Varying Termiticide Application Rate and Volume Affect Initial Soil Penetration

CHRIS J. PETERSON[1]

USDA-Forest Service, Insects, Diseases and Invasive Plants Research Unit, 201 Lincoln Green, Starkville, MS 39759

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ABSTRACT The initial soil penetration of Premise 75 and Termidor SC, containing imidacloprid and fipronil, respectively, were tested in laboratory columns of five different soils. Three combinations of application concentration and volume were used: double the recommended active ingredient concentration at one half the recommended volume (DR), the full concentration and volume (FR), and one half the concentration and twice the volume (HR). In all three cases, the same total amount of active ingredient (0.01 g of imidacloprid for Premise and 0.012 g of fipronil for Termidor) was applied to the same soil surface area (45.36 cm^2). Regardless of soil or application method, the concentration of active ingredient was highest in the top 1 cm of soil. Within each soil, the concentration in the top 1 cm was highest in the DR treatment and lowest in the HR treatment. At each depth below 1 cm, active ingredient concentration was highest in the HR treatment and lowest in the DR treatment. The DR treatment therefore results in a thinner barrier of higher initial concentration in the top 1 cm, whereas the HR treatment results in a thicker barrier but of lower initial concentration in the top 1 cm.

KEY WORDS fipronil, imidacloprid, soil penetration, chemical barrier, termites

In 1956, a rate of 4 liters (1 gallon) of termiticide suspension per 1 square meter (10 square feet) of soil was recommended to provide a chemical barrier to termite infestation in slab construction (Smith 1956). Such insecticides are applied to exposed soil before the placement of a vapor barrier, reinforcing material, and the pouring of concrete. Any of these activities have the potential to disrupt the chemical barrier, which would allow termite infestation of the structure.

The initial soil penetration of termiticide suspensions was examined in the 1960s for chlorinated hydrocarbon insecticides (Beal and Carter 1968, Carter and Stringer 1970, Carter et al. 1970, Carter and Stringer 1971) and more recently for aqueous termiticides (Peterson 2009). In general, these studies found that at the labeled rate the top 1–2.5 cm of soil contained the highest concentrations of active ingredient, with no insecticide penetrating much >5 cm (2 inches) into the soil. In these studies, the active ingredient concentration in soil decreased with increasing soil depth, and increased soil moisture tended to provide a thicker barrier of lower concentration in the top 1 cm.

The desired thickness and soil concentration of a termiticidal soil barrier is still an open question. A thinner barrier of higher initial concentration might remain effective longer by prolonging the time required for the active ingredient to dissipate to below effective levels. A thicker barrier of lower initial concentration, however, might better withstand soil disturbances encountered while the foundation is being prepared. A "perfect" termiticide formulation should penetrate deeply enough to provide a barrier of sufficient thickness to withstand minor disturbance but not penetrate so deeply that the compound is diluted by soil to below the level of effectiveness.

A thicker or thinner barrier might be achieved by varying the application volume and active ingredient concentration. The application volume might be doubled if the active ingredient concentration is cut in half, or the volume might be cut in half if the active ingredient concentration is doubled. The former should provide a thicker barrier, but of lower initial concentration, whereas the latter should provide a thinner barrier of higher initial concentration. In either case, the same amount of active ingredient is applied to the soil surface, but it should penetrate into the soil differently. The product labels for Premise 75 and Termidor SC both allow the application volume to be varied, as long as the active ingredient concentration is adjusted accordingly (Bayer Environmental Science, undated, BASF Corporation 2005).

This study examines the initial penetration of two commercially available termiticide formulations, Termidor SC and Premise 75, when applied at varying application rates and volumes while maintaining a constant rate of active ingredient per unit of soil surface. Five soils were used, four acidic and one

[1] Corresponding author, e-mail: cjpeterson@fs.fed.us.

