

LEACHING OF 2,4-D AND DICAMBA FROM HOME LAWNS

A. J. GOLD, T. G. MORTON, W. M. SULLIVAN, and J. McCLORY

Departments of Natural Resources Science and Plant Science, University of Rhode Island, Kingston,
RI 02881-0804, U.S.A.

(Received May 15, 1987; revised October 5, 1987)

Abstract. Leaching of the broadleaf herbicides 2,4-D and dicamba from home lawns was monitored with ceramic extraction plates placed at a 0.2 m depth beneath undisturbed sod. The site was located on a Merrimac sandy loam. Four treatments, consisting of two rates of herbicide applications coupled with two irrigation regimes, were evaluated on 12 plots. The low herbicide rate consisted of 1.1 and 0.1 kg ha⁻¹ yr⁻¹ of 2,4-D and dicamba, respectively. The high rate used was 3.3 and 0.33 kg ha⁻¹ yr⁻¹ of 2,4-D and dicamba applied in three equal applications. Irrigation treatments were (1) minimal irrigation to avoid drought stress and percolation from the root zone and (2) overwatering at 37.5 mm week⁻¹. Geometric mean concentrations of 2,4-D ranged from 0.55 to 0.87 µg L⁻¹ compared to 0.26 to 0.55 µg L⁻¹ for dicamba. The low application-minimum irrigation treatment generated significantly higher concentrations than the other treatments for both herbicides. The low concentrations observed for both herbicides suggest that excellent degradation conditions exist in the root zone of turfgrass during the summer months when application occurs.

1. Introduction

Two of the most common herbicides used on home lawns are the phenoxy herbicide 2,4-D (2,4-dichloro-phenoxyacetic acid) and the benzoic acid herbicide dicamba (2-methoxy-3, 6-dichlorobenzoic acid). These herbicides are surface applied by homeowners and commercial lawn care companies to control broadleaf weeds such as dandelions (*Taraxacum officinale*) and plantain (*Plantago rugelii*). 2,4-D and dicamba are considered to be among the most mobile pesticides in soil (Helling and Turning, 1968). They have been found to leach in sandy soils and in soils low in organic matter (Bailey and White, 1970; Harris and Warren, 1964; Ogle and Warren, 1954; Weise and Davis, 1964). Miller *et al.* (1974) in their study of groundwater contamination in the Northeastern States, stressed the need for long term studies to determine if home lawn agrichemicals have penetrated the soil zone and entered the groundwater system. The Federal drinking water standard for 2,4-D is 0.1 mg L⁻¹ (EPA, 1976). The EPA recommended maximum advisable level for dicamba in drinking supplies is 0.0125 mg L⁻¹ (Baker, 1985).

White *et al.* (1976) reported little movement of 2,4-D in either subsurface or surface water flow with approximately 100 cm of simulated rainfall per year. Rapid decomposition could explain the low concentrations observed. During the growing season 2,4-D in the soil is usually broken down within 4 to 6 weeks. Dicamba is more persistent in the soil with an active life of 3 to 6 mo; however, degradation begins immediately and soil levels have been found to decrease markedly within the first month (Friesen, 1965).

Any management practice that enhances the probability of water loss immediately after herbicide application could promote off-site contamination. Home lawns are

typically watered without regard for soil moisture status or the water holding capacity of the soil. Excessive watering will increase antecedent soil moisture, thereby promoting leaching and surface water runoff from natural storm events or from the supplemental water alone.

Reapplication of a herbicide during the growing season may maintain high concentrations of the herbicides in the soil that can be transported with water leaching from the site. Nicholaichuk and Grover (1983) found fall applications can result in marked increases in off-site losses of 2,4-D since the rate of microbial degradation slows in cooler weather. The specific objective of this study was to determine the effect of multiple application rates and overirrigation on soil water percolate losses of 2,4-D and dicamba from the root zone of home lawns.

2. Materials and Methods

2.1. SITE DESCRIPTION

Twelve hydrologically isolated plots (2.1×15.2 m) were established at the University of Rhode Island to monitor surface and subsurface water loss from turfgrass. Soil type at the site was a Merrimac sandy loam (sandy, mixed, mesic Typic Dystrochrept). The organic matter content in the upper 20 cm was 2%. Slope on the plots was 2 to 3% with no cross slope.

