GREAT LAKES WATER QUALITY INITIATIVES

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TRANSPORT AND DISSIPATION PATHWAYS OF PESTICIDES IN UPLAND WATERSHEDS EMPLOYING CONVENTIONAL AND CONSERVATION TILLAGE IN ONTARIO

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RATIONALE/OBJECTIVE

The detection of pesticides in surface waters has caused great concern about human and ecosystem health. Concentrations often exceeding water quality guidelines are frequently detected in surface water throughout the growing season, with the highest concentrations being observed in May and June (Thurman *et al.* 1992, Isensee, A. R. *et al.* 1990).

Agricultural pesticides make up the largest percentage of pesticides used in the Great Lakes Basin (Mokley, J. 1989). Significant amounts of pesticides, mostly herbicides are used annually to increase crop yield. As a result of the large amount of pesticides used, they are commonly found in the tributaries of the Great Lakes, but little was known about the transport pathways and processes of herbicides from the point of application in the farmer's field to the point of deposition into the Great Lakes (Buttle, J. M. 1989).

Movement of pesticides from agricultural lands is a complicated process. It depends on several factors including the characteristics of the pesticide (solubility, decay constant etc), and the amount of water travelling through and off the soil from the time the pesticide is applied until degradation (Bowman *et al.*, 1994). Other important associated factors are soil type, soil moisture and soil hydrological properties. The greater the soils ability to hold water the less runoff and percolation will occur resulting in the pesticide remaining in the soil profile for microbial degradation.

Microbial degradation tends to be the most important breakdown route for many soil-applied herbicides, as compared to chemical breakdown processes. Of the factors which influence microbial activity in soil, both moisture and temperature rank amongst the most important. Previous research has demonstrated that tillage practices influence temperature and moisture regimes in soil (Kovar *et al*., 1992). It is a well-established fact that no-till soils appear to be wetter at planting time than conventionally-tilled soils, perhaps because soil cultivation accelerates surface moisture losses, which in turn might also permit those soils to warm up more quickly.

The increase in conservation tillage in the 1980's raised the concern of the potential increase in pesticide use, and the corresponding potential increase of pesticide loss. It was believed that the trend toward less tillage would result in greater weed problems, therefore resulting in a need to increase herbicide usage. This could result in an increase in pesticide loss to surface water. Other perceptions accompanying the increased use of conservation tillage systems were that increased residue would decrease runoff, thereby reducing pesticide loss by surface flow, but possibly increasing pesticide loss through preferential flow (Hinkle, M.K. 1983).

New technologies and better understandings of pesticide movement were required to move to sustainable productions systems. Non-point-source (NPS) models were thought to be a possible tool in educating farmers about pesticide loss and remedial actions which could reduce the environmental impacts of pesticide movement. Field based models such as CREAMS, GLEAMS and DRAINMOD could be used to show the effects of tillage and application timing on pesticide loss. These models have the ability to simulate the movement of sediment, nutrients and pesticides to surface water, tile water and groundwater (Knisel 1980). Several of the models have been modified and combined to give a complete simulation of the movement of pesticides and nutrients from surface runoff to groundwater. The major problem with the models was the lack of applicable data to calibrate these field scale models for Ontario conditions. It was thought that once the models were calibrated, they would be a useful tool in Environmental Farm Planning.

The objectives of this study were:

- ***Determine the impact of tillage practices on soil temperature and moisture profiles, which in turn are important factors in influencing herbicide dissipation patterns in soil.***
- ***Describe pathways and processes for pesticide transport to surface water supplies.***
- ***Employ existing models for predicting pesticide transport and fate***
- ***Recommend remedial measures for reducing pesticide transport to surface and groundwater***

METHODOLOGY

Site Information:

A field site was selected on the Elgin Vessie farm (approximately 2 km northwest of Belmont Ontario), which had previously been part of the Pilot Watershed Study area under the SWEEP program. The experimental site was a *Gobles silt loam* on a gentle west-facing slope (< 7%) which became relatively flat towards the eastern side of the area. Rainfall simulation studies were conducted on the slope area, while the dissipation study was located on the upper flat plateau region east of the slope area. The test area, which had traditionally been conventionally-tilled, was divided east-west through the centre of the field, with the southern half being converted from conventional tillage (CT) to no-tillage (NT) in the spring of 1990 (last tillage, fall 1989). Adjacent test plots, for both the rainfall simulation study and the dissipation study were set out on both tillage practices, and the entire area was planted to grain corn each of the study years.

Herbicide Application:

In the initial year, 1990, a contractor applied the PRIMEXTRA® [metolachlor:atrazine, 1.5:1.0] herbicide to the test area at the recommended rate of 7.5 L/ha of product (3.75 g a.i./ha), using about 187 L/ha of water for application. A portable, back-pack sprayer with a 2-m boom was used for applying the herbicide. On-ground spray densities were monitored with glass petri dishes. Because of problems with spray overlap or missed areas, a new mini-tractor-mounted sprayer was built with a 4-m boom (2 passes/plot rather than 4 passes), and this was used in the successive years.

DISSIPATION STUDY

Herbicide Sampling Protocol:

Since 1991, the soil sampling protocol for herbicides consisted of a 4 x 3 grid-type sampling scheme (12 cores/sample day) in each 9 x 9-m plot (8 x 38" (about 1 m) rows of corn). Soil cores were taken from "in-row" positions from alternate rows about 1 m from the end of each plot (4 samples), and this was repeated twice more at about 2-m intervals. At each subsequent soil sampling, the entire sampling grid was moved about 0.1 m along the respective corn rows.

The soil cores were 3.5 cm diameter, and 30 cm in length. Each soil core was segmented into 0 - 5, 5 - 15 and 15 - 30 cm sections to track downward movement of the herbicides. Pre-treatment sampling was done to establish background levels. Soil samples were taken on treatment day, and at 1, 2, 3, 4, 6, 11 and 20 weeks.

