Fenamiphos Losses Under Simulated Rainfall: Plot Size Effects

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Abstract. *The purpose of this study was to compare two commonly used runoff experimental methods, which have different scales, on measurements of runoff and associated fenamiphos and metabolite losses over a 2−year period. Methods used were 15 m wide by 43 m long (645 m^2) mesoplots and 1.8 m wide by 3 m long (5.4 m^2) microplots, under simulated rainfall (25 mm h^{-1} for 2 h) at 1, 14, and 28 d after fenamiphos application. Mesoplots and microplots were established parallel to a 3% slope on a Tifton loamy sand (Plinthic Kandiudult). All plots were planted to corn (*Zea mays *L.). Target application rate for fenamiphos was 6.7 kg ha^{-1}. Runoff totals and maximum rates for meso− and microplots were similar, with approximately 25% of the rainfall running off mesoplots and approximately 28% running off microplots. Runoff totals and maximum rates from meso− and microplots were each positively correlated (R^2 = 0.89). In both years, fenamiphos lost in runoff decreased with each rainfall event (1, 14, and 28 d after application). The majority of fenamiphos lost in runoff was in the fenamiphos sulfoxide form. Fenamiphos sulfoxide lost over both years from mesoplots ranged from 51% to 93% of the total fenamiphos lost, and loss from microplots ranged from 47% to 100% of the total fenamiphos lost. Runoff from meso− and microplots 1 d after fenamiphos application, a "reasonable worst−case" event, had the greatest fenamiphos losses among events. Total losses of fenamiphos for this event averaged 1.2% (CV = 26%) of applied amount for mesoplots and 1.3% (CV = 47%) of applied amount for microplots. Maximum (seasonal) fenamiphos losses for meso− and microplots were 1.4% of applied for mesoplots and 2.6% of applied for microplots. A positive correlation was obtained between microplots and mesoplots for total losses of fenamiphos + metabolites (R^2 = 0.88), fenamiphos parent (R^2 = 0.89), and fenamiphos sulfoxide (R^2 = 0.81). Relatively poor agreement was found for relatively small losses of fenamiphos sulfone between plot types (R^2 = 0.34). Microplots and mesoplots yielded statistically similar results in terms of runoff and fenamiphos losses; thus, microplot results can be extrapolated up to larger mesoplot areas under these conditions. This has implications for field−scale management and watershed assessment in the Coastal Plain region of the southeast U.S. in that microplot and rainfall simulation results could be useful as statistically valid input datasets to estimate runoff and associated fenamiphos losses from larger areas.*

Keywords. *Metabolites, Nematicide, Pesticide transport, Runoff, Water quality.*

Highly weathered soils in the Coastal Plain region of the southeastern U.S. are susceptible to runoff and erosion. Pesticides are often applied to these soils in the spring when rainfall is characterized by short−duration, high−intensity, convective thunderstorms. Soils are usually bare or crop canopy cover is at a minimum. If pesticides are applied shortly before such a storm, pesticide runoff losses can dominate total annual loss (Wauchope, 1978; Leonard, 1990; Capel et al., 2001).

Pesticide manufacturers are currently using small−scale or "mesoplot" rainfall simulation studies on plots (0.05 to 0.07 ha) to measure pesticide runoff under relatively controlled, "reasonable worst−case" conditions. These studies have typically been made to rebut model predictions made with conservative assumptions, as used in regulatory agency risk assessments, because measuring reasonable worst−case conditions using natural rainfall is problematic (Hendley et al., 1995) Mesoplot experiments are expensive and labor−intensive, but it is believed (and presumably accepted by regulators) that mesoplots are large enough in scale to include or integrate most processes controlling runoff, sediment delivery, and associated pesticide losses as seen at the field scale (Nett and Hendley, 2002). This has not been demonstrated conclusively.

In general, published pesticide runoff experiments using simulated rain have been done on plots much smaller than mesoplots, on the order of a few m^2, and there is debate as to whether such experiments are realistic (Nett and Hendley, 2002). Runoff losses from small plot experiments appear to

Article was submitted for review in August 2002; approved for publication by the Soil & Water Division of ASAE in January 2004.

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  ISSN 0001−2351

fall within the range of values observed in field experiments, when field data are extrapolated to reasonable worst−case conditions (Wauchope and Burgoa, 1995). The use of plots smaller than mesoplot scale would reduce cost and provide the opportunity for more replication and investigation of variability.

Comparing runoff and pesticide losses at different scales and experimental conditions can be difficult. Few attempts have been made to extrapolate these types of results for southeastern conditions (Wauchope et al., 1999; Truman et al., 2001). The question remains: by investigating runoff and pesticide losses under similar experimental conditions, can comparable results be obtained from microplots (5.4 m^2, plot length = 3 m) and mesoplots (645 m^2, plot length = 43 m)?

