● HERBICIDE FACTSHEET

DICAMBA

BY CAROLINE COX

Each year in the United States, about 15 million acres of corn, 1.5 million acres of wheat,[1] and 3 million lawns[2] are treated with the herbicide dicamba. While its name is often not commonly recognized, this wide use, together with concerns about its toxicology and its effects on our environment, make it important to scrutinize dicamba's hazards.

Use

Dicamba is a selective herbicide[3,4] and is used to kill broad-leaved plants growing in corn, rights-of-way, and lawns. Several different forms of dicamba are used as herbicides;[5] the dimethylamine salt and the sodium salt are the most common.[6] (See Figure 1.)

Dicamba was first registered in the United States in 1967.[5]

Common dicamba-containing herbicides are manufactured by Sandoz Crop Protection Corp. with trade names Banvel and Banvel GST,[6] and by PBI/Gordon Corp.[7] with the trade name Trimec. (Trimec also contains the phenoxy herbicides 2,4-D and mecoprop.[6,7])

About 5.6 million pounds of dicamba are used annually in U.S. agriculture and almost all of this, about 5 million pounds, is used on corn.[1,8,9] (See Figure 2 for state-by-state agricultural use.) In addition, the U.S. Environmental Protection Agency (EPA) estimates that U.S. households annually use about 3 million dicamba-containing products (in this case, product refers to a single container).[2] (See Figure 3.) In California, where pesticide use reporting is more complete than in most states, the most common uses of dicamba are in corn, in wheat, in landscape maintenance, and on rights-of-way.[10] (See Figure 4.)

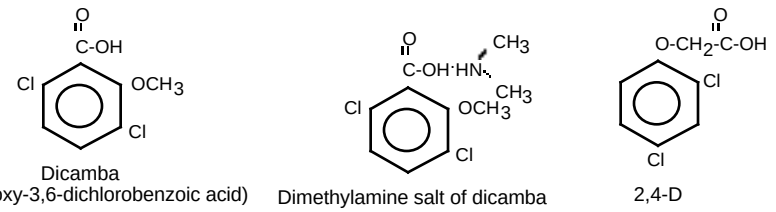
Mode of Action

Dicamba is in the benzoic acid herbicide family, similar in structure and mode of action to phenoxy herbicides like 2,4-D. (See Figure 1.) Like phenoxy herbicides, dicamba mimics auxins, a type of plant hormone, and causes abnormal growth by affecting cell division.[3,4]

Dicamba acts systemically in plants (throughout the entire plant) after it is absorbed through leaves and roots. It is easily transported throughout the plant, and also accumulates in new leaves.[11]

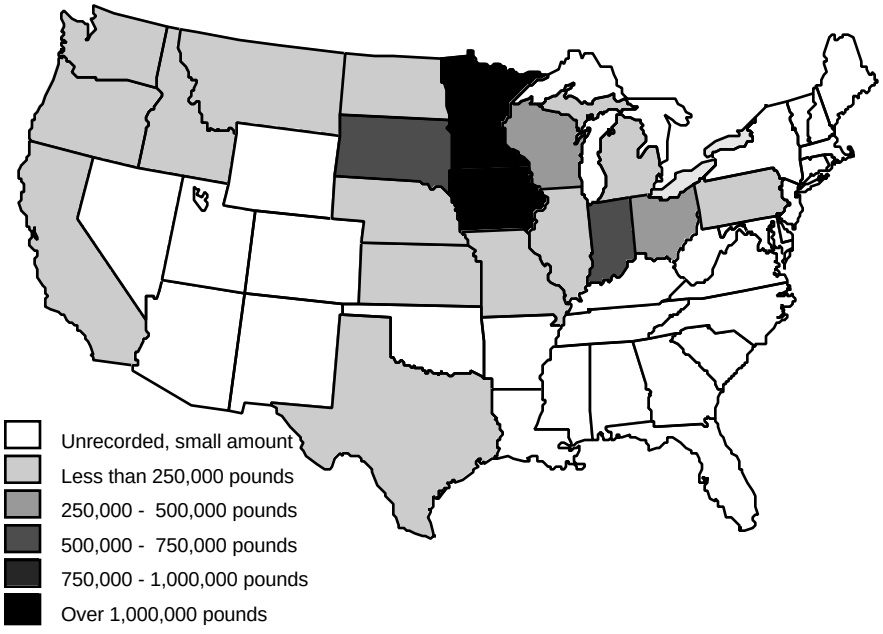
Dicamba also inhibits an enzyme found in the nervous sytem of most animals, acetylcholinesterase.[12] This is the enzyme that is

