From Forest Nursery Notes, Summer 2008

209. Pendimethalin movement through pine bark compared to field soil. Simmons, L. D. and Derr, J. F. Weed Technology 21:873-876. 2007.

Weed Technology 2007 21:873–876

Pendimethalin Movement Through Pine Bark Compared to Field Soil

Lori Duis Simmons and Jeffrey F. Derr*

Preemergence herbicides are commonly applied to nursery containers for control of annual weeds in the production of ornamental plants. Pine bark is a popular container growing medium because it is inexpensive, drains well, is easy to transport, and supports acceptable nursery crop growth. However, little is understood about leaching of herbicides through pine bark. The downward movement of these herbicides through container media may inhibit root growth in sensitive nursery crops and also reduce herbicidal efficacy. Four experiments were conducted at two different irrigation volumes to evaluate depth of pendimethalin movement in packed columns of pine bark and field soil. After 17.5 cm of water was applied over 7 d, pendimethalin moved downward into the 6 to 9-cm depth in 100% pine bark, whereas no movement was detected below the 0 to 3-cm depth in a Tetotum loam soil, as determined by a large crabgrass bioassay. Doubling the irrigation volume to 35 cm of water applied over 14 d did not significantly increase pendimethalin movement in pine bark or field soil. However, it did decrease pendimethalin persistence in the top 0 to 3-cm depth in pine bark. The pine bark had a higher cation exchange capacity than did the field soil. However, the physical characteristics of pine bark, a large volume of void space and low bulk density, resulted in higher hydraulic conductivity rates than in field soil. These factors may be the principal reasons that pendimethalin leached to a greater extent through pine bark than the field soil.

Nomenclature: Pendimethalin; large crabgrass, *Digitaria sanguinalis* (L.) Scop.

Key words: Herbicide leaching, hydraulic conductivity, container media, nursery containers, ornamentals, volume of voids, cation exchange capacity (CEC).

An important means of producing nursery crops is through use of containers. Container growing media is primarily soilless, with pine bark being a common, and sometimes the sole, component. In container production, root growth suppression from dinitroaniline herbicides has been documented in certain shrubs and ornamental grasses (Briggs and Whitwell 2002; Derr and Salihu 1996; Hayes et al.1999; Prevete et al. 1999; Singh et al. 1981, 1984; Thetford and Gilliam 1991). This effect could be due to herbicide leaching into the root zone of nursery crops. There are conflicting results on dinitroaniline movement in field soil and container media as affected by irrigation volume. Oryzalin leached in a Candler sand series to the 1.9- and 4.1-cm depths after application of 3.2 and 12.7 cm of water, respectively (Futch and Singh 1998). Conversely, pendimethalin concentrations in effluent collected from a pine bark : sand mix (6 : 1 by wt), were independent of irrigation volume (Gilliam et al. 1993).

Pendimethalin persistence and movement are influenced by pendimethalin's water solubility and physiochemical characteristics of the growing medium. Dinitroanilines have low water solubilities and high partition coefficients (Webber 1990; Vencill 2002). Soil adsorption of this class of chemicals is related to organic matter content, percent clay, and CEC (Mervosh 2003; Peter and Weber 1985; Weber 1990). Pendimethalin is a neutral compound regardless of soil pH (Nissen et al. 2005), and thus its water solubility is unaffected by pH. The water solubility of pendimethalin is 0.275 mg/L at 25 C (Vencill 2002).

Limited information is available on pendimethalin movement in pine bark. The objectives of this study were to determine pendimethalin leaching in pine bark and field soil at two irrigation volumes, and to relate any differences to physical and chemical properties between the two media.