A mixture of bluegrass and fescue was planted on the site during Fall 1980. The sod was greater than 90% Kentucky Bluegrass (*Poa pratensis* L.) at the onset of the study. To simulate home lawn management, a complete fertilizer was routinely applied. The turfgrass was maintained at a 5.0 to 7.5 cm height, and the clippings were left on the plots. Throughout the study a continuous layer of dead thatch 1.0 to 2.0 cm thick blanketed the surface soil.

A combination of two rates of herbicide application and two irrigation regimes was monitored. Herbicide application began in June 1984 and continued through 1986. Monitoring and analysis were conducted from July 1985 through November 1986 to avoid any anomalies that may have arisen during the first season of application.

2.2. HERBICIDE APPLICATION

The herbicides 2,4-D and dicamba were applied in a manufactured mixture of Trimec[®] (marketed by PPI Gordon, Kansas City, MO) as a liquid mix at a spray rate of 0.12 L m^{-1} . Two application rates of herbicides were compared. The low rate consisted of a single application in June of 1.1 kg ha^{-1} 2,4-D and 0.1 kg ha^{-1} of dicamba. This treatment simulates the standard practice of commercial lawn care companies. The high rate consisted of $3.3 \text{ kg ha}^{-1} \text{ yr}^{-1}$ and $0.33 \text{ kg ha}^{-1} \text{ yr}^{-1}$ for 2,4-D and dicamba, respectively. The high rate resulted from 3 applications per year occurring in April, June, and September. The quantity of herbicide used during each application was 1.1 kg ha^{-1} 2,4-D and 0.1 kg ha^{-1} dicamba. Both herbicides were applied in the amine salt form.

2.3. IRRIGATION SYSTEM DESIGN

Plots were irrigated at two rates. They were (1) a minimal irrigation regime sufficient to minimize drainage and to avoid moisture stress, and (2) a rate to simulate overwatering. Tensiometers were placed in selected plots to monitor soil moisture status. On the minimal irrigation plots, irrigation was initiated when soil water tension measured at the 10 cm depth by tensiometers reached 0.05 MPa. Based on the soil moisture characteristic curve, 1.2 cm of water were applied at each irrigation to return the soil to field capacity (0.01 MPa) while preventing drainage from the root zone. The rate chosen to simulate overwatering was three applications of 1.25 cm each ($3.75 \text{ cm week}^{-1}$), regardless of rainfall. This irrigation depth represents the mean maximum weekly evapotranspiration rate in Rhode Island during the summer months (NOAA, 1982). Irrigation was applied from July 1 to October 8, 1985 and from June 1 to October 1, 1986.

A subsurface sprinkler head system was used to irrigate the study site. Application rate was 5 cm hr^{-1} . Uniformity of application was measured at greater than 90%. Half and quarter circle, flat spray nozzles were employed to ensure controlled isolated applications. In addition, plots receiving different irrigation rates were separated by 1.5 m sod buffers.

2.4. SAMPLING DEVICES

Ceramic lysimeter plates purchased from Soil Moisture Inc., CA were used to measure the flux and quality of soil water percolate. These plates were 27 cm in diameter with a 0.05 MPa air entry value. Soil water percolate samples were collected into PVC vacuum reservoirs standpipes inserted to a depth of 70 cm. Prior to installation the plates and PVC collection reservoirs were rinsed repeatedly with HCl and deionized water as described by Miller (1977).

The soil moisture plates were placed 20 cm below the thatch layer where an abrupt textural change between sandy loam and coarse outwash deposit exists. The depth of root penetration was observed to extend to 15 cm. Concentrations of herbicides that reached the lysimeters were assumed to approximate the maximum concentrations that would travel to the groundwater. To simulate undisturbed drainage, the plates were maintained at a suction of 0.01 MPa.

Soil water percolate samples were collected following any precipitation or irrigation event which generated soil water percolate. Samples were removed from the collection system at 24 hr intervals for volume quantification and chemical analysis. To reduce analysis, individual samples generated by irrigation were composited weekly for each plot. This compositing produced one sample per plot per week for the irrigated treatments. Any samples not analyzed immediately were frozen at $-10 \text{ }^{\circ}\text{C}$.