Figure 1
Dicamba, Its Dimethylamine Salt, and 2,4-D



Dicamba (2-methoxy-3,6-dichlorobenzoic acid) | Dimethylamine salt of dicamba | 2,4-D

Figure 2
Agricultural Uses of Dicamba (1992)



Sources: U.S. Department of Agriculture. National Agricultural Statistics Service. Agricultural Statistics Board. 1993. Agricultural chemical usage: 1992 field crops summary. Washington, D.C. (March.)
California Department of Pesticide Regulation. Information Services Branch. 1993. Summary of pesticide use report data: Annual 1991. Indexed by chemical. Sacramento, CA. (January 25.)

Almost half of the dicamba used in U.S. agriculture is used in Minnesota and Iowa.

■

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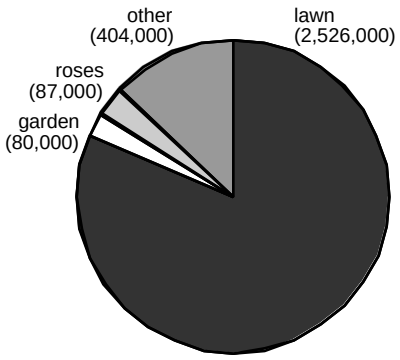
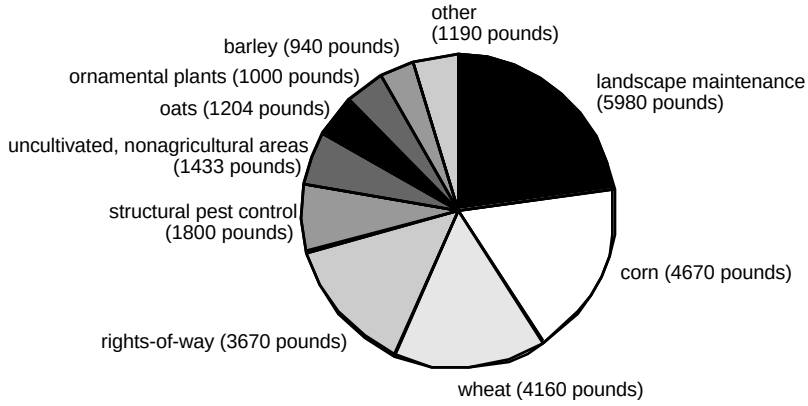
Figure 3
Household Uses of Dicamba



Source: Whitmore, R.W., J.E. Kelly, and P.L. Reading. 1992. National home and garden pesticide use survey: Final report, Volume 1. Executive summary, results, and recommendations. Research Triangle Park, NC: Research Triangle Institute.

Over three-quarters of the dicamba used around U.S. homes is used on lawns.

Figure 4
Uses of Dicamba in California
(pounds per year)



Source: California Department of Pesticide Regulation. Information Services Branch. 1993. Summary of pesticide use report data: Annual 1991. Indexed by chemical. Sacramento, CA. (January 25.)

In California, dicamba is used primarily for landscaping, in corn and wheat production, and along roads, railroads, and other rights-of-way.

inhibited by several common families of insecticides (organophosphates and carbamates). Inhibition of acetylcholinesterase causes a neurotransmitter, acetylcholine, to accumulate and prevents smooth transmission of nerve impulses. In addition, dicamba inhibits the activity of several enzymes in animal livers that detoxify and excrete foreign chemicals.[13]

Acute Toxicity

Dicamba's median lethal oral dose (LD_{50}; the amount that kills 50 percent of a population of test animals) is 1707 milligrams per kilogram (mg/kg) in rats.[14] Female rats are killed by a smaller dose than are male rats.[15]

If we assume humans are as susceptible to dicamba as are laboratory animals, an oral dose of about 3.5 ounces would be required to kill an average-sized (60 kg) human.

