### • HERBICIDE FACTSHEET

# ATRAZINE: ENVIRONMENTAL CONTAMINATION AND ECOLOGICAL EFFECTS

Atrazine, one of the two most commonly used agricultural pesticides in the U.S., is a pervasive water contaminant. It is typically the most common pesticide found in rivers, streams, and groundwater. The U.S. Geological Survey's (USGS's) recent national monitoring study found atrazine in rivers and streams, as well as groundwater, in all 36 of the river basins that the agency studied. It is also often found in air and rain; USGS found that atrazine was detected in rain at nearly every location tested. Atrazine in air or rain can travel long distances from application sites.

In lakes and groundwater, atrazine and its breakdown products are persistent, and can persist for decades. In soils, it is also persistent. Half lives (the amount of time required for 50 percent the atrazine applied to disappear) can be over 100 days in surface layers of soils. Below the surface, atrazine can persist for years.

Low concentrations of atrazine cause a variety of adverse effects in fish, including reduced sperm production, disruptions of normal behavior, kidney damage, and decreased ability to withstand warm temperatures.

The hormone systems of both amphibians and alligators are disrupted by atrazine.

Atrazine causes genetic damage in a variety of plant species, including corn and sorghum (on which it is commonly used). Atrazine also stimulates fungi that cause plant diseases, including the common root rot *Fusarium*.

Atrazine can damage natural communities. For example, in a pond community, atrazine (at a concentration of 20 parts per billion) caused reductions in populations of aquatic plants, aquatic insects, and the fish that feed on them. Simulated drift of atrazine (at 8 percent of typical application rates) modified the abundance and dominance of winter annuals in a Pacific Northwest plant community and also reduced its productivity.

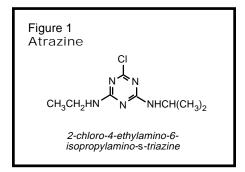
#### BY CAROLINE COX

The herbicide atrazine (Figure 1) is "one of the two most widely used agricultural pesticides in the U.S." according to the U.S. Environmental Protection Agency (EPA). It is primarily used on corn, sorghum, and sugar cane. This article summarizes research about its contamination of the environment and its ecological hazards; an earlier article discussed its toxicology (JPR 21(2):12-20). The first ten sections of this article discuss aquatic ecosystems, where atrazine is a pervasive contaminant. The last six sections, beginning on p.17, discuss terrestrial ecosystems.

## Contamination of Rivers and Streams

Atrazine frequently contaminates rivers and streams, according to the

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U.S. Geological Survey's (USGS's) National Water-Quality Assessment Program (NAWQA) begun in 1991. USGS has compiled data from the first 20 river basins studied by NAWQA and the summary paints a startling picture of atrazine contamination.<sup>2</sup> Atrazine was the most commonly detected pesticide in river basins from all three land uses studied (agricultural, urban, and mixed), and the atrazine breakdown product deethylatrazine was also commonly found. In agricultural basins, USGS found atrazine in about

two-thirds of the samples tested. In urban basins, USGS found atrazine in 70 percent of the samples. In major rivers with mixed land uses, USGS found atrazine in 80 percent of the samples. Concentrations were as high as 120 parts per billion (ppb) in agricultural basins, 14 ppb in urban basins, and 22 ppb in river basins with mixed land uses.<sup>2</sup> At both agricultural and mixed land use sites, concentrations were close to or exceeded the U.S. drinking water standard of 3 ppb in about 5 percent of the samples.<sup>3</sup>

For information about contamination of a particular river basin, the NAWQA web site is an excellent resource: http://water.usgs.gov/pubs/nawqasum.

NAWQA and other studies document important patterns in atrazine's contamination of rivers and streams:

• Atrazine contamination is not geographically restricted. It is common in the midwestern "Corn Belt" where use is widespread, but rivers and streams from all 36 basins that have been studied by NAWQA are contaminated.<sup>4</sup> (See Figure 2.) Contamination is common in locations as diverse as Oregon's Willamette Valley,<sup>5</sup> south-central Texas,<sup>6</sup> Denver, Colorado,<sup>7</sup> and New York's Hudson River.<sup>8</sup>

