MIDWEST STUDIES PROVIDE SOME ANSWERS

ATRAZINE

WATER QUALITY

MAY 1999

The MSEA Water Quality Projects

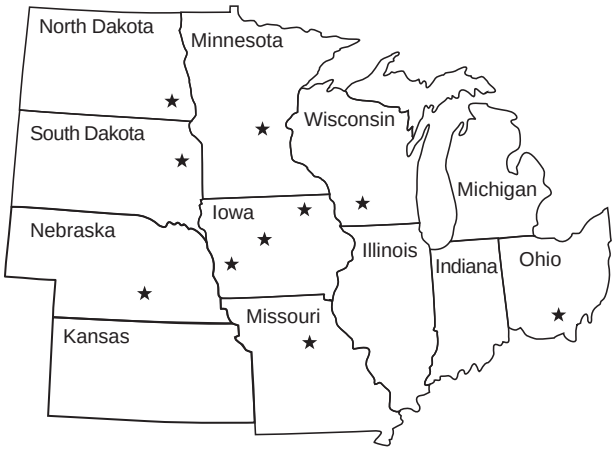
A Model for Protecting Water Quality through Successful Integration of Research and Education

Farmers in the Midwest produce approximately 80 percent of the nation's corn and soybean crops. The impact of practices to produce these crops, specifically the use of fertilizers and herbicides, has created concerns about the quality of our water resources. To address these concerns, the United States Department of Agriculture (USDA) initiated a comprehensive regional project in the Midwest to evaluate and develop profitable cropping systems to safeguard our water resources. The project study sites are known as Management Systems Evaluation Areas (MSEA).

The cornerstone of the MSEA program is the close integration of research and Extension education activities. This integration exists not only within each project, but also among the five states coordinating project efforts.

Ongoing research and educational programs among the projects continue to provide useful information to varied audiences, including farmers, the agricultural industry, local, state, and federal agencies, legislators, special interest groups, etc. Since the initiation of the regional MSEA projects in 1990, combined efforts have provided more than 700 educational programs, disseminating information to some 50,000 users annually. These activities have helped increase awareness, demonstrated new and improved technologies and strategies, and encouraged adoption of cropping practices to reduce agriculture's impact on the region's water resources. This publication provides an overview of MSEA research regarding atrazine and ground water.

Management Systems Evaluation Areas



The USDA initiated five MSEA projects to evaluate and develop profitable cropping systems to safeguard our water resources. The main study sites were established in Iowa, Minnesota, Missouri, Nebraska, and Ohio. The sites, shown above, located in North and South Dakota, and in Wisconsin are coordinated through the Minnesota project.

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Answers

- Leaching of atrazine to ground water does occur, but much less than was suggested by 1980s studies. MSEA research results indicate that atrazine was detected in the ground water at some sites, but almost all concentrations of atrazine were well below the established drinking water standard.

- Ground water is less vulnerable to atrazine contamination than surface water. Atrazine was found to mostly remain in the top 15 cm of soil in production areas until it is degraded.

- Atrazine appears to degrade faster in soils with a history of past use because populations of soil bacteria that help decompose atrazine have increased.

- Atrazine levels in surface waters are a major concern in certain locations. Concentrations of atrazine greater than 150 ppb were observed in surface waters at Walnut Creek, Iowa, in September 1991 and September 1994.

- Proper selection of farming practices can reduce the concentration of atrazine in both ground water and surface water.

- Research in the Northern Cornbelt Sand Plains has shown that, with careful management, sandy soils can be cropped while minimizing degradation to water resources.

- Atrazine seldom reached the water table in the ridge-tillage corn-soybean farming system that was common to many of the study sites.

- Herbicide banding, which reduces the amount applied from one-half to one-third the amount applied with broadcast application, can reduce leaching and decrease the potential for movement.

- Atrazine has the potential to move rapidly in low organic matter content sandy soils, especially when these soils are irrigated.

- Lower application rates reduce potential atrazine contamination. Of all of the management factors that affect herbicide concentration and losses, the total amount of atrazine applied is believed to have the most direct and often the greatest effect.

