

2001

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## Abstract

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## Keywords

Herbicide application method, Surface runoff, Herbicide and sediment losses

## Disciplines

Agriculture | Bioresource and Agricultural Engineering

## Comments

This article is from *Transactions of the ASAE*, 44, no. 4 (2001): 807–812.

Journal Paper No. 18840 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa, Project No. 3509.

# SUBSURFACE HERBICIDE APPLICATION WITH THE MODIFIED JOHN DEERE MULCH MASTER

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**ABSTRACT.** *Subsurface versus surface application can reduce herbicide losses from surface runoff, volatilization, photodegradation, and wind-induced drift. Because distribution in the soil plays an important role in herbicide fate and transport, this study was conducted to analyze the effect of various application methods on herbicide losses with surface runoff. Twelve rainfall simulation plots (three replications of four herbicide application treatments) were established in 1995. Losses of atrazine, metolachlor, and cyanazine with surface runoff were measured for the four different treatments: broadcast spray without incorporation with no-till (NT), broadcast spray with disk incorporation (SD), broadcast spray with Mulch Master incorporation (MR), and subsurface application with incorporation using a modified Mulch Master (MB). For the modified Mulch Master, sprayer nozzles were added to the trailing edges of 61-cm wide Mulch Master sweeps, which were run at a depth of 6 cm. Following herbicide application, rainfall was simulated at 6.35 cm h<sup>-1</sup> for 1.5 h on the 3.1 m × 10.7 m plots. Runoff volumes and soil losses were greatest for NT (3.36 cm and 632 kg ha<sup>-1</sup>), followed by MR and MB, with SD showing the lowest total runoff and sediment losses (0.34 cm and 217 kg ha<sup>-1</sup>). Herbicide losses and concentrations were significantly greater ( $P = 0.10$ ) for NT than for the other three treatments. On the NT plots, runoff began quickly and only occurred on two of the four inter-row areas that had traffic tracks. Herbicide losses decreased in the order of NT, MR, SD, and MB. In addition, MR and MB retained more surface crop residue than SD.*

**Keywords.** *Herbicide application method, Surface runoff, Herbicide and sediment losses.*

**M**odern technology has allowed human needs for food and fiber to be met. However, intensive agricultural chemical use can potentially degrade soil and water resources. A National Research Council report (NRC, 1989) stated that agricultural chemicals are the main source of water pollution today. Therefore, farmers and researchers are in search of practices that can sustain current crop production levels while protecting soil and water quality.

In recent decades, there have been human health and ecosystem concerns for the presence of herbicides in surface water resources. Transport of herbicides with surface runoff and subsurface drainage is a complex process because it depends on many physical, chemical, and environmental factors. The variability of soil types, rainfall conditions, tillage practices, types of herbicide, types of herbicide carrier, and herbicide application methods are some of the factors that affect the movement of herbicides in the

soil-water environment (Baker and Mickelson, 1994; Sadeghi and Isensee, 1997; Ahmed, 1999).

To conserve soil and reduce production costs, farmers are increasingly using conservation tillage and no-tillage systems. Conservation tillage, defined by the condition that 30% of the soil surface be covered by crop residue after planting, can involve some tillage, which allows for incorporation of herbicides while still leaving adequate crop residue on the surface to control erosion. No-till (NT), the extreme end of conservation tillage, uses no tillage and maximizes the potential residue cover. NT minimizes soil losses and has been accepted as an effective erosion control measure (Van Doren et al., 1984; King et al., 1995; Watts and Hall, 1996). However, Sauer and Daniel (1987) reported that NT may not necessarily decrease losses of soil-applied herbicides in runoff water because of increased herbicide concentrations in runoff water and sediments. In some cases, no-till can increase herbicide concentrations and losses with runoff water when compared to conventional tillage (Mickelson et al., 1995).

