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Reducing Long-Term Atrazine Runoff from South Central Nebraska

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REDUCING LONG–TERM ATRAZINE RUNOFF FROM SOUTH CENTRAL NEBRASKA

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ABSTRACT. *Heavy reliance on chemical weed control in field crops of South Central Nebraska has resulted in the appearance of atrazine at concentrations greater than established drinking water standards. Our objective was to evaluate the best management practices for atrazine runoff for the tillage and herbicide management practices common to the region under study. Field experiments were performed to measure edge–of–field atrazine and water loss from disk–till, ridge–till, and slot plant (no–till) management systems. Results indicated less water runoff from no–till (34% less) and ridge–till (36% less) than from disk–till. Similarly, atrazine loss was also less: 24% less for no–till and 17% less for ridge–till than for disk–till. GLEAMS (Groundwater Loading Effect of Agricultural Management Systems) simulations were calibrated using field–measured inputs and verified against observed data from two independent sites. Fifteen different combinations of herbicide application and tillage practices were simulated using 50 years of rainfall data. Compared to pre–emergent broadcast + post application on corn with disk–till, annual reductions in simulated atrazine mass loss for the alternative practices ranged from 17% to 77%. The percent of annual atrazine lost ranged from 0.57% to 1.2%. During the 50–year simulation, annual losses from 7 to 10 years constituted >50% of the cumulative 50–year loss for broadcast and banded application. Based on recurrence interval evaluation, pre–emergent incorporation and pre–emergent banding were most effective at reducing long–term atrazine losses.*

Keywords. *Best management practices, Herbicide, Tillage, Atrazine, Water quality.*

Herbicides are applied to more than 95% of the 34 million hectares of corn and soybeans in the Midwestern U.S. (Hummel and Stoller, 1995). Within the states that form the Upper Midwest, the herbicides alachlor, atrazine, cyanazine, and metolachlor accounted for approximately 73% of the herbicide use in 1982 (Goolsby et al., 1991). In 1991, the most widely used herbicide in the United States was atrazine, which was applied to 66% of all the planted acres (NASS and ERS, 1991). In 1999, atrazine was used on 70% of corn acres in the United States and on 87% of corn acres in Nebraska (USDA, 2000).

The widespread use of herbicides in production agriculture has resulted in herbicides appearing in surface water at concentrations greater than established standards, or maximum contaminant levels (MCL) (U.S. EPA, 1992; Snow and Spalding, 1993; Goolsby and Battaglin, 1993). The results of five surface water quality studies (1983–1992) in the Big Blue River portion of the Blue River Basin in Nebraska (fig. 1) indicated atrazine was the most frequently detected herbicide (Frankforter, 1994). The concentrations of atrazine ranged from 0.05 to 166 $\mu g\ L^{-1}$, with a median of 2.7 $\mu g\ L^{-1}$. Atrazine concentrations in Tuttle Creek Reservoir, located in the Kansas portion of the Blue River Basin, have on occasion exceeded the 3.0 $\mu g\ L^{-1}$ MCL for drinking water established by the U.S. Environmental Protection Agency under the Standard Drinking Water Act (Helgesen, 1995).

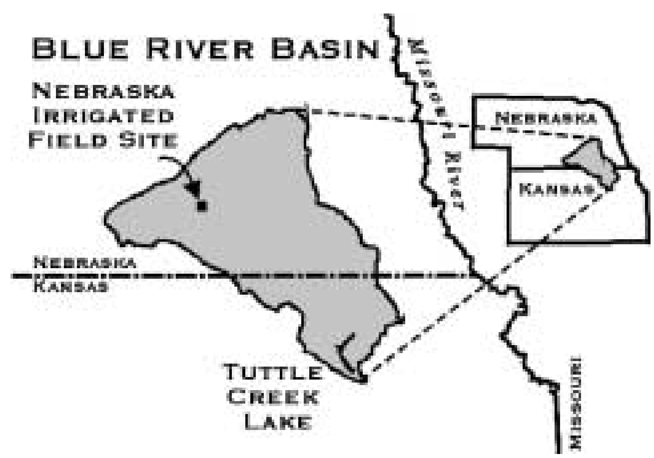

Figure 1. The Blue River Basin of Southeast Nebraska.

