● HERBICIDE FACTSHEET

TRICLOPYR

Triclopyr is a broadleaf herbicide used primarily on pastures, woodlands, and rights of way. Garlon 3A and Garlon 4 are brand names of common triclopyr herbicides. Two forms of triclopyr are used as herbicides: the triethylamine salt (found in Garlon 3A) and the butoxyethyl ester (found in Garlon 4) .

The amine salt of triclopyr is corrosive to eyes. Both the amine salt and the ester are sensitizers and can cause allergic skin reactions.

In laboratory tests, triclopyr caused an increase in the incidence of breast cancer as well as an increase in a type of genetic damage called dominant lethal mutations. Triclopyr also is damaging to kidneys and has caused a variety of reproductive problems.

The ester form of triclopyr is highly toxic to fish and inhibits behaviors in frogs that help them avoid predators. Feeding triclopyr to birds decreases the survival of their nestlings.

Triclopyr inhibits the growth of mycorrhizal fungi, beneficial fungi that increase plants' ability to take up nutrients. Triclopyr also interferes with one step in the process by which atmospheric nitrogen is transformed by microorganisms into a form that is usable by plants.

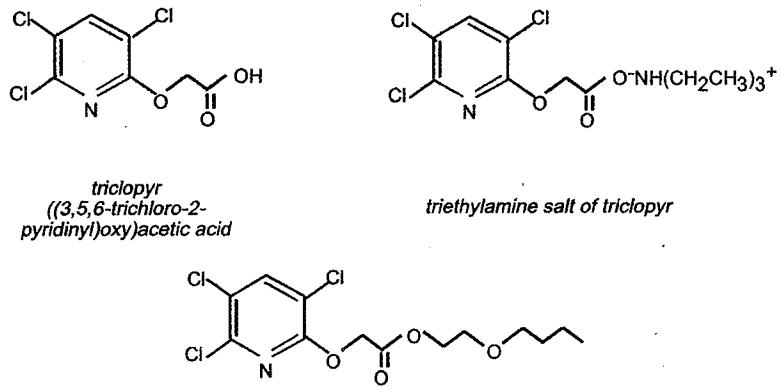
Triclopyr is mobile in soil and has contaminated wells, streams, and rivers. Contaminated water has been found near areas where triclopyr is used in agriculture, in forestry, on urban landscapes, and on golf courses.

The major breakdown product of triclopyr (3,5,6-trichloro-2-pyridinol) disrupts the normal growth and development of the nervous system. In laboratory tests, it also accumulates in fetal brains when pregnant animals are exposed.

BY CAROLINE COX

Triclopyr is a selective herbicide used to kill unwanted broadleaf plants. Triclopyr herbicides contain one of two forms of triclopyr, either the triethylamine salt or the butoxyethyl ester. (See Figure 1.) Triclopyr was first registered as a pesticide in the U.S. in 1979 and its major manufacturer is Dow AgroSciences.[1] It is sold under a variety of trade names, including Garlon 3A,[2] Garlon 4,[3] Pathfinder,[4] Remedy,[5] Turflon,[6] and (in Canada) Release.[7] Garlon 3A contains the triethylamine salt, the others contain the butoxyethyl ester.[2-7] Triclopyr is in the carboxylic acid chemical family.[8]

Figure 1
Triclopyr, Its Triethylamine Salt, and Its Butoxyethyl Ester



Use

According to estimates from the U.S. Environmental Protection Agency (EPA), use of triclopyr in the U.S. totals almost 700,000 pounds per year.[9] Pastures, woodlands, and rights of way account for almost three-quarters of this use while rice is the major agricultural use.[9] An estimated 455,000 applications are made annually to U.S. lawns and yards.[10]

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How Does Triclopyr Kill Plants?

