due in cotton plants from Yuma increased from 0.73 to 1.27 ppm during the 124-day to 168-day post planting interval. The values were confirmed by re-analysis.

Planting seed in or above the diuron layer caused a high initial level of diuron in plants at Phoenix. There appeared to be no difference in the rate of dissipation or in the total accumulation of diuron between the two treatment rates.

In all cases, cottonseed, to which the tolerance of 1.0 ppm is applicable, had residue values of below 0.1 ppm (the lower limit of analytical sensitivity).

In irrigated cotton, preplanting applications of diuron can be used to control annual weeds during the first half of the growing season. Residues of diuron in cottonseed are within tolerance limitations. Factors such as method and rate of herbicide application, depth of planting, and cotton variety, must be understood to make preplanting applications of diuron successful. However, the margin of safety with diuron is small and more selective herbicides may replace diuron in preplanting applications in cotton.

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Influence of Organic Matter, Texture, and Available Water on the Toxicity of Simazine in Soil[1]

R. Grover[2]

Abstract. Addition of organic matter reduced the effectiveness of 2-chloro-4,6-bis(ethylamino)-*s*-triazine (simazine) to oats in Regina heavy clay soil. At high moisture levels, changes in the relative amounts of clay in the soil did not affect the toxicity of simazine. Toxicity of simazine decreased as the soil moisture level was reduced.

Introduction

In several tests (1, 3, 7), simazine was reported to be less toxic on soils high in clay and organic matter content than in sandy soils. The differences in the toxicity of simazine in a series of California soils were correlated with organic matter content, cation exchange capacity, and pH (14). Since these and other soil factors may be correlated with each other (6, 14), caution must be used in interpreting correlation coefficient results (2).

Day (11) found a broad positive correlation of simazine adsorption with organic matter and clay contents in several California soils, using direct adsorption measurements under slurry conditions. In somewhat similar tests, Harris and Warren (10) found that muck adsorbed simazine more strongly than pure bentonite clay. Since water may compete for adsorption sites (9), slurry-type experiments may not give a correct picture of the adsorptive power of a soil in the field where water is not abundant.

The objectives of the present study were to obtain more information on the relative roles of organic matter, soil texture, and available soil moisture on the toxicity of simazine in a prairie soil.

Materials and Methods

Regina heavy clay which contained 2.89% organic matter and 52% clay was collected from the upper four inches of a field at the Regina Experimental Farm. The soil was air-dried and screened before use. Appropriate amounts of shredded and air-dried peat moss were added

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to change the organic matter content. Relative clay content was altered by the addition of silica sand.

The compound 2-chloro-4,6-bis(ethylamino)-*s*-triazine (simazine) was added to the soil as an aqueous suspension of the commercial 50% wettable powder formulation. The appropriate amounts of simazine in 20 ml of water were added to 350 g of soil to give concentrations of 0, 0.2, 0.4, 0.8, 1.6, and 3.2 ppmw on an oven-dry basis. Soil and simazine were thoroughly mixed, first by hand on a plastic sheet and then in a mechanical mixer. After mixing, the soil-simazine mixture was transferred to waxed cardboard pint cartons. Initial soil moisture levels were obtained by alternately adding small amounts of distilled water and treated soil to a carton. The total amount of water added to each carton depended on the desired level of soil moisture. The cartons were covered with lids and the soil and water allowed to come to equilibrium over a 24-hr period. None of the treatments received nutrient supplement. Each treatment was replicated four times and all tests were repeated two to four times.

Thirteen oat seeds (*Avena sativa* L. var. Rodney) were planted in each carton by pressing the embryo ends into the soil so that the distal ends were flush with the soil surface. The cartons then were transferred to a growth chamber maintained at a 16-hr day length. The light intensity was 1800 ft-c one ft from the top of the cartons. The day and night temperatures were 22 ± 1 C and 10 ± 1 C, respectively. For 2 to 3 days, the cartons were loosely covered with lids; after this period, the lids were removed and the oat seedlings were thinned to 10 plants per carton.

Cartons were weighed daily and distilled water was added to the surface to bring each carton to its original weight. The amount of water needed at each 24-hr adjustment was in the range of 30–50 g per carton. The oat plants were cut off at the soil level 21 days after seeding and oven-dried at 75 C for 2 days for dry weight determinations. Effective dosages for 50% reduction in dry weight (ED_{50}) were calculated for each concentration series.

