

PICLORAM

Herbicide Basics

Chemical formula: 4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid

Herbicide Family:

Pyridine (Picolinic acid)

Target Species: broadleaf herbs, vines, and woody plants, esp. leafy spurge

Forms: salt, & ester

Formulations: SL, EC

Mode of Action: Auxin mimic

Water Solubility: 430 ppm

Sorption potential: low

Primary degradation mech:

Microbial and chemical degradation

Average Soil Half-life:

90 days

Mobility Potential: high

Dermal LD50 for rabbits:

>2,000 mg/kg

Oral LD50 for rats:

>5,000 mg/kg

LC50 for bluegill sunfish:

>14.5 mg/L

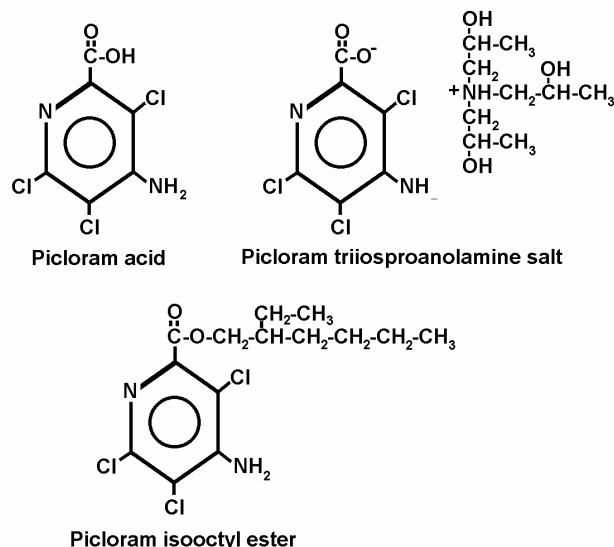
Trade Names: Grazon[®], Tordon[®], Access[®], and Pathway[®]

Manufacturer:

Dow AgroSciences

Synopsis

Picloram kills or damages annual and perennial broadleaf herbs and woody plants. It acts as an “auxin mimic” or synthetic growth hormone that causes uncontrolled and disorganized growth in susceptible plants. Picloram does not bind strongly with soil particles and is not degraded rapidly in the environment, allowing it to be highly mobile and persistent (half-life of picloram in soils can range from one month to several years). In soils, picloram is degraded primarily by microbial metabolism, but it can be degraded by sunlight when directly exposed in water or on the surface of plants or soil. Picloram can move off-site through surface or subsurface runoff and has been found in the groundwater of 11 states. Picloram may also “leak” out of the roots of treated plants, and be taken up by nearby, desirable species. Picloram is not highly toxic to birds, mammals, and aquatic species. Some formulations are highly toxic if inhaled, while other formulations can cause severe eye damage if splashed into the eyes. Because of the persistence of picloram in the environment, chronic exposure to wildlife is a concern, and studies have found weight loss and liver damage in mammals following long term exposure to high concentrations. Concentrations in runoff reported by researchers are often adequate to prevent the growth of non-target terrestrial and aquatic plants, and therefore, picloram should not be applied near waters used for irrigation.



Herbicide Details

Chemical Formula: 4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid

Trade Names: Grazon PC[®], Tordon K[®], and Tordon 22K[®] are picloram salt formulations. Access[®] is mix of triclopyr and picloram esters. Grazon P+D[®], Tordon RTU[®], and Pathway[®] are mixtures of picloram and 2,4-D salts.

Manufacturer: Dow AgroSciences is the primary manufacturer of picloram.

Use Against Natural Area Weeds: Picloram is a dicot-selective, persistent herbicide used to control a variety of annual and perennial broadleaved herbs and woody species. It can persist in an active form in the soil from several months to years, and can also be released from the roots of treated plants into the soil, where other non-target species may take it up and be injured or killed (Hickman et al. 1989). The cut-stump treatment is typically used to control woody species. Examples of weeds successfully controlled using picloram include: leafy spurge (*Euphorbia esula*), knapweeds (*Centaurea* spp.), toadflax (*Linaria vulgaris*), buckthorns (*Rhamnus* spp.), and Russian olive (*Elaeagnus angustifolia*).

