Bull. Environ. Contam. Toxicol. (1995) 54:848–854

Environmental Contamination and Toxicology

Monitoring Herbicide Leaching in Sustainable Vegetable Culture Using Tension Lysimeters

M. E. Byers,[1] D. Tyess,[2] G. F. Antonious,[1] D. Hilborn,[1] L. Jarret[3]

[1]Community Research Service, Kentucky State University, Frankfort, Kentucky 40601, USA
[2]Agronomy Department, University of Nebraska-IANR, Lincoln, Nebraska 68583, USA
[3]United States Department of Agriculture–Soil Conservation Service, Lexington, Kentucky, USA

Received: 16 April 1994/Accepted: 6 December 1994

In Kentucky, "Best Management Practices" (BMP) are recommended for use in sustainable agricultural systems to retard soil, water, and pesticide loss, and therefore preclude non-point source pollution of surface water systems (Anonymous 1989). These practices may include landscape feature alterations which are designed to prevent surface water pollution, but may increase infiltration. If herbicides are used in these production systems, their movement in surface water may be prevented, but their potential to leach may increase. Herbicides used in conventional agriculture may move from the site of application to ground water (Leonard and Knisel 1988, Helling 1986). At least 17 pesticides have been detected in groundwater samples collected from a total of 23 states and about half of these chemicals were herbicides (Cohen et al. 1986). To determine leaching potential, herbicides can be monitored using tension lysimeters. Lysimeters have been used to collect soil percolate since the early 1960's due to their ability to render adequate volumes of water, low failure rate, and minimal alteration of the soil environment (Angle et al. 1991).

The herbicide Command®, commonly known as clomazone, [2-(2-chlorophenyl)methyl-4,4-dimethyl-3-isoxazolidinone], with vapor pressure of 1.44 x 10-4 mmHg, and due to water solubility of 1100 ppm (Carlson 1985) may be suitable for tension lysimeter sampling. Clomazone is a selective pre-emergence herbicide used for weed control in soybeans (Carlson 1985, Warfield et al. 1985) and certain vegetable crops. A paucity of data exists describing clomazone dissipation following soil application. Clomazone has been shown to move off-site by vapor drift (Halstead and Harvey 1988, Thelen et al. 1988) and it may persist in soil (15-cm) for up to three years (Loux et al. 1989). On the other hand, Gallandt et al. (1989) found that clomazone residues on two Montana loamy soils should not carry over and adversely affect wheat production. The use of tension lysimeters to monitor clomazone movement through the vadose zone to depths of 1.5-m in vegetable culture, where BMP's have been implemented has not been published to our knowledge. The objectives of this study were to: 1) determine if tension lysimeters were useful for sampling clomazone, and 2) measure clomazone from vadose zone waters as affected by

Correspondence to: M. E. Byers

soil and water conservative management techniques.

MATERIALS AND METHODS

Field plots were located at the KSU Research Farm, Franklin County, Kentucky. Plot soils were classified in 1990 and found to be fine, silty Lowell Series with 5% organic matter in the control zone, and to be uniform throughout the plot area. Field plot dimensions were 22.0 x 3.7 m (n = 3), and the entire planting site was on a 10% grade. Each plot was planted with green bell pepper transplants (Lady Belle) on June 22. Pepper transplants were spaced every 0.37 m with 10 plants per row. Plots contained ten rows oriented on the contour of the slope. Each plot contained one of three soil management practices; black plastic mulch (1.22 m plastic, 0.91 m exposed, Holland Mulch Layer Model 1275, Holland, MI, 49423), living turf mulch between rows (tall fescue, Kentucky 31), and no mulch (conventional roto-tilled soil). Plots were separated using 15.2-cm plastic edging (Warp's Easy Edge, Warp Bros., Chicago, IL 60651) that was buried to a depth of 10.2 cm. Clomazone was applied at 1.1 kg A.I./ha on June 16, 1992.

