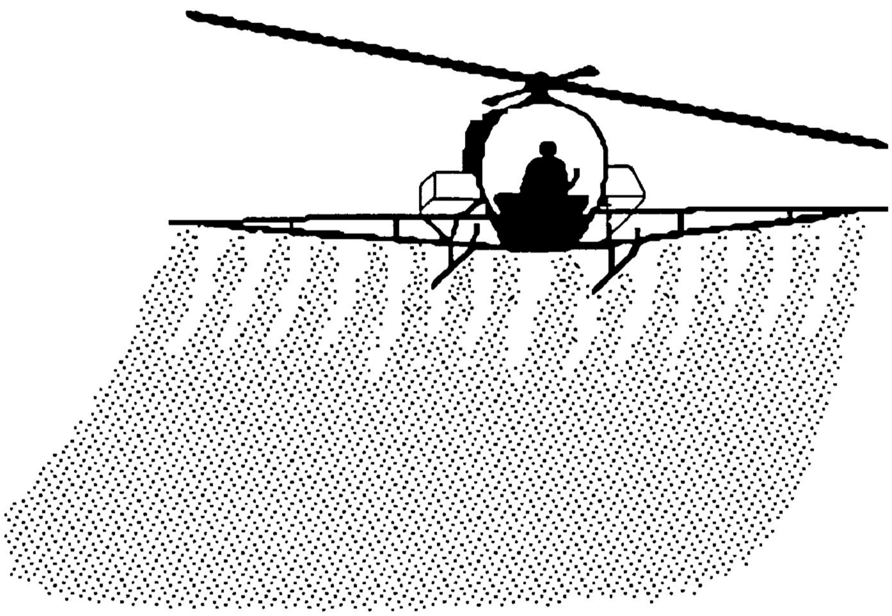
# GLYPHOSATE HERBICIDE FOR THE CONTROL OF ASPEN IN A WHITE SPRUCE PLANTATION IN MANITOBA

by
F. Wayne Bell ©



A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science in Forestry

School of Forestry
Lakehead University
1989

ISBN 0-315-63207-0

F. Wayne Bell

## ABSTRACT

Bell, F.W. 1989. Glyphosate herbicide for the control of aspen in a white spruce plantation in Manitoba. M.Sc.F. Thesis, School of Forestry, Lakehead University, Thunder Bay, Ont. 107 pp.
Major Advisor: Professor R.J. Day.

Three experimental herbicide trials were established within a white spruce plantation located in the Porcupine Provincial Forest of the Mixedwood Section (B.18a) (Rowe 1972) of western Manitoba. The trials were as follows: 1) the aerial application of glyphosate at three rates, 2) the ground application of glyphosate at three rates at three periods of time during the growing season, and 3) the evaluation of the resuckering potential of aspen from the ground spray trial.

The results of these trials indicates that the optimum time to apply glyphosate for white spruce release in Manitoba occurs in mid-late August after the buds have set and during the time when there is relatively little shoot growth. Glyphosate applied at 1.0 $kg.ha^{-1}$ provided the best silvicultural and herbicidal efficacy. In areas where complete control of aspen is not desirable, lower rates of application should be considered. Such areas may include frost pockets or areas of high aesthetic value.

The percent kill and the resuckering potential of aspen was influenced by both the rate and the time of glyphosate application. Rate was more critical than the time of application for both percent kill and regrowth potential. Regrowth potential of aspen on areas treated with 0.5 $kg.ha^{-1}$ was relatively high compared to aspen from areas treated with 1.0 $kg.ha^{-1}$. The full effect of glyphosate on trembling aspen competition did not become apparent until the second year after application.

White spruce showed a positive growth response within two growing seasons after the application of glyphosate in both the aerial and the ground spray trials. Although small gains in height increment were realized, the greatest gains were from diameter and volume increment.

KEYWORDS: Picea glauca, trembling aspen, Populus tremuloides, release, competition control, aerial spray, ground spray, silvicultural efficacy, Vision™, Roundup®.

# TABLE OF CONTENTS

Page

Page

## LIST OF TABLES

Page

# LIST OF FIGURES

Page

Page

## ACKNOWLEDGEMENTS

I wish to thank Prof. R.J. Day, Mr. G. Ardron, Dr. G. Hazenberg and Prof. R. Clarke for their invaluable advice and for their efforts to make this project a success. I also wish to thank Dr. E. Setliff for editing this thesis. I especially thank Ms. Lisa Buse for her editorial work and patience while I completed this project.

Financial support for this thesis was provided by the Canadian Forestry Service under the Program of Research by Universities in Forestry (PRUF); the Manitoba Department of Natural Resources, Forestry Branch; the Canadian Forestry Service Human Resources Development Fund to Lakehead University and Monsanto Canada Inc.

The author gratefully acknowledges the two year scholarship provided by NSERC.

Much appreciated is the advice received from Mr. Richard LaValley with soil analysis and Mr. Hugh Lougheed with Fortran programming.

Also much appreciated is the co-operation extended by the staff of the Manitoba Department of Natural Resources and the Canadian Forestry Service.

I thank the following persons for their technical support: Mr. Patrick Arbothnott, Mr. Patrick Cherneski, Mr. Derrick Cherneski, Mr. Tim Makahoniuk and Mr. David Slack for field work support; Mr. Patrick Arbothnott, Mr. Ancelm Mugasha, Ms. Caroline Hawes and Ms. Judy Wright for laboratory work; and Mr. Neil Fraser, Mr. Ed Hoffman and Ms. Judy Wright for data entry.