Past studies conducted in the Midwest, Southeast, and East under both natural and simulated rainfall have shown that when recommended herbicide rates are applied, up to 5% of the total amount applied may be lost annually (Hall et al., 1972; Ritter et al., 1974; Triplett et al., 1978; Baker et al., 1978; Wauchope, 1978; Baker and Laflen, 1979; Kenimer et al., 1986; Glenn and Angle, 1987). Research has also shown that runoff events that occur soon after application generally contain the greatest herbicide concentrations and account for the greatest herbicide loss (Hall et al., 1972; Ritter et al.,

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1974; Smith et al., 1974; Triplett et al., 1978; Wauchope and Leonard, 1980; Gaynor et al., 1992; Pantone et al., 1992; Gaynor and Van Wesenbeeck, 1995). Rainfall distribution, timing of rainfall after herbicide application, application rate, placement (surface or incorporated), and soil surface condition all play an important role in herbicide loss.

One way to minimize the potential for herbicide movement into surface waters is the use of Best Management Practices (BMPs). BMPs are defined as practices that significantly reduce the potential for herbicide runoff when compared to some standard practice. Conservation tillage, which leaves some or all of the residue from the previous year's crop on the soil surface at planting, is commonly recommended as a means to decrease herbicide runoff, especially for herbicides strongly bound to soil. Some herbicide management practices that may reduce the potential for losses are early pre–emergent broadcast, pre–emergent incorporated, and split application. These practices are dependent on tillage operation and are aimed at minimizing the amount of herbicide at the soil surface available for runoff during expected rainfall periods.

The long–term impacts of various herbicide management practices must be known to allow farmers and natural resource managers to develop strategies to reduce the effects of herbicide runoff. The use of computer simulations to evaluate the effects of herbicide runoff is recommended because long–term runoff experiments are expensive, difficult to conduct, and do not offer timely assessment of new or proposed alternative practices. For herbicide application practices that fall within specified calibration and verification limits, computer simulations can accurately predict runoff volumes, herbicide concentrations, and mass loss. When applied to circumstances that fall outside of a specified calibration range, computer simulations can provide relative comparisons across a range of herbicide application scenarios. Simulations that compare the relative long–term effectiveness of a range of BMPs assist both producers and policy makers when selecting best management practices.

This study was designed to identify tillage and herbicide application practices that have the potential to reduce long–term, edge–of–field atrazine runoff from crop fields in the Blue River Basin in Nebraska. To accomplish this, GLEAMS (Groundwater Loading Effect of Agricultural Management Systems), a non–point–source pollution model (Leonard et al., 1987) was used to simulate long–term atrazine losses. The objectives were: 1) to measure atrazine losses from three tillage treatments; 2) to use observed data to calibrate and verify GLEAMS for South Central Nebraska conditions; and 3) to use the calibrated model to evaluate the relative effectiveness of various tillage/herbicide management practices and recommend BMPs that minimize long–term atrazine loss.

Methods and Procedures

Study Area Characteristics

Calibration and verification data were collected at locations in South Central Nebraska to represent the region's major cropping system: irrigated continuous corn. Within this region, annual precipitation is 68 cm (NCDC, 1994) and annual runoff is 5.7 cm (Gebert et al., 1987).

Model calibration data were collected on an irrigated field site at the University of Nebraska South Central Research and Extension Center, Clay Center, Nebraska (fig. 1). This installation is representative of the level, moderately drained, silt loam soils of the western region of the Blue River Basin. The research plots were located on a Hastings silt loam soil (fine, montmorillonitic, mesic Udic Argiustolls) with 0.5% slope, moderately slow permeability, and organic matter content in the range of 2% to 4% (SCS, 1981).

Field Experiment

Tillage plots consisted of three tillage treatments replicated three times on 0.08 to 0.12 ha plots. Row direction was parallel with the slope. Plots were 3 m wide, planted to continuous corn on 0.75 m wide rows using disk–till, ridge till, or slot plant (no–till). No–till is defined as no soil disturbance from harvest to planting, except for fall anhydrous injection. Disk tillage treatments were performed on 5 May 1997. The first irrigation was performed in every–other furrow on 4 July in wheel–traffic furrows only. Crop residue cover, measured using the line–transect method (Shelton et al., 1993) at the time of planting, was 20%, 30%, and 30% for disk–till, ridge–till, and no–till, respectively. Daily rainfall and temperature data were collected using a weather station adjacent to the plots. Atrazine (2 chloro–4 ethylamino–6 isopropylamino–1,3,5 triazine) was broadcast at a rate of 1.45 kg ha^{-1}, and acetochlor (2 chloro *N*–(ethoxyymethyl)–*N*–(2–ethyl–6–methylphenyl)–acetamide) was broadcast at a rate of 2.24 kg ha^{-1}, under pre–emergent conditions on 6 May. Atrazine was also applied to all treatments as a post–emergent broadcast spray at a rate of 0.78 kg ha^{-1} on 6 June.