2.5. WATER ANALYSIS

A 100 mL subsample of each water sample was acidified by adding 2 mL of concentrated H_2SO_4 and extracted with 50 and 25 mL portions of diethyl ether (Nicholaichuk and

Grover, 1983). The concentrated extracts were esterified with diazomethane followed by solvent exchange with hexane (Cessna *et al.*, 1985). The hexane extracts were analyzed using a Shimadzu 6AM gas chromatograph equipped with a ^{63}Ni electron capture detector. The glass column (2.5 m long by 3 mm id) was packed with 1.5% OV-17 and 1.95% OV-210 on 80/100 mesh Supelco support. The flow rate of 5% CH_4/Ar 99.999% purity carrier gas was 40 mL min^{-1} . Operating temperature for the injection port and detector was 230°C and the column was maintained at 190°C .

To ensure quality control, blanks and known standard samples were passed through the extraction and esterification process. For every twelve extracted samples two duplicates and one distilled water sample were extracted along with the regular samples. Also samples were injected into two different columns in the gas chromatograph and concentrations compared to each other. The percentage recovery for dicamba was 92.3% (SE = 4.1) and for 2,4-D the recovery was 95.7% (SE = 2.0).

Integration of the peaks from standard solutions of dicamba and 2,4-D was performed with a Shimadzu C-R3A integrator. The concentrations of the samples were calculated by extrapolating from the standard line. Because the baseline of the samples was not flat, external standards were injected with approximately 20% of the analyzed samples to maintain the accuracy of the integration. A $1 \mu\text{L}$ portion of the standard dicamba injected directly produced a peak with an area of 26000 ± 1000 while $1 \mu\text{L}$ of the same standard co-injected with a sample increased the peak area by 25000 ± 3500 for dicamba. For 2,4-D, $1 \mu\text{L}$ of standard alone produced an area of 7750 ± 2200 and increased sample signal by 5640 ± 2300 . The lower accuracy of the 2,4-D was due to generally low concentrations and broadening of the peaks during the isothermal run. The detection limits for 2,4-D and dicamba were 0.44 and $0.16 \mu\text{g L}^{-1}$, respectively.

The lysimeter plates and polyethylene storage containers were tested to assess their potential for uptake of the herbicides. Concentrations of 4.4 and $8.2 \mu\text{g L}^{-1}$ of dicamba and 2,4-D, respectively, were passed through the lysimeters. Recovery ranged from 95 to 97%. No attenuation was observed in samples shaken and stored refrigerated in the polyethylene containers for 7 days.

2.6. STATISTICAL ANALYSIS

For each herbicide, data were subjected to analysis of variance procedures using the Statistical Analysis System (SAS Institute Inc., 1982). Significant differences in means were tested using Tukey's hsd method. Within each treatment the mean concentrations of the two herbicides were subjected to a Student's *t*-test. Significant differences for all tests are reported at the 0.05 level.

3. Results and Discussion

3.1. HYDROLOGY

Potential chemical losses depend on the frequency and quantity of leaching. Based on the plate lysimeters, the overwatered plots generated 729 mm of soil water percolate

TABLE I
Number of percolation events generated July 1985–November 1986

	Overwatered treatments	Minimal irrigation treatments
July	7	1
August	15	4
September	12	2
October	4	1
November	3	2
December	0	0
January	2	2
February	0	0
March	0	0
April	0	0
May	0	0
June	11	2
July	12	2
August	13	3
September	13	1
October	2	1
November	2	2
Total events	96	25

compared to 256 mm from the plots receiving minimal irrigation. For the entire study period the number of percolation events per month is displayed in Table I. The minimal irrigation regime produced sporadic percolation events permitting fewer observations of potential chemical losses. Percolation on the overwatered treatment occurred regularly, resulting in frequent collection of soil water percolate throughout the growing season.

3.2. HERBICIDE LOSSES

The frequency of occurrence of varying dicamba and 2,4-D concentrations in soil water percolate is shown in Tables II and III, respectively. Although concentrations ranged from no detect levels to 15 and 38 $\mu\text{g L}^{-1}$ for 2,4-D and dicamba, respectively, the distributions of the concentrations were dramatically skewed toward lower values. For all dicamba treatments, 83 to 95% of the measurements had concentrations less than 1 $\mu\text{g L}^{-1}$, while the 2,4-D treatments had concentrations of less than 1 $\mu\text{g L}^{-1}$ in 54 to 90% of the samples tested.

