HERBICIDE USE IN NORTH AMERICAN FORESTRY:

A Literature Survey and an Assessment of its Environmental Impact and its Future Potential for Forest Management in the Prairie Provinces of Canada

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ABSTRACT

The increasing demand for higher softwood timber products, the shrinking forest land base, and the urgent need for rehabilitation of vast tracts of non-productive forest lands across North America call for rapid implementation of intensive forest management practices and extensive reforestation operations. It has long been realized that the use of herbicides should be an integral part of forest management practices. However, because of public concerns about their alleged environmental hazards, and inadequate research and development efforts, the true potential of herbicides in forest productivity has not been realized. Industry as well as government involvement in research and development of herbicides for forestry has been minimal compared to the agricultural uses of herbicides.

The available information on efficacy, selectivity, environmental chemistry and environmental impact of herbicides with potential for forestry purposes has been reviewed. The major emphasis is on new herbicides evaluated in Canadian forest regions. The gaps in our knowledge of the environmental chemistry and the environmental impact of the new herbicides have been pointed out. The current status of herbicides and herbicide research in Canada has been reviewed. Factors limiting the use of herbicides in Canadian forestry have been discussed and recommendations for a program for the critical needs of the prairie provinces have been made.

SUMMARY

Current Status of North American Forestry

1. The total forest land base in the United States is 299 million ha. The commercial forest land base covers 197 million ha. Only about half of this area may be available for timber production at any one time. Harvest levels have been steadily falling. Demand for wood supply may double by the year 2000 and much of this increased demand has to be imported.

   The total forest land base in Canada is 436 million ha. The productive forest land is estimated at 200 million ha. At present about 800,000 ha is harvested annually. About half of this area does not receive reforestation. This trend has resulted in a backlog of 30 million ha of unregenerated forest land. About 145 million m^3 of timber is lost to insects, disease, fire and inept reforestation practices. The current AAC is fixed at 165 - 175 million m^3, but the CCREM target for the year 2000 is 210 million m^3.

2. Competition from hardwood species and grasses is one of the main factors contributing to stand failure and establishment.

3. In order to meet the present demands and future challenges of society's need for timber products, forest productivity must be increased and vast tracts of unproductive forest lands that have been invaded by deciduous brush and perennial grasses must be replanted.

4. Intensive forest management practices and extensive reforestation operations must be launched in order to remedy the neglect of the past decades. Intensive, efficient and economical methods of vegetation management with least environmental impact must be

employed at once.

The Need for Herbicide Use

1. Non-chemical methods of vegetation control are employed now but they are not efficient and economical and may be counterproductive since they encourage the resprouting of brush in certain situations. Mechanical and prescribed burning methods of brush control are not feasible on certain soils and topography. The physical impact of these methods may be greater, long-lasting and more disruptive of the forest ecosystem than the chemical methods.

2. Herbicides have been used in North American forestry ever since the discovery of the phenoxyacetic acids, however, such herbicide use is not as common and not as widely accepted as the agricultural uses of herbicides. In the U.S., about 80 million ha of corn, wheat and soybeans receive at least one herbicide application per year. Over 20 million kg of 2,4-D and 2,4,5-T were manufactured in 1977 but less than 0.9 million kg of the two herbicides were intended for silvicultural practices. In Canada, about 24.7 million kg of agricultural chemicals is used on about 30 million ha of agricultural land; the forestry uses of all chemicals is 0.45 million kg. The total amount of herbicides currently used on about 75,000 ha of forest land constitutes only 0.5% of the amount used for agricultural purposes.

3. Intensively cultured forest stands have produced more than twice the yield of natural stands. The versatility and selectivity of the herbicides serve all phases of forest management, ranging from weed control in nurseries to site preparation to stand release and improvement. The alternative methods all have limitations and cannot be applied under all circumstances.

Herbicides with Potential for Forest Management Practices

Glyphosate (ROUNDUP): Glyphosate is seen as an effective and promising alternative to the increasingly restricted 2,4,5-T. Possible applications of glyphosate in forest management practices include site preparation, thinning, as well as release operations because of partial tolerance of conifers. Our knowledge of efficacy and selectivity of glyphosate for forestry purposes is substantial.

Hexazinone (VELPAR): Hexazinone is a new triazine herbicide used for site preparation, conifer release, thining, and for weed control in plantations. With the development of VELPAR Gridball, a new concept in herbicide application called the "grid pattern" came into use.

Triclopyr (GARLON): Triclopyr is an auxin-type selective herbicide used for control of woody plants and broadleaf weeds in site preparation and for maintenance of rights-of-way in the U.S. In Canada, it has been evaluated for conifer release, thinning and stump treatment.

Fosamine Ammonium (KRENITE): Fosamine is a slow-acting herbicide like glyphosate which is applied to woody vegetation in late summer. In the U.S., it is used for site preparation and maintenance of rights-of-way. Efficacy and selectivity data for release and thinning operations in the Canadian forest regions are very limited.

Other herbicides that have been evaluated for forestry purposes and that merit further investigation include DPX T6376, karbutilate, sethoxydim (POAST) and HOE 0061.

2,4-D is still the number one herbicide used in North American forestry, but all uses of 2,4,5-T and silvex have been banned in the U.S. 2,4,5-T is becoming increasingly restricted and unavailable in Canada.

The older herbicides that have been used in Canada on a limited scale for weed control in nurseries and plantations as well as in range and woodland management include amitrole, asulam, atrazine, bromacil, dalapon, dicamba, dinoseb, diphenamid, linuron, napropamide, picloram, prometryn, propazine, simazine and tebuthiuron.

Behavior of Herbicides in the Forest Environment

Data on adsorption/desorption, lateral and downward movement, persistence in soil, sediment and water, and chemical/microbiological breakdown of the new herbicides in the forest environment are very limited in the U.S. and almost non-existing for Canadian forest regions. The only data available for environmental chemistry of glyphosate, hexazinone, fosamine and triclopyr are the minimum required data submitted by the industry to Agriculture Canada for registration and hence not accessible for a critical review.

Environmental Impact of Forestry Uses of Herbicides

Our knowledge of the impact of forestry application of herbicides on aquatic and terrestrial life is limited to the U.S. sources. In Canadian forest regions, the available literature on glyphosate is limited to studies on *Daphnia magna*, deer mouse and black-tailed deer in B.C. Data submitted to Agriculture Canada in support of registration of hexazinone, fosamine and triclopyr are still confidential.

Registration Status of Herbicides

In addition to 2,4-D and 2,4,5-T (banned in several provinces) that have been available for forestry uses, glyphosate and hexazinone (by ground application only) have just been registered in Canada. The federal regulatory agencies require data on drift studies before hexazinone can be registered for aerial application. Data gaps on fosamine are chronic toxicity, and persistence and movement under Canadian edaphic and climatic conditions. Chronic toxicity data are needed for registration of triclopyr.

Factors Limiting Herbicide Use in Forestry

1. Lack of registered herbicides. The Canadian forester needs a large number of versatile, selective yet environmentally safe herbicides for various silvicultural purposes.

2. Reluctance of agricultural chemical companies to invest in research and development of herbicides for forestry uses.

3. The foresters are hesitant to promote herbicide uses because of fear of unfavourable publicity it may generate.

4. Lack of trained foresters in herbicide use.

5. Lack of undergraduate teaching on chemical methods of vegetation management.

6. Inadequate research on the use of herbicides by universities and provincial agencies for their local needs.

7. Negative impact of the media.

Recommendations

Registration: Greater coordination among the federal agencies involved in the registration process is required. A national advisory committee on registration of herbicides for forestry uses should be set up.

Education: Vegetation management should become part of the curriculum in forestry schools. More research grants should be allocated to universities. Public forums should be set up so that the public is informed about the use of herbicides, its risks and benefits.

Research: Available information on environmental chemistry and environmental impact of herbicides on aquatic and terrestrial life is very limited. In cooperation with other federal agencies, the CFS should take the initiative and conduct multi-disciplinary research projects on the environmental aspects of herbicides that have proven to be effective and selective for the management needs of the Canadian forester. Herbicide application technology should also be improved.

In cooperation with FPMI, the NoFRC should develop its own capabilities to conduct research on forestry uses of herbicides for the critical/desperate needs of the prairie provinces.

OBJECTIVES

The objectives of this study were to:

- assess the need for herbicides in forest management with particular emphasis on reforestation operations;
- survey the use of herbicides for forest resource management practices in North American forestry with major emphasis on Canadian forestry;
- review available data on efficacy/selectivity aspects of potential forest herbicides with major emphasis on recent additions;
- find the gaps in our present knowledge of the environmental impact of these herbicides, particularly under Canadian climatic conditions;
- review the registration status of the new herbicides, i.e., data requirements, data available and data gaps;
- make recommendations for a research program for the prairie provinces.

PRESENT STATUS OF FORESTRY IN NORTH AMERICA

United States

The total forest land base in the United States is 299 million ha or about one third of the total land area. The commercial forest land base covers 197 million ha. Only about half of this area may actually be available for timber production because of changing ownership objectives and land classification. The U.S. is a net importer of timber. The present downward trends in harvests will continue and contribute to predicted shortages in softwood timber supplies (Anon., 1978). About 11% of the 406 million m^3 of timber used in 1972 was imported. The softwood supply may be 56 million m^3 less than demand by the year 2000 if relative timber prices increase, and 120.4 million m^3 less if prices remain at 1972 levels (Anon., 1974). The U.S. Forest Service predicted that demand for wood may double by the year 2000 and that much of this increased supply must come from non-industrial private forest land. Vast areas of this land, however, have been producing much below capacity (Dierauf, 1978). According to the National Task Force on Forestry, forest productivity is declining rapidly because of lack of basic research (Sundaram and Prasad, 1983).

Severe shortfalls in softwood timber supplies are likely in the Pacific Northwest by 1990. In the South, forest industries developing or expanding forest land base experienced a net loss of about 2.8 million ha, over a span of 10 years, in pine forest types because of inadequate site preparation and reforestation operations. In many areas hardwoods replaced pine on about half of the acreage harvested (Anon., 1978).

CANADA

The total forest land base in Canada is 436 million ha which includes 342 million ha of inventoried and 94 million ha of non-inventoried forest land (Anon., 1982a). About 290 million ha of forest land fall within the 10 provinces. The productive forest land is estimated to be 200 million ha (Reed, 1979). About half of the timber reserve, that is, the difference between the annual allowable cut (AAC) and the actual annual harvest which makes up 17% of AAC, is economically inaccessible (Reed, 1979). The accessible half consists of less valuable species, contains fewer sawlogs, and is generally more remote and hence, transportation costs to the processing plants are much higher.

Currently about 800,000 ha is logged annually. The provincial governments and companies which own 80 per cent of the forest land, replant about 200,000 ha, an additional 200,000 ha regenerates itself naturally, and the remainder, about 400,000 ha, is neglected.

This trend has resulted in a backlog of 30 million ha of unregenerated forest land. Losses of the forest land base area to industrial, urban and recreational uses are estimated at 0.25 - 0.27 million ha (Manville, 1983; Sundaram and Prasad, 1983) annually. Losses to competing vegetation are estimated at one-fifth of the annually harvested area (Manville, 1983).

The B.C. Ministry of forests is currently involved in an assessment of the magnitude of the brush problem in the province (Jones and Boateng, 1983). The extent of the brush problem in all inventory groups is apparent from the following table.

Table 1. Brush Areas of B.C.: Crown Lands (Good and Medium Sites Only)

Brush Group	Hectares
Backlog NSR (Not sufficiently restocked)	342 010
Current NSR (Not sufficiently restocked)	160 350
NC Brush	323 270
Brushed-in SR (Sufficiently restocked)	237 400
Deciduous	1 135 490
Dediduous/Coniferous	551 320
Coniferous/Deciduous	135 780
Total Area	2 885 620

Source: Jones and Boateng, 1983

Damage to forest resources is also considerable. About 90 million m^3 of timber is damaged by insects and diseases, 40 million m^3 is lost because of inept regeneration practices and 15 million m^3 is destroyed by fire. Large forest areas of Manitoba and Saskatchewan have been lost to forest fires. The mountain pine beetle has devastated large timber reserves in Alberta and the infestation is heading north. The AAC has already been exceeded in certain areas of the provinces. Such excesses have resulted in severe shortage of wood, closure of mills, and has created some economic problems in many rural communities across Canada. The critical local shortages of timber are not obvious to the casual observer, and this is one of the reasons why the present state of forestry has been allowed to deteriorate. Recent federal studies indicate that one-tenth of Canada's productive forest land is no longer growing marketable timber (Keating, 1983).

The current level of AAC is set at 165 to 175 million m^3 (Green, 1982) but the Canadian Council for Resource and Environment Ministers' (CCREM) target for the year 2000 is 210 million m^3, a 20% increase over the remaining 16 years. Our national goal is to increase the timber harvest by 50% over the next 25 years (Anon. 1981).

The myth that Canada's vast forest resources are without limit no longer prevails. There is no doubt now that continuous and relentless logging without adequate reforestation operations, particularly since the beginning of this century, has seriously endangered Canada's natural wealth. If future AAC targets are to be met, rapid reforestation operations should be launched and it is with the realization of this urgent need that the new federal renewal policy calls for an increase from $300 million a year to $650 million a year by 1987 (Keating, 1984), even though this increased sum by Ottawa, the provinces, and the industry represents a pitifully small fraction of Canada's forest products earnings which amounted to $23 billion in 1981 and provided one million jobs for Canadians.

In order to remedy the neglect of the past decades and to confront the present and future challenges of society's need for forest products, Canadian forestry must rely increasingly on intensive forest management practices. The rational use of environmentally safe chemicals such as insecticides and fungicides for forest protection and herbicides for regeneration of forests must be accepted as essential forest management techniques of today.

VEGETATION MANAGEMENT IN FORESTRY

Historical Background on the Use of Herbicides

Inorganic salts such as sodium arsenate and ammonium sulphate have been used as herbicides for vegetation management for 60 years. Brush control in Australia and India was documented as early as 1915 (Sutton, 1958). However, the use of herbicides did not gain momentum until after 1945. Although work began on phenoxyacetic acids in 1938, it was not until 1944 when information on biological activity of these chemicals was made public that the activity of 2,4,5-T on woody vegetation was announced and within a few years after the war, it was widely accepted. Within a few years, a large number of organic herbicides such as chloro-s-triazines, amitrole and CIPC were produced. In 1954, about 27,500 ha of brush was treated in Canada (Suggit, 1956) and this increased to 34,000 ha in 1955 (Suggit, 1957). The use of phenoxy herbicides in North American foresty received setbacks in the early 1970's because of the public outcry, often without scientific justification, over their alleged environmental hazards. The RPAR (Rebuttable Presumption Against Registration) process initiated by the

Environment Protection Agency (EPA) in the United States restricted the use of 2,4,5-T and 2,4,5-TP (silvex) and EPA banned all uses of these herbicides in October, 1983.

Herbicide Use in U.S. Forestry

As many as 70 herbicides alone and in combination find some use in forestry, but only 15 herbicides are commonly used (Cutler, 1978). Reliable data are not available for the forest industry, but the U.S. Forest Service use of herbicides during the 15 months of the fiscal year 1976 is presented in Table 2.

Table 1. USFS use of herbicides (July 75 - Sept. 76)

Herbicide	Kg Used	Percent of Use
1. 2,4-D	104,578	55.4
2. 2,4,5-T	38,710	20.5
3. Picloram	27,881	14.8
4. MSMA	5,071	2.7
5. Dalapon	3,341	1.8
6. Simazine	3,281	1.7
7. Atrazine	2,167	1.1
8. 2,4,5-TP (Silvex)	1,690	0.9
9. Dichlorprop	1,059	0.6
10. Dicamba	1,030	0.5
11. Cacodyllic acid	789	-
12. Amitrole	51	-
13. Glyphosate	45	-

Source: Witt, 1978

Over 180,000 kg herbicdes were used for the following purposes:

Table 3. USFS use of herbicides for fiscal year 1976

Kind of Uses	Percent of Uses
Conifer release	59.3
Site preparation	12.8
Right-of-way	11.8
Range rehabilitation	5.5
Thinning	3.6
Aquatic	2.2
Fuel breaks	1.5
Noxious weeds	1.3
General weeds	1.0
Wildlife management	0.8

Source: Witt, 1978

Exact figures on the amount of 2,4-D, and until very recently 2,4,5-T, used in U.S. forestry by other sectors are not available since both compounds are also widely used in agriculture. In 1978 it was estimated that of the 2.7 million kg of 2,4,5-T and 18 million kg of 2,4-D manufactured each year, less than 0.9 million kg of the two were used for silvicultural purposes on approximately 400,000 ha of forest land (Carter et al., 1978). In sharp contrast, about 80 million ha of corn, wheat and soybeans planted annually receive 1 kg/ha or more herbicide. Thus, the amount of herbicide use in forestry represents but a small fraction of the total herbicide usage. Approximately 0.2% of the commercial forest land may be treated in any one year.

With the increasing restrictions on the use of 2,4,5-T in the 1970's, a new generation of herbicides had to be developed. Though none is ever likely to serve as a substitute for 2,4,5-T, four new promising herbicides have been registered over the last five years (Table 4).