Herbicide Extraction and Analysis:

Glass sample bottles (450 mL, screw-capped) containing 100 g of treated soil and 80 mL of extraction solvent (90:10 HPLC-grade methanol:water) were heated in a circulating water bath to 45°C for 15 min., sonicated for 15 min., then tumbled for 30 min. at 40°C in a temperature-controlled cabinet. Samples were left to settle for 30 min., then the supernatant was decanted into vacuum Buchner funnels and filtered. Remaining soil slurries in the sample bottles were extracted a second time and were added (total transfer) to the contents of the first extraction in the Buchner funnels. The soil cake in each Buchner funnel was finally washed with 3 x 20 mL aliquots of extraction solvent. Filtrates were quantitatively transferred to 250 mL volumetric flasks, made to volume with methanol, and centrifuged at 40,000 x g for 20 min. to remove sediment traces before HPLC or GLC analysis.

Atrazine and metolachlor analyses can be done by GLC, using the following operating parameters: Column, J&W DB-17, 0.53 µm x 15 m (megabore, 1.0 µm film); Carrier gas, ultrapure helium (15 - 20 mL/min.); Detector, nitrogen-phosphorus, 260°C; H_2 flow rate, 1 -

3 mL/min.; Injector temperature, 240°C; Injection volume, 2.0 µL (auto-injected); Temperature programs, 165°C initial, 10°C/min. to 250°C. Atrazine eluted near 195°C, metolachlor eluted near 220°C. Minimum detectable concentrations for atrazine and metolachlor were, respectively: 2 to 5 µg/L and 10 to 15 µg/L.

Both atrazine and metolachlor can also be analyzed by HPLC, and have lower detection limits by this method. HPLC was used for low level residues for this reason. Operating Parameters: Column - C_{18}-reversed phase; Mobile Phase: Acetonitrile/Water - approx. 50/50 for atrazine; approx. 60/40 for metolachlor; Flow rates - approx. 1 mL/min.; Wavelength: atrazine -220 nm; metolachlor - 201-205 nm, depending on interferences. For low level samples where there was uncertainty regarding peak location/response, the sample was spiked with a small volume of standard, using a suitable concentration to give a final spiked concentration of approx. 50 µg/mL.

Soil Temperature and Moisture Monitoring

Soil temperatures were continuously monitored from herbicide application date in late May through mid-November with Campbell Scientific CR-21X multiplexed dataloggers (using thermocouples) at 3 depths (2.5, 10, 30 cm), at 4 locations within the duplicate 9 x 9 m-plots on both tillage practices. Data from each probe set (single depth, 4 locations) was sampled at 15-min. intervals and averaged over 4 hr. Each daily average/depth represented 96 readings for each tillage practice.

In 1990 and 1991, soil moisture was monitored on the same temporal and spatial regime as the temperatures, using gypsum block sensors. However, the blocks had a very slow response, were difficult to properly calibrate and disintegrated in the soil by mid-way through the 1991 study. In subsequent years, an automated, multiplexed SoilMoisture Corp TDR (Time Domain Reflectometry) monitoring system was used, employing the same monitoring regime as before. Soil moisture readings were taken on a 4-hour basis from 4 probes at each depth and on each tillage practice, and reported as a daily average (6 x 4 = 24 readings/day/depth)

HERBICIDE TRANSPORT STUDY

The pathways and transport process study was divided into two phases. The first three years consisted of determining the pathways and processes of pesticide transport in surface runoff using rainfall simulation, while the second phase looked at the effects of tillage on the downward movement of herbicides.

Surface Runoff Transport

As described in the site information a section of the rainfall simulation test area was treated with a broadcast application technique. A small portion of the test area on the conventional tilled site had a banded (2.4 l/ha) application in a 10 inch wide strip directly over the corn row. Cultivation during the early stages of crop growth would be used to control weeds between the rows.

Immediately following herbicide application three sets of duplicate $1m^2$ plots were established on both tillage practices. Three sets of six plots were also installed on the conventional site where the banded herbicide application was applied. Six additional plots (three per tillage treatment) were added to collect all natural rainfall events.

TDR probes were installed beneath the plots at depths of 2.5 cm, 8.0 cm, and 12.0 cm to monitor any moisture change during the rainfall simulation event. Readings were taken at two minute intervals starting at the onset of rainfall simulation.

Rainfall simulation runs (2.67 cm of water in ten minutes) were conducted on separate plots at weekly intervals for three weeks starting on the day of herbicide application using the Guelph Rainfall simulator. All runoff volumes were taken at two minute intervals. The total runoff was sub-sampled and analyzed for sediment, nutrient and herbicide concentrations.

The natural runoff events were used to validate the simulated events. All natural runoff events were collected from the plots adjacent to the simulated plots on both tillage practices until about mid August.

Herbicide losses in runoff were reported on an event and annual basis in terms of concentrations, loadings and percent of applied. Sediment loss was reported in loadings (t/ha). Runoff, soil and pesticide data was used to calibrate the transport model (CREAMS).

Surface and Subsurface Transport

Pan lysimeters were developed to collect the subsurface flow. They consisted of heavy gauge sheet metal meter-squared pan. Three drain outlets were inserted on the front of the pan to allow for drainage form the pan. The outlets were connected to a carboy via rubber hose. A metal screen was laid on top of the pan to allow for easy drainage of the water and to prevent soil from blocking the drain outlets.

In November of 1992 after fall tillage, a total of twelve $1m^2$ pan lysimeters were inserted horizontally in the soil at a depth of about 55 cm on both tillage practices (six pans per tillage treatment) using two hydraulic jacks, resulting in minimal surface disturbance. The pans were inserted on a slope parallel to the soil surface. The three drains from the pan emptied into a carboy which was buried beneath the level of the pan. An access tube went from the carboy to the soil surface (Figure 1). The pits were backfilled and the pans were marked with 3M sonds so that they could be easily located in the spring. The pans were left undisturbed for the winter allowing soil to settle and macropores to re-establish.