Percent organic matter was determined in duplicate for the original soil and the mixtures using the chromate titration method of Schollenberger (13) for organic carbon. Percent clay in the original soil only was obtained from duplicate determinations by the hydrometer method of Bouyoucos (4), using the improved hydrometer. Duplicate pH readings were made with a glass-calomel electrode system. Moisture equivalent values were obtained from the Bouyoucos suction method (5). The soil analysis data are given in Table 1.

Table 1. Percent organic matter, percent clay, pH, and moisture equivalent of Regina heavy clay and various soil mixtures.

	Organic matter, %	Total clay, %	pH	Moisture equivalent
Regina heavy clay (RHC)	2.89	52	6.9	60
RHC + peat moss	5.49	52	6.6	70
RHC + peat moss	7.68	52	6.3	75
RHC + silica sand (1:1)	2.95	26	6.7	30
RHC + silica sand (1:3)	2.93	13	6.7	20

Results

The top growth of oat plants grown in Regina heavy clay was progressively less as the concentration of simazine in soil was raised from 0.2 to 3.2 ppm. Plotted on a semi-logarithmic paper, the growth of plants, expressed as percent of control, followed a sigmoid curve (Figure 1).

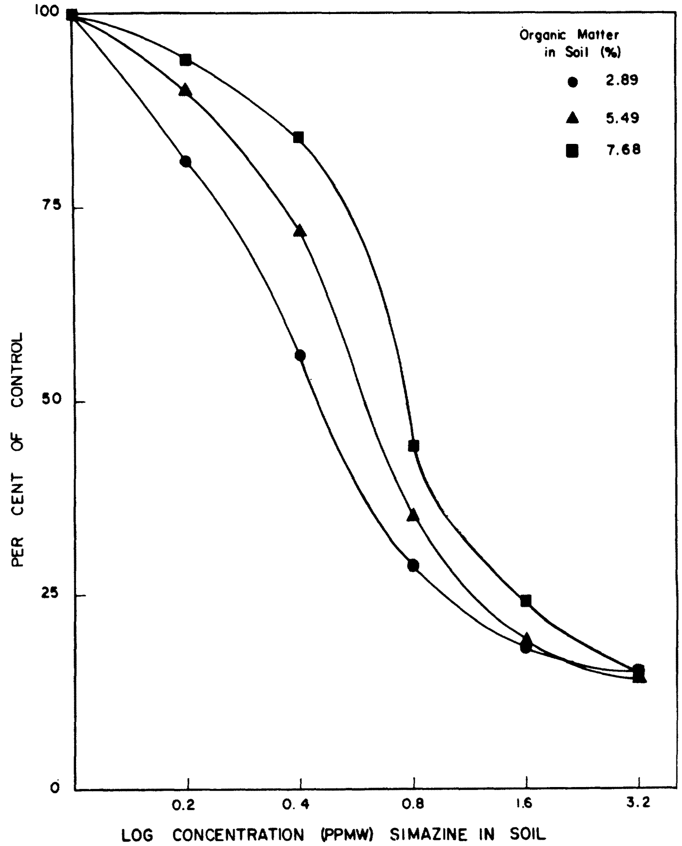

Figure 1. Relative dry weight of oat shoots after 21 days growth in simazine-treated soil maintained at three organic matter content levels.

Initially, the oat seedlings appeared to grow normally at all concentrations without showing any injury symptoms. After about 8 to 10 days when the seedlings were about 7 to 8 cm in height, chlorosis of leaves appeared at the highest concentration and soon after this symptom became progressively apparent at all concentrations of simazine. At the highest rate, the oat plants were dead by the end of the test; the dead tissue was only 15% of the control.

When the peat moss was added to give organic matter contents of 5.49 and 7.68% on an oven-dry basis, the effectiveness of simazine at 0.2 to 0.8 ppm was diminished. The maximum reduction in toxicity was obtained at the highest organic matter level. At 3.2 ppm of simazine, the addition of organic matter had no effect; maximum response was obtained at all levels of organic matter. The ED_{50} values were 0.43, 0.59, and 0.76 ppm for the organic matter levels of 2.89, 5.49, and 7.68%, respectively. Within this organic matter content series, the ED_{50} value increased by approximately 0.16 ppm for increases of 2.6 and 2.2% in the organic matter content of the soil.