Traditional methods of preplant herbicide application often involve a surface broadcast spray followed by one or more incorporation passes with a tillage tool. Incorporation with conventional tillage tools, such as a disk or field-cultivator, reduces the amount of crop residue on the soil surface, which can lead to increased soil loss through wind and water erosion. However, it also moves the herbicide out of the 1 to 2 cm surface "mixing zone" that contributes the herbicide to the surface runoff (Mickelson et al., 1983; Baker and Lafen, 1979).

Although mechanical incorporation has been shown to be extremely effective in reducing surface runoff losses of herbicides, it is also the major contributor to reduced residue

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Article was submitted for review in April 2000; approved for publication by the Soil & Water Division of ASAE in May 2001. Presented at the 1997 ASAE Annual Meeting as Paper No. 97-1052.

Journal Paper No. 18840 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa, Project No. 3509.

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cover. Use of crop residue from the previous year and mulch can reduce sediment concentrations and losses (Glenn and Angle, 1987; Felsot et al., 1990). However, surface-applied herbicides may be intercepted by residue and may wash off later during irrigation or rainfall events (Ghadiri et al., 1984; Boyd et al., 1990; Dao, 1995).

With development of special tools, subsurface herbicide application can provide incorporation with minimal disturbance of surface residue. Wooten and McWhorter (1961) developed a horizontal blade applicator for one-pass herbicide incorporation. Using EPTC (S-ethyl dipropylthio-carbamate), the subsurface application provided better weed control than an identical rate of surface-applied EPTC. Wooten et al. (1966) also achieved satisfactory weed control using a knife injector for subsurface application of EPTC; however, the knife injectors were less efficient than the horizontal blade applicators and required a spacing of 6.35 cm (2.5 in) for effective weed control.

Other researchers have also developed subsurface chemical application tools for controlling weeds. Subsurface spray nozzles were placed on a modified V-plow by Fenster et al. (1963) for weed control in fallow land, leaving the surface residue virtually undisturbed. Hollingsworth et al. (1973) used a subsurface sprayer in conjunction with a root plow for brush control, greatly increasing weed control as compared to the root plow alone. Solie et al. (1983) mounted jet injection manifolds onto a sweep plow. Crop yield and weed control were improved or maintained when compared to disk incorporation.

A point injector for one-pass incorporation was developed by Mickelson (1991) and Mickelson and Baker (1992) to band-apply herbicides at planting. When compared to band spraying, the point injector provided similar weed control and demonstrated potential to reduce environmental losses due to volatilization and runoff.

Desire for one-pass incorporation while maintaining residue levels encouraged the development of the John Deere Mulch Master (Johnson et al., 1993). Chisel plow sweeps 61 cm (24 in) wide followed by two rows of incorporation wheels thoroughly break up, level, and mix the soil. Studies by Mickelson et al. (1995) and Johnson et al. (1993) showed that Mulch Master incorporation leaves higher surface residue levels than single or two-pass disk incorporation. In some cases, pre-tillage residue levels were maintained or improved after one Mulch Master tillage pass. Mickelson et al. (1995) also found that the Mulch Master reduced herbicide losses to the same level as found with disk incorporation of the herbicides.

The study reported here was designed to evaluate the effect of various methods of herbicide application on herbicide losses with surface runoff. Rainfall simulation was used to compare surface runoff herbicide losses between four herbicide application methods, including a subsurface application with a modified Mulch Master. The specific objective of this research was to determine the effects of subsurface application with the modified Mulch Master and other application methods on herbicide concentrations and losses with runoff and sediment.

## MATERIALS AND METHODS

This study was conducted at the Agronomy and Agricultural Engineering Research Center near Ames, Iowa. The soils at the site are predominantly Nicollet, fine loamy, mixed, mesic Aquic Hapludolls in the Clarion-Nicollet-Webster Soil Association (USDA-SCS, 1981). The soils are classified as moderately permeable and somewhat poorly drained. A randomized block design was used to lay out three replications of four application treatments. The treatments included:

- Herbicides broadcast sprayed with immediate disk incorporation (SD)
- Herbicides surface broadcast sprayed with incorporation using a Mulch Master (MR)
- Herbicides subsurface sprayed using the modified Mulch Master sweeps (MB)
- Herbicides broadcast sprayed without incorporation with no-till (NT).

