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Ethoprop Depletion from Soil as Influenced by Simulated Rainfall[1]

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Abstract: Two field microplot tests were conducted in sandy soil to evaluate retention of ethoprop in relation to simulated rainfall levels. Ethoprop was applied at the equivalent of 13.5 kg a.i./ha, and simulated rainfall was added at rates of 2.5, 7.5, 15.0, and 22.5 cm over a 6-day period. Ethoprop concentration in the soil at 5-, 10-, and 40-day intervals indicated that it was depleted rapidly with increased rainfall levels. The 2.5-cm level of simulated rainfall reduced ethoprop concentration to one-half in the 0 to 15 cm depth within 10.7 days, whereas the 22.5 cm of rain shortened this period to 1.7 days. Soil samples taken 10 days after ethoprop treatment and inoculated with *Meloidogyne javanica* indicated that 2.5 cm of rain rendered the nematicide ineffective against *M. javanica*.
Key words: ethoprop, *Meloidogyne javanica*, nematicide, nematode, rainfall.

The nonfumigant nematicide ethoprop (O-ethyl-S,S-dipropyl phosphorodithioate), introduced in 1968 for use on flue-cured tobacco, has been used extensively on the crop for management of *Meloidogyne* spp. Over the past two decades, however, inconsistent nematode control with ethoprop and some other nonfumigant nematicides has been found in Florida (7, 14,17). At least three factors have been suggested to explain this variable performance. First, *Meloidogyne incognita* has been the most common root-knot nematode species found in tobacco, but there is an increasing prevalence of the more aggressive *M. javanica* and *M. arenaria* in Florida and the Southeast (1,2,6,16). Second, a decline in the number of tobacco farms has resulted in shorter rotation intervals, thereby increasing the number of all *Meloidogyne* species in tobacco fields (6, 16,18). A third factor may be excessive rainfall after nematicide application to the deep sandy soils of tobacco-producing regions of Florida (7).

The efficacy and persistence of ethoprop have been related to the amount of rainfall received after treatment of corn on a sandy loam soil (19). Similarly, in lysimeters containing sandy soil, it was found that simulated rainfall of 5.08 cm applied at the second and eighth days after treatment depleted 64% of the nematicide aldicarb (3). Observations of tobacco nematicide trials conducted in Florida over 12 years also have indicated an adverse effect of early-season rainfall on efficacy of nonfumigant nematicides.

The objective of the present study was to evaluate the effect of simulated rainfall on ethoprop content at three soil depths.

Materials and Methods

Two experiments were conducted in a sandy soil (Typic Quartzipsamments thermic coated soil [5], Table 1) in 76-cm-d fiberglass microplots. The microplots were installed 51 cm deep with an additional 10 cm protruding above the soil surface (11). The microplot design prevented water runoff and, thus, lateral movement. Prior to the test, soil was treated with methyl bromide at 760 kg/ha and 1,3-D at 475 liters/ha. The first experiment was a factorial design containing 12 replications. One factor consisted of four simulated rainfall levels of 2.5, 7.5, 15.0, and 22.5 cm, and the other factor was the sampling depth of the soil.

Microplots were irrigated to field capacity (water content of 0.075 cm^3/cm^3) prior to ethoprop application. In the first experiment, liquid ethoprop (formulated as Mocap 6 EC) at the rate of 13.5 kg a.i./ha (calculated as equivalent to 6.00 μg a.i./g of dry weight soil based on a depth of 0–15

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TABLE 1. Physiochemical properties of soil at the experimental site†.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Organic matter (%)	Bulk density (g/cm^3)	pH	Water content at ⅓ bar (cm^3/cm^3)	Saturated hydraulic conductivity (cm/hour)
0–28	93.1	3.9	3.0	1.20	1.53	5.7	7.27	33.1
28–76	93.5	2.7	3.8	0.32	1.55	5.0	5.84	29.3

† Information taken from University of Florida Soil Science Research Report 74-1 (5).

cm in the soil profile) was applied to the soil surface in each microplot. Simulated rainfall was applied by sprinkling water. The rainfall treatment had three split applications as 2.5, 7.5, 7.5, and 7.5 cm the first day; 0.0, 0.0, 7.5, and 7.5 cm 3 days later; and 0.0, 0.0, 0.0, and 7.5 cm 3 days later. During 1985, no natural rainfall was received up to 10 days after ethoprop application. However, by day 40, all microplots had received an additional 30.4 cm of natural rainfall.