Changes in the relative clay content had no significant effect on the toxicity of simazine to oats from simazine concentrations of 0.2 to 3.2 ppm (Figure 2). In this series,

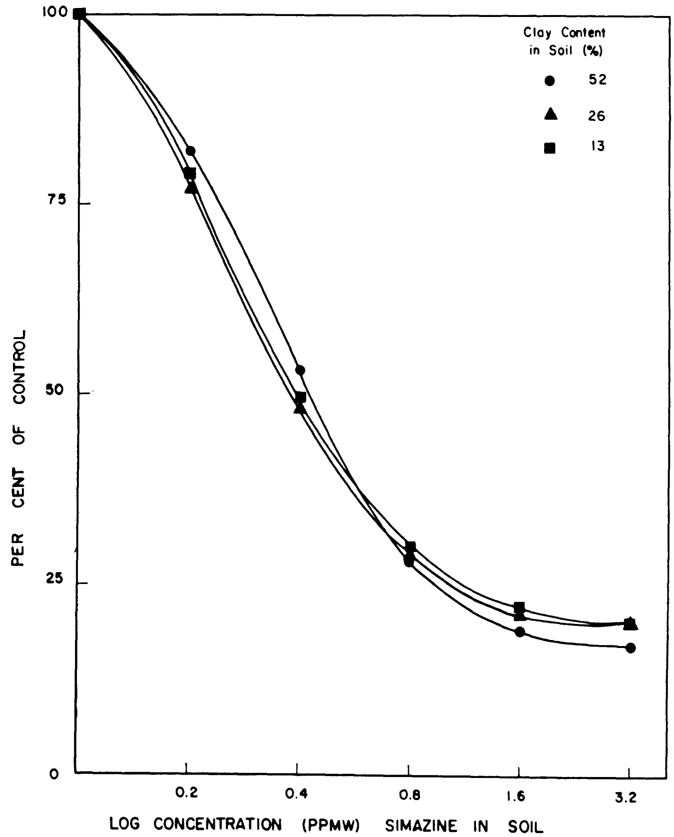

Figure 2. Relative dry weight of oat shoots after 21 days in simazine-treated soil maintained at three clay content levels.

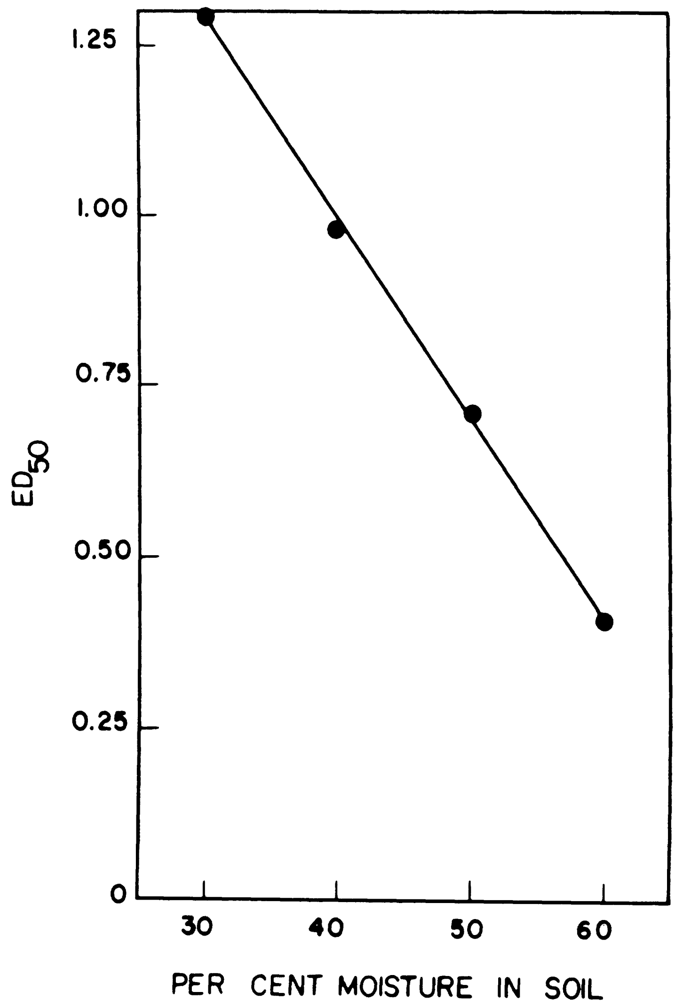

Figure 3. Observed ED_{50} values of simazine in Regina heavy clay at four moisture levels.

silica sand was added to reduce the clay content of Regina heavy clay from 52 to 26 and to 13%. Enough peat moss was added to maintain the organic content at about 2.9% in each texture series. The moisture content of soil in all cartons was maintained at the respective moisture equivalents throughout the course of the experiments. The ED_{50} values in the texture series were 0.42, 0.38, and 0.39 ppm for soils containing 52, 36, and 13% clay, respectively.