Fenamiphos (Nemacur 3EC, Bayer Corp., Research Triangle Park, N.C.) is a soil−incorporated nematicide. Prior to its cancellation, it was one of the few non−fumigant nematicides available, an organophosphate applied to corn, sorghum, tobacco, and turf in the Southeast. Once applied, the fenamiphos parent (F_p) is oxidized at the thio−bridge to a fenamiphos sulfoxide (F_x), which is further oxidized to fenamiphos sulfone (F_o), with the first step being more rapid than the second. (Lee et al., 1986; Leonard et al., 1988; Davis et al., 1993, 1994; Truman et al., 1998). Concentrations of F_x in soils can reach those of F_p (Davis et al, 1996; Johnson et al., 1996), and F_x and F_o have nematicidal activity and are more mobile, with organic carbon adsorption coefficient (K_{oc}) values of 240 for F_p, 40 for F_x, and 45 for F_o. The metabolites are also more persistent in soils with half−lives of 5 for F_p, 28 for F_x, and 14 days for F_o (Ou and Rao, 1986; Lee et al., 1986; Ou et al., 1988; Truman et al., 1998).

To address the question related to comparing runoff and pesticide transport results from different size plots, we conducted 12 simulated rainfall events (six per year) throughout two corn growing seasons on a Tifton loamy sand that included microplots (5.4 m^2) and mesoplots (645 m^2). Our hypothesis was that slope length and time after fenamiphos application influences runoff and fenamiphos losses from the Tifton loamy sand, especially as lengths become long enough to cause greater transport capacity, runoff, and increased potential for entrainment and transport of pesticides. Therefore, this study was conducted to quantify and compare runoff and fenamiphos (and metabolites) losses from 5.4 m^2 microplots (plot length = 3 m) and 645 m^2 mesoplots (plot length = 43 m) throughout two corn growing seasons.

Materials and Methods

Experimental Site and Plot Configuration

The research site was established in 1992 and 1993 at the University of Georgia's Abraham Baldwin Agricultural College teaching farm near Tifton, Georgia (30° 29′ N, 83° 32′ W). The soil studied was a Tifton loamy sand (fine−loamy, siliceous, thermic Plinthic Kandiudult). Properties of the Ap horizon of this loamy sand soil include: 85% sand, 4% clay, 0.8% organic carbon, and a pH of 5.5. These properties were determined with the following methods: dispersed particle size determined by the hydrometer method (Day, 1965), organic carbon measured by the modified Walkley−Black method (Nelson and Sommers, 1982), and pH in H_2O (McLean, 1982).

Field procedures were described by Truman et al. (1993), Sumner et al. (1996), Gascho et al. (1998), Wauchope et al. (1999), and Truman et al. (2001). Briefly, two field sites, each consisting of two microplots (5.4 m^2) and one mesoplot (645 m^2), were established on a Tifton loamy sand (3% slope) (fig. 1). A contour map of the research site is given in Sumner et al. (1996). Each site was turned to a depth of 30 cm with a moldboard plow, and 1.8 m wide beds were formed parallel to the slope two days before the first simulated rainfall event of each year. One day before the second simulated rainfall event of each year at each field site, corn (*Zea mays* L. Deltapine G4543) was planted with two rows per bed spaced 0.91 m apart (69,000 seeds ha^{-1}).

Two microplots (each 1.8 m wide × 3 m long, 5.4 m^2) were established upslope from each mesoplot (fig. 1). Each microplot consisted of two half beds with a wheel track in between. Sheet metal (15 cm wide) bordered the two sides (pushed 10 cm into the soil) and the upslope side of each microplot. A V−shaped sheet metal trough was placed at the lower end of each microplot to collect runoff and fenamiphos. Microplots received identical treatments as mesoplots.

Two mesoplots (each 15 m wide × 43 m long, 645 m^2) consisted of eight beds and were established by placing a soil berm at the upslope end of each plot. Runoff and fenamiphos losses were collected from eight wheel tracks, seven full beds, and two border half−beds intercepted by a V−shaped sheet metal trough placed at the downslope end of each plot. Microplots were representative subsections of mesoplots. Therefore, plot design allowed us to compare results obtained from mesoplots and microplots and to replicate the main

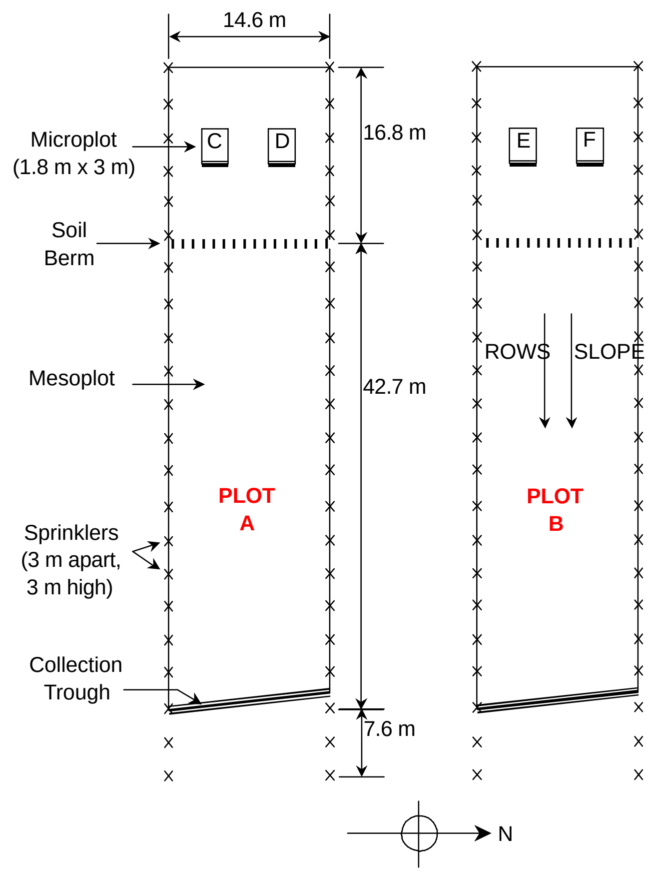

Figure 1. Field plot design for microplots (5.4 m^2, slope length = 3 m) and mesoplots (645 m^2, slope length = 43 m).

treatment effect, which was time after fenamiphos application (expressed in days).

