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Soil Solarization: Technique for Decontamination of an Organophosphorus Pesticide from Soil and Nematode Control

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Quinalphos (O,O-diethyl-O-quinoxalin-2-ylphosphorothioate) is an organophosphorus insecticide. It is applied to soil and also used as a foliar spray. Awasthi *et al.* (1984) reported vertical movement of quinalphos when used as granule in soil. Movement (Karoly *et al.,* 1988) of quinalphos, its persistence (Gopal *et al.,* 1988) and occurrence of its metabolite in soil (Babu *et al.,* 1998) led to the speculation about the possibility of environmental pollution due to its use. Quinalphos was found toxic to four species of soil algae (Meghraj *et al.,* 1986) and it inhibited nitrogenase activity in rice rhizosphere (Rao *et al.,*1983). This raises the question of its affect on soil characteristic and thereby on fertility. The paper proposes a decontamination method for quinalphos in soil.

Plastic mulches have been used predominantly for management of soil moisture, temperature, nutrients, and weed control (Katan *et al.,* 1987). The use of this method on persistence of pesticides have given a variety of results. While terbutryn and ethiofencarb persisted longer in solarized soils, other pesticides namely bromacil, fluridone were not affected by this method but volatile herbicides EPTC and vernolate degraded rapidly (Yarden *et al.,* 1989). The effect of this technique on the persistence of an organophosphorus insecticide has not been studied.

This paper presents the effect of soil solarization on the rate of loss of the pesticide, quinalphos and nematode management. It also explores the utility of polythene mulching as a non-chemical method for enhanced degradation of quinalphos in the field.

MATERIALS AND METHODS

Field experiments were conducted during the summer season (May 31 - June 30) at the farm of Indian Agricultural Research Institute, New Delhi. The experiments were replicated three times in plots of 1.5x10 m^2 size

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using randomized block design. Quinalphos 20 AF was sprayed on the soil surface @ 500 g a.i. ha^{-1} using a knapsack sprayer and the plots were then divided to sub plots of 15x1 m^2. There were two sets of control plots, (i) plots which were sprayed with the insecticide but not covered with polythene (non-mulched), (ii) insecticide was not applied on these plots but they were covered with polythene. Six control plots were not sprayed with the insecticide. Out of these six plots, three were left as such and the other three were covered with polythene sheets. Colorless polythene sheets of 100 µm thickness were used for mulching the soil. The mulching was carried out within 15 min of the application of the insecticide in treated plots. Special care was taken to keep close contact between polythene sheets and the soil surface.

The soil of the experimental plot was of sandy loam texture containing 0.6% coarse sand, 59.7% fine sand, 15.3% silt and 14% clay. The soil was yellowish brown in color. Representative samples of soil were analyzed for pH (8.3), organic carbon (0.042%), phosphorus (9.29 kg P ha^{-1}), potash (309.7 kg K ha^{-1}) and electrical conductivity (0.487 mmhos cm^{-1}) before and after 30 days of mulching. No statistically significant difference was observed in these soil characteristics after the mulching. Soil temperatures were recorded with the help of copper constantan thermocouple (type p alloy), fixed in the plots at 5, 10 and 15 cm depths and a portable digital temperature recorder. The soil temperature recorded at 7.00 h was taken as minimum and that at 14.00 h as maximum temperature.

The maximum and minimum temperatures during the outdoor experiment were 43.1 and 29.0°C, respectively, with average relative humidity of 45.5%. Average sunshine hours recorded were 6.1. There was 72.8 mm rainfall during the period of this study.

Soil samples were taken from each plot periodically for residue analysis, starting from the day of spray (day-0) as well as on 2, 6,10, 15, 20 and 30 days after the spray, using an auger up to a depth of 15 cm. Soil samples were collected from three different depths (10, 20, 30cm) on day-30 only.