# INTRODUCTION

Trembling aspen (Populus tremuloides Michx.) is perhaps the most serious competitor in white spruce (Picea glauca (Moench) Voss) plantations (Haig 1959, Froning 1972, Johnson 1973). Aspen competition slows the growth of white spruce through competition for light, moisture and nutrients; it causes severe mechanical damage by 'whipping' terminal and lateral stems and provides a favourable environment for snowshoe hare (Lepus americanus Erxleben). In a study of mixedwood stand dynamics Kabzems (1952) noted that approximately 48 per cent of all white spruce suffered leader damage due to 'whipping' by trembling aspen. Kagis (1952) estimated that at least one-third of the potential volume of the white spruce is lost because of aspen competition and mechanical damage. Although aspen causes heavy volume losses, it has been the snowshoe hare that has substantially reduced the survival of many newly established plantations (Drew 1988).

White spruce plantations have been established within the Mixedwood Section of the Boreal Forest (B.18a) (Rowe 1972) of Manitoba to provide a necessary long term supply of white spruce sawlog material. The decision to proceed with a pilot scale experiment involving the herbicidal and silvicultural efficacy of glyphosate was based primarily on the assumption that the aspen competition within these plantations will have a devasting effect on potential spruce sawlog yields if it is uncontrolled.

Control of the trembling aspen competition should result in increased survival and growth of the white spruce. Increased survival should occur as a result of decreased damage by hares and increased growth should occur as a result of reduced whipping and reduced competition for light and nutrients. The relative control of the aspen competition and therefore survival and growth of the spruce should be influenced by the time and rate of herbicide application because of seasonal physiological changes in aspen and spruce.

The options for releasing white spruce from aspen are: aerial and ground spraying of herbicides, basal spraying of herbicides on individual trees, hand girdling using axes or specialized tools, machine girdling, felling by power saws or axes, or combinations such as axe frilling and poisoning (Johnson 1986). For large release projects aerial application of herbicides to control aspen competiton is undoubtedly less expensive than labour intensive manual control programs (Johnson 1986). At present, glyphosate and 2,4-D are the only herbicides registered under the Federal Pest Control Products Act that may be aerially applied for forestry use.

The potential of the non-selective herbicide, glyphosate, to control grass, brush, hardwoods and indirectly hares is very high relative to that of the selective herbicide, 2,4-D. Control of trembling aspen by using 2,4-D has been quite variable (Campbell 1988); 2,4-D will kill all above-ground parts, but it will not prevent the aspen from resuckering (Steneker 1976). The resultant stand of dense new aspen suckers may be far more competitive than the original stand of scattered large stems (Campbell 1988). Since grasses are virtually unaffected by 2,4-D, removal of the aspen overstory may actually enhance the competition problem by releasing the highly competive grass (Campbell 1988). Glyphosate kills above ground aspen parts, severely limits aspen resuckering and also provides good control of grass (Expert Committee on Weeds 1984, Campbell 1988).

Glyphosate was developed in the 1960's. It was initially sold under the trade name of Roundup® in Canada for agricultural, industrial and domestic use in 1976. In 1984 it was labelled for use in forestry and for forestry use in 1984. Since January 1987, glyphosate has been sold under the trade name of Vision™ for forestry use. Vision™ is registered for ground and aerial spraying and injection and frill applications for both site preparation and conifer release, including brushing and weeding, for forest management use ($\geq$ 500 ha) and for woodlands management use (< 500 ha).

Although sufficient research has been conducted to license glyphosate for both ground and aerial applications for forestry use, more research needs to be done to refine its silvicultural use for releasing white spruce plantations from trembling aspen competition on fertile sites, such as the deep till soils of the B.18a. Currently, the operational and experimental use of even traditional herbicides such as 2,4-D has been minimal in the prairie provinces (Johnson 1986, Malik and Vanden Born 1986). As a result, questions regarding optimum spray times during the growing season and minimum spray rates associated with these times have not been answered.

The objectives of this study were to evaluate the herbicidal and silvicultural efficacy of aerial and ground applied glyphosate in a recently regenerated white spruce plantation in the Mixedwood Section (B.18a) of the boreal forest of western Manitoba. The primary hypothesis was that removal of trembling aspen competition by an application of glyphosate would result in an increase in the survival and growth of the spruce.

The detailed objectives of the various trials conducted in this study are listed below. These objectives are devided into two main parts, each of which is subdivided into objective statements that are synchronized with the presentation of results.

Part 1. Silvicultural Efficacy: Effect of Glyphosate on White Spruce Crop Trees.

To evaluate the survival, height, diameter and volume growth of outplanted 3+0 white spruce seedlings:

a. following the aerial application of three rates of glyphosate (Trial 1).

b. following the ground application of three rates of glyphosate applied at three times (Trial 2).

Part 2. Herbicidal Efficacy: Effect of Glyphosate on Trembling Aspen Competition.

To evaluate the survival, height and diameter growth of trembling aspen suckers in a burned-over area:

a. Following the aerial application of three rates of glyphosate herbicide (Trial 1).

b. Following the ground application of three rates of glyphosate applied at three times (Trial 2).

c. The resuckering potential of trembling aspen root cuttings following ground application of three rates of glyphosate applied at three times (Trial 3).

## LITERATURE REVIEW

The purpose of this section is to present a summary of the available literature on the following subjects:

a) importance of white spruce and trembling aspen in the Mixedwood Forest Section of the Boreal Forest Region,

b) silvical characteristics of white spruce and trembling aspen, and

c) herbicidal and silvicultural efficacy of glyphosate herbicide.