Runoff volume and herbicide concentration were measured for runoff events from the time of herbicide application through the first irrigation event. Runoff depth was recorded using 51 mm Parshall flumes with mechanical stage recorders or pressure transducers and data loggers. Previous studies by the authors indicated that atrazine concentration in runoff from field plots is generally at its peak early in the event and quickly levels off to a relatively constant concentration that is characteristic of the event (Sauer, 1998). For this study, water samples were collected on the rising limb of the design–storm runoff hydrograph at flow depths of 28 mm and 55 mm. These samples were arithmetically averaged to estimate the average atrazine concentration for the event. Sample collection depths were determined by selecting points at one–third and two–thirds of the estimated peak stage for a 2–year, 24–h, 70 mm design storm (USDA, 1986). Samples were collected in 0.5 L amber glass bottles, retrieved after each runoff event, and refrigerated until chemical analysis was performed at the Water Science Laboratory, University of Nebraska–Lincoln. Analysis was performed using solid phase extraction, gas chromatography, and a mass spectrometer (Cassada et al., 1994; Eichelberger et al., 1988). This procedure is well suited for low concentrations (<1 $\mu g\ L^{-1}$) of herbicides and metabolite residues in runoff water. The reporting limit for atrazine and acetochlor was 0.20 $\mu g\ L^{-1}$.

GLEAMS Modeling

GLEAMS is a computer simulation model developed for field–sized areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the plant root zone (Leonard et al., 1987). The model includes inputs for: 1) hydrology; 2) erosion; 3) pesticide; 4) nutrient; and 5) climate parameters. The hydrology component simulates daily runoff using a 24–h rainfall and modified runoff curve number method. GLEAMS was chosen because it is a widely used, field–scale, continuous simulation model that can accommodate a range of tillage and herbicide application scenarios, including different application dates and types of herbicide application (e.g., incorporation).

Runoff volume and atrazine concentration data collected at the field site was used to calibrate GLEAMS. Because atrazine is moderately adsorbed with a K_{oc} of 100 L kg^{-1} (Comfort et al., 1996), its primary mode of loss from the field will be in the solution phase of runoff. Schmitt et al. (1999) found only 2% of atrazine loss associated with the sediment phase. For these reasons, only atrazine losses in the solution phase are reported for the calibration, validation, and subsequent simulations. Additional model inputs (average monthly values of maximum temperature, minimum temperature, dew point, wind speed, and radiation) were selected from the GLEAMS on–line climate database or the National Climate Data Center database (NCDC, 1994).

To calibrate the hydrologic component of the model, four GLEAMS parameters that have been shown to be sensitive to influencing runoff were calibrated (Knisel et al., 1991). The four parameters were: 1) runoff curve number (CN); 2) crop rooting depth; 3) field capacity; and 4) porosity. Calibration acceptance was based on observation of scatter plots and the slope and coefficient of determination (R^2) from regressing the observed versus the simulated runoff depth. Herbicide parameters were similarly calibrated in order to improve the agreement between simulated and observed atrazine loss values.

Nash and Sutcliffe (1970) defined the coefficient of efficiency, *ce*, as:

$$ce = 1 - \frac{\sum (Y_o - Y_s)^2}{\sum (Y_o - Y_{om})^2} \quad (1)$$

where

Y_o is the observed value.

Y_s is the simulated value.

Y_{om} is the mean of the observed values.

The *ce* can vary from $-\infty$ to +1, and for perfect correspondence, *ce* = 1. A coefficient of efficiency between 0.5 and 1 is considered a good fit.

The calibrated GLEAMS model was verified using independent data collected from 1994 through 1996 on two 0.4 and 0.8 ha runoff plots planted to corn. The field slopes at these sites were 0.5% to 1.0% on a Hastings silt loam soil with atrazine applied at 1.23 to 1.57 kg ha^{-1}, normal rates for the region. Verification of the model was performed to determine if GLEAMS could simulate observed atrazine loss accurately with calibrated parameters. The Nash–Sutcliffe coefficient of efficiency (Nash and Sutcliffe, 1970) was used for model verification.

