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Effect of Surfactant on Leaching of Pendimethalin in Florida Candler Fine Sand

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Herbicides are an essential part of modern horticultural and agricultural production systems. For long-term weed control, application of preemergence herbicides is made directly to the soil that is a common medium for growth of crop plants and weeds. Also, when herbicides are applied postemergence, some of the herbicide drifts away from the foliage onto the soil. In light, sandy soils, high precipitation can further increase the chances of herbicide leaching into subsoil profiles, especially if the herbicides are poorly adsorbed, for example, atrazine and simazine (Hall et al., 1989) . Groundwater contamination caused by herbicide leaching is a concern in major agricultural regions of the world (Hallberg, 1988) . Most herbicides are applied at much higher rates than recommended to offset losses that occur from their site of action in the plant root zone.

Preemergence herbicides for weed management in citrus require soil incorporation, either by irrigation or rainfall into the zone of weed seed germination (the top several inches of soil). Soil incorporation is essential for the area under the canopy of citrus trees since mechanical incorporation may potentially damage citrus roots and low volume irrigation lines. Additionally, it is difficult to achieve complete and even distribution of the herbicide by mechanical means under the canopy. In the absence of soil incorporation, herbicide effectiveness is reduced because of volatilization and photodecomposition (Jain and Singh, 1992).

Herbicide leaching is influenced by several factors, including adsorption of herbicides to soil colloids and soil type (Alva and Singh, 1990), uniformity of water flow (Boesten, 1987), water solubility of herbicides, and physicochemical and biological characteristics (soil pH, soil colloids, bulk density, and pore distribution) (Anderson, 1996). When a pesticide enters the soil, some of it will stick to soil particles, particularly organic matter, through a process called sorption. As more water enters the soil through rainfall or irrigation, the pesticide molecules will move down and may enter soil-water through a process called desorption (Hornsby, 1999). For strongly adsorbed herbicides, soil organic matter content is generally the most important factor—the higher the organic content the less leaching. Leaching of weakly adsorbed acidic herbicides, for example, sulfonylureas and imidazolinones, is much greater in high pH soils (Brown and Kearney, 1991) . One of the most useful indices for quantifying pesticide sorption on soils is the partition coefficient (PC), which is defined as the ratio of pesticide concentration bound to soil organic matter particles to concentration that is dissolved in the soil-water. Thus, pesticides with small PC values are more likely to be leached than those with large PC values (Hornsby, 1999). Beyond the nature of the soil and the amount of water that percolates through it, the extent of leaching also depends on the herbicide properties (Weber, 1972, 1987). More than 12 different pesticides have been detected in the groundwater of at least 24 states in the USA as a result of routine agricultural use (Hallberg, 1986).

Approximately 344,000 ha of citrus are cultivated in Florida, which contributes significantly to the state's agricultural revenue (Anonymous, 1996). Florida's climate allows weeds to grow year-round (Singh and Tan, 1992), and efficient control is only achieved by herbicide use that often requires repeated applications (Muraro and Oswalt, 1996). Herbicide leaching may result in damage to citrus

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trees through greater root contact and groundwater contamination, and may result in economic losses caused by reduced herbicide efficacy. The environmental contamination risk from high rates and repeated applications of preemergence and postemergence herbicides may be reduced by low-rate technology herbicides that have effective, long-duration weed control, or by the addition of additives to herbicides.

Prowl®H_2O formulation of pendimethalin herbicide has been registered for application in bearing citrus groves in Florida, and this formulation is effective in controlling weed germination. Florida soils consist of fine Candler sands that vary greatly in organic matter content. Limited information is available on leaching of pendimethalin in Florida fine Candler soils; therefore, this study was conducted to evaluate the effect of surfactant on the leaching potential of Prowl®H_2O under variable rainfall in Florida Candler fine sandy soils.