### THE MIXEDWOOD FOREST SECTION (B.18a)

The Mixedwood Forest Section (B.18a) of the Boreal Forest Region extends from southern Manitoba to northeastern British Columbia (Rowe 1972). It covers a total area of 33.6 million ha with 16.4 million ha of productive forest land. It is the most productive forest land in Manitoba, Saskatchewan and Alberta. The native forest has with a mean annual increment (M.A.I.) ranging from 1.9 $m^3.ha^{-1}$ in Manitoba to 2.3 $m^3.ha^{-1}$ in Alberta (Bickerstaff *et al.* 1981).

The Mixedwood Forest Section of Manitoba includes the Porcupine, Duck and Riding Mountains, and the Spruce Woods. The most important commercial mixedwood stands available for forest management are located in the Duck and Porcupine Mountains (Johnson 1986). The Duck and Porcupine Mountains are located within the Cretaceous escarpment and are characterized by morainic deposits on the uplands and glacio-lactustrine deposits on the lowlands (Rowe 1972). The soils of the Duck and Porcupine Mountains belong to the grey-wooded group and are calcareous in nature. The soils range from sandy loams to clays and are stone free to very stony (Rowe 1955).

As the name of the section implies, the characteristic forest stands on well-drained uplands are mixtures of trembling aspen, balsam poplar (Populus balsamifera L.), white birch (Betula papyrifera Marsh.), white spruce and balsam fir (Abies balsamea (L.) Mill.). Black spruce (Picea mariana (Mill.) B.S.P.) and larch (Larix laricina (Du Roi) K. Koch) are common species in low wet areas. Jack pine (Pinus banksiana Lamb.) usually dominates sandy areas and drier till soils. Jack pine - black spruce mixtures can be found on the plateau-like tops of the larger hills. White elm (*Ulmus americana* L.), green ash (*Fraxinus pennsylvanica* Marsh. var. *lanceolata* Borkh. Sarg.), Manitoba maple (*Acer negundo* L.) and bur oak (*Quercus macrocarpa* Michx.) occur, as a minor component of the forest cover, in the southeast part of the Section (Rowe 1972). The naturally established forest stands are mainly of fire origin and are even-aged in structure (MacLeod and Blyth 1955).

At present a large surplus of aspen exists in the prairie provinces where approximately 47% of the total Canadian poplar resource, estimated at 191.1 million $m^3$ (Fitzpatrick and Stewart 1968), is located. Trembling aspen makes up 30% (78.7 million $m^3$) of the merchantable wood resource in the prairie provinces (Steneker 1976). Most of this is located in the Mixedwood Section of the Boreal Forest Region (Fitzpatrick and Stewart 1968). Only 4% of the allowable cut of trembling aspen in the three prairie provinces is harvested each year (Steneker 1976). To date, aspen has been used mainly for timber, plywood, veneer and particle board (Steneker 1976).

White spruce has been one of the most important trees in the prairie provinces for lumber (Phelps 1948, Kabzems 1952, Haig 1962) and in Canada for pulpwood and lumber (Stiell 1976). Although white spruce gained in value as manufactured market and export goods little more than eighty years ago (Kabzems 1952), most of the accessible old stands of white spruce/aspen have already been logged over for their spruce component (Johnson 1986). If a long-term supply of commercial white spruce from mixedwoods is to be maintained or increased, successful establishment and protection of regeneration is essential (Brace and Bella 1988).

## SILVICS OF WHITE SPRUCE

This summary of the literature provides an introduction to the factors which influence the initial growth of established white spruce plantations. Detailed discussions of the following topics are not presented in this thesis, because they have been adequately covered in the following reviews: silvics and ecology (Nienstaedt 1957, Sutton 1969), artificial regeneration (Stiell 1976), growth and yield

(Rauscher 1984), white spruce release (Johnson 1986), insect and disease (Johnson 1986), and genetics (Nienstaedt and Teich 1972, Neinstaedt 1982).

Seasonal variability in the tolerance of white spruce to herbicides has been reported by Miller (1958) and Young (1979). In order to minimize herbicide damage, it is important to understand the phenological cycle and early development of the crop species. The following sections outline the phenological cycle and early shoot development of white spruce.

## Dormancy Cycle

Shoot dormancy of white spruce is thought to be a progressive sequential process involving six transitional phases (Smith and Kefford 1964). The sequence of dormancy induction, as described by them, was later modified by Nienstaedt (1966) to give the general sequence of progression of bud dormancy phases for white spruce in southern interior Canada. The developmental phases of the vegetative apex of white spruce were later studied in greater detail by Owens *et al.* (1977). A summary of the bud and shoot development of white spruce is presented in Figure 1.

Chronologically the six phases of the seasonal development of white spruce are as follows:

1. Transitional Spring Burst-State (late April to late May)

This phase is characterized by swelling of the buds and the initiation of bud scale development (Owens and Molder 1976). The incipient swelling is the result of slight expansion of the apical meristem and needle primordia within the buds (Fraser 1962, Clements *et al.* 1971).