Clomazone infiltration was monitored using pressure-vacuum lysimeters (Model 1920, Soil Moisture Equipment Corporation, Santa Barbara, California). Lysimeters were installed on August 8, 1991 according to manufacturer's recommendations using soil coring equipment. Installation included packing silica gel around the ceramic tip, placing the lysimeter into the bore-hole, backfilling with bore-hole soil in reverse order of removal from the borehole, tamping, and capping the borehole with bentonite. Lysimeters were allowed to acclimate for 1 yr prior to sampling. Within each plot treatment, lysimeters were installed at depths 0.3, 0.6 and 1.5 m, with three lysimeters at the top, middle and bottom. Therefore, there were a total of nine lysimeters per each plot treatment. Samples were drawn monthly using acid washed, borosilicate amber bottles (946 ml). Prior to sampling, vacuum was applied to each lysimeter using a vacuum/pressure pump (Pressure Pump Model C, Soil Moisture Company, Santa Barbara, Calif). At the time of vadose zone water sampling, water volumes were recorded and samples transported immediately to the laboratory (15 minutes transport time). Sample volumes varied depending on available soil moisture. In the laboratory, samples were stored in the dark at 4°C until extraction.

Extraction of clomazone from vadose zone water was performed on samples ranging in volume from 50 to 400 ml. Clomazone was separated from vadose zone water samples by partitioning into hexane. Water samples were extracted three times by shaking for 60 seconds with 60, 30, and 20 ml hexane. Hexane fractions were combined, passed through anhydrous sodium sulfate, and concentrated to near dryness using a rotary evaporator (Buchi Rotavapor Model 461, Switzerland). Samples were reconstituted to 15 ml with hexane and then transferred to a sample vial for nitrogen (99.995 purity) stream concentration to 1 ml.

Prior to vadose zone water sample evaluation, extraction efficiencies were determined by spiking 100 ml water samples (n=6) with 3 ug clomazone. The influence of potential chemical differences in water samples from different depths was determined by field spiking samples from the three treatments at each of three depths. To determine storage stability, field spiked vadose zone water samples were tested at 1, 7, and 14 days post-sampling. To determine the efficiency of transfer of clomazone through lysimeters, clomazone spiked water at 1 ug/ml concentration was drawn through a lysimeter in the laboratory and the concentration within the lysimeter was compared to the concentration in the water outside the lysimeter. Clomazone was extracted from spiked water according to the above procedure, concentrated, and analyzed.

Analysis of concentrated samples was accomplished using gas-liquid chromatography (GLC) and GLC coupled mass spectrometry (GC-MS). Samples were injected (1-ul) into GLC (HP Model 5890, Hewlett Packard Co., Palo Alto, CA) equipped with a nitrogen-phosphorus detector (NPD). Injector, oven and detector temperatures were 250, 180 and 250°C, respectively. An HP-1, 15 m, 0.53 mm i.d., megabore column was used (Hewlett Packard Co. Palo Alto, CA). Carrier gas was helium, and flow was set at 17 ml/min. Analysis included a determination of minimal detectable quantity (0.01 ppm) and determination of retention time (2.58 min) under the analytical conditions. All analyses were conducted using external standards to generate a standard curve. Linear regression analysis of raw data regressing over known concentration was performed, and unknown average peak areas were compared to the standard curve. GC-MS analysis included using an HP 5971A Mass Selective Detector (MSD, Hewlett Packard Corp., Palo Alto, CA) in electron ionization (EI) mode. Both inlet and detector temperatures were set at 25°C. Oven temperature was programmed from 75 (hold 1 min) to 235°C (hold 15 min), at 20°C per min. An HP-1, 12 m, 0.23 mm id column was used (Hewlett Packard Co., Palo Alto, CA). Data was analyzed using an analysis of variance (SAS Institute 1988). Least squares means and standard errors are presented.

RESULTS AND DISCUSSION

Lysimeters were determined to have a mean clomazone transfer efficiency of 82%(+/-9). Clomazone transferred through the ceramic tip and was minimally affected by other lysimeter materials. Clomazone has a relatively high solubility in water and therefore did not adsorb to plastic lysimeter walls. On the other hand, compounds such as atrazine [6-chloro-N-ethyl-N (1-methylethyl)-1,3,5,-triazine-2,4-diamine] tend to adsorb to inner wall of PVC lysimeters (Angle et al. 1991). Suction lysimeter transfer efficiency should always be proven for analytes of interest.