The disk was run at a depth of about 10 cm; the Mulch Master was run at a depth of about 6 cm. The previous year's crop was corn (*Zea mays* L.), and all plots other than NT were chisel plowed on 24 June 24 1995. Herbicides were applied to all plots on 14 July 14 1995. Three herbicides were applied to each plot:

- Atrazine [(6-chloro-N-ethyl-N-(1-methylethyl-1,3,5-triazine)-2,4-diamine] at 2.24 kg ha<sup>-1</sup> (2.0 lb ac<sup>-1</sup>)
- Metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)] at 2.80 kg ha<sup>-1</sup> (2.5 lb ac<sup>-1</sup>)
- Cyanazine [2-{{4-chloro-6-(ethylamino)-1,3,4-triazin-2-yl}amino}-2-methylpropionitrile] at 3.36 kg ha<sup>-1</sup> (3.0 lb ac<sup>-1</sup>).

The sprayer equipment was calibrated to apply the herbicides mixed with water at a rate of 234 L ha<sup>-1</sup> (25 gal ac<sup>-1</sup>). All three herbicides have been widely used in the Corn Belt of the U.S. and can be classified as moderately adsorbed herbicides. Rainfall simulation was used to compare herbicide runoff losses between four application treatments.

### SUBSURFACE SPRAY SWEEPS

A sketch of a sweep on the modified Mulch Master is shown in figure 1. For subsurface spraying, a manifold was added to the underside of each of the 61 cm (24 in) wide, low-crown Mulch Master sweeps (fig. 2). Six Tee-Jet model 110015 VisiFlow nozzle tips were fitted to 6.35 mm (0.25 in) o.d. copper tubing and riveted to each sweep. Each stainless steel nozzle was ground down to fit into a 6.35 mm copper solder tee and was then epoxied into the tee. Fittings were soldered together, interconnected by the copper tubing, so that the spray patterns would overlap within 2.54 cm (1 in) of the trailing edge of the sweep. Three nozzles were positioned on each side of the sweep and joined together at the center. The copper tubing with the nozzles was placed on the back/under side of the sweep for physical protection and fitted into the spray line. A 100-mesh screen was placed in-line between each sweep and the spray line to remove particulates. The manifolds were protected from the soil by 1.59 mm (0.063 in) thick plates of sheet metal riveted to the bottom of the sweeps.

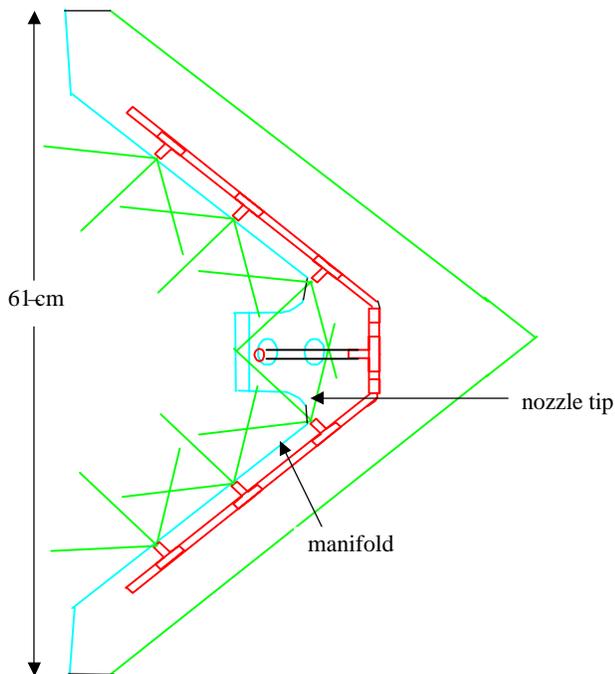


Figure 1. Sketch of the modified Mulch Master sweep.