Long–Term Simulation

After the model was calibrated and verified, 50 years of atrazine runoff were simulated for an array of 15 tillage and atrazine application practices. Rainfall data were obtained using the climate generator CLIGEN (Richardson and Nicks, 1990). The use of fifty–year simulations was based on previous studies by Leonard and Davis (1989) and Leonard et al. (1992). Leonard and Davis (1989) used 50–year simulations with GLEAMS to evaluate relative contaminant loss differences in alternate management practices, while Leonard et al. (1992) used GLEAMS to compare short–term (10–year) versus long–term (50–year) losses.

Actual planting and herbicide application dates vary from year to year. Therefore, simulated planting dates were varied in a normal distribution and ranged from 25 April to 15 May. The median application date was 5 May, which compares favorably with the observed 4 May median corn planting date (50% complete) in South Central Nebraska (Nebraska Agricultural Statistics Service, 1992–1995). Early pre–emergent and post–emergent application dates were selected based on antecedent moisture conditions for the fallow season. Early pre–emergent dates ranged from 10 April to 26 April. Post–emergent application dates ranged from 26 May to 5 June. Median dates were 16 April and 1 June for early and post–emergent applications, respectively.

Leonard et al. (1992) used GLEAMS to illustrate relationships between mean annual herbicide runoff and single event herbicide runoff. They used a recurrence interval analysis to show differences in runoff losses between two different herbicides and found differences in relative long–term losses. They concluded that expressing runoff losses in terms of recurrence intervals over 50 years allows for discussion based on realistic probabilities and can reduce the impact of year–to–year variability. An approach similar to Leonard et al. (1992) was used to evaluate long–term losses and select BMPs for atrazine applications. Recurrence interval is the time required for a value of specified magnitude (i.e., atrazine mass loss) to be equaled or exceeded. Recurrence intervals for average annual atrazine loss were computed using the empirical method described by Gupta (1995) for selected application practices.

Results and Discussion

Field Experiment

Five rainfall events totaling 126 mm were observed during the study period (table 1). Total runoff from the disk–till treatment was 13.6 mm. No–till produced 9.0 mm (34% less than disk–till), and ridge–till produced 8.7 mm (36% less than disk–till). Compared to disk–till, total atrazine mass losses from three sampled runoff events were 17% less for no–till and 24% less for ridge–till. Similarly, acetochlor losses were 1.3% less for no–till and 10% less for ridge–till. Acetochlor loss per unit area decreased with time after pre–emergent application, while atrazine loss per unit area did not decrease. This was attributed to the post–emergent broadcast atrazine application on 6 June, which resulted in additional atrazine loss later in the season.

Total atrazine loss from the three measured runoff events ranged from 86% to 96% of the total runoff and for all tillage practices was less than 0.25% of the total applied. The first irrigation event on 4 July produced smaller atrazine runoff concentrations, but greater runoff volumes compared to natural events, and resulted in less atrazine mass loss (table 1).

Table 1. Daily runoff volume, mean herbicide runoff concentrations, and mass loss for the observation period.

Runoff Events	Tillage	24–h Rain Depth (mm)	Return Period (yr)	Average Runoff Depth (mm)	24–h Runoff Volume (m^3)	Mean Herbicide Concentration (μg L^{-1})		Mean Herbicide Mass loss (g ha^{-1})	
						Atrazine	Acetochlor	Atrazine	Acetochlor
25 May	Disk	32	0.58	0.85	0.94	NS[a]	NS	—	—
	Ridge	32	0.58	0.60	0.70	NS	NS	—	—
	No–till	32	0.58	0.70	0.84	NS	NS	—	—
26 May	Disk	12	0.32	0.9[b]	1.0	NS	NS	—	—
	Ridge	12	0.32	NR[c]	NR	NS	NS	—	—
	No–till	12	0.32	0.20[b]	0.25	NS	NS	—	—
27 May	Disk	28	0.51	7.3	7.5	29	21	1.9	1.4
	Ridge	28	0.51	5.1[b]	6.0	31	25	1.6	1.3
	No–till	28	0.51	4.7[b]	5.5	35	27	1.7	1.3
21 June	Disk	17	0.37	0.2[b]	0.23	130	9.2	0.26	0.02
	Ridge	17	0.37	NR	NR	NS	NS	—	—
	No–till	17	0.37	NR	NR	NS	NS	—	—
24 June	Disk	37	0.68	4.3[b]	5.0	54	3.5	2.3	0.15
	Ridge	37	0.68	3.0[b]	3.5	60	3.7	1.8	0.11
	No–till	37	0.68	3.4[b]	4.0	59	7.5	2.0	0.25
4 July	Disk	35	0.64	8.8	10	8.6	2.1	0.76	0.18
(irrigation)	Ridge	35	0.64	8.2	9.6	11	1.2	0.92	0.10
	No–till	35	0.64	8.2	9.6	10	1.9	0.84	0.16

