

## 2,4-D

### Herbicide Basics

**Chemical formula:** (2,4-dichlorophenoxy) acetic acid

**Herbicide Family:** Phenoxy

**Target weeds:** broadleaves

**Forms:** salt & ester

**Formulations:** EC, WP, SL, GR, SP

**Mode of Action:** Auxin mimic

**Water Solubility:** 900 ppm

**Adsorption potential:** low-intermediate (higher for ester than salt)

**Primary degradation mech:** Microbial metabolism

**Average Soil Half-life:** 10 days

**Mobility Potential:** intermediate

**Dermal LD50 for rabbits:** unknown

**Oral LD50 for rats:** 764 mg/kg

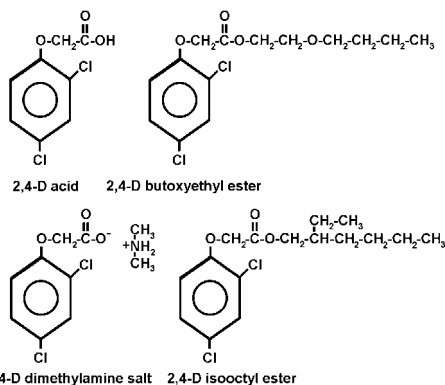
**LC50 for bluegill sunfish:** 263 mg/L

**Trade Names:** Aqua-Kleen<sup>®</sup>, Barrage<sup>®</sup>, and Weedone<sup>®</sup>

**Manufacturers:** Current manufacturers include Aventis, Dow AgroSciences, and Nufarm, U.S.A.

### Synopsis

2,4-D is one of the oldest herbicides used in the United States. It was first developed during World War II and became famous as a component of the controversial Agent Orange used during the Vietnam War. Today, 2,4-D continues to be one of the most commonly used herbicides on the market. Because there is no longer a patent governing the manufacture and sale of 2,4-D, any company is free to produce it. Thus, a variety of inexpensive 2,4-D products are available from different manufacturers. Because it has been in use for so long, many of the studies regarding its behavior in the environment are old (e.g. pre-1980). 2,4-D is a selective herbicide that kills dicots (but not grasses) by mimicking the growth hormone auxin, which causes uncontrolled growth and eventually death in susceptible plants. The half-life of 2,4-D in the environment is relatively short, averaging 10 days in soils and less than ten days in water, but can be significantly longer in cold, dry soils, or where the appropriate microbial community is not present to facilitate degradation. In the environment, most formulations are degraded to the anionic form, which is water-soluble and has the potential to be highly mobile. Ester formulations are toxic to fish and aquatic invertebrates, but salt formulations are registered for use against aquatic weeds. 2,4-D is of relatively low toxicity to animals but some formulations can cause severe eye damage. Certain crops, such as grapes, are highly sensitive to 2,4-D and application of this herbicide should be avoided if they are nearby. Most formulations are highly volatile and should not be applied when conditions are windy or when temperatures are high.



## Herbicide Details

**Chemical Formula:** (2,4-dichlorophenoxy) acetic acid

**Trade Names:** 2,4-D is sold as acid, salt (mostly amine), or ester formulations under many different trade names. Formulations include liquids, water-soluble powders, dusts, granules, or pellets of 2,4-D alone or in mixtures with other herbicides such as picloram and clopyralid. Some trade names include Aqua-Kleen<sup>®</sup>, Barrage<sup>®</sup>, Lawn-Keep<sup>®</sup>, Malerbane<sup>®</sup>, Planotox<sup>®</sup>, Plantgard<sup>®</sup>, Savage<sup>®</sup>, Salvo<sup>®</sup>, Weedone<sup>®</sup>, Weedar<sup>®</sup> and Weedtrine-II<sup>®</sup>.