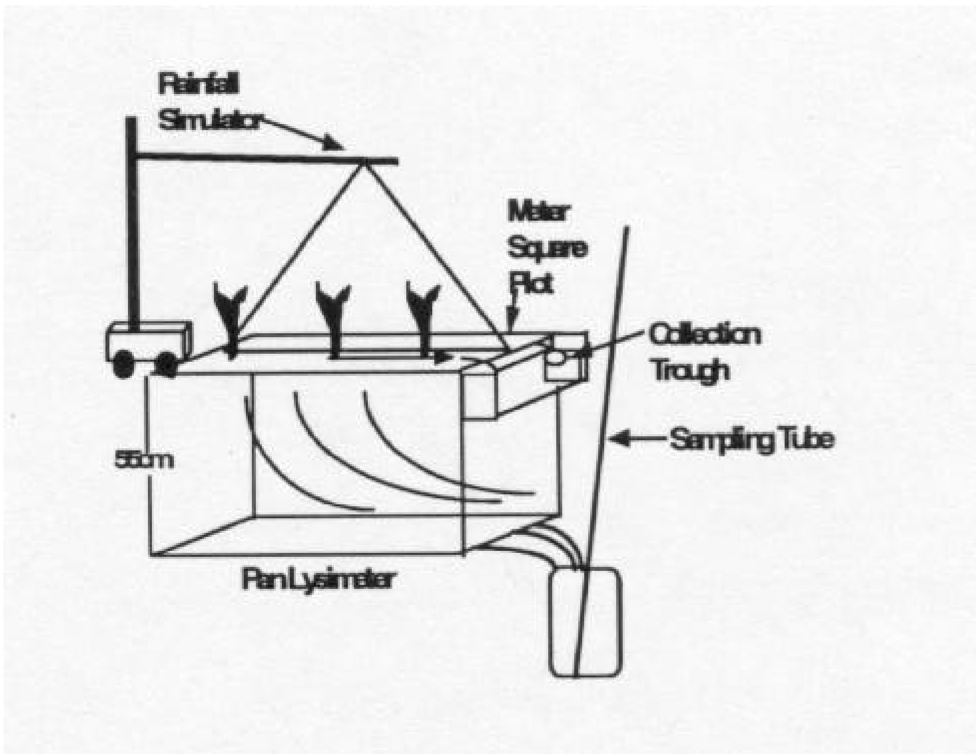

Figure 1. Diagrammatic vertical cross section of experimental setup.

In the spring of 1993 the conventional tilled site was cultivated and both treatments were planted to grain corn. A broadcast herbicide application of atrazine-metolachlor (1:1.5) was applied uniformly to both tillage practices several days after planting. The 1m^2 plots were established over the pan lysimeters. Six plots (two treatments with three reps per treatment) were used for the simulated rainfall events, while the other six plots were used to collect natural events (three reps per treatment). All natural events were monitored until November just prior to fall tillage. TDR probes were installed beneath the plots at depths of 2.5 cm, 25 cm, and 50 cm. to monitor soil moisture changes with time during the rainfall simulation event. Rainfall simulation events (3.18cm in 15 minutes or 2.1mm/min) were conducted at weekly intervals starting on the day of application and continued for 3 weeks. Thereafter rainfall simulation events were conducted on monthly intervals. Prior to each rainfall simulation event the plot was surround by a tarp to prevent excess water from entering the soil profile. All runoff (surface and subsurface) was collected and measured at one minutes intervals, and sub-sampled at two minute intervals. TDR measurements were taken at two minute intervals up to 30 minutes after the rainfall event. All samples were analyzed for herbicide, nutrient and sediment concentrations.

Herbicide losses in surface runoff and subsurface flow were reported on an event and annual basis in terms of concentrations, loadings and percent of applied. Sediment loss was reported in loadings (t/ha). Runoff, soil and pesticide data was used to validate the combined transport model of drainmod/creams/gleams.

FINDINGS

DISSIPATION STUDY

Impact of Changes in Tillage Practice:

The conversion of half the original field to no-tillage (NT) in 1990 initiated a series of changes in the soil profile (Dick and Daniel, 1987), which by most reports, requires five to seven years before reaching a quasi-equilibrium. Crop residues, rather than being incorporated throughout the plough layer remained on the surface of the no-till, relying on soil fauna for decomposition and redistribution. For the first year or so, corn residues remaining on the no-till area still exceeded 60 % by the following spring, but by the fourth year (1993), the active faunal population apparently had redistributed significant amounts of the crop residues below the surface. In 1993, the numbers of vertical earthworm burrowers, primarily *Lumbricus terrestris*, on the no-till area were approximately twice that on the adjacent conventionally-tilled area (CT), while the earthworm biomass was 3-fold greater on the no-till (personal communication, Dr. A.D. Tomlin). Similar results have been reported by U.S.D.A. scientists (Parkin and Berry, 1993). It has been commonly observed that decreasing tillage generally results in greater numbers of earthworms (Berry and Karlen, 1993). The bulk densities of the soil profiles also reflected the impact of surface tillage (Table 1). Whereas the NT bulk densities were relatively constant throughout the profile, as well as throughout the growing season, the bulk density of the surface 10 cm of CT soil was consistently lower.

Table 1. Bulk densities (g cm^{-1}) of soil profiles in adjacent tillage practices in 1993.

Depth (cm)	CT		NT	
	Spring	Fall	Spring	Fall
0 - 5	0.974	0.961	1.277	1.241
8 - 10	1.074	1.164	1.266	1.203
25 - 30	1.272	1.193	1.286	1.308

Temperature and Moisture Profiles

Since the no-till soil was in a state of transition throughout most of the four-year study, this report will focus on data collected during the last year of the program, 1993, as an equilibrium state was being approached. The 1993 daily rainfall and air temperature records for the Belmont field site are shown in the following graph (Figure 2).

Soil Temperature

Soil temperatures for both CT and NT soils at planting time at the end of May were in the 12 to 14°C range. Figure 3 shows the soil temperature profiles for the CT soils throughout the growing season (NT temperature profiles were too similar to distinguish at this scale). Soil temperatures peaked near 24°C for most of July, with a secondary peak in mid-August, after which they steadily declined. Average daily air temperatures (Figure 2) were only slightly greater than surface soil temperatures.

Throughout the entire cropping season (May 27 to Nov. 15), the top 10 cm of the conventionally tilled (CT) soil was 0.4°C warmer, on average, than was the respective No-Till (NT) soil. Over the active growing period from the end of May until September 1, the top 10 cm of the CT soil was 0.6°C warmer than the respective NT soil, but after this time there was very little difference. The greatest temperature differences in the surface layer occurred during the week ending July 8 when the CT soil was 1.2 and 1.1°C warmer at 2.5 and 10 cm than the respective NT soil profile (Figure 4). Variations in [CT - NT] temperature differences seemed to be very similar at both 2.5 and 10 cm depths, with slightly greater differences near the surface, as might be expected. At the 30 cm depth, there was no significant temperature differences between the two tillage practices (< ±0.25°C) throughout the growing season. Because of the large number of collected data represented in each data point (148 points/week), there is a high degree of confidence in their accuracy.