Agricultural Operations and Rainfall Simulation

Agricultural operations and timing of rainfall simulation events are given in table 1. Fenamiphos was broadcast with a tractor−mounted sprayer (spray height = 25 cm) at a nominal application rate of 6.7 kg ha^{-1} (187 L ha^{-1} water). The mesoplot collection trough was covered with plastic during chemical applications. Prior to application, 24 petri dishes were placed throughout the microplot/mesoplot experimental area to measure application rates. Immediately after application, the dishes were collected and placed in the dark and transported to a freezer. Fenamiphos was then incorporated (10 cm depth) by a rotary tiller as required by the label. Fenamiphos in the wheel tracks was not incorporated.

Simulated rainfall was applied using a mesoplot−style rainulator (Coody and Lawrence, 1994; Sumner et al., 1996). Briefly, the rainulator had two rows of irrigation pipe parallel to the side borders of each mesoplot and extended upslope to include both microplots associated with each mesoplot (fig. 1). Aluminum risers were 3 m high and 3 m apart along each row of irrigation pipe. Forty−six 5.6 mm diameter Wobbler off−center rotary action sprinkler nozzles (Senninger Irrigation, Inc., Orlando, Fla.) were operated at 138 kPa and mounted above a pressure regulator. Six simulated rainfall events were conducted over each corn growing season. In this study, we will only discuss the first four events in which fenamiphos losses were measured. Rainfall events occurred 8 d before fenamiphos application (event 1), and 1 (event 2), 14 (event 3), and 28 d (event 4) after application. Before each event, antecedent water content (AWC) for the 0 to 1 cm soil layer was determined gravimetrically. For each

Table 1. Tillage, chemical application, planting operations, and crop growth stages for the experimental site.

Mesoplot	Microplots	Date	Operation
All	All	9 Jan. 1992	Disk twice with harrow to 15 cm.
All	All	4 March 1992	Disk twice with harrow to 15 cm.
A	C, D	4 April 1992	Moldboard plow to 30 cm; form beds. Install berms and flumes.
B	E, F	7 April 1992	
A	C, D	6 April 1992	Event 1: Simulate rainfall on bare, bedded soil.
B	E, F	9 April 1992	
A	C, D	13 April 1992	Re−form beds; broadcast granular fertilizer and fenamiphos; incorporate
B	E, F	15 April 1992	both by rototilling to 12 cm; plant corn (69,000 seeds/ha).
A	C, D	14 April 1992	Event 2: Simulate rainfall on planted beds, 24 h after application
B	E, F	16 April 1992	of fertilizer and fenamiphos.
A	C, D	28 April 1992	Event 3: Simulate rainfall on corn plants. NL = 4 ±0.5 (12).[a]
B	E, F	30 April 1992	
A	C, D	12 May 1992	Event 4: Simulate rainfall on corn plants. NL = 6 ±1 (17).[a]
B	E, F	14 May 1992	Canopy height = 15 cm.
All	All	2 Jan. 1993	Disk twice with harrow to 15 cm.
All	All	30 March 1993	Disk twice with harrow to 15 cm.
A	C, D	5 April 1993	Moldboard plow to 30 cm; form beds, Install berms and flumes.
B	E, F	6 April 1993	
A	C, D	5 April 1993	Event 1: Simulate rainfall on bare, bedded soil.
B	E, F	7 April 1993	
A	C, D	12 April 1993	Re−form beds; broadcast granular fertilizer and fenamiphos; incorporate
B	E, F	14 April 1993	both by rototilling to 12 cm; plant corn (69,000 seeds/ha).
A	C, D	13 April 1993	Event 2: Simulate rainfall on planted beds, 24 h after application
B	E, F	15 April 1993	of fertilizer and fenamiphos.
A	C, D	27 April 1993	Event 3: Simulate rainfall on corn plants. NL = 3 ±0.4 (13).[a]
B	E, F	29 April 1993	
A	C, D	18 May 1993	Event 4: Simulate rainfall on corn plants. NL = 6 ±0.5 (8).[a]
B	E, F	20 May 1993	Canopy height = 15 cm

[a] NL = number of leaves; coefficient of variation (%) given in parentheses.

simulated rainfall event, target rainfall intensity was 25 mm h^{-1} (1.5 mm median drop diameter) for 2 h. Rainfall was measured with a recording rain gauge placed in the center of each mesoplot, and rainfall totals were measured with three rows of 24 catch cups transecting the top, bottom, and center of each mesoplot. Catch cups were also placed around each microplot.