In the third series of experiments, the soil moisture level had a marked effect on the toxicity of simazine to oats. Simazine was added to Regina heavy clay at rates of 0.2 to 3.2 ppm. The soil moisture levels were 60, 50, 40, and 30% on an oven-dry basis. As the moisture level in the soil decreased, simazine was less effective in reducing the top growth of oats. Almost three times as much simazine was required to give 50% reduction in growth when moisture level of the soil was reduced from 60 to 30% (Figure 3). It may be pointed out that at all simazine concentrations, growth of oat plants was increased as the amount of soil water was raised. The maximum growth of oats was obtained at the highest moisture level in the absence of the herbicide.

Discussion

The addition of organic matter to Regina heavy clay reduced the toxicity of simazine to oat seedlings. This direct evidence confirms the reports of earlier workers whose conclusions were based on statistical correlations of data obtained from different soil types (14) or on experiments under agitated slurry conditions (10). Organic matter is known to have high potential adsorptive capacity for certain compounds, including several herbicides (10, 12, 15). Presumably then, the added organic matter removed simazine from soil solution thereby reducing the efficacy of the herbicide. In the present tests, the addition of about 0.16 ppm simazine was required for each 2.2 to 2.6% increase in the organic matter to obtain a 50% reduction in growth of oat plants.

The negative effect of soil clay content on ED_{50} values for simazine in soil indicates that under relatively high soil moisture conditions simazine was equally available to plants irrespective of the concentration of clay in the soil. These results further indicate that if simazine was adsorbed by the clay, it was freely and readily desorbed. This supports the observations of Frissel (8) and Harris and Warren (10) who demonstrated that the adsorption of simazine on montmorillonite and bentonite clays was freely reversible under slurry conditions. Thus, the forces involved in the adsorption of simazine on clay apparently are not as strong as the attraction between simazine and organic matter.

The ED_{50} values for simazine at various levels of organic matter and clay were obtained under optimum soil moisture conditions. In the last experiment reported herein, simazine was more toxic under high moisture conditions than under low moisture conditions (Figure 3). Similar results also have been obtained for other relatively low volatile compounds such as diuron (16).

Bailey and White (2) have suggested that there is competition between the solute and solvent molecules for adsorption sites on the surface of soil colloids. Hance (9) has recently provided evidence to support this theory by showing competition between diuron and solvents for adsorption sites. Diuron was strongly adsorbed on hydrophobic surfaces and there was greater adsorption of diuron from petroleum solution than from aqueous solution. Assuming that simazine (an organic solute) and water (a highly polar solvent) are competing for the adsorptive sites, it is possible to explain the availability of simazine in soil under varying conditions of organic matter, clay, and soil moisture.

Under high soil moisture conditions, the availability of simazine will be determined by the extent of its adsorption on the hydrophobic adsorptive sites, i. e. by the relative amount of soil organic matter. Adsorption of simazine on hydrophilic sites, under these conditions, will be insignificant due to the fact that it is freely desorbed from these sites by the overwhelming number of highly polar water molecules.

Under low soil moisture conditions, on the other hand, the relative availability of hydrophilic adsorptive sites will affect the toxicity of simazine in soil. As the water content in the soil is decreased, more simazine will be adsorbed on the now available hydrophilic surfaces, thereby reducing its toxicity. This would explain the steep rise in ED_{50} value with the decrease in soil moisture level (Figure 3).

In conclusion, direct evidence is provided to show that organic matter content reduced the effectiveness of simazine in soil. At high moisture level, the amount of clay content in the soil did not affect toxicity of simazine. Toxicity of simazine to oats in Regina heavy clay decreased as the soil moisture level was reduced.[3]

[3]Lambert, S. M., et al. (Weeds 13:185–190, 1965) have recently shown that ED_{50} values, divided by the percentage available soil water, should give a straight line when plotted against the ratio of percent organic matter to percent available soil moisture. The fact that the data in Figure 3 conform to this relationship, further indicates the relative importance of soil organic matter and water in the availability of simazine in soils.

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