Table 1. Characteristics of the soils used in this study

Soil	Texture	Silt	Sand	Clay	pH	%OM	CEC	Field capacity (%)
U	Loamy sand	19.8	77.8	2.5	5.2	1.41	4.10	16.6
D	Silt loam	50.0	42.5	7.5	5.3	2.43	15.20	35.9
P	Sandy loam	40.0	55.0	5.0	5.1	0.52	6.00	21.2
H	Sandy loam	27.8	69.8	2.5	5.0	2.17	4.50	17.6
G	Sandy loam	14.8	75.2	10.0	7.8	1.49	NA	20.0

alkaline, representing different soil textures and characteristics.

Materials and Methods

Treatment of Soil. Five soils (Table 1) were used in the current study. These soils reflect different contents of clay, silt, sand, organic matter, pH, cation exchange capacity, and field capacity. These soils and their characteristics were reported in previous publications (Peterson 2007, 2009). In brief, U soil was a loamy sand collected near Union, SC; D soil was a silt loam collected in the vicinity of Dorman Lake near Starkville, MS; P soil was a sandy loam approved by local building codes for construction fill and was collected from Parker Sand and Gravel Co., near Caledonia, MS; H soil was a sandy loam collected from the Harrison Experimental Forest near Saucier, MS; and G soil, the only alkaline soil used in the study, was a sandy loam collected from the Mississippi Agriculture and Forestry Experiment Station greenhouses in Starkville, MS. The Mississippi State University Extension Service conducted the texture analysis and determination of pH, percentage organic matter, and cation exchange capacity. The field capacity was estimated by using methods reported in Peterson (2009).

Each soil was sieved to remove stones and roots and then was air-dried. On the day of treatment, the soil to be tested was weighed and then brought to 10% moisture (by weight) by applying the appropriate amount of water by using a CO_2-powered backpack sprayer and tumbling in a cement mixer for 10 min. The soil was placed into 7.6-cm i.d. by 15-cm plastic tubes and was lightly tamped. Two commonly used termiticides, Termidor SC and Premise 75, were mixed separately at double the recommended label rate (DR treatment), the full rate (FR treatment), and one-half the labeled rate (HR treatment). The prepared termiticide suspensions were applied by using an airbrush to the soil in the tubes at different volumes: 10 ml of the DR suspension, 20 ml of the FR suspension, and 40 ml of the HR suspension. These volumes, respectively, represent one-half the labeled volume but double the active ingredient rate, the full volume of the full-rate suspension, and double the volume of the half-rate suspension. In all three cases, the same total amount of active ingredient (0.01 g of imidacloprid for Premise and 0.012 g of fipronil for Termidor) was applied to the same soil surface area (45.36 cm^2). If all of the applied suspension remained in the top 2.5 cm of soil, the theoretical residues of fipronil and imidacloprid would be 58 and 69 ppm, respectively, assuming a soil bulk density of 1.5 g/ml. After 24 h, a 7.6-cm-diameter dowel was used to push the soil out of the tube in 1-cm increments to 12 cm. Each soil increment was separately placed into labeled resealable plastic bags until the soil moisture and active ingredient concentration could be determined.

Soil moisture was determined for fipronil soils by placing the soil into preweighed aluminum foil weigh boats so that the total mass was between 35.0 and 35.5 g. The soils were placed in an oven (100 °C overnight), and then the dry soil and weigh boat were reweighed. The weight of the foil weigh boat was subtracted from both the fresh and dry weights and the percentage soil moisture (by weight) was found from the mass difference.

Because very low recovery of imidacloprid was observed by using the methods that extract fipronil (C.J.P., unpublished data), no heat was applied to imidacloprid-treated soil at any time. This necessitated that soil moisture be determined by placing soil into preweighed aluminum foil weigh boats so that the total mass was between 15.0 and 15.5 g. The weigh boats were placed in a fume hood and then air dried at room temperature for >24 h and then reweighed. The weight of the foil weigh boat was subtracted from both the fresh and dry weights and the percentage soil moisture (by weight) was found from the mass difference.