Fenamiphos Sampling and Analysis

Runoff from microplots was determined gravimetrically every 5 min for each 2 h rainfall simulation event. At the beginning of each 5 min period, a 500 mL amber glass bottle with Teflon−lined cap was used to collect runoff for fenamiphos determination. The time needed to collect the volume within each glass bottle was recorded. For mesoplots, runoff depth was recorded continuously with an ASTM 60° trapezoidal flume and an ISCO model 1320 recording flowmeter (ISCO, Inc., Lincoln, Neb.). Grab samples of runoff and fenamiphos losses leaving the flume were also collected every 5 min for the first 30 min of runoff, then every 10 min for the rest of each 2 h simulated rainfall event. Glass bottles similar to those used in microplots were used to sample for fenamiphos losses.

Petri dishes were rinsed into 100 mL volumetric flasks with methanol, brought to volume, and then filtered using a syringe filter (Gelman LC13 PVDF 0.45 μm) into 4 mL high−performance liquid chromatography (HPLC) vials. Runoff samples were stored in a refrigerator at 4°C until analyzed and then weighed, stirred, placed in a 500 mL separatory funnel, and extracted twice with 100 mL dichloromethane (Wauchope, 1987). Extracts were combined and evaporated to dryness on a rotary evaporator. Residue was dissolved in 10 mL of methanol and syringe−filtered into two crimp−top 2 mL vials for gas chromatography (GC) and two 4 mL vials for HPLC. For concentrations in the 50 to 500 μg kg^{-1} range, fenamiphos was analyzed by HPLC using a 15 × 0.46 cm column packed with 5 μm diameter C_{18} adsorbent, preceded by a similar 5 cm long guard column, a Perkin−Elmer LC235 diode array detector, and an acetonitrile/water liquid phase with gradient acetonitrile increase. Detection was at 250 (F_p), 235(F_x), and 225 nm (F_o). For concentrations below 50 μg kg^{-1}, a Varian 3400 GC with split/splitless injector, a J&W Scientific DB1301 30 mm column, and a TSD detector were used. Metabolites, F_x, and F_o, were not resolved on the GC column and were analyzed by HPLC only. Recoveries from 1 and 0.1 mg kg^{-1} spiked runoff samples were 60% to 130% for F_p, 85% to 140% for F_x, and 75% to 100% for F_o. No corrections for recoveries were made. Limits of quantitation (LOQ) were 0.5 μg kg^{-1} for F_p (GC) and 2 μg kg^{-1} for F_x and F_o (HPLC).

Calculations and Statistical Analysis

Several events produced runoff samples with fenamiphos and metabolite concentrations near the LOQ, such that some samples were reported as non−detects interspersed with samples that had quantifiable residues. In other cases, individual samples were missing (some were used for spiking purposes). The following rules were applied to missing data: (1) if neighboring samples were <LOQ, then we assigned them a concentration of zero; (2) if a series of samples included non−zero values interspersed with <LOQ values, then a value equal to 0.5 the LOQ (0.25 μg kg^{-1} for F_p and 1 μg kg^{-1} for F_x and F_o) was assigned to <LOQ samples; (3) a single missing value at the beginning or end of an event was given the value of the adjacent sample; and (4) a missing value between two non−zero values was assigned a value equal to the average of the two adjacent samples.

Runoff losses of pesticides were calculated by multiplying sample concentration by the corresponding flow volume and summing the total load (mass) calculated for the event. Flow−weighted average concentration was calculated by dividing total load by total flow. When comparing F_x and F_o losses to original amounts applied, loads were converted to the equivalent F_p mass using the molecular weight ratio.

Runoff and fenamiphos losses from meso− and microplots were compared on an event and within−event basis for the two plot scales. Regression analysis was used to determine relationships between independent and dependent variables. Means and coefficients of variation (CV, %) are given for measured data. Because of concerns about all rainfall simulation plots not being completely replicated, we performed unpaired t−tests, with the probability level used in evaluating the test statistics set at P = 0.05. Because of physical limitations in conducting this field experiment, especially the mesoplots, plot data may be statistically limited, yet differences in runoff and fenamiphos losses were informative and beneficial to producers and regulators interested in using plot data to better understand organism exposure risk and pesticides in runoff. All data analysis was conducted with corresponding functions in Corel Wordperfect Office 2000 Quattro Pro 9.

Results and Discussion

Fenamiphos Amounts Reaching the Soil

Fenamiphos deposits in petri dish spray traps in 1992 were 5.5 kg ha^{-1} (CV = 20%) for plots A, C, and D and 4.5 kg ha^{-1} (CV = 31%) for plots B, E, and F. In 1993, deposits were 5.7 kg ha^{-1} (CV = 19%) for plots A, C, and D and 4.8 kg ha^{-1} (CV = 17%) for B, E, and F. Deposits ranged from 67% to 85% of the nominal rate (6.7 kg ha^{-1}) and were used to calculate runoff loads of fenamiphos as a fraction of applied amounts. Observed deposits are well within reported values with ground−rig applications of other pesticides (Willis and McDowell, 1987).