- Highest atrazine concentrations are found in rivers and streams when there is rain following spring atrazine applications to agricultural land. These pulses of atrazine can exceed the drinking water standard set by EPA and are not removed by conventional water treatment.9 For example, the cities of Lincoln and Omaha, Nebraska, draw their water from wells that are "hydraulically connected" (located near and using the same water) to the Platte River at Louisville, Nebraska. USGS found atrazine above EPA's drinking water standard in one third of the samples of river water from Louisville.<sup>10</sup>
- However, atrazine is often found year round, although concentrations are lower than they are during the spring.<sup>7,11</sup> Atrazine found during

- other seasons probably enters the river from contaminated groundwater. This contamination can originate at "some distance from the river." <sup>11</sup>
- Heavy rainfall and full streams lead to the highest pulse concentrations of atrazine, indicating that it is "a readily available constituent in the watershed that is being washed off in proportion to the amount of excess rainfall (runoff)."<sup>12</sup> Smaller rivers have larger and more abrupt pulses, while in large rivers, elevated concentrations can be spread out over several months.<sup>13</sup>
- There is not a simple relationship between atrazine use and levels found in rivers and streams. USGS scientists recently summarized atrazine loads in the Mississippi River between 1975 and 1997. While atrazine use in this basin declined during this period (from 38,000 to 25,000 tons), atrazine loads in the river did not decrease. <sup>14</sup> In smaller rivers and streams, however, and over a shorter time period (1989-1994), USGS found

- significant decreases in concentration even though use had declined only slightly. One possible explanation is that restrictions in atrazine use were implemented at this time.<sup>15</sup>
- Atrazine contamination of water is not restricted to areas downstream from where it is used. For example, British researchers who intensively studied a small watershed concluded that "atrazine was found at relatively high concentrations when it had not been applied to any of the fields draining to the sampling point."

# Contamination of Groundwater

Atrazine commonly contaminates groundwater. It has been found in the groundwater of all 36 river basins studied by USGS.<sup>4</sup> Atrazine was often the most common pesticide detected. Deethylatrazine, formed when atrazine breaks down, was also common. About one-third of the agricultural well samples were contaminated with atrazine in the first 20 basins studied, as were about 15 percent of the urban samples and 10 percent of the samples from mixed use basins.<sup>2</sup>

For results of USGS monitoring for a particular river basin, the NAWQA web site is an excellent resource: http://water.usgs.gov/pubs/nawqasum.

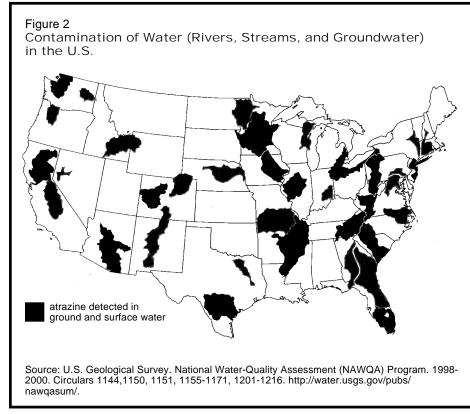
Important reasons for atrazine's presence in ground water are its widespread use and long persistence.<sup>17</sup>

Reducing atrazine use can reduce groundwater contamination. For example, atrazine use in Iowa declined by 12 percent between the mid-1980s and the early 1990s. Over the same interval, the frequency of atrazine-contaminated wells declined 14 percent.<sup>18</sup>

As with rivers and streams, atrazine has contaminated groundwater in areas where it has not used nearby. Researchers from Environment Canada studying prairie springs found atrazine when "it was not used anywhere in the vicinity of the aquifers." They suggest that transport in the atmosphere is the most likely source. <sup>19</sup>

#### Contamination of Rain

Atrazine is commonly found in rain. A USGS compilation of national, multistate, state, and local monitoring



The U.S. Geological Survey found atrazine in both surface water (rivers and streams) and in groundwater in all 36 river basins that the agency has studied.

studies showed that atrazine was found at nearly every site where rainfall was collected.<sup>20</sup> (See Figure 3.) In some cases, concentrations in rain are above drinking water standards.<sup>21</sup> The amount of atrazine deposited in rain can be large. For example, USGS calculates that the rain deposits 110,000 kilograms of atrazine in the Mississippi River basin every year, over one-third as much as is carried annually by the river.<sup>22</sup> Rain also can be a significant source of atrazine in the ocean: University of South Carolina researchers calculated that a two or three day rainstorm deposited atrazine along the South Carolina coast equal to 10 percent of the amount deposited annually by rivers.<sup>23</sup> Rain can carry atrazine long distances; for example, atrazine is deposited in rain in the remote Isle Royale National Park in Lake Superior.<sup>24</sup> Atrazine has also been found in fog in California.<sup>25</sup>

