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Susceptibility of Florida Candler Fine Soil to Herbicide Leaching

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Groundwater contamination resulting from herbicide leaching is a concern in major agricultural regions of the world (Hallberg 1988). In light, sandy soils high precipitation can increase the chances of herbicide leaching into subsoil profiles especially if the herbicides are poorly adsorbed, e.g., atrazine and simazine (Hall et al. 1989). Preemergence herbicides for citrus require soil incorporation either by irrigation or rainfall to the zone of weed seed germination in the top several inches of soil. This is essential under-tree canopy area of the citrus tree since mechanical incorporation has little potential use due to possible damage to citrus roots, low volume irrigation lines, or difficulties of a complete and even distribution of the herbicide. In the absence of soil incorporation of herbicides their potential effectiveness is reduced due to 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, soil pH, inorganic and organic soil collides, bulk density, and pore distribution (Anderson 1996). When a pesticide enters 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 pesticides 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–higher the organic content less is the leaching. Leaching of weakly adsorbed acidic herbicides, e.g., sulfonylureas and imidazolinones was 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 that 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).

In recent years greater environmental risk awareness has arisen regarding the use of soil applied herbicides. Citrus is cultivated in total of 857,687 acres in Florida and contributes a significant portion of the state's agricultural revenue (Florida Agricultural Statistical Services 1996). Florida's prevalent climatic conditions favor

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weeds to grow actively year round (Singh and Tan 1992). High weed pressure in citrus production adversely affects citrus yield. Only efficient control is achieved by herbicides and repeated applications often required for effective control (Muraro and Oswalt 1996). Leaching of herbicides in the lower layers may cause damage to the citrus tree due to greater root contact, poor weed control, groundwater contamination and economic losses due reduced herbicide efficiency. The environmental contamination risk from higher rates and repeated application of pre-emergence and postemergence applied herbicides could possibly be reduced from the low rate technology herbicides having effective and long duration of weed control.

Azafenidin (Milestone) is a new and low rate pre-emergence applied herbicide. Limited information is available on leaching aspect of Milestone. Therefore, this study was conducted to evaluate leaching potential of 'Milestone' and other pre-emergence herbicides under variable rainfall in a Florida Candler fine sand soil.

MATERIALS AND METHODS

The top 4-ft profile (0-30, 30-60, 60-90 and 90-120 cm) of typical well-drained Candler sand (Hyperthermic, uncoated Typic Quartzipsamments) was collected from Davenport, FL known to be free of herbicide residues, where citrus was a major agricultural crop. The soil collection site was a noncrop area that had not been used for agricultural crops for over 10 yr. The soil pH was 5 to 6.5, organic matter was 0.3 to 0.9% and bulk densities of 1.55, 1.57, 1.57 and 1.96 g cm^{-3} were determined gravimetrically for each soil profile, respectively. Soil was air-dried for a week to ascertain uniform compaction for leaching experiments.

Soil leaching columns made of PVC, 137 cm long, 10 cm inner diameter cut into halves longitudinally were used. Silicone ridges were placed cross-sectional at 15 cm intervals along the inner wall to prevent preferential flow of solution along the soil-column interface (Weber et al. 1986). The halves were resealed using an adhesive tape to form a column and the bottom end was fitted with a PVC cap 10 cm height with a drainage hole. A nylon screen was placed at the bottom of PVC cap and columns were packed consistently, by adding soil incrementally from the four depths (0-30, 30-60, 60-90 and 90-120 cm) of the soil profile. The columns were secured upright on a wooden platform, watered to field capacity and allowed to drain overnight prior to leaching treatment.

Three herbicides, e.g., Azafenidin (2-[2,4-dichloro-5-(prop-2-ynyloxy)-phenyl]-5,6,7,8-tetrahydro-2H-[1,2,4]triazolo[4,3-a]pyridin-3-one) (Milestone WG 80% at 50 oz a.i./ha), Diuron (N'-(3,4-dichlorophenyl)-N,N- dimethyurea) (Karmax DF 80% at 7.2 kg a.i./ha) and Norflurazon (4-chloro-5-(methylamino)-2-(a,a,a-trifluoro-m-tolyl)-3(2H)-pyridazinone) (Solicam WG 80% at 9 kg a.i./ha), were evaluated for leaching potential. Herbicide solutions were freshly prepared (Table 1) and were transferred into a 20-mL vial and shaken vigorously in a vortex mixer for 1 min. 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 carried out by dripping de-ionized water from siphon system attached to 1000 mL Erenmeyer flask mounted above the column, over the glass wool to simulate a rainfall of 6.25, 12.5 and 25 cm 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 treatment and before conducting bioassays. There was a control column having water only.

Table 1. Chemical characteristics of test herbicides*

Herbicide	Solubility in water at 25°C	Average partition coefficient	Half-life in soil ($t_{½}$)	Relative leaching potential index (K_{oc}/ $t_{½}$) x10**
	mg/L	mg/L	d	
Milestone	na	298	prolonged	very less
Karmax	42	480	90	53
Solicam	28	700	45-180	233

*Values in this table are taken from Herbicide Handbook, 1994, 1998.
**Taken from Hornsby et al. 1991.