Triclopyr imitates a plant hormone called indoleacetic acid, one of a number of plant hormones classified as auxins. Triclopyr causes the growing tips of the plant to elongate, followed by distortion, withering, and the death of the plant.[8]

Triclopyr is selective (most toxic to broadleaf plants) because grasses are quickly able to transform triclopyr into compounds that do not have hormonal activity.[11]

"Inert" Ingredients in Triclopyr-Containing Products

According to U.S. pesticide law, any ingredients in triclopyr herbicides other than triclopyr are called "inert."[12] Except for acute toxicity testing, all toxicology tests required for registration as a pesticide were conducted with triclopyr, not the combination of ingredients found in commercial products.[13] "Inert" ingredients used in triclopyr herbicides include the amine salt of dodecylbenzenesulfonic acid[14], ethanol,[2] ethylenediamine tetraacetic acid,[2] a petroleum solvent[14] containing kerosene,[3,5-7] polyglycol,[15] ethoxylated sorbitan monooleate,[14] and triethylamine.[2] See "Hazards of Inerts in Triclopyr Products," right, for more information.

Acute Toxicity

Symptoms of short-term exposure to triclopyr include lethargy incoordination, weakness, difficult breathing, and tremors. Anorexia and diarrhea have also been observed in animals exposed to triclopyr.[16]

EPA classifies the triethylamine salt of triclopyr in the agency's highest acute toxicity category for eye irritation. It is "corrosive" to eyes with damage lasting over three weeks. Both the amine salt and the butoxyethyl ester sensitize skin,[17] so that subsequent exposures cause greater allergic reactions than the first exposure.[18]

Subchronic Toxicity

In a subchronic (medium-term, 3 month) laboratory feeding study with rats, triclopyr caused kidney damage (degeneration of tubules). This damage was observed at doses of 20 milligrams per kilogram (mg/kg) of body weight per day.[19]

There are no publicly available subchronic toxicity studies of commercial triclopyr-containing products.

Chronic Toxicity

In a chronic (long-term) laboratory feeding study, rats fed triclopyr developed kidney damage more often than unexposed rats. In a long-term study using dogs, the animals which were fed triclopyr gained less weight, had less hemoglobin (oxygen-carrying molecules) and red blood cells in their blood, and had more microscopic liver damage than did unexposed dogs. These symptoms were observed at doses of 25 mg/kg per day in the rat study and 20 mg/kg per day in the dog study.[20]

A dog study which showed kidney effects at a tenfold lower dose (2.5 mg/kg per day) was originally used by EPA to calculate acceptable exposure to triclopyr.[21] However, this calculation was criticized by triclopyr's manufacturer because of studies the company conducted showing that triclopyr is more slowly excreted by dogs than other animals, and that the dog kidney is more susceptible than the kidney of other animals.[22,23] As a result, EPA classified the kidney damage as "not a toxic response to the test chemical, but a physiologic response of

HAZARDS OF INERTS IN TRICLOPYR PRODUCTS

Health hazards of inerts used in triclopyr herbicides include the following:

Ethoxylated sorbitan monooleate has caused a drop in blood pressure in dogs given the compound for research purposes. It also has caused adrenal gland tumors in laboratory tests of male rats.[1]

Ethylenediamine tetraacetic acid causes eye and skin irritation and is also irritating to the upper respiratory tract.[2] In laboratory tests with rats, it caused a variety of birth defects: cleft palate, eye defects, and abnormal skeletons.[3]

Kerosene causes severe eye irritation and is also irritating to the upper respiratory tract. Inhalation of kerosene causes fatigue, headache, dizziness, and incoordination.[4] Other symptoms include euphoria, a burning sensation, disorientation, and drowsiness.[5]

Petroleum solvent (with Chemical Abstracts Service registry number 64742-48-9) is damaging to kidneys and to the nervous system. These effects have been demonstrated in both exposed workers and laboratory tests. Some neurological effects are long-lasting or irreversible.[6]

Triethylamine is damaging to eyes and can cause abnormal vision[7] and irreversible damage.[8] It is extremely destructive to skin and the upper respiratory tract. Symptoms of exposure include coughing, wheezing, headache, and nausea.[8]