# Persistence in Lakes and Ponds

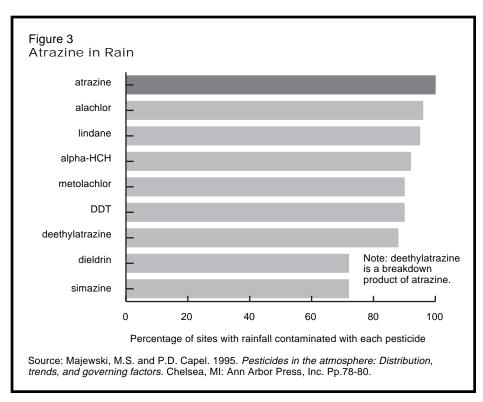
According to EPA, atrazine "should be somewhat persistent" <sup>26</sup> in lakes or

other water bodies with still water. In fact "somewhat persistent" may be an understatement. For example, USGS scientists estimate that persistence in deep lakes "may exceed 10 years" 24 and calculated that breakdown of atrazine in Lake Superior is "very slow (about 1 percent per year)."27 Swiss scientists came to similar conclusions after studying a group of lakes: a small amount of atrazine degraded during the summer, otherwise the only losses of atrazine were by flushing. In 1989, Switzerland instituted "drastic application restrictions" for atrazine, but the amount of atrazine in the lakes did not decrease through 1994.28

Persistence in ponds is less, but still significant. German researchers found, for example, that the atrazine concentration in experimental ponds in April was over half what it had been the previous September, immediately after addition of atrazine.<sup>29</sup>

#### Persistence in Groundwater

Atrazine is persistent in groundwater. For example, in a laboratory study,



The USGS compiled national, multistate, state, and local studies of pesticide contamination of rain. Atrazine was the most common pesticide the agency detected and was found at almost every site.

the half life for atrazine in ground-water sediments was almost 6 years<sup>30</sup> and a two month study "did not show a significant decrease"<sup>31</sup> in atrazine concentrations. In Delaware, USGS researchers estimated that the atrazine breakdown product deethylatrazine persisted for 25 years.<sup>32</sup>

### Effects on Fish

In laboratory studies, atrazine has a wide variety of effects on hormone systems. (See JPR 21(2):14-15.) Such effects can also occur in fish. For example, the startlingly low concentration of 0.04 ppb reduced the release of a sex hormone from testes cells in Atlantic salmon and reduced their milt (sperm) production by about 50 percent, according to a study by British fisheries biologists.<sup>33</sup> (See Figure 4.)

A USGS study of fish from 11 river basins nationwide had similar results.<sup>34</sup> The researchers found a striking relationship between pesticide contamination of river water and the ratio of the "female" sex hormone to the "male" sex hormone in fish. (Quotes indicate that both hormones are found in animals of both genders.) In female fish, levels of a "female" hormone are normally 4 times higher than levels of a "male" hormone, but this ratio declined at higher pesticide concentrations. At the highest pesticide concentrations (2.9 ppb), amounts of the two hormones were equal, as is typical for male fish from uncontaminated water. The steepest decline in the hormone ratio occurred at concentrations less than 1 ppb. USGS says that data are "not sufficient to determine which specific pesticides or groups of pesticides could be responsible."34 However, atrazine appears to be important. For example, in the Platte River at Louisville, Nebraska, the site with the highest dissolved pesticide concentrations, atrazine was found in every sample, with peaks above 20 ppb.<sup>35</sup>

Effects on fish behavior have been observed when they are exposed to extremely low concentrations of atrazine. At a concentration of 0.5 ppb, the behavior of goldfish was affected: researchers observed more "burst swimming," a sudden spurt of non-directed movement, followed by

immobilization of the fish. Burst swimming is a part of the normal alarm reaction of goldfish, but when this behavior occurs frequently, it "can increase the vulnerability of fish to predation."<sup>36</sup> At a concentration of 1 ppb, reproductive behaviors are disrupted. Male salmon normally respond to the smell of urine from female salmon that have recently laid eggs. However, atrazine (1 ppb) reduces this response.<sup>37</sup>

