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IMPACT OF TILLAGE AND PLACEMENT METHODS ON TERBUFOS INSECTICIDE RUNOFF

M. Mamo, W. L. Kranz, E. R. Douskey, S. Kamble, J. F. Witkowski

ABSTRACT. *On a national scale, the damage caused by corn rootworm (*Diabrotica virgifera virgifera *LeConte), can cause economic loss of up to $650 million annually. To limit these losses, corn producers apply terbufos insecticide to approximately 11% of all corn acres at a time when there is a high probability of intense precipitation. When combined with low vegetative cover and disturbed soil surfaces, there is a high potential for terbufos transport into surface water bodies. Increased public concern for environmental contamination from the use of agricultural chemicals has prompted many crop growers to look for crop production practices that minimize the transport of insecticides by surface runoff. A field experiment was conducted at the Haskell Agricultural Laboratory in northeast Nebraska in the spring of 1989 to develop best management practices for applying corn rootworm insecticides. The objective of the study was to determine the influence of three tillage practices (DISK, NOTILL, and PLOW) and two insecticide placement methods (BAND and FURROW) on the transport of terbufos insecticide (Counter®) with runoff water resulting from high intensity simulated precipitation after chemical application. A randomized complete block design of four replications was utilized. Treatments were laid out in a split-plot fashion with tillage as the main plot and insecticide placement as the subplot. Corn was planted up-and-down hill in 0.76 m row spacings on a Nora silt loam (fine-silty, mixed, mesic Udic Haplustoll) with a field slope of 6 %.*

Water runoff was not significantly affected by either tillage practice or insecticide placement method ($P < 0.05$). Sediment losses from NOTILL plots were significantly less than from the DISK and PLOW treatments. Overall, terbufos transport was significantly affected by tillage practice with the NOTILL treatment resulting in less terbufos transport than the PLOW or DISK treatments. However, terbufos transport was not affected by placement method. Samples collected 10 and 20 min after runoff initiation indicated that sediment-adsorbed terbufos accounted for more than 90% of total terbufos transport. No significant differences in the sediment-adsorbed levels were noted due to tillage treatment or insecticide placement method ($P < 0.05$). Tillage and insecticide placement methods significantly affected the dissolved terbufos concentration, especially for samples collected 20 min after runoff initiation where the BAND placement was greater than the FURROW placement. Within tillage treatments, the PLOW treatment had greater dissolved terbufos concentration than the NOTILL treatment after 20 min of runoff.

Keywords. *Terbufos insecticide, Rainfall simulation, Runoff.*

Corn (*Zea Mays L.*) is a major grain crop throughout most of the Midwest. According to the National Agricultural Statistics Service (NASS), over 3.2 million ha of corn were grown in 2002 in Nebraska alone (USDA-NASS, 2003). Corn grown in monoculture is susceptible to damage from a variety of insects. The damage by corn rootworm (*Diabrotica virgifera virgifera* LeConte), in particular, can cause significant economic loss of $650 million annually on a national scale (Gray, 2000). Consequently, corn acres are treated with a substantial amount of soil-applied insecticide. According to NASS's agricultural chemical use database, about 11% of the corn crop in United States was treated with terbufos in 2001 (USDA-NASS, 2002). An additional 15% of the U.S. corn crop was treated with other soil-applied insecticides. Reliance upon insecticides to minimize economic losses caused by corn insect pests has increased the potential for environmental contamination. Increased awareness by the public of the impact of agricultural chemicals on water quality has prompted investigations to determine proper chemical use practices.

Knowledge of insecticide behavior in the microenvironment of the soil is essential for developing Best Management Practices. Fate of an insecticide is influenced by its solubility in water, partitioning coefficient and soil physical and chemical properties. Soil insecticides, including terbufos, are largely nonionic and their potential for transport within the soil is a function of their adsorption and solubility. Helling (1971) found that mobility of nonionic pesticides was inversely proportional to the field soil water capacity, organic matter, and clay content, and the soil cation exchange capacity. Terbufos is strongly adsorbed by organic matter

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(Felsot and Dahm, 1979; Bowman and Sans, 1982) and rapidly oxidizes based on soil pH and percent organic carbon content (Laveglia and Dahm, 1975).