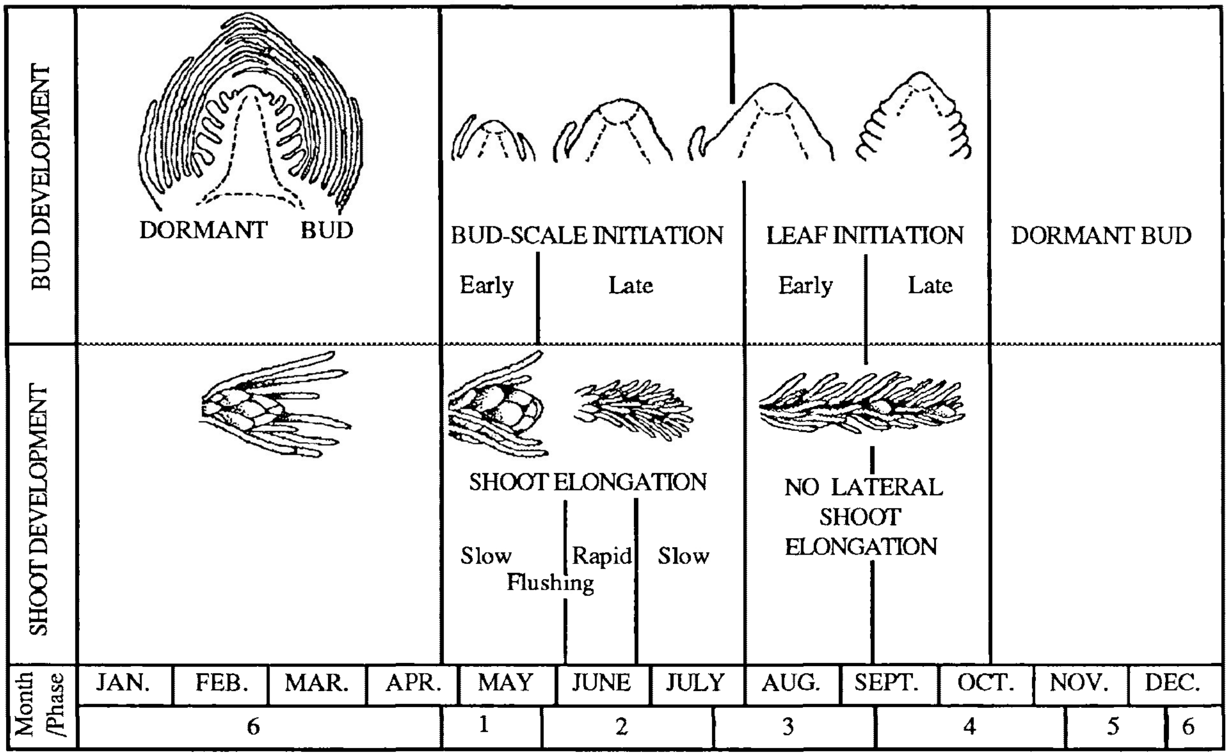



Figure 1. The developmental phases of the vegetative apex of white spruce at Prince George, British Columbia (Owens *et al.* 1977).

2. Spring Steady-State of Elongation Growth (Late May to Mid-July)

This is a period of rapid shoot extension followed by a period of slow shoot extension and of continued bud scale initiation and development (Owens *et al.* 1977). The amount of shoot extension is determined by the number of stem units initiated the previous summer and by the response of the spruce to the current growing environment (Cannell and Sheppard 1982). The period of most rapid shoot elongation ends soon after the summer solstice on June 21 (Fraser 1962, Owens et al. 1977). During the period of rapid shoot elongation the new shoots are succulent and very easily damaged by frost (Gross 1983, Nienstaedt 1985) or low rates of 2,4-D (Miller 1958). By mid-July white spruce begins to express a marked increase in herbicide tolerance.

3. Transitional Phase of Dormancy Development (Mid-July to Mid-September)

Shortening photoperiod initiates the cessation of shoot extension and the onset of dormancy (Vaartaja 1957, Pollard 1974, Glerum 1982), but flushing and free growth may occur under favourable growing conditions. Bud scale development is complete and buds visually appear dormant. At Chalk River, Ontario the transition from bud scale initiation to needle initiation occurred between July 11 and July 24 (Pollard 1973).

This is a period of rapid meristematic activity in bud apices as the needle primordia are initiated (Nienstaedt 1966, Pollard 1973, Owens and Molder 1976). Owens *et al.* (1977) observed that the period of rapid needle initiation lasted for about six weeks between the end of July and mid-September. The highest rate of needle initiation is at the beginning of this period (Pollard 1973). An average of six primordia are initiated per day from early August until mid-September (Pollard 1973). Temperature and, to a lesser degree, soil moisture and light intensity are among the most important factors influencing needle initiation (Pollard and Logan 1977). Approximately five weeks of favourable temperatures (>25 $^{o}$C) are required for satisfactory bud formation in white spruce (Pollard and Logan 1977).

White spruce has a low tolerance to frost during this period. If chilling interrupts needle primordia initiation, subsequent shoot growth potential can be severely reduced (Pollard and Logan 1977).

Herbicide release work is almost exclusively carried out during the latter half of this phase. During this phase white spruce is very tolerant even to relatively high application rates of 2,4-D (Miller 1958).

4. Dormant Steady-State (Mid-September to Early-November)

For the later half of this phase, white spruce is truly dormant in that no mitotic activity occurs within the bud apices. Owens *et al.* (1977) observed that the vegetative buds are not truly dormant until mid-October. White spruce continues late leaf initiation from the beginning of this state until mid-October (Figure 1). By early October the needles of the vegetative buds are generally well-formed (Fraser 1962) and by mid-October all of the leaf primordia for the next growing season have been formed (Owens *et al.* 1977). White spruce in this state will not flush under conditions of light, temperature and nutrition normally suitable for growth (Samish 1954).

Very little herbicide release work is carried out during the this phase. The white spruce is very tolerant of herbicide applications, but the trembling aspen has generally begun to lose its foliage by this time (Sayn-Wittgenstein 1961).

