Reducing Atrazine Loss in Central Texas

Project 03 – 15

Final Report

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Texas Cooperative Extension
And
Texas Agricultural Experiment Station

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Executive Summary

Atrazine is a very popular weed control management tool for corn and grain sorghum producers in Central Texas. Atrazine is primarily applied broadcast in the Spring across corn and grain sorghum fields as a preemerge broadleaf weed control measure. By applying atrazine across the entire surface of a corn or grain sorghum field, atrazine is at risk of moving off-target during intense storm events common to Central Texas in the Spring. Given the amount of atrazine used in this manner and the potential for atrazine to move off-target in surface runoff, evaluation of alternative application methods for atrazine was warranted.

This project was established and conducted to provide a field-level platform to demonstrate best management practices (BMPs) related to the application of atrazine in corn production systems, to evaluate model predictions associated with atrazine movement, and to disseminate findings to producers in Central Texas.

The BMP demonstration work was completed to evaluate various chemical application methods and their impact on off-target losses of atrazine in surface runoff from corn production areas in the Texas Blackland Prairies. The BMPs studied included incorporation of atrazine and the placement of atrazine in a band. Incorporation refers to the pre-plant incorporation (PPI) of a chemical prior to planting of the crop. The placement of atrazine in a narrow band in the area where the crop is to be planted is known as banding (BAND). These two applications were compared to the traditional method of broadcast applying atrazine across the entire surface of the field and allowing rainfall to incorporate the atrazine.

The two application techniques (PPI and BAND) studied and compared to the traditional broadcast treatment (BROAD) reduced concentrations of atrazine in surface runoff in both years of the study. When compared to the BROAD treatment, atrazine losses from the PPI treatment were reduced by approximately 90% in 2004 and over 65% in 2006. The BAND treatment also showed a reduction in atrazine lost in surface runoff verses the BROAD treatment for each of the two years of the study (87.1% in 2004 and 56.0% in 2006).

Average weed control across each of the seasons was better when using the traditional BROAD application method. However, both the PPI and BAND treatments had weed control in the 80 percentage range for 2004 but weed control decreased during 2006 for both application methods.

Though differences in weed control were experienced between the BROAD, PPI, and BAND application methods, yield reduction differences between treatments were not as large. The BAND treatment out yielded the other two treatments in 2004 and the PPI treatment out yielded all treatments in 2006. No real trends were established in determining which application treatment should be the most consistent high yielding method. However, the results of this project show that the PPI and BAND treatments

which are designed to reduce off-target losses of atrazine in surface runoff can produce yields comparative to the BROAD application treatment.

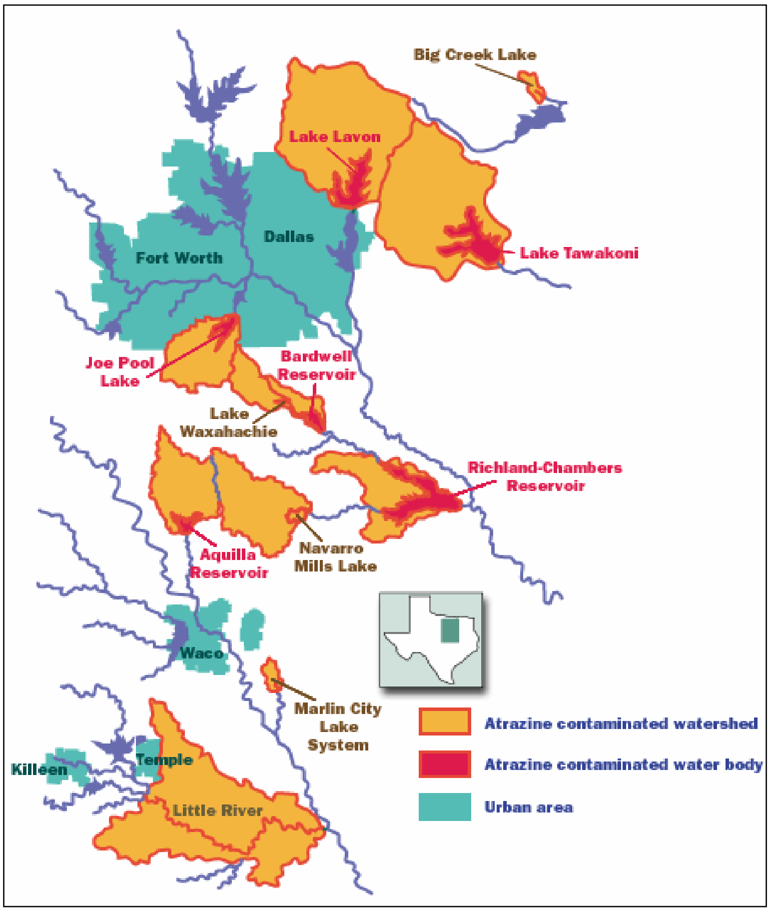
By employing the PPI and BAND treatments designed to reduce off-target losses of atrazine in surface runoff, a corn or grain sorghum producer can reduce the risk of atrazine contamination of the surface waters of Texas while maintaining acceptable yields. Therefore, producers in areas with risk of atrazine contamination to surface water should consider using the PPI or BAND treatment as part of their natural resource protection plan.

Ducks swimming in Big Creek Lake, one of the atrazine-impacted reservoirs in Texas.

Project Introduction:

Atrazine ranks as one of the most widely used herbicide in Texas crop production. Its popularity can be attributed to its effectiveness, residual weed control, and low cost of treatment. Though used mainly in corn and grain sorghum production, atrazine can also be found in products such as "weed and feed" and other weed management products used in the home landscape.

Figure 1: Atrazine-impacted Watersheds in Central Texas



Atrazine is used primarily as a pre-emergent to control annual broadleaf weeds and some annual grasses. Atrazine is traditionally applied across the entire crop production area in a broadcast and uniform manner. This helps ensure adequate coverage of the targeted weed control area. Rainfall or irrigation moves the atrazine into the upper soil profile to where weeds germinate. As weeds germinate, they take up atrazine through the root zone. Weeds susceptible to atrazine herbicide are affected by the disruption of photosynthesis. Weeds emerge but are unable to convert light to chemical energy required for food production and eventually die through starvation.

Given its popularity and the method of broadcasting the material across thousands of acres of corn and grain sorghum, concerns related to off-target losses of atrazine in surface runoff have grown across Texas. Atrazine is moderately soluble and, thus can move in surface water runoff from the intended target to unintended areas such as streams, rivers, or lakes. Atrazine also can be adsorbed onto the surface of soil and move in sediment in runoff water and eventually deposited into non-target areas. These losses of atrazine in surface runoff have raised concerns in several water bodies located primarily in the Central Texas Blacklands (Figure 1).

Several of these water bodies are designed to provide public drinking water in Central Texas and have recorded detections of atrazine in both drinking water and ambient surface water. These detections have led to discussions on how to reduce off-target losses of atrazine. The complete ban of the use of atrazine in corn and grain sorghum production systems has been proposed. However, such a ban has been estimated to increase weed control costs in Texas by approximately $45 million annually. These increased costs are a result of increased cost of using atrazine alternatives for weed control and loss of revenue associated with reductions in crop yields.