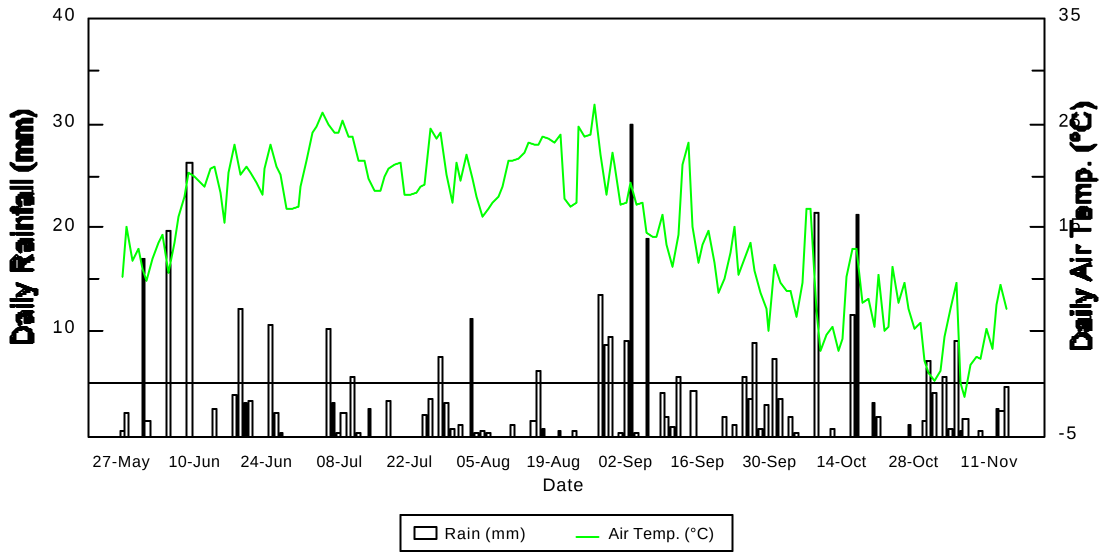

Figure 2.. Daily Rainfall and Air temperatures, 1993.

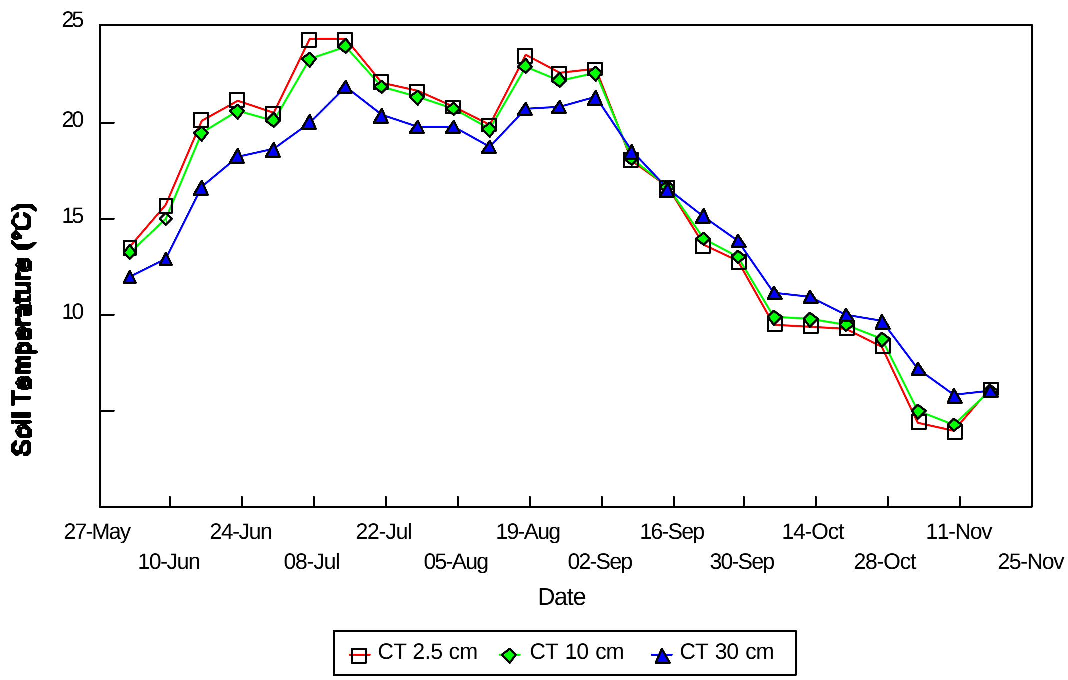

Figure 3. Soil temperatures in CT soil, weekly averages.

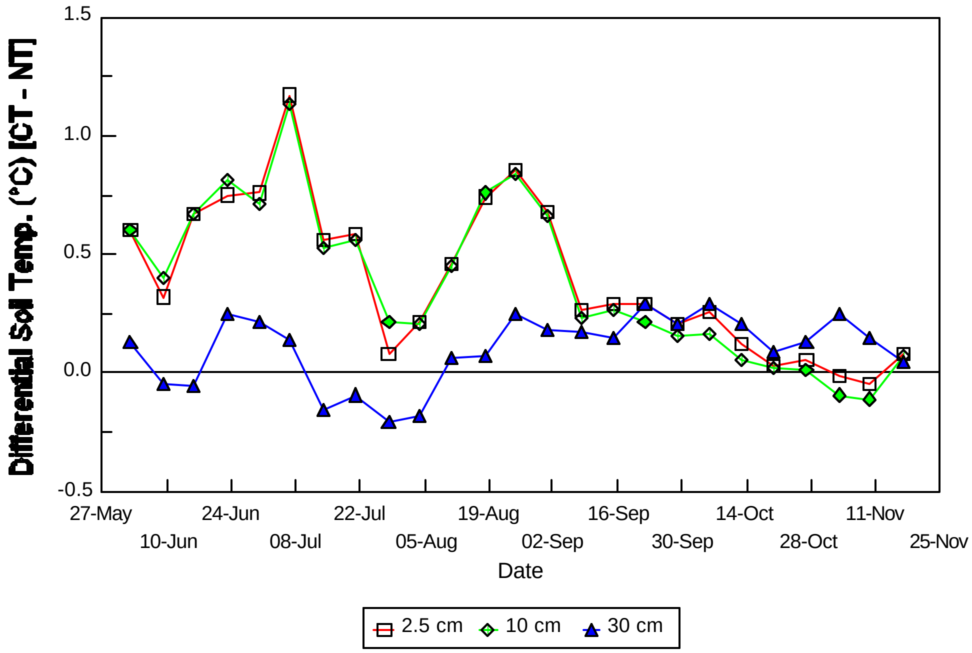

Figure 4. . Differential soil temperatures [CT - NT], weekly averages.