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3. National Library of Medicine. Hazardous Substance Data Bank. 2000. Ethylenediamine tetraacetic acid. http://toxnet.nlm.nih.gov. Retrieved Nov. 13.
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5. National Library of Medicine. Hazardous Substances Data Bank. 2000. Kerosene. http://toxnet.nlm.nih.gov. Retrieved Nov. 13.
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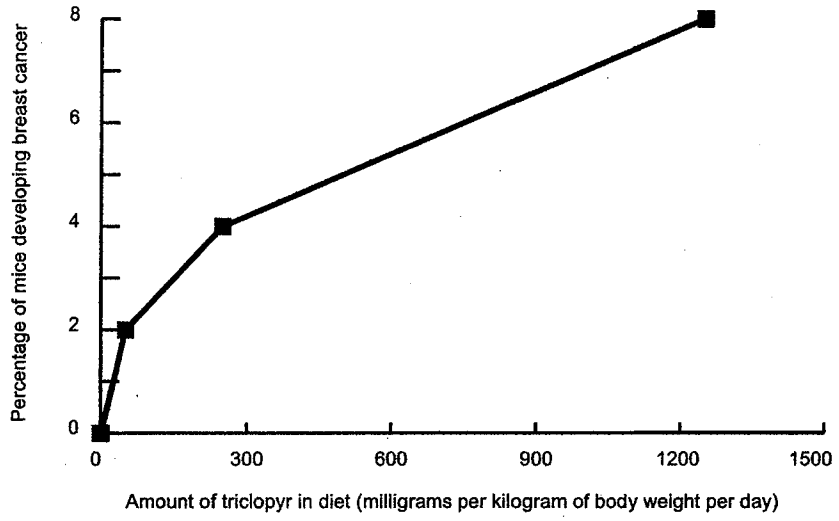
Figure 2
Triclopyr and Breast Cancer



Source: U.S. EPA. Office of Prevention, Pesticides, and Toxic Substances. 1996. Carcinogenicity peer review of triclopyr. Memo from McMahon, T.F., and E. Rinde, Health Effects Div., to R. Taylor, Registration Div. and T. Luminello, Special Review and Reregistration Div. Washington, D.C., May 9.

In laboratory studies with both mice and rats, triclopyr caused a significant increase in the incidence of breast cancer. However, EPA's evaluation of these studies concluded that it was not possible to classify triclopyr's ability to cause cancer.

the dog"[24] and did not use the results in its more recent evaluation of triclopyr.[24]

There are no publicly available chronic toxicity studies of commercial triclopyr-containing products.

Mutagenicity

Triclopyr's mutagenicity (ability to cause genetic damage) has been studied in a variety of laboratory tests. One study looked at triclopyr's ability to cause dominant lethal mutations in rat embryos. Dominant lethal mutations are mutations in sperm that cause the death of the embryo fertilized by the defective sperm, and are studied by counting the number of dead embryos in pregnant animals. In a study of female rats mated with males who had been dosed with triclopyr, the frequency of embryo loss increased at the middle and high dose (7 and 70 mg/kg).[25]

In seven studies of other kinds of genetic damage that were submitted by triclopyr's manufacturer in support of its registration as a pesticide, no mutagenicity was observed.[25]

There are no publicly available mutagenicity studies of commercial triclopyr-containing products.

Carcinogenicity

Triclopyr's carcinogenicity (ability to cause cancer) has been studied in rats and mice. In both species, feeding of triclopyr significantly increased the frequency of breast cancer (mammary adenocarcinomas).[26] (See Figure 2.)

In EPA's evaluation of these studies, the agency called this carcinogenic response "marginal."[26] EPA therefore classified triclopyr as a Group D carcinogen, one that is "not classifiable as to human carcinogenicity,"[26] even though EPA's guidelines call for classifying pesticides as carcinogens if they cause cancer in laboratory tests of more than one species.[27]

In male rats, triclopyr caused an increase in the frequency of adrenal tumors.[26]

There are no publicly available carcinogenicity studies of commercial triclopyr-containing products.

Effects on Reproduction

Triclopyr, its triethylamine salt, and its butoxyethyl ester have all caused reproductive problems in laboratory tests. Rats fed triclopyr for two generations had smaller litters and smaller offspring than did unexposed rats. Pregnant rats fed the amine salt had offspring that weighed less and had more skeletal abnormalities than offspring from unexposed rats. Pregnant rabbits fed the amine salt had fewer litters, fewer live fetuses, and more embryo loss than did unexposed rabbits. Pregnant rabbits fed the ester had fewer live fetuses, more embryo loss, and offspring with more skeletal abnormalities than did unexposed rabbits. These reproductive problems occurred at doses of 100 and 250 mg/kg per day.[28]

Recently, pesticide regulators, researchers, and the general public have become increasingly concerned about more subtle effects on reproduction. Of special concern has been the possibility that pesticides might interfere with the development of the nervous system. A new (1999) study shows that the major breakdown product of triclopyr causes this kind of effect. See "Hazards of Triclopyr's Major Metabolite," p. 18 for details.

