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Degradation of Fenamiphos in Agricultural Production Soil[1]

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Abstract: Nematicides are used to control a wide variety of nematodes on many crops; unfortunately, oftentimes the control they provide is erratic. This erratic behavior is not always predictable and has been associated with chemical, physical, and biological degradation of nematicides. Their accelerated degradation is an agricultural problem that has been observed in crop monocultures and in other crop production systems where a biodegradable compound is repeatedly applied to the same soil. The problem can occur in field soil and golf course greens; it is not unique to any single nematicide or class of nematicides, but rather to many classes of pesticides. As indicated by the population density of root-knot nematodes (*Meloidogyne incognita*) in the soil in a 6-year sweet corn-sweet potato-vetch rotation, the efficacy of the nematicide fenamiphos diminished during the third year. Therefore, use of the nematicide applied immediately before planting sweet corn, sweet potato, and vetch should not exceed 3 years. After 3 years, the crop rotation and(or) the nematicide should be changed.

Key words: control, degradation, enhanced degradation, fenamiphos, management, *Meloidogyne incognita*, nematicide, nematode, root-knot nematode, rotation.

Nematicides are used to control a wide variety of nematodes on many crops. These compounds may disappear in soil through chemical, physical, and biological mechanisms (Jones and Estes, 1995; Ou, 1991; Ou et al., 1993; Rajagopal et al., 1986; Smelt et al., 1989; Vonk et al., 1992). The degradation products (metabolites) of nematicides have been implicated in attracting soil microflora capable of accelerated degradation of the parent compound (Jones and Estes, 1995; Norris et al., 1991; Ou and Rao, 1986; Rajagopal et al., 1986). Repeated application also can lead to enhanced degradation of the parent compound and its metabolites (Anderson, 1989; Davis et al., 1993; Ou, 1991; Ou et al., 1994) and loss of nematicidal efficacy (Chung and Ou, 1996; Hall et al., 1988; Johnson et al., 1992; Ou et al., 1994; Rohde et al., 1980).

Fenamiphos (ethyl 3-methyl-4-(methylthio) phenyl (1-methylethyl) phosphoramidate) is a nematicide-insecticide with low volatility. In soil it is rapidly oxidized to fenamiphos sulfoxide, which is then oxidized more slowly into fenamiphos sulfone (Leonard et al., 1988, 1990; Ou, 1991; Ou and Rao, 1986; Ou et al., 1994; Simon et al., 1992). Fenamiphos sulfoxide and fenamiphos sulfone have pesticidal activity and toxicity similar to that of fenamiphos (Waggoner and Khasawinah, 1974), but fenamiphos sulfoxide and fenamiphos sulfone are much more mobile (Bilkert and Rao, 1985; Lee et al., 1986) and persistent (Davis et al., 1993; Leonard et al., 1990; Ou and Rao, 1986) in soils than fenamiphos. In unenhanced soil, the half-life for fenamiphos sulfoxide in laboratory studies was approximately 81 days (Lee et al., 1986). With fenamiphos having only a 2-day half-life and the sulfone a 16-day half-life, the sulfoxide would be expected to be the dominant form that remains active in soil following application of fenamiphos. Johnson et al. (1981b, 1982) and Leonard et al. (1988) found half-lives for the total fenamiphos residue in soil to range from 10 to 20 days on coastal plain soils of the southeastern United States. Degradation of fenamiphos varies with the history of soil exposure to the chemical (Chung and Ou, 1996; Johnson et al., 1992; Ou, 1991; Ou et al., 1994), soil type (Johnson et al., 1981b, 1982), tillage methods (Minton et al., 1990), and microorganisms present in the soil (Ou, 1991; Ou and Rao, 1986; Ou and Thomas, 1994). Total toxic residue of fenamiphos in soil generally does not persist longer than 30 days under field conditions in the southeastern United States (Johnson et al., 1982; Leonard et al., 1990; Minton et al., 1990; Ou et al., 1993).