Runoff

Total runoff (R_{tot}) and maximum runoff rate (R_{max}) for each event and plot type are given in table 2. After correcting total runoff for plot area, R_{tot} values for each event and plot type were the same order of magnitude. Averaged over the 2−year study period, 25.0% of the rainfall that fell on the mesoplots ran off, while 24.8% of the rainfall that fell on the microplots ran off. Coefficients of variation for R_{tot} over the 2−year study ranged from 1% to 30% (average = 9%). Variation in R_{tot} was due in part to differences in antecedent water content at the beginning of each event and differences in soil surface conditions and plant development. Antecedent water contents for the event occurring 8 d before fenamiphos application were at least three times greater than those for events 1, 14, and 28 d after fenamiphos application for corresponding years (table 2). Runoff from micro− and mesoplots was up to 30% and 36% greater, respectively, for events 14 d and 28 d after fenamiphos application than for

Table 2. Runoff from micro− and mesoplots for events 1 through 4 during 1992 and 1993.[a]

Event	DAA (d)	I (mm/h)	AWC (%)	LA (cm^2)	Mesoplot R_{tot} (mm)	Microplot R_{tot}[b] (mm)	Mesoplot R_{max} (mm/h)	Microplot R_{max}[b] (mm/h)	Mesoplot R (%)	Microplot R (%)
1992										
1	−8	24.7 (04)	5.7	−−	10 (30)	11 (24)	10 (16)	15 (10)	20	22
2	1	24.9 (01)	0.8	−−	8 (13)	11 (05)	9 (18)	15 (07)	16	22
3	14	24.2 (01)	1.8	65 (23)	13 (01)	15 (01)	12 (08)	17 (06)	27	31
4	28	24.7 (01)	1.1	440 (23)	13 (08)	15 (03)	11 (05)	15 (03) *	26	30
1993										
1	−8	25.3 (01)	2	−−	10 (05)	12 (01) *	10 (10)	15 (03) *	20	24
2	1	25.9 (01)	0.6	−−	14 (07)	15 (03)	16 (03)	19 (03) *	28	30
3	14	26.1 (01)	0.6	17 (24)	16 (10)	18 (14)	14 (07)	20 (15)	33	37
4	28	24.7 (01)	0.7	620 (16)	15 (13)	16 (06)	11 (14)	18 (01) *	30	32

[a] DAA = days after pesticide application, I = rainfall intensity, AWC = antecedent water content (%) of the 0 to 1 cm soil layer, LA = leaf area, and R_{tot} and R_{max} are total runoff and maximum runoff rates.
[b] * = means for mesoplots and microplots statistically different at the 0.05 level.

corresponding values for events occurring 8 d before and 1 d after fenamiphos application. Event 3 (14 d after fenamiphos application) generally had the greatest runoff amounts among the four events studied each year. Events occurring 8 d before and 1 d after fenamiphos application were conducted under freshly tilled conditions without any crop canopy, whereas events 14 d and 28 d after fenamiphos application were conducted under a sealed or crusted condition with an increasing corn canopy. Leaf area was an order of magnitude greater for the event that occurred 28 d after fenamiphos application, as compared to that for the event occurring 14 d after fenamiphos application (table 2). For events 14 d and 28 d after fenamiphos application, the soil surface developed surface seals or crusts due to raindrop impact of previous events, resulting in decreased infiltration and increased runoff. Even though the texture of the Tifton loamy sand is dominated by sand (85% sand), it is susceptible to surface sealing/crusting (Radcliffe et al., 1991; Chiang et al., 1993).

Similar trends were found for R_{max}, (mm h^{-1}) in that R_{max} values for each event and both plot types were of the same order of magnitude. However, R_{max} values for microplots were generally greater than corresponding values from mesoplots over the 2−year period (P = 0.02 to 0.003). Antecedent water content, changes in the soil surface due to raindrop impact, and corn canopy influenced R_{max} in similar ways as R_{tot}. Variation in R_{max} values, as indicated by coefficients of variation, ranged from 1% to 27% and averaged 12%.

Fenamiphos in Runoff

In each year, all forms of fenamiphos (F_p, F_x, F_o) lost in runoff decreased with each rainfall event (1, 14, and 28 d after application) (table 3 and fig. 2). Comparing 1992 to 1993, total fenamiphos (F_{tot}) losses from meso− and microplots were about the same for the event that occurred 1 d after fenamiphos application. F_{tot} losses from meso− and microplots for events 14 d after fenamiphos application and 28 d after fenamiphos application were greater for 1992 than 1993. In most events, the majority of fenamiphos lost was in the F_x form. F_x lost over both years from mesoplots ranged from 0.07 to 64 g ha^{-1} and on average was 51% to 93% of the F_{tot} lost. Similarly, F_x lost over both years from microplots ranged from 0 to 79.5 g ha^{-1} and on average was 47% to 100% of the F_{tot} lost. Truman et al. (1998) found similar results in that F_x was the dominant compound lost, with 70% to 99% of the measured F_{tot} being F_x. For both plot types and years, the percentage of fenamiphos lost in runoff in the F_x form generally increased with time (1 d to 28 d after fenamiphos application). Runoff differences of fenamiphos were not due to formulation differences, as only traces of F_x or F_o (<0.5%) were found in the petri dishes, and formulation itself contains only traces of the oxides (Davis et al., 1996). Similar results were found in an experiment done the same years on a similar soil (Johnson et al., 1996). Field oxidation rates of F_p to F_x are greater than those for F_x to F_o and are sensitive to soil water and temperature conditions and microbial activity (Truman et al., 1998).