On TNC preserves in Idaho, Minnesota, Montana, and Oregon, picloram has been used successfully against cinquefoil (*Potentilla recta*), several knapweed and thistle species (*Acroptilon repens*, *Centaurea maculosa*, *C. diffusa*, *C. solstitialis*), toadflax (*Linaria vulgaris*), birdsfoot trefoil (*Lotus corniculatus*) and hoary cress (*Cardaria draba*). In each case, control results were reported as good to excellent. Dave Carr and Dave Hannah (unpublished data) found that native forb densities on plots treated with picloram up to five years earlier at TNC's Pine Butte Swamp preserve in Montana, were significantly lower than forb densities on untreated plots. In general, picloram does not harm grasses, but repetitive treatments and higher application rates can negatively damage native grasses (Clint Miller, personal observation).

Because of its picloram's persistence in the environment, it is often the herbicide of choice for controlling leafy spurge (*Euphorbia esula*). Leafy spurge is not effectively controlled by other less persistent herbicides. Natural area managers and researchers have found picloram to be more effective against leafy spurge than glyphosate, 2,4-D or triclopyr. It is usually regarded, however, as adequate only to contain or reduce spurge infestations, and generally cannot eliminate them. It effectively top-kills leafy spurge but often fails to adequately damage the deep, extensive root systems. Imazapic (sold as Plateau[®]), a relatively new herbicide, is being tested against leafy spurge and may prove to be more effective than picloram in some circumstances.

Picloram is often sold mixed with 2,4-D, and this formulation has also been used in natural areas against herbaceous species including leafy spurge and spotted knapweed (*Centaurea maculosa*), and in cut-stump treatments against a variety of woody species, particularly in prairie preserves. It was reportedly effective when immediately applied to cut stumps of glossy and common buckthorn (*Rhamnus frangula*, *R. cathartica*), Russian olive (*Elaeagnus angustifolia*) and Siberian elm (*Ulmus pumila*) on Tallgrass Prairie Preserves in

western Minnesota. It was ineffective and allowed resprouting when used on the native redbud (*Cercis canadensis*).

Mode of Action: Picloram is an “auxin mimic” or synthetic auxin. This type of herbicide kills susceptible plants 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 picloram and other auxin-mimic herbicides have not been fully described, but it is believed to acidify the cell wall, which loosens the cell wall and allows cell elongation. Low concentrations of picloram can stimulate RNA, DNA, and protein synthesis leading to uncontrolled cell division and growth, and, ultimately, vascular tissue destruction. High concentrations of picloram can inhibit cell division and growth.

Dissipation Mechanisms:

Summary: Picloram is metabolized slowly by microbes and can be degraded through photolysis when directly exposed to sunlight. The half-life of picloram in soils can vary from one month to three years depending on soil and climate conditions. Other methods of chemical degradation do not occur readily. Picloram does not bind strongly with soils and can be highly mobile, moving to soil depths of two meters and laterally to one km. It is not highly volatile.

Volatilization

Picloram does not volatilize readily when applied in the field (T. Lanini, pers. obs.). The potential to volatilize, however, increases with increasing temperature, increasing soil moisture, and decreasing clay and organic matter content (Helling et al. 1971).

Photodegradation

Picloram is readily degraded when exposed to sunlight in water or on the surface of plant foliage and soils (Merkle et al. 1967; Johnsen & Martin 1983; Cessna et al. 1989; Woodburn et al. 1989). Photodegradation will occur most rapidly in clear, moving water (WSSA 1994), and slowly when exposed on the soil surface. Merkle et al. (1967) reported 15% degradation of picloram after one-week exposure on soil, compared to 65% from exposure in an aqueous solution. There is some evidence that photodegradation occurs more rapidly at higher elevations (Johnsen & Martin 1983) possibly due to increased UV radiation (Merkle et al. 1967). Photolysis of picloram results in the generation of at least two organic acid photoproducts (Woodburn et al. 1989).