DOI: 10.1614/WT-06-186.1

* Research Assistant and Professor, Virginia Tech, Hampton Roads Agricultural Research and Extension Center, 1444 Diamond Springs Road, Virginia Beach, VA 23455-3363. Corresponding author's E-mail: jderr@vt.edu

Materials and Methods

General Conditions. Columns were constructed from 35-cm-long sections of polyvinyl chloride pipe with an internal diam of 5 cm. The ends were sealed with threaded caps, and 0.6-cm tubing was used in the center of each cap for drainage. Landscape fabric was placed at the bottom of each end cap. Construction sand was packed in the bottom 4 cm of each column. Next the columns were uniformly packed with 24 cm of pine bark or field soil. Columns were filled with 15 cm of air-dried growing medium, and tapped on a hard surface 30 times. This was repeated until a total of 24 cm of growing medium was uniformly packed into each column. The columns were saturated with water from the bottom up, and allowed to drain for 24 h, at which time the downward movement of water had ceased. Surfaces of the pine bark or field soil columns were then treated with an emulsifiable concentrate formulation of pendimethalin at 3.4 kg ai/ha with the use of a pipette and compared to nontreated columns. After the last water application, the columns were allowed to drain for 24 h. The pine bark or field soil was plunged out in sections into an aluminum dish and then transferred into a 3.8-cm-diam pot. Sections were as follows: 0 to 3 cm, 3 to 6 cm, 6 to 9 cm, 9 to 12 cm, 12 to 18, and 18 to 24 cm from the media surface. Each pot was seeded with 0.6 ml of large crabgrass seed. Two weeks later, large crabgrass root weight and length were recorded. Ten plants were randomly selected. Growing medium was removed by rinsing the roots in water, with manual removal of large bark particles. Plants were blotted on a cloth and root lengths were recorded. Shoot and root were separated and total fresh weights of all 10 plants were recorded. Percent control was calculated by comparing large crabgrass root weight and root length in treated columns to that in nontreated ones.

The experiments were conducted in a greenhouse, with an average high temperature of 28 C and a low of 14 C. Experimental design was a randomized complete block with four replications. Each experiment was repeated. Because there were no significant trial-by-treatment interactions, results were averaged across the two trials. Data were subjected to quadratic regression as well as analysis of variance, and means were separated with the use of Fisher's LSD (P = 0.05). A Student's *t* test (P = 0.05) was used to compare large crabgrass root weights and root length in treated columns to those in nontreated columns.

Leaching in Pine Bark. Soil columns were filled with 100% pine bark. With the use of a buret, water was applied at 2.5 cm per column every day for 7 d after pendimethalin application. The water was applied at a rate of 52 ml in 15 min per column. As described previously, the columns were separated into sections and placed into pots. Large crabgrass was seeded and then harvested.

Leaching in Pine Bark Versus Field Soil at 17.5-cm Irrigation. This experiment was similar to the previous one, except half of the columns were packed with field soil (Tetotum loam [fine-loamy, mixed, thermic Hapludults]) (Hatch et al. 1985) and the other half with pine bark. Half of the columns for each growing medium were treated with pendimethalin and the other half were not treated. Irrigation volume was 2.5 cm of water per day for 7 d after pendimethalin application.

Leaching in Pine Bark Versus Field Soil at 35-cm Irrigation. This study was identical to the previous one except columns were irrigated at a rate of 2.5 cm a day for 14 d after pendimethalin application.

Physical and Chemical Analyses of Pine Bark and Field Soil. Physical analyses included particle size distribution, bulk density, hydraulic conductivity, and volume of voids. Prior to physical analysis, all field soil was air dried and passed through a number-10 sieve (2-mm mesh size). All chemical analyses and percent sand, silt, and clay for field soil were done by the Soils Laboratory, Crop and Soil Environmental Science Department, at Virginia Tech (Mullins and Heckendorn 2005). The following chemical analyses were performed: pH, CEC, percent organic matter, and percent organic carbon. All analyses were repeated.

The field soil and pine bark were put through a series of sieves (4.76 mm, 2.00 mm, 1.00 mm, 0.053 mm) to determine particle size distribution. Amount remaining on each sieve was weighed and percent mass distribution was calculated. Bulk density was determined for pine bark and field soil in the same manner. A container with a known volume was packed with medium, then dry weight was recorded.