Problem Definition / Background:

Atrazine is the most widely used herbicide in Texas corn and grain sorghum production. With its widespread use, atrazine has been detected in Texas groundwater and surface water. The detections of atrazine in surface water have been concentrated, mainly, in the Central Texas Blacklands including the counties of Milam, Falls, Ellis, Hill and Delta. Reports presented by the Texas Commission on Environmental Quality (TCEQ, 2000) indicate the presence of atrazine in eight public water supply lakes and one public water supply drawn from a river in Texas. These reports suggest atrazine is entering the public water supplies through surface runoff from corn and grain sorghum cropland and urban landscapes. Banning atrazine does not appear to be the answer because of the adverse economic impact on agricultural producers. It is estimated that Texas corn producers, as a whole, would face a total increase in the cost of production (based on increase in cost of production of using an alternative herbicide and decrease in income caused by yield reductions associated with increased weed populations and crop injury) of over $45,000,000 (USDA 1995). Given the reality that producers economically need to have continued access to atrazine coupled with the need to reduce off-target losses of atrazine in surface runoff, a concerted effort must be taken to study the benefits of reducing tillage, maintaining residues on the soil surface, and using alternative atrazine application practices on the target area to maintain weed control, reduce off-target losses, and maintain/increase yields.

Two BMPs, incorporation of atrazine at application time and banding at a reduced rate at planting, were recommendations of agricultural producers in Hill County which contains the majority of the watershed of Lake Aquilla. Lake Aquilla is the only public water supply reservoir indicated on the 2000 Texas Water Quality Inventory and 303(d) list as impaired for atrazine (TCEQ, 2000). In the TMDL Implementation Plan (TCEQ, 2001), TCEQ and Texas State Soil and Water Conservation Board (TSSWCB) included incorporation and banding as prescribed methods of atrazine application in the Aquilla watershed. Water quality data from central Texas corn and sorghum production areas need to be collected and evaluated to show that these two BMPs can reduce off-target losses of atrazine in surface runoff without sacrificing weed control and reducing crop yield. According to the Lake Aquilla TMDL Implementation Plan, failure to do so could lead to outright banning of the use of atrazine in the Aquilla watershed by Texas Department of Agriculture.

Project Objectives:

The primary objectives of this project are centered around the demonstration of alternative means of protecting water quality from atrazine contamination and assessment of their impacts by simulating field conditions over a long period of time through model runs. Specific objectives studied included:

1. Demonstrate the effects of alternative tillage practices and atrazine application practices on protecting water quality by reducing atrazine losses;

2. Develop educational materials and present the demonstration results at agricultural meetings, field days, and conferences;

3. Validate the ***CroPMan*** simulation model with measured atrazine losses to facilitate simulating long-term losses of atrazine and the probabilities of meeting EPA standard for safe drinking water; and

4. Analyze the economic costs, profits, and the cost effectiveness (amount of reduction in atrazine loss per dollar cost) of alternative tillage methods.

Demonstration Work at Stiles Farm:

Demonstration plots were set up at the Stiles Foundation Farm near Thrall, Texas. This site was chosen because it is located in the Central Texas Blackland Prairie and, therefore, has similar soils to the atrazine-impacted watersheds. Atrazine movement in surface runoff should closely reflect that which is experienced in corn production areas of the arazine-impacted watersheds. The Stiles Farm also hosts one of the largest on-farm educational field days in Central Texas drawing some 150 to 250 people to the event each year. By establishing the plots at Stiles, producers and ag. industry personnel involved in the use of atrazine in Central Texas could tour the plots and see first-hand demonstration results.

The application methods studied included the traditional broadcast method (BROAD), preplant incorporation (PPI), and banding (BAND). Broadcasting of atrazine is applying the material to the entire soil surface across the field. After application, the herbicide is incorporated by the actions of rainfall or irrigation.

PPI of atrazine is the mechanical mixing of atrazine into the soil profile after surface application. Once the material is broadcasted across the soil surface, atrazine is mechanically mixed into the soil with a farm implement such as a rotary hoe, spring-tooth hare, or disk. This action mixes the atrazine into the two to three inches of soil below the surface, thus reducing the risk of off-target losses of the herbicide in surface runoff.

The BAND application of atrazine places the product in the area where the crop is planted. In most cases, using this application method reduces the total amount of material applied to the field by 50 to 66 percent as compared to the BROAD method. Untreated areas between rows then require an early-season mechanical cultivation to reduce any weed pressure present between crop rows. This application management strategy reduces the risk of off-target losses of atrazine in surface runoff by reducing the total amount of product introduced to the environment.

Methods Used to Study Application Management Strategies:

To thoroughly evaluate the three application management strategies, a demonstration site was established on the Stiles Farm near Thrall. Each of the three application management strategies (BAND, PPI, and BROAD) were studied for effectiveness in reducing off-target losses of atrazine in surface runoff. In addition, the PPI and BAND application methods were compared to BROAD method for % weed control and yield.

The treatments were applied to four 38-inch rows by 50 feet long plots and replicated four times. Each plot was bermed on each side and both ends to prevent storm-generated runoff water from exiting the plot from where it originated. Runoff was collected from the first runoff event of the season by the use of a combination of automatic stormwater runoff and passive water samplers placed at the lower end of each plot. Average slope of the plots was 3 to 5 %.

The runoff from each of the individual plots was collected and analyzed for concentration of atrazine in µg/L (parts per billion) in the surface runoff by the Texas Agricultural Experiment Station (TAES) pesticide fate research lab in College Station and average for each treatment. Weed control ratings and crop yield were taken and averaged for each application treatment. Data was collected in 2004, 2005, and 2006. Given environmental conditions associated with drought, extraction failures in the laboratory, and other problems encountered in the field, no data is presented for the 2005 production year. Yield variations between 2004 and 2006 reflect dry conditions experienced during the mid and late growing season in 2004. Averages for each treatment are reported in Table 1.

Discussion and Conclusions of from this Study:

As reported in Table 1; the two applications techniques (PPI and BAND) studied and compared to the BROAD treatment reduced concentrations of atrazine in surface runoff in both years of the study. When compared to the BROAD treatment, atrazine losses from the PPI treatment were reduced by approximately 90% in 2004 and over 65% in 2006. The BAND treatment also showed a reduction in atrazine lost in surface runoff verses the BROAD treatment for each of the two years of the study (87.1% in 2004 and 56.0% in 2006).

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In 2006, no-till plots were established in previous year's stubble to study effects of no-till on off-target losses of atrazine in surface runoff, % weed control, and corn yields. The no-till plots showed major promise as a atrazine management strategy. This is due to the reduction in off-target losses of atrazine in surface runoff (lowest of all treatments) and the % weed control and yield (greatest among all the treatments studied).

Application Method	**Avg. Atrazine Lost (µg/L)**		**Avg. % Pigweed Control**		**Avg. Yield (bu/acre)**	
	2004	**2006**	**2004**	**2006**	**2004**	**2006**
BROAD	155.7	234.1	94.6	87.5	35.0	94.8
PPI	16.2	79.1	88.4	75.3	30.0	97.4
BAND	20.1	102.9	84.0	57.6	67.0	89.0
No-Till	NA	75	NA	87.2	NA	101.6

Note: NA indicates study did not include no-till plots in 2004 (residue not established until after 2004 harvest.