Tests to determine efficiency of liquid/liquid extraction of water samples yielded recoveries of 90%(+/-5). This is in agreement with data found by FMC researchers using similar procedures (Anonymous 1986). There were no differences in transfer efficiencies for field spiked samples from day 1 through

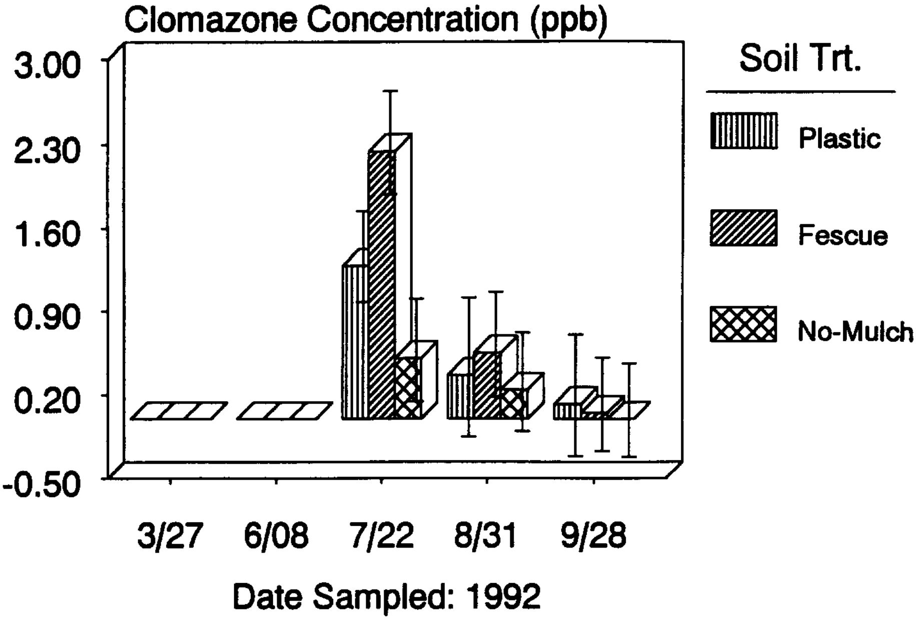

Figure 1. Influence of soil treatment and sampling date over all depths on concentration of clomazone in tension lysimeters.

day 14 and all approximated 90%. Samples were considered to be stable during a 14-day storage, which was the maximum storage time during this study. For samples drawn in the three treatment plot areas, no differences in extraction efficiencies existed and all approximated 90%.

The influence of sampling date on clomazone concentration in suction lysimeters is shown in Figures 1 and 2. No clomazone was detected on either the 3/27/92 or 6/08/92 sampling dates, which was prior to the 1992 date of application. Clomazone had been applied to these plots during 1991 and it was necessary to determine if there was residual herbicide present since published data indicated the potential for carry over (Loux et al. 1989). By 7/22/92, there existed sufficient available soil moisture to sample the vadose zone, and clomazone was detected. Prior to each post application sampling rainfall occurred. Rainfall and intensities were 4.8 and 3, 0.6 and 0.4, 4.3 and 2.8, and 2.2 cm and 0.9 cm/hr on 7/22, 7/31, 8/28, and 9/18, respectively. Significantly ($P>0.05$) greater infiltration occurred in the fescue soil treatment on 7/22/92 relative to the plastic mulch and no-mulch treatments, but by 8/31 differences were not statistically significant . Landscape features such as elephant grass have shown to preclude runoff and conserve soil and water (Thomas 1988). Fescue strips and plastic mulch installed on the contour would act similarly in reducing runoff and appeared to increase infiltration.

All clomazone concentrations in all treatments decreased with time (Figure 2). Over all treatments, mean concentrations at depths of 0.3 and 0.6 m significantly