- Improved irrigation management can reduce potential atrazine contamination. Careful water management and special techniques such as split N applications and banding herbicides over the row can reduce leaching of certain agricultural pesticides and fertilizers.

Although atrazine was detected in the ground water at most MSEA sites, these concentrations were usually well below the maximum contaminant level (MCL).

Atrazine findings at the MSEA sites

Although atrazine was detected in the groundwater at most of the MSEA sites, these concentrations were almost always well below the maximum contaminant level (MCL). The MCL for atrazine, established by the Environmental Protection Agency (EPA), is 3 parts per billion (ppb) for atrazine.

Groundwater contamination from pesticides is a problem only in localized areas where soil conditions allow rapid transport to shallow groundwater. (See Table 1). However, atrazine levels in surface waters remain a concern in certain locations.

Installation of ground water monitoring wells.

INTRODUCTION

For the last 30 years in the Midwest, atrazine has been one of the most intensively used herbicides for pre-emergent and post-emergent weed control on corn and sorghum. Atrazine provides foliar and residual, broad-spectrum weed control, can be used with both conventional and conservation tillage systems, provides a high margin of crop safety, and is cheaper than most of its possible replacements.

Although atrazine has had numerous positive impacts on agricultural production, widespread atrazine use has had some adverse impacts. Most notably, atrazine has reached surface and ground water at some locations. Because many of these water resources are used for drinking water, atrazine is a concern.

Several studies in the early 1980s detected atrazine and other herbicides in ground water. Atrazine detections in ground water especially alarmed rural residents who rely on shallow private wells for domestic drinking water.

Concerns about atrazine contamination of ground water generated questions and prompted serious discussion in the agricultural, scientific, environmental, and regulatory communities. Questions were also raised about how farming practices might be changed to prevent atrazine contamination of ground water.

In response to these concerns and questions, the United States Department of Agriculture (USDA) created a network of research projects at sites throughout the Midwest called Management Systems Evaluation Areas (MSEA).

ATRAZINE FINDINGS AT THE MSEA SITES

Although atrazine was detected at all MSEA sites except in Ohio, which took more than 6,000 samples, the concentrations detected in ground water were far lower than anticipated. At most MSEA sites, atrazine concentrations were well below the MCL of 3ppb (see Figure 1). In Nebraska, atrazine concentrations exceeded the MCL in only 10 percent of the samples, and in Treynor, Iowa, in only 7 percent of the samples. Only three of the nine sites had more than 2 percent of their total number of samples with atrazine concentrations exceeding 1 ppb: Iowa's Deep Loess Research Station (13 percent of samples); Wisconsin Sand Plains (5 percent of samples); and Nebraska (69 percent of samples).

At the Nebraska site, the increased movement into the ground water compared to all other sites occurred mainly because of the combination of highly permeable material between the root zone and the shallow water table (12-15 ft. to water), and increased water movement driven by irrigation or heavy rainfall. The greatest increase in atrazine concentrations at the water table occurred when the soil profile was wet and 1 to 3 inches of rainfall occurred within a few days of atrazine application.

At the Deep Loess Research Station in Iowa, the primary transport methods for atrazine are runoff, and leaching through the soil profile to shallow ground water. The shallow ground water eventually emerges as local streamflow.