Soil Moisture

Soil moistures (v/v) initially were in the 33 to 40% range at planting time, with the exception of the CT surface soil which was in the 25 to 30% range (Figure 5). Moisture contents continued to decrease until the end of August, when cooler temperatures and more frequent rainfall gradually returned moisture contents to the initial May levels by mid-November.

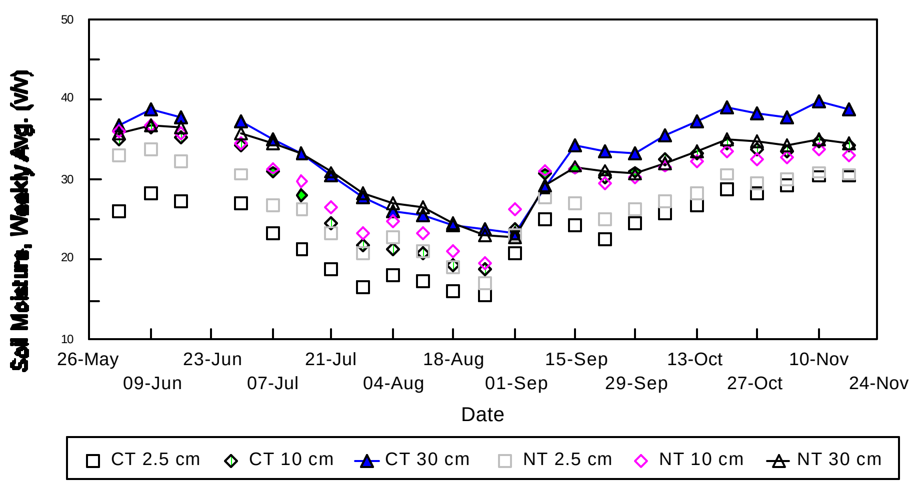

Figure 5. Soil moisture (v/v) in CT & NT plots; weekly averages.

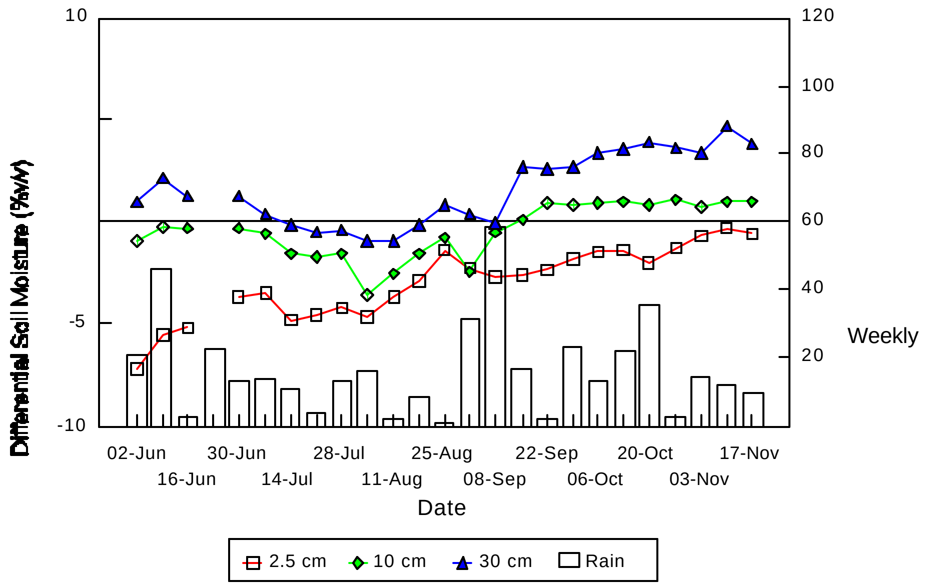

Figure 6. **Differential soil moisture, [CT - NT] (v/v%) at 3 depths; weekly averages**.

Initially, the NT surface moisture content was about 7% greater than adjacent CT levels (33 vs 26%, v/v), largely as a result of the fluffing and subsequent drying of the CT soil by cultivation prior to planting. This difference [CT - NT] gradually decreased to about 2% by the end of August (Figure 6). At the 10 cm depth, the NT soil was slightly wetter than the CT soil (< 3% difference) through the end of August. In early September, several substantial rains wetted up both CT and NT profiles (Figure 5,6). Interestingly, the CT soil at both 10 and 30 cm was 2 to 5% wetter than the respective NT soils through mid-November, while the CT surface soil was slightly drier than the NT surface soil. Perhaps some larger channels/pores in the NT soil may have rapidly conducted inflowing rain through the upper profile, rather than retaining it to the degree that the CT profile did.

Herbicide Dissipation

Herbicide dissipation in soil is largely a microbially-driven process, the kinetics of which are greatly influenced by soil factors such as temperature, moisture and nutrient availability. Since available soil oxygen levels determine whether microbial processes will be aerobic or anaerobic, the moisture levels relative to saturation will determine the available pore space, and thus oxygen levels in the soil. The relationship of herbicide degradation to soil temperature and moisture is probably rather complex, since microorganisms tend to have optimal activity ranges.