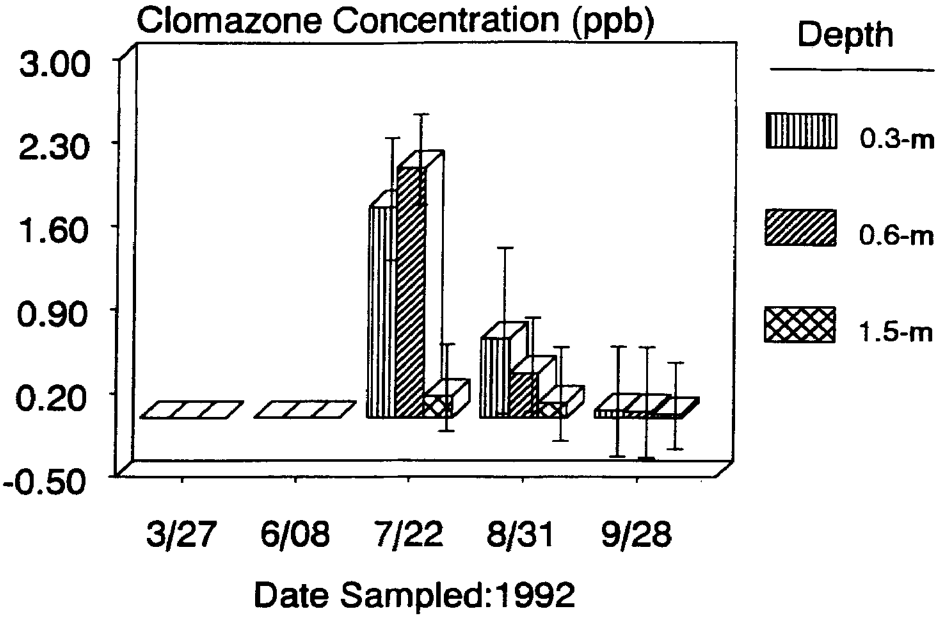

Figure 2. Influence of soil depth and sampling date over all soil treatments on concentration of clomazone in tension lysimeters, Kentucky State University Research Farm, Franklin County, Kentucky, 1992.

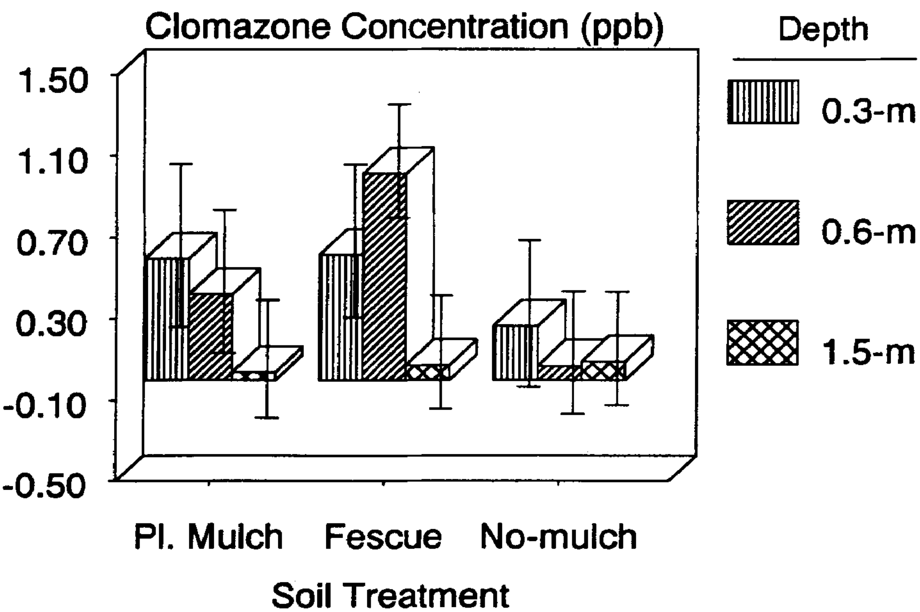

Figure 3. Influence of soil treatment and depth over all dates sampled on concentration of clomazone in tension lysimeters, Kentucky State University Research Farm, Franklin County, Kentucky, 1992.

exceeded concentrations at 1.5 m ($P<0.001$) on 7/22/92. Mean concentrations at all depths decreased to > 0.06 ppb by 9/28/92. Mean concentrations in lysimeters at 1.5 m never exceeded 0.21 ppb. Clomazone was applied and

incorporated to yield a concentration of approximately 1.1 ppm (1.1 kg A.I. / 1.2 million kg soil per ha/15-cm). Mean concentrations of clomazone in lysimeters were in the sub-ppb range at 1.5 m. Therefore, from 0.3 to 1.5 m soil depth, a three order of magnitude decrease in clomazone concentration was observed. By 49 d post application, Loux et al. (1989) found no clomazone in Cisne silt loam soil cores below 7.5 cm, however, they did find clomazone below 7.5 cm depth at 150 d in the Drummer silty clay loam.