Table 1: Atrazine lost (µg/L), % weed control, and corn yield (bu/ac) for 2004 and 2006.

Building berms to enclose each plot for runoff collection

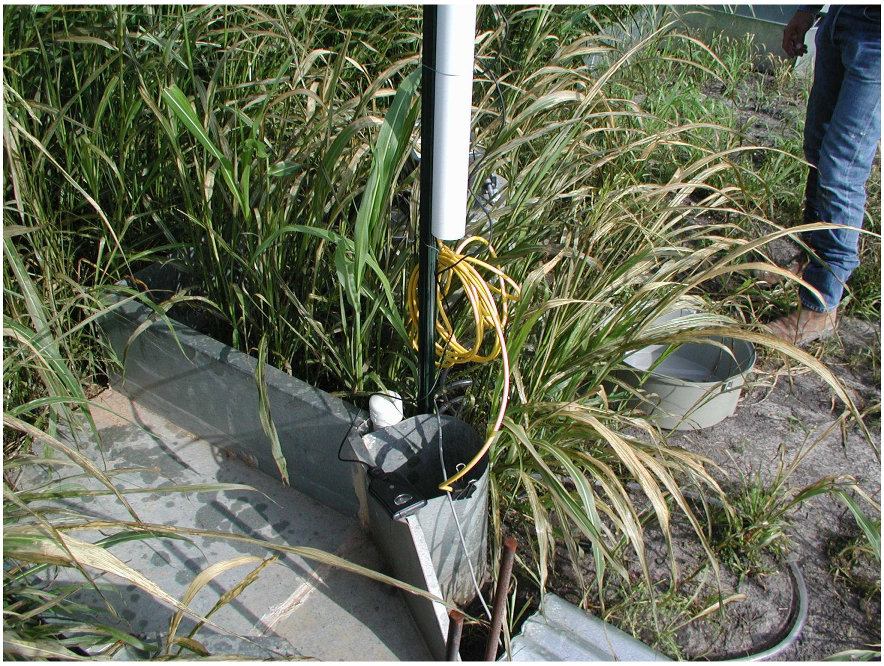
View of one of the individual treatment plots complete with berms and collection flume.

Fred Moore, TCE in College Station, making a broadcast application of atrazine to demonstration plots

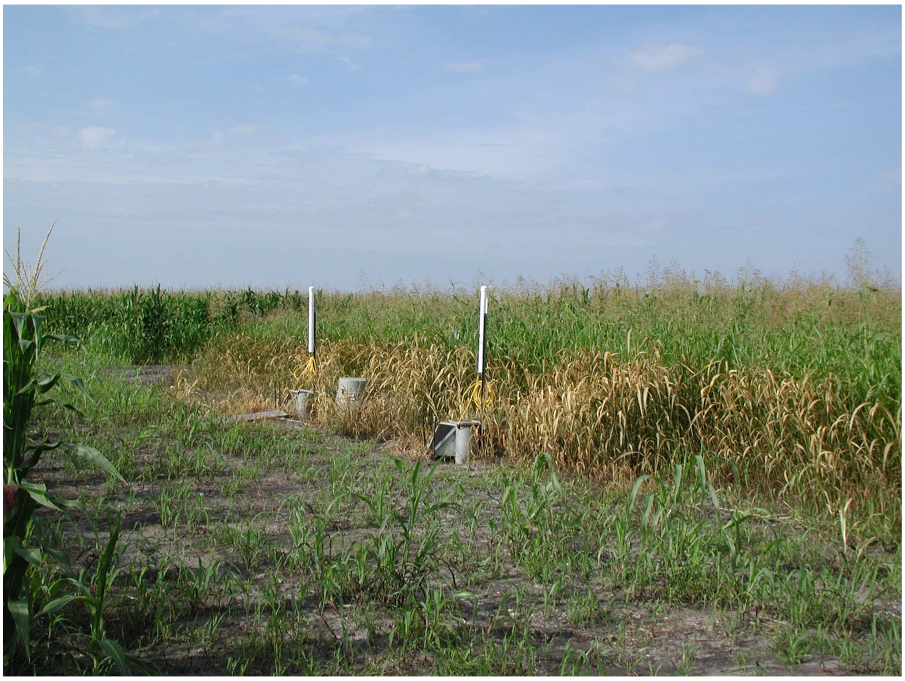
Use of rotteria for mechanical incorporation of atrazine after application.

Mechanically incorporated atrazine after application and
before planting with a rotta-tiller

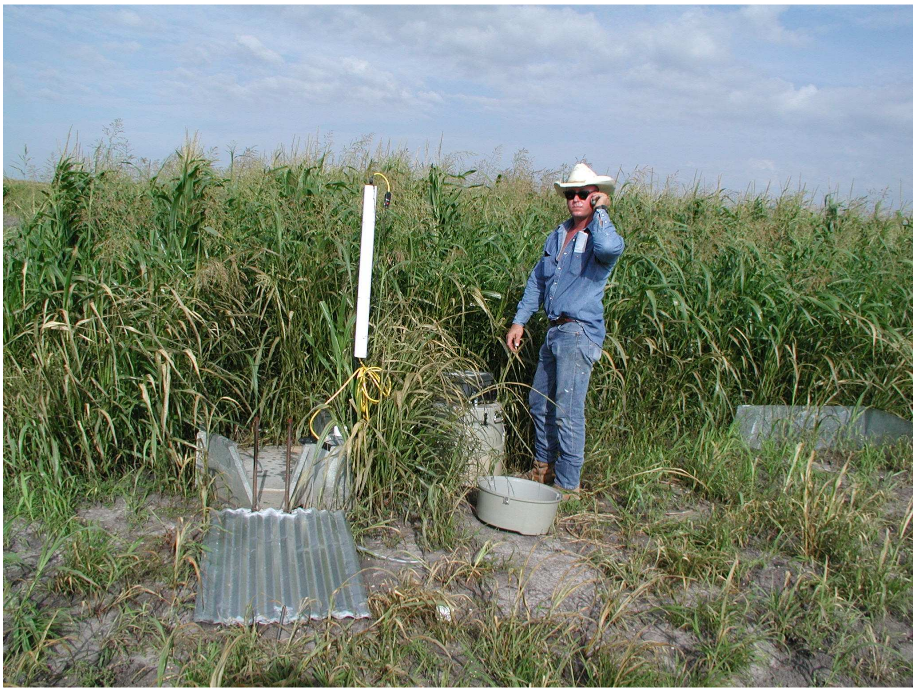
Corn emerging in demonstration plots



Flume complete with a pressure transducer and datalogger to calculate flow for use in modeling effort



Datalogger and Isco Sampler setup to collect runoff samples



Roger Cassen of the TAES Blackland Research Center in Temple servicing an Isco automatic sampler.

Passive runoff collection tube setup.

Scott Senseman, TAES Research Scientist in College Station, recovering runoff water from a passive sample collection unit.

Presentation of Educational Results:

The Stiles Foundation Farm Filed Day served as the main method of direct presentation of educational information generated from this project. Table 2 outlines efforts and contacts made during Stiles Foundation Farm Field Days.