Table 4. Use of New Herbicides by USFS in 1982

	Ground Application		Aerial Application	
Herbicide	Amount (kg)	Area (ha)	Amount (kg)	Area (ha)
Hexazinone				
Conifer release	3,177	2,348	903	507
Site prep.	656	345	1,458	718
Rights-of-way	183	90	-	-
Fosamine				
Conifer release	4	0.4	274	81
Rights-of-way	1,670	496	18	1.6
Glyphosate				
Conifer release	1,260	1,228	2,641	1,600
Site prep.	5,036	3,333	2,245	1,016
Rights-of-way	578	275	-	-

Triclopyr				
Conifer release	54	95	1,123	516
Site prep.	21	28	919	372
Rights-of-way	183	102	339	90

Source: USDA Forest Service, 1983.

A total of 192,672 kg of herbicides was applied by USFS to 99,245 ha of National Forest System Lands in 1982. Only 58,691 kg of this total was applied by air to 22,743 ha of forest land.

Herbicide Use in Canadian Forestry

Brush control, whether mechanical or chemical, is considered basic forest management. The need for prudent use of herbicides as an effective tool in silvicultural operations has been recognized ever since the introduction of the phenoxy herbicides. In Canada, herbicides have been used primarily for the control of undesirable hardwood species, the release of conifers, site preparation, and suppression of brush. Small amounts of phenoxy and other selective non-persistent herbicides have also been used in forest nurseries. The use of herbicides as well as other chemicals in forestry, however, has lagged far behind that of agriculture. Agricultural uses of all chemicals total 24.7 million kg; the forestry use of all chemicals is 0.45 million kg or less than 2%. The total amount of herbicides used in Canadian forestry is about 0.5% of the total amount used in agriculture.

Currently, 3.5 million kg active ingredient of 2,4-D is used in the four western provinces of Canada. Only 15,500 kg of this total was used on 62,000 ha of British Columbia's 52 million ha of forest land. Herbicides account for only 18% (90,000 kg) of the total amount of all pesticides used in Canadian forestry. The area treated annually is variously estimated at over 50,000 ha (Sundaram and Prasad, 1983; Manville, 1983) to 75,000 (Anon., 1983b) which represents about 0.2% of the 30 million ha of non-productive forest lands. Individual treatment areas usually do not exceed 100 ha. Herbicide use in forestry, though still very limited, is more common in B.C. and the eastern provinces than the prairies (Table 5).

Table 5. Use of 2,4-D (2.25 - 4.5 kg/ha) in 1980-81

Province	Hectares
Ontario	30,000
New Brunswick	16,200
British Columbia	10,000
Quebec	8,100
Nova Scotia	6,100
Manitoba	1,000
Saskatchewan	120
Alberta	120
Total	71,640

Source: Carlson and Prasad, 1981.

A survey of herbicide use in Canadian forestry was conducted by Ayling and Graham (1978). A questionnaire was prepared and sent to 250 individuals employed by government agencies, industries, or educational institutes. They were asked to review the past, present and future role of herbicides in their forestry operations. About 63% of those who responded indicated that herbicides have or will have a major role in their forest management operations.

Table 6. Herbicide in use in Ontario Forestry as Indicated by Respondents (by percent replies)

Herbicide	Replies (%)	Rate (kg/ha)	Area Treated (ha/yr)
Simazine	32.3	2.2 - 5.6	822* (2,100)+
2,4-D	22.9	0.9 - 5.6	7,200 (14,400)+
2,4-D + 2,4,5-T	14.6	1.4 - 3.4	16,880
Paraquat	7.3	1.5	23,452
Amitrole	6.3	0.6 - 2.2	118
Cacodylic acid	5.2	injected	68
2,4,5-T	3.1	1.1 - 2.2	860
Atrazine	2.1	2.2 - 6.7	-
Pronamide	2.1	1.7 - 2.8	20

Diphenamid	2.1	7.8	76
Chlorthal	2.1	3.4 - 5.6	42

* Minimum hectares treated annually.

\+ Total of all acreages given by respondents. Some replies indicated annual values, others presented only an acreage figure without indicating year or years. These values therefore may overestimate the total area treated.

Source: Ayling and Graham (1978).

The results of a survey conducted in 1983 on herbicide use in 1982 by the B.C. Ministry of Forests and B.C. Forest industry have been summarized by Humphreys (1983).

Alternative Methods of Vegetation Management

Manual

Manual methods of vegetation management consist of hand slashing with chain saws and machetes. Manual control is feasible only in sparsely vegetated areas. It is useful in conifer release operations because of its selective nature. Its practical application is severely limited by the labor force availability, transportation and logistic costs of a large number of workers and the monotonous and intensive nature of the work. Mechanical damage of the crop species is inevitable and the risk of injury to the workers is always there. It is less effective than chemical or prescribed burning practices because the regrowth of cut hardwood stems is usually rapid and profuse.

The economic advantage of chemical (2,4-D) over manual control of competing vegetation in plantations of northern pine in Wisconsin is illustrated in Table 7. Five hand cuttings were needed to obtain the level of conifer release produced by one chemical treatment.

Table 7. Cost and Response of Red Pine-Black Spruce Plantation to Release. Areas: 36 ha, Age: 40 years

Method of Treatment	Cost/ha ($)	Total Cost ($)	Yield (Cords)	Total Value ($)
Herbicide (aerial)	45	6,120	12,240	1,224,000
Herbicide (ground)	225	30,600	12,240	1,224,000
Hand* (chain saw ax, etc.)	625	85,000	12,240	1,224,000
No release			4,420	353,600

*Five retreatments at $125 each.

Source: Anonmyous (1977).

As a recent example, the cost of chemical release operations for 1981-82 in Ontario was $900,000. If the operation had been attempted manually, it would have required 1,300 men at a total cost of $15 million to complete the task (Green, 1982). Therefore, it is obvious that manual vegetation control is economically not a sound proposition.

Mechanical

Mechanical methods include bulldozing, shearing, crushing, chopping, disking and bedding. In addition to providing temporary weed control, these treatments also facilitate slash disposal and subsequent regeneration operations. Mechanical methods are feasible on gentle topography and on relatively dry soils and where there are no large rocks, boulders, stumps or large decaying logs. Since heavy machinery is used, it cannot be applied on slopes and uneven topography because of erosion hazard. Because of compaction problems, mechanical methods can not be employed on wet soils either.

Scalping involves the use of a hoe to clear a space around the planted seedling so that the immediate surrounding is relatively free of the above-ground component of competing vegetation. Below-ground components are only partially removed and lateral roots from the surrounding vegetation of the scalp usually remain active (Newton, 1967). Small scalps may not be effective in providing any relief from moisture competition. Because of re-invasion by weeds (Newton, 1974) under many circumstances, scalping does not ensure survival of the seedling conifers.

Scarification is complete removal of all surface vegetation and any obstacles to planting such as dead and decaying logs and stumps. If the site is not scarified adequately, regeneration from rhizomes, root systems, and resprouting from stumps will occur just like before. The exposure of large expanses of bare mineral soil and abundant light may encourage the regeneration of seral annual grasses and weed species.

Furrowing was used in the U.S. and eastern Canada in intensive reforestation projects. However, because of deep furrows, equipment travel in the area became difficult and potential for erosion was also magnified (White, 1975).

Cultivation methods are not suitable on steep slopes, rocky sites and uneven topography. Weed re-encroachment on a cultivated site will occur before the conifer seedlings get full benefit from cultivation.

Fire

Burning the residual brush and slash after harvest is a common practice that assists in the establishment of a new stand. Burning must be timed to avoid extremely dry or wet conditions. The "brown and burn" technique is increasingly favored where the vegetation is desiccated after very light aerial application of herbicides and then set on fire to remove the aerial biomass. This technique is effective for site preparation but competition from sprouting vegetation may necessitate herbicide application for release operations (Carter et al., 1978). Prescribed burning is most easily used on level or gently rolling terrain. In broken topography and on steep slopes it is difficult to burn uniformly and to control the fire. Proper weather and fuel conditions for a successful prescribed fire are infrequent and may not occur at all in some locations in a given season. Therefore, the workers and equipment must remain idle for days or weeks awaiting proper atmospheric conditions. When topography, fuel conditions and weather are appropriate, fire may be effectively used. But it is not very reliable for continuing operations. Therefore, additional mechanical and chemical operations are needed for adequate site preparation and conifer release operations (Carter et al., 1978).

Adverse Ecological Effects of Non-chemical Alternatives

Mechanical Methods

Although mechanically prepared sites revegetate rapidly, the drawbacks of this method are greater fire hazards through fuel concentration, soil compaction and erosion and subsequent nutrient leaching. Mechanical damage to the crop trees is often unavoidable. Bernstein and Brown (1978) conducted a study in Oregon using chain saws. Over 30% of Douglas fir and western pine were damaged or covered with slash by workers while trying to release them from brush competition. The slash hazard created was also extreme. The physical changes of wildlife habitat brought about by mechanical methods eliminated all site protection and removed all shelter for animals. Other adverse effects were localization of nutrients and maximization of microclimate extremes (Newton, 1975). Mechanical site preparation removes the litter and exposes the mineral soil which contributes to non-point pollution of water.

Fire

Slash burning results in certain ecological changes such as mineralization of forest litter, nutrient loss and erosion. However, the extent of this change is very variable depending on the properties of the fuel, the soil type, the site and the prevailing atmospheric conditions when the fire is set (Ahlgren and Ahlgren, 1960). A complete assessment of the complex ecological changes resulting from burning practices is beyond the scope of this review.

Application of slash burning is limited by logistic, legal and environmental constraints. In the U.S., changes in air pollution regulations may limit this practice (Dierauf, 1978).

Justifications for the Use of Herbicides

Forest productivity is dependent on intensive, economical yet environmentally safe management practices. Intensively cultured forest stands have produced more than twice the yield of natural stands (Wahlenberg 1965; Hansbrough, 1970). The economic benefits and production rates for various alternatives in two regions of the U.S. are illustrated in Table 8. Mechanical methods of vegetation management necessitate a large capital investment. Chemical methods are generally preferred not only for their lower cost but also for greater efficiency and safety compared to other treatments.

The alternative methods all have limitations and cannot be applied under all circumstances. The mechanical methods are too damaging for established stands. Their use is also restricted by topography and soil

Table 8. Typical allocation, costs, and production rates of various weed control practices in two regions of the United States.

Weed Control Practices	Douglas Fir Region Annual % of Reforested Land Treated	Typical Treatment Cost	Typical Production Rate	Southern Pine Region Annual % of Reforested Land Treated	Typical Treatment Cost	Typical Treatment Rate
		($/ha)	(ha/day)	($/ha)	(ha/day)	
Site preparation:						
Chemical	10	37	162	25	37	243
Mechanical	30	173	4	55	124	4
Manual	<1	247	<0.4	<1	148	<0.4
Burning	20	126	16	70	25	16
None	50	-	-	10	-	-
Release:						
Chemical	70	25	162	50	25	243
Manual	<1	272	<0.4	<1	148	<0.4
None	30	-	-	50	-	-

Chemical = aerial application of 2,4,5-T by conventional helicopter.

Mechanical = shearing of brush with bulldozer.

Manual = hand cutting of brush with chain saw or machete.

Prescribed burning = broadcast burning of slash or brush.

Source: Carter et al., 1978.

conditions. Winter scarification which became as common as summer and fall scarification by 1975 in Alberta, has led to heavy vegetation reinvasion (Hellum, 1977). Prescribed burning cannot be used for release operations until conifers have matured beyond the stage of sensitivity to low ground fire. It is useful primarily as a site preparation treatment (Lawrence and Walstad, 1978).

The versatility and selectivity of the herbicides serve all phases of forest management, ranging from soil preparation to stand release and improvement. The herbicides used in forestry are seldom intended to kill the competing vegetation. They suppress weed species so that growth of conifers is favored for a brief period. Unlike agricultural crop production which receives at least one herbicide treatment every year, a forest stand receives one or two applications in 40 to 60 years. Aerial application of herbicides for site preparation rarely kills more than 80% of the woody stems (Carter, 1972). The surviving vegetation produces browse and shelter valuable to wildlife, whereas mechanical methods remove all existing stems. Mast production is delayed for a longer time on mechanically prepared sites. Carter et al. (1975) demonstrated that wildlife habitat was more diverse on chemically prepared sites than on mechanically prepared sites in an Alabama survey. Since herbicide applications have no physical impact, wildlife habitat is modified largely in the ratio of favored food species (Newton, 1975).

Herbicide treatments conserve water and protect the watersheds, whereas mechanical methods destabilize the soil. In an assessment of the ecological impacts of alternatives to the use of herbicides, Kimmins (1975) concluded that "unfortunately, we do not know enough about the potential environmental consequences of these alternatives to claim with confidence that they will necessarily be ecologically superior to the careful use of herbicices".

FORESTRY USES OF HERBICIDES

Site Preparation

When forests are disturbed by fire, blown down by wind, or harvested, they often revert quickly to seral plant communities dominated by perennial grasses and forbs. Eis (1980) observed at several sites in the interior of British Columbia that vegetation that grew under the canopy of white spruce and alpine fir was replaced by aggressive pioneer species after logging of the conifers. Annuals were the first to invade the harvested sites, followed by biennials and perennials. With the change of environment after harvesting and slash burning, the composition of vegetation also changed as full exposure to the sun eliminated most of the shade-tolerant species, and pioneer species invaded the logged-over sites. The species change was practically completed in four years. Reforestation of such sites with native conifers frequently fails. By the time the spring planting of conifer seedlings is completed, herbaceous plants are already established and compete successfully with conifers for available nutrients and most critically deplete available soil moisture.

Therefore, control of grasses and forbs either before or concurrent with planting is normally necessary for adequate survival of the conifers. In the U.S., aerial spraying is used before planting or seeding. Several types of ground equipment can also be used to suppress the unwanted woody vegetation, grasses and forbs.

Conifer Release

Release of conifers from competing hardwood vegetation is essential during the critical years of establishment in order to ensure survival and improve growth rates. For this purpose, herbicides are applied mainly by air. Aerial application is the only alternative, especially where roads are lacking or where large areas are to be treated within a short time. The hardwood competition usually consists of small hardwood sprouts or seedlings, about the same age as conifer seedlings but with higher growth rates. The older and larger hardwoods left from the previous stand may also be part of the competition. Shrubs appear to be a serious hindrance to regeneration of white spruce in the interior of British Columbia (Arlidge, 1967). About 237,000 ha of forests was classified as not satisfactorily restocked, mostly probably due to competing vegetation (Eis, 1980).

In conifer release, the main aim is to divert the resources of the site, such as soil moisture, nutrients and sunlight, from the competing hardwood vegetation to conifer seedlings. The complete removal of a number of plant species from a plant community is not considered desirable for several reasons. Other species may invade which may pose serious competition or may be difficult to control. The animal-use pressure on the target plants to be controlled is not transferred to the desirable woody plants.

Releasing conifers from a brush overstory results in certain changes in microclimate conditions for the trees such as changes in light intensity and quality, diurnal variation in environmental and plant temperatures and soil moisture losses (Gratkowski, 1967). During the critical growth period in early spring, light may be a limiting factor in growth of conifers beneath a brush overstory. Released conifers receive more direct sunlight enriched in both the ultraviolet and infrared ends of the spectrum.

Release of softwood vegetation from hardwood competition in mixed wood cutovers where the two are intimately associated, as in the mixed wood stands of western Newfoundland (Richardson, 1979), cannot be achieved mechanically because mobile brush-clearing machines that completely clear swaths up to 2 m wide are not selective for this kind of operation. Many of the sites are too steep or rocky which makes the operation of such heavy equipment hazardous.

Timber Stand Improvement

Thinning of dense stands is a standard silvicultural operation carried out several times during the life of a commercial stand in order to provide optimum growth conditions for crop trees. Low-quality individuals are removed. Thinning is defined as "the removal of trees primarily for the benefit of the increment or quality of the balance of the stand" (Finnis, 1967). Conventional thinning is carried out with a saw or axe. The chemical methods are basal spraying or the "hack and squirt" method. Chemical thinning has several important advantages over conventional felling methods. Since chemical methods eliminate the main task of pulling down and dragging stems, they reduce investment costs in equipment, improve safety, provide additional shelter and nesting for birds, and eliminate long-distance hauling of heavy supplies and equipment. Reduction of cumbustible fuel on the ground, stiffness of treated stands against wind and snow, reduction of slash hindrance, protection against sun-scald and resistance to insect attack are additional advantages of chemical thinning (Finnis, 1967).

Weed Control in Nurseries and Young Plantations

In nurseries, a wide variety of selective non-persistent herbicides is used to control broadleaf weeds and grasses at any stage of the nursery crop production such as seed beds and transplant beds.

Herbicides are also used to control weed vegetation in the early stages of the development of hardwood or softwood plantations. Weed control is particularly critical during the establishment stage in young plantations (Sutton, 1958). The two main types of competition are competition from grasses and other herbaceous vegetation and from decidous woody weeds (Sutton, 1970).

Other Uses of Herbicides

- Maintenance of utility rights-of-way.

- Maintenance of fire breaks.
- Pre-harvest killing of commercial timber.
- Control of noxious weeds.
- Improvement of water yield by modifying stand density and species.
- Habitat improvement for fish by controlling weeds along lakes and water courses.
- Increase forage production for livestock and pasture and rangeland.