The influence of soil depth and soil treatment on clomazone concentration was determined across all sampling dates (Figure 3). For the fescue soil treatment, significant differences ($P<0.001$) between mean clomazone concentrations at 0.6 m depth and 1.5 m depth existed. Mean concentrations of clomazone in lysimeters decreased in plastic mulch soil treatments to 0.04 ppb at 1.5 m, although concentrations at this depth were not found to be significantly different from other concentrations. The no-mulch soil treatment yielded mean concentrations of clomazone in lysimeters of < 0.26-ppb at 0.3 and 0.6 m, and 0.09 ppb at 1.5 m.

The use of landscape features to retain the soil bank and enhance the long-term viability i.e. "Sustainability" of agricultural lands has been thought to increase infiltration of water and, perhaps infiltration of agricultural chemicals. Conservation tillage systems have volumetric water contents which exceed those of conventional tillage (Lindstrom et al. 1984). However, increased biological activity in conservation systems has been suspected to reduce persistence of agricultural chemicals in the vadose zone (Dao 1987). In the present study, movement through the vadose zone in the most conservative soil treatment (fescue) was greater than conventional tillage (no-mulch). However, the fescue treatment mean clomazone concentrations were very low and only traces at any depth were detected by September 28, 1992. There are no data that describe the impact of ppb and sub-ppb concentrations of clomazone on environmental or human health.

Acknowledgments. We thank Dr. D.R. Layne for critical review of this manuscript. We appreciate the assistance of the United States Geological Survey for preparing and installing lysimeters, and funding undergraduate research assistants. This research was supported by USDA grants to Kentucky State University - Community Research Service, under agreements KYX-10-90-16P and 91-38814-6259.

REFERENCES

Angle JS, McIntosh MS, Hill RL (1991) Tension lysimeters for collecting soil percolate. In: Nash RG and Leslie AR (eds) Groundwater residue sampling

design. ACS Sym Ser 465. Am Chem Soc Washington, DC, p290-299
Anonymous (1986) Command herbicide water residue method. FMC Corporation. Agricultural Chemical Group. Princeton, NJ
Anonymous (1989) Ketucky Nonpoint Source Management Program. Commonwealth of Kentucky, Natural Resources and Environmental Protection Cabinet, Division of Water. Frankfort, Kentucky
Carlson DB (1985) Command Herbicide-chemical data. FMC Corp, Philadelphia, Pennsylvania
Cohen SZ, Ciden C, Lorber MN (1986) Monitoring ground water for pesticides. In: Garner WY, Honeycut RC, Nigg HN, (eds) Evaluation of pesticides in ground water. ACS Sym Ser No 315, Am Chem Soc, Washington, DC, p170
Dao HD (1987) Behavior and subsurface transport of agrochemicals in conservation systems. In: Fairchild DM (ed) Ground water quality and agricultural practices, Lewis Publishers, Chelsea, Michigan, p 175
Gallandt ER, Fay PK, Inskeep WP (1989) Clomazone dissipation in two Montana soils. Weed Technol 3:146-150
Halstead SJ, Harvey RG (1988) Effect of rate and carrier on clomazone movement off-site. Weed Technol 2:179-182
Helling CS (1986) Agricultural pesticides and ground water quality. Proc Ag Impacts on Ground Water Quality Conf. August 11-13. Omaha, Nebraska
Leonard RA, Knisel WG (1988) Evaluating groundwater contamination potential from herbicide use. Weed Technology 2:207-216
Lindstrom MJ, Vorhees WB, Onstad CA (1984) Tillage system and residue cover effects on infiltration in northwestern corn belt soil. J Soil and Water Conserv 39:140-143
Loux MM, Liebl RA, Slife FW (1989) Availability and persistence of imazaquin, imazethapyr, and clomazone in soil. Weed Science 37:259-267
SAS Institute (1988) SAS/STAT User's Guide Release 6.03. SAS Institute, Campus Drive, Cary, North Carolina
Thomas GW (1988) Elephant grass for soil erosion control and livestock feed. In: Moldenhauer WC and Hudson NW (eds) Conservation farming on steep lands, Soil and Water Conserv Soc, Ankeny, Iowa pp 188-193
Thelen KD, Kells JJ, Penner D (1988) Comparison of application methods and tillage practices on volatilization of clomazone. Weed Technol 2:323-326
Warfield TR, Carlson DB, Bellman SK, Cuscar HL (1985) Weed control in soybeans using Command. Weed Sci Abstr 25:105