Year	Attendance	Poster Presented	Plots Toured	Proceedings
2004	150	yes	yes	no
2005	165	yes	yes	yes
2006	152	yes	yes	no
2007		no	no	yes

Table 2: Summary of attendance and activity associated with field days at the Stiles Foundation Farm.

In addition, information generated from the demonstration plots were posted on the TAMU variety testing website located at http://varietytesting.tamu.edu/corn&grainsorghum/resources.htm#variety during the appropriate year.

A publication has been developed reporting the results of the demonstration work related to the three application techniques studied. This publication will be converted to a Texas Cooperative Extension (TCE) e-publication and placed in the TCE bookstore located at http://www.tcebookstore.org. A copy of this publication is attached in the appendix.

Corn plots ready for viewing during the Stiles Foundation Farm Field Day.

Monty Dozier, TCE in College Station, is shown presenting results of the Atrazine BMP study at a Stiles Foundation Farm Field Day.

Paul Baumann, TCE Weed Control Specialist from College Station presented corn herbicide information during the Stiles Foundation Farm Field Day.

Crowd gathering at Stiles Foundation Farm for presentation on demonstration plots.

Poster setup in the educational exhibit area of the Stiles Foundation Farm Field Day (a copy of the educational poster presented in the appendix).

Model predictions and determining economics of application techniques:

This simulation study analyzed and compared five tillage and application strategies with the conventional broadcast method of application without immediate incorporation, letting subsequent rainfall automatically achieve incorporation. The five alternative strategies were: (1) disk incorporated, spring applied; (2) banding, 1/3 rate applied at planting over the seed row; (3) no-tillage, spring applied; (4) disk incorporated, fall and spring split applications each at ½ rate; and (5) no-till, fall application at ½ rate plus banding at planting at 1/3 rate.

Field losses, measured in terms of loads, were generally less than 2% of the amount applied, ranging from a low of 0.05oz/ac/yr for the loam soil using banding at 1/3 rate to 0.47 oz/ac/year with no-tillage, spring applied on the Houston Black clay. Yet probabilities of exceeding the Safe Drinking Water Act of 3 µg/L or parts per billion (ppb) based on 100 years of weather were never lower than 25% for any of the strategies and exceeded 90% probability with both no-till strategies.

Two soil types, clay and loam, were analyzed for differences in surface losses and the loam soil always lost less than clay but incurred significantly higher leaching losses. The strategies that minimized surface losses on both soils were the spring applied, disc incorporated; banding at 1/3 rate applied at planting; and fall and spring split applications at ½ rate, disk incorporated. The largest losses occurred with both no-tillage strategies.

Costs of production favored the conventional non-incorporated strategy, the banding strategy, and disk incorporation of one spring application.

The most cost effective strategy which reduced atrazine loss the most for the least cost was the banding strategy. The next most effective strategy was disk incorporation of one spring application.

A copy of the full report is attached in the appendix.

Conclusions:

The field demonstration results and the modeling efforts clearly show that use of atrazine application techniques and use of no-till can reduce off-target losses of atrazine in surface runoff. By employing these techniques, a corn or grain sorghum producer can reduce the risk of atrazine contamination of the surface waters of Texas while maintaining acceptable yields. Therefore, producers in areas with risk of atrazine contamination to surface water should consider using one of the described application techniques or no-till as part of their natural resource protection plan. Such actions will aid in keeping the atrazine in the intended application target zone for maximum weed control and net returns for ag. producers while reducing off-target losses on atrazine into streams, rivers, and lakes of Central Texas.

APPENDIX

A Lesson in Atrazine and Its Management

Monty Dozier[1], Paul Baumann[1], Scott Senseman[2], Wyatte Harman[3], and Tom Gerik[3]

Introduction

Atrazine ranks as one of the most widely used herbicide in Texas crop production. Its popularity can be attributed to its effectiveness, residual weed control, and low cost of treatment. Though used mainly in corn and grain sorghum production, atrazine can also be found in products such as "weed and feed" and other weed management products used in the home landscape.

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Several water bodies designed to provide public drinking water in Central Texas have recorded detections of atrazine in both drinking water and ambient surface water. These detections have led to discussions on how to reduce off-target losses of atrazine. The complete ban of the use of atrazine in corn and grain sorghum production systems has been proposed. However, such a ban has been estimated to increase weed control costs in Texas by approximately $45 million annually. These increased costs are a result of increased cost of using atrazine alternatives for weed control and loss of revenue associated with reductions in crop yields.

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[1] Texas Cooperative Extension; College Station, TX
[2] Texas Agricultural Experiment Station; College Station, TX
[3] Texas Agricultural Experiment Station; Temple, TX

Rather than ban the product, work has been conducted to determine the effectiveness of atrazine application management strategies in reducing off-target losses of atrazine in surface runoff while still maintaining acceptable weed control and crop yields.

Application Mangement Strategies Studied

The application methods studied included the traditional broadcast method (BROAD), preplant incorporation (PPI), and banding (BAND). Broadcasting of atrazine is applying the material to the entire soil surface across the field. After application, the herbicide is incorporated by the actions of rainfall or irrigation.

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BAND	20.1	102.9	84.0	57.6	67.0	89.0

Acknowledgements

The participants of this study would like to thank the Stiles Farm staff for assistance in conducting this study. Appreciation is also extended to the Texas State Soil and Water Conservation Board in Temple, Texas and the United States Environmental Protection Agency for financial support of this project through the Section 319(d) of Clean Water Act grant program.

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A NEW AND UNIQUE STUDY AT THE STILES FARM:
PROTECTING WATER QUALITY FROM ATRAZINE CONTAMINATION

Monty Dozier,CES, College Station, TX.,, Wyatte Harman and Tom Gerik, Blackland Research Center, Temple, TX.

This demonstration is cooperatively funded by the Texas State Soil and Water Conservation Board, Temple, Texas, Cooperative Extension Service, and the Texas Agricultural Experiment Station.

BACKGROUND

Water quality is being impacted by widespread use of herbicides, some allegedly harmful to humans. One herbicide under close scrutiny is atrazine, a commonly used herbicide in corn and sorghum. Because of the long residual, rainstorms cause runoff of soluble and adsorbed atrazine, sometimes exceeding the safe drinking water maximum of 3 ppb established by the USEPA. During the past ten years, some metropolitan water supplies in the Blackland Prairie region of central Texas have been found to contain high levels of atrazine. This study assesses protective implications of reducing atrazine runoff using alternative tillage practices that can easily be implemented by corn and sorghum producers.

OBJECTIVES

The objective of the study is to determine the relative losses of atrazine applied at different times and with different tillage practices when producing corn. The tillage practices being compared in the study include:

- Non-incorporation of atrazine following broadcast application;
- Preplant incorporation of atrazine by discing immediately following or during broadcast application;
- Banding of atrazine over the seed row—about 33% of the land area will receive atrazine—and row cultivating for weed control; and
- Broadcast application of atrazine using no-tillage practices, i.e. Roundup-ready corn production.