Acute exposure to dicamba causes skin irritation and some skin sensitization in laboratory tests, as well as severe eye irritation. The eye damage can be irreversible.[5]

Dicamba also causes other acute effects. Congested lungs, hemorrhages, poor digestion, inflamed kidneys, and engorged livers occured in sheep fed doses of 500 mg/kg.[16]

Acute effects can occur in exposed humans. Symptoms in worker poisonings reported to EPA included muscle cramps, shortness of breath, nausea, vomiting, skin rashes, loss of voice, and swollen glands.[17]

Neurotoxicity

A study of certified pesticide applicators in Minnesota found that a group who applied only herbicides experienced a 20 percent inhibition of the nervous system enzyme acetylcholinesterase (AChE). Researchers were retrospectively able to document that the workers with reduced AChE activity applied significant amounts of dicamba and that they had not applied other chemicals in common. In addition, the researchers demonstrated AChE inhibition in laboratory tests.[12] Neurological effects of dicamba have also been noted in dogs and chickens.[18,19]

Chronic Toxicity

Feeding dicamba to rats for 90 days caused decreases in weight and in the amount of food consumed. Increased dead cells and abnormal live cells were found in exposed rats' livers.[17]

Reproductive Effects

Dicamba's effects on the reproduction of laboratory animals cause concern because of the low doses that cause problems. In rabbits, the most sensitive species tested, doses over 3 mg/kg per day increased the number of fetuses lost or resorbed by the mother.[20]

Exposure of mallard eggs to Banvel caused reduced, stunted growth in the mallard embryos as well as eye malformations.[21]

Concerns about reproductive effects are heightened by a manufacturing contaminant, 2,7-dichlorodibenzo-p-dioxin. (See Figure 5.) In pregnant rats, this contaminant causes abnormalities, suppression of tissue growth, and lesions in fetal hearts.[22]

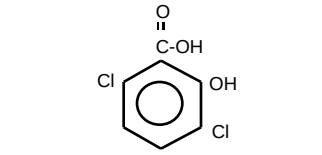
Mutagenicity

A 1990 study showed that injections of dicamba significantly increased the "unwinding rate" (single strand breaks) of the genetic material (DNA; deoxyribonucleic acid) in rat livers. The same study also looked at effects on human blood cell cultures and found that exposure to dicamba caused an increase in unscheduled DNA synthesis as well as a slight increase in sister chromatid exchanges (exchange of genetic material between chromosome pairs).[23]

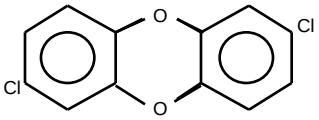
Earlier studies had shown that dicamba caused mutations in two bacteria.[24] Dicamba has also caused mutations in pollen mother cells of the plant *Tradescantiapaludosa*.[25] In addition, Gabonil, (dicamba and MCPA), caused an increase in the frequency of chromosome aberrations in barley.[26]

These results are consistent with a 1973 study which found that pesticide applicators using dicamba and other pesticides had a

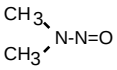
Figure 5
Contaminants, Metabolites, and "Inert" Ingredients Found in Dicamba-containing Products