Atrazine movement in the medium-

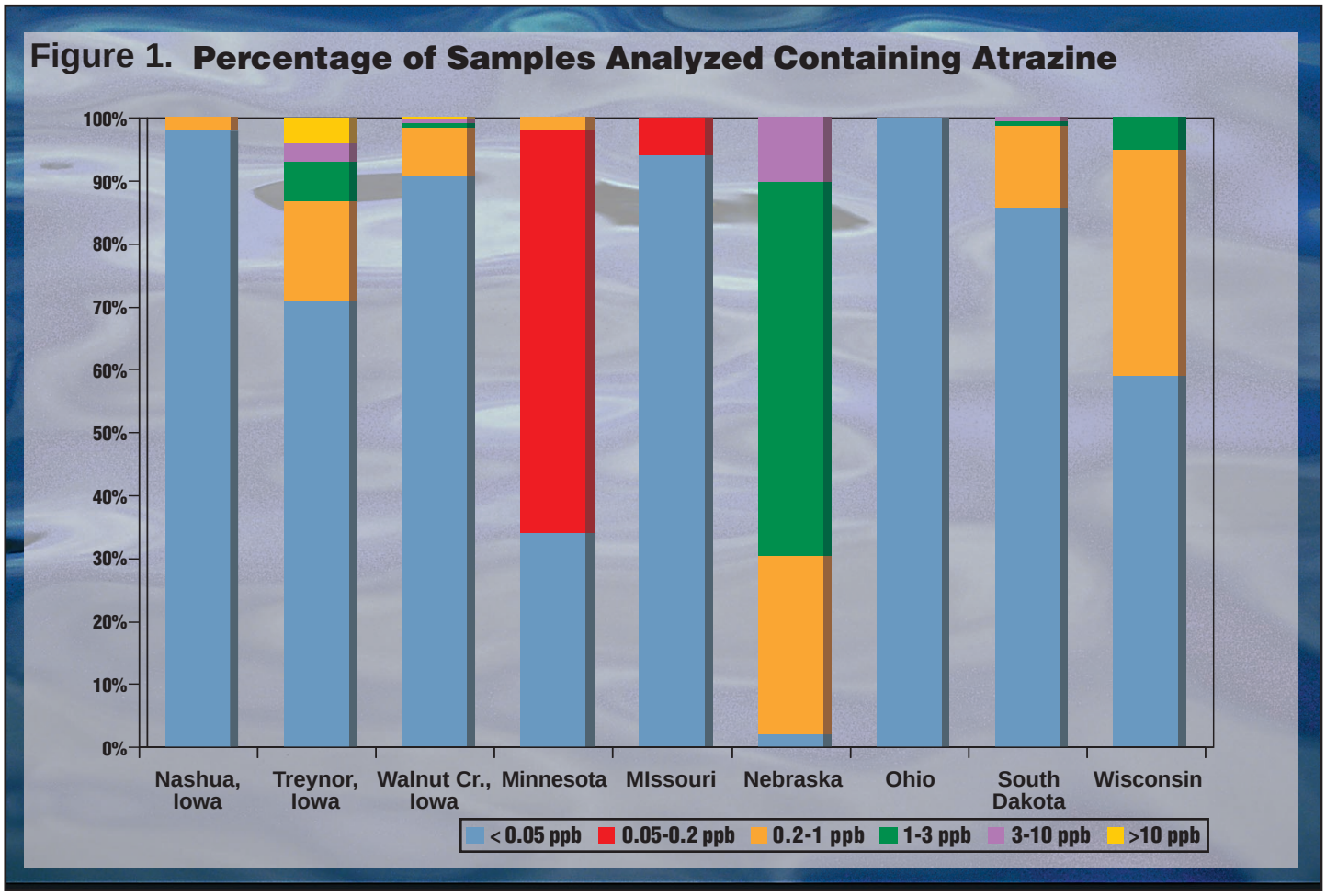
MSEA research indicates that most of the atrazine remains near the soil surface until it is either used or degraded. Atrazine did not accumulate over several growing seasons; soil organisms decomposed most of the atrazine within several months after application.

textured sands at the Wisconsin site is related to very rapid water movement through the soil profile and the soil's very low adsorption capacity. Despite this rapid water movement, atrazine was barely detectable in ground water 2 ft. below the water table.

At the Brookings, South Dakota site, the maximum concentration of atrazine (0.9 ppb) occurred one year after application, following early spring rains of more than 13 in. These conditions resulted in the aquifer water levels rising 6.5 ft. The exact route the atrazine followed to reach ground water at this site is not known. Leaching from the surface soil or the water table rising into the root zone were both likely causes.

Extensive soil sampling and analysis at most MSEA sites found that most of the applied atrazine remained near the soil surface, bound by the organic matter, until it was either degraded or used. Atrazine was found not to accumulate over several growing seasons, and soil organisms helped decompose most of the atrazine within several months after its application.