An additional objective of the study is to utilize the atrazine runoff results from the demonstration to validate a computerized simulator that can be used for farm decision-making on different soil types, extreme slopes, and in varying climates. This information will be valuable in guiding farmers in safer methods of using atrazine across the state.

METHODS AND PROCEDURES

Four tillage demonstrations will be replicated four times on slightly varying slopes at the Stiles Farm. The 2004 corn treatments do not include a no-tillage treatment of corn because the demonstration plots were in cotton in 2003.

Runoff samples will be taken each rainfall event that runoff occurs during the 2004 growing season beginning with planting to determine the concentrations of atrazine. Thereafter, water samples of runoff events will be taken from the time atrazine is applied preplant to the end of subsequent growing seasons.

Soil samples will be taken preplant and after harvest of each growing season to determine seasonal changes in atrazine carryover at the recommended rate of application. This will provide an assessment of the potential of reducing soil carryover by banding at a 33% rate.

Volume of runoff will be measured with volumetric flumes for each runoff event and correlated with water samples to determine the quantity of atrazine lost. This facilitates comparing the seasonal loss of that applied.

PRELIMINARY RESEARCH

An early study of atrazine losses at the USDA Grassland, Soil and Water Conservation Laboratory, Temple, Texas, found that using a chisel-plow in corn production resulted in atrazine runoff losses of less than 2% of the amount applied and sediment losses were less than 0.03% of the amount applied (Pantone et al. 1996). These experimental results were later utilized to verify the accuracy of a computerized simulation model developed for assessing alternative production practices and related environmental and crop yield impacts. It can simulate long-term weather, multiple soils, many combinations of crop rotations, and other cultural practices. The chances of favorable outcomes of a management strategy, say that of adopting no-tillage corn, can be assessed over a 100-year timeframe using a base period and location of weather.

Following validation of the simulation model using historical weather and area crop yields in a watershed of central Texas in which atrazine was a contaminant in drinking water supplies, the model was subsequently used to predict the effects on atrazine runoff and sediment losses of adopting alternative tillage practices (Harman et al. 2004). Though several strategies were simulated (300 times) to evaluate the probabilities of atrazine losses occurring, the four practices being demonstrated at the Stiles Farm in 2004 and 2005 were ranked from lowest losses to highest losses as follows:

1. Banding at a reduced rate coupled with row cultivation was most effective in reducing atrazine losses (LOWEST);
2. Immediate incorporation of atrazine when broadcast applied preplant;
3. No-tillage with Roundup-ready corn; and
4. Non-incorporation of a broadcast application (HIGHEST).

Figures 1 and 2 illustrate the average simulated losses and the losses as a percent of applied for the four tillage practices being demonstrated at the Stiles Farm

FUTURE QUESTIONS

Future questions to be answered by the new and unique Stiles Farm atrazine runoff demonstration include:

1. Are the results of the computerized simulation study above correct?
2. If not, how do they differ?
3. If so, what are the economics of implementing more effective practices to reduce atrazine runoff?
4. Will corn yields be affected by banding coupled with row cultivation?

DEMONSTRATION RESULTS AND IMPLICATIONS

Results and implications of the Stiles Farm demonstration of atrazine runoff will be distributed in a joint publication by the Texas Cooperative Extension and Texas Agricultural Experiment Station. It will be entitled:
“Enviro-friendly Use of Atrazine: A guide for Central Texas”.

LOOK FOR THIS USEFUL GUIDE AT UPCOMING STILES FARM FIELD DAYS AS OUR RESULTS BECOME AVAILABLE.

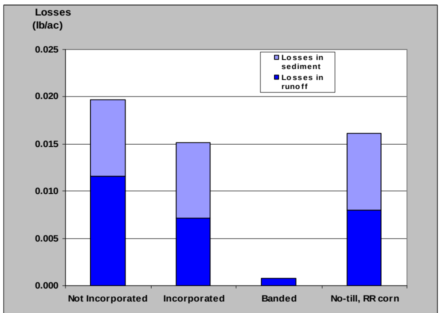

Figure 1
Smulated Losses of Atrazine from Alternative Tillage Strategies

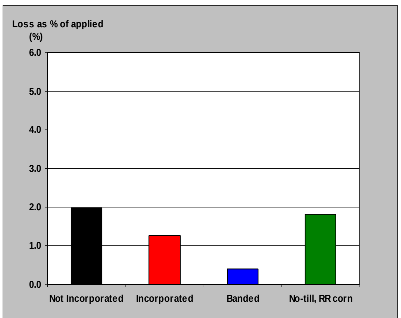

Figure 2
Simulated Atrazine Losses as % of Applied with Alternative Tillage Strategies

In partial fulfillment of an atrazine demonstration project supported by the Texas State Soil and Water Conservation Board:

ATRAZINE FIELD LOSSES: A SIMULATION STUDY OF MITIGATION STRATEGIES

by

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ATRAZINE FIELD LOSSES: A SIMULATION STUDY OF MITIGATION STRATEGIES

ABSTRACT

Atrazine losses from corn and sorghum fields are an alleged threat to the safety of drinking water. The EPA safe level for atrazine concentration is 3 ppb. This simulation study analyzes and compares five tillage and application strategies with the conventional broadcast method of application without immediate incorporation, letting subsequent rainfall automatically achieve incorporation. The five alternative strategies were: (1) disk incorporated, spring applied; (2) banding, 1/3 rate applied at planting over the seed row; (3) no-tillage, spring applied; (4) disk incorporated, fall and spring split applications each at ½ rate; and (5) no-till, fall application at ½ rate plus banding at planting at 1/3 rate. Field losses, measured in terms of loads, were generally less than 2% of the amount applied, ranging from a low of 0.05oz/ac/yr for the loam soil using banding at 1/3 rate to 0.47 oz/ac/year with no-tillage, spring applied on the Houston Black clay. Yet probabilities of exceeding 3 ppb based on 100 years of weather were never lower than 25% for any of the strategies and exceeded 90% probability with both no-till strategies. Two soil types, clay and loam, were analyzed for differences in surface losses and the loam soil always lost less than clay but incurred significantly higher leaching losses. The strategies that minimized surface losses on both soils were the spring applied, disc incorporated; banding at 1/3 rate applied at planting; and fall and spring split applications at ½ rate, disk incorporated. The largest losses occurred with both no-tillage strategies. Costs of production favored the conventional non-incorporated strategy, the banding strategy, and disk incorporation of one spring application. The most cost effective strategy which reduced atrazine loss the most for the least cost was the banding strategy. The next most effective strategy was disk incorporation of one spring application.

INTRODUCTION

Atrazine is the most widely used herbicide in Texas corn and grain sorghum production. With its widespread use, atrazine has been detected in Texas groundwater and surface water. Detections of atrazine in surface water have been reported in central Texas by the Texas Commission on Environmental Quality. These reports indicate that atrazine is entering the public water supplies through surface runoff from corn and grain sorghum cropland and urban landscapes. Banning atrazine does not appear to be the answer because of the adverse economic impact on agricultural producers. A decade ago, it was estimated that Texas corn producers, as a whole, would face a total increase in the cost of production (based on increase in cost of production of using an alternative herbicide and decrease in income caused by yield reductions associated with increased weed populations and crop injury) of over $45,000,000 (USDA 1995). The monetary consequence is likely larger now with currently higher corn prices. Given the reality that producers need to have continued access to atrazine coupled with the need to reduce off-target losses of atrazine in surface runoff, a concerted effort must be taken to study means of reducing atrazine field losses.