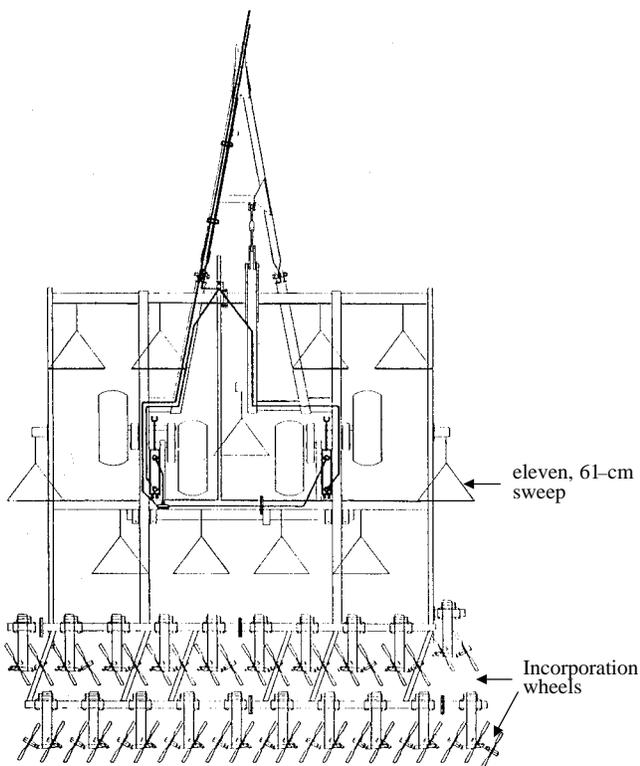


Figure 2. Schematic of the Mulch Master.

#### RAINFALL SIMULATION

Twelve 3.1 m × 10.7 m (10 ft × 35 ft) plots were established with slopes between 1% and 5%. Sheet metal borders, 20 cm wide, were driven 10 cm into the ground to hydrologically isolate the plots from the surroundings. Rainfall simulation was performed on 15 and 16 July 1995 (one event for each plot), using a rotating boom rainfall simulator as described by

Swanson (1965). The rainwater was applied to the plots, two at a time, at a rate of 63.5 mm h<sup>-1</sup> for 1.5 h totaling 95.2 mm. After runoff began, runoff volume samples were taken initially at 5-min and later at 10-min intervals to determine average flow rates over the duration of the runoff event. Composite runoff water samples were collected during the intervals (by periodically passing the mouth of a glass jar under the outflow) for later use in sediment and herbicide concentration analysis. Samples were stored for no more than 2 months in a refrigerator until extraction and analyzed within 5 months after extraction at the ISU Agricultural Engineering Water Quality Laboratory. From each runoff sample jar, duplicate subsamples were taken for total solids analysis. Well-mixed 20 mL aliquots were weighed, oven dried at 105° C, and reweighed in duplicate. The results were expressed as g of sediment per L of runoff water.

#### CHEMICAL ANALYSIS

Herbicide analyses were performed using gas-liquid chromatography (GLC). Sediment was first separated from runoff water in a 250 mL stainless steel cup using a model IEC B-20A refrigerated (maintaining a temperature of 4° C) centrifuge spinning at 8000 rpm for 30 min. Water was separated from the sediment by decanting it into a 250 mL glass beaker. Ten glass beads, 1 mL distilled-deionized water, and 5 mL toluene were then added to the remaining sediment. The stainless steel cups were rotated at 60 rpm for 1 h on a vertical plane rotator, followed by 1 h upright shaking at 250 rpm on an orbital shaker. The mix was allowed to settle for 30 min and the toluene extracts were decanted into test tubes. The steel centrifuge cups were then oven dried for 24 h at 105° C to obtain the dry sediment weight.