There are no publicly available studies of how commercial triclopyr-containing products affect reproduction.

Effects on Birds

Triclopyr decreases the survival of newly hatched nestlings. In tests with mallard ducks, ducklings hatched from eggs laid by mother ducks that were fed triclopyr had a survival rate that was between 15 and 20 percent lower than the survival rate of ducklings from unexposed mothers. Effects occurred at concentrations in the ducks' food of 200 parts per million (ppm).[29,30]

Effects on Fish

According to EPA, the butoxyethyl

ester form of triclopyr is the form that is most toxic to fish. The ester is "highly toxic" to four of the five species tested: rainbow trout, bluegill sunfish, coho salmon, and the tidewater silverside. The most sensitive life stage and species in laboratory tests is the yolk-sac fry of the coho salmon, with a median lethal concentration (LC_{50}; the concentration that kills half of a population of test animals) of less than 0.5 ppm.[31]

Triclopyr's butoxyethyl ester also affects fish behavior. In laboratory tests with rainbow trout, concentrations of 0.6 ppm resulted in rapid respiration, flared gills, and erratic, disoriented swimming.[32]

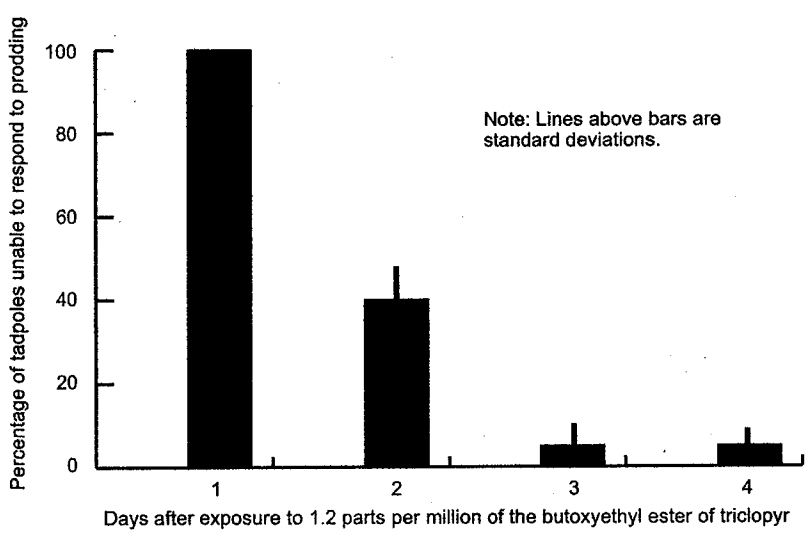
A field study in Ontario, Canada, found similar effects of the butoxyethyl ester on fish. In lake enclosures about half of the tested rainbow trout died at concentrations of 0.45 ppm and mortality reached 100 percent at concentrations of 0.69 ppm. Reduced growth occurred at even lower concentrations, 0.25 ppm. The Canadian researchers also found reduced growth in young rainbow trout following application of the ester to a forest stream.[33]

The concentration of the triethylamine salt required to kill fish is much greater than that of the butoxyethyl ester.[34] However, effects on behavior ("voluntary neuromuscular control was lost and all the fish lay flaccid on the bottom, with irregular and labored breathing,"[32] according to the description written by the researchers who conducted this study) have been observed at lower concentrations, one-half the LC_{50}.[32]

Effects on Frogs

A study of three species of frogs in Ontario, Canada, found that low concentrations of triclopyr butoxyethyl ester inhibited their avoidance behavior. Tadpoles normally move when touched or prodded; this behavior helps them escape predation. Tadpoles of all three species exposed to just over 1 ppm of triclopyr lost their avoidance response, and either "twitched in place or were completely unresponsive" when prodded. (See Figure 3.) The researchers, from Trent University and the Canadian Wildlife Service, concluded that exposure to 1.2 ppm of triclopyr "is likely to paralyze the more sensitive tadpoles, and such exposure may occur in a managed forest system."[35]

Figure 3
Triclopyr and Tadpole Behavior



Source: Berrill, M. et al. 1994. Effects of low concentrations of forest-use pesticides on frog embryos and tadpoles. *Environ. Toxicol. Chem.* 13:657-664.