Microbial Degradation

Although microbial degradation of picloram is generally slow, it is believed to be the major pathway of picloram degradation in soils (Spiridonov et al. 1987; WSSA 1994). The primary metabolites produced during microbial degradation are degraded through microbial metabolism more rapidly than the parent compound (WSSA 1994). Conditions that favor microbial activity such as high soil moisture and temperature can increase the rate of microbial degradation of picloram (Merkle et al. 1967; Phillips & Feltner 1972, Michael et al. 1989; Watson et al. 1989).

Adsorption

Picloram has a very low adsorption capacity in most soil types ($K_{oc}=16$ mL/g). High organic content, heavy soil texture, low pH, high hydrated iron and aluminum oxide contents, and low soil temperature can increase the adsorption capacity (Merkle et al. 1967; Farmer & Aochi 1974; Neary et al. 1985; Liu et al. 1997). Rates of adsorption also increased with time (McCall & Agin 1985). Unlike many other herbicides, however, clay content does not affect the adsorption capacity of picloram (Grover 1971; Farmer & Aochi 1974).

Chemical Decomposition

Hance (1967) determined that the half-life of picloram due to chemical degradation alone is between 9 and 116 years. Non-biological chemical degradation is therefore not regarded as an important process in the dissipation of picloram from soil (Hance 1967).

Behavior in the Environment

Summary: Picloram is water-soluble, does not bind strongly to soil particles, and can be persistent and mobile in the environment. In plants, picloram is either metabolized (in non-susceptible species) or can remain intact for some time (in susceptible species). Unabsorbed picloram may photodegrade or be washed-off by rainfall. Absorbed picloram may be released into soil by passive transport in plant roots, and can then be taken up by nearby plants.

Soils

Picloram is not readily degraded in soils and can be persistent and mobile. Estimates of the persistence of potentially toxic concentrations vary from a few months to three years, depending on soil and environmental conditions (Scrifres et al. 1972; Fryer et al. 1979; Johnsen 1980; Norris et al. 1982; Neary et al. 1985; Smith et al. 1988; Bovey & Richardson 1991; Close et al. 1998). In soils where picloram persists for long periods of time, it has high potential to move vertically and horizontally, which can lead to contamination of water sources and non-target (terrestrial and aquatic) sites. Smith et al. (1988) reported that one and two years after treating a site with 3.38 kg/ha of picloram, residues were found in the soils and groundwater of an untreated site one km away.

Differences in the half-life of picloram between soil types are difficult to compare because the rate of degradation of picloram varies with time (Fryer et al. 1979). A half-life calculated from residues measured shortly after application will tend to be significantly shorter than those calculated from data collected several months after application (Deubert & Corte-Real 1986). In general, reports of the half-life of picloram vary from less than a month to more than three years (Deubert & Corte-Real 1986; WSSA 1994; Close et al. 1998). In addition, degradation rates can vary with soil depth. Soils where picloram can leach to deep layers may retain picloram for significantly longer periods, probably because significantly smaller microbial populations reside at lower soil depths. Close et al. (1998) used an herbicide movement and persistence model to estimate a half-life of 203 days for the top 30 cm and 986 days for the 30-70 cm layer of silt loam soils in New Zealand.

The mobility of picloram in soils is determined by the adsorption capacity of the soil, soil moisture, and post-application rainfall (Smith et al. 1988). In heavy textured soils with a high organic content that can bind the herbicide, picloram tends to remain in the top 30 cm (Merkle et

al. 1967; Jotcham et al. 1989). In sandy soils or soils with cracks and fissures that allow it to flow to lower depths, picloram has been found more than two meters deep (Phillips & Feltner 1972). Rainfall following application will aid horizontal and vertical movement of picloram in the soil (Merkle et al. 1967; Smith et al. 1988).