Most rootworm insecticides are soil applied at planting when the probability for rainfall is high, and when the soil surface is not well protected by vegetation. Soil applied insecticides adsorbed to soil particles may be transported away from the application site via surface runoff thereby reaching surface water systems. In addition, if the insecticide application is followed immediately by intense rainfall, some insecticide can leach through the soil profile. Contamination of groundwater and surface water by agricultural chemicals such as fertilizers and pesticides in Nebraska and elsewhere in the United States is well documented (Weil et al., 1990; USEPA, 1990a,b; USDA, 1991).

Selection of crop production practices that reduce environmental contamination by pesticides can be achieved by implementing best management practices (BMPs) such as conservation tillage (Baker et al., 1978; Triplett et al., 1978; Sauer and Daniel, 1987), and selection of appropriate pesticide placement techniques (Baker and Laflen, 1979; Baker et al., 1982). However, the effectiveness of BMPs to reduce pesticide transport depends upon many factors including properties of the pesticide, the timing and method of application, and agronomic practices such as tillage and irrigation management (Baker and Johnson, 1983).

Insecticides are commonly applied to the soil at planting using a band over the crop row followed by a light incorporation or by directly applying into the seed furrow (Kenimer et al., 1997). Placement decisions are typically based upon equipment available, convenience to the producer, and efficacy of the application method. Little information has been available to address the potential for insecticide transport with runoff immediately following application for the western portion of the corn producing area of the United States.

Tillage practices impact surface runoff and erosion in numerous ways. Research in Illinois found that runoff of soil-applied insecticides can be influenced by tillage methods (Felsot et al., 1990) and chemical placement methods (Kenimer et al., 1997). Conservation tillage in conjunction with contouring provided a greater reduction in terbufos transport than moldboard plow, chisel or ridge till systems (Felsot et al., 1990). Kenimer et al. (1997) reported that terbufos transport from moldboard plow treatments were less when placed in-furrow than when banded. These research efforts were conducted in the eastern portion of the corn belt where differences in soil properties may not represent conditions in the High Plains.

Tillage systems that leave crop residue on the soil surface reduce soil erosion (Laflen et al., 1980; Dickey et al., 1985; Jasa et al., 1986), but runoff may be as great as from conventional tillage (Siemens and Oschwald, 1978; Laflen and Colvin, 1981). Cogo et al. (1984) found that crop residues absorbed the impact of raindrops, and soil surface roughness affected soil losses during a rainfall simulation study. Wauchope (1978) suggested that pesticides with water solubility greater than 10 mg L^{-1} were prone to be transported with surface runoff waters. Stinner et al. (1986) found that terbufos insecticide degraded more rapidly in untilled than plowed soil. Their research indicated that tillage selection was crucial to eliminating transport of agri-chemicals to offsite water bodies.

The combined effects of tillage practices and insecticide placement on terbufos transport have not been investigated sufficiently for the High Plains area where intense rainfall events are more common. The studies reported so far used rainfall intensity that was only 63 mm h^{-1}. The environmental damage resulting from translocation of soil-applied pesticides due to a single intense precipitation event could be more significant. In addition, the high toxicity of terbufos (oral LD_{50} =1.6 mg/kg for rats; dermal LD_{50} = 1.0 mg/kg for rabbits; and LC_{50}(96-h) = 0.004 mg/L for bluegill), its use by corn producers, and the coincidence of application timing with heavy precipitation seasons justified the study of the impact of tillage practices and terbufos placement methods for the High Plains area.

The objective of this study was to conduct a field experiment to evaluate the effect of tillage practice and insecticide placement method on the transport of terbufos (Counter®) with sediment and runoff water resulting from intense rainfall that occurs within 24 h of insecticide application.