Normally, tadpoles dart away when prodded. This behavior helps them escape from predators. Green frog tadpoles exposed to the ester form of triclopyr ate unable to respond normally; they either twitch in place or remain still.

Effects on Beneficial Insects and Spiders

Triclopyr can impact populations of beneficial insects and spiders, those that provide an economic benefit to agriculture, by killing plants on which the insects and spiders depend for food and shelter. For example, in a study of carabid (ground) beetles and spiders in a hawthorn hedgerow around an agricultural field in the United Kingdom, spraying with a triclopyr-containing herbicide caused decreases in populations of both predators.[36] In addition, the triclopyr herbicide Grazon was toxic to a spider mite used as a biological control agent to reduce populations of gorse. Typical application rates caused over 60 percent mortality. The authors concluded that "even low rates of these chemicals are likely to prevent mite establishment."[37]

Effects on Oysters

Oyster larvae are more susceptible to triclopyr than other estuarine or marine animals. In a test with embryos and larvae of the Eastern oyster, all individuals developed abnormally at a concentration of 87 ppm.[38]

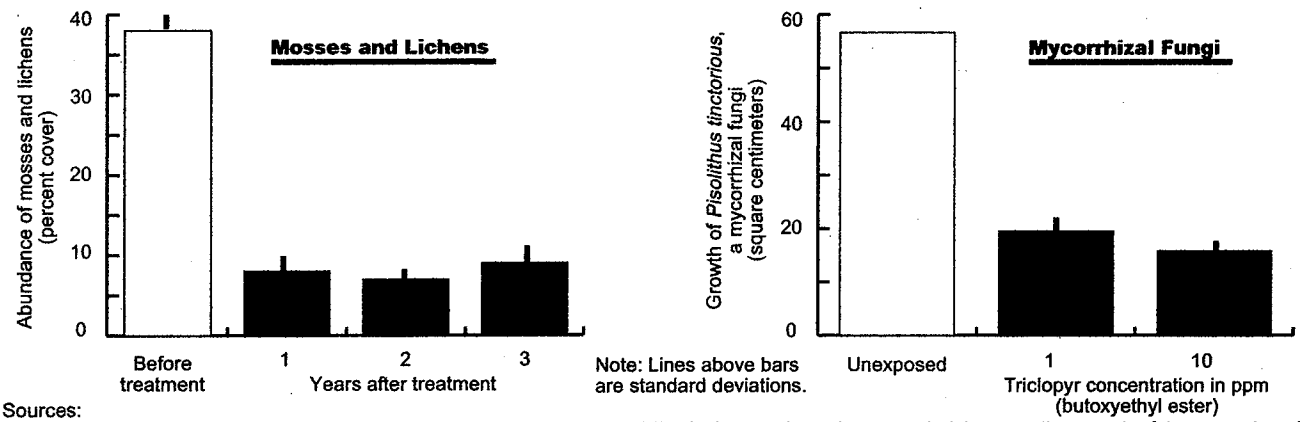
Effects on Small Mammals

Treatment of a Canadian spruce plantation with the triclopyr herbicide Release decreased populations of the red-backed vole, the second most abundant small mammal. Triclopyr treatment decreased vole populations; they were reduced by about 80 percent from those in untreated areas one year after treatment. In the second year after treatment, vole populations were still reduced over 50 percent compared with untreated areas.[39]

Complex Ecological Interactions

While complicated ecological effects of a pesticide are rarely studied, studies of

Figure 4
Examples of Triclopyr's Effects on Nontarget Plants



Sources:
Estok, D., B. Freedman, and D. Boyle. 1989. Effects of the herbicides 2,4-D, glyphosate, hexazinone, and triclopyr on the growth of three species of ectomycorrhizal fungi. *Bull. Environ. Contam. Toxicol.* 42: 835-839.
Newmaster, S.G., F.W. Bell. and D.H. Vitt. 1999. The effects of glyphosate and triclopyr on common bryophytes and lichens in northwestern Ontario. *Can. J. For. Res.* 29:1101-1111.

