

Synopsis

Summary for the Operational Forester

Introduction

When choosing a herbicide for vegetation management, efficacy is usually the first criterion. However, effectiveness of the herbicide should not be the only concern. What about its fate in the environment? What happens to that portion of the herbicide that does not reach or is not used up by its target? What are the processes involved in dissipating the herbicide in the environment and reducing its toxicity? What is the potential for the herbicide moving off (the applied) site with rain or melt water? Will the herbicide leach down through the soil profile? What may be the impact if the herbicide inadvertently reaches an aquatic environment and how will it dissipate? These are important concerns; questions that you may be asking yourself or may be faced with by an inquisitive public or landowner. The answers are based on an understanding of how the properties of a particular herbicide cause it to interact with a specific environment. This understanding allows us to predict the behaviour of the herbicide in the forest environment.

The following six pages focuses on understanding this interaction. The information included in the summary can be readily divided into two topic areas:

- 1) How the different properties of the environment affect the fate of herbicides, and

The Fate of Herbicides in the Forest Environment

- 2) Some physical and chemical properties of current herbicides used in forest vegetation management in British Columbia.

This information is provided to assist you in understanding the fate of a herbicide beyond its target and in choosing the appropriate herbicide for the environment to which it will be applied.

Definition of Terms

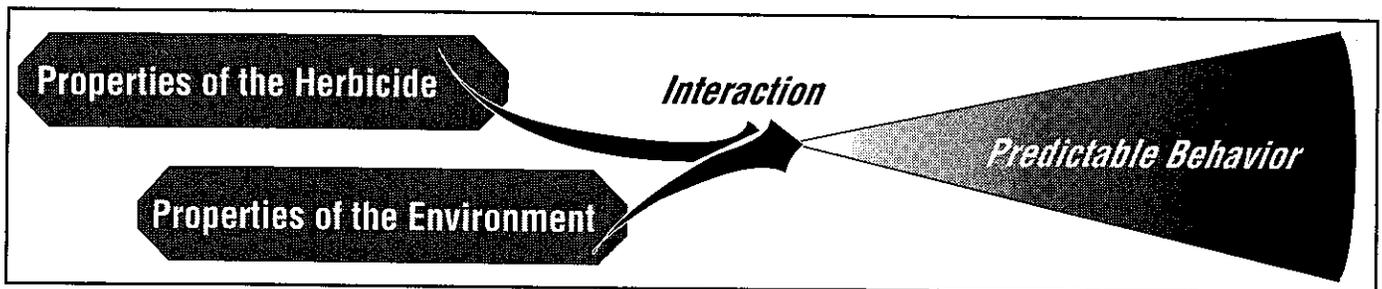
Toxicity: The degree to which a substance is poisonous or injurious to a plant or animal.

Acute Toxicity: The potential for a herbicide to cause ill health or death within a few hours to a few days after a single dose or exposure.

LC₅₀: A statistic used to indicate degree of toxicity. It is normally expressed in weight per unit volume as the ppm (parts per million) of a herbicide in the air or water sufficient to kill half of the test animals exposed for the predetermined period of time, usually 96 hours.

LD₅₀: A statistic used to indicate degree of toxicity. It is expressed as the number of milligrams of a toxicant per kilogram of body weight of an animal, sufficient to kill 50% of such animals.

Chronic Toxicity: An adverse effect which results from exposure to many small doses of a herbicide over a long period of time.



FOREST RESOURCE DEVELOPMENT AGREEMENT

Bioaccumulation: The uptake and temporary storage and accumulation of a herbicide from the environment by an organism.

Biomagnification: The increase in concentration of a herbicide through the trophic levels of a food chain.

Absorption: The movement of a herbicide from the surface into a body.

Adsorption: The adherence of a herbicide to the surface of a plant or soil particle.

Degradation: The reduction of a complex chemical to a less complex form by chemical or biological processes.

Photodecomposition: The degradation of a complex substance such as a herbicide into more simple compounds from the action of sunlight.

Leaching: The movement of a herbicide through a soil by water.

Mobility: The movement of a herbicide through a soil.

Solubility: The amount of a herbicide that will dissolve in a given amount of another substance (e.g. water).