Sampling ground water from multi-level monitoring wells.



In contrast to the relatively rapid degradation of atrazine in the soil, degradation becomes extremely slow when atrazine enters the ground water.

Taking soil samples for ag-chemical determination.

Degradation, which is most prominent in the upper 1 ft. of the soil profile, occurs most easily in soils that bind atrazine to the organic carbon components and keep it near the soil surface until it is either used or degraded. Soils with low organic carbon (less than 2 percent) and clay (less than 20 percent) are more susceptible to atrazine leaching.

Research at the MSEA sites strongly suggests that atrazine was fairly immobile and mostly remained near the soil surface until it was degraded (broken down into metabolites). Soils with high levels of organic carbon in the topsoil (4-7 percent) and clay in the top 5 ft. of the profile (20-40 percent) help hold atrazine near the soil surface. Degradation was most rapid in areas with a long history of atrazine use prior to the MSEA research, which favored the establishment of microbes that help decompose atrazine.

Atrazine degraded rapidly at the MSEA sites. In Ohio, half of the atrazine dissipated in 35 days (i.e., a half-life of 35 days). In North and South Dakota, atrazine could be found in the top 6 in. of the soil for two weeks after application, and little atrazine moved beyond that depth.

At the Aurora, South Dakota site, more than 80 percent of the atrazine remained after 112 days. At this site, virtually no degradation occurred in samples taken below the topsoil (0 to 1 ft.). Once herbicides moved out of the topsoil, there was slower degradation, less binding to the soil, and a greater potential for movement to the aquifer.

At both the Goodwater Creek Watershed in Missouri and the Walnut Creek Watershed in Iowa, the most significant impact of atrazine on ground water quality is not from leaching the soil profile to ground water from fields, but runoff to surface waters. Runoff at these sites carries a high load of herbicides into streams from which it can enter floodplain sand and gravel aquifers recharged by the streams.

In contrast to the relatively rapid degradation of atrazine in the root zone in the soil above the water table, degradation becomes extremely slow when atrazine enters the ground water. Nebraska's studies showed that the half-life of atrazine in a shallow aquifer was 17-19 years.

ATRAZINE AND ITS METABOLITES

There is growing awareness that metabolites, products of the breakdown of atrazine, may also impact the nation's water resources. While many commonly used pesticides have established MCLs, few of the corresponding metabolites have had such levels determined. At some sites, detection of deethylatrazine (DEA), one of the metabolites of atrazine, was more common than the presence of the parent atrazine in both ground water and surface waters.

In both Missouri and Minnesota, atrazine metabolites were found in ground water samples at very low concentrations, but at slightly greater concentrations than atrazine itself. At the Wisconsin site, DEA was the main metabolite found; and it was found twice as frequently as atrazine. In Ohio, atrazine metabolites are just

Crop rotations, tillage, herbicide management, and irrigation all impact atrazine movement, and subsequently, loss of atrazine to ground water and/or surface waters. However, MSEA research indicates that the the level of impact varies from site to site.

beginning to be detected, at low concentrations, after five years of intensive research and ground water sampling.

SURFACE WATERS AT THE WALNUT CREEK AND GOODWATER CREEK WATERSHEDS

Because the MSEA program mandate was to specifically study chemical transport to ground water, surface water was not initially emphasized. However, surface water monitoring was included at the Iowa and Missouri sites since runoff was documented as an important pollutant transport route in the hydrology at these locations.

While atrazine has been detected in ground water at low concentrations throughout the Midwest, the reverse may be true for surface waters. Surface water is comprised of precipitation, runoff, and the natural and artificial components of baseflow, such as ground water discharge, lateral seepage, interflow, and artificial subsurface drainage. MSEA researchers are continuing to gather data about the effects of soil, climate, cropping system and management practices, and water management practices on surface water quality. While these findings will be reported in future MSEA studies, it is worth summarizing a few findings here.