Ten days after ethoprop application, eight 2.5-cm-d soil cores were collected at each of three depths: 0–15, 15–30, and 30–45 cm from six replications. Rainfall interrupted sample collection after four of the six replicates were collected. The two remaining replicates were sampled 24 hours later and assigned a rainfall value that reflected this incidental rainfall. The soil from each microplot and depth was composited, and two 400-cm^3 samples were removed. One sample was stored frozen until ethoprop content was determined. Frozen soil samples were coded and were sent to Analytical Development Corporation, Monument, Colorado for ethoprop analysis. Ethoprop was determined according to the method of Hudson (8). The other sample was used in a bioassay study. Soil samples were taken from the remaining six replications at day 40 following ethoprop application.

Cumulative ethoprop retentions in 0–15, 0–30, and 0–45 cm depths were calculated from ethoprop content determined in 0–15, 15–30, and 30–45 cm soil layers. These values and sampling time were used to compute time (days) required for depletion of 50% of the applied ethoprop by water movement, as well as other factors such as biological degradation. The mathematical computations for the 50% depletion time were done employing the following standard half life calculation formula:

$$N = N_0(\tfrac{1}{2})^{t/k}$$

where N = ethoprop content at sampling time (μg/g of soil); N_0 = amount of ethoprop applied (μg/g of soil); t = sampling time (days); and k = time in days for 50% ethoprop depletion. Based on analysis of soil from the plots prior to treatment, ethoprop content of the soil was determined to be negligible.

The soil for the bioassay study was placed in 10-cm-d pots. Each pot was inoculated with 2,000 *M. javanica* eggs and juveniles, and a 3-month-old 'NC 2326' tobacco seedling was transplanted into each pot. These pots were maintained in a greenhouse for 50 days. At that time, root gall ratings were made on a 0–4 scale with 0 = no visible galls and 4 = 76–100% of the root system galled. Eggs were extracted from roots with sodium hypochlorite (9) and counted.

The microplot test was repeated in 1987 using simulated rainfall levels of 2.5, 7.5, and 15.0 cm, each replicated eight times. Methodology was similar to that of the first experiment. Soil samples for ethoprop analysis were collected from four replications at 5 and 40 days after application. Natural rainfall of 2.5 cm occurred before the sampling at day 5. Data were subjected to two-way analysis of variance (21).

RESULTS

The simulated rainfall levels significantly influenced ($P \leq 0.05$) ethoprop content at different soil depths. Ethoprop content at 10 days decreased with rainfall at the 0–15 and 15–30 cm depths following a quadratic relationship (Figs. 1A,B). However, ethoprop levels at the 30- to 45-cm depth appeared to increase with rainfall up to 15 cm and then declined with further water application (Fig. 1C).

With 2.5 cm of simulated rainfall, the ethoprop content in the 0- to 15-cm soil layer changed from the 6.00 μg/g calculated at application to 3.00 μg/g (50% of ethoprop applied) in 10 days (Fig. 1A). An ethoprop content of approximately 1.25 μg/g of soil (21% of ethoprop applied) was found at the 15- to 30-cm soil depth (Fig. 1B), whereas only 0.40 μg/g (7%) was found at the 30- to 45-cm depth (Fig. 1C). Approximately 22% of the ethoprop applied was not accounted for in the 0- to 45-cm depth in the treatment with 2.5 cm of simulated rainfall.

With 7.5 cm of simulated rainfall, an ethoprop content of only 1.25 μg/g of soil remained in the top 0 to 15 cm of soil, representing a 79% reduction from the initial concentration. The ethoprop level at the 15- to 30-cm depth was 1.10 μg/g of soil. Simulated rainfall at the 7.5-cm level resulted in disappearance of 45% of the ethoprop from the active root zone at soil depths of 0 to 45 cm within 10 days. The rainfall and ethoprop concentration trends (Fig. 1) showed that 22.5 cm of rainfall over 6 days could cause up to an 85% ethoprop depletion within 10 days in the 0- to 45-cm soil depth.