Volatilization: The process of changing the physical state of a herbicide from liquid to vapour. It is directly related to the vapour pressure of the herbicide.

Concept of Degree of Hazard/Risk

As with most other forest management activities the use of chemicals in the forest introduces a source of danger, i.e. a hazard. This hazard can be defined in terms of the risk of inducing adverse effects to non-target organisms. The degree of risk is based on:

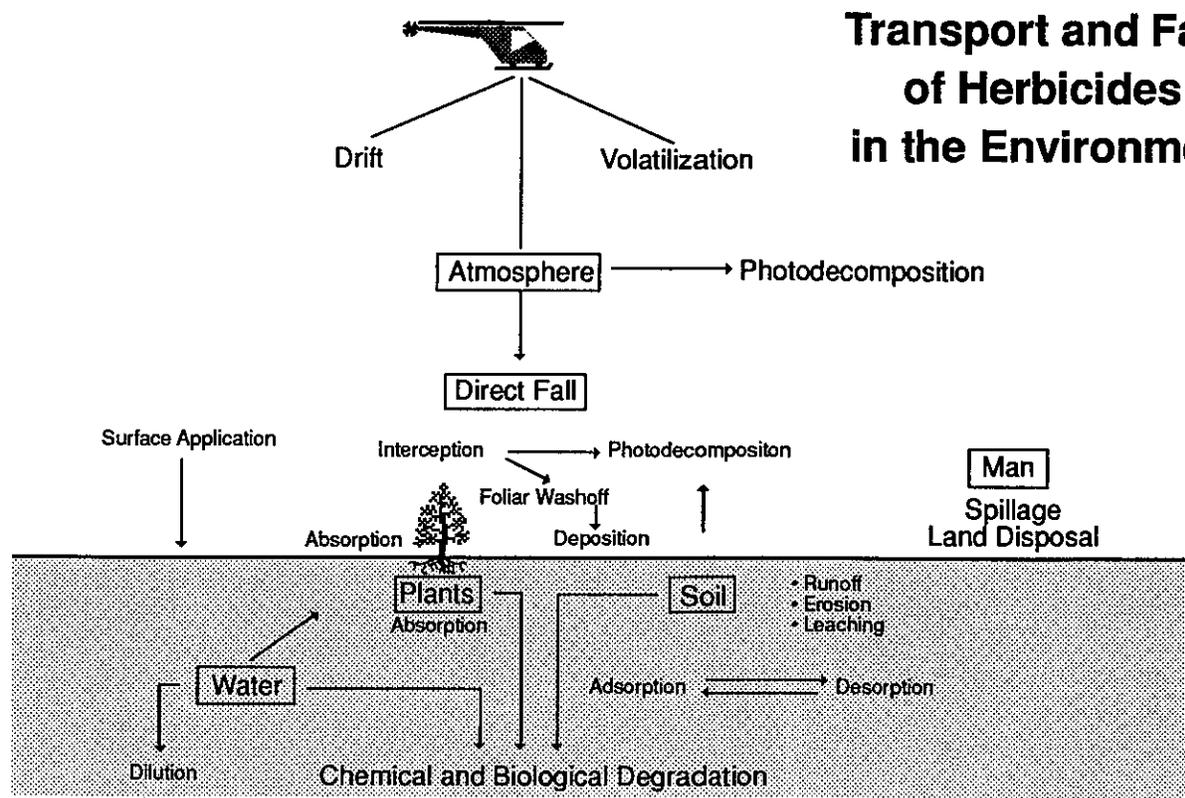
- toxicity of the chemical, and
- likelihood of exposure of non-target organisms to toxic doses.

The toxicity of a herbicide is a fixed property. However, the likelihood of exposure results from the behaviour of the herbicide in the environment and is dependent on:

- method of application
- persistence
- mobility

A good understanding of the relationships between each of these three factors and the likelihood of exposure will reduce the risk associated with the use of herbicides by helping choose the right herbicide for a particular environment and application.