MATERIALS AND METHODS

The study was conducted at the University of Nebraska Haskell Agricultural Laboratory located near Concord, Nebraska, approximately 40 km west of Sioux City, Iowa. The soil was a Nora silt loam (fine-silty, mixed, mesic Udic Haplustoll) (USDA-NRCS, 1978). Soil samples collected at the site indicated the soil was 12% sand, 66% silt, and 20% clay with an organic matter content of 3.4% and the surface soil had a pH of 5.4. Field slope averaged 6%.

The statistical design was a randomized complete block with four replications. Each block consisted of three tillage treatments and a check randomly assigned to whole plots and two insecticide placement methods randomly assigned to sub-plots. Statistical analyses were performed to determine differences due to tillage practice, terbufos placement, and all possible interactions using the Statistical Analysis System analysis of variance procedure (Littell et al., 1996). Significant differences were based on F tests ($P < 0.05$).

Each tillage main plot included 16 rows of corn approximately 15 m in length. Insecticide placement subplots included 8 rows 15 m in length. Each runoff plot was 2.4 by 4.9 m including three rows of corn isolated on three sides by galvanized steel borders. A 150 mm I.D. PVC pipe with a 2.6 m long by 100 mm wide slot cut lengthwise was used to collect runoff. To prevent bypass flow around the collection pipe, a piece of galvanized steel bent in an “L” shape was pressed into the soil at the down stream end of the plot. The base of the “L” was directed into the PVC pipe.

All tillage and planting operations were conducted up-and-down hill to encourage runoff. Tillage practices included moldboard plow plus double disk (PLOW), single disk (DISK), and no-till (NOTILL). The check (CHECK) treatment was a moldboard plow plus double disk without insecticide application. Tillage practices prior to the study consisted of a single disking followed by planting corn in a continuous corn rotation. Residue cover was determined from 20 photos from each treatment using procedures presented by Laflen et al. (1981). Crop residue covered an average of 6.8%, 27.6%, and 45.5% of the soil surface for the PLOW, DISK, and NOTILL treatments, respectively.

An eight-row John Deere Model 7100 planter equipped with standard insecticide placement boxes was used to plant corn and apply terbufos (Counter® 15G). Insecticide granules were surface-applied as a 180-mm wide band behind the packing wheels with light incorporation (BAND) or directed into the open seed furrow (FURROW) at a rate of 1.1 kg ha^{-1} of active ingredient (AI). Following tillage, corn was planted at a rate of 43,750 plants/ ha in 0.76-m rows on 22, 24, 30, and 31 May 1989 for replications 2, 1, 4, and 3, respectively. Multiple planting dates were used to insure that soil surface conditions were the same, and to allow each replication to receive the simulated rainfall within 24 h of terbufos application.

A continuous-application rainfall simulator modeled after Shelton et al. (1985) was used to apply water at a rainfall intensity of 112 mm h^{-1}. This application rate was greater than reported by other researchers (Felsot et al., 1990; Kenimer et al., 1997), however, rainstorms with this intensity are common in the western portion of the corn belt. The simulator consisted of six square pattern nozzles mounted on an overhead frame. Complete details about the rainfall simulator construction and operation were presented in Kranz and Eisenhauer (1990). Simulated rainfall depth was monitored using rain gauges located at the four corners of each subplot. The research protocol called for simulated rainfall for a duration of 1.5 h after runoff initiation. Since the times to runoff initiation varied among plots, total simulated rainfall depths were different, not constant.

Beginning 2.5 min after runoff initiation, samples were collected for sediment content. Samples were collected at 2.5, 7.5, 12.5, 17.5, 22.5, 27.5, 32.5, 42.5, 52.5, 62.5, 77.5, 92.5 min after runoff initiation. Each sample was collected by passing a 400-mL glass jar under the outflow tube until the jar was full. Sediment content samples were allowed to settle for five days, weighed, decanted, oven dried (48 h at 50°C), and reweighed to determine sediment content.