**Manufacturer:** Current manufacturers include Aventis, Dow AgroSciences, Nufarm U.S.A., and many others.

**History:** 2,4-D is commonly known as a component of the controversial herbicide Agent Orange, which was extensively used by the U.K. in Malaysia and by the U.S. military during the Vietnam War to defoliate jungle regions. Pure 2,4-D and 2,4,5-T (the other component of Agent Orange) are relatively non-toxic. Agent Orange's infamy was primarily due to dioxin contamination of the 2,4-D and 2,4,5-T herbicides that it contained. 2,4-D is now manufactured with a process that produces no dioxin as a contaminant. It proved impossible to produce 2,4,5-T that was free of dioxin contamination, so its manufacture and sale have been prohibited in the U.S. since 1983. Small quantities of this dioxin is highly toxic, and has been linked with producing birth defects in mammals and increased rates of cancer.

**Use Against Natural Area Weeds:** 2,4-D controls many terrestrial and aquatic broadleaf weeds, but has little or no affect on grasses. Weeds that have been treated with 2,4-D in natural areas include: Canada thistle (*Cirsium arvense*), *Cardaria* spp., crown vetch (*Coronilla varia*), Russian knapweed (*Acroptilon repens*), water hyacinth (*Eichhornia crassipes*), and sulfur cinquefoil (*Potentilla recta*).

On some TNC preserves, 2,4-D has been used with moderate to high success against Canada thistle (*Cirsium arvense*). On TNC preserves in Oregon, hoary cress (*Cardaria draba*) was treated when in bud or flower for seven years, and although a few plants still appear every year, the weed has been nearly eliminated. Land stewards in Montana found that 2,4-D amine plus picloram is cheaper but less effective against leafy spurge than higher rates of picloram (Tordon<sup>®</sup>) alone. However, lower application rates may cause less environmental damage. Formulations that contain 2,4-D mixed other herbicides, such as Crossbow<sup>®</sup> (2,4-D and triclopyr), Curtail<sup>®</sup> (2,4-D and clopyralid), Pathway<sup>®</sup> (2,4-D and picloram), and Weedmaster<sup>®</sup> (2,4-D and dicamba), have been used on TNC preserves with varying degrees of success.

**Mode of Action:** 2,4-D is an "auxin mimic" or synthetic auxin. This type of herbicide kills the target weed by mimicking the plant growth hormone auxin (indole acetic acid), and when administered at effective doses, causes uncontrolled and disorganized plant growth that leads to plant death. The exact mode of action of 2,4-D is not fully understood, and it is possible that it causes a variety of effects which are fatal when combined. It is believed to acidify the cell walls which allows the cells to elongate in an uncontrolled manner. Low concentrations of 2,4-D can

also stimulate RNA, DNA, and protein synthesis leading to uncontrolled cell division and growth, and, ultimately, vascular tissue destruction. On the other hand, high concentrations of 2,4-D can inhibit cell division and growth. Plant death typically occurs within three to five weeks following application.

### **Dissipation Mechanisms:**

*Summary:* In soils 2,4-D is degraded primarily by microbes. The fate of 2,4-D in the environment is largely dependent on the ambient pH (Aly & Faust 1964). At pH levels above 7, 2,4-D is converted rapidly to the anion (negatively charged) form, which is more susceptible to photodegradation and microbial metabolism, and less likely to adsorb to soil particles. At pH levels < 4, microbial degradation is inhibited, and 2,4-D retains its molecular form and resists degradation (Johnson et al. 1995a). Most formulations of 2,4-D are volatile (T. Lanini, pers. com.).

### Volatilization

Most formulations of 2,4-D can be highly volatile and care should be used in their application. The most volatile of the 2,4-D esters, methyl and isopropyl, have been banned in the U.S. (Que Hee & Sutherland 1981), but some volatile ester formulations of 2,4-D remain available. Both localized and widespread damage from using 2,4-D have been reported (WHO 1984). To reduce the amount lost to vaporization, low-volatile (long-chain) ester formulations are available. In addition, the alkali and amine salt formulations are much less volatile and may be more appropriate for use where esters could volatilize and damage non-target plants (WHO 1984). Additionally, the potential for 2,4-D to volatilize increases with increasing temperature, increasing soil moisture, and decreasing clay and organic matter content in the soil (Helling et al. 1971).

