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SOIL EROSION AND PESTICIDE TRANSPORT FROM AN IRRIGATED FIELD

KEY WORDS: Pesticide, kelthane, runoff, transport, polymer, polyacrylamide, and sediments

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ABSTRACT

A field experiment was conducted to study the effect of an anionic polyacrylamide injection in irrigation water on kelthane runoff and sediment transport from a lima bean soil. Periodic runoff water samples from the polymer treated and untreated control furrows were collected from three irrigations and were analyzed for suspended sediments, total sediments and kelthane residues by standard techniques. In addition, water in- and outflow rates were measured periodically to calculate the effect of polymer treatment on water infiltration. The total and suspended sediments in the polymer treated furrows were significantly lower than the untreated ones. Kelthane concentrations in the runoff water in individual furrows were dependent on suspended solid load. During the two post-treatment irrigations (8 h each), only 0.16 and 0.30% of the applied kelthane was observed in the runoff from the treated and untreated plots, respectively.

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The present findings show promising implications of polymer application in reducing pesticide contamination through runoff from agricultural fields.

INTRODUCTION

Soil erosion from croplands is a worldwide problem which not only degrades soil productivity, but also silts up streams and water reservoirs (Holy, 1980). As a consequence of extensive use of pesticides in agriculture, soil erosion by runoff water has led to pesticide contamination of surface waters (Cohen et al., 1984; Domagalski and Dubrovsky, 1991; Seybold et al., 1994). Although only 1-2% of the applied pesticide was detected in runoff and tile drain waters from treated agricultural fields (Knisel, 1980; Beck, 1980; Spencer et al., 1985), biological magnification of these low concentrations may harm biological systems.

From a large field trial on 20 pesticides, Spencer et al. (1985) concluded that concentrations and amounts of pesticides in runoff water depend on pesticide characteristics, method and rate of application, time elapsed between application and irrigation, irrigation efficiency, soil and crop management practices. They reported an average of 1-2% of the applied herbicides and <0.1% of applied insecticides in runoff. These losses decreased at a first-order rate with time and were not correlated with sediment load in runoff water.

A number of high molecular weight polymers are commercially available for soil application and are intended to influence soil dispersion, flocculation and aggregate stability. Application of these polymers in irrigation water has been demonstrated to be effective in increasing water infiltration and reducing erosion in furrow irrigated fields (Lentz et al., 1992; McCutchan et al., 1994; Sojka and Lentz, 1994). Potentially, erosion reduction could contribute to reduction of pesticide loss from the field when they are adsorbed on the eroded soil particulates. Agassi et al. (1995) found that the pesticide napropamide [2-α-naphthoxy)-N,N-diethylpropionamide] transport was linearly related to the amount of fine soil particulates eroded in a miniature synthetic furrow system in the laboratory. This paper reports the results of an experiment conducted on a farmer's field to determine the effectiveness of polymer application to irrigation water to reduce erosion and pesticide transport from the field.

EXPERIMENTAL

Kelthane [1,1-bis-(chlorophenyl-2,2,2-trichloroethanol], commonly known as dicofol, is a sister compound of DDT and used as a miticide in various crops like cotton, fruits, vegetables and ornamentals. It is slightly water-soluble (0.8 mg L^{-1}) and has a high soil sorption coefficient (K,, = 5,000 mg g^{-1}). It has a half-life of 45 days in soil and a low vapor pressure of 4.0 x 10^{-7} cm Hg (Wauchope et al., 1992).

The field experiment was conducted at Patterson, California. The field had a history of kelthane application for the last three years. A lima bean crop was planted on two-row 1.52 m beds. The soil is classified as Capay clay (fine montmorillonitic, thermic Typic Haploxererts) with 45% clay, about 1.5% organic matter, and a neutral pH. The furrows were approximately 243 m long with a gradient of 0.5%.