At the Walnut Creek site in Iowa, atrazine loads calculated at several stream discharge sites showed that herbicide loss is affected by changing weather patterns. Stream flow is primarily a function of the subsurface drainage discharge within the watershed. Evapotranspiration and subsurface drainage account for more than 90-95 percent of the annual precipitation. Atrazine concentrations in subsurface drainage waters ranged from no detections to 0.5 ppb. Runoff occurs from a small number of fields in the Walnut Creek watershed and it contributes to less than 0.1 percent of the total loss of the atrazine applied.

Atrazine concentrations in Walnut Creek ranged from nearly 7 percent of the amount applied to fields in 1993, with the occurrence of multiple runoff events, to less than 0.2 percent in 1994, with no runoff events.

Concentrations greater than 150 ppb were observed in Walnut Creek in September of 1991 and 1994. These large concentrations were detected in water from a subsurface drainage outlet of an 875-acre watershed, and were believed to be related to the practice of cleaning field sprayers in preparation for winter storage and spraying the rinsate from the tanks on land areas above the subsurface drainage system.

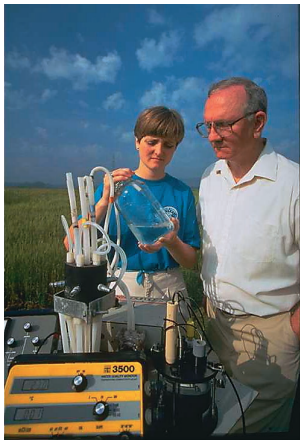
Atrazine in the runoff in the Walnut Creek Watershed could be reduced by using conservation tillage practices. For example, ridge-tilled fields have had no runoff with measurable atrazine losses since 1991.

For the claypan soils of Missouri's Goodwater Creek Watershed, atrazine contamination of surface water by runoff is a concern. These claypan soils contain a restrictive soil layer that limits water infiltration. While this inhibits leaching it increases runoff; with approximately 30 percent of the annual precipitation leaves the field as

Analysis at a water quality laboratory.

According to MSEA research, of all the management factors that affect herbicide concentration and losses, the total amount of atrazine applied is believed to have the most direct and often the greatest effect.

Extensive ground water sampling helps researchers understand the benfits of different farming systems.



Norman Fausey (right) of the USDA-ARS and Martha Jagucki of the USGS collect ground water samples.

runoff. During the spring and early summer following chemical application, atrazine concentrations in runoff have been from 30 to 100 ppb. From a no-till field, without soil incorporation of atrazine, peak concentrations have been observed to exceed 1,000 ppb. By late summer the atrazine concentration in the runoff is usually below 3 ppb. In this watershed, runoff accounts for 85 percent of the total streamflow.

To date, none of the changes in farming practices on the research and demonstration areas within the Goodwater Creek Watershed have reduced atrazine concentrations in runoff to near the drinking water standard. Reduction of these concentrations will require increased adoption of farming practices which use less herbicide or completely eliminate the potential for runoff during the critical two-month period of May to June.

EFFECT OF MANAGEMENT PRACTICES ON WATER MOVEMENT

Crop rotations, tillage, herbicide management and irrigation all impact atrazine movement, and subsequently, loss of atrazine to ground water and/or surface waters. However, MSEA research found that the level of this impact varied from site to site.

Crop Rotation

In Ohio, data collected in 1993 indicate that annual application (three years) of atrazine in the continuous corn management system resulted in an increase in atrazine-degrading microorganisms. Extensive laboratory analysis determined that atrazine was degraded much more quickly in the continuous corn system than the corn-soybean-wheat management system where it was applied every third year because, in the continuous corn system, populations of soil bacteria that helped decompose atrazine had increased.

Shallow ground water under a corn and soybean rotation was protected from atrazine degradation in the sandy soils of the Northern Cornbelt Sand Plains. This farming system used banded atrazine application over only one-third of the soil surface every year. The same did not hold for a continuous corn farming system where atrazine was broadcast over the entire soil surface, annually. Although average atrazine concentrations in ground water were very low (<0.2 ppb) atrazine's metabolite, deethylatrazine, often was detected in ground water, approaching 3 ppb occasionally.