Percolation rate/saturated hydraulic conductivity was measured with the use of a modified constant head method (Topp 2002). Columns were packed with either 20 cm of pine bark or with 6 cm of field soil. Columns were saturated from the bottom up for 24 h. A constant head of water was maintained at 7 cm (pine bark) and 10 cm (field soil) with the use of a siphon. Cross-sectional area of each column was 20.3 cm^2. Hydraulic conductivity was calculated with the use of the Darcy equation (Freeze and Cherry 1979).

Table 1. Impact of 17.5 cm of water on pendimethalin movement in pine bark as indicated by a large crabgrass bioassay.

	Large crabgrass	
Depth from surface	Root weight[a]	Root length[b]
Cm	% of nontreated	
0–3	7[c]	7[c]
3–6	39[c]	33[c]
6–9	46[c]	69[c]
9–12	80	88
12–18	91	100
18–24	97	103
LSD (P = 0.05)	11	10

[a] Mean nontreated root weight was 0.11 g. $Y = 0.001x^2 + 0.0807x + 2.582$ ($R^2 = 0.8022$)

[b] Mean nontreated root length was 6.7 cm. $Y = 0.001x^2 + 0.0515x + 2.7887$ ($R^2 = 0.7755$)

[c] Significantly less than the nontreated based on Student's *t* test (P = 0.05).

Volume of voids determines the volumetric distribution of solid, air, and water. Pine bark was placed in 80-cm^3 containers and field soil in a 60-cm^3 containers, and dry weights were recorded. Next the containers were placed in a water bath and allowed to saturate for 24 h, allowing all void spaces to fill with water. The level of water in the water bath was equal to depth of soil in each container. The containers were covered with plastic wrap to prevent upward movement of water caused by evaporation. Each container was placed over a funnel, and all free water was collect for 2 h, at which time drainage had ceased. This volume of water collected represents the water occupying the macropore space, and the volume of water remaining in each container represents the micropore space. Finally, each container was weighed and recorded.

Calculation of volume of voids was as follows:

V_{mac} = volume of free water collected, macropore space

M_{mic} = mass of water remaining in container, micropore space

M_{mic} = dry wt. − wet wt.

ρ_w = density of water

V_v = volume of voids, percent basis

V_t = total volume of container

$$V_v = (V_{mac} + (M_{mic}/\rho_w))/V_t$$

Results and Discussion

Leaching in Pine Bark. Pendimethalin leached into the 6 to 9-cm depth in pine bark after 17.5 cm of water was applied, based on significant reductions in large crabgrass root weights and root lengths for treated columns compared to nontreated ones (Table 1). Stunted roots with swollen tips, consistent with pendimethalin injury, were also noted through this depth (data not shown). There was no significant difference between nontreated columns and treated columns at the 9 to 12-cm, 12 to 18-cm and 18 to 24-cm depths based on the *t* test.

Table 2. Impact of 17.5 cm of water on pendimethalin movement in pine bark and field soil, as indicated by a large crabgrass bioassay.

	Large crabgrass			
	Root weight		Root length	
Depth from surface	Bark[a]	Soil	Bark[b]	Soil
Cm	% of nontreated			
0–3	6[c]	4[c]	11[c]	5[c]
3–6	31[c]	93	29[c]	100
6–9	58[c]	99	67[c]	98
9–12	97	103	90	93
12–18	100	100	104	94
18–24	94	99	105	92
LSD (0.05)	7	7		

[a] Root weight $y = -3 \times 10^{-5}x^2 + 0.1619x + 1.6658$ ($R^2 = 0.6934$).

[b] Root length $y = 0.0015x^2 - 0.0102x + 3.6823$ ($R^2 = 0.8405$).

[c] Significantly less than nontreated based on Student's t test (P = 0.05).