This study examines the potential for reducing field losses of atrazine in corn production in central and south-central Texas, a region where most soils have slow to moderate infiltration characteristics and produce substantial runoff when intense rainstorms occur. The region is one of increasing corn acreage with an 80% increase occurring since 1985. Current corn planted acreage of over 750,000 acres has occurred as a result of shifts from grain sorghum, cotton, and wheat over this past two decades (Texas Agricultural Statistics Service, 1985 and 2005). During this period, atrazine has been rapidly adopted as the primary weed control herbicide. Without effective weed control, yield losses would be severe in this region having over 30 inches annual rainfall.

OBJECTIVES

The primary objective of this project is to demonstrate in field plots alternative means of protecting water quality from atrazine contamination and assess their sustained impacts by simulating field conditions over a long period of time, a shortcoming of year-to-year field demonstrations. Specific objectives include the following:

1. Demonstrate the effects of alternative tillage practices and atrazine application practices on protecting water quality by reducing atrazine losses;

2. Develop educational materials and present the demonstration results at agricultural meetings, field days, and conferences;

3. Validate the ***EPIC*** simulation model with measured atrazine losses to facilitate simulating accurate long-term losses of atrazine and to assess the probabilities of meeting the EPA safe drinking water standard; and

4. Analyze the economic costs and the cost effectiveness (amount of reduction in atrazine loss per dollar cost) of alternative tillage practices and application strategies.

METHODS AND PROCEDURES

The methodological approach consisted of establishing four alternative tillage and atrazine application practices for corn production at the Stiles Foundation farm. These plots were used to monitor atrazine runoff losses. They were also utilized to educate and demonstrate environment-friendly alternatives at recent Sties Foundation field days.

<u>Measuring the Effects of Tillage on Atrazine Losses in Field Demonstrations.</u>

Four tillage treatments were demonstrated:

1. The common practice of applying atrazine pre-emerge without incorporation;
2. Pre-emerge application of atrazine with immediate incorporation;
3. Banding of atrazine at 33% rate; and
4. No-till corn production (Roundup Ready) with broadcast applied atrazine.

The above descriptions of each tillage practice are self-explanatory. Records of each practice including tillage type and date, planting date, and atrazine application rate and date were used in validating the simulation model and for simulating long-term atrazine losses. This complimentary use of a computerized simulation tool is a good example of estimating long-run impacts from short-term field research results.

Automated runoff samplers were placed in three replicated plots to collect water samples during rainfall events. All samples were analyzed for atrazine concentrations. Three rainfall events occurred within a month of planting during the 2006 corn season. Twelve samples were collected for an hour for each rain from three replicated plots of the four treatments. The first six samples of each event were composited as were the last six samples. The two composite samples were then analyzed for each plot, making a total of six samples per treatment for three rainfall events. The two sample analyses were averaged for each plot and all replicated samples were, in turn, averaged for analyzing treatment effects and validation of the model.

Validation of *EPIC*, A Crop and Pesticide Simulation Model.

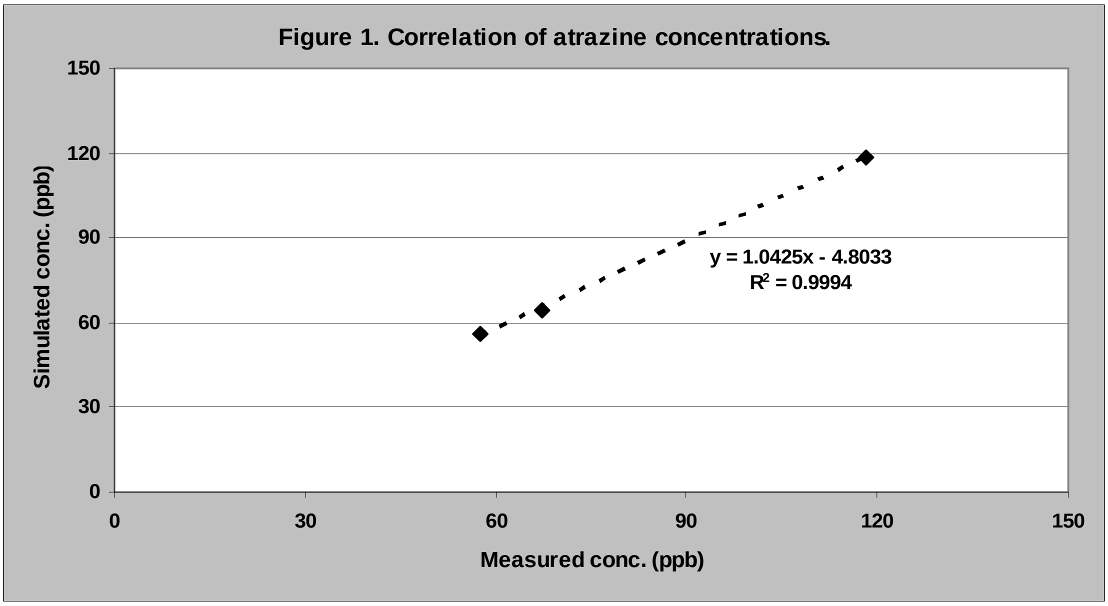
Successful simulations of various production practices depend on complete and accurate characterization of land and water resources, production inputs, and field operations. This necessitates accurate characterization of soils, slopes, historical weather, cultural practices, crops and rotations, and management options. These data were developed from several sources including National Weather Service climatic data; Natural Resource Conservation Service soils and land slope data, and Stiles Foundation farm demonstration field records.

The accuracy of simulating long-term impacts on atrazine runoff losses of alternative BMPs depends on validating the ***EPIC*** (***E***nvironmental ***P***olicy/***I***ntegrated ***C***limate) model (Williams et al. 1989), a crop and environmental simulation model, with measured data from a controlled production situation. A basic familiarity with ***EPIC*** is necessary to understand how crops and pesticides are simulated over time. ***EPIC*** was developed for a USDA national study in the mid-1980's to assess the effect of soil erosion on crop productivity. Since the time of the 1985 USDA National Resource Conservation Assessment, ***EPIC*** has been expanded and refined to facilitate simulation of many more processes important in agricultural management including nitrogen and phosphorus uptake as well as nutrient runoff, sediment losses, soil adsorption, volatility, and mineralization. Major components include weather, hydrology, erosion, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, and plant environment control. Presently, many pesticides are included in fate and transport functions also. Though weed, insect, and disease control per se are not simulated, a nutrient/pesticide fate model, ***G***roundwater ***L***oading ***E***ffects of ***A***gricultural *M*anagement ***S***ystems (***GLEAMS***) is contained in ***EPIC*** to simulate pesticide transport by water and sediment as a function of soil organic carbon content and a linear adsorption isotherm (Leonard et al. 1987). In this project, a Windows® interface for the ***EPIC*** model called ***WinEPIC*** will be utilized for user-friendliness and efficiency of running batch runs of similar but slightly revised parameters such as different tillage practices, atrazine application strategies, and soil types (Harman et al., 2005)

In addition to accurately simulating the planting date, date and type of tillage operations and atrazine rate and date of application, successful model validation also depends on accurate daily rainfall and temperature input data. The ***EPIC*** model is a daily time-step simulator that uses daily rainfall, average daily solar radiation, average daily humidity, average daily wind speed, and maximum and minimum daily temperatures as a basis for plant growth. Weather records from the Stiles Foundation farm headquarters were utilized for the 2006 validation period.