5. Transitional Dormancy Release Phase (Early-November to Mid-December)

In order to break dormancy the buds must receive a period of chilling. Bud chilling requirements are met after about four to six weeks of temperatures near $0^{\circ}C$ (Nienstaedt 1966). Once the chilling requirements are met the stock will be in the nondormant steady-state.

6. Nondormant Steady-State (Mid-December to Late April)

White spruce will remain in an inactive state throughout the winter if temperatures remain near or below $0^{\circ}C$ (Winton 1964). Bud flush will readily occur under favourable growing conditions.

## Shoot Growth

The shoot growth of white spruce is controlled by genetic characteristics and is influenced by climatic conditions, site characteristics, damage from wildlife and competition. An understanding of each of the factors influencing the growth of white spruce is necessary prior to understanding the results of removing competitive species.

### Growth in Relation to Genetic Characteristics

The shoot growth of white spruce is determinate, that is, the annual complement of new foliage is predetermined by the primordia formed in the previous year's bud (Pollard and Logan 1977). Elongation growth is simply the expansion of internodes and previously formed needle primordia (Nienstaedt 1966).

The seasonal shoot and root growth patterns of 1 1/2 + 1 1/2 white spruce have been described by Day (1985). Height, root collar diameter and root growth of white spruce commence in early May; height growth ends with bud set in late July and root collar diameter and root growth end with the onset of dormancy in October (Figure 2). The rate of root growth is lowest during the periods when bud scale and leaf intiation are the most rapid.

In general, white spruce planted stock grows slowly for the first few years after outplanting. This period of post-planting height growth depression, known as "check", is widely recognized throughout most of Canada (Stiell 1976). By definition, a tree is considered to be in check until it has achieved a rate of terminal growth equivalent to that which it would have attained in the next season in the nursery (Mullin 1964). Typical symptoms of check in white spruce seedlings are short, greenish-yellow needles; poor retention of needles that are two or more years old; small buds and very slow growth (Sutton 1975).

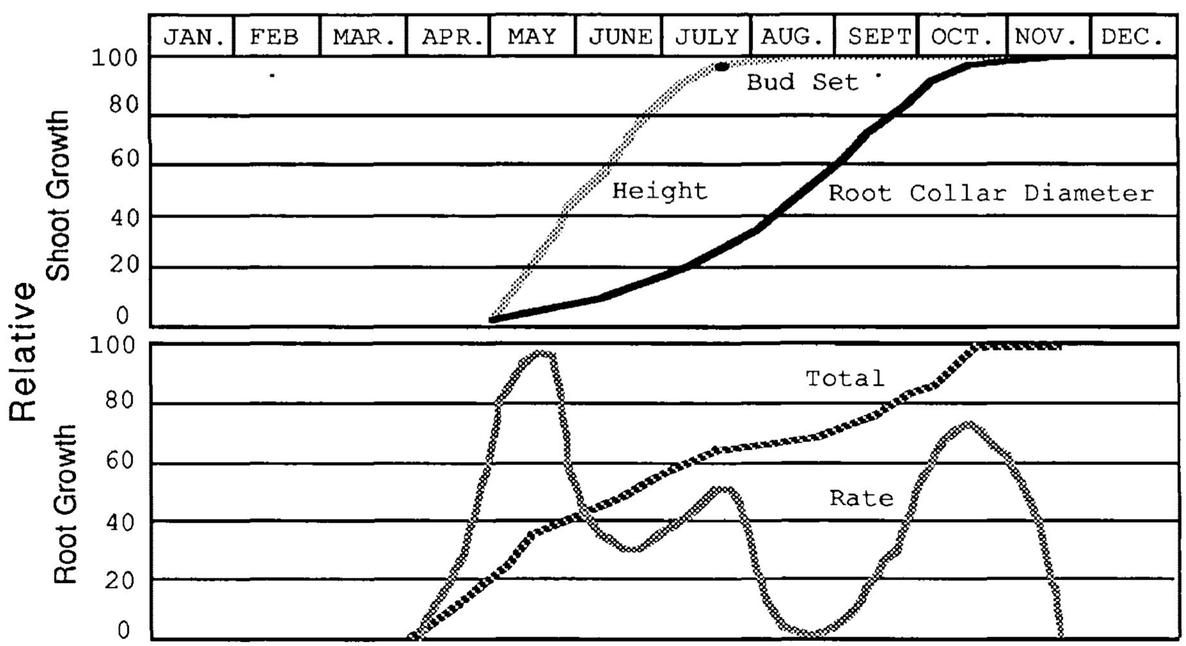



Figure 2. The relative shoot and root growth of 1 1/2 + 1 1/2 white spruce at Thunder Bay, Ontario (Day 1985).

## Growth in Relation to Climatic Factors

White spruce will not develop well on sites repeatedly exposed to late spring frosts (Nienstaedt 1985). Sites which are susceptible to late frosts include kettles, flats, slightly depressed basins surrounded by higher land or by a rim of timber and valleys prone to cold air inversion (Stoeckeler 1965).

The degree of damage caused by late spring frosts depends on the phase of bud development at the time of freezing (Cayford *et al.* 1959), the size of the tree and the degree of exposure (Clements *et al.* 1971). Shoots with partially grown needles are usually damaged more readily than shoots with fully expanded needles or dormant buds (Wright *et al.* 1977). Because frosts are caused by temperature inversions, damage from late spring frosts occurs more frequently in shorter spruce than taller spruce and more among open grown spruce than protected spruce (Clements *et al.* 1971). Lateral branches are usually damaged more severely than terminal shoots (Wright *et al.* 1977).