Materials and Methods

A site was selected near Davenport, Florida, USA, that was formerly a citrus grove but had been free from agricultural crops for more than 15 yr and was known to be free of herbicide residues. This soil is typical of a well-drained ridge soil found throughout Central Florida. Soil samples were collected from the top 4-ft profile (0–12, 12–24, 24–36, and 36–48 in.) of typical, well-drained, fine Candler sand (Hyperthermic, uncoated Typic Quartzipsamments). The soil samples were air-dried for a week to obtain uniform compaction for leaching experiments.

The study was conducted using soil leaching columns made of polyvinyl chloride (PVC) pipe, 137 cm long and 10 cm inner diameter, cut into halves longitudinally. Silicone ridges were placed cross-sectionally at 15 cm intervals along the inner wall to prevent preferential flow of applied herbicide solution along the soil–column interface (Weber et al., 1986). The halves were resealed using an adhesive tape (Professional HVAC tape, Scotch brand) to form a column, and the bottom end was fitted with a PVC cap 10 cm in height with a drainage hole. A nylon screen with Whatman filter paper was placed at the bottom of the PVC cap, and columns were packed consistently by adding soil incrementally from the four depths (36–48, 24–36, 12–24, and 0–12 in.) of the soil profile. The columns secured upright on a wooden platform, were watered to field capacity, and were allowed to drain overnight prior to leaching treatment.

The chemical characteristics of Prowl®H_2O herbicide are: solubility in water at 25°C is 0.275 mg/L, K_{ow} is 15,200. The typical field half-life is 44 d, but the half-life varies with soil temperature and moisture. Mobility of pendimethalin strongly depends on clay and organic matter content, where it is strongly adsorbed. Average organic carbon sorption coefficient (K_{oc}) value of pendimethalin ranges from 13,000 to 17,200 mL/g under clay content of 11.2% to 19.2% and organic carbon from 0.8% to 3.8% (Vencill, 2002) .

Effect of surfactants HM9754 and HM9679 on leaching potential of herbicide Prowl®H_2O (pendimethalin: N-(1-ethylpropyl)-2,6-dinitro-3,4-xylidine) was evaluated. Treatment solutions were freshly prepared treatment solutions (Table 1), were transferred into a 20-mL vial, and were shaken vigorously in a vortex mixer for 1 min. A control replicated column, having no herbicide treatment, was also kept to compare the movement of herbicide into treated columns. The top surface of the soil column was made as a plain uniform surface, and the columns were leveled. Whatman Filter paper No. 4 was placed on the surface, and then a 1.25-cm layer of silanized-grade glass wool was placed on the surface to ensure proper spread and uniform solution flow through the column while leaching was being performed. Leaching was performed by dripping deionized water from a siphon system attached to a 1000-mL Erlenmeyer flask mounted above the column, over the glass wool, to simulate a rainfall of 6.25 and 12.5 cm/ha at 2.5 cm/hr. The flow rate was monitored periodically to ensure uniform leaching. Columns remained intact for 18 hr after application of rainfall treatments and before conducting bioassays. There were three replicated columns for each herbicide and simulated rainfall treatment.

Afterward, columns were split open longitudinally by removing the tape on one side and slicing the soil along the center, starting from the bottom of the column, after removing the PVC cap at the end of the soil column. Three shallow furrows were made on the soil surface, with a distance of 2.5 cm between each furrow, using a one-meter ruler. Winter ryegrass (*Lolium multiflorum* L.) germination is sensitive to any herbicide. Therefore, seeds of winter rye grass as a bioindicator species were planted uniformly in each furrow, and the seeds were covered with adjacent soil (Lavy and Santelmann, 1986). The bioassay columns were mist-irrigated at regular intervals and were fertilized as needed to maintain adequate plant growth. The distance moved by herbicide, as indicated by plant death or injury symptoms exhibited in the growing seedlings in soil columns, was recorded. A recording of the distance moved was made 21 d after planting seeds of ryegrass in column halves, and the distance was averaged to obtain a single observation value for each replicate column.