[a] NS – No Sample. Hydrograph peak insufficient to generate sample.
[b] Based on only one plot.
[c] NR – No Runoff.

Calibration and Verification

Four parameters were used to calibrate the model for runoff depth. Rooting depth did not change between treatments. Minor differences between tillage treatments were seen in field capacity and soil porosity (table 2). The calibrated runoff curve number was 82 for disk–till, 80 for ridge–till, and 79 for no–till. These differences were expected because the tillage plots had been in the same controlled–traffic tillage treatment for 20 years. The calibrated value for soil half–life was 60 days, and the calibrated organic carbon partition coefficient (K_{oc})was 70 L kg^{-1}. These values were within the range of 18 to 120 days for half–life, and 38 to 163 L kg^{-1} for K_{oc} reported by Hornsby et al. (1996).

Regressing observed versus simulated runoff resulted in y–intercepts near zero and best fit slopes (and R^2) of 0.98 (0.75) for disk–till, 1.10 (0.75) for ridge–till, and 1.37 (0.88) for no–till (fig. 2). Comparison of the observed and simulated atrazine runoff concentration and mass loss indicated that the model was generally able to match edge–of–field losses within a factor of two (table 3). Hedden (1986) reported that for site–specific models, such as GLEAMS, simulated and observed values should agree to within a factor of two.

Table 2. Hydrology parameters used in GLEAMS simulations as determined by calibration.

Tillage	Soil Type	Land Slope (%)	Curve No.	Rooting Depth (m)	Field Capacity[a] (cm^3 cm^{-3})	Soil Porosity[a] (cm^3 cm^{-3})
Disk	Silt loam[b]	0.5	82	1.2	0.35	0.43
Ridge	Silt loam[b]	0.5	80	1.2	0.34	0.40
No–till	Silt loam[b]	0.5	79	1.2	0.35	0.40

[a] 0 to 25 cm depth.
[b] Hastings silt loam (Hydrologic Group B), field slope 0.5%.

To determine if the calibrated model could adequately predict runoff and atrazine loss, simulation results were compared to data from two independent field sites, one under disk–till with broadcast atrazine application and the other under ridge–till with banded atrazine application. No independent verification data were available for the no–till treatment. The model predicted atrazine loss: 1) with the ratio of simulated to observed atrazine mass loss within a factor of two for four of six verification cases (table 4); and 2) with a coefficient of efficiency (*ce*) of 0.83 between measured and simulated atrazine concentration, and 0.87 between measured and simulated mass loss (Nash and Sutcliffe, 1970).

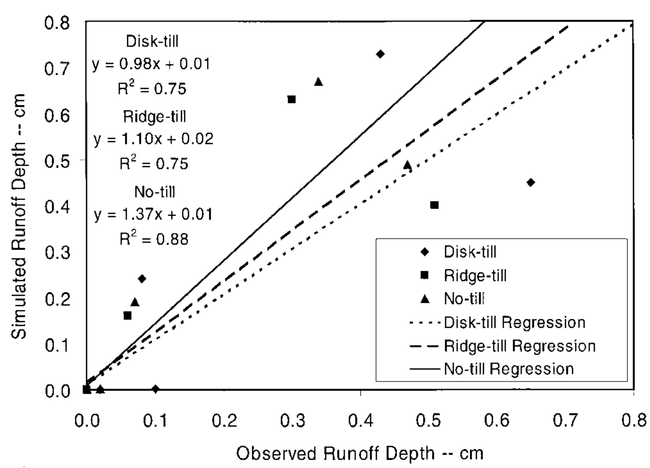

Figure 2. Simulated versus observed runoff depths for GLEAMS calibration.

Table 3. Model calibration results: comparison of simulated and observed atrazine concentrations and mass loss.