Tillage

A primary benefit of no-till systems is erosion control. Infiltration of water into the soil usually increases, thus reducing runoff, which in turn reduces soil detachment and losses. Compared with conventional tillage, no-till reduces runoff but increases the likelihood of nitrate and herbicide leaching to ground water. However, research from the Missouri MSEA site has shown that the increased chance of leaching may not apply to all claypan soils.

In the ridge tillage corn-soybean farming system common to several of the study sites, atrazine seldom reached the water table. The exception was Wisconsin, where some atrazine

A combination of best management practices may help reduce herbicide leaching.

did reach the water table, but much less atrazine leached to ground water under the ridge-tillage system than in conventional and no-tillage systems.

The Missouri MSEA researchers compared conventional tillage with no-till and found that no-till systems provide many benefits on erodible soils, although mean annual runoff actually increased 18 percent over that from tillage practices that disturb the soil.

At the Nashua, Iowa site, losses via subsurface drainage systems were greater under the no-till and ridge tillage systems compared with the chisel and moldboard plow systems. Of the five different tillage systems studied at this site, banding decreased atrazine leaching relative to broadcast applications.

Amount of Atrazine Applied

Of all the management factors that affect herbicide concentration and losses, the total amount of atrazine applied is believed to have the most direct and often the greatest effect. The method and timing of herbicide application can also have major effects on concentrations and losses. Banding reduces the amount applied to one-third or one-half the amount applied with broadcast application.

However, of three Missouri MSEA experimental fields, the field which received the least atrazine had the most detections of atrazine and DEA in ground water. This suggests that variations in soil properties and hydrology are just as important for herbicide leaching as application rate.

Irrigation Management

Irrigation has great potential to increase the amount of water that moves through the soil profile. Atrazine, which does not bind strongly to sandy soils with low organic matter content, therefore has potential to move rapidly with the irrigation water on these soils. A combination of best management practices may help reduce herbicide leaching. For example, the combination of banding herbicide applications and proper irrigation management can reduce the amount of herbicide applied and reduce the potential for excessive water applications, thus reducing the potential for herbicide leaching.

Five of the nine MSEA sites (Minnesota, North Dakota, South Dakota, Wisconsin and Nebraska) used irrigation as part of their farming system.

At the Nebraska site in 1991, most ground water samples in the upper one-fourth of the aquifer had atrazine concentrations near 6 ppb. Improved irrigation management was in part responsible for concentrations being reduced to less than 2 ppb by 1995. Natural recharge during the extremely wet summer of 1995 also played a very important role in the reduction of concentrations. In the spring of 1996, a heavy rain within a day of herbicide application resulted in the leaching of atrazine, and a subsequent increase in atrazine concentration in the upper part of the aquifer. Clearly, even the best management on highly permeable soils will not totally eliminate the potential for herbicide leaching.

Minnesota's MSEA project studied three irrigated cropping systems on their permeable sand plain soils: ridge-tillage-corn-soybean rotation, full-width

Using nested wells to determine the quantity and quality of ground water.

Band-applied herbicide controls weeds in the row. Applying the herbicide in a band over the row can reduce the amount of herbicide applied to the field by two-thirds compared to broadcast application. Weeds between the rows are controlled with a cultivator.

Proper selection of farming practices such as timing and placement of herbicide application, tillage and crop rotation, and proper irrigation management can help reduce the concentration of atrazine in both ground water and surface waters.

tillage-continuous corn, and full-width tillage-potato-sweet corn rotation. Banded atrazine applications over the row were used on the ridge tillage system. In 1992-94, herbicides were applied broadcast at a rate of 1.5 lb. active ingredient per acre to continuous corn, and in a 6-inch band over the row at planting to sweet corn and rotation corn. Even in the permeable sandy soils, the result was only six detections in 1,000 water samples with concentrations between 0.05 to 0.09 ppb.