Runoff water was also sampled for terbufos concentration beginning 5 min after runoff initiation. Samples were collected at 5, 10, 15, 20, 25, 40, 60, and 90 min after runoff initiation. Each sample was collected by passing a 400-mL glass jar under the outflow tube until the jar was full. Jars were immediately capped, placed in plastic bags, and transported directly to a freezer maintained at -20°C until chemical analyses were performed. Since the chemical half-life for terbufos is typically greater than 10 days, and rainfall simulations began immediately after application, the chemical analyses were restricted to terbufos, and not its two metabolites (terbufos sulfone and terbufos sulfoxide). All analyses were conducted using standard gas-liquid chromatography techniques. Complete details of the extraction and chemical analysis procedures were reported by Douskey (1991).

Terbufos concentration samples collected 10 and 20 min after runoff initiation were separated into the sediment and water components prior to storage in the freezer. Chemical analyses of the water and sediment were conducted separately to determine the partitioning of the insecticide between dissolved and sediment-adsorbed phases. Consequently, those samples are reported on separately and were not used in the goodness-of-fit analyses for runoff or terbufos transport.

RESULTS AND DISCUSSION

PRECIPITATION AND RUNOFF

Total precipitation, runoff, sediment, and terbufos transport for each tillage treatment and terbufos placement method are presented in table 1. Total application depths ranged from 161 to 224 mm for DISK FURROW and PLOW BAND plots, respectively. Significant differences were identified in the application depths between placement methods ($P < 0.05$). Within tillage treatments, the PLOW BAND treatment received significantly greater precipitation than the PLOW FURROW treatment ($P < 0.05$). Since the simulated precipitation was applied for 90 min following the initiation of runoff (that ranged from 3 to 11 min after the application started), the range in application depth is most indicative of differences in soil surface storage and infiltration rate among individual plots.

Runoff losses were not significantly affected by tillage practice or insecticide placement method (table 1, $P < 0.05$). However, water runoff did range from 60.0 to 79.6 mm for the DISK BAND and PLOW BAND tillage treatments, respectively (table 1). As previously mentioned, soil surface storage and infiltration rates were largely responsible for these differences. Terbufos placement did not affect runoff rates for any tillage treatment. These results indicate that terbufos transport would be the result of differences in terbufos concentration or sediment content.

As expected, tillage treatment significantly affected sediment loss (table 1; $P < 0.05$). The NOTILL treatment produced significantly less sediment loss than the DISK and PLOW plots. The difference in residue cover and surface disturbance among the tillage treatments did affect sediment transport from the field site. There were no differences due to terbufos placement or interaction between terbufos placement and tillage treatment with respect to sediment

Table 1. Summary of water application, water runoff, sediment loss, and terbufos transport data collected during a rainfall simulation study at Concord, Nebr. in 1989.

	Tillage Practice				Analysis of Variance[a]		
	Disk	Notill	Plow	P > F	Tillage	Place.	T * P
Water application depth (mm)					P > F		
Band	196	181	224	0.17	0.46	0.01*	0.39
Furrow	161	164	161	0.99			
P > F	0.14	0.45	0.02*				
Water runoff (mm)							
Band	59.95	70.45	79.60	0.33	0.67	0.51	0.49
Furrow	75.07	74.03	74.50	0.997			
P > F	0.21	0.75	0.69				
Sediment loss (kg ha^{-1})							
Band	9683	1985	24330	<0.001*	<0.01*	0.99	0.62
Furrow	8530	3330	24092	<0.001*			
P > F	0.53	0.47	0.91				
Terbufos transport (g ha^{-1})							
Band	27.73	4.46	51.09	0.01*	<0.01*	0.24	0.62
Furrow	20.94	3.00	31.30	0.13			
P > F	0.62	0.91	0.16				

[a] Statistical significance of ANOVA main effects are given by the probability of the F-test ($\alpha = 0.05$). Significant differences are indicated by *; T * P is the Tillage × Placement interaction.

loss. Thus, tillage practice alone was responsible for differences in sediment loss.