3,6-dichlorosalicylic acid



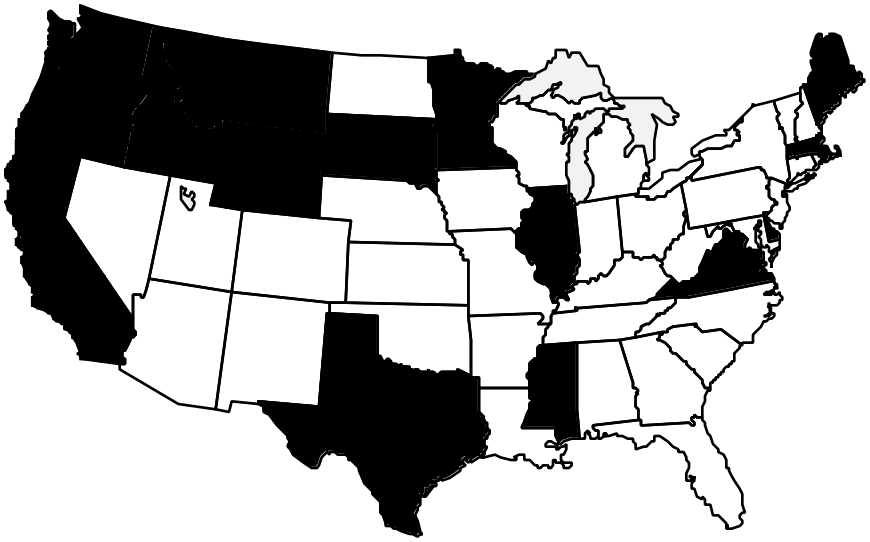
2,7,-dichlorodibenzo-p-dioxin



dimethylnitrosamine

ethylene glycol

Figure 6
Dicamba-contaminated Ground Water in the United States



States in black are those in which dicamba-contaminated groundwater has been reported.

Sources: U.S. EPA. Prevention, Pesticides and Toxic Substances. 1992. Pesticides in ground water database A compilation of monitoring studies: 1971-1991. National summary. Washington, D.C. (September.)
Idaho Division of Environmental Quality. 1992. Pesticide concentrations in ground water from laboratory analyses, as of March 1992. Unpublished raw data. Boise ID: Idaho Dept. of Health and Welfare.
U.S. Dept. of the Interior. Geological Survey. 1992. Multiple station analyses for pesticides in ground water samples collected by the U.S. Geological Survey in Washington. Unpublished raw data. Tacoma, WA.
Oregon Health Division. 1993. Nitrates and organic chemicals found in La Pine area drinking water wells, October 1993. Press release. Oregon Human Resources News. Portland, OR. (October 5.)
Domagalski, J.L. and N.M. Dubrovsky. 1992. Pesticide residues in ground water of the San Joaquin Valley, California.*J. Hydrol*. 130:299-338.

Dicamba-contaminated groundwater has been found in 17 states, including all of the Pacific Northwest states.

higher frequency of gaps and breaks in their chromosomes during spray season than during the winter when they were less exposed.[27]

Carcinogenicity

A recent (1992) study of farmers by the National Cancer Institute found that exposure to dicamba approximately doubled the farmers' risk of contracting the cancer non-Hodgkin's lymphoma two decades after exposure.[28]

Two potentially carcinogenic contaminants of dicamba increase concerns about cancer. The contaminant 2,7-dichlorodibenzo-p-dioxin[29] is not as potent a carcinogen as its notorious chemical cousin 2,3,7,8-TCDD, but it has caused leukemia and lymphoma, liver cancer, and cancer of the circulatory system in a 1979 study of male mice conducted by the National Toxicology Program. (No significant increases in cancer were found in female mice or rats of either sex.)[30] Dicamba's dimethylamine salt can be contaminated with dimethylnitrosamine, small amounts of which cause cancer in laboratory animals.[31]

Although dicamba has been registered for use in the U.S. for almost 30 years, only inadequate laboratory tests of dicamba's ability to cause cancer have been submitted to EPA.[29] The quality of some of the tests appears to be seriously lacking. For example, one test was judged inadequate because " tumors were removed periodically."[18]