Water

Because picloram is water-soluble and does not bind strongly to soil, it is capable of moving into local waterways through surface and subsurface runoff (Michael et al. 1989). The extent to which picloram enters a waterway depends largely on the type of soil, rates of application, rainfall received post-application, and distance from point of application to nearest water body or groundwater (Trichell et al. 1968; Baur et al. 1972; Mayeux et al. 1984). In general, the larger the buffer between treated sites and surface water bodies or groundwater, the smaller the potential for water contamination. Picloram runoff from sites treated with aqueous spray and those treated with pellets (pellets are no longer available in the U.S.) at the same rate does not differ significantly (Bovey et al. 1978). Once in a waterway, picloram may be degraded through photolysis, especially in clear and moving water. Woodburn et al. (1989) found the half-life of picloram in water was 2 to 3 days.

Maximum herbicide runoff generally occurs following the first significant rainfall, after which runoff concentrations drop to lower levels that can persist for up to two years post-application (Scrifres et al. 1971; Johnsen 1980; Mayeux et al. 1984; Michael et al. 1989). Concentrations of 50 ppb are enough to prevent the growth of leafy spurge and concentrations of <1 ppb will inhibit the growth of many common food crops. Runoff concentrations of >1 ppb are common following the application of picloram at recommended rates even under low-runoff conditions (Baur et al. 1972; Bovey et al. 1978; Mayeux et al. 1984; Neary et al. 1985; Michael et al. 1989; Bovey & Richardson 1991). Groundwater concentrations of 0.01-49 micrograms/L have been reported in 11 states (EXTOXNET 1996), and Smith et al. (1988) found picloram in groundwater one km off-site and 35 months following application of 3.38 kg/ha of picloram.

Most researches have concluded that picloram runoff concentrations are not great enough to be a hazard to aquatic species. These concentrations however, could damage crops if used for irrigation, and have been shown to cause damage to the submersed macrophytes *Potamogeton pectinatus* L. and *Myriophyllum sibiricum* Komarov (Forsyth et al. 1997). Because many studies were conducted under laboratory conditions, it is difficult to draw conclusions regarding the impact of picloram contamination in wildland aquatic systems.

Vegetation

In non-susceptible species such as grasses, picloram is metabolized rapidly, while in susceptible species, picloram can remain intact for extended periods (WSSA 1994). When applied to soil, picloram is readily absorbed by plant roots. When applied to foliage, the majority of picloram (70-90%) remains in the leaves and only a small percentage is conducted to stems and roots (Meikle et al. 1966; Cessna et al. 1989; Hickman et al. 1990). Unabsorbed picloram remaining on leaf surfaces may photodegrade in sunlight or be washed off with rainfall or irrigation. Picloram absorbed by plants can be released into the soil by passive transport through the roots and then taken up by roots of other nearby plants (Hickman et al. 1990). Therefore, even

selective application of picloram to specific target plants could potentially harm nearby desirable plants.

Environmental Toxicity

Birds and Mammals

Picloram is “slightly to practically nontoxic” to birds and mammals. The LD50 for rats is >5,000 mg/kg (WSSA 1994). For bobwhite quail and mallard duck the LD50s are >5,000 and >2,510 mg/kg, respectively. However, because of the long-term persistence of picloram in the environment, chronic exposure of wildlife to picloram is of concern. John-Greene et al. (1985) evaluated the potential effects of chronic picloram exposure in New Zealand white rabbits and concluded that there was weight loss in rabbits receiving 200-400 mg/kg/day, but no embryotoxic or teratogenic responses occurred. Liver damage has also been associated with chronic exposure, but only at very high doses that would not be expected from normal pesticide application (EXTOXNET 1996).