TERBUFOS TRANSPORT

The influence of tillage practices and terbufos placement methods on terbufos transport is presented in table 1. Overall, the percent of applied terbufos that was transported from the field plots ranged from 0.3% to 3.7% for the NOTILL and PLOW tillage treatments, respectively. Tillage practice did significantly impact terbufos transport but terbufos transport was not affected by placement method ($P < 0.05$). Though not statistically significant, at least 32% greater terbufos transport was produced from the BAND than FURROW placement methods ($P = 0.24$). Within tillage treatments, the magnitude of terbufos transport followed NOTILL< DISK<PLOW that corresponded with sediment loss values indicating that the availability of disturbed soil influenced terbufos transport. These results point to the potential for offsite water quality impacts, however, the level of terbufos transport would not impact the efficacy of the chemical to control corn rootworms.

Figure 1 illustrates the relationships between terbufos transport and surface water runoff for the NOTILL, DISK, and PLOW tillage treatments. Mean water runoff values for four replications at each sampling time interval are included in the graph. Best fit curves, with the 10- and 20-min samples removed due to sample analysis procedures, followed an exponential function for all tillage treatments. Goodness-of-fit coefficients show that the resulting curves represented over 95% of the variation in the data set for each tillage treatment. The form of the equation represents the diminishing access of precipitation to applied terbufos that results from some terbufos transport off the field earlier in the precipitation event.

Table 2 presents chemical analysis results for samples collected at 10 and 20 min after runoff initiation to estimate the proportion of terbufos that was sediment-adsorbed and dissolved in the surface runoff. Sediment-adsorbed terbufos concentrations were not significantly influenced by either tillage practice or insecticide placement method at either collection time ($P < 0.05$). However, there was a strong trend toward insecticide placement method influencing the amount of sediment-adsorbed terbufos at the 20-min collection time ($P = 0.08$). This was most likely due to most of the terbufos being isolated in the application band that prevented it from being transported with water runoff.

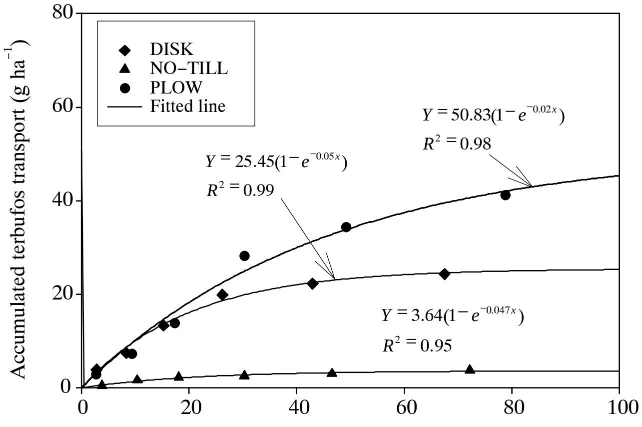

Figure 1. Accumulated terbufos transport vs. accumulated water runoff for the NOTILL, DISK, and PLOW tillage treatments recorded at Concord, Nebr. in 1989. Mean water runoff values for four replications at each sampling time interval are included in the graph.

Table 2. Summary of terbufos sediment-adsorbed and dissolved concentrations for samples collected 10 and 20 min following runoff initiation.[a]

	Tillage Practice				Analysis of Variance[b]		
	Disk	Notill	Plow		Tillage	Place.	T * P
	Terbufos Conc. (µg ml^{-1})			P > F	P > F		
10 min							
Sediment-adsorbed							
Band	10.71	0.69	7.11	0.16	0.53	0.49	0.25
Furrow	3.43	5.42	3.58	0.91			
P > F	0.16	0.36	0.49				
Water-dissolved							
Band	0.038	0.005	0.02	0.13	0.35	0.09	0.36
Furrow	0.004	0.003	0.01	0.94			
P > F	0.05*	0.89	0.38				
20 min							
Sediment-adsorbed							
Band	5.80	8.36	10.93	0.73	0.80	0.08	0.85
Furrow	0.37	2.80	0.83	0.92			
P > F	0.41	0.40	0.14				
Water-dissolved							
Band	0.017	0.00	0.024	0.003*	0.01*	<0.01*	0.10
Furrow	0.004	0.00	0.004	0.73			
P > F	0.06	1.00	<0.01*				

[a] 10 and 20 min are subsampling times after runoff initiation.