Fipronil was extracted from treated soil by using a Dionex ASE 200 (Salt Lake City, UT) accelerated solvent extractor using a 70:30 mixture of acetonitrile: acetone and the extracts were analyzed by using gas chromatography with electron capture detection as reported in Peterson (2009).

Imidacloprid was extracted from soil following the method of Peterson (2007), where 10 g of air-dried soil was placed into glass jars and 20 ml of an acetonitrile: water (80:20) mixture was added. The jars were shaken for 4 h at 200 rpm. The extracts were allowed to settle overnight and then were vacuum filtered by using Whatman G4 glass fiber filters. Extracts were analyzed for imidacloprid content by using the high-performance liquid chromatography with UV detection method of Peterson (2007).

A split-plot arrangement was used in a randomized complete block design (blocked by soil), with each container (combination of application method and compound) as the whole plot factor and soil depth as the subplot factor. The study had three replicates. Mixed analysis of variance (PROC MIXED, SAS Institute 2001) was used to determine significance due to soil, application method, and depth.

Results and Discussion

Soil Moisture Analysis. Soil moisture after application can be used as an estimate of how the compounds might penetrate the soil, assuming that the active ingredients penetrate similarly to water. Formulation did not affect the penetration of the water

Table 2. Initial penetration of fipronil in columns of five different soils treated at one half the labeled rate but with twice the volume (HR), the full labeled rate and the full volume (FR), and at double the labeled rate but with half the volume (DR)

Soil depth	P soil			D soil			H soil			G soil			U soil		
(cm)	HR	FR	DR	HR	FR	DR	HR	FR	DR	HR	FR	DR	HR	FR	DR
1	14.8	17.3	19.2	44.2	49.6	76.8	42.7	45.6	59.7	36.9	48.6	71.6	22.6	23.9	42.1
2	15.4	15.3	18.2	32.9	48.1	41.5	11.0	6.8	5.5	41.8	29.2	15.7	10.8	18.7	21.9
3	12.4	13.2	6.9	28.1	27.6	0.5	3.3	0.5	1.1	17.8	2.9	0.4	11.2	9.9	4.0
4	8.9	6.6	0.6	25.6	0.6	0.5	0.5	0.1	0.1	3.1	0.1	0.1	10.2	5.7	0.3
5	5.4	0.7	0.0	14.1	0.3	0.3	0.1	0.0	0.1	0.5	0.0	0.0	9.3	1.5	0.1
6	2.4	0.1	0.0	2.1	0.7	0.0	0.0	0.0	0.3	0.5	0.2	0.0	7.2	0.3	0.0
7	0.9	0.1	0.0	0.2	0.7	0.1	0.1	0.0	0.0	0.0	0.1	0.0	5.6	0.1	0.1
8	0.4	0.0	0.1	0.1	0.1	0.2	0.2	0.0	0.1	0.0	0.0	0.0	3.1	0.1	0.0
9	0.1	0.2	0.1	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0
10	0.0	0.0	0.1	0.1	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.7	0.0	0.1
11	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.1	0.0
12	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.4	0.0	0.0	0.3	0.1	0.2	0.0	0.0

All reported values are in ppm by weight of soil.

into the soil, indicating that penetration of the active ingredient might not have been different. The top depth in any combination of soil and application method usually had the highest soil moisture, and soil moisture generally decreased with increasing depth to a maximum depth beyond which the suspension did not penetrate. Soil moisture at any given depth within any soil generally increased in the order of DR (lowest moisture), FR, and HR (highest moisture), corresponding to the total volume of application suspension applied. Similarly, the maximum depth of penetration generally increased with an increase in application volume. Exceptions to these patterns occurred in the HR treatment of P soil, where all soil depths had roughly the same soil moisture, and in the HR treatment of U soil, where soil moisture generally increased with soil depth. U soil had a lower field capacity than did the other four soils, and the increased application volume may have saturated the soil, causing the water to pool at the bottom of the polyvinyl chloride pipe.