In Manitoba, spring-frosted white spruce seldom flush again during the year of damage. For this reason, frost damage in successive years may be lethal (Rowe 1955).

Late spring frosts can cause multiple leadering in white spruce (Hofstra *et al.* 1982, Nienstaedt 1985). Although frost has an immediate impact on form by causing multiple leadering, multiple leadered trees are rare in spruce plantations over 10 years of age in Ontario (Gross 1985). This indicates that white spruce has the ability to recover from multiple leadering.

## Growth in Relation to Site Factors

Soil properties such as organic matter content, texture, pH and microclimate have been related to the height growth of white spruce. For example, Rowe (1955) reported that the number of years required to reach breast height ranges from 10 to 15 years for natural stock growing on mineral soil and about 20 to 30 years or more for natural stock rooted in decayed wood.

White spruce grows best on loamy soils, but will also grow well on sands and clays provided that water is not a limiting factor

(Nienstaedt 1957). White spruce will tolerate a wide range of moisture conditions, but growth will be reduced on overly wet or dry sites (Nienstaedt 1957). The best height growth of white spruce occurs on wet telluric sites and the poorest on wet non-telluric sites (Kirby 1962). Jarvis *et al.* (1966) report that the survival of white spruce plantations set out on fresh to moist till soils is greater than that of plantations set out on dry sands. Planted stock at the Petawawa Forest Experiment Station generally required six years to reach breast height on most sites, but required about 12 years to reach breast height on dry sites (Stiell and Berry 1973).

White spruce will tolerate a wide range in soil pH. Although white spruce is generally classed as being adapted to acid soils it can grow well on calcareous soils, such as those found in the B.18a region of Manitoba (Stoeckeler 1938).

In the Lake States, Carmean and Hahn (1981) found that the time to reach breast height for naturally established white spruce was site dependent. However, the early height growth of planted white spruce is difficult to predict and site index curves for planted white spruce cannot be reliably extended below about 15 years (Stiell 1976).

Thrower (1986) studied 46 white spruce plantations in north central Ontario and found that years to reach breast height since planting ranged from 3.7 to 11.3 years with an average of 7.4 years.

## Growth in Relation to Wildlife Damage

The snowshoe hare is the main problem animal in young mixedwood stands (Drew 1988). Damage and mortality to white spruce from hares is severe enough that it must be considered in the planning of silvicultural operations in the Mixedwood Section of Manitoba (Johnson 1986).

Most damage caused by hares occurs during the winter months. During the winter the hares will often browse on the terminal and lateral buds of the spruce (Shirley 1941). This browsing can deform and retard the growth of the spruce. Repeated browsing can kill white spruce less than one metre tall (Rowe 1955).

Since winter browsing can occur on stems up to 60 cm above the snow line (Keith *et al.* 1984), white spruce is susceptible to damage until it is approximately two metres tall (Johnson 1986). Because snowshoe hares do not dig through snow for food, young conifers are protected once they are covered with snow (Radvanyi 1987).

Damage to conifers by showshoe hares is closely related to the cyclic rise and fall of the hare population (Aldous and Aldous 1944) and to the amount of ground cover (Rowe 1955). Hare populations peak approximately every ten years. Damage to spruce is low while the hares are at the low ebb of the population cycle, but increases as the hare population increases. Since the last peak in the Porcupine Mountain of Manitoba occurred in 1980 the next peak in their population is expected to reoccur around 1990.

Throughout the population cycle most damage caused by hares is in areas of dense cover (Aldous and Aldous, 1944 Rowe 1955). Rowe (1955) observed that damage from hares is confined to aspen-covered or brushy areas. Since hares seldom go farther than 200-400 m from cover (Keith *et al.* 1984), reduction of snowshoe hare damage can result from a "no cover - no rabbits approach". The application of herbicides could be utilized subsequent to planting and regrowth of competing vegetation to reduce cover and winter food supplies for snowshoe hare (Radvanyi 1987).

## Growth in Relation to Competition

White spruce is considered to be a shade tolerant species (Baker 1949) that requires at least 20% of full sunlight for high survival and at least 40% for optimum height growth (Shirley 1941). Logan (1969) found that white spruce is capable of maintaining full height growth potential anywhere between 45 and 100% of full sunlight.

According to Dobbs (1972), "Virtually every study that has been concerned with the problem of securing white spruce regeneration has implicated vegetation as a major factor with which to contend". Since white spruce normally grows on the most productive forest soils it often grows in association with aspen, alder (Alnus B. Ehrh.), hazel (Corylus L.), birch (Betula L.), willow (Salix L.) and grasses (Rennie et al. 1985). Grass, brush, aspen and snowshoe hares are the primary factors providing the *coup de grace* to regenerated spruce in the Mixedwood (Drew 1988).

Grass competition has caused both severe mortality and height growth reductions in newly established spruce plantations (Stephens 1965, Lees 1970, Drew 1988). Competition from Canada bluejoint (Calamagrostis canadensis (Michx.) Nutt.) can be significant until thespruce exceeds the maximum height (1.2m) of Canada bluejoint (Haeussler and Coates 1986).

Trembling aspen, which grows in profusion from root suckers, is perhaps the most serious competitor of white spruce plantations (Johnson 1986). Trembling aspen not only competes with the spruce for available light, moisture and nutrients but it also provides a favourable environment for snowshoe hare. The effect of aspen on the height growth of white spruce begins when the spruce are very young. Cayford (1957) noted that the time required for naturallly established white spruce to grow to breast height from stump height was 7.1 years for open grown seedling and 8.7 years for suppressed seedlings. In general, the height growth of trembling aspen exceeds that of open grown spruce for the first 30 years, and that of suppressed spruce for the first 30 to 40 years (Cayford 1957).