California Aqueduct irrigation water was pumped through a manifold as schematically illustrated in Fig. 1. One arm of the manifold delivered untreated water to four metered outlets which distributed water to individual furrows. The other arm of the manifold contained a solution injector apparatus through which a concentrated polymer solution was injected at a rate to achieve a 10 mg L^{-1} concentration of polymer in the irrigation water. The polymer was a long-chain (high molecular weight), moderately charged, anionic polyacrylamide manufactured by Allied Colloids, Inc. with a trademark of SOILFIX G1. The polymer solution was passed through four metered outlets to individual furrows which were randomly selected. The flow rate of water to each furrow was adjusted to 2.25 $m^3 h^{-1}$ for the first irrigation and 3.38 $m^3 h^{-1}$ for later irrigations.

Flow near the end of each furrow was measured by collecting water in a container of known volume for a measured period of time. A 19-L bucket was installed with its top flush with the furrow bottom. An apparatus placed in the furrow funneled the flowing water and sediment into the

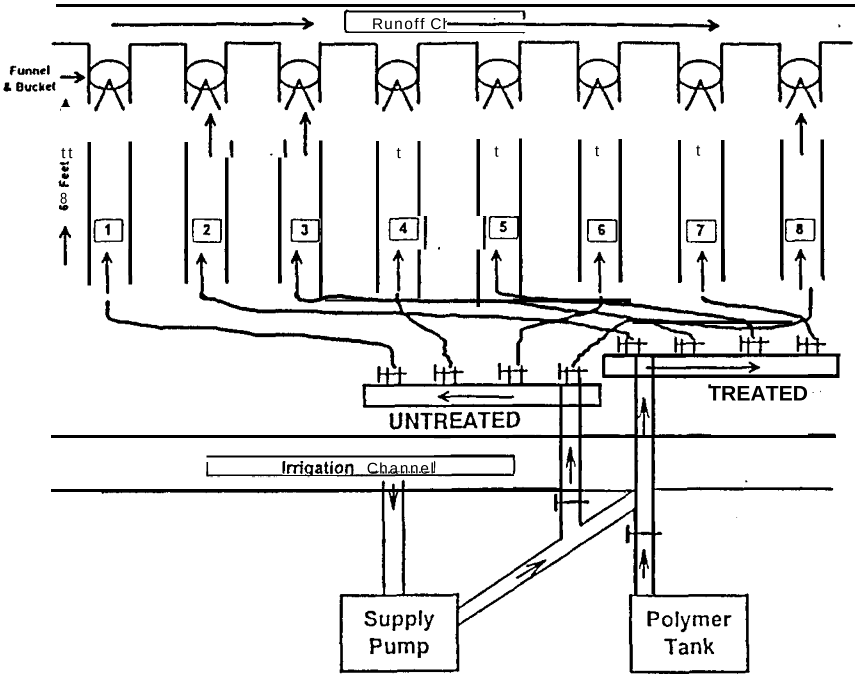

FIGURE 1.
Diagram of field experimental setup and design.

bucket. Except for when samples were being taken, the water flowed through the funnel into a full bucket which overflowed into the last segment of the furrow. At sampling time, water was pumped from the bucket and water flowing into the bucket through the funnel was collected in containers set aside for sediment and pesticide analyses. After the samples were collected, the water in the bucket was again pumped out and the time to fill the bucket was recorded. Samples were collected every 15 min during the first hour after the water reached the sampling site and hourly thereafter. Water collected in the glass sampling bottles for kelthane analysis were stored and transported to the laboratory in ice coolers, and then extracted immediately.

Sampling was done three times during the year. A pre-crop irrigation was applied April 23, 1994 and the sampling represents kelthane background residues before pesticide application or crop planting. The lima beans were planted on May 13, 1994 and kelthane was ground-sprayed at the rate of 1 kg ha“ ***on*** June 13, 1994 to control mites. Sampling was done on June 23, 1994 during the first irrigation after pesticide application. An irrigation was applied on July 12 but no water samples were taken during that irrigation. Water samples were collected on the next irrigation which occurred on July 27. The field had been cultivated prior to the latter irrigation.

Eight randomly-located soil samples (O-15 cm) were collected with a hollow tube auger from the ridges or furrows at different times during the year. The soil samples were stored in glass jars and transported to the laboratory in ice coolers.