Five hundred gram of soil samples, taken before the application of the insecticide, 30 days after mulching and quinalphos application, were collected for analysis of soil characteristics and extraction of nematodes. The nematodes were extracted using Cobb’s sieving and decantation technique (Cobb, 1918). The soil residues were kept on double layer of tissue paper supported by wire-mesh and then placed in a petriplate containing tap water. After two days of extraction, the nematode suspension was counted under stereospecific binocular microscope. A representative subsample of soil weighing 50 g was extracted with acetone-hexane (1: 1, v/v) for 6 hrs using a Soxhlet apparatus. The solvent containing the extracted pesticide was passed through a layer of anhydrous sodium sulfate.

The residues of quinalphos were determined by gas chromatography using Varian 3400 GLC equipped with a thermionic specific detector. Temperatures of the column (2 m long x 2 mm id) filled with 3% OV-17 on chromosorb WHP was maintained at 210°C and that of the injector and detector at 220°C and 260°C, respectively. Flow rate of nitrogen (carrier gas) was maintained at 30, hydrogen at 4 and air at 100 ml min^{-1}. Sensitivity of the pesticide for half scale deflection was 0.01 µg ml^{-1} and limit of detection was 0.0006 mg kg^{-1}. Retention time of quinalphos was 2.2 min.

The identity of the pesticide was confirmed by analyzing on capillary column (cross-linked polydimethylsiloxane column HP 1; 10 m long x 0.53 mm id x 2.65 µm film thickness) fitted in Hewlett Packard 5890 A Series II GC. The temperature of column, injector and detector (electron capture) were set at 200, 250 and 300°C, respectively. The retention time of quinalphos was 5.37 at a nitrogen flow rate of 10 ml min^{-1}.

RESULTS AND DISCUSSION

Mean soil temperatures recorded with and without polythene covering at three different depths (5, 10 and 15 cm), presented in Table 1, show that the average maximum soil temperatures under covered soil was 7 to 9°C higher than in uncovered soil. Higher maximum temperatures of covered soil could be explained by two factors - greenhouse effect and prevention of evaporation (Avissar *et al.,* 1986). The minimum temperatures of covered soil also increased but only marginally. More than 50°C temperature was recorded in mulched soil at 5 cm depth, but unmulched soil did not attain 50°C temperature at any of the three depths. Temperature varied with the soil depth. While the maximum soil temperature decreased with depth, the minimum temperature increased due to an increase in the thermal capacity and decrease in the heat conductivity of soil with increase in soil depth. Organophosphorus pesticides are known to be degraded in an alkaline medium (pH of the soil was 8.3) and their rate is enhanced by increase in temperature. Similar report about dissipation of organochlorine insecticide aldrin and heptachlor due to increase in temperature is described (Gopal and Mukherjee, 1994).

Table 1. Mean soil temperatures (°C) recorded during the experimental period

Depth (cm)		With polythene covering	Without polythene covering
5	Max	54.6 ± 5.64	45.7 ± 3.90
	Min	34.3 ± 2.35	32.1 ± 2.20
10	Max	47.4 ± 4.48	40.2 ± 3.21
	Min	34.5 ± 2.36	32.3 ± 2.21
15	Max	44.1 ± 4.19	37.1 ± 2.56
	Min	35.1 ± 2.40	33.2 ± 2.29

Populations of four types of nematodes, namely *Rofylenchulus reniformis, Pratylenchus zeae, Tylenchorhynchus vulgaris and Helicotylenchus dihystera* were drastically reduced by mulching along with quinalphos spray (Table 2). The mulching was effective in controlling the nematodes even in lower layers of the soil (20 and 30 cm depth) as compared to quinalphos applied on plot surface without mulch and control plots where neither mulching nor quinalphos was applied (Prasad *et al., 1995).*

Table 2. Effect of quinalphos and mulching on nematode population

Treatment	*Rotylenchulus reniformis*	*Pratylenchus zeae*	*Tylenchor-hynchus vulgaris*	*Helicotylenchus dihystera*
Control	260	50	200	70
Mulch	10	0	50	10
Mulch+ Quin-alphos	10	0	10	0