NEW FOREST MANAGEMENT HERBICIDES

(Review of Efficacy/Selectivity Data)

Glyphosate (ROUNDUP)

During the last ten years that glyphosate has been in use in Europe and North America, mainly for agricultural purposes, hundreds of articles have appeared on this herbicide. Lange et al. (1973) referred to glyphosate as probably the most promising new herbicide since the discovery of 2,4-D. Glyphosate is seen as an effective and promising alternative to the increasingly restricted 2,4,5-T.* Possible applications of glyphosate in forest management practices include nurseries, site preparation, thinning as well as release operations because of partial tolerance of conifers. The herbicidal effect of

* In the Maritimes, trials have been conducted with glyphosate since 1977 as a substitute for brushkiller formulations of 2,4-D and 2,4,5-T (Hallet and Dufour, 1983).

glyphosate does not reach a maxium until about two years after treatment.

Site Preparation

The first documented study on the use of glyphosate for vegetation control in coniferous plantations in the prairies was by Corns and Cole (1973). Glyphosate was tested in a clear-cut area near Hinton, Alberta at 2.2 and 3.3 kg/ha before or the day after planting one-year old seedlings of white spruce and lodgepole pine. When evaluated two years later, mortality of lodgepole pine was 12 and 48% for the post-planting applications at 2.2 and 3.3 kg/ha, respectively, compared with 16% for the control. Mortality of white spruce in the same period was 24 and 36% for the two rates compared with 16% for the control. Pre-planting applications at 2.2 did not appear to have any adverse effect on either of the two species. Control of grasses, mainly hairy wild rye (*Elymus innovatus* Beal.) was satisfactory during the first year.

The residual toxicity of glyphosate to conifer seedlings planted soon after treatment has been investigated by several researchers. Corns (1978a) evaluated selectivity of glyphosate (3.9 kg/ha) to lodgepole pine and white spruce seedlings planted at different times after spraying a sandy soil with a cover of mixed perennial grasses near Devon, Alberta. Observations recorded 5, 8 and 11 weeks after spraying indicated that both species, especially pine, were injured if planted 0-3 days after herbicide application.

Blackmore (1978) studied the effects of glyphosate on control of perennial grasses, mainly marsh reed grass (*Calamagrostis canadensis* (Michx.) Beauv.), and survival of one-year old lodgepole pine and white spruce planted one day after cutover forest land was sprayed. Three experiments were established in west-central Alberta in the spring and summer of 1976. Alder clumps, scattered forbs and fireweed (*Epilobium angustifolium* L.) were also present on the site. In the first experiment, glyphosate was tested in mid-June at 4.5 kg/ha on 28 and 56-cm diameter planting spots and 1.2 m x 2.5 m strips with and without fertilizer tablets. Initial control of the above-ground vegetation was excellent but two years after herbicide application, all treatments except the strip treatments were as weedy as the control. In a second experiment, early August application of glyphosate at 4.5 kg/ha provided superior weed control compared to June application. There was about 50% re-invasion of grasses and forbs in the scalps. In the third experiment, glyphosate was tested at 1.1 - 5.6 kg/ha in mid-summer and planting of pine was delayed until the following spring. Control of vegetation was equally good with all rates one year after application. When the experimental sites were visited two years later, vegetation control in all strips was inferior to results from spring application (Blackmore and Corns, 1979). Grass re-invasion was complete but not as tall or as dense as in the controls.

Blackmore (1982) visited the above experimental sites 4-5 years after planting to observe the long-term response of conifers to the herbicide treatments. Where pine was planted in mid-June one day after treatment, survival rates were 94-96% compared to 86% for controls, and the increases in height increment were 84-100% of control. Survival rate for spruce was 92% comapred to 82% for the control. The increase in height was not significant. Where pine was planted one day after treatment in mid-summer, pine survival was 55% in the glyphosate-treated strips compared to 79% in the control. Most of the mortality occurred soon after planting. The increase in height of the surviving seedlings was 35%. In the third experiment, where pine was planted 10 months after mid-summer treatment, survival was 93% compared to 72% for the control.

The results of the above trials suggest that delayed planting is preferable since it allows early and safe planting operations in the spring season without having to wait for sufficient vegetation to get established for an effective pre-planting herbicide application that same year. Scalping and planting immediately after spraying is another alternative (Blackmore and Corns, 1979).

Proper timing of application of glyphosate for control of the main brush species before transplanting conifer seedlings is another aspect that has received attention by several workers. Hughes and Horvath (1979a) obtained satisfactory control of 1-m tall wild blackberry by late summer application of glyphosate at 4.5 kg/ha in Delta, B.C. In another trial in Mission, B.C., satisfactory control of 0.25 - 3.0 m tall brush including alder, vine maple, Douglas-fir, Western cedar, Western hemlock, thimbleberry, salmonberry, huckleberry, bracken fern and salal was achieved with 2 kg/ha. Salmonberry and broom were completely killed. In a third trial, early July application of glyphosate at 2 kg/ha was slightly less effective on the above species. A dose of 8 kg/ha, however, almost completely killed all of the species. Hack and Squirt treatments applied with four cuts per tree at the rate of 1 and 2 ml per cut were tested on 20 - 25 m tall alder, big leaf maple, Western cedar, Western hemlock and balsam fir trees on July 20 in Mission, B.C. Good control of alder, fair control of balsam fir, cedar and hemlock was achieved. Defoliation of maple was 75% at the 2-ml rate.

Taylor (1979a) obtained excellent control of salmonberry (1 m), willow (1.5 m), alder (1 - 2 m) and Juncus spp. (0.20 - 0.25 m) at 1.7 and 2.2 kg/ha used for site preparation at Haney, B.C. The survival rate of 2-year old bare-root Douglas-fir seedlings was significantly improved.

Release of Conifers

O'Sullivan and Barnes (1977) reported excellent control of alder at 1.1 - 4.5 kg/ha applied on June 14, July 14, August 11 and September 13 at Haney, B.C. All rates were detrimental to 2 - 3 year old Douglas-fir at the earlier dates but selectivity was improved drastically when treatment was delayed until September. Sutton (1978) found that a dose of 2.2 kg/ha was highly effective against 6-year old trembling aspen, white birch, beaked hazel, mountain maple and several shrub species commonly competing with white spruce in the boreal forest. Although survival of white spruce was reduced by all herbicide treatments, there was an increase in mean second-year height increment of established white spruce compared to control and cleared plots. Increasing the rate from 2.2 to 13.4 kg/ha did not result in increased weed control.

Gardner (1978) investigated the effectiveness of glyphosate in releasing a young white spruce plantation on a boreal mixed-wood site in east-central Saskatchewan. A range of concentrations (0.5, 1.0, 3.0, 4.0%) was tested on two dates, July 19 and August 23. The lower concentrations (0.5 and 1.0%) were most effective and released the conifer seedlings with minimum damage. The earlier applications resulted in superior vegetation control but crop injury was greater. The injury symptoms were top dieback, poor vigor, chlorosis, very slow, partial or retarded flushing, stunted needles on current year's growth, chlorotic buds and mortality. Gardner suggested that mid-August would be the best time to apply glyphosate for release of white spruce because at this stage the current year's height increment would be completed and bud development would be well advanced. The seedlings would be more resistant to foliar application of glyphosate and the herbaceous vegetation and shrubs would still be susceptible.

Taylor (1979b) evaluated early and late summer performance of glyphosate at rates of 1.1 kg/ha and above applied with a mist blower (1100 L/ha) or a spinning disc applicator (22 L/ha) in order to release 4-6 m tall Dogulas-fir and hemlock from competing brush species that included alder (4.5 m), willow (4.5 m) and salmonberry (2-3 m). Excellent control of the three species was achieved at 1.7 kg/ha. Complete control of alder was obtained even at 1.2 kg/ha with the mist blower. The spinning disc applicator was not as effective as the mistblower. Variation of the spray volume between 550 and 1650 L/ha or addition of $(NH_4)_2 SO_4$ or surfactant did not improve efficacy. Excellent crop selectivity was observed with all treatments.

Aerial application of glyphosate was tested with a helicopter at the rate of 1.1 and 2.2 kg/ha and 19-95 L/ha volume of water for release of spruce, balsam fir and white pine in New Brunswick (Ingratta, 1979). All treatments were safe on the crop species. Efficacy decreased with lower water volumes and was more critical with the lower rate of herbicide. Complete control of pin cherry and poplar was obtained at 1.1 kg/ha with 95 L/ha water. Control of raspberry was 90% at 2.2 kg/ha and that of willow was 80% at 1.1 kg/ha. Using fixed-wing aircraft, Ingratta (1979) tested glyphosate on two sites for release of one-year old jack pine in early September and for release of a mixed stand of jack pine (5-year old) and black spruce (3-year old) in mid-July. No injury was observed on jack pine with the late summer application but the July application severely injured both conifers. Excellent control of poplar, pin cherry, alder, raspberry, willow, fireweed, red maple and brome grass was observed with the split application at 1.1 kg/ha. In another aerial application with helicopter, glyphosate was applied at 1.1 kg/ha in 22, 56 and 112 L/ha water for release of 2-year jack pine in New Brunswick (Ingratta, 1980). When evaluated two years later, the average height of jack pine seedings was 90 cm in the treated plots compared to 15-20 cm in the control. Excellent control of poplar, grey birch, red maple, pin cherry, willow and speckled alder was observed with all water volumes.

In Nova Scotia, aerial application of glyphosate was evaluated at the rate of 1.7 and 2.2 kg/ha with 34 and 56 L/ha water on 8.1-ha plots in order to release red spruce, red pine and balsam fir (Ingratta, 1980). The treatments were safe on conifers. Control of white birch, pin cherry, raspberry, alder, willow and grasses was excellent at 1.7 kg/ha. The lower water volume was not adequate for grass control. Control of red maple was 75-90% at 2.2 kg/ha.

Richardson (1980) compared the potential of glyphosate with that of triclopyr, the phenoxy acids and brush cutting for release of softwood regeneration from hardwood competition on a rich mixed-wood cutover site in western Newfoundland. The softwoods included balsam fir, white and black spruce and white pine. The main hardwood species were white birch and pin cherry. The ground vegetation was dominated by raspberry and fireweed. When evaluated one year after treatment, glyphosate proved to be the most effective treatment. It reduced hardwood stem density by 70% whereas brush cutting increased the hardwood population by 247%. Softwood injury from glyphosate was much less than from the other herbicides.

Thinning

Tree-injection of glyphosate for clearing young stands and disposing of residual trees on clearcut areas were tested by Wile (1981) near Plaster Rock, New Brunswick in June 1979. A hypo-hatchet was used to inject a 20% aqueous solution of glyphosate into young trees, mainly spruce and balsam fir, at the rate of 2 ml/2.5 cm, 2 ml/5 cm and 2 ml/7.5 cm diameter at breast height (dbh). The lowest rates, 2 ml/7.5 cm dbh provided satisfactory control of fir, spruce, white birch and aspen.

Stump Treatment

Stump treatment of 60-year old red and sugar maple with 40% and 50% (v/v) glyphosate/oil in the oil chamber of a chain saw to control suckering was not as effective as application with knapsack sprayer (Ingratta, 1979). Huston and Arsenault (1980) also reported good sucker control of red maple stumps using knapsack sprayer. The results, however, were not comparable to 2,4-D + 2,4,5-T used in oil. Offord and Campbell (1981) obtained effective control of cull hard maple (125 years old) with complete girdling and half strength glyphosate at 1 or 2 ml/7.5 cm dbh.

Plantations

Glphosate at 2.1 kg/ha in mid-August, after conifer needles were "hardened", was safe on a 5-year old red pine plantation in northern Ontario and provided effective control of eastern alder (*Alnus rugosa* Spreng), aspen and grasses (Prasad, 1983).

Hexazinone (VELPAR)

Hexazinone is a new triazine herbicide which gives contact as well as residual control. It is applied as a pre-emergence or a post-emergence foliar spray during active plant growth. Moisture is essential for activation of pre-emergence applications. Hexazinone is readily absorbed through root and foliage. A nonionic surfactant enhances its contact action. Translocation is apoplastic and its mechanism of action appears to be the inhibition of photosynthesis (Anon., 1983a). The commercial formulations used in forestry are VELPAR L Weed Killer, miscible liquid, 25% hexazinone; and VELPAR Gridball Brush Killer, pellet, 10% hexazinone.

With the development of VELPAR Gridball, a new concept in herbicide application called the "grid pattern" came into use. The grid pattern treatment places a pellet every 2 m on the forest floor. The pellets can be dropped by hand or deposited from a helicopter equipped with a Simplex seeder. As soon as VELPAR Gridballs come in contact with soil moisture, they crumble and the active ingredient is released which then moves into the soil. The herbicide is then taken up by the target plants' root system. In the U.S., this herbicide is used for conifer release and site preparation. In the southern states, the pelletized form is more common. The Gridball generally used in forestry is 2 ml in volume. This formulation is not effective in heavy clay soils with high organic matter contents (Harvey, 1978).

Site Preparation

Blackmore and Corns (1978) studied the residual activity of hexazinone (VELPAR 10% pellets), applied at the rate of 2.2 - 5.6 kg/ha, on one-year old spruce and lodgepole pine seedlings planted one month after herbicide application. The soil at the experimental site, located near Grande Prairie, Alberta, was a sandy clay loam with a 10 - 15 cm cover of peaty organic matter and a dense stand of marsh reed grass. When evaluated 11 months later, vegetation control was 80 - 90%. Survival, leader length and dry weight of spruce were significantly lower than control. Pine seedlings were not adversely affected and did not differ from control seedlings.

Harvey and Day (1981) tested the survival and growth of conifer seedlings planted one year after site preparation with hexazinone applied in a grid pattern either as concentrated solution with a "Spotton-gun" or Gridball pellets distributed by hand. The results indicated that hexazinone would be an effective herbicide for site preparation and conifers could be planted safely the following year. In three other trials in Ontario, Harvey and Day (1981) evaluated the efficacy of hexazinone applied as a concentrated solution with "Spotton-gun" or Gridball pellets against aspen in 5 to 10-year old cutover sites. June applications were more effective than late July or August applications. They suggested that a grid pattern of "spots" of concentrated solution of hexazinone applied on the basis of 2.4 kg/ha can be a very effective site preparation technique that will allow weed control concurrent with planting operations. They recommended that three spots of 0.375 g a.i./spot of hexazinone or three 2 ml Gridball pellets should be placed in a triangular pattern 1 m from jack pine and black spruce and 0.5 m from white spruce. Four to six spots or pellets should be placed around mature residual aspen.

Lehela and Campbell (1981) and Mattice and Campbell (1981) reported excellent control of bluejoint grass, red raspberry and goldenrod with 4.5 kg/ha of hexazinone used for site preparation in early spring in Ontario. Injury on jack pine, white and black spruce was observed during the first season but measurements during the second year indicated that the conifers recovered even from the 9 kg/ha application.

Pre-plant and post-planting applications of hexazinone were tested for weed control in 2 + 2 black spruce at Mt. Steward, P.E.I. (Huston and Cunningham, 1982). Pre-planting application at 2 kg/ha resulted in excellent control of grasses (Poa, Agrostis, Agropyron), buttercup and yarrow. No crop injury was observed. The post-emergence application resulted in slight crop injury but provided excellent control of goldenrod in addition to the weeds mentioned. In a different forest region, Dimock et al. (1983) also investigated pre-planting and post-planting applications of hexazinone at two sites in Enterprise, Oregon and Eniat, Washington. Applications at 2.2 kg/ha intended for site preparation for 2-year old Douglas-fir and ponderosa pine, resulted in effective and lasting control of herbaceous vegetation.

At one site, the two conifers responded with exponential growth increases over a 6-year period. For Douglas-fir and ponderosa pine, respectively, the herbicide treatment increased tree height by 70 and 58%, stem diameter by 69 and 70% and stem volume by 650 and 387% as compared to untreated check. Conifers did not exhibit any phytotoxicity symptoms to pre- or post-planting applications at either of the two sites.

Conifer Release

Standish (1981) tested liquid and Gridball pellets of hexazinone at 1.2 - 2.4 kg/ha in an old cutover boreal forest site overgrown with dense brush mainly aspen poplar. Both formulations resulted in satisfactory control of aspen poplar with no significant differences between the two. Jack pine, white and black spruce were planted in the treated site the following year. Assessments on survival and growth of conifers carried out three months after planting showed that the seedlings were established well and survival ranged between 84 and 100%. Control of aspen was also excellent. In another trial, aerial applications of Gridball pellets were tested in the spring at the rate of 12 and 24 kg/ha on two sites for conifer release (Standish, 1981). A helicopter equipped with a Simplex aerial seeder capable of distributing the pellets in a random grid pattern was used. Control of trembling aspen (1 - 12 m) and birch was excellent. White spruce was more tolerant than jack pine.

Some confiers are more sensitive to hexazinone application at flushing time. Campbell (1982) observed that broadcast applications of hexazinone at 1-2 kg/ha over the top of flushed Douglas-fir and white spruce resulted in severe injury while similar applications over unflushed black spruce and scotch pine were safe. Selectivity of black spruce was quite variable.