The decanted water samples were filtered (through 15 cm diameter, medium porosity, slow flow rate, 5 μm pore size filter paper) to remove any sediment carried over in the decanting process. Although some clay-sized particles could possibly pass through the filter, based on herbicide adsorption coefficients of less than 20 (for all three herbicides), 100 mg of sediment would have to pass through to affect the herbicide concentration results by 2%. The clarity of the filter water indicated that this was not the case. A 100 g aliquot of the decanted water sample was placed into a 250 mL boiling flask, and 50 mL of toluene was added by weight (43.3 g). The water-toluene mix was shaken on the orbital shaker at 250 rpm for 1 h, allowed to separate for 30 min, and then the toluene extract was decanted.

All toluene extracts were analyzed using a Tracor 560 gas-liquid chromatograph equipped with a model 702 N-P thermionic detector and a Tracor 770 autosampler. Helium at a flow rate of 18 cc min<sup>-1</sup> was the carrier gas, and reaction gases were hydrogen and air with flow rates of 3.5 and 100 cc min<sup>-1</sup>, respectively. Column temperature was a constant 160° C, with the inlet at 246° C. Separation of the herbicides was accomplished using a 10% DC-200/2.0% OV-225, 0.63 cm diameter × 1.8 m long packed column. Data were recorded with a Spectra-Physics 4270 integrator and a Fisher Recordall 5000 strip chart recorder. Concentration values of herbicides were converted into percent recovery and were found to be with a range of 95.3% to 102.3%.

Percent surface residue for the NT plots, and before and after tillage for the other plots, was determined using a photographic method (Lafren et al., 1981). Slide photographs were taken at the top, middle, and bottom (a total of three

slides of each plot) and were projected onto a 10 × 10 point grid to determine percent residue cover.

## RESULTS AND DISCUSSION

Spring chisel plowing preceding any secondary tillage reduced residue cover by approximately 30%, when comparing to the NT plots (table 1). The residue-preserving advantage of the Mulch Master can also be seen in table 1, where the percent residue cover remaining after secondary tillage and rainfall was not reduced, but actually increased on average. The increase in residue cover was due to buried residue that reappeared on the soil surface during herbicide incorporation using the Mulch Master. Wash off with rainfall may also have been a factor; although for NT, residue cover decreased with rainfall. The tandem disk, used on the SD plots, reduced residue cover by 14%.

Both runoff volumes and sediment losses increased in the order of SD < MB < MR < NT (table 1). Although the NT plots had the highest residue cover, the runoff volumes and sediment losses for NT were significantly higher than for the other three treatments (however, even for NT, the sediment loss was only 632 kg ha<sup>-1</sup>, which is not severe for a rain of 63.5 mm h<sup>-1</sup> for 1.5 h). This difference can be attributed to the wheel-tracking effect from implement traffic. In these controlled-traffic plots, all field operations (including the herbicide application) in the last two years were such that two of the four row middles received all the wheel tracking. During rainfall simulation, it was observed that runoff for NT only occurred in these two row middles. Based on wheel width, at least 30% of the area of the NT plots was wheel tracked. Typically, the percentage of area compacted by wheel tracks in general no-till systems would be in the range of 10% to 20%.

Surface runoff began only 6 min after rainfall began for the NT plots; the other treatment plots averaged 38 min before surface runoff began (table 1). Although the disked plots had the lowest residue cover, with deeper secondary tillage (about 10 cm), and therefore greater initial infiltration and ponding, the runoff volume and sediment loss were not

significantly different from MB and MR, which were run at a depth of about 6 cm. There still seemed to be sufficient residue cover to keep the SD plots from surface sealing during this first rainfall event after tillage.