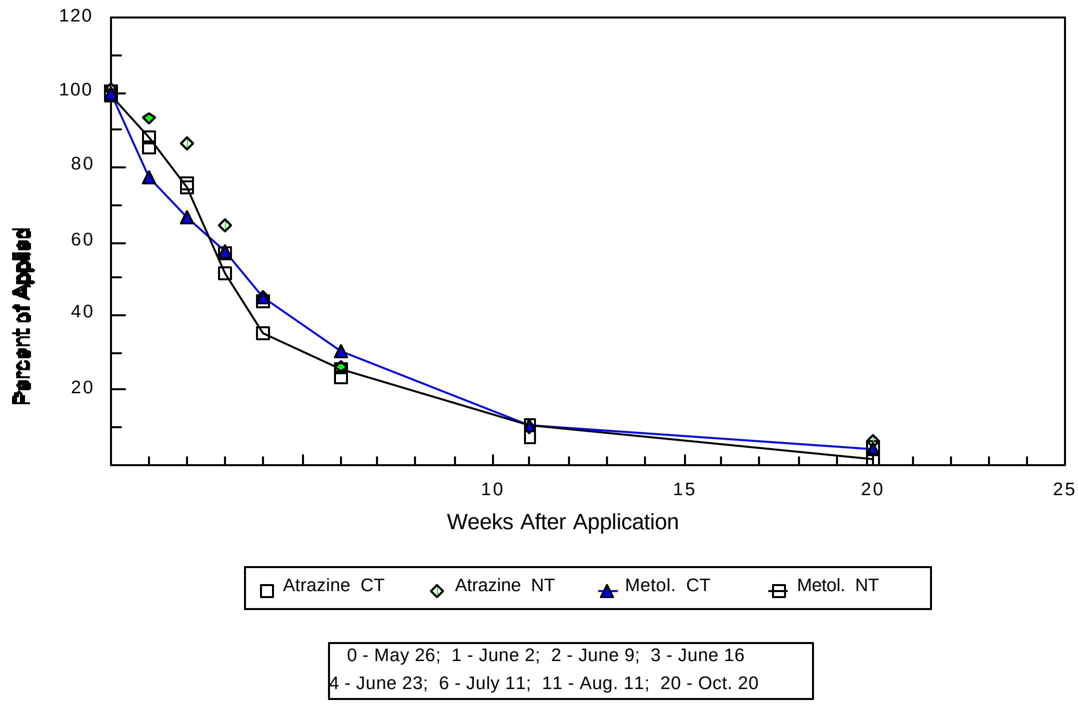

Figure 7. Dissipation of atrazine and metolachlor on CT and NT plots in 1993.

When either, or both temperature and moisture levels are outside these optimums (below or above), then degradation rates decrease. Therefore the impact of soil temperature and moisture upon microbial activity depends on whether these factors act in concert or in opposition to each other as they influence microbial processes. For this reason, the impact of temperature and moisture upon herbicide dissipation may tend to be rather site specific.

In the 1993 field dissipation study, there appeared to be possible tillage effects upon the disappearance rates of atrazine and metolachlor during the first 2 to 4 weeks following application (Figure 7). Both herbicides applied on CT soil appeared to decrease more rapidly following application than when applied on the NT soil (approx. 7 to 10% faster in the first two weeks). After this time, there were no further differences in disappearance rates associated with tillage practice. The DT_{50} values (time for 50% disappearance) for both atrazine and metolachlor were in the 3 to 4 week range, which is reasonably comparable to values obtained in a previous lysimeter study using a light textured sandy soil (Bowman, 1994). The disappearance rate for atrazine might have been expected to have been somewhat longer in this silty loam soil. Possibly some soil binding of the atrazine, not readily extracted by the methanol/water extractant may have anomalously given the appearance of greater disappearance rates than actually was the case (Khan, 1991; Winklemann and Klaine, 1991).

During the first few weeks following herbicide application, the NT surface soil was about 0.5°C cooler (about 12.5°C), and about 5 to 7% (v/v) wetter (about 33%) than its CT counterpart. These soil conditions would likely have been on the low side of the temperature optimum, and perhaps on the high side of the moisture optimum for microbial activity. Thus it is possible that these soil conditions could have retarded herbicide disappearance rates during this period.

HERBICIDE TRANSPORT STUDY

Generally higher surface runoff volumes were obtained from the conventional tillage site from both simulated and natural events. This pattern remained constant throughout the summer. Several natural rainfall events exceeded the rainfall amount and intensity from the simulated events.

Sediment loss was consistently higher from the conventional tillage sites throughout the growing season (Figure 8). The natural events exhibited the same pattern within tillage practices.

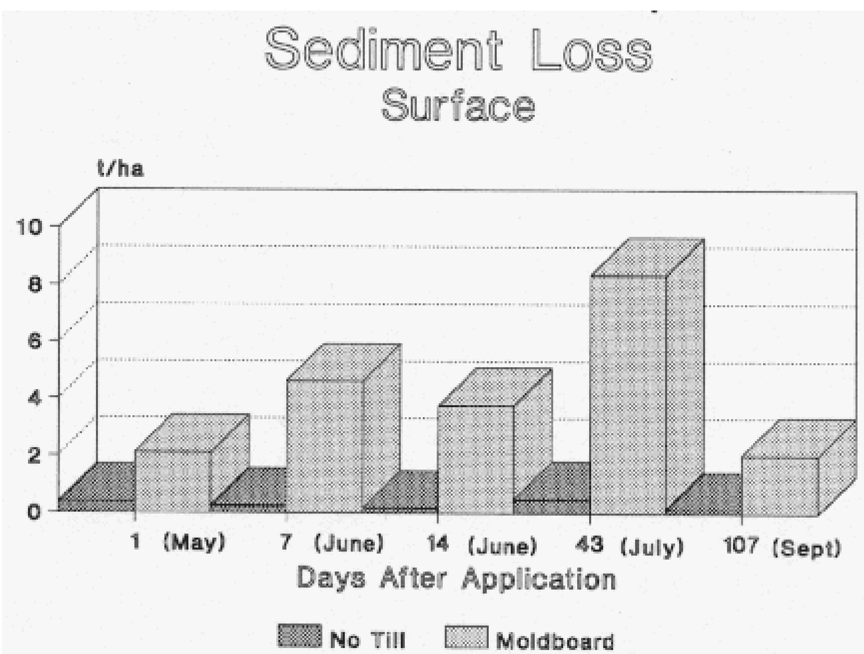

Figure 8 Sediment Loss on CT and NT.

As previously found (Bowman *et al*. 1994, Thurman *et al*., 1992) highest pesticide losses occurred when rainfall events followed shortly after herbicide application. This is when herbicides are most susceptible to surface runoff probably due to the lack of sufficient time for soil binding to occur. These single events often resulted in herbicide losses that ranged from 3.5 to 6.5 percent of herbicides applied, with concentrations in runoff exceeding water quality guidelines for both tillage treatments. There was no statistical difference between the tillage treatments for pesticide loss under the broadcast application method, however the banded application technique resulted in a reduction in herbicide loss by up to 50 percent. Under natural events the metolachlor concentrations in surface runoff from the banded application techniques were below water quality guidelines. On the broadcast application site atrazine was detectable in the surface runoff until September. The herbicide concentrations from the banded application method was no longer detectable after the first month following herbicide application.