Afterwards, columns were split open longitudinally by removing the tape on one side and slicing the soil along the center, starting from the column bottom. Three shallow furrows were made on the soil surface with 2.5 cm apart using a ruler. Seed of winter rye grass (*Lolium perenne* L.) as bio-indicator species was planted uniformly in each furrow and covered with adjacent soil (Lavy and Santelmann 1986). The bioassay columns were mist-irrigated at regular intervals and 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, were made 21 d after planting of each half of the column and averaged to obtain a single observation value.

Experiments were conducted as factorial design with simulated rainfall and herbicides as two factors. There were three replications and the experiments were repeated twice (as Experiment 1 and Experiment 2). Data were subjected to factorial analysis of variance (ANOVA) with mean separations using Fisher's Protected Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

The results are presented on the basis of distance moved by the herbicide treatment and the phytotoxic symptoms appeared on ryegrass. Herbicide soil movement is governed largely by the amount and frequency of water applied depending on the soil type (Weber and Miller 1989). In general, leaching extent of all test herbicides was increased with the amount of water applied from 6.25 to 25 cm (Table 2). This is consistent with the findings of other researchers (Boesten 1987; Futch and Singh 1999). In field conditions, rainfall intensity on an average may be less than the water application rate in this study, but annual rainfall is more likely higher than 10 cm in most areas. The interaction between the distance moved by the herbicide treatment and rate of irrigation water application was significant at 5% level of significance when the data of two experiments were combined. Therefore, the results of both experiments are given.

Table 2. Effect of simulated rainfall on the leaching of test herbicides

	Rainfall (in./ha)		
Herbicide	6.25 cm	12.5 cm	25 cm
Experiment 1:	Distance moved by herbicide (cm)*		
Milestone	22.4	37.8	100.8
Karmax	12.0	19.8	26.2
Solicam	19.6	47.0	100.8
Control (no herbicide)	0.0	0.0	0.0
LSD (P = 0.05)		11.7	
Experiment 2:			
Milestone	19.3	45.0	105.4
Karmax	13.5	16.5	27.7
Solicam	19.6	32.3	80.8
Control (no herbicide)	0.0	0.0	0.0
LSD (P = 0.05)		12.2	

*Observation taken 3 WAT.

The results indicated that the test herbicides had different leaching potential: Karmax (low mobility), Solicam and Milestone (high mobility). Karmax is taken up by the established root system and therefore, its phytotoxic symptoms appeared a week later than the other herbicides. Karmax moved from 12 to 26.2 cm, Solicam and Milestone from 19.6 to 105.4 cm (almost the column length) in the soil as the application of water increased from 6.25 cm to 12.5 cm (Table 2; Expt 1, 2). In Experiment 1, results indicated no significant difference in the movement of Solicam and Milestone at either rate of water application (Table 2; Expt 1), while in case of second experiment, there was a significant difference in the distance moved at 25 cm rate of water application, however, no difference with other rates of water applied

(Table 2; Expt 2). The results confirm the findings of Futch and Singh (1999) that leaching of herbicides increased with the amount of water applied.

The data agreed to the values of organic carbon sorption coefficient (K_{oc}) published in herbicide handbook (Table 1) and to PC values (Hornsby 1999), which describes the relative attraction of the 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). Milestone has soil-organic carbon sorption coefficient (K_{oc}) of 298, which indicate that Milestone does not bind strongly to soil particles. After application, susceptible bioindicator rye grass quickly exhibited necrotic symptoms and died within days of emergence. Milestone is absorbed through the roots and shoots of susceptible plants. Translocation in the xylem or phloem is weak, explaining the limited postemergence activity of Milestone on plants (Amuti et al. 1997). 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 less than 100 in sandy soil should be used with caution due to higher leaching potential (Buttler et al. 1992).

Table 3. Effect of herbicide averaged across different rainfall

	Average distance moved by herbicide (cm)*	
Herbicide	Experiment 1	Experiment 2
Milestone	52.6	53.1
Karmax	19.3	19.3
Solicam	55.6	44.2
LSD (P = 0.05)	6.6	7.1

Further, when the effects of rates of water applied were averaged for individual herbicide, there was no significant difference in the distance moved by Milestone and Solicam herbicides (Table 3). The results are in agreement that herbicide leaching is affected by the amount of rainfall (Weber and Miller 1989). From the results, it appeared that Milestone is a leachable herbicide and its leaching increased with the amount of water. The estimated leaching will provide important information about Milestone as compared to the prevailing herbicides. Therefore, citrus and other growers should be aware of the leaching potential of the herbicide, which they are going to apply. Herbicides should be selected that have minimum leaching potential to avoid groundwater contamination as a result of their application. Hence, this information will be an important factor in regards to the groundwater pollution.

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