Given the apparent log normal distributions, geometric mean concentrations were computed and statistical tests were performed on log transformed data (Tables IV and V). For each treatment geometric mean concentrations of 2,4-D were significantly higher than dicamba concentrations on both overwatered treatments and on the high application-minimal irrigation treatment. This increase could be related to the different application rates; 2,4-D was applied at rates 10 fold greater than dicamba.

Based on the results of the mean separation tests the low application-minimal irri-

TABLE II

Frequency distribution of dicamba concentration ($\mu\text{g L}^{-1}$) in soil water percolate (1985 and 1986)

Treatment	≤ 1.0	1-5	5.0-10	> 10
High dicamba High water <i>n</i> = 119	93%	3%	2%	2%
High dicamba Low water <i>n</i> = 44	95%	3%	0	2%
Low dicamba High water <i>n</i> = 134	90%	6%	3%	1%
Low dicamba Low water <i>n</i> = 38	83%	11%	8%	8%

TABLE III

Frequency distribution of 2,4-D concentration ($\mu\text{g L}^{-1}$) in soil water percolate (1985 and 1986)

Treatment	≤ 1.0	1-5	5.0-10	> 10
High 2,4-D High water <i>n</i> = 131	90%	7%	1.5%	1.5%
High 2,4-D Low water <i>n</i> = 47	72%	26%	2%	0
Low 2,4-D High water <i>n</i> = 138	80%	19%	1%	0
Low 2,4-D Low water <i>n</i> = 41	54%	41%	5%	0

gation treatment generated significantly higher concentrations than the high application and overwatered treatments for both herbicides. Several studies have indicated that microbial degradation is accelerated in soils with high moisture content (Burnside and Lavy, 1965; Phillips, 1968). Degradation rate kinetics of 2,4-D have been found to consist of a slow phase and a rapid phase. Parker and Doxtader (1983) found that at 20 to 27 °C soil moisture tensions > 0.01 MPa increased the duration of the slow phase, resulting in reduced degradation. The minimal irrigation treatments routinely had soil moisture conditions associated with prolonged slow phase degradation.

TABLE IV

Seasonal and cumulative geometric mean concentrations ($\mu\text{g L}^{-1}$) of dicamba in soil water percolate

Treatment	Summer ^a 1985 and 1986	Fall 1985 and 1986	Cumulative mean 7/85–11/86
0.33 kg ha ⁻¹ yr ⁻¹ Overwatered	0.23 ^b (n = 88)	0.37 (n = 31)	0.26b ^c (n = 119)
0.33 kg ha ⁻¹ yr ⁻¹ Low water application	0.29 (n = 31)	0.71 (n = 10)	0.34ab (n = 41)
0.11 kg ha ⁻¹ yr ⁻¹ Overwatered	0.27 (n = 91)	0.36 (n = 43)	0.29b (n = 124)
0.11 kg ha ⁻¹ yr ⁻¹ Low water	0.42 (n = 29)	1.62 (n = 9)	0.55a (n = 38)

^a No percolation occurred from the root zone during spring.^b n = number of samples analyzed.^c Means within a column followed by the same letter are not significantly different ($p \leq 0.05$) based on Tukey's hsd test.

TABLE V

Seasonal and cumulative geometric mean concentrations ($\mu\text{g L}^{-1}$) of 2,4-D in soil water percolate

Treatment	Summer ^a 1985 and 1986	Fall 1985 and 1986	Cumulative mean 7/85–11/86
3.3 kg ha ⁻¹ yr ⁻¹ Overwatered	0.51 (n = 96) ^b	0.68 (n = 35)	0.55b ^c (n = 131)
3.3 kg ha ⁻¹ yr ⁻¹ Low water application	0.68 (n = 33)	0.86 (n = 14)	0.72ab (n = 47)
1.1 kg ha ⁻¹ yr ⁻¹ Overwatered	0.62 (n = 88)	0.61 (n = 50)	0.62b (n = 133)
1.1 kg ha ⁻¹ yr ⁻¹ Low water application	0.79 (n = 28)	1.08 (n = 13)	0.87a (n = 41)

^a No percolation occurred during spring.^b n = number of samples analyzed.^c Means within a column followed by the same letter are not significantly different ($p \leq 0.05$) based on Tukey's hsd test.