The 1-L water sample was extracted into a total of 250 mL hexane (100, 75, and 75 ml) by liquid-liquid partitioning. The hexane extracts were dried through anhydrous Na_2SO_4 and concentrated to 5 mL final volume.

Thus, the concentration in the water sample was concentrated 200 times before analysis. For soil samples, 50 g of the soil samples were extracted into hexane:acetone (4:1) for 4 h by Soxlet extraction. The extracts were dried and concentrated to 5 mL. Kelthane standard (99% purity) was dissolved in DI water to make a 50 μg/mL standard solution. Three blank 50-g soil samples (5% moisture) were spiked with 2 mL of the prepared standard solution. The spiked samples were mixed thoroughly with a glass rod in 3 minutes. Then 25 g of each spiked soil were transferred to a Soxhlet thimble and stored in darkness in freezer (0°C) for 24 h. On the next day, the soil thimbles were extracted by Soxhlet method, using 125 mL of hexane and 125 mL of acetone which were poured onto the soil thimbles. The extraction process took 8 h and the extraction temperature was set at 65°C. When the extraction was finished, the extracted samples were filtered through sodium sulfate and the volumes of the extracted samples were brought down to 25 mL by a roto-vap. Then, the concentrated samples were transferred to vials for analysis by 5980 Hewlett-Packard gas chromatograph. The gas chromatography conditions were injection temperature of 230°C, injection volume of 2 μL with splitless injection, colulmn temperature of 220°C, column type being DB608 (0.53 mm ID, 30 m length), electron capture detector temperature of 350°C, flow rate of N_2 gas (99.999% pure) being 45.5 mL min^{-1}, and minimum detection limit of 1.6 $\mu g\ L^{-1}$.

Water samples were separately analyzed for total sediment and concentration of finer particulates, hereafter referred to as suspended solids. The total sediment was determined by filtering the samples through crucibles supported with 2.1 cm GF/glass microfiber Whatman papers, drying the material at 105% for 1 h and weighing the accumulated sediment. The suspended solids concentration was measured by stirring the sample and allowing the particulates to settle for 5 min. At that time, 6 mL of suspension from the top were siphoned and placed into colorimeter tubes. The optical transmittance was measured at 410 nm wavelength in the colorimeter. A calibration curve between optical transmittance vs. known concentration of particulates in suspension was created to determine the suspended solids concentration in the sample.

RESULTS AND DISCUSSION

The time for water in the furrows to reach the sampling site ranged from 6 to 9 h for the first irrigation. On the latter two sampling dates, the water reached the sampling site in l-3 h. The more rapid advance during the latter irrigations compared to the first was caused by the imposed higher water in-flow rates and reduced infiltration rate later in the season.

The total sediment concentration in the samples collected at different times for treated and untreated furrows are presented in Table 1. With one

TABLE 1.
Total Sediment Load in Runoff Water from Polymer Treated and Untreated Furrows.

	Total sediments* (g L^{-1})					
	Treated			Untreated		
Sampling time (min)	4/23	6/23	7/27	4/23	6/23	7/27
0	0.227	0.297	7.393	1.441	0.708	11.334
15	0.533	0.295	6.436	2.699	0.696	18.063
30	0.404	0.339	6.169	4.768	0.858	10.178
45	0.362	0.334	7.208	5.862	0.727	8.096
60	0.321	0.276	6.304	1.479	0.751	10.814
120	0.146	0.319	5.736	1.469	0.512	9.170
180	0.045			1.334		
240	0.049	0.259	6.788	1.380	0.537	**9.069**
480		0.213	7.931		0.418	7.243
1260		0.244			0.533	

*Average of four replicates.

exception, the total sediment concentration for a given sampling time was consistently higher in the untreated than the treated furrows. The sediment concentration was much higher during the last sampling date than the first two dates. This result was probably caused by the combination of having the field cultivated prior to the last irrigation and the higher water flow rate. Although the field had been tilled prior to the April 23 test, the lower flow rate and the higher infiltration rate probably contributed to the comparably low sediment concentration on that date. The polymer caused the fine particulates to flocculate and settle, as will be reported below, but the settled floccules were observed to be transported by the flowing water. The capacity to transport floccules is enhanced by the higher water flow rate.