Both herbicide concentrations and runoff losses increased in the order of MB < SD < MR < NT (tables 2 and 3). Higher herbicide concentrations with NT were most likely due to wheel tracking in the plots, which caused more and earlier runoff. This coincides with the results from a rainfall simulation study by Baker and Laflen (1979), which showed significantly higher herbicide concentrations with runoff for wheel-tracked plots versus the non-wheel-tracked plots. Franti et al. (1998) also reported that herbicide concentrations for runoff occurring from no-till plots for a single event were three to five times greater than from tilled plots. The two Mulch Master treatments were similar in their runoff and sediment losses; however, the flow-weighted concentrations (total herbicide loss/total runoff volume) for all herbicides were lower for MB. This was most likely due to the improved distribution of the herbicides below the mixing zone for the MB plots.

Herbicide losses with runoff water and sediment are given in table 2. With the highest runoff volumes, sediment losses, and herbicide concentrations (tables 1 through 3), the total herbicide losses for the NT plots were much greater than for the incorporated plots, averaging 150, 114, and 234 g ha<sup>-1</sup> for atrazine, metolachlor, and cyanazine, respectively (table 2). Total losses were not significantly different at the 10% level for SD, MR, and MB treatments.

Figure 3 shows the percent herbicide losses with runoff water and sediment. All of the herbicides used in this study can be classified as moderately adsorbed, or herbicides that are lost primarily with surface runoff water. Percent losses increased in the order of MB < SD < MR < NT. Total herbicide losses for the incorporated treatments were less than 0.5% in all cases; NT losses were 6.7%, 4.1%, and 6.9%, for atrazine, metolachlor, and cyanazine, respectively. The lower percent runoff losses of metolachlor could possibly be due to some photo-degradation prior to the rainfall event (Jiang, 1997).

**Table 1. Average surface residue, runoff volumes, and sediment losses.**

Treatment <sup>[a]</sup>	Surface residue (%) <sup>[b]</sup>		Average slope (%)	Average time until start of runoff (min)	Runoff volume (cm)	Sediment loss (kg ha <sup>-1</sup> )
	Pre-tillage	After rainfall				
MB	47b	49b	2.4	36	0.38b	262b
MR	47b	56ab	3.1	35	0.60b	366b
NT	81a	77a	2.8	06	3.36a	632a
SD	52b	38b	2.7	40	0.34b	217b

<sup>[a]</sup> MB = Incorporation with modified Mulch Master, MR = Broadcast spray with modified Mulch Master, NT = Broadcast spray without incorporation over no-till, SD = Broadcast spray with disk incorporation

<sup>[b]</sup> Means with the same letters are not significantly different at the 10% confidence level.

**Table 2. Flow-weighted concentrations and total herbicide losses (total chemical loss/total runoff volume).**

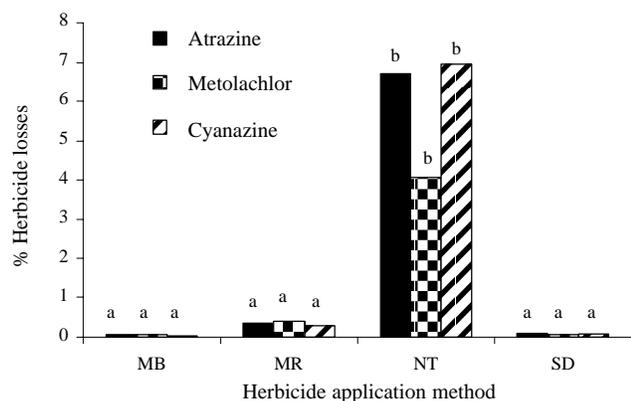
Treatment	Atrazine <sup>[a]</sup>		Metolachlor <sup>[a]</sup>		Cyanazine <sup>[a]</sup>	
	Concentration (µg L <sup>-1</sup> )	Loss (g ha <sup>-1</sup> )	Concentration (µg L <sup>-1</sup> )	Loss (g ha <sup>-1</sup> )	Concentration (µg L <sup>-1</sup> )	Loss (g ha <sup>-1</sup> )
MB	27.2c	1.03b	36.7c	1.39b	39.5c	1.49b
MR	132b	7.96b	188b	11.3b	159b	9.53b
NT	446a	150a	339a	114a	696a	234a
SD	60.6bc	2.07b	47.2c	1.61b	71.8bc	2.45b

<sup>[a]</sup> Means with the same letters are not significantly different at the 10% confidence level.