[b] Statistical significance of ANOVA main effects are given by the probability of the F-test ($\alpha = 0.05$); significant differences are indicated by *; T * P is the Tillage × Placement interaction.

The influence of placement method on dissolved terbufos concentration in runoff water was more direct. Our results indicate a strong trend between terbufos placement and the terbufos concentration in the surface runoff at the 10-min sampling time (table 2; $P = 0.09$). This was due to the lower concentration for the DISK FURROW than the DISK BAND treatment ($P = 0.05$). At the 20-min sampling time, the dissolved terbufos concentration was significantly affected by tillage and terbufos placement methods. The results for tillage stem from the no-detect determination for the NOTILL tillage treatments for both BAND and FURROW placement methods (table 2). The concentration of dissolved terbufos was significantly less for the PLOW FURROW ($P < 0.05$) and showed a strong trend for less terbufos concentration in DISK FURROW ($P = 0.06$). Though all the dissolved terbufos concentrations were low, these results again suggest that access between the applied terbufos and water runoff is the key factor.

DISCUSSION

Overall, the concentration of sediment-adsorbed terbufos was greater than dissolved in surface water runoff. This result was anticipated due to the relative magnitude of the adsorption coefficient compared to the solubility of terbufos in water (Felsot et al., 1990). These results are in agreement with those of Felsot et al. (1990) for northwest Illinois. Our results, however, do not agree with those of Kenimer et al. (1997), who reported greater concentration of terbufos dissolved in surface water runoff than sediment–adsorbed terbufos for southern Illinois. The northwestern and southern Illinois sites had considerably different residue covers (0.9% to 49% and 4% to 9%, respectively), so when combined with greater field slope, it is anticipated that a greater amount of soil loss would be recorded for the northwestern Illinois site. Our research had a range of crop residue cover between 7% and 45%, which corresponds well with the northwestern Illinois site. In addition, the organic matter was 1% to 2% greater at the northwestern Illinois site. The organic matter at our site was closer to the level reported for the southern Illinois site. These factors do not point to why terbufos responded differently in the work by Kenimer et al. (1997). Possibly the water quality used for the simulation and soil pH could be partially responsible.

The impact of surface tillage on terbufos transport indicates that cropping systems designed to reduce surface runoff and erosion would reduce terbufos transport into surface waters. This would favor practices that maintain crop residue cover and encourage development of soil structure such as no-till or ridge-till systems. However, we found that no-till practices under rainfed corn production systems were not successful in eliminating the potential for offsite transport of terbufos insecticide. Thus, ensuring that a chemical application is needed using Integrated Pest Management techniques may be the most effective means of safeguarding surface waters.

SUMMARY AND CONCLUSIONS

A rainfall simulation study was conducted to determine the impact of tillage practice and insecticide placement method on terbufos transport due to an intense rainfall event following terbufos application. Water runoff was not influenced by either tillage or insecticide placement methods. Sediment losses were greatest for the PLOW treatment followed in magnitude by the DISK and NOTILL treatments. Overall, between 0.3% and 3.7% of the applied terbufos was transported from the application site with runoff waters. Sediment-adsorbed and dissolved terbufos concentrations were consistently greater for BAND than FURROW placement method. However, only dissolved terbufos concentrations for samples collected 20 min after runoff initiation were significantly impacted by placement and tillage methods ($P < 0.05$). Results suggest that the use of no-till planting systems and, if a soil insecticide is needed, application using in-furrow applicators should result in the least amount of transport even when the field is exposed to an intense precipitation event following insecticide application.

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