Clubbed roots were not found in those depths, indicating that pendimethalin did not leach below 9 cm. However, large crabgrass root weight and length were significantly less in the 9 to 12-cm depth compared to the 18 to 24-cm depth based on an LSD comparison, suggesting that a small amount of pendimethalin may have leached into the 9 to 12-cm zone. Quadratic regressions were significant for treated root weight ($R^2 = 0.8022$) and root length ($R^2 = 0.7755$).

Leaching in Pine Bark Versus Field Soil at 17.5-cm Irrigation. Pendimethalin movement was not detected past the 0 to 3-cm depth in field soil nor past the 6 to 9-cm depth in pine bark after 17.5 cm of water was applied, based on large crabgrass root weights in treated versus nontreated columns (Table 2). Large crabgrass root lengths in treated pine bark were significantly less in the 9 to 12-cm depth compared to the 12 to 18- and 18 to 24-cm depths, suggesting that a small amount of pendimethalin leached into the 9 to 12-cm depth. A similar finding occurred in the previous study (Table 1). Regression statistics for pine bark found root length ($R^2 = 0.8405$) to be the better predictor of herbicide movement than root weight ($R^2 = 0.6934$). Regressions conducted on field soil results were not significant, indicating no leaching below the 0 to 3-cm depth. Thus, pendimethalin leached deeper in columns of pine bark than in columns of field soil.

Table 3. Impact of 35 cm of water on pendimethalin movement in pine bark and field soil, as indicated by a large crabgrass bioassay.

	Large crabgrass			
	Root weight		Root length	
Depth from surface	Bark[a]	Soil	Bark[b]	Soil
Cm	% of nontreated			
0–3	27[c]	5[c]	17[c]	6[c]
3–6	46[c]	103	36[c]	104
6–9	63[c]	102	57[c]	101
9–12	93	106	89	104
12–18	94	100	93	105
18–24	97	101	96	101
LSD (0.05)	10	8	4	8

[a] Mean nontreated root weight for bark = 0.10 g and soil = 1.5 g. Root weight $Y = -0.256x^2 + 10.24x - 3.113$ ($R^2 = 0.8492$).

[b] Mean nontreated root length for bark = 6.9 cm and soil = 8.0 cm. Root length $Y = -0.2759x^2 + 11.351x - 17.644$ ($R^2 = 0.9517$).

[c] Significantly less than nontreated based on Student's t test (P = 0.05).

Table 4. Particle size distribution of pine bark and field soil.

	Mass distribution	
Particle size	Pine bark	Field soil
Mm	%	
< 0.053	1	10
0.053–1.00	31	61
1.00–2.00	18	29
2.00–4.76	29	0
> 4.76	21	0

Leaching in Pine Bark Versus Field Soil at 35-cm Irrigation. Irrigating the columns with 2.5 cm of water for 14 d did not change the leaching pattern of pendimethalin in pine bark or field soil (Tables 2 and 3). After 35 cm of irrigation, large crabgrass root weights and lengths were significantly less in treated columns for the 0 to 3-, 3 to 6-, and 6 to 9-cm depths in pine bark, and in the 0 to 3-cm depth in field soil, compared to nontreated columns. Large crabgrass root weights and lengths were similar in treated and nontreated columns below the 9-cm depth in pine bark and below the 3-cm depth in field soil. Regression statistics for pine bark again found root length ($R^2 = 0.9517$) to be the better predictor of herbicide movement than root weight ($R^2 = 0.8492$).

No herbicide symptoms were detected below the 0 to 3-cm depth in the field soil (Table 3). Several other studies have also found little to no leaching of dinitroaniline herbicides in field soil (Elliott et al. 2000; Gilliam et al. 1993).