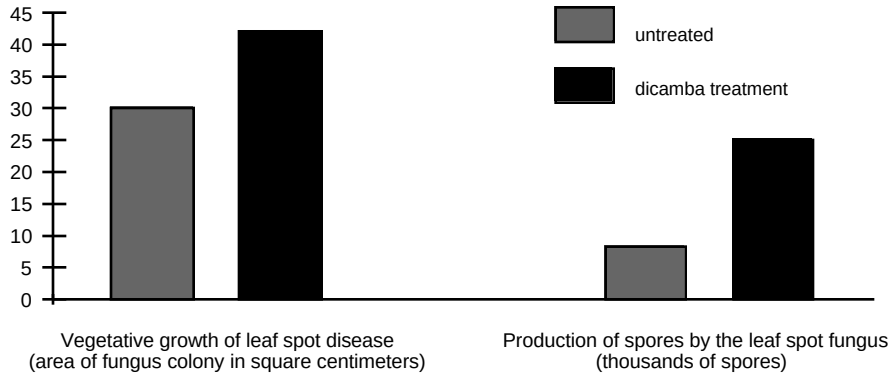
Human Exposure

Humans are exposed to dicamba while they or their neighbors are using the herbicide in the yard or garden, while using it on the job, through drinking of contaminated water, and through eating contaminated food. The result is that large numbers of Americans are contaminated with dicamba. An EPA-funded study found that 1.4 percent of the sample population had dicamba residues in their urine. While this is a small percentage, it means that 2.3 million Americans are contaminated with dicamba.[32]

Household use: Americans make an estimated 6 million applications annually of dicamba-containing herbicides.[2] Because these applications are made to heavily-used areas like lawns and gardens, the potential for exposure of household residents is high. Dicamba volatilizes (evaporates) easily[33] from plant surfaces, particularly when temperatures are over 85°F. Under agricultural conditions, these vapors can drift up to 5 or 10 miles; thus there is potential for contamination following a neighbors' use of the chemical.[34]

Occupational use: A study of two crews using truck-mounted and hand-held sprayers to apply dicamba found dicamba residues in air samples from the truck cab, on the drivers' and applicators' hands, and in urine samples. Dermal exposure (through the skin) was responsible for more contamination than breathing of contaminated air, according to the researchers. Interestingly, the highest residues were measured in urine from a driver,

Figure 7
Increase in the Severity of a Plant Disease
Caused by Dicamba Treatment



Source: Hodges, C.F. 1992. Vegetative growth and sporulation of Bipolaris sorokiniana on infected leaves of *Poa pratensis* exposed to postemergence herbicides*Can. J. Bot.* 70:568-570.

Leaf spot, a disease of bluegrass, grows faster and produces more spores following dicamba treatment of the grass.

although sprayers did all of the mixing, loading, and hand-spraying. Residues were still detectable at the end of the study (72 hours after spraying) and the authors note that this means that dicamba levels in workers would rise if they were applying dicamba daily during a five-day work week.[35] In addition, cholinesterase inhibition following use of dicamba has been measured in pesticide applicators.[12]

Contaminated water: Dicamba is "relatively water-soluble" and "mobile in soils."[36] This means that it is likely to contaminate both ground and surface water. In a study that compared soil mobility of 40 pesticides, dicamba was one of three with the highest mobility;[37] these results are consistent with another study of 26 pesticides, in which dicamba was more water soluble than all but three.[38] In two studies, dicamba was adsorbed (held to soil particles) less than the other pesticides tested, even though one was atrazine, a pesticide that has caused problems because of its tendency to contaminate water.[38,39]

Tests for dicamba contamination in water are consistent with these observations. Dicamba has been found in the drinking water supplies of Cincinnati, Ohio; New Orleans, Louisiana; Philadelphia, Pennsylvania; and Seattle, Washington.[40] It has also been found in ponds, rivers, and lakes in the U.S. and Canada.[40,41,42] Certain studies have found dicamba contamination to be pervasive. For example, a study of the Padilla Bay, Washington watershed found dicamba at all but one of the sampling stations.[43] A study of two Canadian watersheds found dicamba throughout the sampling period[44] and a study of a third Canadian watershed found dicamba residues in 95 percent of the snowmelt samples tested.[45] (The following year, when herbicide use by local farmers was lower because of drought, no dicamba was found in the snowmelt.) EPA's water quality database indicates about one-third of the surface water samples analyzed contained dicamba.[19] In addition, dicamba has been found in the effluent from sewage treatment plants in Chattanooga, Tennessee and Lake Tahoe, California.[40]

Dicamba has also been found in groundwater in Msec, Czechoslovakia;[46] Ontario[47] and Saskatchewan,[45] Canada; and in 17 states in the U.S.[38,48-51] (See Figure 6.)