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Nematode population densities, root-gall indices, and yield of sweet corn (*Zea mays* var. *saccharata* cv. Merit) and sweet potato (*Ipomoea batatas* cv. Jewel) as affected by fenamiphos in an annual sweet corn-sweet potato-vetch (*Vicia villosa* cv. Cahaba White) cropping system were determined over 6 years (Johnson et al., 1992). Treatments were applied, and their location remained the same each year. *Meloidogyne incognita* race 1 was the most significant plant-parasitic nematode in the soil. Numbers of second-stage juveniles (J2) in untreated plots ranged from 0 to 10/150 cm^3 soil in sweet corn and from 3 to 294/150 cm^3 soil by November 1981 in untreated plots of sweet potato, the most susceptible crop in the experiment. Numbers of J2 in the soil were low in 1981 and were not affected ($P = 0.05$) by fenamiphos treatments on sweet corn or sweet potato. Numbers of J2 continued to increase in 1982 and 1983 and reached the highest level on sweet potato in 1984. Numbers of J2 were lower in fenamiphos-treated plots than in untreated plots on most sampling dates in 1982 and 1983, and increased in fenamiphos-treated plots in October 1983. The numbers of J2 were not different ($P = 0.05$) in fenamiphos-treated plots of sweet potato than in untreated plots in 1984, 1985, and 1986. In 1985 and 1986, the numbers of J2 were not different ($P = 0.05$) in fenamiphos-treated vs. untreated plots of all crops for most sampling dates. The large numbers of J2 in untreated plots of vetch and sweet corn after 1983 appeared to be a carryover population from sweet potato. Sweet potato was a good host for *M. incognita*, and sweet corn maintained the surviving nematode population. Earlier research showed that *M. incognita* J2 enter roots of sweet corn, cause little or no galling, and produce eggs (Johnson, 1975; Johnson et al., 1981a). Numbers of J2 in untreated plots of *M. incognita*-resistant vetch declined from November to February each year.

As indicated by the numbers of *M. incognita* J2 in the soil, the efficacy of fenamiphos diminished on sweet potato, the most susceptible crop, after 1983. Based on results of this study, fenamiphos applied before planting sweet corn, sweet potato, and vetch for control of *M. incognita* should not exceed three consecutive years. Thereafter, the crop rotation and(or) the nematicide should be changed. We previously reported similar results with ethoprop (Hall et al., 1988). Enhanced degradation of a number of pesticides occurs in soils with a history of previous exposure to the chemical (Dowler et al., 1987; Ou, 1991; Ou et al., 1993; Racke and Coats, 1990).

Later, soil was collected from the field plots of the 6-year sweet corn-sweet potato-vetch experiment (Johnson et al., 1992) to determine if the rates of fenamiphos, fenamiphos sulfoxide, and fenamiphos sulfone degradation were affected by previous nematicide applications. Soil was collected separately from plots in the same field where fenamiphos had been applied four times over 2 years and from plots where fenamiphos had not been applied (Davis et al., 1993). The predominant component was fenamiphos, which began immediately to degrade into fenamiphos sulfoxide (Fig. 1A). Fenamiphos degradation and the formation of fenamiphos sulfoxide were faster in nonautoclaved soil than in autoclaved soil.

The concentration of fenamiphos present immediately after granular fenamiphos was mixed into the soil (0 days) did not differ among treatments. At all subsequent sampling times, less fenamiphos was recovered from nonautoclaved soil than from autoclaved soil. Concentrations of fenamiphos in autoclaved soil with fenamiphos history were not different from those in autoclaved soil without fenamiphos history.

The amount of fenamiphos sulfoxide extracted from nonautoclaved soils generally increased during the first 2 to 5 days before decreasing with time (Fig. 1B). In nonautoclaved soils, a history of fenamiphos application resulted in lower levels of fenamiphos sulfoxide than was extracted from soil without fenamiphos history. The lower levels detected from days 5 to 14 indicated that the rate of fenamiphos sulfoxide degradation was faster in soil with a history of fenamiphos application.