In Alberta, Drouin (1983) established field experiments at several locations where a granular formulation of hexazinone containing 20% active ingredient was tested at 14 and 28 kg/ha for release of conifers. The herbicide was broadcast with a cyclone seeder in early May. Excellent control, release and canopy opening were observed at the high rate of application. In another trial, granular hexazinone was tested for conifer release on a 15% slope in order to monitor the lateral movement of the herbicide. Crop tolerance was rated at 7 (on a scale of 0 to 9) and mortality was insignificant. "Puddling" or "streaking" of the herbicide was not observed. Good canopy opening and release and excellent control of competing vegetation were obtained.

Thinning

Blackmore and Corns (1978) tested several formulations of hexazinone as streak treatments for possible opening of over-dense stands of lodgepole near Hinton, Alberta. The treatments included Velpar 10% pellets applied as a central streak of 2.5 - 5 cm but calculated on the basis of 1.1 - 11.1 kg/ha, VELPAR pellets broadcast over the entire plot at the rate of 5 - 11.1 kg ai/ha, VELPAR wettable powder applied as a streak and VELPAR Brush-balls as 1, 2, 4 balls in a spot in the centre of the plots. VELPAR pellets were more effective than liquid application of wettable powder. The highest rate (11.1 kg/ha) was less effective. Herbicide thinning of lodgepole pine was most effective as a band or streak application which resulted in less injury to the remaining pine stands than broadcast application. In another trial, VELPAR Gridballs (0.56 g a.i. per ball) placed at a spacing of 91 cm killed alder in 3 months but was also injurious to pine.

Wile (1981) evaluated tree-injection of hexazinone for clearing young stands and disposing of residual trees, mainly spruce and balsam fir, on clearcut areas of Plaster Rock, New Brunswick in June, 1979. Undiluted VELPAR liquid was injected with a hypo-hatchet at the rate of 2 ml/5 cm and 2 ml/7.5 cm dbh. Application with a spot gun was tested at the rate of 8 ml/2.5 cm dbh and 4 ml/spot at 2-m square spacings. VELPAR Gridballs were also tested at the rate of one ball per 1.7 m^2. Spot gun treatment was most effective, especially on white birch and aspen, but killed or damaged more trees than intended because the roots of adjacent trees that were to be saved as crop trees also absorbed the herbicide. Only pin cherry and to some extent sugar maple were susceptible to Gridball application. White birch was intermediate. Spruce, fir, red maple and striped maple were resistant. Tree-injection at the higher rate of 2 ml/5 cm dbh was effective on most species except large red maple.

Plantations

Broadcast as well as directed spray application of hexazinone at 1 kg/ha provided excellent control of cinquefoil, goldenrod and evening primrose in a 5 - 6 year old white spruce plantation in Cedar Point, Ontario (Parson and Irwin, 1982). Effective control of aspen was obtained with 10 L/ha of VELPAR liquid. Control of eastern alder (*Alnus rugosa* Spreng) and grasses was poor. Crop tolerance was excellent.

Triclopyr (GARLON)

Triclopyr is an auxin-type selective herbicide for control of woody plants and broadleaf weeds. Compared to other auxin-type herbicides, it is more effective in controlling oaks, ash and other root-sprouting species. Triclopyr is readily absorbed by both leaves and roots, is translocated basipetally as well as acropetally, and accumulates in the meristematic tissues. Its mechanism of action appears to be similar to that of phenoxyacetic acids (Anon., 1983a). Triclopyr was initially developed for industrial use including the mainteanance of utility rights-of-way. Over 50 woody species are controlled at 1.1 - 2.2 kg/ha (Byrd and Colby, 1978). The water-soluble triethylamine salt formulation has been favored for industrial purposes, while the oil-soluble, water-emulsifiable ethyleneglycol butyl ether ester as well as the amine formulation have been found to be effective for forestry purposes (Gratkowski et al., 1978). In the U.S., triclopyr (GARLON) is registered for site preparation and for rights-of-way (Warren, 1980; Heinrichs, 1982). Triclopyr has also been known as XRM-4021, XRM-3724 and Dowco 233.

Brush Control/Site Preparation

Hughes and Horvath (1979) obtained generally poor results with mid-August application of triclopyr tested at 1 - 4 kg/ha on 25 - 300 cm tall salmonberry, bracken, spiera and hemlock, but good control of vine maple and huckleberry was observed at Mission, B.C. In another site at Delta, B.C., Hughes (1980) reported satisfactory control of dense growth of evergreen blackberries with fully-developed leaves with 2.25 and 3 kg/ha of triclopyr applied in late June. Other herbicides including glyphosate, dicamba, amitrole, picloram, fosamine and dicamba + 2,4-D were ineffective. Similar results were obtained when triclopyr was compared with the above herbicides in mid-July at Surrey, B.C.

Campbell (1981) summarized the 1981 results of experiments conducted in eastern Canada and concluded that a combination of triclopyr ester + glyphosate, both at low rates, looked promising for brush control.

Release of Conifers

Aerial application of triclopyr was tested at 0.9 and 1.75 kg/ha in early September in order to release 6-year old jack pine in New Brunswick (Mazerolle, 1979). Over 90% defoliation of red maple, white birch and pin cherry was observed a year later at the higher rate. Stem dieback was 80% for white birch and 30% for other species. Excellent selectivity was observed on jack pine. In another aerial application intended for release of 2-year old white spruce in the Blackbrook district, New Brunswick, triclopyr was tested at 0.6 - 2.8 kg/ha in late August (Mazerolle, 1981). Good control of hazel, aspen and elderberry was achieved above 0.8 kg/ha while control of raspberry, sugar maple, beech and willow was poor even at the highest rate. No injury was observed on conifers. When evaluated two years after application, 100% control of poplar and willow was observed at 0.8 and 1.7 kg/ha, respectively. Combination of triclopyr and glyphosate at 0.6

+ 0.5 kg/ha improved control of sugar maple and beech but it was still unacceptable.

Aerial release of 2-year old plantation of mixed Norway spruce and red pine was tested with triclopyr at 0.75 and 1.0 kg/ha by Mazerolle and McNally (1981) in Hants County, Nova Scotia in mid-August. No injury was observed on conifers. Control of raspberries was 84% at 1 kg/ha. No control of red maple or next year's regrowth of raspberries was achieved with these rates. When evaluated two years after application, control of soft maple was still unacceptable but raspberry control was 78% at 1 kg/ha (Mackasey et al., 1982).

Richardson (1980) compared the efficacy of triclopyr with glyphosate, 2,4-D + 2,4,5-T and mechancial treatments for control of hardwood competition in mixed wood cutover sites in western Newfoundland where the main regenerating softwood was balsam fir, white and black spruce. The main brush species were white birch, pin cherry, alder and mountain maple. The ground vegetation included raspberries and fireweed. Triclopyr (triethylamine formulation) applied at the rate of 1.9 kg/ha in approximately 700 L/ha volume of water in early July was not as effective as the other two herbicide treatments. Two years later, only 26% reduction in total brush population was recorded. Triclopyr was as active as the other herbicides on white birch (69% control). Triclopyr proved to be far superior to mechanical treatment since the latter resulted in 245% increase in total brush population. About one-third of all balsam fir stems treated with triclopyr or 2,4-D + 2,4,5-T had dead or twisted shoots, probably attributable to the fact that the herbicides were applied before the current season's new growth had hardened. Triclopyr was more effective in controlling herbaceous vegetation, about 45%, than other herbicices.

Preliminary trials with triclopyr-plus-glyphosate tank mixes indicate a potential for broad-spectrum efficacy with reduced quantities of herbicide (McCormack and Saviello, 1981). The timing of triclopyr ester and amine alone and in combination with glyphosate for control of hardwood brush in two sites in Maine was investigated by McCormack and Saviello (1981). Predominant brush species on the two sites were red maple, quaking aspen, gray birch, paper birch, beech and pin cherry. One of the sites was well stocked with red spruce, balsam fir and white pine. Triclopyr was tested at 0.8, 1.7, 3.4 kg/ha and in combination with glyphosate at 0.2 + 0.3 and 0.4 + 0.6 kg/ha in June, July, August and September. The results indicated that the combinations of triclopyr and glyphosate show excellent potential for effective brush control at a reduced cost by requiring reduced rates of application. With appropriate timing of application, these combinations are suitable for site preparation and conifer release operations. Site preparation would be made most effective when the herbicide is applied in June and release treatments would be most secure during August 15 - September 1 under Maine conditions. The ester formulation was more active than the amine in late summer applications. Some conifer injury recorded for early applications can also be avoided by late August applications.

Thinning, Stump Treatment

Warren (1976) reported that with the exception of cedars, nearly all woody plants can be controlled with tree injection of triclopyr. Thinning of overstocked conifers and hardwoods can be achieved simultaneously, thus providing immediate release to the remaining conifers. Recent trials in California indicated that tree injections of triclopyr are also effective on black oak (*Quercus kelloggii*) and tanoak (*Lethocarpus densiflorus*) in fall and spring applications; where Douglas-fir and coast redwood (*Sequoia sempervirens*) were closely intermingled with oaks, the herbicide caused no injury to conifers (Warren, 1980). Treatments on freshly cut stumps of black oak and tanoak were also promising. Fall applications were more effective than spring treatments and there was little difference between full and half strength applications. Application to cut stumps must be made before the surface suberizes.

In New Brunswick, tree-injection of triclopyr was tested by Wile (1981) for clearing young stands and disposing of residual trees on clearcut areas in June 1979. Undiluted Garlon was injected into young trees, mainly spruce and balsam fir, at the rate of 2 ml/5 cm and 2 ml/7.5 cm dbh with a hypo-hatchet. The higher rate was effective on white birch and aspen. White spruce, fir, yellow birch and willow were resistant. Pin cherry was intermediate.

Basal sprays of triclopyr in combination with extenders were tested on various hardwood tree species in north central U.S. (Melichar and Geyer, 1982). Undiluted thin-line basal spray of triclopyr effectively controlled a number of sapling-size hardwood species. Water dilution decreased hardwood tree control. These trials indicated that 2% triclopyr in oil is most effective in killing various hardwood species, and can be used as a standard to test the efficacy of other herbicides used as basal sprays. None of the experimental extender treatments (oil substitutes) was as effective as 2% triclopyr in oil.

Fosamine Ammonium (KRENITE)

Fosamine ammonium, also known as DPX 1108, is a slow-acting herbicide like glyphosate. It is applied to woody vegetation during the 2-month period prior to autumn coloration. The herbicide is then abosrbed by leaves, buds and stems of deciduous plants with little or no effect until the following spring when susceptible woody plants fail to develop leaves and eventually die. Pines and herbaceous vegetation may show a response soon after application. Suppression of terminal bud growth is observed on moderately susceptible to resistant species. Acropetal and basipetal translocation of ^{14}C-labelled material has been observed. However, normal field results with non-labelled herbicide indicate that complete coverage of all parts of the woody species is necessary for effective control under field conditions (Anon., 1983).

In the U.S., fosamine is registered for site preparation and maintenance of utility rights-of-way. In the southern U.S., the herbicide has caused mortality, especially among southern pines, when used for release purposes. However, fosamine is increasingly used for site preparation in the Pacific Northwest (Heinrichs, 1982).

Site Preparation

Spring applications of fosamine at 4.5, 6.7 and 9.0 kg/ha with 6.25% surfactant in 450 L/ha water volume used as directed spray to the lower half of trees did not control mixed brush species, mostly Western hemlock, alder and some Western cedar and vine maple (Hughes and Horvath, 1977). When evaluated in the autumn of the following year after treatment, the treated sections of alder, hemlock, vine maple and thimbleberry were defoliated but the upper parts were only slightly affected. Little response due to rate was observed. It was suggested that complete coverage of the brush was essential for effective control. In another trial at Delta, B.C., Hughes and Horvath (1979) obtained acceptable control of wild blackberry with 4.5 kg/ha of fosamine + wetting agent applied in late September. Control of evergreen blackberries, however, was poor with 4.5 kg/ha of fosamine and 0.5% Du Pont WK wetting agent (Hughes, 1981). In another experiment, Hughes and Horvath (1979) tested fosamine with and without wetting agent at 4 and 6 kg/ha for brush control in mid-August in Mission, B.C. The dominant species were 25 - 30 cm tall. The best average control of all woody vegetation was obtained with 4 kg/ha plus a wetting agent. Control of alder, thimbleberry, willow, salmonberry and bracken was satisfactory. Salal and huckleberry were resistant. In a third trial, with the exception of huckleberry, the average control of the other woody vegetation was less than satisfactory (6 on a scale of 0 to 9) with 4 and 6 kg/ha used with or without wetting agent.

Sprague and McCormack (1982) tested fosamine at 4.4, 6.7 and 9 kg/ha for suppression of dense stands of raspberry (*Rubus idaeus* L. var. *strigosus* (Michx.) Maxim) in conifer clearcuts in Maine. The herbicide was applied on three dates, July 31, August 27 and September 15. When evaluated a year later, only the mid-September applications proved to be effective.

Release

Very little work on conifer release in the boreal forest region has been done since this herbicide became available for research purposes in Canada. The limited data available suggest that fosamine can be used for conifer release at 4-6 kg/ha in late summer after final bud set of conifers for control for deciduous species including poplar, willow, thimbleberry, salmonberry, alder, bigleaf and vine maple (Anon., 1982c).

Thinning

Tree injection of fosamine for clearing young stands and disposing of residual trees on clearcut areas was tested in New Brunswick in July by Wile (1981). Undiluted Krenite was injected at the rate of 2 ml/5 cm and 2 ml/7.5 cm dbh with a hypo-hatchet. Balsam fir, spruce and tamarack were all sensitive while black ash and red maple were resistant. Aspen was intermediate. All white birch trees were dead or damaged in one site, but only 17% in another site.

Karbutilate (TANDEX)

Karbutilate is used for control of annual and perennial broadleaf weeds and grasses and woody species. It can be applied pre- or post-emergence and is absorbed primarily through the roots. Its mode of action is inhibition of the Hill reaction (Anon., 1983).

Blackmore (1978) tested karbutilate (TANDEX 4% granules) for control of herbaceous vegetation for site treatment near Hinton, Alberta. The herbicide was broadcast by hand at the rate of 7.8 and 15.7 kg/ha in early July one day before planting white spruce and lodgepole pine seedlings. Two months later, 90% control of grasses, mainly marsh reed grass, and broadleaved plants was observed in plots treated with 15.7 kg/ha and 60 - 80% control in plots treated with 7.8 kg/ha. A year later, control declined to 70 and 80% in plots treated with 7.8 and 15.7 kg/ha, respectively. Survival of both conifers was significantly reduced by the higher rate. Leader height of pine was reduced significantly by both rates compared to control. In another trial in the same area, Corns (1978a) tested karbutilate (4% granules) at 2.2 - 22.0 kg/ha in order to kill a 95% stand of dense stunted lodgepole pine trees, 2-3 m tall with a density of 20 or more per square meter. The herbicide was spread by hand in mid-July. When evaluated a few months later, 75% of the plants were dead or injured at 11 kg/ha. It was concluded that a rate of 11 kg/ha applied by aircraft as broadcast pellets or granules is most likely useful in thinning of dense stands. Pellets have the advantage that some trees will be spared whereas broadcast spray application will affect all trees to some extent. In another experiment on a drier site where trees were less than 1 m tall, though with a higher density of 30-45 stems/m^2, karbutilate pellets were more effective even at 5.6 kg/ha. About 10% of the trees were unaffected.

Streak treatments with karbutilate 4% granular at 5.6 - 11.1 kg/ha, 5.6 kg/ha of the WP (wettable powder) formulation as liquid streaks and 11.1 kg/ha of WP formulation as broadcast were tested for possible opening of over-dense lodgepole pine (Corns, 1978b). The objective was to provide dead bands, so that the surviving trees would have open edges for improved growth. Thirteen months later, the WP liquid streaks had killed a 1 m strip. The pellets provided a 1.8 m band while the broadcast treatment killed most of the plants within the plots during the first three months. The rather significant spread of herbicidal effect outwards from the 2.5 - 5 cm streak was very important for this purpose. In another experiment, strip application was tested in June, 1978 on 2 - 4.5 m tall lodgepole pine with 15 - 20 stems/m^2 with a stem diameter of 2 - 4 cm (Corns, 1979). When evaluated in September of 1979, karbutilate (4% granular) had killed strips 1 - 1.4 m wide. The results of these experiments indicate that aerial application of streak or band treatments could have more uniform results than general broadcast application of herbicide pellets. It is recommended that feasibility of using an aerial application mechanism with dispensers about 2 - 5 m apart should be explored. General broadcast application will affect all trees to some extent and hence will make it unsuitable for thinning operations.

Since broadcast application of karbutilate at rates intended for vegetative control cannot be selective, grid placement as compared to the more complete coverage achieved with sprays, pellets or granules is receiving research attention (Scifres et al., 1978). Control of woody vegetation with karbutilate applied by hand in an exact grid pattern was not different from aerial application at the same rate. Karbutilate eliminated all vegetation in a 25 - 45 cm diameter circle, depending on concentration of the active ingredient in the pellet.