The major pathway for herbicide loss following application was found to be through surface runoff. Between 90 to 95 % of the atrazine and 80 to 85 % of the metolachlor in the runoff was in the solution phase from both tillage practices. As time elapsed, the amount of herbicide in solution decreased while the amount attached to sediment increased for both herbicides. Similar results were reported elsewhere (Bowman *et al*., 1994, Wauchope 1987, Leonard, 1988).

Higher subsurface volumes were obtained from the no till sites. There was little to no flow from conventional sites (Figure 9). This pattern was also observed by Gish *et. al*. (1991) Even though there was higher subsurface flow was from the no till sites, the total water loss was higher from the conventional tilled sites. As found with the dissipation study, the no till soil was usually at a higher moisture content.

Several recent studies have suggested that macropores may have the ability to transmit water through the soil taking agronomic chemicals with it. Shipitalo, M. J. *et al*. (1990) found that the first rainfall event following herbicide application had a substantial effect on the herbicide movement through soil blocks. Similar results were observed in this study. Pesticide concentrations were highest when a rainfall event immediately followed herbicide application.

Pesticide concentrations in subsurface flow exceeded water quality guidelines from both tillage treatments for up to three weeks following herbicide application. Herbicide loss in subsurface flow was concentrated in the aqueous phase. Atrazine was present in subsurface flow up to September, however, by this time the metolachlor was no longer detectable. Approximately 1.0 % of the herbicide applied was lost through subsurface flow on the no till simulated plots and 0.05 % from conventional tilled plots.

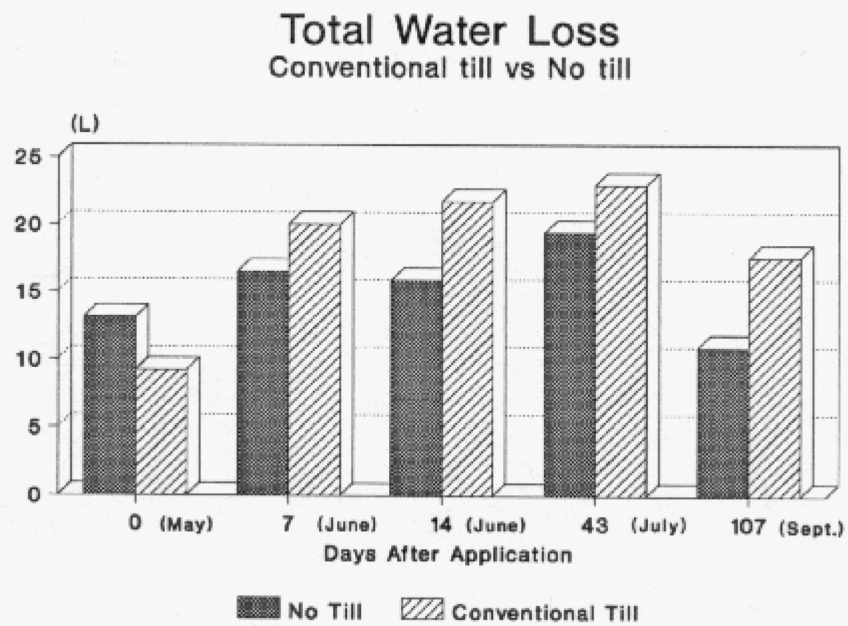

Figure 9 Runoff loss, surface and Subsurface.

Even though subsurface flow was greatest from no till, the combined herbicide loss from surface and subsurface was not statistically different from conventional tilled site. Similar results were found by Gish *et. al*.(1991). This resulted from the larger volume of surface runoff from the conventional tilled plots. Surface sealing seemed to occurred on the conventional tilled site preventing infiltration and increasing surface runoff.

The field scale model CREAMS was calibrated using the data collected from the $1m^2$ plots. The model predicted annual pesticide losses in surface water of up to 10 percent of applied, which was comparable to the actual data collected from the simulation plots. The model also predicted annual sediment and runoff losses that were comparable to the actual simulated events.

CONCLUSIONS

DISSIPATION STUDY

1. Temperature and moisture profiles in adjacent CT and NT-managed fields tended to be measurably different throughout the cropping season. NT soils were slightly cooler and considerably wetter just after planting, largely because of the induced surface drying in the CT soils as a result of cultivation.

2. The disappearance rates for atrazine and metolachlor were somewhat retarded in NT soils, relative to adjacent CT soils during the first few weeks following herbicide application. After the fourth week disappearance rates were similar under both tillage practices. Because of the large number of factors influencing microbial decomposition of herbicides, the impact of tillage practice upon herbicide decomposition (through temperature and moisture effects) tends to be rather complex and site specific.

3. The temperature and moisture-monitoring system used in this study was capable of tracking heat and water fluxes through the soil profile, and would be very useful as an aid in ground truthing small-scale field models for water and solute transport. Based on rainfall, air temperature and the soil monitors (temperature, moisture), it would be possible to calculate mass balances of water and heat storage in the soil, and perhaps to even observe the development of surface seals on CT soil during the growing season.

4. The decrease in the amount of tillage, as the shift was made from CT to NT practices, resulted in significant increases in soil faunal activity (2X increase in population; 3X increase in biomass). Earthworms and other soil animals play an important role in crop residue decomposition and redistribution in the soil profile, as well as providing macrochannels for water and solute transport in the soil profile.

HERBICIDE TRANSPORT STUDY

1. No till systems reduce soil erosion losses significantly, while at the same time, under proper management requiring no more herbicides than conventional cropping systems.

2. Banded pesticide application technique decrease usage, and decrease pesticide concentrations in surface runoff to the point where they meet water quality guidelines after several weeks following herbicide application.

3. Even though preferential flow did not contribute to a high percentage of herbicide loss, the herbicide concentrations in the subsurface flow still exceeded water quality guidelines. This indicates that tile drains could still be a significant pathway for herbicide transport to the Great Lakes.