Aquatic Species

Picloram is “slightly to moderately toxic” to aquatic species (EXTOXNET 1996). The LC50 (96 hours) for rainbow trout, bluegill sunfish, and fathead minnow are 19.3 mg/L, 14.5 mg/L, and 55 mg/L, respectively (EXTOXNET 1996). These values are above the peak runoff concentrations reported by researchers under various environmental conditions (Baur et al. 1972; Bovey et al. 1978; Neary et al. 1979; Johnsen 1980; Mayeux et al. 1984; Lym & Messersmith 1988; Smith et al. 1988; Michael et al. 1989; Bovey & Richardson 1991). Mayes et al. (1987) evaluated the toxicity of picloram to rainbow trout life stages and concluded that picloram is not an acute or chronic hazard to aquatic species when used as directed. Gersch et al. (1985) evaluated the acute and chronic toxicity of picloram to the aquatic invertebrate *Daphnia magna*, and found an LC50 (48 hours) of 68.3 mg/L. The authors concluded that these findings corroborated the “low toxicity” rating of picloram to wildlife and aquatic species (Gersch et al. 1985).

Other Non-Target Organisms

Breazeale and Camper (1972) evaluated the effects of picloram on three soil microbes. Picloram had no effect on two species, *Erwinia carotovora* and *Bacillus* sp., but inhibited growth in *Pseudomonas fluorescens* by 28.8%. Experiments by Dow AgroSciences concluded that picloram does not bioaccumulate in organisms, reducing the potential that it could be passed through the food chain to various animals including humans (Mullison 1985).

Application Considerations:

Brian Winter, TNC land steward in western Minnesota, recommends mixing a dye (e.g., Highlighter[®]) with the picloram formulation for use against leafy spurge, so treated and missing areas are easy to spot. Treated areas should be checked for regrowth in June and individual spots sprayed with a backpack sprayer. An additional benefit of using a dye is that the chance of overspray is minimized.

Safety Measures:

Picloram acid and its derivatives can be highly toxic if inhaled. Severe eye damage can also be caused by picloram. Product labels and Material Safety Data Sheets should be thoroughly reviewed prior to use and all precautionary measures followed to prevent dangerous exposure.

Human Toxicology:

As with all herbicides, applicators are at greatest risk of exposure to potential toxicants. Libich et al. (1984) reported that workers applying picloram on electric right-of-ways with hand-held spray guns were exposed to airborne residues of <0.2-10.5 micrograms per cubic meter of air. These workers later excreted <0.01-1.30 mg of picloram for every kilogram of body weight through their urine (Libich et al. 1984).

In a study of the fate of picloram in humans, six volunteers were given picloram either orally or dermally at 0.5 or 5.0 mg/kg of body weight. Study results found that picloram was absorbed rapidly through the gastrointestinal tract when ingested but passed through skin slowly with dermal exposure (Stevens & Sumner 1991). After 72 hours over 90% of the ingested picloram was passed through unchanged in the urine. The volunteers reported no adverse effects (Stevens & Sumner 1991).

The Suggested No-Adverse-Response Level for picloram recommended by the National Research Council's Safe Drinking Water Committee is 1.05 ppm (Mullison 1985). At least one study found picloram runoff concentrations in excess of this amount (2.3-3.3 ppm) when applied as pellets at the rate of 2.24 kg/ha to soils of the Blackland Prairie in Texas (Bovey et al. 1978). The pellet formulation of picloram, however, is no longer available in the U.S. Picloram and its derivatives can be highly toxic when inhaled and can cause severe eye damage. EPA classified picloram as a "Group E" compound, or a chemical that has not shown evidence of carcinogenicity in humans (EPA 1995).