After 40 days, rainfall affected ($P \leq$

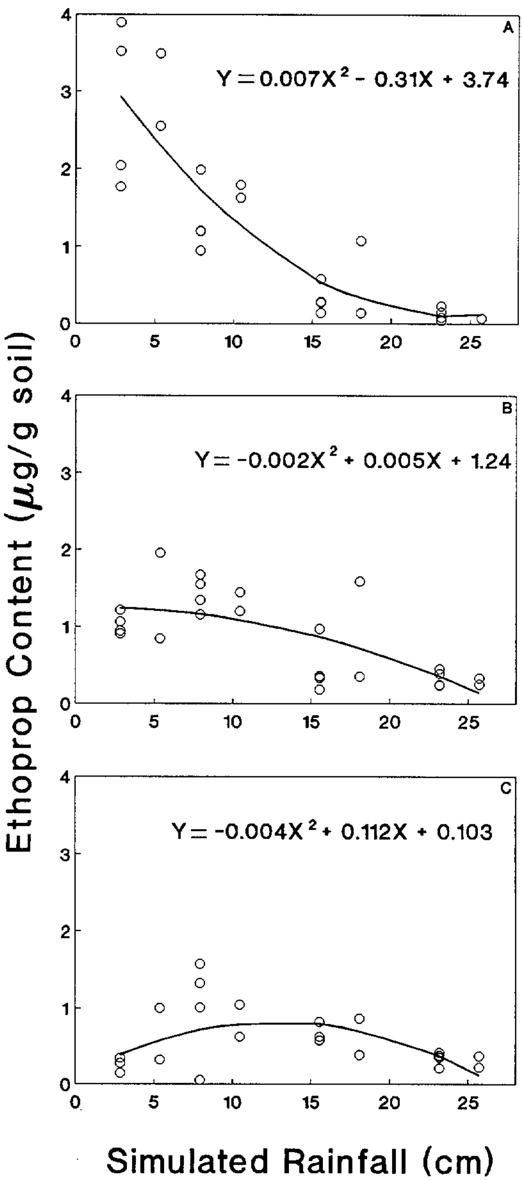

FIG. 1. Relationship between simulated rainfall (cm) and ethoprop content in soil (μg ethoprop/g soil) at three depths in the soil profile, 10 days after ethoprop application, 1985. A) 0- to 15-cm soil depth. $R^2 = 0.77, P \leq 0.01$. B) 15- to 30-cm soil depth. $R^2 = 0.49, P \leq 0.01$. C) 30- to 45-cm soil depth. $R^2 = 0.32$, $P \leq 0.05$.

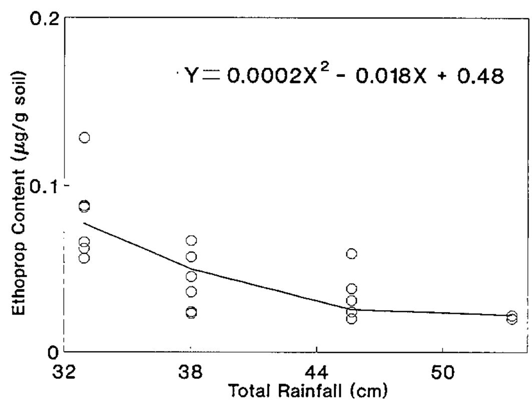

FIG. 2. Relationship between total rainfall (cm) and ethoprop content (μg ethoprop/g soil) in soil at a 0- to 15-cm depth, 40 days after ethoprop application, 1985. $R^2 = 0.63$, $P \leq 0.01$. Relationship not significant ($P \leq 0.05$) at 15- to 30-cm and 30- to 45-cm depths (data not shown).

0.01) the ethoprop distribution only within the top 0- to 15-cm depth (Fig. 2). The ethoprop level in this layer was reduced to less than 1% of the initial content calculated at application. Natural rainfall and biological degradation probably masked any further simulated rainfall effect at the lower depths.

Data from the second experiment showed that ethoprop content decreased from an estimated 6.00 μg/g to 3.00 μg/g of soil (50% depletion) in the top 0 to 15 cm of soil within 5 days with 5.0 cm of total rainfall (Fig. 3). During the same period, 10.0 cm and 17.5 cm of rainfall caused 75% and 85% ethoprop depletions, respectively, in this soil layer. Decrease of ethoprop concentration with rainfall at the 0- to 15-cm soil depth followed a quadratic relation (Fig. 3). No significant effect ($P \leq 0.05$) of rainfall on ethoprop concentration was observed for the soil depths of 15 to 30 cm and 30 to 45 cm. Because of an additional 2.5 cm of natural rainfall prior to the 5-day sampling period, the effect of 2.5 cm of water application on ethoprop distribution could not be evaluated as in the earlier study.