Triclopyr has a variety of effects on plants which are not intended to be targets of its herbicidal activity. Triclopyr treatment reduces the abundance of mosses and lichens in forest ecosystems. It also reduces the growth of beneficial mycorrhizal fungi.

triclopyr have found unexpected impacts on several levels of an ecosystem.

Two studies by researchers from Oklahoma State University looked at the link between triclopyr treatment and the abundance of parasitic worms in cotton rats and cottontail rabbits in an area of oak forest and tallgrass prairie. In both studies, certain species of parasites were less common in animals trapped in areas that had been treated with triclopyr. These parasites use insects and mites as hosts during part of their life cycle. Triclopyr, by reducing vegetation and therefore increasing temperatures on the forest floor, reduced populations of these insects leading to reduced populations of the parasites. A study of intestinal roundworms in mice conducted in the same forests had similar results.[40-42]

Use of triclopyr to kill unwanted vegetation on loblolly pine plantations also resulted in complex ecological interactions. Triclopyr-treated trees were approximately twice as likely as untreated trees to be damaged by the tip moth. The tip moth damage then increased the risk for fusiform rust, a pine disease.[43]

A third example of complex ecological interactions involves populations of slugs and snails in spruce forests. The slugs and snails are used as "indicators of ecosystem change" because they are important components of boreal ecosystems and vulnerable to pesticide effects because they are relatively immobile. A Canadian study found that areas treated with the triclopyr herbicide Release had approximately half as many slugs and snails as did untreated areas. The reduction in numbers of slugs and snails was attributed to lack of vegetation: because plants were killed by the triclopyr, the soil surface was warmer and drier and there was less leaf litter deposited on the soil.[44]

Effects on Nontarget Plants

As a broadleaf herbicide, triclopyr efficiently kills many species of plants. However, it can also have unintended effects on plants that are not the target of the herbicide application. These effects include drift damage, genetic damage, inhibition of mycorrhizal fungi, reduction of nitrogen cycling, damage to mosses and lichens, and stimulation of algae blooms.

Drift damage: Because it is a potent herbicide, tiny amounts of triclopyr can damage sensitive plants. For example, nine species of ornamental annual flowers were damaged by triclopyr in amounts equivalent to 0.05 percent of the maximum application rate recommended on product labels[45]; less than 0.1 percent of the maximum label rate damaged peanut and cucumber seedlings[46]; and less than 1 percent of the maximum rate is sufficient to reduce yield of cotton plants.[47] When EPA assessed risks from drift of triclopyr,[48] they concluded that one low-rate use, ground applications on rice, did not exceed the agency's "level of concern," but "in all other registered uses for both triclopyr triethylamine and triclopyr butoxyethyl ester, the level of concern for acute risk to nontarget plants"[48] was exceeded.

Genetic damage: In dividing onion root cells, triclopyr butoxyethyl ester causes the formation of abnormal chromosomes.[49]

Mycorrhizal fungi: Triclopyr herbicides inhibit the growth of a number of species of mycorrhizal fungi. (See Figure 4.) These are fungi that grow in or near plant roots and increase the uptake of nutrients by the plant. The most sensitive species are inhibited by concentrations of 0.1 ppm.[50,51] Using the GLEAMS

(Groundwater Loading Effects of Agricultural Management Systems) model developed by the U.S. Department of Agriculture,[52] the U.S. Drug Enforcement Agency calculated that soil concentrations of the triethylamine form of triclopyr used at typical application rates would equal or exceed the concentrations that have inhibited the growth of mycorrhizal fungi.[53]

Nitrogen cycling: Atmospheric nitrogen must be transformed by microorganisms before it is usable by plants as a nutrient. One step in this process, transformation of ammonia to nitrite, is inhibited by triclopyr. A laboratory study at the Swedish University of Agricultural Sciences found that triclopyr was more potent in reducing this activity than about 70 percent of the 48 pesticides tested.[54]