At slightly higher concentrations, other effects occur. Stress (measured by an increase in blood protein) occurred in rainbow trout at a concentration of 3 ppb.<sup>38</sup> At 5 ppb, Goldfishes' grouping behavior decreased,<sup>36</sup> swimming behavior of zebrafish was altered,<sup>39</sup> and kidney damage occurred in rainbow trout.<sup>40</sup> At 10 ppb, the ability of shiners to withstand warm temperatures decreased<sup>41</sup> and trout kidneys were damaged.<sup>42</sup>

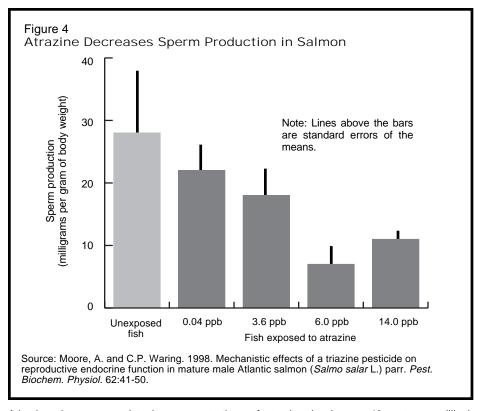
Significant effects on reproduction of fish can occur at slightly higher atrazine concentrations. The number of offspring produced by bluegill sunfish was over 90 percent less in ponds treated with 20 ppb of an atrazine herbicide than in untreated ponds. The small number of offspring produced was related to the lack of prey for the bluegills. Atrazine killed the aquatic plants in the ponds, and greatly reduced the number of insects available as food. Bluegill in the treated ponds had less than 20 percent as much prey in their stomachs as did fish in untreated ponds. The numbers of mayflies, dragonflies, and beetles were particularly reduced. (20 ppb was the lowest concentration tested in this study.)43 A similar experiment, lasting three years instead of four months, had similar results.44

#### Effects on Snails

Researchers from the University of Barcelona showed that freshwater snails searched for algae at a higher speed in streams treated with 15 ppb atrazine than they did in untreated streams. The snails in treated streams also had different searching patterns.<sup>45</sup>

### Effects on Amphibians

Two studies have documented effects of atrazine on amphibians at rela-



Atlantic salmon exposed to low concentrations of atrazine (as low as 40 parts per trillion) produced less sperm than unexposed fish. Researchers initiated sperm production by exposing the fish to urine from female fish who had been laying eggs.

tively low concentrations. A study conducted by scientists at the University of Mississippi found that concentrations of 20 ppb increased mortality of tadpoles of the frog *Hyla chrysoscelis*. A USGS study of larval tiger salamanders found that 75 ppb of atrazine caused blood levels of one growth hormone (thyroxine) to rise and another (corticosterone) to decrease. The result was to slow down the salamanders' metamorphosis. 47

### Effects on Alligators

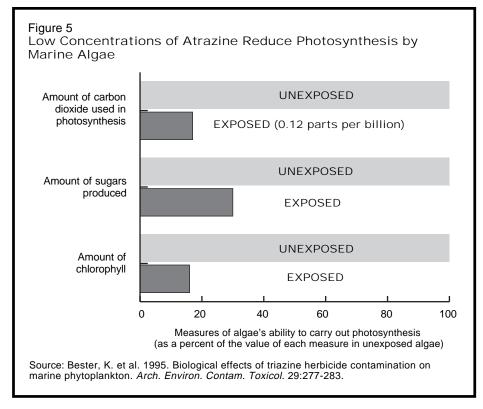
Intensive studies over the last decade have evaluated the effects of hormone-disrupting pollutants on Florida alligators. Atrazine, because it is a frequent water contaminant was included in some of these studies. Led by a zoologist from the University of Florida, these studies showed that atrazine inhibited activity of two hormones, one related to estrogen and one related to progesterone, in female alligator oviduct. In addition, atrazine increased the activity of an enzyme that con-

verts "male" sex hormones into "female" ones. The activity of this enzyme in male hatchlings from eggs treated with atrazine was intermediate between that typically found in males and that typically found in females.<sup>49</sup>

# Effects on Aquatic Arthropods

Concentrations of 20 ppb caused dramatic declines in the abundance and diversity of plant-eating insects in experimental ponds in a study conducted at the University of Kansas. The number of adult insects emerging from the treated ponds was almost 90 percent less than emergence in untreated ponds, and diversity was almost 60 percent less.<sup>50</sup>

