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Persistence of Terbuthylazine in Soils

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Terbuthylazine, a non-selective herbicide developed by Ciba Geigy, is a triazine herbicide, as are simazine, terbutryn and atrazine. Terbuthylazine is a broad-spectrum herbicide registered for control of most annual grasses and broadleaf weeds in rubber, oil palm and cocoa plantations and in orchards as well as on non-crop land. This herbicide was introduced into the Malaysian market in the 1980's under the name of Gardporim^R.

The persistence of triazine in soil depends on the rate of application and such environmental factors as soil moisture, temperature, pH and constituents (WSSA 1989). Weber and Weed (1974) reported that higher soil temperature and moisture enhance degradation of triazine, and that adsorption and bioactivity of the herbicide was correlated with organic matter and clay content and other soil parameters. Organic matter was the primary adsorbing surface in the soil (Weber and Weed 1974; Nishimoto and Rahman 1985). The influence of organic content of the soil is illustrated by the fact that the half-life of simazine ranged from 22 to 44 days, depending on organic content of the soil (Walker and Thompson 1977). Degradation of atrazine has been reported to be faster in moist soil than in dry soil (Walker and Zimdahl 1981). The active ingredients of triazine are stable chemical compounds which, however, degrade rapidly in soil due to microbial activity (WSSA 1989). The maximum movement of terbuthylazine under natural rainfall was 20 cm after 21 days (Bowman 1989). While much is known about the activity and mode of action of other compounds in the triazine group, little quantitative information is available concerning the mode of dissipation of terbuthylazine from soil, especially under tropical conditions. Experiments were therefore conducted to determine the persistence of terbuthylazine at various moisture levels and temperatures in two different soil types.

MATERIALS AND METHODS

Two different soils were used: sandy loam soil (80% sand, 6% silt, 14% clay and 1.2% organic C at pH 5.1) and organic soil

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(44% sand, 12% silt, 45% clay and 55% organic C at pH 3.1). The herbicide used in the study was terbuthylazine as Gardporim^R (2[tert-butylamino]-4-chloro-6-[ethylamino-s-triazine]). The experiments were conducted in a university greenhouse under natural lighting conditions with temperatures that fluctuated between 25 and 32 C. The experimental design was a randomized complete block, and data were subjected to an analysis of variance with mean separation by Duncan's multiple range test.

Four species, viz. cucumber (*Cucumis sativus* L.), corn (*Zea mays* L.), Chinese cabbage (*Brassica chinensis* L.) and spinach (*Amaranthus viridis* L.), were bioassayed to define linearly the concentration range of the herbicide in the soils used for field and greenhouse studies. The required volume of the herbicide was thoroughly mixed with air-dried soil to obtain a concentration of 20 ppm. Other required concentrations were prepared by diluting the treated soil with untreated soil. The concentrations used were 0, 0.1, 0.3, 1.0, 3.0, 5.0, 8.0, 10.0, 15.0 and 20.0 ppm. Treated soil (1.0 kg of each concentration for each herbicide) was transferred into pots, each containing 200 g. First-order linear regression curves were obtained by plotting the average plant fresh weight of five replicates as a percent of the untreated control against log herbicide concentration.

Seven 18-kg batches of air-dried soil from each site were treated to obtain a final concentration of 20 ppm. After mixing, nine 2-kg portions for each sampling date were kept in polyethylene bags. The bags were divided into three groups, each having a soil moisture level of either 20, 50 or 80% field capacity for sandy loam soil and 50, 80 and 100% field capacity for organic soil. Bags of each moisture level were kept in a growth incubator at either 25, 30 or 35 C and weighed weekly; the soil was stirred after adding water in order to maintain the required moisture level. Nine 2-kg bags of soil for each moisture-temperature combination were frozen at 4 C on day 0, 1, 7, 14, 21, 28, 42 and 56. There were two replicates for each temperature and each moisture level.

After day 56 of incubation, samples were thawed and air-dried overnight. Each 2-kg sample was then mixed and split into ten 200-g portions, each of which was placed in a styrofoam pot; ten cucumber seeds were planted in each pot at a depth of 1 cm. After emergence, plants were thinned to five/pot. Seven days after emergence, the plants were cut at soil level and fresh weights were recorded. The concentration of herbicide in the soil was determined by referring to a dose-response curve that was run concurrently. Half-lives were calculated assuming first-order kinetic behaviour.