### Photodegradation

2,4-D degrades rapidly in sunlight under laboratory conditions, but photodegradation has not been demonstrated in the field (Halter 1980). Crosby and Tutass (1966) reported half-lives (the time it takes for half of the total amount of herbicide applied to be dissipated) of 50 minutes for 2,4-D salts and five minutes for 2,4-D esters under laboratory conditions. Aly and Faust (1964) obtained similar results in the lab but concluded that sufficient levels of ultraviolet radiation from sunlight are not likely in the field. In addition, Johnson et al. (1995 a & b) reported that 2,4-D degradation rates in soils remained relatively constant with and without sunlight, suggesting that photodegradation is not an important process in the field.

### Microbial Degradation

In soils 2,4-D is degraded primarily by microbes. Hemmett and Faust (1969) concluded that the size of the microbial population, the concentration of 2,4-D, and the ratio of the two factors determine 2,4-D degradation rates. Soil conditions that enhance microbial populations (i.e. warm and moist) facilitate 2,4-D degradation (Foster & McKercher 1973). In addition, 2,4-D has been shown to dissipate more rapidly in soils that were previously treated with 2,4-D, presumably because there was an increase in 2,4-D degrading bacteria after the first application (Oh & Tuovinen 1991; Smith & Aubin 1994; Shaw & Burns 1998).

There are conflicting reports as to whether microbial degradation occurs in aquatic systems (Que Hee & Sutherland 1981; Wang et al. 1994a; EXTTOXNET 1996). Microbial degradation can take place in bottom sediments if the appropriate microbial population is present and the pH level is sufficiently high, but it is not likely to occur in the water column (Que Hee & Sutherland 1981). Under acidic conditions, microbial activity can be severely inhibited (Sandmann et al. 1991). Differences in reported half-lives may arise from differences in the microbial populations at the study sites (Shaw & Burns 1998). Some aquatic systems may have few of the microbes that readily degrade 2,4-D, while others may have many 2,4-D degrading microbes.

### Adsorption

Salt formulations are water-soluble and do not bind strongly with soils. Ester formulations can adsorb more readily to soils. In the field, ester formulations tend to hydrolyze to the acid form, particularly in alkaline conditions, and, consequently, do not adsorb to soil particles in significant quantities (Aly & Faust 1964).

Johnson et al. (1995a) found that soil organic content and soil pH are the main determinants of 2,4-D adsorption in soils. Adsorption increases with increasing soil organic content and decreasing soil pH (Johnson et al. 1995a). Inorganic clays can also bind 2,4-D particles. A relatively high concentration of clay particles however, is required to bind small concentrations of 2,4-D (Aly & Faust 1964). Additionally, as the herbicide concentration increases, the percentage of herbicide adsorbed decreases, possibly because the number of binding sites on soil particles are finite and become filled (Johnson et al. 1995a).

### Chemical Decomposition

Chemical decomposition is the degradation of an herbicide to one or more of its components via chemical reactions. 2,4-D is relatively persistent in the environment, and does not readily undergo chemical degradation, relative to other herbicides (Que Hee & Sutherland 1981). The hydrolysis of the ester formulations to its acid and alcohol compounds, however, can occur readily in alkaline waters (Que Hee & Sutherland 1981; Muir 1991). Additionally, the 2,4-D salt formulations dissociate to a salt and an acid in the environment (Smith 1988).