DPX T6376

DPX T6376 appears to have potential as a conifer site preparation herbicide in forestry. In addition to its effectiveness on common brush species, it can be applied season-long, as long as active foliage is present. Sajdak (1982) evaluated the performance of this herbicide for site preparation purposes in northern Lake States. At 62 g/ha, 90% control of aspen and 80% control of red maple was obtained. Control of sugar maple was 65% at 500 g/ha. When evaluated one year after application, excellent control of hazels, willow and sweetfern was obtained at 62 - 187 g/ha. Red pine, jack pine, white spruce and European larch were planted in April after broadcast application at 311 - 500 g/ha in September. No phytotoxicity was observed at the end of the first year. Blackshaw and Standish (1981) obtained excellent control of poplar (3 m), aspen (3 m), willow (2.75 m) and Canada thistle (0.3 m) at 0.25 - 1 kg/ha. Control of wild raspberry (0.5 m) and spruce (1 m) was not satisfactory.

Drouin (1983) tested spring application of DPX T6376 at 0.5 kg/ha near Lesser Slave Lake, Alberta. Excellent control of all herbaceous plants was observed, but control of grasses and fireweed was poor. Severe chlorosis of white spruce was observed. In another trial, seasonal applications of DPX T6376 were evaluated at 70, 250 and 500 g/ha. White spruce and lodgepole pine (14 cm) were planted in treated soil 1, 3 and 5 weeks after spraying. Crop tolerance scores for white spruce at 70 and 250 g/ha were 6 and 9 for spring and summer, respectively. Lodgepole pine was severely injured by fall applications. Heavy rains and excessive soil moisture also contributed to the reduced vigor of pine trees. The differences between the 1-, 3- and 5-week post-spray planting were negligible. Adequate weed control ranging from 7 to 8 was observed on herbaceous weeds, but control of grasses and fireweed was poor.

BAS 9052 (Sethoxydim)

Bas 9052 selectively controls most annual and perennial grasses in broadleaf crops. It is applied post-emergece and is absorbed fairly rapidly through the foliage. Use of an oil increases efficacy, possibly due to increased uptake. Rainfall received 4 - 5 hours after application will not reduce efficacy. Translocation is acropetal and basipetal and the site of action in grasses is in the meristematic region (Anon., 1983).

Campagna (1981) observed excellent selectivity on Norway Spruce and black spruce with 0.15 and 0.3 kg/ha post-emergence applications of BAS 9052 in June in southern Quebec. Control of barnyard grass and quackgrass was fair to poor. Huston and Arsenault (1981) tested BAS

9052 + Atplus 411F at 0.5 + 3 kg/ha in mid-July on fall-seeded conifers that were just emerging at the experimental site near Charlottetown, P.E.I. Excellent selectivity was observed on balsam fir, European larch, white spruce and white cedar.

HOE 0061

HOE 0061 has potential for control of woody vegetation in site preparation operations. Derksen and Blouw (1981) observed excellent top kill of willow (20 cm) at 1.5 - 2.5 kg/ha applied in early June at Portage la Prairie, Manitoba. McVicar et al. (1981) tested HOE 0061 at 1.25 - 3.50 kg/ha for control of western snowberry (30 cm) in rangeland at Meecham, Saskatchewan on June 30. Seven weeks after application, 69 - 99% defoliation was observed with the range of concentrations. Even the lowest rate tested provided superior defoliation compared to picloram or glyphosate.

OLD FOREST MANAGEMENT HERBICIDES

Amitrole (AMITROL-T, AMIZOL)

Amitrole is used for control of perennial broadleaf weeds and grasses. It is applied to the foliage where it is absorbed slowly and has good translocation. It inhibits chlorophyll formation and regrowth from buds (Anon., 1983). Mixtures of amitrole with more persistent herbicides such as simazine are used for general weed control (White, 1975). Hallet and Burns (1980) tested amitrole at 0.7 kg/ha on 1 + 0 and 2 + 1 white spruce on August 20 in New Brunswick. Good weed control was achieved and no crop injury was apparent when evaluated two weeks after application.

Asulam (ASULOX F)

Asulam controls several perennial grasses including Johnson grass, crabgrass, and also dock and bracken fern in Christmas tree plantations and reforestation areas. It is readily absorbed by foliage. Use of surfactants increases its absorption and it translocates acropetally and basipetally. In certain grasses, it translocates from leaves into the root system where it can affect the dormant buds on the rhizomes. Its site of action appears to be the meristematic regions of the plant (Anon., 1983).

In forestry, asulam is used for site preparation and release of conifers from bracken fern and grasses. Asulam can be safely used to release Douglas fir, noble fir and ponderosa pine seedlings (Steward, 1976). Steward et al. (1979) tested aerial application of asulam for release of conifers from western bracken in late summer of 1973 at four large diverse sites in western Oregon. Asulam effectively controlled dense stands of western bracken for at least two years. Cover was reduced by an average of 74% on four sites. The differences between 3.4 and 6.7 kg/ha applications were not significant on percent cover, number of stems/m^2 and average height of bracken. The addition of a surfactant (0.2%) did not affect degree of bracken control in a consistent manner. Addition of surfactant helped in reduction of stand, but not cover of bracken. Asulam did not affect post-treatment height growth of Douglas-fir seedlings at either rate. Defoliation and bud damage was observed on a few trees. Late-season application after height growth had ceased did not significantly damage Douglas-fir even at twice the recommended rate. Noble fir, however, was damaged when asulam was applied with a surfactant. Post-treatment height was significantly reduced. Bud damage and defoliation also increased considerably. It was concluded that an application of 3.4 kg/ha without surfactant used after full frond emergence should provide adequate control of western bracken for either site preparation or conifer release.

At Aliston, Ontario, Hinks (1981) tested asulam at 2.25 - 4.5 kg/ha in mid-July, 1979 for control of bracken (full frond) in Scotch pine (1 m) and white spruce (0.8 m). Excellent control of bracken was achieved for at least two years. Asulam was safe on white spruce, but it resulted in chlorosis of the needle bases of Scotch pine in September, 1979 and stunting of the leader growth in 1980 at 4.5 kg/ha. The new growth in 1980 was normal.

Asulam used as 5.5 kg/ha was not effective on sedge and beargrass at three sites in the Cascade range (Dimock, 1981).

Bromacil (HYVAR)

Bromacil is used for control of a wide range of annual and perennial grasses and broadleaf weeds and certain woody species. It is sprayed or spread dry as granules on the soil surface, preferably just before or during a period of active growth of weeds.

The water soluble formulation is used undiluted with an exact hand gun applicator for control of brush. Bromacil is most readily absorbed through the root system and to a lesser extent through the foliage and stem. Addition of a surfactant to the spray enhances foliar activity. Bromacil is a potent and specific inhibitor of photosynthesis (Anon., 1983).

In forestry, the main application of bromacil is in thinning operations. Corns and Gupta (1971) tested bromacil at 6.7 - 18 kg/ha for control of grasses and other mixed vegetation including 4 -7-year old regenerating white spruce near Hinton, Alberta. The results after a year later indicated that the effective dose for weed control was phytotoxic to spruce seedlings. Corns and Cole (1972) planted one-year old white spruce and lodgepole pine seedlings in plots treated with 6.6 - 20 kg/ha bromacil. The higher dosages that provided effective control of the grasses were injurious to pine.

Bromacil (HYVAR 10% pellets) was tested at 1.1 - 22.0 kg/ha in order to kill up to 95% stand of dense stunted lodgepole pine trees (2 - 3 m, 200 or more/m^2) near Hinton, Alberta (Corns, 1978). The herbicide was applied by hand in mid-July. Several weeks later, 87% of the trees were dead or injured at 11 kg/ha. On a drier site in the same locality, even 5.6 kg/ha killed all the trees. In another trial, Corns (1979) compared streak treatments with Hyvar 10% pellets at 5.6 - 11.1 kg/ha, 5.6 kg/ha of the WP formulation along a 2.5 - 5 cm strip in the centre of 2.5 m x 2.5 m plots, as well as broadcast application of pellets at 11.1 kg/ha, for possible thinning of over-dense lodgepole pine. The broadcast application at 11.1 kg/ha killed almost all the trees in the plots within three months. Thirteen months later, the WP formulation at 5.6 and the pellets at 5.5 and 7.7 had killed a band 1.5 m wide. In another experiment, strip application of bromacil (HYVAR 10% pellets) was tested in June, 1978 on 2 - 4.5 m lodgepole pine with a stem diameter of 2 - 4 cm and a density of 15 - 20/m^2. By September of 1979, application rates of 7.8 and 13.2 kg/ha had killed strips 1 - 1.4 m wide.

Basal spray and stem injection of the liquid formulation of bromacil have been investigated for thinning purposes during the last few years. Undiluted Hyvar XL was injected at the rate of 2 ml per 5 - 7.5 cm of dbh with a hypo-hatchet for cleaning young stands of mostly spruce and balsam fir to free the best trees for increased growth and to kill unwanted residual hardwood trees (Wile, 1981). This experiment was carried out in a mixed wood stand in New Brunswick. The stem injection treatment at 2 ml/5 cm dbh resulted in killing or damaging 50% of spruce but fir was not affected. The spot gun application at 8 ml/2.5 cm dbh killed spruce, tamarack and white birch. Aspen was intermediate and fir was resistant. The grid placement at the rate of 8 ml per spot at 1.8 m square spacings resulted in the death of spruce, aspen, pincherry and striped maple. White birch was intermediate and fir was resistant. In a similar trial, (Standish (1981) examined "Spot Gun" application of undiluted Hyvar XL (8 ml/5 cm stem diameter) to the root collar area of trembling aspen (1 - 6 m), black poplar (1 - 6 m) and willow (1 - 3 m) in the spring. When evaluated 15 months later, 90, 88 and 77% control of trembling aspen, black poplar and willow, respectively, were observed.

Dalapon (DOWPON)

Dalapon is used pre- or post-emergence for control of annual and perennial grasses. Addition of a wetting agent usually enhances the activity of the herbicide. It is absorbed by roots and shoots and is translocated throughout the plant. Dalapon accumulates in young tissues (Anon., 1983).

In forestry, dalapon is used for control of grasses in site preparation operations. The sodium salt of dalapon is very active against quackgrass and other perennial grasses. It is taken up by roots, but is most active when applied to foliage (Sutton, 1970). Dalapon is often applied tank-mixed with atrazine in order to broaden its weed control spectrum. Dimock (1981) reported satisfactory control of sedge with pre-planting application of atrazine + dalapan at 3.3 + 6.6 kg/ha at three locations in the Cascades, Oregon. The activity of the herbicide treatment persisted until the third year. Survival of white pine and Shasta fir and Engelman spruce increased. Dimock et al. (1983) investigated the performance of pre- and post-planting applications of dalapon, atrazine and dalapon + atrazine for control of perennial grasses and forbs in planting - site preparation operations for two year old ponderosa pine and Douglas-fir at several locations in Washington and Oregon. Dalapon + atrazine used at 9 + 4.5 kg/ha provided better control of the target species than either herbicide used alone. The dominant grasses on the experimental sites included Idaho fescue (Festuca idahoensis Elm.), pinegrass (Calamogrostis rubescens Buckl.), intermediate wheatgrass (Agropyron intermedium (Host) Beauv.) and orchardgrass (Dactylis glomerata L.). The common forbs were heartleaf arnica (Arnica cordifolia Hool), yarrow (Achillea millefolium L.) and sedge (Carex spp.). Survival of ponderosa pine and Douglas-fir over a 6-year period was 64 and 73%, respectively with 9 kg/ha of dalapon. The combination increased survival of the two conifers to 82 and 84%. Corresponding increases in yield were 432 and 349%, 73 and 54% in height, 63 and 46% in diameter, respectively, for ponderosa pine and Douglas-fir. Protecting the seedling from direct spray proved beneficial in two experiments, but seemed unnecessary in four other sites. Mixtures of the two herbicides can combine the advantages of the two by providing control of a broader spectrum of both grasses and forbs, more lasting control and improve conifer survival and growth. The mixture could effectively prepare sites and provide efficient weed control for up to four years.

Dicamba (BANVEL)

Dicamba is used pre- and post-emergence for control of annual broadleaf weeds. Foliar and soil applications control phenoxy-tolerant broadleaf weeds and brush species. Dicamba can be applied as aerial, ground or basal treatment. It is readily absorbed by leaves and roots and readily translocated via both the apoplast and symplast systems (Anon., 1983).

Huston and Arsenault (1980a) tested dicamba at 5 g/L water for red maple stump treatment in the fall of 1979 at P.E.I. Sucker control was evaluated the following summer. Mean number of suckers/stump was 2.5 for dicamba, compared to 15.9 for the untreated stumps. Dicamba proved to be superior to glyphosate and hexazinone at comparable rates, but slightly less effective than 2,4-D + 2,4,5-T in oil.

Dinoseb (PREMERGE)

Dinoseb controls seedling weeds and grasses. It does not control established perennial weeds and grasses except with repeated treatments. Dinoseb can be applied pre-planting, pre-emergence, post-emergence or directed post-emergence to conifers. Dinoseb salts are readily washed from the foliage but the oil solution is more resistant. It has direct contact effect and causes cell necrosis. It is not translocated (Anon., 1983).

Huston and Arsenault (1980b) tested pre-emergence application of dinoseb at 4 kg/ha soon after spring seeding of red pine at P.E.I. No reduction in stand or vigor of the conifer seedlings was observed two months later. Control of groundsel, shepherd's purse and annual bluegrass was excellent. Control of corn spurry was fair. In another trial, post-emergence application of dinoseb was tested at 1 kg/ha on fall-seeded white spruce (Hston and Arsenault, 1980c). Good control of shepherd's purse, groundsel, pineapple weed, corn spurry and annual bluegrass were obtained and the treatment appeared safe on white spruce.

Diphenamid (ENIDE)

Diphenamid is a selective surface-applied pre-emergence herbicide that controls grasses and certain broadleaf weeds. Light rain will improve its effectiveness. It can be applied after transplanting conifer seedlings but before weed emergence. Diphenamid has only a low level of foliar activity and conifers show tolerance. It is absorbed via the roots and translocates through the roots, stems and leaves.

Duncan and Reffle (1979) tested pre-emergence applications of diphenamid at 2.24 - 6.72 kg/ha one day after seeding jack pine and black spruce at Swastika, Ontario. Both conifers exhibited excellent tolerance. Survival was 90% even at the highest rate. Satisfactory control of grasses was also observed. In another experiment, at Kemptville, Ontario, Klappart and MacDuff (1979) evaluated the performance of diphenamid at 4.5 - 18 kg/ha at two sites. Weed control was fair and no injury was observed on 1 + 0 European larch and 1 ± 0 white pine seedlings.

Bunting and McLeod (1979) tested pre-emergence application of diphenamid at 4.5 - 18 kg/ha soon after fall sowing of white pine in a loamy sand with 5% organic matter at Orno, Ontario. When evaluated next autumn, no significant differences were found for average seedling germination and average total dry weight between treated and control plots. Weed control was poor since 49 - 69% reduction in weed population was observed for the range of concentrations studied. In P.E.I., Huston and Arsenault (1980b) tested pre-emergence application of diphenamid at 4 kg/ha soon after spring seeding of red pine. No reduction in stand and vigor of the conifers was observed two months later. Control of corn spurry and annual blue grass was satisfactory, that of groundsel fair and that of shepherd's purse poor.

Linuron (LOROX)

Linuron controls germinating and newly established broadleaf weeds and grasses. Sprayed on the soil surface, it is absorbed through the roots and translocates up in the xylem. It is a strong inhibitor of the Hill reaction (Anon., 1983).

Huston and Arsenault (1980b) tested pre-emergence application of linuron at 0.5 and 1.0 kg/ha after spring seeding of red pine at P.E.I. No reduction in stand or vigor of the seedlings was observed at 1 kg/ha. At 0.5 kg/ha, control of groundsel was fair, control of corn spurry, annual bluegrass and shepherd's purse was excellent.

Napropamide (DEVRINOL)

Napropamide is normally applied pre-emergence to the soil surface for control of most annual grasses and many broadleaf weeds. It has some post-emergence activity. It is translocated via xylem to stems and leaves. It inhibits the development and growth of roots of grass weeds (Anon., 1983).

Klappart and MacDuff (1979) examined the performance of napropamide at 2.2 - 11.2 kg/ha for weed control at two sites in 1 - 0 European larch and 1 - 0 white pine on a loamy sand soil with 5% organic matter at Kemptville, Ontario. No injury was observed on white pine. However, the highest rate reduced larch shoot length and root dry weight by 42 and 62% respectively. Good to excellent control of a wide variety of broadleaf weeds was achieved at 4.5 kg/ha and higher rates. On a similar soil at Orno, Ontario, Bunting and McLeod (1979) tested pre-emergence applications of napropamide at 1.1, 2.2 and 4.5 kg/ha soon after fall sowing of white spruce. When evaluated next fall, no significant differences were found for average seedling germination and average total dry matter of conifers in the treated and control plots. Percent reduction in weed population ranged from 81 to 95% for the range of applications. In another trial, napropamide was tested pre-emergence at 1.1 - 9 kg/ha soon after fall application of white spruce. The following summer, the same plots received the same rates of napropamide as post-emergence applications. Pre-emergence application caused stunting of the leaders and deformation of roots specially at the higher rates. Post-emergence application did not have any effect on stand, but foliage color was affected.