Table 3. Fenamiphos and metabolites losses from micro− and mesoplots for events 2 through 4 during 1992 and 1993.[a]

Event	DAA (d)	Mesoplot F_p (g/ha)	Microplot F_p (g/ha)	Mesoplot F_x (g/ha)	Microplot F_x (g/ha)	Mesoplot F_o (g/ha)	Microplot F_o (g/ha)	Mesoplot F_{tot} (g/ha)	Microplot F_{tot} (g/ha)	Fraction of Amt. Applied: Mesoplot (%)	Fraction of Amt. Applied: Microplot (%)
1992											
2	1	28 (27)	35 (33)	23 (01)	33 (65)	0.2 (00)	0.4 (71)	57 (24)	68 (46)	1.2 (34)	1.4 (53)
3	14	2 (69)	1 (35)	28 (24)	14 (46)	2 (20)	0.9 (66)	32 (26)	15 (46)	0.7 (35)	0.3 (44)
4	28	0.1 (48)	0.1 (13)	10 (35)	5 (44)	1.3 (38)	0.6 (26)	12 (35)	6 (42)	0.3 (43)	0.1 (45)
1992											
2	1	13 (06)	20 (27)	50 (28)	45 (61)	0.5 (14)	0.9 (40)	64 (24)	66 (43)	1.2 (15)	1.2 (36)
3	14	0.3 (53)	0.3 (32)	8 (53)	6 (34)	0.3 (100)	0.2 (102)	9 (55)	7 (34)	0.2 (59)	0.1 (43)
4	28	0.1 (35)	0.0 (00)	0.4 (80)	0.4 (77)	0 (00)	0 (00)	0.5 (29)	0.4 (77)	0.01 (00)	0.01 (76)

[a] F_p, F_x, and F_o = fenamiphos (parent, sulfoxide, sulfone) losses for each 2 h rainfall event. Losses are expressed as g/ha of F_p. F_{tot} = total fenamiphos losses ($F_p + F_x + F_o$) expressed as grams of F_p. Application rates (kg/ha) for plots A, C, and D = 5.5 (1992) and 5.7 (1993). Application rates (kg/ha) for plots B, E, and F = 4.5 (1992) and 4.8 (1993). Values in parentheses are coefficients of variation (%).

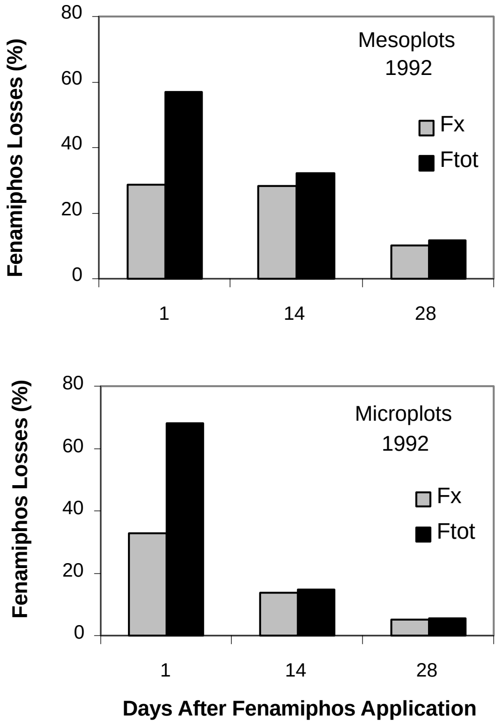

Figure 2. Total fenamiphos (F_{tot}) and f. sulfoxide (F_x) losses (g ha^{-1}) for simulated rainfall events occurring 1, 14, and 28 d after fenamiphos application from meso− and microplots, 1992. Percentages = F_x/F_{tot}.

A 50 mm storm in 2 h has an average return time in this region of 1.05 years (Q. L. Ma and J. L. Hook, unpublished data, 1998), which would not seem to pose much risk in terms of an extreme rainfall−runoff event. However, when such a storm occurs 24 h after pesticide application, as occurred in the first event after fenamiphos application, an extreme scenario relative to soil cover and pesticide application is created. This scenario has been adapted by mesoplot experimenters as a "reasonable worst−case" event, although its probability for various regions has not been documented. Runoff and fenamiphos losses for the event occurring 1 d after fenamiphos application are given in tables 2 and 3 and figure 3. This event was conducted under freshly tilled conditions without any crop canopy, yet runoff from meso− and microplots during this event was not the greatest among events. Greater runoff occurred in later events, when the soil surface was still relatively bare and a surface seal had developed. The "reasonable worst−case" characteristics of the event that occurred 1 d after fenamiphos application coincided with greatest fenamiphos losses among events. F_{tot} losses for this event averaged 60 g ha^{-1} or 1.2% (CV = 26%) of applied amounts for mesoplots and 67 g ha^{-1} or 1.3% (CV = 47%) of applied amounts for microplots. Maximum F_{tot} losses were 80 g ha^{-1} (1.4% of applied) for mesoplots and 119 g ha^{-1} (2.6% of applied) for microplots. Most of the fenamiphos lost during this event was in the F_x form (fig. 2).