Experiments were conducted as factorial design with simulated rainfall and herbicide treatments as two factors. Means were separated using Student-Newman-Keuls Test least significant difference (LSD) at $p = 0.05$ (Agriculture

Table 1 Effect of rainfall and surfactants on the leaching of pendimethalin herbicide

Treatments	Herbicide rate lb a.i./ha	Simulated rainfall (cm/ha)			
		6.25	12.5	6.25	12.5
				% reduction in leaching	
Prowl®H_2O	6.60	4.03 ± 0.49b[a]	6.8 ± 0.35a		
Prowl®H_2O + 1 gal HM 9754	6.60	3.03 ± 0.14d	3.53 ± 0.51c	24.8[b]	48.1
Prowl®H_2O + 2 gal HM 9754	6.60	2.31 ± 0.32e	2.43 ± 0.12e	42.7	64.3
Prowl®H_2O + 1 gal HM 9679	6.60	1.67 ± 0.60f	2.28 ± 0.31e	58.6	66.5
Prowl®H_2O + 2 gal HM 9679	6.60	2.15 ± 0.73ef	1.68 ± 0.15f	46.6	75.3
LSD (p = 0.05)			0.43		

[a] Mean distance of herbicide moved ± SD (n = 6); means followed by the same letter across row and column do not differ significantly

[b] Calculated on the basis of distance moved with surfactant over no surfactant

Research Manager statistical package, Gylling Data Management, Inc., Brookings, SD, USA). Both studies had 3 replications and were repeated. Data from the two experiments were combined after performing a test of homogeneity of variance.

Results and Discussion

The soil pH determined was 5 to 6.5 with an organic matter content of 0.3% to 0.8% of different soil profiles. The bulk density determined gravimetrically for each soil depth was 1.56, 1.65, 157, and 1.86 g cm^{-3}. Percent sand, silt, and clay contents were 96.5, 2.0, and 1.5, respectively.

The effect of surfactant incorporation and rainfall treatments on Prowl®H_2O herbicide are presented on the basis of distance moved by herbicide treatment as shown by phytotoxic symptoms appeared on ryegrass germinating seedlings. Weber and Miller (1989) reported that herbicide soil movement is governed largely by the amount and frequency of water applied depending on soil type. In general, leaching of Prowl®H_2O herbicide was increased significantly when the simulated rainfall water increased from 6.25 to 12.5 cm/ha (Table 1). Similar findings were reported by other researchers (Boesten, 1987; Sharma and Singh, 2001) for herbicides other than Prowl®H_2O. Annual rainfall intensity is more likely higher than 10 cm in most areas, but in field conditions rainfall intensity on average may be less than the water application rate in this study. Therefore, it may be possible that the distance moved by the herbicide under the high rainfall condition may be greater than the distance value obtained under 12.5 cm rainfall.

The results indicated that Prowl®H_2O herbicide had some leaching potential, which was indicated by the distance moved under different rates of rainfall treatment. The distances moved by Prowl®H_2O with no surfactant were 4.03 ± 0.49 cm and 6.8 ± 0.35 cm under 6.25 and 12.5 cm rainfall treatments, respectively. Addition of surfactant HM9754 1 gal/ha significantly reduced leaching of Prowl®H_2O under both simulated rainfall treatments by 24.8% and 42.7% under 6.25 cm rainfall (Table 1). Addition of 2 gal/ha HM9754 further reduced leaching of Prowl®H_2O significantly by 48% to 64.3% under 12.5 cm than no surfactant. The value of the distances moved by herbicide Prowl®H_2O with HM 9754 at 2 gal/ha was 2.31 ± 0.32 and 2.43 ± 0.12 cm under 6.25 and 12.5 cm of simulated rainfall, respectively. The differences between two surfactants were not significant but distances traveled under the application of Prowl®H_2O with HM9679 were lower than that of HM 9754 surfactant. A study by Sharma and Singh (2001) reported the different leaching potential of different herbicides, for example, Karmax (low mobility), and Solicam or Milestone (high mobility). Karmax moved from 11.94 cm to 26.2 cm, and Solicam or milestone moved from 19.6 to 100 cm (almost the column length) in the soil as the application of water increased from 6.25 in. to 25 cm.