### **Behavior in the Environment**

*Summary:* The World Health Organization (1984) concluded that 2,4-D does not accumulate or persist in the environment. The primary degradation mechanism is microbial metabolism, but mineralization and possibly photolysis may also play a role. The average half-life (the time it takes for the herbicide concentration to decline by 50%) is 10 days, but rates of degradation can vary from several hours to several months or longer. Degradation rates are determined by the microbial population, environmental pH, soil moisture, and temperature (Que Hee & Sutherland 1981; Sandmann et al. 1988; Wilson et al. 1997). The type of 2,4-D formulation applied does not significantly affect the rate of degradation (Wilson et al. 1997).

### Soils

2,4-D may be applied in acid, salt, or ester formulations, but in most cases, each of these formulations are apparently converted rapidly to the acid form once it contacts soil (Foster & McKercher 1973; Smith 1988; Wilson et al. 1997). Consequently, the rate of dissipation from soils is often the same regardless of the formulation of 2,4-D that is applied (Wilson et al. 1997).

Half-lives are short, ranging from a few days to several months but detectable residues can persist for up to a year (McCall et al. 1981).

Degradation is almost entirely through microbial metabolism. Soil conditions that maximize microbial populations (i.e. warm and moist with a high organic content) maximize degradation rates (Foster & McKercher 1973; Ou 1984; Johnson & Lavy 1992; Han & New 1994; Johnson et al. 1995a; Veeh et al. 1996). Wilson et al. (1997) found that adequate soil moisture was the most influential parameter affecting degradation rates. Cold, dry soils can hold 2,4-D residues for significantly longer periods (Que Hee & Sutherland 1981). In at least one case, however, excessive soil moisture was shown to hinder 2,4-D degradation (Foster & McKercher 1973). In relatively dry soils with low bacterial counts, fungi play an increasingly important role in the degradation of 2,4-D (Ou 1984; Han & New 1996). Johnson et al. (1995b) found that dissipation rates did not differ significantly between rice field soils and bare ground, suggesting that plants do not play a significant role in eliminating 2,4-D from soils.

Lag times of up to eight weeks during which 2,4-D degradation is slow, have been reported following the first application of 2,4-D to soil (Audus 1960). These lags may indicate how long it takes for the abundance of 2,4-D degrading microbes to build up. Soils previously treated with 2,4-D do not exhibit a time lag and lose 2,4-D rapidly, presumably because of a pre-existing 2,4-D degrading microbial community (Sandmann et al. 1991).

Most formulations of 2,4-D do not bind tightly with soils and, therefore, have the potential to leach down into the soil column and to move off-site in surface or subsurface water flows. Leaching of 2,4-D to 30 cm has been reported (Johnson et al. 1995a). In many cases, extensive leaching does not occur, most likely because of the rapid degradation of the herbicide (Que Hee & Sutherland 1981). Where 2,4-D does leach, however, it will be more persistent because populations of microbes responsible for the degradation of 2,4-D tends to decrease with soil depth (Wilson et al. 1997).

2,4-D can also be lost from soils through volatilization. Volatilization rates are determined by the temperature and molecular form of the herbicide at the surface of the soil, which, in turn, is determined primarily by the soil's pH (McCall et al. 1981). In general, dry, alkaline soils with high organic content will be less likely to lose 2,4-D to volatilization (Que Hee & Sutherland 1981).

#### Water

2,4-D will change form and function with changes in water pH (Que Hee & Sutherland 1981). In alkaline (high pH;  $\text{pH} > 7$ ) waters, 2,4-D takes an ionized (negatively charged) form that is water-soluble and remains in the water column. Theoretically, in water of a lower pH, 2,4-D will remain in a neutral molecular form, increasing its potential for adsorption to organic particles in water, and increasing its persistence (Wang et al. 1994a). 2,4-D is most likely to adsorb to suspended particles in muddy waters with a fine silt load (Que Hee & Sutherland 1981), but little adsorption has been observed in the field (Halter 1980).