During the first 70 to 75 min of simulated rainfall, runoff rates for meso− and microplots gradually increased to a quasi−steady−state rate of 4 to 5 mm h^{-1}, while fenamiphos losses increased to event maximums (fig. 3). During this time, runoff was only occurring from tractor wheel tracks. From 75 min until the end of the simulation, runoff rates for meso− and microplots increased further to event maximums, with microplots having greater rates. At the same time during the event, fenamiphos (all forms) losses decreased from maximums. During this time, the freshly tilled seedbeds became saturated and reconsolidated; thus, runoff increased further due to contributions from the wheel track and seedbeds. Runoff samples high in one analyte generally tended to be high in others, indicating similar rates of extraction from soil and dilution by rainfall of all solutes. For mesoplot A, a sharp concentration increase was seen in the few minutes after simulated rainfall was shut down, but runoff continued from the plots (fig. 3). This runoff still transported fenamiphos, but without dilution by rainfall. These trends occurred in both years on both plot types (Wauchope et al., 1999; Truman et al., 2001). Losses in this study, especially for the extreme scenario (1 d after fenamiphos application), were considerably higher than the field results of Truman et al. (1998), who observed <0.1% losses, but under natural rainfall (less severe) conditions. Unpublished mesoplot studies of fenamiphos by the Bayer Corp. were similar to the fenamiphos losses presented in this study (P. N. Coody, Bayer Corp., personal communication). The losses reported here are also consistent with those of other incorporated pesticides, specifically trifluralin (Wauchope, 1978), given that fenamiphos is more soluble (400 vs. 0.3 mg/L) and less soil sorptive than trifluralin.

Scale Comparison: Mesoplots vs. Microplots

By design, microplots were representative subsections of mesoplots; therefore, a true scale comparison could be made. Runoff losses for each event and plot type were similar, with ~25% of the rainfall running off mesoplots and ~28% running off microplots. In addition, maximum runoff values for each event and both plot types were of the same order of magnitude, yet over the 2−year study period, maximum runoff values per event for microplots were greater than corresponding values for mesoplots (P = 0.02 to 0.003). R_{tot} and R_{max} values from meso− and microplots were positively correlated (R^2 = 0.89 for both relationships). Microplots and mesoplots had statistically similar runoff amounts, in part because of changes in the soil surface with each subsequent rainfall event as a result of surface sealing/crusting, which decreases infiltration and increases runoff. Processes governing surface sealing within an event and crusting between events would be expected to be equally active among plot types. In addition, runoff and sediment yields for the Tifton loamy sand are related to slope length (Truman et al., 2001), not plot width. Therefore, differences in the corresponding width to length ratios for microplots (~2:3) and mesoplots (~1:3) had little effect on runoff losses.

F_{tot} losses in 1992 and 1993 were similar for the event occurring 1 d after fenamiphos application. However, in both years, microplots had less F_{tot} losses for events occurring 14 d and 28 d after fenamiphos application. Decreases in F_{tot}, from the event occurring 1 d after fenamiphos application to the event occurring 14 d after fenamiphos application, were 1.8 times for mesoplots and 4.5 times for microplots in 1992. Likewise, the decrease in F_{tot} from the same two events was 7.5 times for mesoplots and 9.5 times for microplots. Decrease in F_{tot} from the event occurring 14 d after fenamiphos application to the event occurring 28 d after fenamiphos application was about the same for meso− and microplots for both years (~3 times in 1992 and ~17 times for 1993).