Mosses and lichens: Mosses and lichens are important parts of forest ecosystems, contributing to nutrient cycling, production of high-quality seedbeds, and maintenance of appropriate moisture content. Application of the butoxyethyl ester of triclopyr reduced the diversity of mosses and lichens on a replanted clearcut in Ontario, Canada, by 60 percent. The abundance of mosses and lichens at the same site was reduced 75 percent. (See Figure 4.) The reductions persisted for the duration of the study, two years.[55] In a laboratory study, triclopyr damaged membranes and decreased photosynthesis in the lichen *Peltigera*.[56]

Algae: Treatment of a Canadian stream with concentrations of the ester form of triclopyr designed to mimic an accidental overspray caused an increase in the growth of algae in the stream. This algae bloom persisted for 40 days. Researchers believe that the algae growth was either the result of excessive nutrients, if the algae used the triclopyr as a source of nutrients, or a result of triclopyr's activity as a plant hormone.[57]

Endangered Species

According to EPA's assessment of triclopyr's risks to endangered species, the agency's "levels of concern"[58] are exceeded for the triethylamine salt of triclopyr for birds, mammals, and aquatic and terrestrial plants. For the butoxyethyl ester, "levels of concern"[58] are exceeded for birds, mammals, fish, aquatic invertebrates, estuary species, and aquatic and terrestrial plants. EPA has not yet determined what protective measures are necessary.[58]

Persistence in Soil

Triclopyr's persistence in soil is variable. According to EPA, half-lives (the amount of time it takes for half of an applied chemical to break down or move away from the treatment site) of triclopyr measured in field studies varied from 10 to almost 100 days. In general, half-lives were longer on forestry sites than they were on agricultural sites.[59]

EPA also reported that enough triclopyr persisted in field studies to reduce the yield of cucumber plants for 3 or 4 months after treatment with the triethylamine salt, depending on application rate.[60] A field study in western Oregon found that triclopyr persisted for a year after treatment with the amine salt.[61] EPA also reports persistence of over a year in another field study.[62]

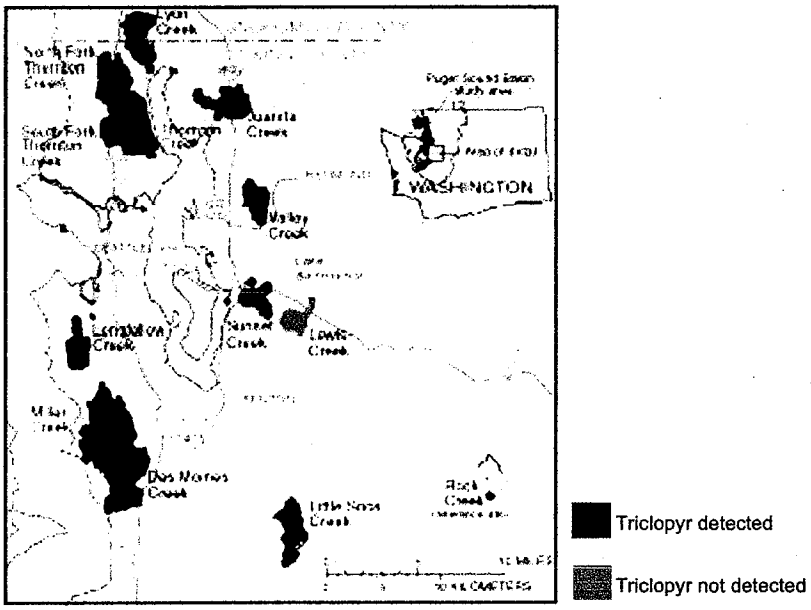
Mobility in Soil

According to EPA, triclopyr is "very mobile" in soil.[63] Triclopyr molecules are not strongly held by soil or sediment particles.[64]

Contamination of Water

Ground water: Since triclopyr is mobile in soil, as well as "somewhat persistent," EPA "believes this chemical has the potential to leach to ground water."[65] Although there has been "limited monitoring for triclopyr in ground water,"[65] studies have found triclopyr contamination

Figure 5. Triclopyr in Urban Streams



Sources:
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U.S. Geological Survey. Undated. Puget Sound Basin NAWQA data. http://wa.water.usgs.gov/pugt/fs.09-99/data.ecy.

Triclopyr was found in all but two of the urban streams studied by the USGS near Seattle, Washington.