The kelthane concentrations in the various samples are presented in Table 2. The lowest concentrations were measured on April 23, which represented background levels from treatments applied in previous years. The highest concentrations were measured on June 23 during the first irrigation after kelthane application. The kelthane concentrations in the samples were considerably lower on August 27 than on June 23. Two or more factors could contribute to the reduced concentrations. First, much of the pesticide residue on the soil surface would have been removed during the first irrigation or subsequently lost by volatilization. Secondly, a cultivation occurred prior to the July 27 irrigation which could have caused a mixing of the pesticide in the top layer leaving less exposed at the surface for transport with the irrigation water.

The kelthane concentration in the polymer-treated water was lower than the untreated water, except for June 23 where the concentrations are comparable for the treated and untreated waters.

The amount of pesticide transported from the field by runoff is a function of the concentration of pesticide in the water and the quantity of runoff. The infiltration rate of the soil was characterized by subtracting the average outflow rate from the average inflow rate. During the June 23 irrigation, the

TABLE 2.
Kelthane Residues in Runoff Water from
Polymer Treated and Untreated Furrows.

Sampling time (min)	Kelthane residues* (μg L^{-1}) Treated 4/23	Treated 6/23	Treated 7/27	Untreated 4/23	Untreated 6/23	Untreated 7/27
0	0.286	10.580	1.157	0.532	9.751	3.256
15	0.220	8.145	1.162	0.396	8.121	3.008
30	0.186	5.029	0.841	0.440	5.970	3.345
45	0.175	6.003	0.855	0.428	5.562	1.929
60	0.230	7.047	0.585	0.387	6.741	2.004
120	0.102	2.285	0.758	0.365	4.993	1.854
180	0.122			0.188		
240	0.076	3.692	0.417	0.234	3.958	1.085
480		3.451	0.329		4.842	1.085
Runoff loss (g ha-‘)		1.761	0.234		2.608	0.861
(percent)		0.140	0.021		0.244	0.076

infiltration rates in the treated and untreated furrows were 19.28 and 14.74 L min^{-1}, respectively. During the July 27 irrigation the average infiltration rates for the treated and untreated furrows were 13.23 and 10.21 L min^{-1}, respectively. Evidently, the added polymer in the water contributed to an increased infiltration rate during both irrigations. There was also an overall decrease in infiltration rate as the season progressed. The losses of kelthane in runoff reported in Table 2 were derived by multiplying the average flow rate between the samples with the respective kelthane concentrations. The amount lost in the runoff from the treated furrows was 67% of that lost in the untreated furrows on June 23. On July 27 the amount of pesticide in runoff in the treated furrows was 27% of that in the untreated furrows. Overall, far less than 1% of the applied kelthane was lost in runoff water.

Agassi et al. (1995) investigated the relationship between soil erosion and napropamide transport. Napropamide transport was linearly related to the amount of fine soil particulates eroded. There was no relationship between napropamide transport and total soil mass eroded. The relationship between kelthane concentration and suspended solids concentration (fine particulates) for the June 23 irrigation are presented in Fig. 2. There was no relationship between the kelthane concentration and suspended solids during this irrigation. However, there was an increasing concentration of kelthane with increasing suspended solids in samples collected during the irrigation on July 27 (Fig. 3). In both cases, the polymer was effective in reducing the concentration of suspended solids. However, during the June 23 irrigation, the reduction in suspended solids was not correlated with reduced kelthane concentration in the runoff.

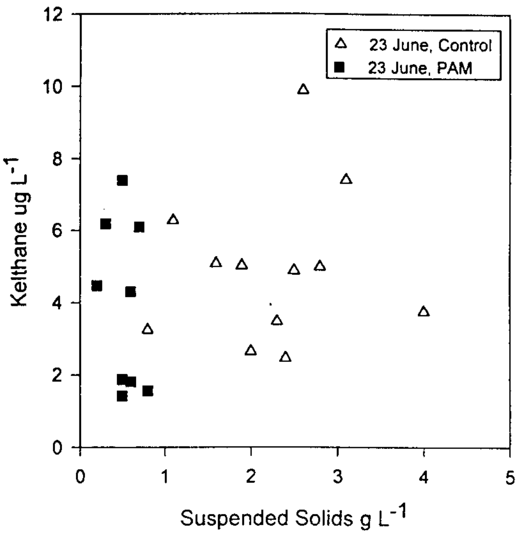

FIGURE 2.
Relationship between kelthane concentration and suspended solids concentration in runoff water for the June 23 irrigation.