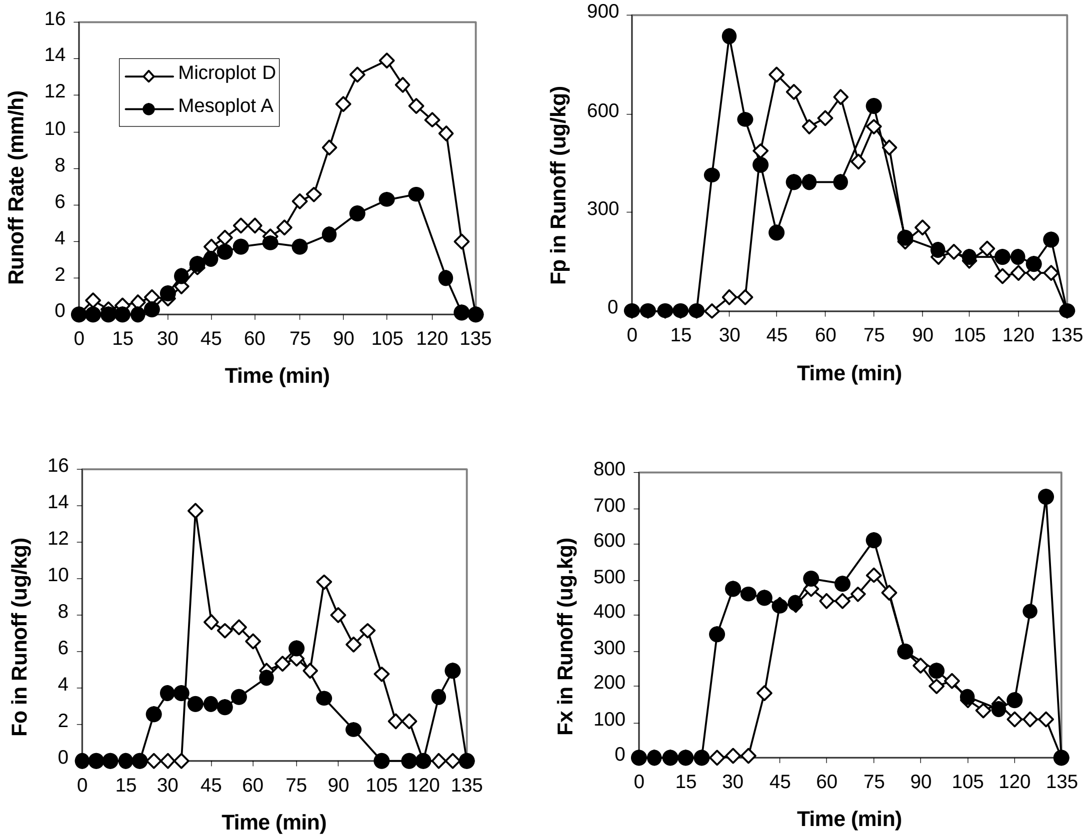

Figure 3. Runoff (mm h^{-1}) and fenamiphos parent (F_p), f. sulfoxide (F_x), and f. sulfone (F_o) losses (µg kg^{-1}) for simulated rainfall events occurring 1 d after fenamiphos application from mesoplot A and microplot D, 1992.

Microplots and mesoplots had statistically similar fenamiphos losses. Overall, a positive correlation was obtained between F_{tot} losses from micro− and mesoplots ($y = 0.8x + 7.5$, $n = 16$, $R^2 = 0.88$). Positive correlations were also found between micro− and mesoplots for F_p and F_x ($n = 12$, $R^2 = 0.89$ and 0.81). Relatively poor agreement was found for F_o between plot types ($n = 12$, $R^2 = 0.34$).

Summary and Conclusions

We quantified and compared runoff and associated fenamiphos losses from two plot sizes under simulated rainfall (25 mm h^{-1} for 2 h) at 1, 14, and 28 d after fenamiphos application over a 2−year period. Mesoplots (15 m wide × 43 m long, 645 m^2) and microplots (1.8 m wide × 3 m long, 5.4 m^2) were established on a Tifton loamy sand (3% slope). All plots were planted to corn (*Zea mays* L.). Target application rate for fenamiphos was 6.7 kg ha^{-1}. The following conclusions can be made:

- Fenamiphos deposits on petri dishes ranged from 67% to 85% of the nominal rate (6.7 kg ha^{-1}). Deposit amounts were used to calculate percent runoff losses.
- Total runoff for each event and plot type was similar, with ~25% of the rainfall running off mesoplots and ~28% running off microplots over the 2−year period. R_{tot} and R_{max} values from meso− and microplots were positively correlated ($R^2 = 0.89$ for both relationships). Over the 2−year period, R_{max} values per event were generally greater for microplots than for corresponding values from mesoplots. Differences in runoff among events were attributable to differences in initial water content for a given event and differences in surface seal and plant canopy development.
- In each year, fenamiphos (F_p, F_x, F_o, and F_{tot}) lost in runoff decreased with each rainfall event (1, 14, and 28 d after application). The majority of fenamiphos lost in runoff was in the F_x form. F_x losses from mesoplots averaged 51% to 93% of F_{tot}. Similarly, F_x losses from microplots averaged 47% to 100% of F_{tot}.
- The event that occurred 1 d after fenamiphos application was considered a reasonable worst−case event. Runoff from meso− and microplots during this event was not the greatest among events, yet this event had the greatest fenamiphos losses among events. F_{tot} losses for the event occurring 1 d after fenamiphos application averaged 60 g ha^{-1} (1.2% of applied amount) for mesoplots and 67 g ha^{-1} (1.3% of applied amount) for microplots. Maximum event−total fenamiphos losses were 80 g ha^{-1} (1.4% of applied) for mesoplots and 119 g ha^{-1} (2.6% of applied) for microplots. This extreme event, as defined by rainfall, soil, and pesticide application conditions, increased the risk for fenamiphos losses via runoff and off−site water quality degradation.
- A positive correlation was obtained between F_{tot} ($R^2 = 0.88$), F_p ($R^2 = 0.89$), and F_x ($R^2 = 0.81$) losses from micro− and mesoplots. Relatively poor agreement was found for F_o between plot types ($R^2 = 0.34$).
- Micro− and mesoplots yielded statistically similar results in terms of runoff and fenamiphos losses. Thus, it appears that microplots can be used in some situations to obtain the same results as mesoplots, with the additional advantage

of greater replication for less cost. This has implications for field management and watershed assessment in the Coastal Plain region of the Southeast in that microplots and rainfall simulation results could be used to estimate runoff and fenamiphos losses from larger areas.

Acknowledgements

The authors express their appreciation to the University of Georgia's Abraham Baldwin Agricultural College in Tifton, Georgia, for the use of experimental land and equipment for this experiment, and to Chris Clegg, Regina Hornbuckle, and A. R. Abdel−Rahman for sample analysis. This work was supported in part by a USDA National Research Initiative Grant.

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