Extractable Imidacloprid and Fipronil. Application method had the most obvious effect on active ingredient concentration in the soil. Within any combination of soil and compound, there was a significant interaction between application method and soil depth ($P < 0.0039$). The active ingredient concentration was always highest in the top 1 cm of any soil receiving any treatment, and the concentration in the top 1 cm increased in the order of HR, FR, and DR. The deepest penetration in all cases was seen in the HR treatment, whereas penetration was less deep in the FR treatment and the least deep in the DR treatment. For the DR treatment, penetration was limited to the top 3–5 cm for both compounds in all soils, was limited to the top 4–6 cm in the FR treatment and to the top 4–10 cm in the HR treatment (Tables 2 and 3).

The effect of soil depended on the application method and soil depth. For each compound, there was a significant three-way interaction between the effects of soil, application method, and soil depth on fipronil ($F = 7.49$; df = 88, 330; $P < 0.0001$) and imidacloprid ($F = 4.89$; df = 88, 329; $P < 0.0001$) concentration. Fipronil and imidacloprid penetrated the most deeply in U and P soils, and the deeper penetration was accompanied by lower initial concentrations than were seen in the other soils. As mentioned, the concentration of either compound was highest in the top 1 cm for the DR treatment and the least in the HR treatment. Mass balance was not attempted in this study, but the extraction methods used

Table 3. Initial penetration of imidacloprid in columns of five different soils treated at one half the labeled rate but with twice the volume (HR), the full labeled rate and the full volume (FR), and at double the labeled rate but with half the volume (DR)

Soil depth	P soil			D soil			H soil			G soil			U soil		
(cm)	HR	FR	DR	HR	FR	DR	HR	FR	DR	HR	FR	DR	HR	FR	DR
1	35.7	58.1	64.0	66.4	88.1	97.9	60.8	69.3	95.0	47.2	66.3	103.5	16.2	21.9	34.9
2	27.0	31.0	19.3	27.2	14.7	4.8	40.6	25.4	7.5	28.2	22.8	19.8	10.0	14.4	13.8
3	21.8	10.2	2.7	7.4	0.4	0.0	23.0	0.9	0.7	18.4	4.4	0.5	7.7	7.2	2.4
4	8.8	2.3	0.1	1.0	0.0	0.0	5.3	0.1	0.1	4.8	0.2	0.0	6.0	3.3	0.0
5	4.3	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.0	0.0	4.4	1.1	0.0
6	1.7	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	3.2	0.2	0.0
7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0
8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

All reported values are in ppm by weight of soil.

produce 89–100% recovery of both compounds in these soils (Peterson 2009).

There were no obvious differences between the patterns of penetration of imidacloprid and fipronil within any given soil. In general, increasing the application suspension concentration while reducing the application volume resulted in less penetration (thinner barriers) with a higher active ingredient concentration in the top 1 cm.

There was a clear relationship between the penetration of the application suspension (as evidenced by soil moisture) and penetration of the active ingredient (as evidenced by residue analysis). The application suspension and active ingredient penetrated the most deeply when a larger volume was applied. However, the combination of a lower suspension concentration and a larger volume resulted in a lower active ingredient concentration in the top 1 cm of the soil. Such a thicker barrier might better withstand minor soil disturbance. As well, Smith et al. (2008) found that termites were less able to tunnel through thicker barriers of lower active ingredient concentration than they were through thinner barriers of higher concentration. However, it has been commonly observed that the dissipation rate of termiticides depends on initial concentration; degradation is faster at lower active ingredient concentrations (Racke et al. 1994, Saran and Kamble 2008). Therefore, the lower concentrations in the thicker barrier might degrade to below effective levels more quickly than will a thinner barrier of higher concentration.

Making the chemical barrier thicker or thinner may be desired to prevent termite infestation of a structure. A direct relationship between treated barrier thickness and active ingredient concentration in terms of termite infestation will be taken up in a further study, and is not addressed by the study reported here.

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