The Sparta sand at the Wisconsin site appears to have considerably better internal drainage than the Zimmerman fine sand in Minnesota, although both soils have small percentages of clay. The higher sand content of the Sparta soil, in association with its low clay and organic matter constituents, results in a greater potential for water movement and herbicide leaching. While all sandy soils need careful water management, Sparta sand is particularly sensitive to irrigation and requires special techniques (i.e., managed irrigation applications, split N applications, banding herbicides over the row) to minimize leaching of certain agricultural pesticides and fertilizers, and to supply sufficient water to meet crop needs.

Proper crop production practices can help reduce the risk of contamination of water resources by atrazine throughout the Midwest. However, practices that are effective in some areas may not be effective in others.

SUMMARY

Collectively, across the Corn Belt, MSEA researchers detected small amounts of atrazine moving to ground water. Movement of atrazine to the ground water was soil and water management specific. There was, however, one common factor: practices which reduced the amount of atrazine applied and provided careful water management further reduced the potential of atrazine movement to ground water.

The MSEA studies determined that atrazine can reach surface and ground water by several routes. Water movement through the soil profile to a depth below the root zone increases the chance of atrazine leaching to ground water, or being diverted to surface waters via artificial subsurface drainage.

Soil factors play a pivotal role in the way and amount of atrazine that can move to either surface water or ground water. Natural soil conditions which may help reduce the potential for agricultural chemical movement to ground water may actually increase the risk of surface water contamination by runoff and subsurface drainage flow from agricultural fields.

In general, sandy textured, low organic matter content soil materials transmit water more quickly and retain atrazine to a lesser extent than soils that contain more clay and organic matter. Soils which have poor natural drainage tend to have greater losses of atrazine in runoff and in subsurface drainage waters, if artificial drainage is present.

Although atrazine was found in lower concentrations in the aquifers studied than was expected, MSEA researchers detected atrazine in ground water more often than any other herbicide studied at these sites. These results occurred, in part, because of extensive use and the slow degradation of atrazine in deeper subsoils and in aquifers. Several studies in different MSEA research locations established that atrazine-degrading microorganisms are present in soil water systems, but their activity in ground water is limited. Because of this limited activity, changes in farming practices may not result in significant changes in ground water-atrazine concentrations for several years if it is already present.

Many aquifers used as drinking water supplies throughout the Midwest lie beneath glacial till deposits, making them less vulnerable to contamination than shallow alluvial aquifers. Rainfall patterns in the first weeks following herbicide application were important factors in the potential amount of atrazine that may be lost and the route of the loss at all sites.

Results of the MSEA studies led researchers to conclude:

- Leaching of atrazine to ground water can occur, but much less than was suggested by earlier studies.
- Ground water is less vulnerable to atrazine contamination than surface water.
- Atrazine levels in surface waters are a concern in certain locations.
- Proper selection of farming practices such as timing and placement of herbicide application, tillage and crop rotation, and irrigation management can reduce the concentration of atrazine in both ground water and surface waters.
- Lower application rates reduce potential atrazine contamination.
- Atrazine degrades faster in soils with a history of past use because populations of soil bacteria that help decompose atrazine have increased.

FUTURE DIRECTIONS

As a result of the MSEA investigations, a number of issues have emerged which have been identified as critical to addressing nonpoint source pollution, enhancing natural resources, and promoting a more sustainable agroecosystem. There are a number of research needs that have been identified which address these emerging issues:

- Further study of atrazine levels in surface waters.
- The study of atrazine metabolites in both surface and ground waters, and their significance.
- The lack of full understanding of the movement, degradation patterns, and environmental impact of postemergence and new generation herbicides that may replace atrazine.
- The full application of precision farming practices and their potential impact on environmental quality and transferability among locations.
- The role of buffer strips and other riparian systems in herbicide removal from shallow subsurface and surface water flows.
- The role and benefits of subsurface drainage water management to address herbicide and nitrate losses in drainage waters. For more information about subsurface drainage water management, see Bulletin 871, *Agricultural Drainage: Water Quality Impacts and Drainage Studies in the Midwest.*

This publication is available at: **http://ohioline.ag.ohio-state.edu/b871/.**

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