Much lower concentrations (0.1 and 1.0 ppb) caused declines in the population of water fleas in experiments conducted at a lake in northern Germany. In enclosures treated with atrazine, the populations of water fleas were less than 1/10 of the populations in untreated enclosures.<sup>51</sup> In an-



Exposure of North Sea algae to extremely low concentrations (0.12 ppb) of atrazine caused a decrease in the ability of the algae to photosynthesize. Triazine herbicides are typically found in the German Bight, part of the North Sea, at this concentration.

other experiment with water fleas, concentrations of 5 ppb during development skewed the sex ratio so that more males than expected were born.<sup>52</sup>

#### Effects on Algae

An expert panel convened by Ciba Crop Protection, atrazine's major U.S. manufacturer, to look at ecological risks of atrazine concluded that algae were "the most sensitive organisms" but recovered quickly or reestablished so that "ecologically important" effects required concentrations above 50 ppb. 53 However, a variety of studies have documented effects well below 50 ppb. Examples include the following:

- German scientists measured reductions in photosynthesis and productivity of marine algae at 120 parts per *trillion* (0.12 ppb), a concentration at which triazines are often found in the North Sea.<sup>54</sup> (See Figure 5.)
- French scientists found that 2 ppb of atrazine changed the abundance of the dominant algae species in experimental ponds.<sup>55</sup> This team of re-

- searchers also showed that 10 ppb inhibited the growth of the bluegreen algae in the spring but stimulated growth during the summer.<sup>56</sup>
- British and Belgian biologists found that concentrations of atrazine above 3 ppb reduced chlorophyll levels in algae in experimental streams and concentrations above 11 ppb reduced the amount of algae.<sup>57</sup>
- German scientists measured almost a 25 percent reduction in photosynthesis in a freshwater green algae exposed to 12 ppb of atrazine.<sup>58</sup>
- Biologists from the University of Nebraska found that 12 ppb of atrazine reduced the amount of algae in experimental streams.<sup>59</sup>
- A study conducted by EPA researchers in experimental Minnesota wetlands found that algae exposed to 15 ppb were less productive than algae is untreated wetlands. This decrease in productivity led to a decrease in the amount of nutrients taken up by the algae.<sup>60</sup>
- Another team of German scientists

showed that 20 ppb of atrazine reduced the abundance of algae in experimental ponds.<sup>61</sup>

All of these studies take on increased significance because of other studies which document the conditions under which atrazine is most toxic to algae. One such study was conducted by scientists from the University of Nebraska and the U.S. Fish and Wildlife Service. The study showed that a species of algae from the Platte River (Nebraska) exposed to chronic atrazine contamination at low levels (1 ppb) was more susceptible than unexposed algae to pulses of higher concentrations such as commonly occur in the spring and early summer. The researchers commented on the "important environmental implications" of these findings because their exposure scenarios mimicked those found in the Platte River. 62 A second study (by the French researchers mentioned above) showed that algae communities are most sensitive to atrazine in the early summer. 63 A third study (by researchers at Western Illinois University) found that low concentrations of the insecticide malathion increased the toxicity of atrazine to algae.64 Malathion is one of the most frequently detected insecticides in rivers and streams.2

#### Effects on Aquatic Plants

The Ciba expert panel mentioned above also considered the effect of atrazine on aquatic plants and concluded "atrazine concentrations of 20  $\mu$ g/L [ppb] result in little or no adverse effects on the function of aquatic plant communities." However, a variety of studies have documented effects at or below 20 ppb. Examples include the following:

- Researchers from the University of Ulm (Germany) showed that 2 ppb of atrazine decreased photosynthesis of a water moss to about 10 percent of that in unexposed plants.<sup>65</sup>
- A biologist from the University of Sydney (Australia) found that 10 ppb of atrazine caused a decrease in photosynthesis of a seagrass.<sup>66</sup>
- Smithsonian Institution scientists measured 50 percent mortality and reduced reproduction of wild celery exposed to 12 ppb of atrazine.<sup>67</sup>

 Researchers from the University of Kansas showed that concentrations of 20 ppb reduced the growth and abundance of aquatic plants in experimental ponds.<sup>44</sup>

# Effects on Aquatic Ecosystems

The effects on individual species summarized above can have special impacts on entire aquatic communities. For example, in the study of water fleas (see pp. 15-16), researchers found that populations declined after treatment with very low concentrations of atrazine (0.1 and 1.0 ppb), only when the entire community was studied. The population decline was caused because the water fleas did not have enough food to produce eggs. However, tests with the water flea alone, or with the water flea together with an algae that is an important food source, showed effects only at much higher concentrations. Including competitors and predators is a likely reason for the increased sensitivity of the experiment with natural communities.<sup>51</sup>