Hallet and Burns (1980) tested napropamide at 2.2 kg/ha after autumn sowing of black spruce and balsam fir in P.E.I. When evaluated the following summer, it was observed that germination had been reduced, but excellent weed control was obtained. In another trial in P.E.I., Huston and Arsenault (1980b) tested the efficacy and selectivity of napropamide at 2 kg/ha soon after spring seeding of red pine. No reduction in stand and vigor was observed. Control of corn spurry and annual bluegrass was satisfactory, that of groundsel and shepherd's purse was fair. In Thunder Bay, Ontario, Polhill and Waywell (1982) obtained effective control of red root pigweed and mustard species with 2 - 8 kg/ha of napropamide applied soon after spring planting jack pine and white spruce. The treatments were safe on jack pine, but significant reduction in the stand of white spruce was observed.

Phenoxyacetic Acids

2,4-D, the oldest of the phenoxy herbicides, is also the most widely used in forestry, especially in combination with other herbicides. 2,4-D is used in all phases of vegetation management, particularly in site preparation and conifer release. It is also extensively used in rights-of-way maintenance, control of noxious weeds, and other specific uses. About 1500 products containing 2,4-D are registered with EPA, though not all are registered for forestry purposes.

2,4,5-T is the second most important and until very recently the second widely used herbicide in forestry. A vast number of references on the use of phenoxyacetic herbicides for forestry uses in North America is available. Coverage of the available information on the efficacy and selectivity of these compounds is beyond the scope of this review.

2,4,5-TP (silvex) was banned in the U.S. in October 1983. 2,4-DP (dichlorprop) is still used in U.S. forestry, but on a limited scale.

Picloram (TORDON)

Picloram is used for control of most annual and perennial broadleaf weeds and general woody vegetation control. The liquid formulation can be applied aerially or by ground equipment. The granular formulation can be applied by hand or commercial granular applicators. It is most effective just before rain. Picloram is readily absorbed by roots, shoots and from stem injection or girdle and translocates acropetally and basipetally and accumulated in new growth. Grasses are generally resistant to picloram.

A vast number of references on the use of picloram alone and in combination with other herbicides for forestry purposes is available. Reference will be made to a few research reports in this review.

Corns (1978) tested picloram (TORDON 10% pellets) at 5.6 and 11.1 kg/ha in order to kill up to 95% of a dense lodgepole pine stand (2 - 3 m tall, 20 or more/m^2) near Hinton, Alberta. The herbicide was applied by hand in mid-June. About 90% of the trees were dead or injured by August at 5.6 kg/ha. In another trial on a drier site, where the trees were less than 1 m (30 - 45 stems/m^2), there were no survivors at 5.6 kg/ha. In another experiment, streak treatments with picloram (TORDON 10% pellets) at 3.3 - 7.7 kg/ha and broadcast treatment at 7.7 kg/ha were tested for possible opening of oven-dense stands of lodgepole pine. By providing dead bands, open edges to the remaining plants will be provided for improved growth. TORDON pellets were applied as a central streak 2.5 - 5 cm wide in 2.5 m x 2.5 m plots. The broadcast treatment had almost completely killed all the trees within the plots in three months. Thirteen months later, streak treatment at 5.6 kg/ha had killed a strip 1.5 m wide. In another experiment in a nearby site with

2-4.5 m tall trees, 6.6 kg/ha affected plants along a band 2 md wide (Corns, 1978).

Hughes and Horvath (1979a) reported satisfactory control of blackberry (Rubus laciniatus), 1 m tall, with 2.2 kg/ha late summer application of picloram in Delta, British Columbia. In another experiment at Mission, B.C., Hughes and Horvath (1979b) obtained satisfactory control of 25 - 300 cm tall Western hemlock, and huckleberry with a 2 kg/ha mid-August application of picloram. Control of sala was incomplete. In another experiment, a 2 kg/ha application of picloram in mid-August provided an average control rating of 8.5 on alder, vine maple, Western cedar, Western hemlock, thimbleberry, salmonberry and sala.

Tebuthiuron (SPIKE 80W, HERBEC-20)

Tebuthiuron is sprayed or spread dry as granules or pellets on the soil surface just before or during period of active growth of weeds. Initial control is enhanced by rain. Tebuthiuron is readily absorbed through roots, less through foliage and readily translocated. Phytotoxic symptoms suggest that it inhibits photosynthesis (Anon., 1983).

Hughes and MacDonald (1983) tested tebuthiuron (80% WP) concentrated solution as a basal directed spray in the spring. The rates used were a 1.5-second squirt applied at 4.5 kg/ha to 2200 trees/ha and a 3-second squirt applied at 9 kg/ha to the same population. The lower rate tested on small trees gave exceptional control of Douglas-fir, birch, Western hemlock, cottonwood and alder. Control of Western cedar was poor with both rates.

Two formulations of tebuthiuron, HERBEC 20 and SPIKE 80W were tested at 14 and 8 kg/ha, respectively, in a 5-year old red pine plantation in mid-August, after the new growth had hardened. Both formulations were extremely phytotoxic to red pine. Excellent control of aspen was achieved with both compounds. Satisfactory control of alder and fair control of grasses was obtained with SPIKE 80W. HERBEC-20 was poor on alder and grasses.

Triazines

The chloro-s-triazines and methylthio-s-triazines are used for control of grasses and forbs in conifer site preparation, plantations, and for general weed control in nurseries. The triazine herbicides are the most commonly used herbicides in Christmas tree plantations (White, 1975). They are used alone or in combination with other translocated herbicides in order to prolong the period of weed control and reduce soil moisture losses. Simazine is the only herbicide that can be applied safely at the recommended dose of 4.5 kg/ha to conifer foliage at all seasons. Atrazine will injure conifers since it can be absorbed through foliage. Herbicidal activity of atrazine is faster but not as durable as that of simazine because of its shorter persistence in the soil. In plantations, atrazine is used in combination with simazine or alone at 2 kg/ha. Prometryn and propazine are used mainly for weed control in nursery seedbeds.

Atrazine/Simazine

Corns and Gupta (1971) evaluated atrazine and simazine at various rates ranging from 6.7 to 20.5 kg/ha on perennial grasses, mainly hairy wild rye, and other mixed vegetation on a clearcut site near Hinton, Alberta. The rates were adequate for vegetation control, but proved to be phytotoxic to some regenerating white spruce (4-7 years old) present on the site. In another trial, Corns and Cole (1972) planted 1-year-old spruce and lodgepole pine seedlings 1 year after application of atrazine and simazine at 6.7 and 20 kg/ha. Both conifers tolerated the lower rate but spruce was injured at the higher rate. In a supplementary experiment, atrazine was tested at 4.4 and 5.6 kg/ha on native grasses and white spruce. There were also 1-year-old seedlings of lodgepole pine and white spruce planted before or the day after herbicide application. Two years later, mortality of pine planted after atrazine spraying was 40 and 32% for 4.4 and 5.6 kg/ha, respectively; white spruce mortality was 80 and 92% at the two rates. Planted pine was more tolerant of atrazine than planted spruce. Von Althen (1972) evaluated the effect of several cultivation treatments, simazine, and simazine + fertilizer on survival of 4-year old white pine and white spruce in Ontario. After 8 years it was concluded that white pine achieved satisfactory survival only on plowed and disced plots that were also treated with simazine at 3.4 to 13.2 kg/ha.

Corns and Blackmore (1978) evaluated the performance of atrazine + simazine and a mixture of atrazine + simazine and hexazinone on herbaceous vegetation, and the tolerance of conifers planted immediately after the treatments near Fox Creek, Alberta. Survival of pine and spruce planted directly into unscalped plots treated with atrazine, simazine, and atrazine + simazine + hexazinone (2.5 + 2.5 + 2.0 kg/ha) was generally acceptable. Leader length measurements indicated, however, that growth of the conifers was considerably less in herbicide-treated plots than in control plots. Seedlings planted into scalps with the herbicide mixture applied immediately prior to scalping had superior growth compared to control. Vegetation control in plots treated with simazine or atrazine was fair to poor but it was acceptable in plots treated with a mixture of the three triazines.

Use of atrazine and simazine for grass control and establishment of conifers is quite common in the Pacific Northwest (Newton, 1973). Eckert (1979) evaluated pre-plant treatments of atrazine at rates of 2.2 to 9.0 kg/ha for control of perennial grasses and the establishment of jeffrey pine and ponderosa pine transplants in the Sierra Nevada. The dominant grasses were intermediate wheat grass [Agropyron intermedium (Host) Beauv.], wheat grass [Agropyron intermedium var. trichophorum (Link) Hallac.], crested wheat grass [Agropyron desertorum (Fisch.) Schult], common rye (Secale cereale L.) and smooth brome (Bromus inermis Leyss.). The most effective and consistent rates were 6.7 and 9.0 kg/ha which reduced grass herbage biomass by an average of 72% over a 3-year period and increased average final survival of the conifers from 1% on the control to 66% on the treated plots. Control of grasses was satisfactory at these rates for at least 3 to 4 years after treatment. The effective treatments also resulted in increased stem diameter and leader growth.

Atrazine has demonstrated particular success for preparing reforestation sites in grass plant communities (Crouch, 1979; Eckert, 1979; Gratkowski et al., 1979; Steward and Beebe, 1974), but perennial grasses and forbs resist control by atrazine (Newton, 1974). Since atrazine is not effective on many broadleaf weeds, atrazine has often released broadleaf weeds as well as conifers which have reduced survival and growth of seedlings. To control grasses and broadleaf weeds, low-volatile esters of 2,4-D have been added to atrazine (Newton, 1970), but this combination has injured conifers in some areas, so Gratkowski (1979) tested atrazine alone at 4.4 kg/ha and in combination with 2,4-D at 4 + 1.5 kg/ha as broadcast applications to control grasses and forbs before conifer break in new Douglas-fir plantations. Four experiments were conducted on moist sites and three in drier sites in southwest Oregon. On the moist sites, grass control did not increase survival or vigor of tree seedlings. On the drier sites, survival on plots sprayed with atrazine was 48% compared to 23% in control plots. The combination treatment resulted in poor survival and growth. Atrazine used alone was effective in reducing grass cover the first summer after application and a considerable reduction was observed early in the second summer.

The use of triazines has been recommended for site preparation in uncultivated sod in the northeastern region of U.S. and eastern Canada. White (1975) evaluated the performance of pre-plant applications of simazine (2.2 - 6.6 kg/ha) and simazine + atrazine, both at 2.2 kg/ha, along 61-76 cm strips after mowing the existing weeds.

Planting of conifer seedlings 7-10 days after treatment was recommended.

Cyanazine

Post-emergence applications of atrazine at 2.2 kg/ha and atrazine + cyanazine at 1.5 + 1.5 kg/ha were tested on black spruce and Norway spruce a year after planting (Campagna, 1981). Satisfactory control of grasses including barnyard grass and quackgrass was obtained. However, all treatments resulted in some phytotoxcity to Norway spruce. Dimock et al. (1983) evaluated pre-plant and post-plant applications of cyanazine + atrazine at 3 + 1.5 kg/ha for control of grasses and forbs as planting-site preparation treatment for 2-year old seedlings of ponderosa pine and Douglas-fir in Washington and Oregon. The pre and post applications resulted in moderate control of grasses. The post applications reduced forbs moderately.

Prometryn/Propazine

Prometryn sprayed at 2 kg/ha 4 days after 1 + 0 Japanese larch seedling were planted in a sand loam with 5% organic matter reduced the number of seedlings significantly compared to controls and the standard treatment, napropamide at 8 kg/ha (Klapprat and MacDuff (1979). Bunting and McLeod (1979) tested pre-emergence applications of prometryn at 1.1 and propazine at 0.6, 1.1 and 2.2 kg/ha 1 day after fall-sowing of white pine in a loamy sand with 5% organic matter at Orno, Ontario. No significant differences were found for average seedling germination and average total dry weight, sampled 1 year later, between the treated and control plots. All treatments resulted in greater than 94% reduction in weeds.

Bunting and McLeod (1979) tested post-emergence applications of propazine at 1.1 and 1.2 kg/ha and prometryn at 0.6 kg/ha on red pine. The seeds were sown in November 1978 and the treatments were applied on 14 June, 1979. Seedling survival counts and oven-dry weights recorded 4 - 5 months later showed no significant reduction due to herbicide treatments. In another trial, red pine seeds were sown in the fall of 1977 and herbicides were applied immediately afterwards. Seedling counts in the summer of 1978 indicated that the 0.6 and 1.1 kg/ha applications of prometryn and propazine did not affect seedling density and growth. The 2.2 kg/ha application of prometryn reduced density by 23%, diameter by 10%, height by 18% and dry weight by 10%.

Greenhouse applications of prometryn at 1.1 and 2.2 kg/ha one day after seeding black spruce and jack pine resulted in satisfactory control of grasses, however, the seedlings were severely injured and died at 2.2 kg/ha (Duncan and Reffle, 1979). In another trial, Duncan (1979) tested prometryn at 0.56 and propazine at 0.3 - 1.1 kg/ha one day after sowing black spruce in a well decomposted peaty black muck covered with 0.5 cm of silica grit. Germination, height and oven dry weight of jack pine seedlings were reduced slightly at the highest rate of propazine. Germination of black spruce in the presence of prometryn at 0.6 kg/ha was 73% compared to 87% for the control. Control of broadleaf and grasses was satisfactory with both herbicides at all rates tested. Hallet and Burns (1980) found that early summer application of prometryn at 1.1 kg/ha after fall seeding of black spruce and balsam fir enhanced germination in field plots in P.E.I.

Polhill and Waywell (1982) tested propazine at 0.5 - 2.0 kg/ha and prometryn at 0.8 - 3.0 kg/ha two days after sowing white spruce in a low organic matter sandy loam with hydro mulch in Thunder Bay, Ontario. Even the lowest rate of the 2 herbicides provided effective weed control but also severely reduced the spruce stand. In another trial on jack pine nursery seedbeds where the dominant weeds were mustard species and red root pigweed, prometryn provided the best weed control even at 0.5 kg/ha but killed all the seedlings. Propazine was safe on pine but poor on weeds.

Laupert and Moore (1981) found prometryn (0.4 - 1.4 kg/ha) safe on white cedar applied 3 weeks after spring planting in P.E.I. In another trial in P.E.I., Huston and Arsenault (1981) tested propazine at 1 kg/ha on fall-planted conifers just as they were emerging in the spring. European larch, Easter white cedar and particularly white spruce were all injured. Only balsam fir showed good tolerance.

FATE OF HERBICIDES IN THE FOREST ENVIRONMENT

(Review of Data on New Herbicides)

The Soil Environment

Adsorption:

Sprankle et al. (1975) studied the adsorption of glyphosate on a clay loam and muck soil. Up to 56 kg/ha of the herbicide was rapidly inactivated. The initial inactivation of glyphosate in soil is by reversible adsorption to clay minerals and organic matter.

Fosamine ammonium which is a highly water soluble herbicide is rapidly adsorbed onto soil particles (Anon., 1983). The discrepancy between high TLC R_f values and actual leaching under field conditions may indicate that it forms insoluble salts or complexes with soil minerals (Han, 1979).

The Freundlich isotherm constants (K-values) for hexazinone were 0.2 (slope 0.95) and 1.0 (slope 1.05) for a sandy loam and silt loam, respectively (Rhodes, 1980a). These values suggest low adsorption.

Adsorption of triclopyr is not very strong and the degree of adsorption depends on soil organic matter and pH (Anon., 1983).

Leaching:

Due to very strong adsoprtion, glyphosate is non-leachable in field soils (Ruppel, 1977).

Han (1979) studied leaching of fosamine ammonium under field conditions in Florida, Delaware and Illinois. Despite the very high water solubility of 120 g/100 g water and high TLC R_f values, very little or no leaching of this compound or its ^{14}C-labelled degradation products was observed under actual field conditions or in soil column studies. After a total precipitation of 165 cm over the course of one year, 93% of ^{14}C activity was still in the top 10 cm of Delaware silt loam. Even in the Florida fine sand, after 40.4 cm of rain over a period of 6 months, 62% of the ^{14}C was still in the upper 10 cm.

The soil-thin layer chromatography data obtained by Rhodes (1980a) place the hexazinone in Class 4 in the mobility class defined by Helling and Turner (1968). Triclopyr may leach in light soils under high rainfall conditions (Anon., 1983a).

Degradation

Complete and rapid degradation of glyphosate occurs in soil and/or water microbiologically and through chemical breakdown processes (Ruppel, 1977). Aminomethyl phosphonic acid, the only significant metabolite, also undergoes rapid degradation in soil. Losses through photodegradation or volatilization are neglibible.

Lab biometer flask studies showed that microbial decomposition of fosamine ammonium to $^{14}CO_2$ was 45 - 75% complete after 90 days of incubation in the dark (Han, 1979). Some reincorporation of ^{14}C into soil organic matter was observed, especially in forest soils. Fosamine disappearance from bottom sediment occurred over a period of 3 months or less (Anon. 1977).

Hexazinone is degraded by microbial action (Rhodes, 1980a). No degradation occurred when herbicide-treated sandy loam and silt loam were incubated under anaerobic conditions for 60 days.

Degradation of triclopyr is also microbial. The herbicide is Oapidly photodegraded with a half-life of 10 hr in water at 25°C (Anon., 1983).

Persistence

Up to 90% of glyphosate was dissipated in two out of three soils in 12 weeks (Ruppel, 1977).

