chiral acetamide pesticide metalaxyl: Enantioselective degradation and chiral stability in soil. *Environ. Sci. Technol.* **2002**, *36*, 221−226.
(9) Buerge, I. J.; Poiger, T.; Muller, M. D.; Buser, H. R. Enantioselective degradation of metalaxyl in soils: chiral preference changes with soil pH. *Environ. Sci. Technol.* **2003**, *37*, 2668−2674.
(10) Muller, M. D.; Poiger, T.; Buser, H. R. Isolation and identification of the metolachlor stereoisomers using high-performance liquid chromatography, polarimetric measurements, and enantioselective gas chromatography. *J. Agric. Food Chem.* **2001**, *49*, 42−49.
(11) Wang, P.; Jiang, S.; Liu, D.; Zhang, H.; Zhou, Z. Enantiomeric resolution of chiral pesticides by high-performance liquid chromatography. *J. Agric. Food Chem.* **2006**, *54*, 1577−1583.
(12) Goss, C. A.; Morgan, D. G.; Harbol, K. L.; Holmes, T. J. Case of enantiomer impurity identification by normal-phase chiral high-performance liquid chromatography with optical rotation and mass spectrometric detection. *J. Chromatogr., A* **2000**, *878*, 35−43.
(13) Klein, C.; Schneider, R. J.; Meyer, M. T.; Aga, D. S. Enantiomeric separation of metolachlor and its metabolites using LC−MS and CZE. *Chemosphere* **2006**, *62*, 1591−1599.
(14) Buser, H. R.; Muller, M. D. Environmental behavior of acetamide pesticide stereoisomers. 1. Stereo- and enantioselective determination using chiral high-resolution gas chromatography and chiral high-performance liquid chromatography. *Environ. Sci. Technol.* **1995**, *29*, 2023−2030.
(15) Yokley, R. A. Syngenta Report number 383-97; Syngenta Crop Protection, Inc.: Greensboro, NC, 1997.
(16) Cheung, M. W.; Yokley, R. A. Report ABR-94094, Syngenta Study number 105-91; Syngenta Crop Protection, Inc.: Greensboro, NC, 1995.
(17) Technical Bulletin (ASH-I-20325-02-4), ChiralPak AS-H; Chiral Technologies: Exton, PA.
(18) U.S. Environmental Protection Agency. Pesticide Programs, Good Laboratory Practice Standard, Final Rule (40 CFR, Part 160); Federal Register, 1989; Vol. 54, number 158, pp 34052−34074.
(19) Geyer, R.; Peacock, A.; White, D.; Lytle, C.; Berkel, G. Atmospheric pressure chemical ionization and atmospheric pressure photoionization for simultaneous mass spectrometric analysis of microbial respiratory ubiquinones and menaquinones. *J. Mass Spectrom.* **2004**, *39*, 922−929.
(20) Robb, D.; Covey, T.; Bruins, A. Atmospheric pressure photoionization: An ionization method for liquid chromatography−mass spectrometry. *Anal. Chem.* **2000**, *72*, 3653−3659.
(21) Thurman, E. M; Ferrer, I.; Barcelo, D. Choosing between atmospheric pressure chemical ionization and electrospray ionization interfaces for the HPLC/MS analysis of pesticides. *Anal. Chem.* **2001**, *73*, 5441−5449.

Received for review April 26, 2006. Revised manuscript received June 30, 2006. Accepted July 3, 2006.

JF061186+