Similar complex interactions were found in a University of Kansas experiment that used experimental ponds to mimic natural communities. Decreases in aquatic plants led to decreases in the insects and tadpoles that use the plants for food and shelter, and then to decreases in the number of fish which feed on the insects. The authors of the study concluded that "a whole ecosystem can produce or experience effects of the chemical, or lack of effects, that are difficult to identify when only a portion of the ecosystem is used for the assessment."<sup>44</sup>

### Contamination of Air

Atrazine is often found in air. Monitoring studies have found atrazine in air both near areas where the herbicide has been used in corn or sorghum production<sup>68-71</sup> as well as in areas distant from atrazine use. Examples of remote locations where atrazine has contaminated air samples include the Bering Sea<sup>72</sup> and the southern shore of Lake Superior.<sup>71</sup> (See Figure 6.)

#### Persistence in Soil

The results of field studies measur-

ing atrazine's half-life vary widely as is the case with many pesticides. (The half-life is the time taken for 50 percent of the atrazine applied to disappear, including leaching, runoff, break down, and vaporization.) The shortest half-life in one compilation by the U.S. Department of Agriculture (USDA) is 13 days, and the longest is 173 days.<sup>73</sup> Another USDA compilation for just the north central U.S. reviews studies with half-lives between 14 and 109 days.<sup>74</sup>

These relatively long half-lives mean that significant amounts of atrazine persist for more than a year. For example, French scientists intensively studied the fate of atrazine in the upper meter of soil in a corn field on an experimental farm, with applications rates approximately 1 kilogram per hectare (0.9 pounds/acre). They found that about 40 percent persisted from one year until the next. To USDA researchers found that residues of atrazine persisted for two years after treatment in an Iowa corn-soybean farm.

In certain types of soils, atrazine can be particularly persistent. Danish researchers found that soil from a freshwater wetland was unable to completely break down atrazine.<sup>77</sup> Because of atrazine's long persistence in wetlands, USDA and Clemson University scientists calculated that a wetland buffer would have to be at least 100 meters (325 feet) wide in order to mitigate atrazine-contaminated runoff.<sup>78</sup>

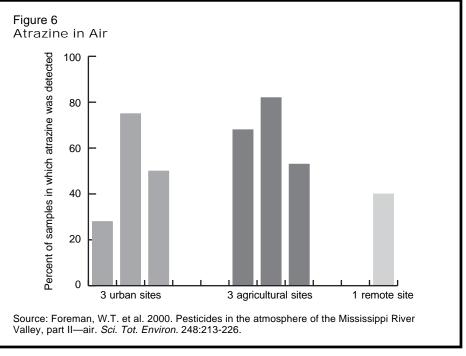
Subsurface soils break down atrazine only slowly: For example, atrazine persisted almost 3 years in soil 150 cm (5 ft.) below the surface of a University of Arkansas experimental farm.<sup>79</sup> Subsoil beneath an industrial area where atrazine had been applied for 20 years leached atrazine 8 years after the last application was made.<sup>80</sup>

#### Effects on Earthworms

A study conducted by researchers from a Hungarian university showed that earthworms living in soil treated with an atrazine herbicide grew more slowly and reproduced less than earthworms living in untreated soil.<sup>81</sup>

#### Effects on Insects

As an herbicide, it is perhaps surprising that atrazine has adverse effects on insects. However, atrazine can cause genetic damage in insects, kill beneficial insects, and increase the



A study of air along the Mississippi River found atrazine contamination was widespread; it occurred in both urban and rural air as well as in air from a remote site near Lake Superior.

potency of insecticides.