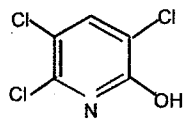
in wells in two states, Virginia and Texas.[65] The GLEAMS model indicates that the triethylamine salt of triclopyr amine is more likely to move through soil and into ground water than the butoxyethyl ester.[66]

Surface Water: Triclopyr also contaminates rivers and streams. A recent national monitoring program conducted by the U.S. Geological Survey (USGS) found triclopyr in 8 of the 20 river basins studied.[67]

On a smaller scale, a USGS study of 10 urban watersheds near Seattle, Washington, found triclopyr at 90 percent of the sites sampled,[68] indicating that contamination of urban streams with triclopyr may be widespread. (See Figure 5.) Triclopyr has also contaminated streams following aerial forestry applications; rivers following applications to rice fields; and surface water following golf course applications.[61,69-72]

The GLEAMS model indicates that the butoxyethyl ester of triclopyr is more likely to run off into surface water than its triethylamine salt.[73]

Figure 6
3,5,6-Trichloro-2-pyridinol (TCP)



Triclopyr's major metabolite.

Hazards of Triclopyr's Major Metabolite

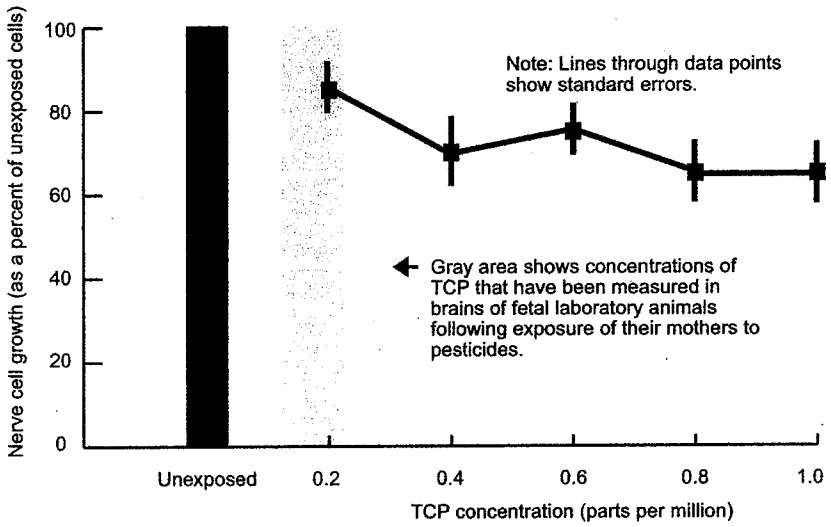
The most common breakdown product of triclopyr in mammals, as well as in soil and water, is 3,5,6-trichloro-2-pyridinol.[74] (TCP; See Figure 6.) TCP has also been found in meat and meat fat.[75] Interestingly, TCP is a major metabolite of the organophosphate insecticide chlorpyrifos.[76]

The most significant health hazard identified for TCP is that it may be especially hazardous to children. Recently (1999), EPA researchers studied the ability of TCP to disrupt the development and maturation of the nervous system that occurs in fetuses, infants, and children. Using a laboratory test system (a cell culture), the researchers showed that exposure to TCP inhibits neurons (nervous system cells) from undergoing normal growth. Concentrations of only 0.2 ppm were sufficient to disrupt growth.[77] (See Figure 7.) Concentrations equal to this level have been measured in the brains of fetal laboratory animals whose mothers were exposed to pesticides. In addition, when researchers compared TCP concentrations in brains of fetal laboratory animals with those in their mothers' brains, the fetal concentrations were between two and four times greater than those in maternal brains, suggesting that TCP accumulates in fetal brains.[78]

TCP also disrupts the functions of mitochondria, structures in virtually all cells that convert food into energy usable by the cell. In a study using mitochondria from rat liver cells, concentrations of 2 ppm TCP reduced four measures of mitochondrial function by at least 30 percent.[79]

TCP also poses a variety of environmental hazards: it is "very mobile" in a variety of soil types and is also often more persistent than triclopyr itself[59]; it is toxic to soil bacteria (based on tests of a model species)[80]; and it is toxic to chicken embryos.[81]

Figure 7
Effect of TCP on the Growth of Nerve Cells



Source:
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In laboratory studies relatively low concentrations of TCP inhibit the growth of nerve cells.

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