**Table 3. Herbicide losses with runoff water and sediment.**

Treatment	Chemical losses with water <sup>[a]</sup>			Chemical losses with sediment <sup>[a]</sup>		
	Atrazine (g ha <sup>-1</sup> )	Metolachlor (g ha <sup>-1</sup> )	Cyanazine (g ha <sup>-1</sup> )	Atrazine (g ha <sup>-1</sup> )	Metolachlor (g ha <sup>-1</sup> )	Cyanazine (g ha <sup>-1</sup> )
MB	0.94b†	1.32b	1.43b	0.09b	0.06c†	0.07b
MR	7.61b	10.1b	9.05b	0.35b	1.13b	0.48b
NT	148a†	112a	231a	1.70a	1.93a	2.64a
SD	1.87b	1.30b	2.25b	0.20b	0.31c	0.20b

<sup>[a]</sup> Means with the same letters are not significantly different at the 10% confidence level.



**Figure 3. Percent of applied herbicide losses with runoff water and sediment.**

Generally, conservation tillage, at least on an annual basis, reduces runoff and chemical losses and increases soil water infiltration (Kanwar et al., 1990; Edwards et al., 1993; Isensee and Sadeghi, 1996). However, results from this study for a single rain after tillage showed higher runoff volumes and sediment and herbicide losses under the NT plots than under the tilled plots. This is believed due in part to compaction of a larger area than normal wheel traffic.

Higher herbicide losses from NT plots, when compared to the tilled plots during the first rainfall event after application, were similar to the findings of other researchers (Martin et al., 1978; Kenimar et al., 1987; Franti et al., 1998; Ghidey and Alberts, 1998). However, a single runoff event evaluation of herbicide losses related to tillage and residue cover may not be sufficient to determine typical herbicide losses under conservation tillage practices. Franti et al. (1998) found that a reduction in total runoff amounts, based on three runoff events, significantly reduced the total herbicide losses under no-till compared to till.

## SUMMARY AND CONCLUSIONS

This study evaluated the effectiveness of various herbicide application methods in reducing sediment and herbicide losses through surface runoff during a rainfall simulation experiment in 1995. The results of the study showed that soil incorporation and subsurface herbicide application with the Mulch Master can reduce herbicide losses through surface runoff when compared to surface application with no-till. The statistical analysis of the results indicated that lack of tillage (combined with compaction effects in the form of wheel tracks) on runoff quantity and quality for the first storm after herbicide application was significant: wheel tracks in the NT plots reduced infiltration,

leading to runoff volumes over five times those of plots receiving primary and secondary tillage. Although average runoff volumes and sediment losses increased in the order SD < MB < MR < NT, only NT was significantly different from other treatments.

Had this study been performed later in the growing season, when rainfall energy would have caused some surface sealing on tilled soil not protected by crop residue, these results would likely have been different, with the NT plots having lower runoff volumes as compared to the tilled plots. However, the first rainfall-runoff event after herbicide application (and tillage) is usually most important in determining herbicide runoff losses.

Runoff volume and sediment loss were not lowest for the MB plots, but losses of all herbicides were lowest from the MB plots, which can be attributed to subsurface placement of the herbicides with the modified Mulch Master. Flow-weighted concentrations and total herbicide losses increased in the order MB < SD < MR < NT. Although MB was not significantly lower than SD or MR (at the 10% level), these averages indicate that the subsurface application is performing at least as well as the traditional disk incorporation. Modification of Mulch Master sweeps for subsurface application also showed a reduction of herbicide losses in surface runoff water during the first runoff event after application. There is also a potential reduction in losses to the atmosphere of pesticides applied with the modified Mulch Master due to minimized volatilization during and after application, which is beneficial to environment. This factor was not measured in this study but should be investigated in future studies.

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