The half-life of fosamine applied at recommended rates was about one week under field conditions in Florida, Delaware and Illinois (Han, 1979). Greenhouse soil studies indicated a half-life of about 10 days. A metabolite, carbamoylphosphonic acid (CPA) was found several days after application, but 3-6 months later, all ^{14}C-fosamine and its metabolite, ^{14}C-CPA, had disappeared completely. According to another source documented by EPA (Anon., 1977), fosamine is converted to CPA in 2 weeks which is then oxidized to CO_2 and humic acid fraction within 8 weeks.

Rhodes (1980a) studied persistence of hexazinone under field conditions with 3.7 kg/ha applications. The half-life of intact hexazinone was 1 month in Delaware, 2 months in Illinois, and 6 months in Mississippi. Time for 50% loss of total radioactive residues was 3-4 months in Delaware, 6-7 months in Illinois and 10-12 months in Mississippi. In greenhouse studies, the half-life of intact hexazinone was less than 4 months in a silt loam and sandy loam. Neary et al. (1983) monitored the persistence of hexazinone (10% pellets) applied on 23 April at 1.7 kg/ha in 60-80 year old pine-hardwood mixed forest in Georgia. The concentration of residues was quantified periodically in the forest litter. Residues in litter increased at the end of June which coincided with the time of maximum defoliation of the forest. The hexazinone contents of the first leaves shed was 3 ppmw (oven dry weight). Concentration increased to 6 ppmw during the third month after application which coincided with the greatest rate of leaf deposition. Intact hexazinone constituted about 71-76% of the residues in the litter. Small amounts were detectable in the litter up to one year after date of application.

Triclopyr has a half-life of 46 days, depending on soil and climatic conditions (Anon., 1983a).

Aquatic Environment

Glyphosate has a low propensity for off-site movement (Ruppel, 1977). The highest concentration found in runoff occurring one day after treatment of four watersheds in Georgia with 9 kg/ha was 5.2 mg/L. Up to 4 months after treatment, 4 μg/L was detected. The maximum amount of glyphosate transported in runoff was 1.85% of the amount applied. The first runoff accounted for 99% of the total amount transported (Edwards et al., 1980). Very little, if any, glyphosate or its decomposition products would reach the watersheds (Sprankle et al., 1975).

Studies with ^{14}C-fosamine ammonium salt in water have indicated that it is stable for extended periods in neutral or alkaline water, but is slowly hydrolyzed under weakly acidic conditions to carbamoyl phosphonic acid. Sunlight and photosensitizers have little effect on its stability (Han, 1979).

A water solubility of 33 000 ppm at 25°C makes hexazinone susceptible to leaching and off-site movement in storm runoff. Neary et al. (1983) studied off-site movement of hexazinone (10% pellets), applied at 1.7 kg/ha to four watersheds in Georgia, in stormflow and baseflow. A total of 26 storms were monitored between April 26, 1979. and May 27, 1980. Residues in runoff peaked in the first storm after application and declined with subsequent storms. The total amount of hexazinone transported in runoff averaged 0.53% of the applied amount. Two metabolites were also found in low-to-trace amounts in runoff for up to 7 months after application. Subsurface movement of hexazinone appeared in streamflow 3-4 months after application and accounted for 0.05% of the amount applied. A second-order perennial stream below the treated wahtershed periodically contained residues of <44 ppbw.

In another study in Alabama, Miller and Bace (1980) found concentrations up to 2400 ppbw from direct fall of pellets into a forest stream during an aerial application. Concentrations decreased to 110 ppbw within 24 hrs and to <20 ppbw after 10 days.

Rhodes (1980b) studied decomposition of ^{14}C-hexazinone in water. Based on a 5-week data, the amount of decomposition under both artificial and natural sunlight was about 3 times greater in standard reference water and 4-7 times greater in natural river water. Degradation in natural river water was 3 times the amount in distilled water. At the end of the 5-week exposure period, about 10% of the ^{14}C in the river water with sediment was found in sediment. About 67% of ^{14}C was extracted from the sediment. Dilute aqueous solutions of hexazinone incubated in the dark at 15, 25 and 37°C were stable for 5-8 weeks at pH 5, 7 and 9.

Triclopyr has a water solubility of 440 ppm at 25°C. Once in water, it stays in solution and will not be adsorbed onto sediment or organic matter. Its rate of degradation in water is quite high because of its susceptibility to photodegradation and microbial attack (Dow Chemical, 1983).

Data Gaps

Almost all data available on adsorption,leaching, persistence and off-site movement of glyphosate, fosamine, triclopyr and hexazinone come from U.S. sources. Persistence data under Florida conditions would hardly have any application in the boreal forest. Future research efforts should be directed to environmental chemistry aspects of these herbicides.

IMPACT OF HERBICIDES ON THE FOREST ENVIRONMENT

(Review of Data on New Herbicides)

Aquatic Environment

Glyphosate has a minimal effect on the microflora (Ruppel, 1977). Hildebrand et al. (1980) studied the effects of glyphosate on population of *Daphnia magna* in a forest pond at the University of British Columbia. *Daphnia* is a common inhabitant of fresh water and its population could be adversely affected by any changes in the food source which happens to be algae. *Daphnia* in turn forms a significant part of the diet of fish. The results indicated that survival of these organisms did not show any signficant variation between control and experimental treatments at field dose, 2.2 kg/ha, 10X and 100X field dose and at three exposure times. Sullivan et al. (1980) found that diatom and testation populations which are food sources of Daphnia were not adversely affected by glyphosate.

^{14}C-hexazinone residues in blueguill sunfish exposed to water containing hexazinone at 0.01 and 1.0 ppm for 28 days were found to reach a maximum after 7-14 days of exposure (Rhodes, 1980b). The maximum bioaccumulation was in the viscera at both exposure levels. The fish were then transferred to fresh water for 2 weeks. After one week of exposure to fresh water, the residue levels decreased by over 90% and nothing was detected after 2 weeks. There were no adverse effects observed on fish during the course of the experiment.

Neary et al. (1983) monitored hexazinone residues in streams below treated watersheds in Georgia during the course of 13 months when 26 storms occurred. It was concluded that the low and intermittent concentrations of hexazinone and its metabolite (less than 44 ppbw, mainly intact hexazinone) in the stream did not expose aquatic organisms to toxic levels. Mayack et al. (1982) confirmed this conclusion by a concurrent study of benthic organisms in the stream. No bioaccumulation of hexazinone or its residues occurred in aquatic invertebrates and macrophytes. No species composition and diversity shifts were observed. Neary et al. (1983) concluded that application of hexazinone at recommended rates for vegetation management should not produce any adverse environmental effect on water quality or aquatic ecosystems.

Toxicity of fosamine to the few organisms tested was negligible. Bioaccumulation has not been observed in aquarium studies. Residues in fish were comparable to concentrations in water (Anon., 1977).

Behavior in the environment and toxicity of 2,4-D, picloram, atrazine, MSMA, fosamine, glyphosate and dinoseb to anadromous fish habitat in western North America were recently reviewed by Norris et al. (1983).

Impact on Soil Microflora

Han and Krause (1979) studied the effect of fosamine on soil-nitrification bacteria under laboratory conditions in soil incorporated with 0.5, 5 and 20 ppm. There was no adverse effect on the microorganisms during a 5-week period. Populations and species of soil bacteria and fungi in three agricultural soils treated with 10 ppm were found to be unaltered over a 8-week period. In agar plates, fosamine showed no fungicidal effect even at 100 ppm. It appears that at the concentrations normally used for vegetation management, and with the susceptibility to microbial attack that is characteristic of many of the organic herbicides, the risk of serious and permanent interference with normal soil microbiological processes is remote (Kimmins, 1975).

Terrestrial Wildlife

Indirect effects from herbicide applications include ecological changes in vegetation cover and diversity. At certain successional stages, such alterations in vegetation result in changes in small mammal distribtuion and abundance. Sullivan and Sullivan (1981) studied the effects of forest application of glyphosate on reproduction, growth and survival responses of a deer mouse (Peromyscus maniculatus) population at Maple Ridge, B.C. They concluded that field applications of glyphosate did not have any apparent effect on the dynamics of deer mouse population.

The effect of glyphosate on food preference and consumption of captive-raised Black-tailed deer was studied by Sullivan and Sullivan (1979) at the University of British Columbia. Deer given a choice of control or glyphosate-treated (2.2 kg/ha) alder and alfalfa browse showed no preference or ate more of the treated foliage. The authors concluded that spraying brush with glyphosate should not prevent deer from feeding of foliage in the affected area. According to P. Mineau, Canadian Wildlife Service (personal communication) who reviewed the data, "these conclusions are somewhat naive".

Borrecco et al. (1972) reported that black-tailed deer use of treated areas increased during the period of vegetation recovery from herbicide applications in Oregon.

Data Gaps

With the exception of a few research reports from British Columbia, our knowledge of the environmental impact of herbicides comes from U.S. sources. Even glyphosate and hexazinone (by ground application) have been registered with the minimum required data. There is a definite need for research on the environmental impact of herbicides in Canadian forest regions. Data submitted by industry to Agriculture Canada for registration of glyphosate, triclopyr, fosamine and hexazinone cannot be discussed since they are still confidential.

HERBICIDE RESEARCH IN CANADA

Forest Pest Management Institute (FPMI)

As a national institute, FPMI was given the mandate in 1981 to initiate herbicide research for forest resource management purposes in Canada. The aims of the Institute's Herbicide Research Project are to accelerate the development of new herbicides, to refine and improve methods of utilizing existing products, and to improve application technology and formulation characteristics to enhance effectiveness of the herbicides while maintaining their impact on the forest ecosystem to a minimum. The current research and development program underway at FPMI as presented by Sundaram and Prasad (1983) at the "Herbicide Workshop" at Brandon, Manitoba in March, 1983 includes the following studies.

1. Screening and development of new herbicides with potential for forest management operations under controlled environmental conditions.
2. Herbicide formulation research in order to enhance efficacy.
3. Evaluation of field performance of the herbicides.
4. Environmental chemistry and development of the methodology for detection of herbicide residues and their adjuvants.

5. Assessment of the environmental impacts of the forestry uses of herbicides on non-target fauna.

The FPMI herbicide research and development team has established contact with CFS regional research centres and provincial forest agencies in order to assess the vegetation management needs of each region. They are actively involved in coordinating all research efforts on herbicides with other provincial and federal agencies. The FPMI herbicide R&D team has also established contact with their counterparts at Forest Pest Management, U.S. Forest Service. These contacts are aimed at exchange of information on pesticide registration, impact evaluation, technology transfer, social and environmental concerns, data gaps in available knowledge of forest pesticides and sharing of pesticide use data. Possibilities of joint research between CFS and USFS have also been discussed (Green and Reynolds, 1983).

In order to broaden the scope of activities of the FPMI Herbicide Research Project, a herbicide residue analytical laboratory has been established in order to enable the scientists to carry out research on persistence, mobility, degradation and fate of the forest herbicides and their metabolites in the aquatic and terrestrial environment of the forest ecosystem. As part of the facilities extension for the Project, a greenhouse and spray chamber have also been constructed for basic screening of herbicides.

CFS Research Centres

Available literature such as the Research Reports of the Expert

Committees on Weeds and Technical Notes of the CFS Research Centres indicate that research has been conducted on forest herbicides including the new herbicides with potential for forestry uses. However, the current research efforts underway are not adequate for the pressing needs of each area. The herbicide research capabilities of the Regional Centres must be developed further. The research efforts of the Regional Centres are aimed mainly at generating efficacy and selectivity data. The environmental chemistry of the herbicides such as persistence, movement, degradation, and fate of the forest herbicides in aquatic and terrestrial environment have received little attention.

Most of the research reports abstracted in ECW summaries come from the Pacific, Maritimes and Newfoundland Forest Research Centre. At the Northern Forest Research Centre, some research was carried out mainly on the phenoxyacetic herbicides since 1960's, however, it was not until 1981 that the urgent need for herbicide research in the prairies was realized and research on new herbicides was initiated in Alberta and Manitoba (Drouin, 1983). Current research in progress is on the following herbicides:

1. Liquid formulation of hexazinone (VELPAR L).
   Replicated experiments have been established at Faust, Lesser Slave Lake and Economy Tower, Grande Prairie in order to examine the performance of VELPAR L for release and thinning of lodgepole pine, jack pine and white spruce.

2. VELPAR Granular 20%.

   Replicated field trials have been established at Saddle Hills and Economy Tower, Grande Praire, in order to test the potential of the granular formulation of VELPAR for conifer release and site preparation.

3. DPX T6376.

   Replicated field experiments have been established at Faust, Lesser Slave Lake in order to test the efficacy of DPX T6376 against grasses, broadleaf weeds and competing woody vegetation, and to evaluate tolerance of conifers to different doses and season of application of the herbicide.

4. Fluazifop-butyl (FUSILADE)

   The potential of fluazifop-butyl is under investigation at Faust, Lesser Slave Lake, for conifer release and site preparation.

The proposed herbicide field tests in Alberta and Manitoba for 1984-85 include continued assessment of the established field trials, increased field tests on hexazinone liquid as over-the-top hydraulic spray applications at different seasons, and efficacy tests on hexazinone granular, DPX T6376 and fluazifop-butyl.

Provincial Agencies

The research activities of the provincial agencies are mainly limited to operational uses of the very few herbicides that are registered or have temporary use permits. The B.C. Ministry of Forests has had greater involvement in operational uses of herbicides compared to other provincial agencies. The current goal of the B.C. Ministry of Forests is to treat about 70,000 ha within the next 4-5 years as indicated in Table 9.

Table 9. Basic silvicultural goals of B.C. Ministry of Forests.

	1983-84	1984-85	1985-86	1986-87	1987-88
			-(hectares)-		
Planting	85 000	86 400	91 000	93 600	100 300
Site Preparation	76 600	88 100	93 000	101 000	116 400
Brushing & Weeding	7 599	13 900	13 900	15 200	18 200

Source: Five-Year Forest and Range Resource Program, 1983-88
Province of British Columbia, Ministry of Forests

An assessment of the current needs and use status of herbicides, current and proposed future research activities of the provincial forestry agencies of the prairies was done recently by Drouin (1984). Alberta Forest Service and Alberta Energy and Natural Resources were also contacted to determine the current and future needs of the province for forest herbicides.

Alberta

The current needs of the province are extreme to critical for control of aspen/poplars and grasses in conifer release and site preparation operations. Considerable areas of harvested sites have not been satisfactorily restocked because of perennial grasses such as marsh reed grass (Hellum 1977; Blackmore, 1978).

The operational uses of herbicides by the provincial agencies in Alberta in 1973 were as follows (N. Barker, Alberta Forestry Service personal communication):

- one-replicate trials with 2,4-D and glyphosate.
- spot application of VELPAR L at two areas in coopeation with Du Pont Canada.
- limited aerial application of VELPAR L.
- limited aerial application of 2,4-D.

The proposed provincial herbicide research program, which has not been approved yet, includes the following operations for 1984-85:

- aerial application of VELPAR L and ROUNDUP on 2000 - 4000 ha in 1984 and over 10,000 ha by 1985 (Drouin, 1984).
- follow-up treatments of Velpar L at Lac La Biche.
- a public hearing is planned on the use of herbicides by the Slave Lake Forest this year (N. Barker, personal communication).
- demonstration sites in cooperation with companies involving priority herbicides with various dosages, formulations and techniques.

Saskatchewan

Herbicides are desperately needed for the control of aspen/poplars in conifer release and site preparation operations. The current operational use of herbicides is negligible. Small scale aerial applications of 2,4-D by P.A. Pulp and Paper Co. have been tried. Research on new herbicides or new techniques is non-existing.

Manitoba

Herbicide needs for stand improvement, plantations and nurseries are critical. Operational uses of herbicides are negligible and research on new herbicides is non-existing.

Research at Universities

Research on forestry uses of herbicides by the universities have been minimal until recently. Most forestry schools do not even offer a course in vegetation management as part of their undergraduate curriculum. The FPMI is participating in the Program of Research by Universities in Foresty (PRUF). Environment Canada has allocated funds to PRUF which will be awarded to universities undertaking herbicide research in forestry. The following projects have been launched (Ennis, 1983):

1. Determination of the persistence, leaching and degradation of hexazinone in selected boreal forest soils. University of Toronto.
2. Determination of persistence, lateral and downward movement of triclopyr in selected Canadian forest soils. University of Guelph.
3. Development of analytical techniques and determination of the

persistance, lateral and downward movement of glyphosate in selected Canadian forest soils. University of Toronto.

The Role of ECW

The Expert Committee on Weeds plays an important national role in documenting, summarizing and disseminating research data to research workers in the provincial and federal agencies, agro-chemical industries and universities. Unfortunately, standards for reporting and evaluation of research results in forestry were not satisfactory until very recently. It was during the 36th annual meeting of ECW (W. Section) in November, 1982 that the new Silvicultural Section was added to the Research Report. A new Silvicultural Group was established and held four organizational meetings concurrent with the 37th annual meeting of ECW (W. Section) in November-December 1983.

REGISTRATION OF HERBICIDES IN CANADA

The Registration Procedure

Canada's registration process is one of the most stringent in the world (Anon.,1983b) and that is one of the main reasons why as late as December, 1983, there were only two herbicides registered for forestry uses. There are four federal acts which govern the registration, marketing and application of any pesticide in Canada:

1. Pest Control Products Act (Agriculture Canada) which deals with

registration, use patterns and environmental issues.