Transport and Fate of Herbicides in the Environment



Properties of the Environment and How They Affect the Fate of Herbicides

Soil

Texture: The degree of adsorption of the herbicide in the soil is highly dependent on soil texture. Coarse-textured soils (e.g. sand) offer only a few charge sites per unit volume, reducing the capture rate of oppositely charged herbicide molecules. Fine-textured soils (e.g. clay) have many charge sites, increasing the capture rate and consequently immobilizing more of the herbicide molecules.

Organic matter: Has many charge sites per unit volume to immobilize charged herbicide molecules (many more than clay).

pH: Generally, as pH decreases (i.e. increasing acidity), adsorption of herbicide molecules is greater and mobility is lower.

Permeability: Reducing soil permeability (e.g. skid roads and landings) generally increases the potential for surface erosion, and consequently increases the potential for surface transport of herbicides attached to soil particles.

Site

Moisture regime: The rate of degradation of a herbicide is a function of, among others, soil moisture. Degradation rates can be severely reduced in a saturated soil (anaerobic medium), or under very dry conditions. For water-soluble soil-mobile herbicides, excess water (through flooding or high water table) can increase the potential for off-site movement, and decrease the rate of degradation.

Slope: Downslope movement of herbicides may occur either in soil solution (for soil-mobile herbicides) or attached to soil particles on erodible soils. The potential for both of these processes occurring increases with the steepness of slope.

Microbial activity: The number, kinds and activity level of microorganisms directly affect rates of microbial degradation, one of the most important ways of breaking down herbicides. Microbial activity and consequently the rate of microbial degradation of a herbicide are increased under favourable conditions of soil temperature, moisture, pH and organic matter content (these favourable conditions are individually described above and below).

Climate

Rainfall regime: Rainfall can wash herbicides off the vegetation (if the rainfall occurs within a few hours after spray). It can also cause surface erosion resulting in transport of the herbicide and can facilitate leaching and horizontal movement of herbicide within the soil. Leaching is more severe under continuous rather than intermittent rainfall.

Temperature: Cold and extremely hot conditions can reduce the level of microbial activity and consequently the level of microbial degradation of the herbicide. Temperature also influences adsorption through its effects on the solubility and vapour pressure of the herbicide. A decrease in temperature decreases solubility, which increases adsorption and vapour pressure, which decreases volatilization.

Snowmelt: Large amounts of water can be released over a short period of time onto a soil still frozen. This can facilitate overland movement of herbicides both in solution state and adsorbed on soil particles.

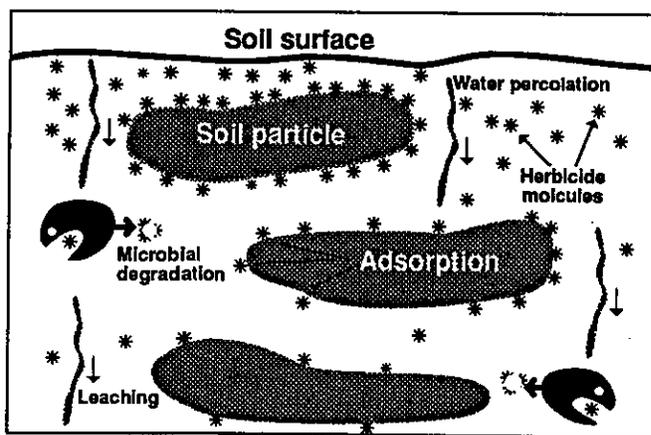
Wind: Wind can cause spray drift as well as movement of herbicide-laden dust particles.

Solar radiation: Affects rates of photodecomposition.

Fate of Herbicides in the Soil

Whether a herbicide has reached the soil directly or has been washed off a plant, it may be subject to several or all of the following processes:

- adsorption/leaching/runoff
- chemical and microbial degradation
- photodegradation
- volatilization



Adsorption is a complex phenomenon which depends on the properties of the chemical (Table 1) and the nature of the soil. With extensive adsorption, both downward movement (leaching) and lateral movement (runoff) will be retarded and the amount of herbicide available for plant uptake through the roots will be reduced.

Adsorption immobilizes the herbicide while chemical and microbial processes degrade it. Microbial degradation is by far the major route for dissipation of herbicides from the soil (Table 1).

Both volatilization and photodegradation are negligible processes for the herbicides reviewed in Table 1.