The mean recoveries of quinalphos from soil fortified at 1 and 0.1 mg kg^{-1} were found to range from 85-92%. In the control samples (collected from the plots in which no pesticide was applied), no peak was observed at the retention time of quinalphos. Table 3 shows that average residues of quinalphos in both mulched and unmulched soil were similar in magnitude on day-0 (1 hour after the application). Slightly less initial residues in mulched soil samples than in unmulched soil may be due to physical contact of the soil with the polythene sheet which was spread immediately after applying the pesticide and subsequently removed after 1 hour for collecting 0-day soil samples. For finding the statistical differences between the residues of quinalphos found in non-mulched and mulched plots, the data were subjected to paired t test. The t-value was found to be 0.936 for zero day and 1.371 for two day. Since the calculated t-values are less than the table value (4.303) for 95% confidence interval and two degrees of freedom, the difference in initial samples are not statistically significant. The difference is however evident in the amount of residues found in samples drawn from 10 day onward. The extractable pesticide residues dissipated below detectable limit (0.0006 mg kg^{-1}) in mulched soil on day-15 as compared to day-30 in unmulched soil. In day-6 soil samples, percentage dissipation of quinalphos in unmulched and mulched soil was 83.6 and 98.0%, respectively. Similar percent dissipation (98) was recorded only by day-15 in unmulched soil. Quinalphos residue levels were recorded in trace amounts (0.001 mg kg^{-1}) in non mulched soil by day-20 as compared to day-10 in mulched soil, indicating that quinalphos residues rapidly diminished in soil during solarization when compared to non-solarized control.

Table 3. Residues of quinalphos in soil with or without mulching

Sampling days	Average residues (± S.D.) in mg kg^{-1}		t-value
	Non mulched	Mulched	
0 (1h)	0.1100 (0.0150)*	0.0960 (0.0153)	0.936 < $t_{0.05,\ 2\ d.f.}$
2	0.0350 (0.0120)	0.0233 (0.0050)	1.371 < $t_{0.05,\ 2\ d.f.}$
6	0.0180 (0.0025)	0.0010 (0.0017)	
10	0.0060 (0.0010)	Tr	
15	0.0016 (0.0006)	ND	
20	Tr	ND	
30	ND	ND	
Depth in cm			
10	0.084	ND	
20	ND	ND	
30	ND	ND	

* Standard deviation is given in parenthesis
Tr - Trace (<0.001 mg kg^{-1}), ND - Non detectable (<0.0006 mg kg^{-1})

The pesticide residues were found only in top 10 cm layer in unmulched soil and not in lower depth of 20 and 30 cm showing that this organophosphorus pesticide did not leach under the conditions of this experiment. The same has been observed with another organophosphorus insecticide phorate. According to Eto (1974), organophosphorus pesticides do not move freely in soils with water and the loss by leaching depends on the type of soil used besides the nature of the pesticide.

The rate of dissipation of the pesticide in sterilized soil (unpublished results) kept in the laboratory was slower as compared to its rate observed in unsterilized field soil. This is evident from almost four-fold increase in the half-life of quinalphos in sterilized soil (9.84 d) as compared to that observed in unsterilized control soil (2.75 d). Getzin (1968) has also reported that the time for 50% degradation of a similar organophosphorus pesticide zinophos in autoclaved and non-autoclaved soil was 9 and 2 weeks, respectively. It can be inferred that naturally occurring microorganisms present in the field soil are involved in the degradation of quinalphos. Sterilization by autoclaving sufficiently reduces the microbial activity so that the half life of the pesticide is increased to 9.84 days in sterilized soil. Our results derive support from those of Yarden *et al.* (1989). They observed increased microbial activity potential in soil exposed to elevated temperatures realized by solarization and reported enhanced loss of fungitoxic activity of Carbendazim during artificial heating in a simulation experiment.

Table 4. Difference in half life after mulching

Treatment	Half life(days)	Regression Equation
Non Mulched	2.75	Y = -1.1008 - 0.1093x
Mulched	1.30	Y = -1.1807 - 0.2308x

Apart from microbial activity, abiotic factors responsible for accelerated degradation of quinalphos in mulched soil can be due to high humidity and rise in temperature of the soil. The study establishes the usefulness of mulching technique as a non-chemical method for decontamination of soil from the residues of quinalphos, without affecting the soil adversely.

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