The ***EPIC*** simulation model was successfully validated for three of the four treatments. The exception being the banding treatment for which measured concentrations were unexpectedly high and similar to the disk-incorporated concentrations. Banded concentrations were expected to be significantly lower since the rate applied was equivalent to 1/3 of the normal broadcast rate. However, in this treatment, atrazine was not applied broadcast but rather at approximately the same nozzle rate in a narrow 10-inch band directly over the corn row. Since the three rainfall events were light, ranging from 0.8 to about 1 inch, it may be that the runoff stream followed the press wheel grooves of the planter where the banded atrazine was concentrated. Thus, a representative mixing of runoff was not attained from the atrazine-free soil area and the banded strip. The lack of uniformly distributed runoff likely resulted in a relatively high concentration of atrazine in the banded treatment.

The three rainfall events of 2006 resulted in small runoff quantities and high concentrations of atrazine as can be seen in Figure 1. The close proximity of the large black diamonds to the dotted regression line indicates the high correlation of measured versus simulated atrazine concentrations for the three following treatments: 1. Non-incorporated broadcast application in the spring; 2. Disc incorporated broadcast application in the spring, and 3. No-tillage of a broadcast application in the spring. The beta coefficient determined by regression of the measured values with the simulated values is equal to 1.0425. This is near 1.0, representing a 45 degree line on which all points of measured and simulated values would be perfectly correlated (not shown). Additionally, the correlation coefficient, r, is equal to 0.9997. Thus, the ***EPIC*** model is validated for these tillage treatments demonstrated at the Stiles Foundation farm.



Long-term Simulations of Corn Production.

A major limitation of demonstrating practices in field plots is the short number of seasons that are usually included in a demonstration. In the case of environmental impacts such as atrazine losses, this is a severe limitation unless by chance wide extremes in rainstorm intensities and amounts occur during the demonstration period. A major advantage of using a simulation tool such as ***EPIC*** is that many climatic scenarios can be assessed in a short time and probabilities of losses can be estimated. Another advantage of using a simulation tool is that other practices including alternative atrazine application strategies such as timings of application, alternative tillage intensities, and soil types can be rapidly simulated.

The long-term simulation analysis in this project includes twelve scenarios including two soils typical of dominant central Texas soils—a clay and a loam—each using six tillage practices and atrazine strategies of which the first four are those being demonstrated at the Stiles Foundation farm and the last two are additional management options:

#1-The common practice of no incorporation of a pre-emerge spring application of atrazine preceded by normal preplant tillage operations;

#2-Immediate incorporation of the pre-emerge application of atrazine preceded by normal preplant tillage operations;

#3-Banded application at a reduced rate (33%) at planting time preceded by normal preplant tillage operations;

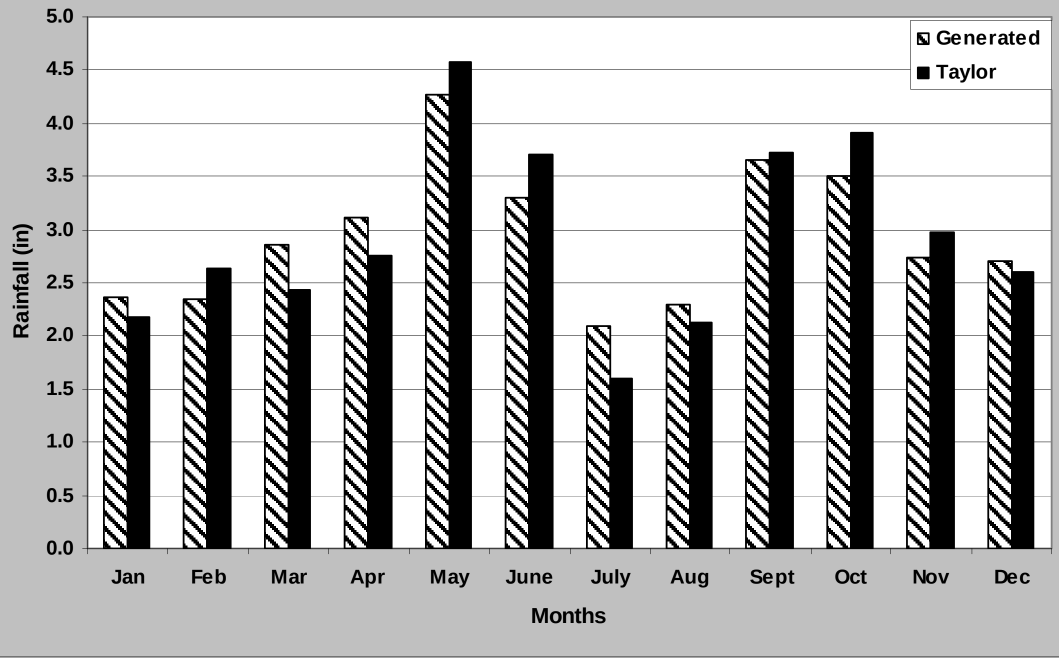
#4-No-tillage corn production with a broadcast spring application of atrazine plus fall and spring applications of Roundup® + 2,4D (Landmaster®) at rates adequate for weed control;

#5-Split broadcast applications of atrazine incorporated immediately—1/2 rate in the fall and 1/2 in the spring; and

#6-No-tillage in the fall with an atrazine application at ½ rate broadcast folllowed by Landmaster® and a 1/3 rate of atrazine banded at planting.

The simulation period was 100 years and included randomly generated weather based on long-term weather records of Taylor, Texas, about 7 miles west of the demonstration site. From the 100 simulations, long-term average atrazine losses and probabilities of attaining an EPA safe drinking water standard of 3 ppb were estimated with each tillage practice and atrazine application strategy. Figure 2 indicates the generated monthly distribution of rainfall compared with the 1960-2005 monthly average rainfall at Taylor, Texas. The correlation is high: r = 0.95. The average atrazine losses for 100 years of simulation are presented in Table 1 for two soils, a Houston black clay and a Crockett loam. The two soils have different characteristics with respect to runoff, infiltration, and percolation. The Houston Black clay soil is typically one of slow infiltration and high runoff but leaching losses through the root zone are usually minimal, whereas the Crockett loam soil has a much higher infiltration rate resulting in lower runoff.

Figure 2. Actual versus generated monthly average rainfall, Taylor, Texas.