Physical and Chemical Analyses of Pine Bark and Field Soil. Particle size analysis found that the majority of pine bark particles were greater than 1.0 mm in diameter, whereas only 29% of the field soil particles were greater than 1 mm (Table 4). No soil particles were larger than 2 mm, but particles larger than 2 mm constituted 50% of pine bark, by weight. CEC increased with decreasing particle size for pine bark (Table 5). CEC and bulk density for pine bark were 39.32 $cmol^+/kg$ and 0.25 g/cm^3, respectively (Table 6). Others have reported similar results: bulk densities from 0.20 to 0.27 g/cm^3 and CEC from 45 to 97.9 $cmol^+/kg$ (mEq/100 g) (Brown and Pokorny 1975; Daniels and Wright 1988; Grey et al. 1996). On a volume basis, CEC for pine bark was approximately twice that of the field soil. However, on a weight basis, CEC of the pine bark was approximately nine times higher than that of the field soil.

Water movement through pine bark is an important part in understanding chemical transport processes. Saturated hydraulic conductivity or percolation rate measures the rate at which water moves downward through a soil. Percolation rates were 2.0 cm/s and 6.98×10^{-4} cm/s for pine bark and field soil, respectively (Table 6). The pine bark had a much greater volume of air space or macropores (41%) than did the field soil (4%). This combination of a large

Table 5. Physical and chemical properties of different particle sizes of pine bark.

Particle size	Bulk density	CEC[a]	CEC[a]	Organic matter	pH
Mm	g/cm^3	cmol$^+$/kg	cmol$^+$/cm^3	%	
< 0.053	0.37	99.34	0.03656	73.36	5.7
0.053–1.00	0.28	74.92	0.02124	57.94	5.2
1.00–2.00	0.24	64.14	0.01511	67.69	5.3
2.00–4.76	0.23	50.15	0.01150	71.96	5.2
4.76>	0.21	30.09	0.00619	71.35	5.0

[a] Abbreviation: CEC, cation exchange capacity.

Table 6. Physical and chemical properties of pine bark and field soil.

Media	Bulk density	CEC[a]	CEC	Organic matter	pH	Percolatio rate	Volume Air	Volume Water	Volume Solid
	g/cm^3	cmol$^+$/kg	cmol$^+$/cm^3	%		cm/s	%		
Pine bark	0.25	39.32	0.00998	63.51	5.1	2.0	41	35	24
Field soil	1.24	4.42	0.00547	3.16	5.5	6.98×10^{-4}	4	47	49

[a] Abbreviation: CEC, cation exchange capacity.

volume of macropores, low bulk density, and few fine particles resulted in high percolation rates, which may be responsible for greater pendimethalin movement in pine bark than field soil.

Pendimethalin leached more readily in pine bark columns than in field soil columns. The majority of the herbicide was contained in the upper 9 cm of pine bark, regardless of irrigation volume. No pendimethalin was detected below the 0 to 3-cm depth in the field soil. The pine bark had a higher capacity to adsorb cations than the field soil. However, physical characteristics, such as high percolation rates and large volume of macropores combined with daily irrigation in container nursery production, make leaching of pendimethalin more likely in pine bark than in field soil.

Literature Cited

Briggs, J. and T. Whitwell. 2002. Effect of prodiamine formulation on injury to ornamentals. Pages 384–388 *in* Southern Nursery Association (SNA) Research Conference Proceedings, Volume 47. Atlanta, GA: SNA.

Brown, E. F. and F. A. Pokorny. 1975. Physical and chemical properties of milled pine bark and sand. J. Am. Soc. Hort. Sci. 100: 119–121.

Daniels, W. L. and R. W. Wright. 1988. Cation exchange properties of pine bark growing media as influenced by pH, particle size, and cation species. J. Am. Soc. Hortic. Sci. 113: 557–560.

Derr, J. F. and S. Salihu. 1996. Preemergence herbicide effects on nursery crop root and shoot growth. J. Environ. Hortic. 14: 210–213.