Runoff Event	Tillage	Concentration (μg L^{-1}) Observed	Simulated	Mass Loss (g ha^{-1}) Observed	Simulated	Ratio[a] Conc.	Mass Loss
27 May	Disk–till	28.7	23.0	1.90	1.03	0.80	0.54
24 June		54.4	63.0	2.30	4.58	1.16	1.99
27 May	Ridge–till	30.7	25.0	1.60	1.01	0.81	0.63
24 June		59.6	62.0	1.80	3.90	1.04	2.17
27 May	No–till	35.0	26.0	1.70	1.29	0.74	0.76
24 June		59.0	63.0	2.00	3.70	1.07	1.85

[a] Ratio of simulated to observed values.

Simulated Long–term Atrazine Losses

Atrazine losses for 50 years were simulated for 15 different combinations of tillage and atrazine application methods (table 5). Eight practices represented popular management practices currently used for full–scale crop production in the region, with seven additional practices simulated for comparison. Year–to–year variation in atrazine runoff was large, with standard deviations about the same magnitude as the annual average (table 5). Simulated annual atrazine loss for the practices ranged from 0.57% to 1.2% of the annual applied active ingredient.

The simulated annual loss for each year was plotted in ascending rank order as a percentage of the cumulative 50–year loss (fig. 3). By ranking annual losses this way, it was discovered that only a few years contributed to more than 50% of the cumulative 50–year loss. One year contributed nearly 14% of the total 50–year atrazine loss for broadcast applications and >14% for banded applications. In the year that these losses occurred, 97% of the annual atrazine runoff was caused by one 59 mm, 24–h rainfall event in May that produced 23 mm of runoff and occurred only one day after application. Such large rainfall events, while infrequent, contribute significantly to the total loss. Large rainfall events also occurred close to the dates of application in the other years that contributed to a large percentage of the total losses. Such dramatic runoff events cause only a few years out of 50 to contribute a significant percentage of the total atrazine loss. For banded applications, only seven years contributed to >50% of the total 50–year atrazine loss.

For the pre–emergent broadcast or banded applications with a median application date of 5 May, 74% to 76% of annual atrazine loss occurred in May. Therefore, a 30–day period following atrazine application, termed the May Loss, was compared over the 50–year period. When the annual May Loss was compared as a percent of the cumulative 50–year May Loss, 53% of the atrazine loss is attributed to only 6 out of the 50 months for banded application, and 52% of the atrazine loss is attributed to only 8 out of 50 months for broadcast application.

Table 4. Model verification results: comparison of simulated and observed atrazine concentrations and mass loss.

Tillage	Runoff Event: 24–h Rain Depth (mm)	Runoff Event: Return Period (yr)	Concentration (μg L^{-1}) Observed	Simulated	Mass Loss (g ha^{-1}) Observed	Simulated	Ratio Conc.	Mass Loss
Disk–till	39.1	0.73	396	268	25.4	27.2	0.67	1.07
	31.5	0.57	24	40	0.01	7.5	1.68	75
	39.1	0.73	111	147	2.84	4.58	1.32	1.61
Ridge–till	21.3	0.42	51	31	1.40	0.46	0.61	0.32
	54.6	1.21	13	11	1.10	2.10	0.85	1.90
	14.2	0.34	22	10	0.02	0.01	0.46	0.50
			ce = 0.83[b]		ce = 0.87[b]			

[a] Ratio of simulated to observed values.
[b] ce = coefficient of efficiency (n = 6) for simulated concentration or mass loss.

Table 5. Tillage and atrazine application practices and simulated annual losses for 50–year atrazine runoff simulations.

Atrazine Application Practice	Tillage Practice	Pre–emergent Application (kg ha^{-1})	Post–emergent Application (kg ha^{-1})	Total Rate Applied (kg ha^{-1})	Mean Annual Loss (g ha^{-1} yr^{-1})	Standard Deviation (g ha^{-1} yr^{-1})	Reduction[a] (%)
Pre–emergent broadcast + post[b]	Disk	1.40	0.56	1.96	24	21	0
Pre–emergent broadcast	Disk	1.40	0.00	1.40	17	19	29
Pre–emergent incorporated + post	Disk	1.40	0.56	1.96	15	10	38
Pre–emergent incorporated	Disk	1.40	0.0	1.40	8.0	6.3	67
Post–emergent broadcast[b]	Disk	0.00	0.56	0.56	7.4	6.8	69
Pre–emergent broadcast + post[b]	Ridge	1.40	0.56	1.96	20	18	17
Pre–emergent broadcast	Ridge	1.40	0.00	1.40	14	17	42
Pre–emergent banded	Ridge	0.70	0.00	0.70	6.9	8.6	71
Post–emergent broadcast[b]	Ridge	0.56	0.00	0.56	5.9	5.6	75
Pre–emergent broadcast + post[b]	No–till	1.40	0.56	1.96	19	18	21
Early pre–emergent broadcast + post	No–till	1.68	0.56	2.24	18	16	25
Pre–emergent broadcast	No–till	1.68	0.00	1.68	16	20	33
Pre–emergent broadcast[b]	No–till	1.40	0.00	1.40	13	17	46
Early pre–emergent broadcast	No–till	1.68	0.00	1.68	11	13	59
Post–emergent broadcast[b]	No–till	0.00	0.56	0.56	5.6	5.5	77