## Growth in Relation to Release From Competition

Results from studies to determine the effects of manual release of white spruce from trembling aspen competition show conclusively that all ages and sizes of white spruce respond to release (Jarvis *et al.* 1966). Nienstaedt (1957) reported that white spruce is capable of responding to release even after tolerating 40 to 50 years of suppression. Kagis (1952) found that 80-yr-old white spruce will respond to release if they are not severely whipped by the trembling aspen. Steneker (1967) reported that in intermediate aged mixedwood stands, diameter increments of white spruce of all size classes can be increased up to 100% by removal of the trembling aspen overstory. He also reported that the response of height growth to release is directly related to stand structure. White spruce with crowns in direct contact with and immediately below those of aspen have the most noticeable response and may double their height growth when released.

Steneker (1963) recommends that white spruce be released early in life to achieve the most benefit from the release, and that at the latest, it should be released before it comes into contact with the crown of the aspen. If herbicides are to be used to release white spruce, a sufficient height differential between the aspen and spruce canopy must exist to prevent leader whipping from the dead standing aspen (Steneker 1976). Many studies confirm the necessity of removing the aspen overstory from white spruce at an early age in order to achieve maximum growth of the white spruce (Shirley 1941; Cayford 1957; Lees 1967; Logan 1969; Steneker 1963, 1967, 1976; Johnson 1986).

Complete removal of the aspen is not recommended since mixedwood stands are less susceptible to spruce budworm, white pine weevil and yellow-headed sawfly infestations than pure white spruce stands (Jonhson 1986). If white spruce is in an area subject to frost damage, the most "successful" weed control obtained by herbicide application can be the most detrimental to newly established spruce because of excessive frost damage (Sutton 1984).

Post-spray assessments should be delayed until at least the second season after a herbicide application. Sutton (1975) reported that first-year height increment of 1 + 2 white spruce planted on an area chemically site prepared to remove grass competition was not substantially different than white spruce grown on control plots. By the end of the first growing season, the spruce on the treated site had better foliage colour and bud development than the untreated trees. Significant differences in height increment between the treated and untreated spruce were noted in the second and third growing seasons following outplanting. In the third growing season the treated spruce were superior to the untreated spruce in terms of foliage colour, bud size, needle length, needle retention, total mass and sturdiness.

## SILVICS OF TREMBLING ASPEN

The important silvical characteristics of trembling aspen for establishing and evaluating a herbicide project are its reproduction methods, growth habits and seasonal photosynthate translocation patterns. The latter two interact with glyphosate and effect herbicidal efficacy. In order to study the change in the foliage of trembling aspen following the application of herbicide, an inexpensive non-destructive method of evaluating the foliage must be used. An increase or decrease in the white spruce growth can then be compared to changes in the amount of trembling aspen foliage.

## Reproduction of Trembling Aspen

Although trembling aspen is a prolific seed producer, little regeneration originates from seed because of small seed size and the exacting requirements for germination and seedling establishment (Shirley 1941, Steneker and Wall 1970). Trembling aspen regenerates almost exclusively by means of root suckers which develop from the lateral roots of parent trees (Steneker and Wall 1970). Thus more emphasis will be placed on factors influencing root suckering than on factors influencing seeding.

## Factors Affecting the Germination of Aspen Seed

The seeds of trembling aspen are very small, approximately 4.5 million weigh one kilogram (Shirley 1941). On moist seedbeds, germination begins soon after seed fall and is completed in a day or two (Brinkman and Roe 1975). Before aspen will successfully reproduce from seed a number of conditions must be satisfied: 1) there must be an abundance of seed available, 2) there must be a good seedbed and 3) there must be sufficient moisture so that the seeds may germinate quickly (Kirby *et al.* 1957). Unless the seeds fall on mineral soil their chances of survival are poor.

## Factors Affecting Resuckering

Trembling aspen has a wide spreading and very shallow root system consisting of from three to six lateral roots. Trembling aspen suckers originate from these lateral roots (Sandburg and Schneider 1953). The initiation and survival of root suckers is related to apical dominance of the parent clone (Farmer 1962), root characteristics (Sandburg and Schneider 1953), light, temperature, soil moisture and nutrient supplies. Each of these factors will be reviewed to determine the most critical factors which may influence the regeneration of trembling aspen following an application of glyphosate.

Apical Dominance

Root suckering is controlled through apical dominance of the tree crown, principally by auxins (Farmer 1962, Schier 1973a, Steneker 1974). Complete inhibition of root sucker development, noted in undisturbed aspen, changes to partial inhibition after the flow of auxins is reduced or eliminated after damage to the stem or roots (Eliasson 1971b). Bud initiation and shoot outgrowth begins once the concentrations of auxin in the roots fall below inhibitory levels (Farmer 1962, Steneker 1974).

The number of suckers produced by aspen root cuttings is inversely related to the quantity of endogenous auxin present in the root bark at the time that the cuttings are collected. For example, 72% of the variation in the sucker production of three clones was associated with auxin content (Schier 1973b).

Root suckers originate in the region of the pericycle, near the cambium of the root bark (Sandburg and Schneider, 1953). Although sucker buds formed in previous years may be present and locally numerous on a root cutting, laboratory tests show that 95% of successful suckers originate from buds formed in the same season (Sandburg and Schneider 1953).