Degradation mechanisms are difficult to isolate in the field and laboratory studies of microbial degradation and photolysis are conflicting. In sediments with sufficient microbial populations,

2,4-D can be degraded in a matter of hours (Aly & Faust 1964). When applied to eel grass along the coast of Prince Edward Island and New Brunswick, 2,4-D dissipated from the water within 20 days (Thomas & Duffy 1968). Wang et al. (1994b) however, found no significant degradation of 2,4-D in either sterilized or natural waters without sediments collected from four rivers in China. In this study, approximately 80% of the applied herbicide remained in the water after 56 days (Wang et al. 1994b). In other studies, 2,4-D was removed within hours by photodegradation (Aly & Faust 1964; Crosby & Tutass 1966). Aly and Faust (1964) concluded, however, that it was unlikely that a sufficient amount of ultraviolet radiation would reach the surface of natural waters to degrade 2,4-D.

Que Hee and Sutherland (1981) reported that concentrations of most 2,4-D residues found in lakes and streams are < 1 ppm, although concentrations of up to 61 ppm have been reported immediately following direct application to water bodies. These concentrations are well above the 0.1 ppm established as “permissible” levels for potable water by the U.S. E.P.A. (EPA 1998). Treated water should not be used for irrigation because concentrations as low as 0.22 ppm can damage soybeans and probably other crops (Que Hee & Sutherland 1981).

### Vegetation

2,4-D residues taken up by plants remain intact in the foliage until it is lost as litter and degraded in soils (Newton et al. 1990). Fruits from treated trees have been found to retain 2,4-D residues for up to seven weeks (Love & Donnelly 1976, in Que Hee & Sutherland 1981).

## **Environmental Toxicity**

### Birds and Mammals

2,4-D is considered of moderate toxicity to animals, although LD50 levels vary significantly between formulations and animal species (Ibrahim et al. 1991). The majority of LD50 values range between 300-1,000 mg/kg. For example, the LD50 for 2,4-D acid in rats and bobwhite quail is 764 mg/kg and 500 mg/kg, respectively. Some animals such as dogs, however, are significantly more sensitive to 2,4-D organic acids than are rats and humans (Ibrahim et al. 1991). In 1991, Hayes et al. reported a significant increase in the occurrence of malignant lymphoma among dogs whose owners applied 2,4-D to their lawns.

2,4-D can bio-accumulate in animals. In Russia, residues of more than ten times the allowable level were found in eggs, milk, and meat products served by public caterers and one study reported residues in 46% of tested cattle (Que Hee & Sutherland 1981). Risk to browsing wildlife, however, is low, Newton et al (1990) analyzed 2,4-D residues in forest browse following aerial application to forests in Oregon and found them to be below the concentrations known to cause effects in mammals.

### Aquatic Species

LC50 levels for bluegill sunfish and rainbow trout are 263 and 377 mg/L, respectively. Wang et al. (1994b) studied bioaccumulation of 2,4-D in carp and tilapia and found that accumulation of up to 18 times the ambient concentration occurred within two days of exposure. 2,4-D was found in oysters and clams in concentrations up to 3.8 ppm, and it persisted for up to two months (Thomas & Duffy 1968). The highest concentrations of 2,4-D were generally reached shortly after application, and dissipated within three weeks following exposure.

2,4-D can accumulate in fish exposed to concentrations as low as 0.05 ppm (Wang et al 1994b) and concentrations of 1.5 ppm can kill the eggs of fathead minnows in 48 hours (Thomas & Duffy 1968). After animals are removed from contaminated waters, they tend to excrete residues.

#### Other Non-Target Organisms

Moffett and Morton (1971) found that honey-bees directly sprayed with 2,4-D showed no injury and no residues were found in the bees or their honey (cited in Que Hee & Sutherland 1981). These results, however, are questionable as the LD50 for honey-bees is only 1 microgram/bee (WSSA 1994).