RESULTS AND DISCUSSION

Since it was assumed that degradation of the herbicide followed first-order kinetics, the data in Tables 1 and 2 are presented as half-lives. R^2 values were 0.9 in sandy loam and 0.7 in organic soil. Since cucumber was found to be the most sensitive of the four bioassay species tested, it was used as the bioassay species for the determination of residues.

In sandy loam soil, the half-life of terbuthylazine was shorter with increasing temperature in all moisture levels tested (Table 1). Its half-life ranged from 5 to 38 days, depending on soil moisture and temperature. The half-life of terbuthylazine was shorter with soil moisture at 50% field capacity than at 20 and 80% field capacity. It seems that for sandy loam, 50% field capacity is probably near the optimum moisture content for degradation of terbuthylazine.

The half-life of terbuthylazine in organic soil was comparatively shorter than in sandy loam, especially at higher temperatures (Table 2). At 35 C, the half-life of terbuthylazine was quite consistent across varying soil moistures. In organic soil, temperature appears to be the crucial factor in determining degradation rate of terbuthylazine.

It appears that the optimum level for the degradation of terbuthylazine in sandy loam soil is the least favourable (at least at lower temperatures) for its degradation in organic soil.

An increase in herbicide degradation at higher soil moisture levels is expected since higher moisture levels hinder herbicide adsorption onto soil particles, making herbicide molecules more readily available for degradation by soil microbes. Our result agree with those of Hamaker (1972), who found that under aerobic conditions, the herbicide degradation rate increased with increasing soil moisture content but tended to plateau at high moisture content and saturation levels (Hamaker 1972). This probably explains the shorter half-life of terbuthylazine in organic soil at 80 and 100% field capacity soil moisture (Table 2). As mentioned earlier, microbial decomposition is the major avenue for dissipation of most herbicides from soils, with chemical degradation accounting for less than 2% of the observed field losses under field conditions (Beestman and Deming 1974). Reports of studies with a wide range of compounds have been published (Zimdahl and Gwynn 1977; Walker 1978) showing the expected effect of increased degradation rates with increasing soil moisture up to field capacity. Leaching was not found to make a significant contribution to dissipation of the herbicide from the soil under temperate conditions (Beestman and Deming 1974); however, that may not be the case under tropical conditions.

Increased degradation rates of many herbicides at increased temperature have been confirmed in numerous field studies (e.g. Burnside et al. 1969). There is evidence that herbicide degradation rates are increased at higher temperatures which, in most instances, probably reflects increased microbial activity, especially in organic soil. The higher organic matter content in soil may result in higher microbial activity which consequently

Table 1. Half-life (days) for terbuthylazine in sandy loam soil at different temperature and moisture levels.

Moisture (% field capacity)	Temperature (C)		
	25	30	35
20	38a	29a	14a
50	15c	7c	5c
80	22b	16b	11b

Means within a column followed by the same letter are not significantly different at 0.05 probability level.

Table 2. Half-life (days) of terbuthylazine in organic soil at different temperature and moisture levels.

Moisture (% field capacity)	Temperature (C)		
	25	30	35
50	33a	25a	3a
80	11b	7b	2a
100	9b	6b	2a

Means within a column followed by the same letter are not significantly different at 0.05 probability level.

degrades terbuthylazine. It has been reported that bacterial and fungal populations of the soil are usually not significantly altered by the application of triazines (Voets et al. 1974).

The shorter half-life of terbuthylazine in organic soil may also be in part due to adsorption to soil constituents. The biological activity of triazine herbicides has been shown to be related to relative contents of organic matter and clay minerals in the soil (Day et al. 1968). Terbuthylazine is more readily adsorbed onto soils containing a higher proportion of organic matter (Bowman 1989). Adsorption increased and bioactivity decreased with a decrease in the pH of the system. Adsorption reduces the amount of available herbicide in the soil solution, therefore reducing the herbicide's effect on the bioassay species tested. This experiment has focused on the effects of soil temperature and soil moisture and speculated only on the effects of soil pH and soil adsorption. Further experiments that could define soil pH and adsorption effects would be a useful complement to the present study.

Half-lives of terbuthylazine were found to be comparatively shorter under these tropical conditions than in temperate regions (Hamaker 1972). Therefore, under tropical conditions, the herbicide studied is not expected to accumulate in the agricultural soil ecosystem, nor to cause any detrimental effect on subsequent crops.

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