[a] Percent reduction is based on loss pre–emergent broadcast plus post application on disk tillage.
[b] Denotes additional practices selected for comparison only, not primarily used in the study area.

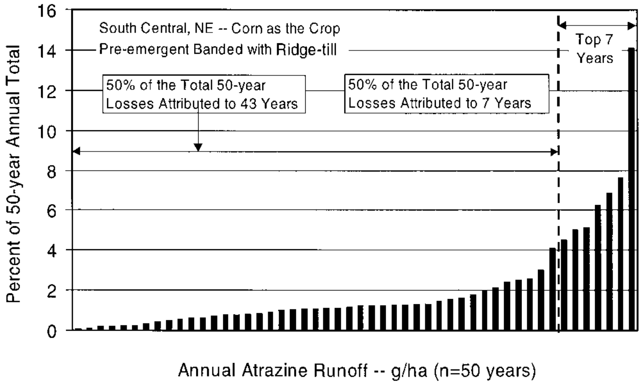

Figure 3. Ranked plot of simulated annual atrazine mass loss as a percent of cumulative 50–year loss.

Finally, examining all the individual runoff events from the May Loss throughout the 50–year period revealed that, for pre–emergent banded application with ridge–till practices, 51% of the 50–year total May Loss is attributed to only 8 out of 110 events. This suggests that at all scales—annual, monthly, and single–event—there are a few events, months, or years that contribute disproportionately to their occurrence. Therefore, a return interval or frequency analysis should help in evaluating long–term atrazine losses.

Best Management Practices

Simulated atrazine loss for a 50–year recurrence interval was 3 to 11 times greater than atrazine loss for a 5–year recurrence interval (figs. 4 and 5). This suggests that BMPs need to address the relatively infrequent (>10–year recurrence intervals) runoff events that make up 50% of the long–term mass losses. Because most of the total 50–year atrazine loss is attributed to these 7 or 8 runoff events, reduction of these less frequent, but large, events can result in a significant reduction in the total 50–year atrazine loss.

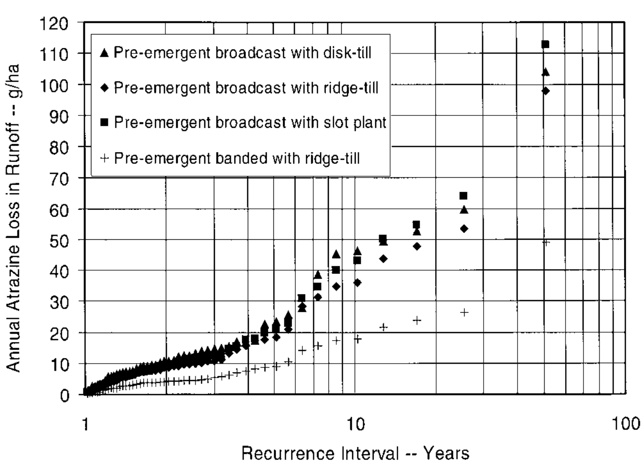

Figure 4. Recurrence intervals of simulated annual atrazine mass loss for selected pre–emergent herbicide application practices.