2. Environmental Contaminants Act (Environment Canada and Health and Welfare Canada) which deals with environmental pollution and human health hazards.
3. Migrating Birds Convention Act (Environment Canada) which is intended to protect birds.
4. Fisheries Act (Fisheries and Oceans) which aims to protect fish and spawning grounds.

Technical data required for registration of forestry herbicides by Agriculture Canada, the registration agency in this country, should follow the following format (Anon., 1982a).

Section A - Name, chemical identity, physical and chemical properties, complete composition and method of analysis of the product.
Section B - Amount, frequency and timing of application of the product. Include a copy of the proposed labelling.
Section C - Full reports and data of investigations made with respect to the effectiveness of the product.
Section D - Complete reports on toxicology studies, safety of the product to humans, domestic animals, fish, birds, wildlife and the environment.
Section E - Herbicide residues in soil and water.

All or part of the data submitted will be reviewed by the following seven agencies:

1. Pesticide Section, Agriculture Canada.
2. Laboratory Services Division, Agriculture Canada. Confirmation and/or development of analytical methodology.
3. Pest Control Products Section, Environmental Health Directorate, Health and Welfare Canada. Review of occupational and environmental helath aspects.
4. Canadian Wildlife Service, Environment Canada. Review of impact studies on wildlife.
5. Environmental Protection Service, Environment Canada. Review of disposal and decontamination methods.
6. Fish Habitat Management Branch, Fisheries and Oceans Canada. Review of impact on aquatic life.
7. Canadian Forest Service, Environemnt Canada. Review of efficacy and selectivity data and environmental safety of the herbicide by FPMI.

Registered Herbicides

1. Forest Management Category (>500 ha)
   (a) For site preparation and conifer release by ground and aerial application.
      - ESTERON 600, 2,4-D low volume ester, for hardwood brush species.
      - ESTERON 3-3E, 2,4-D + 2,4,5-T low volume esters for hardwood brush species.

  - ESTERON T-6E, 2,4,5-T low volume esters for hardwood brush species.
  - For. Ester EC, 2,4-D low volume ester for hardwood brush species.
  - ROUNDUP, (glyphosate) for hardwood brush species, perennial grasses and broadleaf weeds.

(b) For site preparation by aerial application.

  - Weedone IBK, 2,4-D + 2,4,5-T low volume esters for woody plants.

(c) For site preparation and conifer release by ground application.

  - VELPAR L (hexazinone) for control of hardwood species, perennial grasses and broadleaf weeds.

(d) For individual tree treatment (hack and squirt)

  - Formula 40-F, 2,4-D amine for control fo willow and red alder.
  - Later's 2,4-D Amine 500 for willow and alders.

2. Woodlands Management Category (<500 ha)

The followng herbicides have been registered for site preparation by ground application.

- ASULOX F, asulam for control grasses and bracken fern.
- PRINCEP Nine-T, simazine for grasses.
- PRINCEP 4-G, simazine for grasses.
- PRINCEP 80, simazine for grasses and hardwood brush.
- SIMODEX 80W, simazine for weed control.

- SIMODEX FL, simazine for grasses and broadleaf weeds.
- SIMAZENE 80, simazine for grasses and broadleaf weeds.
- AMIZINE, amitrole for weed control.

Task Force on Pesticides in Forest Management

The Canadian Council of Resource and Environment Ministers (CCREM) established a Task Force which first met in December 1981. The aims of the Task Force were to facilitate field testing of pesticides with potential for forest resource management and to hasten the registration review process for these chemicals (Anon., 1982b). Twelve pesticides which included glyphosate, hexazinone, triclopyr and fosamine ammonium were placed on Agriculture Canada's priority list for registation. According to Murray Anderson (Alberta Forestry Service) and F. Y. Chang (Pesticides Section, Agriculture Canada), the Task Force has been successful in fulfilling its goals. The most notable achievement of the Task Force this year is the registration of glyphosate (ROUNDUP) for forestry uses.

Status of New Forest Herbicides in Canada

Fosamine Ammonium (KRENITE)

Efficacy data: Adequate.

Environmental toxicology: Data available on general toxicity to wildlife and fish, acute toxicity, subacute toxicity, dermal, eye and inhalation toxicity.

Data gaps: Chronic toxicity.

Environmental chemistry: Data available on adsorption and leaching characteristics, microbial breakdown, loss from photodecomposition and/or volatilization.

Data gaps: Persistence and movement under Canadian edaphic and climatic conditions.

Registration status: Registered for industrial brush control only. No agricultural uses registered. Temporary registration which was granted in 1980 for forestry use was extended for another year. Health and Welfare Canada (HWC) and Canadian Wildlife Service (CWS) asked DuPont to submit data on 2-year chronic feeding study and Environmental Protection Service (EPS) requested more data on persistnece. At first DuPont agreed to undertake these studies but later on they refused to do so. KRENITE is no longer on Agriculture Canada's "Priority List" and FPMI has discontinued further field tests on this product. DuPont's Manager for Registration and Development, C.W. Bingeman stated: "We reached an impasse with HWC over chronic studies".

Triclopyr (GARLON)

Efficacy data: Adequate.

Environmental toxicology: Data available on general toxicity to fish and wildlife, acute oral toxicity, subactue toxicity, toxicity to skin and danger through inhalation.

Data gaps: Chronic toxicity.

Environmental chemistry: To be determined, appears to be inadequate.

Registration status: Registration package for industrial brush control was submitted in 1980 by Dow. Registration package for forestry uses was submitted in late 1982 after completion of some environmental impact studies. HWC require outstanding data from Dow. Fisheries and Oceans are still reviewing the toxicology data. An environmental impact study conducted by a consultant on stream invertebrates in N.B. has been submitted but has not been reviewed yet. CWS has a concern of a general nature over availability of brush browsing animals after a spray application. EPS has just started reviewing the label instructions for container disposal and the data for persistence and mobility.

Hexazinone (VELPAR)

Efficacy data: Adequate.

Environmental toxicology: Data available on general toxicity to wildlife and fish, acute, subacute, and chronic toxicity, toxicity to skin and possible danger through inhalation.

Data gaps: Fish accumulation and metabolism.
Environmental chemistry: Data available on decomposition by UV light, metabolism and persistence in plants, microbial breakdown under controlled conditions.

Data gaps: Leaching, adsorption/desorption, long-term field dissipation aquatic impact uses, anearobic soil metabolism, aerobic and anaerobic aquatic metabolism, drift studies.

Registration status: Initially DuPont entered two products for registation, a liquid and a grid ball formulation. The grid ball was later withdrawn. VELPAR L is registered for industrial brush control and as soil sterilant for weed control. Registration for forestry uses by ground application only was granted in March, 1984. However, it will take a few years before full registration is granted for forestry uses. The delay in registration is due to outstanding data from DuPont and to the fact that this herbicide was on the IBT list. HWC require outstanding data from DuPont. Data gaps are rat reproduction studies for two generations and two litters. The company is not pursuing this matter. Data submitted to Fisheries and Oceans on a study on a river stream have not been reviewed yet. EPS requires data on leaching, field persistence, persistence in sediment and aquatic habitat. Data on drift studies are needed before aerial application can be considered for registration.

Glyphosate (ROUNDUP)

Glyphosate was initially registered as industrial brush killer and for some agricultural uses. Glyphosate was on the IBT list and Monsanto provided long-term replacement studies. Application for registration of glyphosate for forestry uses had been submitted to Canada as early as 1978. As early as late 1973, Fisheries and Oceans were awaiting from their regional respresentatives and CWS had a concern of general nature over availability of brush to browsing animals after a herbicide treatment. Aerial as well as ground application of glyphosate were registered for forestry uses in February, 1984.

Other Herbicides

Other herbicides that have potential forestry uses in Canada but have not yet been considered for registation include karbutilate, dicamba, atrazine, BAS 9052 (sethoxydim), picloram, tebuthiuron and dalapon.

PROBLEMS CONFRONTING CANADIAN FORESTRY

Lack of Registered Herbicides

Until the beginning of 1984, 2,4-D and 2,4,5-T were the only herbicides registered for forestry uses. Since some provinces have banned the use of 2,4,5-T, 2,4-D was the only herbicide available. Since the production of 2,4,5-T has stopped, the existing stocks will not last long. The forestry community is very pleased to have access to glyphosate now even though it cannot serve as an exact substitute for 2,4,5-T. In the U.S. at least 12 herbicides have been registered for forestry uses in all states (Anon., 1983a) and up to 18 herbicides have been registered in Washington State (Jones and Boeteng, 1983). The Canadian forest manager needs a large range of registered herbicides available to him which will allow for more effective treatments, more selectivity in weed eradication, and lower toxicity where treatments might have an adverse impact on fish and wildlife. Since herbicides act selectively, if the forest manager has a variety of herbicides at his disposal, he can select the one which will control the most competitive weed species with the minimum disturbance to other flora and fauna on the site.

The Registration Process

According to R. Carrow, chairman of the Task Force on Herbicide Use in Forestry, as quoted by Drouin (1983d), "the main obstacle is the registration process itself - the system is just not working". One of the difficulties encountered while compiling information on the status of new herbicides was that the various federal agencies were very reluctant to release information. Lack of registration standards for forest herbicides and lack of close coordination among the various federal agencies involved in the process of registration are other factors that contribute to the long delay experienced in registation of herbicides.

Because of additional requirements unique to Canada to document the safety of chemicals for use in non-crop land it appears less likely that some of the promising herbicides like triclopyr, fosamine, tebuthiuron and DPX T6376 will be registered in the near future. In order to help the manufacturers decide whether or not to pursue registration of herbicides for forestry there is a critical need for federal regulatory personnel to define the protocols of required data in advance to facilitate industrial decision making and to assure that research funds are not wasted (Anon., 1983c).

Reluctance of Agricultural Chemical Companies

Since the market potential is very limited in forestry, the manufacturers are reluctant to invest in research and development of new products for forestry uses. The manufacturers maintain that in order to obtain forestry registrations in Canada they have to provide a lot more data than they did to obtain a U.S. registration (Anon. 1983c). It appears that as long as the herbicides used in agriculture make up a large percentage of forestry usage, the unwillingness of the manufacturers to invest in forestry research will not change. A similar attitude prevails in the U.S. (Newton, 1975). Manufacturers are also reluctant to register a use pattern that will represent a small segment of the market but potentially a lot of controversy (Anon. 1983c).

Reluctance of Foresters

The political climate relating to pesticides, in general, and the unfortunate analogies that have been made over the past ten years in reference to military use of herbicides in Viet Nam, has limited the acceptance of herbicides in forestry. Timber companies are hesitant to promote practices that would attract unfavorable publicity (Newton, 1975). Because of this reluctance some timber companies are not very keen on conducting research on herbicides.

Other factors that have limited the research and development of herbicides for vegetation management include, briefly:

- Lack of foresters trained in herbicide use.
- Lack of forest weed control researchers.
- Inadequate teaching and research on vegetation management at forestry schools.
- Negative impact of the media which has reinforced more imaginary than real dangers of the consequences of rational use of herbicides in forestry.

RECOMMENDATIONS

Registration

It is recommended that there should be greater coordination among the federal agencies involved in the registration process. A national advisory committee on registration of forest herbicides should be set up. The membership of the committee should include scientists from the federal regulatory agencies, herbicide specialists and environmental scientists from FPMI and other CFS research centres and representation from universities. As Rod Carrow, chairman of the Task Force stated, "the CFS should take a more aggressive stand in responsibility, to have its needs recognized by the process, to rid itself of the double standards and illogical rules for Agriculture vs Forestry and stress the need for more cooperation".

Education

- Universities and forestry schools should have a required undergraduate course in vegetation mangement.
- More research grants should be provided to universities through Program of Research for Universities in Forestry (PRUF) so that research can be initiated in the interdisciplinary fields of forest science/soil science/weed science.
- Public forums should be set up so that the public is fully briefed on the issues, choices, benefits and risks involved in forest herbicide projects.

Research

Available information on environmental chemistry and on the environmental impact of forest herbicides under Canadian climatic conditions, particularly in the boreal forest, is very limited. Research should be initiated in the following areas:

- Persistence, lateral and downward movement, degradation and adsorption/desorption characteristics of hexazinone, triclopyr, fosamine, DPX T6376, tebuthiuron, karbutilate and picloram in selected forest soils under controlled and field conditions.
- Fate of the potential forest herbicides in streams, lakes and the sediment.
- Impact on browsing animals during the transient period when their food is in short supply.
- Impact on aquatic organisms.

Herbicide application technology should be improved in order to obtain maximum effectiveness while maintaining or reducing the risks to the applicator and the environment to a minimum.

Research should be coordinated with the herbicide reserach teams of USFS, possibly through a bilateral, cooperative agreement. There should be exchange of information through joint workshops.

Who Should Fill Data Gaps

Since the agricultural chemical companies do not have the material incentive to conduct research on environmental impact and environmental chemistry of promising herbicides with forestry potential because of limited market opportunities for such products, the burden falls on federal agencies. Lack of required environmental data on herbicide use in Canadian forest regions is one of the main reasons that so few herbicides are available today. Since the CFS alone cannot finance such studies, a jointly funded research program should be initiated by the federal departments of Environment, Agriculture, Energy and Natural Resources, Health and Welfare and Fisheries and Oceans.

Where Should Research Be Conducted

The herbicide research capabilites of FPMI and CFS's regional research centres should be improved and expanded. The Herbicide Research Project of FPMI has made a good start with the screening of new herbicides and development of new formulations and application technology. The promising herbicides should then be passed on to the regional establishments for replicated field tests and, eventually, limited aerial applications. The FPMI should also improve its capabilities in herbicide residue analysis.

The currently fragmented research program carried out by the regional establishments should be better coordinated and the FPMI should assume the leading role in this coordination.

Provincial agencies should be encouraged to conduct herbicide research and there should be cooperative research projects between the provincial and regional forestry personnel.

Universities that possess the analytical instrumentation for residue detection should be provided with funds so that they can get involved in environmental chemistry studies.

RESEARCH PROPOSAL FOR PRIAIRIE PROVINCES

There is no doubt that research as well as operational uses of herbicide in the northern forest region have lagged far behind British Columbia and the eastern provinces of Canada. Vast areas of the harvested sites that have been replanted or allowed to regenerate itself naturally are insufficiently restocked. Competition from perennial grasses and aspen/poplars have significantly contributed to poor stand establishment and survival (Hellum, 1977; Blackmore, 1978). The experimental and operational uses of even the traditional vegetation management herbicides, 2,4,D and 2,4,5-T, by the provincial agencies have been minimal. The need for herbicides in the three provinces is critical to desperate (Drouin, 1984), yet there is hardly any approved plan on paper (N. Baker, personal communication) for 1984 or the years after. A proposal for a "Working Group on Herbicides Use in Forestry in Alberta" was circulated in May, 1984 (S. Navratil, Alberta Energy and Natural Resources, personal communication), however, a year later there is still no concrete action, apparently because of lack of funds.

The critical needs of the northern region for forestry herbicides and the lack of initiative/competence by the provincial agencies compels the Northern Forest Research Centre to develop its own research capabilites independenttly of FPMI while maintianing coordination with that institute.

Herbicide Research Plan for NoFRC

The classic approach to a research program would start with the A-level screening tests as developed by CRAFTS Experimental Design at Oregon State University. The A-level screening trials are designed to identify treatments that may be useful in vegetation management and to determine which treatments merit further investigation. These tests are designed to obtain preliminary data on method, timing, spectrum of biological activity, rates of application and formulation effects. The A-level studies can be installed to study the efficacy and selectivity of herbicides for site preparation, conifer release or stand establishment.

The candidate herbicides for A-level screening tests under field conditions, however, must be selected from a wide range of experimental compounds received from the manufacturers. Since the FPMI is already involved in basic screening of herbicides on a wide range of crop trees and brush species under controlled environmental conditions, it would be a duplication of research effort if herbicide research at NoFRC starts with the basic screening tests. Up to two years can be lost until promising herbicides are identified for replicated field trials. Therefore, it is proposed that NoFRC should start limited field trials with the candidate herbicides identified by the FPMI.

Phase I

1984 - Planning

- Limited field trials with herbicides nearing registration on selected forest soils.

Phase II

1985 - Select best rates and timing of application from 1984 trials.

1986 - Monitor persistence and movement of soil-applied herbicides in established experiments.

- Replicated field trials on promising herbicides that may become available.

Phase III

1987 - One-replicate large plots with treatments identified from Phase II.

- Monitor persistence and movement of soil-applied herbicides in established experiments.

Multi-Disciplinary Research Team

	Professional	Technical
1984	Weed Scientist	1 Forestry summer student
1985	Weed Scientist	1 Forest Prot. technician
		+ 1 Forestry summer student
1986	Weed Scientist	1 Forest Prot. technician

	Analytical/SoilChemist	+	Summer help
1987	Weed Scientist		1 Lab technician
	+ Soil Chemist	+	2 Forest Prot. technicians
		+	Summer help
1988	Weed Scientist		1 Greenhouse technician
	+ Soil Chemist	+	2 Forest Prot. technicians
	+ Forest Physiologist	+	1 Lab technician
		+	Summer help.

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