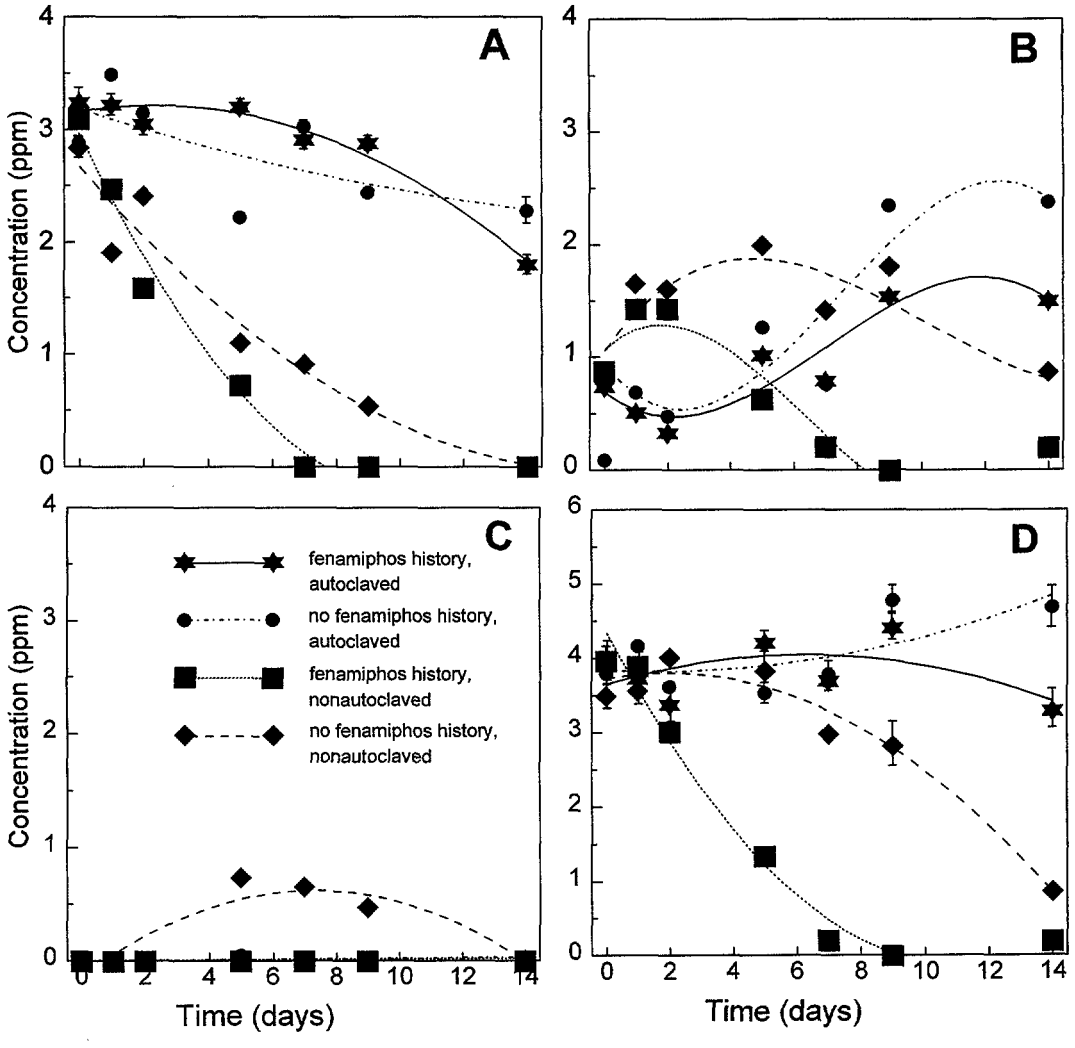

FIG. 1. Concentration of nematicidal compounds for 14 days after incorporation of fenamiphos 15G. Bars represent one standard error of the mean of six replications. Errors bars smaller than the data point markers are not drawn. A) Fenamiphos. B) Fenamiphos sulfoxide. C) Fenamiphos sulfone. (D) Total toxic residue (Davis et al., 1993).

Concentrations of fenamiphos sulfone were lower in autoclaved soil than in nonautoclaved soil at 1, 2, and 4 days after application (Fig. 1C). In nonautoclaved soil, less fenamiphos sulfone was extracted from soil with a history of fenamiphos application than from soil without such history at 5 days after application and all sampling dates thereafter. Total toxic residue concentrations of fenamiphos in nonautoclaved soil with a history of fenamiphos application declined to 0 ppm 14 days after application (Fig. 1D).

The differences between autoclaved and nonautoclaved soil suggest that fenamiphos degradation is biologically mediated, but Ashton (1982) cautioned that autoclave sterilization may also affect the physical and chemical properties of a soil. Microorganisms with the ability to degrade fenamiphos and its metabolites appear to be present even in soil never treated with fenamiphos. Accelerated degradation may occur if microorganisms are conditioned by previous exposure to fenamiphos to preferentially metabolize fenamiphos (Anderson, 1989) or if

microorganisms are selected for more efficient metabolism of fenamiphos, fenamiphos sulfoxide, or fenamiphos sulfone.

The more rapid degradation of fenamiphos in nonautoclaved soil indicates that fenamiphos degradation is biologically mediated. Fenamiphos total toxic residue is degraded more rapidly when soil has been exposed previously to fenamiphos. This accelerated degradation appears to be due primarily to an increase in the degradation rate of fenamiphos sulfoxide, a nematicidal metabolite of fenamiphos. The more rapid degradation of fenamiphos sulfoxide in nonautoclaved soil with a fenamiphos history than in soil with no fenamiphos history demonstrates that previous applications of fenamiphos can lead to more rapid degradation of the nematicide. Similar results were reported from banana plantations (Anderson, 1989), turfgrasses (Ou et al., 1994), and other crops (Johnson et al., 1992). Since this accelerated degradation was not observed in autoclaved soil, accelerated degradation is probably biologically mediated.

Because fenamiphos, fenamiphos sulfoxide, and fenamiphos sulfone have nematicidal properties (Waggoner and Khasawinah, 1974), the accelerated degradation of any of these compounds could reduce efficacy of the nematicide. The accelerated degradation of fenamiphos has been documented (Anderson, 1989; Davis et al., 1993; Johnson et al., 1992; Ou, 1991; Ou et al., 1993). More research is needed to identify specific microorganisms involved in the accelerated degradation of fenamiphos sulfoxide.

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