Fate of Herbicides in the Water

Mechanisms for dissipation of herbicides in the aquatic environment include:

- dilution
- adsorption on sediments
- chemical and/or microbial breakdown
- volatilization and photodegradation

Microbial action is the most prevalent form of herbicide degradation in water. Other methods and routes of degradation are discussed in Table 1.

Routes of Entry into Aquatic Environments

Stream contamination is probably the biggest environmental concern in the forest because water is the habitat for many species of plants and animals and because water may be utilized downstream for domestic, industrial and agricultural purposes as well. The magnitude and duration of exposure of organisms in forest waters is largely determined by the route of entry and subsequent behaviour of the chemical in the aquatic environment.

Possible routes of entry include:

- direct application to surface waters
- drift from nearby spray areas
- mobilization in ephemeral streams
- overland flow
- leaching

Direct application and drift are largely controlled by the method of application and the operator. Improvements in technology, regulations and applicator training have almost eliminated the occurrence of herbicides entering the aquatic environment by these two routes of entry. The other three routes are essentially controlled by the envi-

ronment (thus the need to know your environment).

Mobilization in ephemeral streams: Soil-mobile herbicide residues present in seasonal stream beds or in areas of high water tables may be mobilized and transported towards larger water bodies following heavy rainstorms.

Overland flow: Overland flow occurs infrequently on forest lands, but erosion can transport herbicides adsorbed on soil particles into the aquatic environment.

Leaching: Deep leaching of herbicides is not likely to occur in forest environments because of the fine textures and organic matter content of forest soils. Also, herbicides used in B.C. are not persistent enough to allow significant leaching to occur (i.e. greater than 1 meter).

Bioaccumulation

Bioaccumulation is a function of:

- the level of fat in the animal
- the ratio of solubility of the herbicide in fat to its solubility in water

Consequently, bioaccumulation occurs most in organisms with storage fats and which are exposed to chemicals that have a high fat solubility and a low water solubility (such as DDT).

Forest herbicides show little tendency to bioaccumulate because their solubility in water is high (Table 1).

Risk Management

Knowing how a herbicide interacts with its environment, its behaviour is more predictable. Consequently, legislation and policy – such as the examples listed – have been established to manage the risk involved with using herbicides:

- the necessity to complete extensive studies on environmental fate before full registration can occur.
- the requirement for buffer strips and pesticide free zones around all water bodies to minimize the possibility of herbicides entering the aquatic environment.
- the successful completion of a pesticide applicators courses by project leaders.
- a permit system requiring referrals to numerous other agencies.
- the establishment and enforcement of WCB safety requirements.

TABLE 1. Environmental properties of herbicides used in British Columbia for forestry vegetation management

COMMON NAME Trade Name	Mode of Uptake	Water Solubility	FATE IN SOILS				
			Adsorption	Potential for Leaching	Potential for Runoff	Chemical/Microbial Degradation	Photodegradation/Volatilization
GLYPHOSATE Vision® formerly Roundup®	Foliage and cut stem surfaces	High: 1.2g/100g	Very Strong: Highest to organic matter and clays, low in sands	Minimal	Minimal	No chemical degradation. Rapid microbial degradation, half life = 60 days in favourable conditions.	Both are negligible
2,4-D Amine Forestamine® Guardsman® Formula 40®	Stem, cut surfaces, some foliar uptake.	Very high: 300g/100g	Parent acid is strongly adsorbed to organic matter but weakly adsorbed to clays. The extent of adsorption depends on formulation. 2,4,D acid is relatively mobile (class 4), however in forest soils leaching is generally confined to the top 10 cm.	The potential for leaching of the parent acid is low when organic matter is present. Potential for leaching increases with increases in soil pH.	Because of its high mobility, significant runoff could occur from soils low in organic matter content and where rainfall is high. This would generally not be the case for forest soils.	Through both chemical and microbial processes 2,4-D esters and amines are quickly converted to the parent acid. Under favourable conditions (i.e. high organic matter content, adequate moisture, warm temperatures and high pH) half life of 4-5 days has been reported. For less ideal conditions half life = 1 - 2 months. Degradation of the acid is mostly microbial.	Amount of photodegradation in the field is unknown. Low volatility for amines and esters.
2,4-D Ester Forester® Esteron®	Foliage	Insoluble in water		The potential for leaching is lower for the ester formulation than for the amine.			
HEXAZINONE Velapri®	Mostly roots, some foliar uptake.	High: 3.3/100g	Low adsorption, increases with amounts of organic matter and clay.	Classified as very mobile (class 4), washed into soil with rainwater, can leach several cm into the soil.	On dense soils with low organic matter and areas of high rainfall, runoff of hexazinone may be expected.	Primarily microbial degradation. Reported half life from one month to 1 year, longer for colder, wetter soils.	Photodegrades on soil surface. Volatilization is negligible.
TRICLOPYR Garlon 4® (ester)®	Foliage and stem cut surfaces.	Ester: very low Ester degrades rapidly to acid (<1 day) Acid: high 4.3g/100g	Ester: strong adsorption Acid: weak adsorption and considered mobile. Adsorption increases with amount of organic matter and clay.	Acid is leachable in soils with low clay and organic matter content (generally not the case for forest soils).	On compacted soils with low organic matter and areas of high rainfall, runoff of triclopyr (acid) may be expected.	Primarily microbial degradation. Reported half life: 46 to 156 days, longer for wetter colder sites. Chemical degradation negligible.	Photodegradation on the soil and volatilization are negligible.