References

- Baur, J. R., R. W. Bovey, and M. G. Merkle. 1972. Concentration of picloram in runoff water. *Weed Sci.* 20(4):309-313.
- Bovey, R. W., and C. W. Richardson. 1991. Organic chemicals in the environment. *J. Environ. Qual.* 20:528-531.
- Bovey, R. W., C. Richardson, E. Burnett, M. G. Merkle, and R. E. Meyer. 1978. Loss of spray and pelleted picloram in surface runoff water. *J. Environ. Qual.* 7(2):178-180.
- Breazeale, F. W., and N. D. Camper. 1972. Effect of selected herbicides on bacterial growth rates. *Appl. Microbiol.* 23(2):431-432.
- Cessna, A. J., and J. Waddington, and S. Bittman. 1989. Residues of 2,4-D and picloram in aspen poplar and soil after application with a roller. *Can. J. Plant Sci.* 69:205-212.
- Close, M. E., L. Pang, J. P. C. Watt, and K. W. Vincent. 1998. Leaching of picloram, atrazine and simazine through two New Zealand soils. *Geoderma* 84:45-63.
- Deubert, K. H., and I. Corte-Real. 1986. Soil residues of picloram and triclopyr after selective foliar application on utility rights-of-way. *J. Arbori.* 12(11):269-272.

- E.P.A. 1995. Picloram. R.E.D. Facts. Prevention, Pesticides and Toxic Substances. EPA-738-F-95-018.
- EXTOXNET. 1996. Picloram. Pesticide Information Profiles. Extension Toxicology Network. <http://ace.orst.edu/info/extoxnet/>.
- Farmer, W. J., and Y. Aochi. 1974. Picloram sorption by soils. *Proc. Soil Sci. Soc. Amer.* 38:418-423.
- Forsyth, D. J., P. A. Martin, and G. G. Shaw. 1997. Effects of herbicides on two submersed aquatic macrophytes, *Potamogeton pectinatus* L. and *Myriophyllum sibiricum* Komarov, in a prairie wetland. *Environ. Pollut.* 95:259-268.
- Fryer, J. D., P. D. Smith, and J. W. Ludwig. 1979. Long-term persistence of picloram in a sandy loam soil. *J. Environ. Qual.* 8(1):83-86.
- Gersich, F. M., D. L. Hopkins, and D. P. Milazzo. 1985. Acute and chronic toxicity of technical picloram (4-amino-3,5,6-trichloropicolinic acid) to *Daphnia magna* Straus. *Bull. Environ. Contam. Toxicol.* 35:121-126.
- Grover, R., and G. G. Bowes. 1981. Picloram residue levels for the control of leafy spurge regrowth. *Can. J. Plant. Sci.* 61:661-664.
- Hance, R. J. 1967. Decomposition of herbicides in the soil by non-biological chemical processes. *J. Sci. Food Agric.* 18:544-547.
- Helling, C. S., P. C. Kearney, and M. Alexander. 1971. Behavior of pesticides in soil. *Adv. Agron.* 23:147-240.
- Hickman, M. V., C. G. Messersmith, and R. G. Lym. 1990. Picloram release from leafy spurge roots. *J. Range Manage.* 43(5):442-445.
- Johnsen, T. N., Jr. 1980. Picloram in water and soil from a semiarid pinyon-juniper watershed. *J. Environ. Qual.* 9(4):601-605.
- Johnsen, T. N., Jr., and R. D. Martin. 1983. Altitude effects on picloram disappearance in sunlight. *Weed Sci.* 31:315-317.
- John-Greene, J. A., J. H. Ouellette, T. K. Jeffries, K. A. Johnson, and K. S. Rao. 1985. Teratological evaluation of picloram potassium salt in rabbits. *Food Chem. Toxic.* 23(8):753-756.
- Jotcham, J. R., D. W. Smith, and G. R. Stephenson. 1989. Comparative persistence and mobility of pyridine and phenoxy herbicides in soil. *Weed Tech.* 3:155-161.
- Libich, S., J. C. To, R. Frank, G. J. Sirons. 1984. Occupational exposure of herbicide applicators to herbicides used along electric power transmission line right-of-way. *Am. Ind. Hyg. Assoc. J.* 45(1):56-62.
- Liu, L., J. A. Dumas, and C. L. Cacho. 1997. Picloram groundwater contamination from pasture use. *J. Agric. Univ. P. R.* 81(3-4):211-218.
- Lym, R. G., and C. G. Messersmith. 1988. Survey for picloram in North Dakota groundwater. *Weed Tech.* 2:217-222.
- Mayeux, H. S., Jr., C. W. Richardson, R. W. Bovey, E. Burnett, M. G. Merkle, and R. E. Meyer. 1984. Dissipation of picloram in storm runoff. *J. Environ. Qual.* 13(1):44-49.
- Mayes, M. A., D. L. Hopkins, and D. C. Dill. 1987. Toxicity of picloram (4-amino-3,5,6-trichloropicolinic acid) to life stage of the rainbow trout. *Bull. Environ. Contam. Toxicol.* 38:653-660.
- McCall, P. J., and G. L. Agin. 1985. Desorption kinetics of picloram as affected by residence time in the soil. *Environ. Toxicol. Chemistry* 4:37-44.