#### **Application Considerations:**

The most volatile of the 2,4-D esters, methyl and isopropyl, have been banned in the U.S. (Que Hee & Sutherland 1981), but some volatile ester formulations of 2,4-D remain available. Both localized damage from immediate drift, and widespread damage resulting from clouds of volatilized 2,4-D, have been reported (WHO 1984). To reduce the amount lost to vaporization, low-volatile (long-chain) esters are available. In addition, the alkali and amine salts are much less volatile and may be more appropriate for use where esters could volatilize and damage non-target plants (WHO 1984). Volatilization also can be reduced by using corn oil or cottonseed oil adjuvants (WHO 1984). Spray nozzles should deliver a coarse spray and 2,4-D should not be applied when wind speeds exceed five miles per hour (Hansen et al. 1984).

#### **Safety Measures:**

The acid and salt formulation can cause severe eye damage, while the ester formulation can cause moderate damage. Extra care should be taken to avoid splashing or other exposure of eyes to 2,4-D mixtures. The use of safety goggles is highly recommended.

When 2,4-D is used as an aquatic herbicide, do not treat the entire water body at one time. Treat only one-third to one-half of any water body at any one time, to prevent fish kills caused by dissolved oxygen depletion.

#### **Human Toxicology:**

2,4-D can be absorbed through the skin or through the lungs if inhaled. Applicators of 2,4-D, particularly those using back-pack sprayers, are at greatest risk of exposure (Ibrahim et al. 1991; Johnson & Wattenberg 1996). Libich et al. (1984) reported airborne residues of 1-35 micrograms/cubic meter of air when 2,4-D was applied using hand-held spray guns along power line right-of-ways. These workers later excreted <0.01-30 mg/kg of body weight in their urine. Absorption through the skin accounts for 90% of the 2,4-D absorbed by applicators (Ibrahim et al. 1991).

Once in the body, 2,4-D is distributed rapidly with the greatest concentrations appearing in the kidneys and liver (Johnson & Wattenberg 1996). The majority of the compound is excreted unmetabolized (Ibrahim et al. 1991). Due to its solubility in water, 2,4-D is not believed to accumulate in tissues, but is excreted in the urine in less than a week (Shearer 1980; Ibrahim et al. 1991; Johnson & Wattenberg 1996). Nevertheless, some agricultural workers and other

applicators have experienced long term complications including pain, paresthesias (tingling or numbness), and paralysis following exposure to 2,4-D (Shearer 1980).

Accidental inhalation resulted in one reported case of acute poisoning (Stevens & Sumner 1991). Symptoms included brief loss of consciousness, urinary incontinence, vomiting, muscular hypertonia (an abnormal increase in skeletal or smooth muscle tone), fever, headache, and constipation. Workers that entered an area shortly after treatment with 2,4-D experienced weakness, headache, dizziness, stomach pains, nausea, brief loss of consciousness, and moderate leukopenia (an abnormal reduction in the number of white blood cells, often reducing immune system function) (Stevens & Sumner 1991).

In 1991, a panel with expertise in epidemiology, toxicology, exposure assessment, and industrial hygiene convened to review the evidence available regarding the human carcinogenicity of 2,4-D (Ibrahim et al. 1991). The panel found that case-control studies showed evidence of a relationship between 2,4-D exposure and non-Hodgkins lymphoma in humans, with some studies showing an increased risk with increased exposure level (Ibrahim et al. 1991). Non-Hodgkins lymphoma is the human equivalent of the canine malignant lymphoma found to be associated with 2,4-D exposure in dogs (Hayes et al. 1991). When all evidence was evaluated, however, the panel could not find a cause-effect relationship between exposure to 2,4-D and human cancer (Ibrahim et al. 1991).

In another study of human exposure, female applicators were found to have a significant increase in cervical cancer associated with 2,4-D application. Due to the many confounding factors that make identification of cause and effect mechanisms difficult, other expert review panels including the U.S. EPA, Agriculture and Agri-food Canada, and the World Health Organization concluded that 2,4-D alone is not carcinogenic (Ibrahim et al. 1991; Mullison and Bond 1991).

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