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FATE IN WATER			IMPACT ON NON-TARGET ORGANISMS			Bioaccumulation Potential
Chemical Degradation	Microbial Degradation	Photo-Degradation	Aquatic Organisms	Soil Organisms	Birds, Insects, Mammals	
None	Half life approximately two weeks, major route of degradation.	Negligible	Toxicity classed as slight. 96 hr LC ₅₀ (trout): 32mg/l (Vision®) Surfactant: 2mg/l	Impact is minimal to nil under aerobic and anaerobic conditions.	Low toxicity to wildlife birds and insects. LD ₅₀ (mammal): 5400 mg/kg (Vision®) LD ₅₀ (birds): 4640 mg/kg	None
In the aquatic environment formulations of 2,4-D amine or ester dissociate or hydrolyse rapidly to the acid.	Rapid where water is warm and nutrient rich, i.e. conditions where micro-organisms flourish. Substantially slower in less favourable conditions.	Negligible	Toxicity classed as low. 96 hr LC ₅₀ (trout): 250mg/l	2,4-D is readily decomposed by soil organisms, and non toxic to these.	Low hazard to bees and other insects from direct toxicity. Few effects on birds observed. Low toxicity to mammals. LD ₅₀ (mammal): 300-2000 mg/kg.	None
		Negligible	Some formulations of esters can be moderately toxic, however the esters rapidly hydrolyze to the acid form. 96 hr LC ₅₀ (trout): 1 mg/l (ester)	2,4-D is readily decomposed by soil organisms, and non toxic to these.	Low hazard to bees and other insects from direct toxicity. Few effects on birds observed. Low toxicity to mammals. LD ₅₀ (mammal): 300-1000 mg/kg. LD ₅₀ (birds): 400 mg/kg (acid)	None
Negligible	The major cause of hexazinone reduction in natural waters.	Photodegradation can be responsible for up to 30% of breakdown in a period of 5 weeks.	Toxicity classed as low: 96 hr LC ₅₀ (trout): 872 mg/l.	Non toxic. Tests have shown no effect on fungus or nitrifying bacteria.	Low toxicity to mammals and birds. No data for insects. LD ₅₀ (mammal): >3000 mg/kg LD ₅₀ (birds): 2250 mg/kg	None
Minor	Quantitative data unavailable, considered negligible.	Major pathway for dissipation. half life = 10hrs (at 25°C)	Ester formulation is moderately toxic. 96 hr LC ₅₀ (trout): 0.7 - 2.24mg/l. However, the ester is rapidly hydrolyzed to the less toxic acid. 96 hr LC ₅₀ (trout): 117 mg/l (acid).	Non toxic.	No data available for insects. Low toxicity to birds and mammals. LD ₅₀ (mammal): 2300 mg/kg LD ₅₀ (birds): 1698 mg/kg	None

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