Contaminated food: Dicamba residues have been found on sweet corn,[52] tomatoes,[52] and wheat (both the straw and the grain).[53]

Effects on Wildlife

Fish: Although dicamba is characterized as "slightly toxic" or "practically nontoxic" to fish,[5] there are wide variations in its acute toxicity. For example, one study found that the concentration of dicamba required to kill half of a test population (called the LC_{50}) of bluegill was 600 parts per million (ppm). In the same study, researchers determined that if the herbicide was adsorbed onto vermicullite, it was 30 times more toxic.[54] In another study, no effects on yearling coho salmon were observed at concentrations of dicamba up to 100 ppm. However, yearling coho were killed by much smaller doses (0.25 ppm) during a seawater challenge test which simulates their migration from rivers to the ocean.[55] In addition, acute toxicity varies widely among fish species. For example, rainbow trout are killed by concentrations less than a tenth as great as those that kill mosquito fish.[54]

The toxicity to fish of dicamba-containing herbicides may be increased by the products used with them. For example, in 1992, forty fish were killed in Douglas County, Oregon, by the adjuvant added to Weedmaster, an herbicide containing dicamba and 2,4-D.[56]

Little is known about effects on fish other than acute toxicity.

Other Aquatic Organisms: Dicamba's toxicity to aquatic organisms smaller than fish shows similarities to its toxicity to fish. It is characterized as "practically nontoxic"[5] to aquatic invertebrates and, as an herbicide, it would not be expected to be acutely toxic to aquatic animals. However, tests show wide variations among species. For example, the crustaceans seed shrimp, glass shrimp, and fiddler crabs all are killed by concentrations over 100 ppm. However, other crustaceans (water fleas and amphipods) are killed by concentrations a tenth as much or less (3.9 - 11 ppm).[54] Little is known about effects on aquatic invertebrates other than acute toxicity.

Effects on Nontarget Plants

Since dicamba can damage or kill most broad-leaved plants, any unintended exposure can have important consequences. These effects have been studied mostly in agriculture and little is known about impacts on native plants.

Drift: Drift of dicamba occurs when it moves during or after application to a different site. The following effects have all been documented as a result of dicamba drift: abnormal leaf growth, floral development, and yield in dry beans;[34] reduced

quality, and increased skin ulcers in potatoes;[57,58] reduced yield, reduced sugar production, and increased sugar losses after harvest in sugar beets;[59] and reduced plant height and yield in soybeans.[60] Drift in amounts as low as 1 gram per hectare (about 0.01 ounces per acre) can damage susceptible crops. This is less than a hundredth of the typical agricultural application rate (2 to 4 ounces per acre).[61] Widespread damage from drift has occured when applications are made when temperatures are over 85 degrees.[34]

Plant diseases : Treatment of bluegrass (*Poa pratensis*) with dicamba under greenhouse conditions caused an increase in growth and sporulation of the fungus *Bipolaris sorokiniana*, the cause of a leaf spot disease of bluegrass. (See Figure 7.) Field studies showed consistent results.[63] Dicamba treatment also increases the incidence of another disease, take-all infection of winter wheat, in field experiments.[63]

Effects on germinating seedlings : Researchers studying red oak tree regeneration following clear-cutting of Pennsylvania forests documented that applications of dicamba reduced germination of oak seedlings.[64] The effects of dicamba on germination of seeds from other trees or from herbaceous plants do not appear to be well studied.