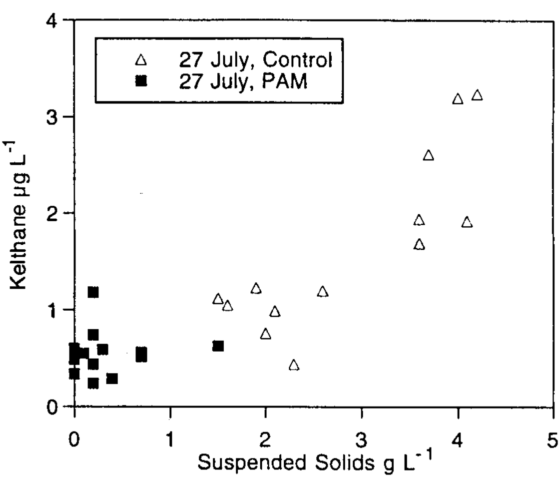

FIGURE 3.
Relationship between kelthane concentration and suspended solids concentration in runoff water for the June 27 irrigation.

The field had been previously irrigated before kelthane application. The furrow bottoms are relatively smooth after an irrigation, and kelthane would have been distributed over this smooth surface. Thus, the kelthane would have been readily exposed to the water flowing in the furrow and a small fraction of it would have become dissociated from the particulates and become dissolved in water. On the other hand, the cultivation prior to July 27 irrigation mixed the surface and made for a rough furrow bottom. Under these conditions, the amount of kelthane adsorbed on the fine patticulates transported by water would have been a larger percentage of the total kelthane transported. Thus, this resulted in a significant relationship between kelthane concentration and suspended solids concentration.

Based on the above analysis, one can conclude that the difference in amount of kelthane lost from the field in the treated and untreated furrows is almost entirely associated with the effect of polymer in increasing infiltration rate on June 23. On the other hand, the difference on July 27 is a combination of the polymer increasing the infiltration rate and decreasing the amount of suspended solids leaving the field.

The kelthane concentrations in the soil samples taken on different dates are presented in Table 3. Note that the concentrations on April 23 prior to kelthane application were lower than on subsequent dates. The lower concentration in the soil taken at the bottom of the furrow on July 27 than

TABLE 3.

Kelthane Residues in Soil During Different Runoff Sampling Dates.

Sampling date	Kelthane residues* ($\mu g\ g^{-1}$) Treated	Untreated
4/23/94 (ridge)	0.062	0.050
6/23/94 (furrow)	0.273	0.318
7/12/94 (ridge)	0.193	0.198
7/27/94 (furrow)	0.095	0.103
8/18/94 (ridge)	0.196	0.214

*Average of four replicates.

June 23 probably was a result of the mixing associated with the cultivation between those two dates. Note that the concentration in the ridge was about the same for both sampling dates. Since the total amount of kelthane removed from the field through runoff was very small, there is no significant difference between the samples taken from the treated and the untreated furrows.

CONCLUSION

The use of polymers in furrow irrigated fields can reduce the runoff loss of pesticides such as kelthane via a combination of two mechanisms. The polymers can increase infiltration rates thus reducing the amount of runoff water which transports pesticides; and the polymer greatly reduces the suspended solids concentration and moderately reduces the total sediment concentration to which pesticide may be adsorbed and carried from the field. The latter mechanism is particularly important when the pesticide is mixed into the soil by cultivation following pesticide application. Unfortunately, the farm management practices did not allow us to check the effect of cultivating following pesticide application but before irrigation or cultivating the soil immediately before pesticide application. Both of these practices may lead to reduced pesticide removal by runoff and also enhance the relative effectiveness of the polymer treatment.

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