Elliott, J. A., A. J. Cessna, W. Nicholaichuk, and L. C. Tollefson. 2000. Leaching rates and preferential flow of selected herbicides through tilled and untilled soil. J. Environ. Qual. 29: 1650–1656.

Freeze, R. A. and J. A. Cherry. 1979. Physical properties and principles. *In* Groundwater. Englewood, NJ: Prentice-Hall. Pp. 15–30.

Futch, S. H. and M. Singh. 1998. Use of soil columns as a method to simulate herbicide movement in soil at various rainfall rates. Proc. South. Weed Sci. Soc. 51: 96–97.

Gilliam, C. H, D. Fare, and D. Lecompe. 1993. Herbicide movement in container media. Pages 312–313 *in* Southern Nursery Association (SNA) Research Conference Proceedings, Volume 38. Atlanta, GA: SNA.

Grey, T. L., G. R. Wehtje, B. F. Hajek, C. H. Gilliam, G. J. Kever, and P. Pace. 1996. Adsorption, mobility, and filtration of metolachlor in container media. J. Am. Soc. Hortic. Sci. 121: 478–482.

Hatch, D. R., J. E. Belshan, S. M. Lantz, G. R. Swecker, and D. E. Starner. 1985. Soil survey of Virginia Beach, Virginia. U.S. Department of Agriculture Soil Conservation Series, in cooperation with Virginia Polytechnic Institute and State University. Blacksburg, VA. 131 p.

Hayes, C. K., C. H. Gilliam, G. J. Keever, and D. J. Eakes. 1999. Effects of herbicide and time of application on pampas grass grown in containers. J. Environ. Hortic. 17: 185–189.

Mervosh, T. L. 2003. Sorption of the herbicides isoxaben and oryzalin to soils and container media. J. Environ. Hort. 21: 11–15.

Mullins, G. L. and S. E. Heckendorn. 2005. Laboratory Procedures: Virginia Tech Soil Testing Laboratory. Blacksburg, VA, Virginia Cooperative Extension Publication 452-881 http://www.ext.vt.edu/pubs/cses/452-881/452-881.html#L9 Accessed March 19, 2007.

Nissen, S. J., T. M. Sterling, and D. Momuth. 2005. Root absorption and xylem translocation. Lincoln, NE: Plant and Soil Science eLibrary, University of Nebraska at Lincoln. http://plantandsoil.unl.edu/croptechnology2005/pages/index.jsp?what=topicsD&topicOrder=1&informationModuleId=1057703469. Accessed April 4, 2007.

Peter, C. J. and J. B. Weber. 1985. Adsorption and efficacy of trifluralin and butralin as influenced by soil properties. Weed Sci. 33: 861–867.

Prevete, K. J., G. Legnani, T. Whitwell, and R. T. Fernandez. 1999. Prodiamine tolerance of newly planted ornamentals. Pages 366–369 *in* Southern Nursery Association (SNA) Research Conference Proceedings, Volume 44. Atlanta, GA: SNA.

Singh, M., N. C. Glaze, and S. C. Phatak. 1981. Herbicide response of container-grown Rhododendron species. HortScience. 16: 213–215.

Singh, M., S. C. Phatak, and N. C. Glaze. 1984. Response of two container-grown Ilex species to preemergence herbicides. HortScience. 19: 117–119.

Thetford, M. and C. H. Gilliam. 1991. Herbicide use in propagation: effects on rooting and root growth of stem cuttings. J. Environ. Hort. 9: 21–23.

Topp, G. C. (Ed.). 2002. Methods of Soil Analysis. Part 4. Physical Methods. Madison, WI: Soil Science Society of America. p. 916.

Vencill, W. K. (Ed.). 2002. Herbicide Handbook. 8th ed. Lawrence, KS: Weed Science Society of America. p. 493.

Weber, J. B. 1990. Behavior of dinitroaniline herbicides in soils. Weed Technol. 4: 394–406.

Received November 20, 2006, and approved May 1, 2007.