The data agreed to the values of clay content of the fine Candler sand and organic carbon sorption coefficient (K_{oc}) published in the herbicide handbook (Vencill, 2002), which describes the relative adsorption of herbicide to the soil materials and, hence, its movement in the soil: the lower the number, the greater the potential to leach (Hornsby et al., 1991). The relative adsorption of pendimethalin is high under high clay and organic matter content, and it is extremely low in fine Candler sand; therefore, the distance moved by pendimethalin or its leaching is very low. Low leaching values obtained in this study are in compliance with the soil properties of fine Candler sand. Pendimethalin is soil applied and absorbed by roots and coleoptiles, which explains no postemergence activity of the herbicide on plants (Vencill, 2002). Pesticides with high persistence and a strong sorption rate are likely to remain near the soil surface, increasing the chances of being carried to a stream or lake via surface runoff. In contrast, pesticides with high persistence and a weak sorption rate may be readily leached through the soil and are more likely to contaminate groundwater (Hornsby et al., 1991). Herbicide having K_{oc} value of <100 in sandy soil should be used with caution because of their higher leaching potential (Buttler et al., 1992). Pendimethalin is strongly adsorbed in soils having high clay and organic matter content.

Table 2 Effect of surfactant on the leaching of pendimethalin herbicide when averaged across rainfall treatments

Treatments	Herbicide rate lb a.i./ha	Distance moved (cm)
Prowl®H_2O	6.60	5.41 ± 1.49a[a]
Prowl®H_2O + 1 gal HM 9754	6.60	3.28 ± 0.49b
Prowl®H_2O + 2 gal HM 9754	6.60	2.37 ± 0.24c
Prowl®H_2O + 1 gal HM 9679	6.60	1.97 ± 0.57d
Prowl®H_2O + 2 gal HM 9679	6.60	1.91 ± 0.57d
LSD (p = 0.05)		0.30

[a] Mean distance of herbicide moved ± SD (n = 12); means followed by the same letter do not differ significantly

Further, comparing the rates of water applied in the study revealed that the movement of herbicide increased with the increasing rates of water, which was consistent with the results obtained by Boesten (1987) and Weber and Miller (1989). Incorporation of the surfactant helped to reduce the movement of the herbicide by 39.4% to 64.7% depending on the rate and type of surfactant. When averaged across rainfall treatments, the distance moved by Prowl®H_2O alone was 5.41 cm. There was significant reduction in the leaching of herbicide with the addition of surfactant HM9754 and HM9679 when averaged across the rainfall treatments (Table 2). An increase in the rate of HM9754 to 2 gal/ha, significantly decreases the leaching of Prowl®H_2O. The reduction in leaching of Prowl®H_2O was significantly higher (64.7%) with the addition of HM9679 surfactant than HM9754 (56.2%). There was no difference in leaching between the two rates of HM9679. The average distance moved by rainfall treatments when averaged across the herbicide treatments was 2.20 cm and 2.78 cm at 6.25 cm and 12.5 cm rainfall, respectively.

The effect of surfactant on Prowl®H_2O leaching revealed that Prowl®H_2O does not leach more than 7 cm in Florida Candler fine sand and that the addition of a surfactant further reduced the leaching of Prowl®H_2O. This estimated leaching will provide important information about Prowl®H_2O as compared to the prevailing herbicides. It is important for citrus and other growers to understand this important aspect of the leaching potential of the herbicide they are going to use. Selection of herbicide with minimal leaching potential will avoid groundwater contamination as a result of their application. Hence, this information will be an important factor with regard to the groundwater pollution.

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