Atrazine losses are simulated for each of three components: soluble atrazine lost in runoff, soluble lost in leachate, and organic lost in sediment. Surface losses represent edge-of field conditions; not in-stream or reservoir conditions. Average treatment differences in surface losses of atrazine for the 100-year simulations are shown by soil type in Table 1. For the Houston Black clay simulations, disk incorporation resulted in the least soluble plus sediment atrazine loss of 0.08 oz/ac/yr (leachate on this soil was negligible). The highest average loss of 0.47 oz/ac/yr was from no-tillage with one early spring application. The next highest loss of 0.27 oz/ac/yr was from no-tillage, fall applied at ½ rate and atrazine banded at 1/3 rate at planting. The common practice of tilling and applying atrazine in early spring with no immediate incorporation lost 0.20 oz/ac/yr, third highest. In addition to disk incorporation, other superior treatments to non-incorporation included two split applications at ½ rate in the fall and spring and banding at 1/3 rate at planting. Compared with non-incorporation, incorporating atrazine reduced average annual losses 60%, banding 55%, and incorporating two ½ rate split applications in the fall and spring reduced the average loss 50%.

The ***EPIC*** simulation results also captured the soil differences. For example, the leachate losses of atrazine from the Crockett loam ranged from 22.5% to 51.5% over the treatments compared with negligible leaching losses from the Houston Black clay, Table 1. While total atrazine losses from the loam soil were sometimes equal to or higher than those of the clay soil considering the high percentage leachate (not shown), surface losses in runoff and sediment including both soluble and organic atrazine were always lower with the loam soil.

Table 1. Summary of atrazine losses by tillage practice and application strategy for two soil types.

	Houston Black Clay			**Crockett Loam**		
Strategy	**Surface Loss[1/]**	**Surface Loss/ Applied**	**Leached/ Total Loss**	**Surface Loss[1/]**	**Surface Loss/ Applied**	**Leached/ Total Loss**
	(oz/ac)	(%)	(%)	(oz/ac)	(%)	(%)
Disk incorporated-one spring application	0.08	0.86	Ng[2/]	0.06	1.22	51.5
Band- plant application, 1/3 rate	0.09	2.63	Ng[2/]	0.05	2.05	29.6
Non-incorporated-one spring application	0.20	2.04	Ng[2/]	0.14	2.07	28.2
Disk incorp.-fall & spring split applic., ½ rate	0.10	1.05	Ng[2/]	0.07	1.30	47.9
No-till- fall ½ rate applic. + 1/3 rate band at plant	0.27	1.37	Ng[2/]	0.21	3.30	22.5
No-till-one spring application	0.47	4.84	Ng[2/]	0.33	4.06	18.0

[1/] Surface losses include organic atrazine lost in sediment and soluble atrazine lost in runoff. Leaching losses are excluded.
[2/] Ng = negligible

Surface losses from the Crockett loam were minimized with banding, disk incorporation, and disk-incorporated split fall and spring applications, each at ½ rate. Their average losses were 0.05, 0.06, and 0.07 oz/ac/yr, respectively. Similar to the clay soil, highest losses of 0.33 oz/ac/yr and 0.21 oz/ac/yr occurred with the no-tillage spring applied treatment and no-tillage, ½ rate fall applied plus banding at 1/3 rate respectively. The conventional spring applied, non-incorporated treatment lost 0.14 oz/ac/yr. Compared with non-incorporation, average annual losses were reduced 64% when banded, 57% when atrazine was spring applied once and incorporated, and 50% when split applications were disk incorporated.

Losses as a percentage of the amount applied varied from a low of 0.86% using disk incorporation to a high of 4.84% with no-tillage and one spring application on the Houston Black soil. Likewise, the range was 1.22% to 4.06% on the Crockett loam soil. The non-incorporated conventional application practice lost a total of about 2% on both soil types. This agrees closely with earlier work on Houston Black clay soils and a recent watershed simulation analysis of atrazine losses in the Aquilla Lake watershed, both in central Texas (Pantone et al., 1996 and Harman et al., 2004).

Considering EPA safe drinking limits, none of the treatments were completely safe all of the time. Of the 100 years simulated, for both soils the probability of exceeding 3 ppb ranged from 25% to 35 % for banding, 33% to 37% for one spring application, disk incorporated, 44% to 56% for split fall and spring applications, each disk incorporated, and was 45% for both soils using the conventional non-incorporation tillage practice. All no-tillage scenarios had greater than 90% probability of exceeding 3 ppb. These probability implications give further merit to using TMDL guidelines in lieu of concentrations as safe drinking limits since concentrations tend to increase as runoff decreases.

<u>Economics of Tillage Practices to Reduce Atrazine Losses.</u>

Each of the six tillage practice and atrazine application strategies above utilized different machinery items which affected fuel, labor, and repair costs. Labor was priced at $10/hour and diesel fuel at $2.50/gallon. Machinery complements differed among the scenarios resulting in different depreciation costs by alternative. The same operations were used for each of the soils facilitating a single cost analysis. Table 2 indicates the operating and depreciation costs per acre for each alternative strategy.

The least cost options with regard to total costs were the non-incorporated, spring applied and banded 1/3 rate strategies at $147/ac and $148/ac, respectively. While the lowest cost alternative is a common practice in central Texas, it was one of the largest atrazine-loss strategies. The highest cost alternative was no-tillage, spring applied, $158/ac, and was also one of the largest atrazine-loss strategies. The two disk-incorporation strategies that resulted in the lowest atrazine losses of one spring application and of two split applications had costs of $150/ac and $155/ac, respectively. The no-till ½ rate fall application followed by banding at 1/3 rate cost $152/ac.

Table 2. Estimated costs of alternative tillage practices and atrazine application strategies.

Treatment	Operating Cost	Depreciation Cost	Total Cost/ac	Cost Tradeoff[1/]
	$/ac	$/ac	$/ac	$/oz
Non-incorporated, spring app.	125	22	147	(base)
Disk incorporated, spring app.	127	23	150	25-38
Banded @ 1/3 rate, plant app.	123	25	148	9-11
No-till, one spring app.	140	18	158	na[2/]
Disk incorp. fall & spring ½ rate app.	130	25	155	80-114
No-till, ½ rate fall + 1/3 rate band app.	133	19	152	na[2/]

[1/] The range of values represents Houston Black clay and Crockett loam soils, respectively.
[2/] na = not applicable since costs increased along with larger atrazine losses for these strategies.

In addition to the cost analysis, an enviro-economic tradeoff analysis is useful in analyzing the added cost to achieve a unit reduction in atrazine loss. This type analysis is useful to policymakers, water district managers, and other stakeholders in providing cost-offsetting incentives to corn and sorghum producers to implement mitigating strategies to reduce atrazine losses from their production fields. Because most atrazine losses constitute a threat to reservoirs in central Texas and are of less threat to groundwater, tradeoff values are calculated for surface losses only, excluding leachate. Based on the conventional non-incorporated practice, Table 2, lowest costs per ounce reduction in surface atrazine loss of $9/oz to $11/oz for clay and loam soils, respectively, were attained by the strategy of banding at 1/3 rate. The second lowest costs per ounce reduction of $25/oz to $38/oz for the two soils were attained by disk incorporating a spring application of atrazine. The highest costs per ounce reduction of $80/oz to $114/oz were attained by disk incorporation of two split ½-rate applications in the fall and spring. The other two strategies which included no-tillage practices increased atrazine losses over the conventional, non-incorporated strategy and therefore an enviro-economic tradeoff was not applicable.

ACKNOWLEDGEMENTS

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