The high rate treatments, which consisted of reapplication of herbicides at 8 to 11 week intervals may have created and sustained active microbial populations, stimulating rapid breakdown and the subsequent low concentrations in leachate that were observed. No increase in concentrations were observed in the second year of sampling, suggesting that the annual degradation rate precluded accumulations of either herbicide. Lower temperatures have been found to slow microbial degradation and soil water percolate generated in the fall had higher concentrations of both herbicides than summer percolate samples (Tables IV and V).

Because percolation from the minimal irrigation treatments was approximately one-third of that from the overwatered treatments, mass loss of both herbicides from the root zone was less on the minimal irrigation treatments than the overwatered treatments. The low application-overwatered treatment generated the highest losses by mass and percentage of application for both herbicides. The total amount of 2,4-D and dicamba recovered in the percolate from this treatment was 4.5 and 2.1 g, respectively, representing 0.4 and 1.0% of the respective herbicide applied during the study.

The concentrations of dicamba and 2,4-D in soil water percolate parallel the results of previous studies. Baker *et al.* (1985) observed dicamba concentrations in subsurface drainage wells from agricultural fields that ranged from 0 to $6.1 \mu\text{g L}^{-1}$ with a mean concentration of 0.21 and $0.12 \mu\text{g L}^{-1}$ for two separate wells. The pesticide 2,4-D was detected in only one sample at a concentration of $0.40 \mu\text{g L}^{-1}$. White (1976) reported concentrations of 2,4-D of less than $1 \mu\text{g L}^{-1}$ in subsurface leachate.

4. Conclusions

The low concentrations observed for both herbicides suggest that excellent conditions for degradation exist in the root zone of turfgrass during the summer months when application occurs. The decaying thatch-soil interface that develops on bluegrass sod creates an aerobic zone high in usable organic matter that can enhance microbial activity and serve as a potential adsorption site for the herbicides. Given the current water quality standards, routine applications of 2,4-D and dicamba to home lawns do not appear to threaten groundwater quality.

Acknowledgements

Financial support by USDA/Northeast Pesticide Impact Assessment Program and the Rhode Island Water Resources Center is gratefully acknowledged. Contribution from the Rhode Island AES, Kingston, RI 02881 as Journal Paper No. 2382.

References

- Bailey, G. W. and White, J. L.: 1970, *Residue Review* **32**, 29.
 Baker, J. L.: 1985, in F. M. D'Itri (ed.), *A Systems Approach to Conservation Tillage*, Lewis Publ. Inc., Chelsea, MI.
 Baker, J. L., Kanwar, R. S., and Austin, T. A.: 1985, *J. Soil Water Cons.* **40**, 516.
 Burnside, O. C. and Lavy, T. L.: 1965, *Weeds* **14**, 211.
 Cessna, A. J., Grover, R., Kerr, L. A., and Aldred, M. L.: 1985, *J. Agric. Food Chem.* **33**, 504.
 EPA: 1976, *Quality Criteria for Water*, USEPA, Washington, D.C.
 Friesen, H. A.: 1965, *Weeds* **13**, 30.
 Harris, C. I. and Warren, G. F.: 1964, *Weeds* **12**, 120.
 Helling, C. S. and Turner, B. C.: 1968, *Science* **162**, 562.
 Miller, J. H.: 1977, *A Comparison of Cation Sampling in Forest Soils by Tension and Tension-Free Lysimeters*, Final Report Forest Service, pp. 1-24.
 Miller, D. W., Deluca, F. A., and Tessier, T. L.: 1974, *Groundwater Contamination in the Northeast States*, U.S. EPA Office of Res. and Dev. EPA-660/2-74-056.

- Nicholaichuk, W. and Grover, R.: 1983, *J. Environ. Qual.* **12**, 412.
NOAA: 1982, *Technical Paper NWS 33*, p. 51.
Ogle, R. E. and Warren, G. F.: 1954, *Weeds* **3**, 257.
Parker, L. W. and Doxtader, K. G.: 1983, *J. Environ. Qual.* **12**, 553.
Phillips, W. M.: 1968, *Weed Science* **16**, 144.
SAS Institute, Inc.: 1982, *SAS User's Guide: Statistics*, SAS Institute, Inc., Cary, NC.
Weise, A. F. and Davis, R. G.: 1964, *Weeds* **12**, 101.
White, A. W., Asmussen, L. E., Hauser, E. W., and Turnbull, J. W.: 1976, *J. Environ. Qual.* **5**, 487.