- **Genetic damage:** According to studies conducted at Berhampur University (India) and Western Illinois University, atrazine, both alone<sup>82</sup> and in a commercial product,<sup>83</sup> caused sexlinked lethal mutations in fruitflies.
- Beneficial insects: Insects that kill agricultural pests are often called beneficial insects. Atrazine herbicides can kill some species of these insects. For example, the International Organization for Biological Control found that the atrazine herbicide Gesaprim 50 caused over 99 percent mortality of a predatory beetle and over 50 percent mortality of both a parasitoid wasp and a predatory fly. In the field portion of this study, only mites, a relative of insects and spiders, were tested, but the atrazine herbicide caused over 50 percent mortality of one of the two predatory species tested.<sup>84</sup> Another study found effects on soil insects in an experimental corn field after atrazine treatment. Populations of springtails, immature beetles, and immature flies were reduced over 50 percent four months after treatment.85
- **Synergy:** Synergy occurs when the potency of two compounds mixed together is greater than the sum of their individual potencies. Atrazine synergistically increases the toxicity of insecticides in the organophosphate chemical family, including malathion, methyl parathion, and chlorpyrifos, as well as DDT, a notorious chlorinated hydrocarbon. <sup>86,87</sup> (See Figure 7.) Atrazine and insecticides are frequently found together in urban streams. <sup>88</sup>

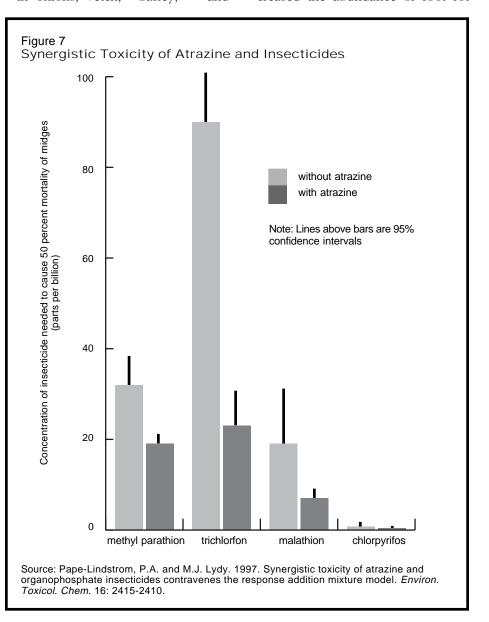
### Effects on Terrestrial Plants

As an herbicide, by definition atrazine is acutely toxic to most plants. However, atrazine also has other kinds of important effects on plants including the ability to cause genetic damage and the ability to stimulate disease-causing fungi.

 Genetic damage: Some of the early research done concerning atrazine's ability to cause genetic damage was done with sorghum, a crop on which atrazine is often used. Two studies done at Kansas State University showed that atrazine, applied at typical agricultural rates, caused chromosome abnormalities. Researchers from the University of Illinois and Hope College (Illinois) found similar results in experiments with corn: applications of a commercial atrazine product at a typical agricultural rate doubled the frequency of a mutation in pollen grains. Laboratory studies have shown that atrazine also can cause genetic damage in onions, vetch, barley, b

Tradescantia (spiderwort).95

• **Diseases:** Research showing that atrazine can stimulate disease-causing fungi dates from the 1960s and 1970s. Researchers from Auburn University showed that concentrations of atrazine about two times what would be expected under typical rates of use stimulated the growth of *Sclerotium rolfsii*, a "destructive" fungi that parasitizes plant roots. 6 Researchers from Michigan State University showed that atrazine increased the abundance of root rot



Atrazine increases the toxicity (lowers the lethal concentration) of common insecticides to a midge, *Chironomus tetans*, that is an important part of aquatic food webs.

(*Fusarium*) in soil. Concentrations of 5 parts per million (ppm), about what would be expected under typical application rates, caused approximately a 2.5-fold increase in the number of root rot spores. A field study had similar results. Presearchers at Pennsylvania State University showed that atrazine treatment (1 and 5 ppm) of a corn variety that is resistant to maize dwarf mosaic virus increased the susceptibility of the corn to the virus.

# Development of Atrazine Resistance

Several weeds have developed resistance to atrazine; that is, they are not killed by amounts of atrazine that would normally cause mortality. For example, atrazine-resistant strains of the weeds *Chenopodium* and *Amaranthus* were collected from corn fields that had been treated with atrazine for 12 years. <sup>99</sup> Rigid ryegrass developed resistance to atrazine after 5 seasons of use. <sup>100</sup>

# Effects on Natural Plant Communities (Terrestrial)

Like all pesticides, if atrazine drifts from the application site, it can impact surrounding areas. An EPA study looked at the effects of airborne atrazine at fractions (8 and 16 percent) of the amounts applied in agriculture in order to document some of these impacts. The study found that atrazine modified the abundance of certain species in a community of Pacific Northwest plants that were winter annuals. The most dominant species was replaced and the community overall was simplified. Community productivity, the amount of plant material produced, decreased. 101 \*

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