In the first experiment, estimates of time required for 50% depletion of ethoprop after 10 days showed significant ($P \leq 0.05$) inverse relationships to rainfall (Table 2). For example, it was estimated that with 7.5 cm of rainfall it took 5.1 days

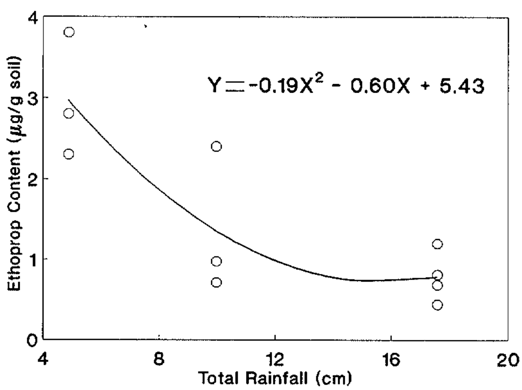

FIG. 3. Relationship between total rainfall (cm) and ethoprop content (μg ethoprop/g soil) in soil at a 0- to 15-cm depth, 5 days after ethoprop application, 1987. R^2 = 0.73, $P \leq 0.01$.

TABLE 2. Time (days) calculated for 50% depletion of ethoprop from soil at four rainfall levels and three soil depths, 1985.

Simulated rainfall (cm)	Soil depth (cm)		
	0–15	0–30	0–45
2.5	10.7[+]	22.3	34.8
7.5	5.1	9.9	15.6
15.0	2.6	4.3	6.3
22.5	1.7	2.7	3.4

[+] Days required for 50% depletion of ethoprop, calculated using soil ethoprop content at 10 days.

for half of the ethoprop to disappear from the 0- to 15-cm depth of soil, whereas with 22.5 cm of water application, 50% depletion occurred after 1.7 days. Similar calculations for 40-day samples showed that the time for 50% depletion of ethoprop was shortened to 6.5 days for the 0- to 15-cm depth with the 2.5-cm water application.

Ethoprop data for the samples collected at 5 days in the second year of the study indicated that 5.0 cm of rainfall caused 50% of the ethoprop to dissipate in the top 0- to 15-cm soil depth within 5.2 days (data not shown). Relationships between ethoprop depletion and rainfall for the 0- to 30- and 0- to 45-cm soil depths were not significant in 1987.

The bioassay results from greenhouse studies in the first experiment indicated that root gall index ratings (ranging from 1.7 to 2.5 on a scale of 0–4) and egg production (ranging from 24,900 to 26,900 *M. javanica* eggs per plant) were not affected ($P \leq 0.05$) by levels of simulated rainfall.

DISCUSSION

The half-life of ethoprop in field tests has been found to vary from 3 to 30 days (19,20) in light-textured soil. Huvar (10) and Brodie (4) suggested that ethoprop moved downward with water. Rohde et al. (19) observed 90% dissipation of the pesticide within 3 weeks in the 0- to 10-cm soil depth. However, Smelt et al. (20) found little downward movement of ethoprop in soil beyond an incorporation depth of 10–15 cm in a sandy loam soil with organic matter content of 1.7%. The results of the present study show considerable vertical movement of ethoprop as evidenced by increased concentration with rainfall at lower depths in a sandy soil (O.M. = 1.20%). For example, ethoprop concentration in the 30- to 45-cm depth initially increased with rainfall, became constant, and then decreased with further rainfall, suggesting a vertical leaching mechanism. Johnson et al. (12) also observed higher concentrations at lower soil depths for fenamiphos in corn plots, although fenamiphos is less soluble in water than ethoprop. The soil and water partition coefficient value for ethoprop is 120 and water solubility is less than 0.075%, suggesting restricted mobility in soil. However, soils with low organic matter and clay content have poor retentive capacity for most nematicides (15).

According to Rohde et al. (19), ethoprop contents of even 4.6–5.6 μg/g of soil are too low for adequate control of nematodes on field corn and southern peas. Based on our study, 10-day samples contained 3.00 μg or less ethoprop per g of soil. These ethoprop concentrations were probably too low to greatly affect nematode population densities as shown by the bioassay results. Thus, as little as 2.5 cm of rainfall in a soil at field capacity may deplete ethoprop concentrations below levels required for effective nematode control.

Results from this study suggest that excessive rainfall or irrigation shortly after application can significantly affect the retention of ethoprop in sandy soils such as those found in Florida. Rainfall or high soil moisture causes a decrease in pesticide concentration in the root zone and thus hastens the recovery of nematodes from the impact of the pesticide (13).

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