Soil fertility : L-asparaginase is an enzyme found in soil microbes that is important in soil nutrient cycling and nitrogen mineralization. In Iowa agricultural soils applications of Banvel reduced L-asparaginase activity between 8 and 17 percent, depending on soil type. Researchers believe that this could "lead to a reduction in the amount of N [nitrogen] derived from soil organic material" and thus impact soil fertility.[65] Dicamba is also toxic to two nitrifying bacteria[66] and two algae thought to "contribute significantly to the processes involved in soil fertility."[67]

Persistence

Dicamba's persistence increases its potential for effects on humans, other animals, and plants. While its half-life (the time required for one-half of a dicamba application to break down) typically is between one and six weeks,[5] it can persist much longer. In field studies, dicamba's persistence has been as long as 12 months (the duration of the study) in a Florida oak and pine forest[68] and almost 13 months in Nova Scotia agricultural soils.[69] The half-life of dicamba increases as temperatures decrease; the half-life at 40°F is over 6 times the half life at 80°F.[70] Dicamba also persists longer in dry soils than in wet soils.[71]

Secret "Inert" Ingredients

Most dicamba-containing herbicides contain ingredients that the pesticide manufacturer calls trade secrets. These ingredients are called "inerts," although they are neither biologically or chemically inert. Almost all of the toxicology and environmental fate testing required by EPA for the registration of dicamba is done with dicamba alone, not with the complete herbicide formulation (active ingredient + "inerts") as it is sold and used.

Trimec, for example, is almost 60 percent "inert" ingredients. Fallowmaster, containing a mixture of dicamba and glyphosate, is over 75 percent "inert" ingredients, and Banvel is almost 40 percent "inerts."[6]

The identity of most of these "inert" ingredients is not publicly available. Several, however, have been identified. Fallowmaster and Banvel CST contain ethylene glycol.[6] (See Figure 5.) Acute exposure to ethylene glycol causes incoordination, slurred speech, convulsions, rapid heart beat, cardiac arrhythmias, and degeneration of kidney cells. Chronic effects include some delayed nervous system damage, "external malformations" in fetuses of laboratory animals exposed to ethylene glycol, and a decrease in male fertility (also in laboratory animals).[72] Fallowmaster also contains a trade secret surfactant classified as "hazardous" by the federal Occupational Safety and Health Administration. [6]

Contaminants

Dicamba is contaminated during its manufacture with 2,7-dichlorodibenzo-p-dioxin. In addition, dimethylamine salts of dicamba can also be contaminated with dimethylnitrosamine.[29] For toxicological concerns about these contaminants, see "Reproductive Effects" and "Carcinogenicity," p. 31. Dicamba products can also be contaminated with up to 20 percent of 3,5-dichloro-2-methoxy benzoic acid, an isomer of dicamba. This isomer is retained longer than dicamba in the bodies of laboratory animals.[73]

Summary

Dicamba is a selective herbicide used to kill unwanted broadleaf plants in corn and wheat, along rights-of-way, and in lawns. Its chemical structure and mode of action in plants in similar to that of the phenoxy herbicides.

In humans, exposure to dicamba is associated with the inhibition of the nervous system enzyme acetylcholinesterase and an increased frequency of a cancer, non-Hodgkin's lymphoma. In laboratory animals, exposure to dicamba has caused decreases in body weight, liver damage, an increased frequency of fetal loss, and severe, sometimes irreversible eye damage. Dicamba has caused genetic damage in human blood cells, bacteria, and barley.

Dicamba can be contaminated with cancer-causing nitrosamines and a dioxin which has been shown to cause birth defects and several cancers in laboratory animals.

Dicamba is mobile in soil and has contaminated rivers, ponds, and groundwater. In the U.S., dicamba-contaminated groundwater has been found in 17 states.

Dicamba volatilizes (evaporates) easily and has been known to drift for several miles following applications at high temperatures.

Dicamba can inhibit some of the organisms important in soil nutrient cycling and thus impair soil fertility. Its use has also been associated with an increase in the frequency of some plant diseases.

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