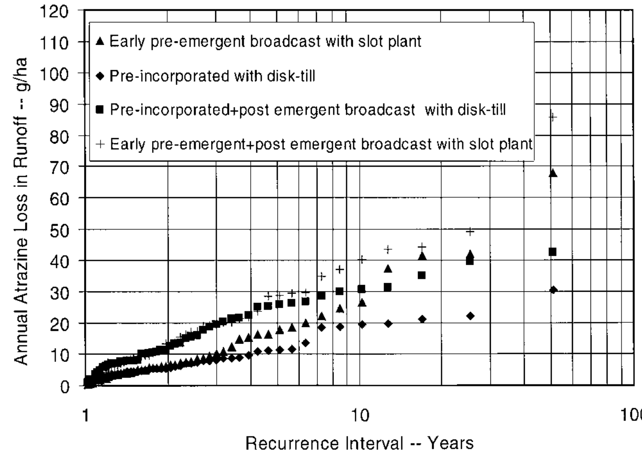

Figure 5. Recurrence intervals of simulated annual atrazine mass loss for selected early–pre–emergent and pre–emergent incorporated herbicide application practices with and without post–emergent application.

The recurrence interval assessment indicates certain practices that will reduce the long–term losses for events of greater recurrence interval. For example, pre–emergent banded application with ridge–till significantly reduced losses for all recurrence intervals (fig. 4). Early pre–emergent broadcast application with no–till and pre–incorporated application with disk–till both reduced losses for recurrence intervals less than 10 years, but early pre–emergent application had significantly greater losses for recurrence intervals greater than 10 years (fig. 5). The most effective practices are pre–emergent banded application on ridge–till systems (fig. 4) and soil incorporation on disk–till systems (fig. 5). While other practices can effectively reduce atrazine loss for more frequent storms, i.e., recurrence intervals under 10 years, only pre–emergent banded with ridge–till and pre–emergent incorporated with disk–till significantly reduced the losses from the less–frequent but high–runoff storms. What these practices have in common is that less herbicide is on the soil surface during periods of potential runoff in May and early June, either from a reduced application rate or by incorporation of the herbicide below the soil surface mixing zone.

Comparing mean annual atrazine loss for the 50–year period for all 15 practices to the mean loss from the pre–emergent + post–application with disk–till shows that reductions ranged from 17% to 77% (table 5). Reductions of atrazine loss >50% can be achieved for all three tillage practices using at least one herbicide management practice: a pre–incorporated application for disk–till, a pre–banded application for ridge–till, an early–pre–emergence application for no–till, or a post–emergent application practice for any of the three tillage practices.

BMPs that provide long–term reductions in atrazine loss must address the less frequent, or large recurrence interval, losses. Based on the recurrence interval evaluation, the pre–emergent practices that did this best were pre–emergent banded application with ridge–till, and pre–emergent incorporated with disk–till. These two pre–emergent practices show substantial atrazine loss reduction at recurrence intervals greater than 10 years (figs. 4 and 5).

SUMMARY AND CONCLUSIONS

A natural rainfall field study was conducted on a silt loam soil on a 0.5% slope, furrow irrigated, corn field in South Central Nebraska to compare spring runoff volume and herbicide loss from three tillage treatments that included disk–till, ridge–till, and no–till. Results showed that: 1) disk–till produced the greatest volume of runoff with no–till and ridge–till having 34% and 36% less volume respectively; 2) compared to disk–till, total herbicide mass loss from three sampled runoff events was reduced by 17% and 24% for atrazine and 1.3% and 10% for acetachlor for no–till and ridge–till, respectively; 3) the first irrigation event produced greater runoff volumes compared to natural runoff events, but smaller herbicide concentrations, resulting in less herbicide mass loss; and 4) for all tillage practices, the atrazine and acetochlor loss for the spring runoff was less than 0.25% of that applied.

Fifty–year runoff simulations of atrazine losses using a calibrated GLEAMS model were completed. Year–to–year variation in atrazine runoff was large, with standard deviations about the same magnitude as the annual averages. The magnitude of annual atrazine runoff varied between 0.57% and 1.2% of the amount applied.

For the 50–year simulations, the 7 to 10 greatest atrazine loss years contributed more than 50% of the cumulative 50–year loss. These greatest annual loss years had recurrence intervals greater than 10 years. At all scales—annual, monthly and single–event—atrazine losses from a few events, months, or years contributed disproportionately to their occurrence. Based on recurrence interval evaluations for several tillage/herbicide management practices, pre–emergent banded application with ridge–till and pre–emergent incorporated with disk–till showed the greatest reductions in annual atrazine loss for recurrence intervals greater than 10 years. Practices that were most effective in minimizing average long–term atrazine loss were pre–emergent banded application with ridge–till, early pre–emergent with no–till, incorporation application with disk till, and post–emergent application for all tillage practices.

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