4. For soil applied herbicides, 85 - 90 percent of the herbicide loss at the time of application is in the aqueous phase and not with the sediment in both surface and sub-surface flow. Therefore it is critical to control surface runoff as well as sediment losses especially closely following herbicide application. As time progresses, herbicides bind to the soil, therefore decreasing the risk of surface transport or leaching to the tiles drains.

5. Calibrated models have been found to be an important management tool to help determine agricultural areas sensitive to soil erosion and herbicide loss. The ability to show the effects of different management practices on soil erosion and herbicide loss will have great potential for use in Environmental Farm Planning.

NEW TECHNOLOGIES AND BENEFITS

The development of pan lysimeters allows the ability to do a mass water balance and determine the effects of tillage on soil hydrological properties and contaminant transport. They also provide the ability to get a better understanding of the seasonal changes in soil hydrological properties. They provide a relatively low cost screening method to study various pesticides and cropping practices, allowing research to focus on agricultural practices that pose a potential threat to water quality.

The availability of automated temperature and moisture (multiplexed TDR) systems now make it possible to accurately track moisture and temperature fluxes in soil profiles. This permits a more precise description of the micro-environment which greatly influences the disposition of applied agrochemicals. Multiplexed, automated TDR systems became available only within that past two years.

The data which was collected over the five year study will be useful for calibrating and evaluating computer models for Environmental Farm Planning. Once the models have been calibrated they can be used to demonstrate the effects of management practices on pesticide movement. They will be valuable tools in showing the farmers the benefits of old techniques such as banding herbicide applications to reduce herbicide and soil loss through conservation tillage.

IMPLICATIONS FOR GREAT LAKES BASIN ECOSYSTEM

Pesticide transport form agricultural land is a wide spread problem in the Great Lakes Basin. Up to this point the true pathways and processes of pesticide movement from agricultural lands were not clearly understood. As we move toward more sustainable farming systems, it is imperative that we more fully understand the cropping systems we use. This study has made some important observations regarding some of the changes which take place as a conventionally-tilled system is converted to a no-tillage practice. In order to fully appreciate the impact of these changes, it is necessary to monitor some of the important parameters controlling crop growth and performance, such as soil temperature and moisture. A better understanding of the micro-ecosystem will be an aid in optimizing inputs, and in reducing nutrient and pesticide inputs to the Great Lakes system.

With the information and data collected from this studied researchers will be better able to predict possible areas of concern. Using provincial databases scientist will be able to determine susceptible areas of pesticide movement based on soil type, crop distribution, pesticide use and tile drain information. These areas can than be targeted for educational and incentive programs to increase farmer awareness and decrease the potential pesticide loss. Models calibrated from the data can be used to show the effects of management practices on pesticide movement form agricultural lands.

TECHNOLOGY TRANSFER

The study has shown that pesticide movement may be a wide spread problem from both surface runoff and tile flow. It has shown that surface runoff and tile flow are significant pathways for pesticides reaching the Great Lakes ecosystem.

Even though banded applications of herbicides is an old practices, it is not a wide spread practice. The results of this study should be used to increase the awareness and the benefits of banded application of herbicides on conventional and minimum tilled sites.

The highest potential for pesticide loss occurs shortly after herbicide application. This information has to be transferred to the farmers so that they will be better able to decrease herbicide loss through proper timing of application (not prior to a predicted rainfall).

GAPS NEEDING FUTURE RESEARCH

1. Further multi-year studies of this type need to be conducted on paired tillage sites such as this, but at sites where the NT soil has reached an equilibrium state. Although crop yields were unfortunately not recorded in this study, it was obvious

that the corn stand on the NT site was considerably inferior to the adjacent CT site for the first three years when the NT soil was in a transition state. In the final year (1993), the crop stand was at least as good on the NT as on the CT site. Perhaps much of this improved crop quality may be related to increased faunal activity which aided in redistributing surface organic debris, nutrients and water.

2. Conducting herbicide residue studies at the intermediate plot scale, as in this study, brings with it a number of specific challenges, from a research perspective. From a technology standpoint, further efforts are needed to develop and standardize methodology to deal with these problems:

a. Herbicide Application

Once the plot dimensions exceed the size of common sprayer boom lengths (about 1 to 2 m), custom sprayers have to be assembled to provide the required application accuracy and precision on soils varying in both roughness and firmness. Perhaps the only accurate (albeit expensive) solution to this problem may be a motorized sprayer boom which travels on a track straddling the plot, and is propelled at a precise rate. Application consistency problems which totally invalidate the data from a research standpoint would not be even noticed from an agronomic perspective.

b. Soil Sampling for Herbicide Residues

The soil sampling strategy for determining herbicide residues is as much as challenge as is their application. Taking relatively large numbers of random soil cores in the plots throughout the growing season does not necessarily guarantee reliable, consistent results. Herbicides applied to raised row areas may well be redistributed to lower areas with heavy rains, and their movement and dissipation behaviour may well vary considerably between wheel track and row positions. Therefore it is necessary to select a consistent sampling strategy to help minimize such sampling errors. One example of this strategy is the grid-type sampling procedures that we adopted in the second year of this study, in which soil samples were confined to in-row positions. It is also advisable to increase the cross-sectional area of the soil core sample, especially for the first few days or weeks when the herbicide residue is largely concentrated in the surface soil layer.

3. Further research is needed on pesticide application techniques more appropriate for a no till system, such as spot spraying and delayed spraying that would be , and would lead to improved water quality through a reduction in pesticide use, as well as a reduction in pesticide loss. The application technique and timing, would have to include a detailed crop management strategy.

4. This project studied pesticide loss under a continuous grain corn cropping system. Many farmers use crop rotations to help in weed control, which decrease pesticide use. There is a need to look at several cropping systems and pesticides to determine if the same potential threat to water quality exists under different cropping practices. As well, a more detailed analyses of crop response to herbicide application techniques must be conducted. Farmers need to know the effects on crop yield before they can make educated decisions on pesticide use.

5. The research was conducted on a silt loam soil. The ability for preferential flow will not be the same between soil types. There is a great necessity to look at different soil types to see if the same conditions apply.

6. It has been established that preferential flow is an important pathway for surface water contamination on a small plot scale. This information needs to be verified at a field scale level using tile drains to quantify the amount of herbicide loss, and determine and if there is a the potential threat to water quality. Larger plots would also change surface runoff results, thereby possible increasing the potential for preferential flow on a no till system.

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