- Meikle, R. W., E. A. Williams, and C. T. Redemann. 1966. Metabolism of Tordon herbicide (4-amino-3,5,6-trichloropicolinic acid) in cotton and decomposition in soil. *J. Agr. Food Chem.* 14(4):384-387.
- Merkle, M. G., R. W. Bovey, and F. S. Davis. 1967. Factors affecting the persistence of picloram in soil. *Agron. J.* 59:413-415.
- Michael, J.L., D. G. Neary, and M. J. M. Wells. 1989. Picloram movement in soil solution and streamflow from a coastal plain forest. *J. Environ. Qual.* 18:89-95.
- Mullison, W. R. 1985. A toxicological and environmental review of picloram. *Proc. West Soc. Weed Sci.* 38:21-92.
- Neary, D. G., P. B. Bush, J. E. Douglass, and R. L. Todd. 1985. Picloram movement in an Appalachian hardwood forest watershed. *J. Environ. Qual.* 14(4):585-592.
- Neary, D. G., J. E. Douglass, and W. Fox. 1979. Low picloram concentrations in streamflow resulting from forest application of Tordon-10K. *Proc. South. Weed Sci. Soc.* 32:182-197.
- Norris, L. A. 1986. Accuracy and precision of analyses for 2,4-D and picloram in streamwater by ten contract laboratories. *Weed Sci.* 34:485-489.
- Phillips, W. M., and K. C. Feltner. 1972. Persistence and movement of picloram in two Kansas soils. *Weed Sci.* 20(1):110-116.
- Scifres, C. J., R. R. Hahn, J. Diaz-Colon, and M. G. Merkle. 1971. Picloram persistence in semiarid rangeland soils and water. *Weed Sci.* 19(4):381-384.
- Smith, A. E., D. Aite, R. Grover, L. A. Kerr, L. J. Milward, and H. Sommerstad. 1988. Persistence and movement of picloram in a northern Saskatchewan watershed. *J. Environ. Qual.* 17(2):262-268.
- Spiridonov, Y. Y., V. G. Shestakov, V. S. Bonadarev, N. S. Trunovaskaya, and A. V. Varovin. 1987. Contributions of the principal biological and physicochemical processes to the detoxification of picloram in soil. *Soviet Soil Sci.* 19(3):41-45.
- Stevens, J. T., and D. D. Sumner. 1991. Herbicides. Chapter 20 *in* Handbook of pesticide toxicology, Vol. 3, Classes of herbicides. W.J. Hayes, Jr. and E. R. Laws, Jr. eds. Academic Press, Inc. San Diego, California. 1576 pages.
- Trichell, D. W., H. L. Morton, and M. G. Merkle. 1968. Loss of herbicides in runoff water. *Weed Sci.* 16:447-449.
- WSSA. 1994. Herbicide handbook. Weed Society of America. Champaign, Illinois. 352 pp.
- Watson, V. J., P. M. Rice, and E. C. Monnig. 1989. Environmental fate of picloram used for roadside weed control. *J. Environ. Qual.* 18:198-205.
- Woodburn, K. B., D. D. Fontaine, E. L. Bjerke, and G. J. Kallos. 1989. Photolysis of picloram in dilute aqueous solution. *Environ. Toxicol. Chem.* 8:769-775.

Date Authored: April 2001