Suckers often originate in clusters along the lateral roots of trembling aspen, but only one or two of the suckers within a cluster will dominate and continue to grow (Sandburg and Schneider 1953). Emerging suckers can quickly produce sufficient quantities of auxin to inhibit both the initiation of new suckers and the growth and development of adjacent but younger suckers (Schier 1973a). Schier 1973a) observed several 10-cm long root cuttings which had over 200 emerging apices, but only 10% of them developed into suckers.

Although sucker occurrence decreases with increased root diameter, the number of suckers produced is insignificantly affected by root diameter (Starr 1971, Schier 1975, Perala 1978). In natural populations most aspen suckers arise from lateral roots that are less than 2.5 cm in diameter (Sandburg and Schneider 1953, Farmer 1962, Kemperman 1978).

Parent Clone

Sucker production has been shown to vary between clones (Farmer 1962, Maini 1968b, Schier 1973, Bell 1983), between ramets of a clone, between roots of a ramet (Schier 1978) and between sections of individual roots (Steneker 1974, Kroes 1979).

Root Characteristics

Neither anatomical characteristics nor individual properties of roots (e.g. age or position in the root system) are not strongly associated with suckering inhibition (Sandburg and Schneider 1953). Suckering potential is similar in root cuttings with 7 to 15 growth rings obtained from trees that range in age from 20 to 150 years (Horton and Maini 1964). Injured root segments, however, usually do not form suckers (Elliasson 1971b).

Root carbohydrate reserves are an important factor in the reproduction of aspen by root suckering. These affect the initial growth and survival of suckers, but usually have little influence on the number of suckers produced (Tew 1970, Schier and Johnston 1971). The number of suckers initiated appears to be more closely related to hormone levels and ratios than to root carbohydrate reserves (Schier and Johnston 1971); however, exceptionally high or low carbohydrate levels may limit the number of suckers produced (Schier and Zasada 1973).

The level of root carbohydrate reserves varies with the time of year. Carbohydrate levels are lowest immediately after leaf flush; increase during the growing season and are highest prior to the onset of dormancy in the fall (Tew 1970). The seasonal changes in root carbohydrate reserves affect the length of time in which suckers are initiated and the vigour of sucker growth. Root cuttings collected in the fall commence suckering later and continue to sucker for up to two months longer than those collected in the spring (Zufa 1971). Sucker growth is also more vigorous from root cuttings collected during the dormant season than from cuttings collected shortly after foliation (Schier and Zasada 1973, Steneker 1974).

An elongating sucker depends on root carbohydrate reserves until it emerges at the soil surface and produces leaves (Schier and

Johnston 1971). When leaves are produced, sucker growth becomes increasingly more dependent upon photosynthate produced by the leaves than on reserve carbohydrates (Vogt and Cox 1970).

In general, the length of root cuttings does not affect the number of suckers produced, but does affect the growth of the suckers. Height varies directly with the root length (Steneker and Walters 1971). Sucker dry weight and diameter also vary directly with cutting length (Perala 1978).

## Light, Temperature, Soil Moisture and Nutrients

Light intensity does not have an effect on very early growth of suckers (Sandburg and Schneider 1953, Eliason 1973) but does affect the form of suckers and the development of roots from root cuttings. Suckers grown at low light intensities (550 ft-c) are thinner and taller than those grown a higher light intensities (1,700 ft-c) (Farmer 1963). Increased light intensity stimulates development of new roots and results in a more even rate of height growth and more rapid, firm secondary growth of sucker stems than reduced light intensities (Sandburg and Schneider 1953).

Temperature greatly influences the number of suckers produced by aspen roots (Maini and Horton 1966). Minimum, optimum and maximum temperatures for sucker formation are 20°C, 24°C and 35°C, respectively (Maini and Horton 1966). Soil temperatures below 20°C cause a reduction in suckering.

Only well-aerated root cuttings form suckers. Root cuttings placed in saturated or flooded soils perform poorly and may be subject to rot (Maini 1968b).

Laboratory studies show that height and diameter growth of *Populus* clones are affected by nitrogen application levels (Cheng 1947).

## Shoot Growth of Aspen

The most important factors influencing the early shoot growth of trembling aspen which are relevant to this project are genetic characteristics, site conditions, and intra- and inter-specific competition.

Growth in Response to Genetic Characteristics

Trembling aspen seedlings can attain heights of 30.0 cm or more in the first growing season, 1.8 to 2.5 m in 5 years, 7.8 m in 13 years and 11.4 m in 20 years (Shirley 1941).

Trembling aspen suckers grow more quickly than seedlings during the first few years after initiation (Shirley 1941). This is because they are supported by the root system of the parent tree which provides the suckers with nutrients and moisture. Suckers also develop feeder roots which supplement the nutrients provided by the parent root system (Brinkman and Roe 1975). Vigorous suckers may grow as much as 2.0 m in their first year, but subsequent height growth will average between 30.0 and 60.0 cm annually, depending on the site (Steneker 1976).

Growth in Response to Site Conditions

Trembling aspen grows on a wide range of sites from dry sands to wet clays. Its growth is generally better on fresh to moist clay loams and moist sandy loams than on dry sands or wet clays (Steneker 1976). Einspahr and Benson (1968) report that trembling aspen reached its maximum development on loamy lime rich glacial drift. Brinkman and Roe (1975) observed that at age 50 the height of trembling aspen ranged from 30 m on deep fertile loams to 13 m on dry sands, rock outcrops, water logged mineral or peat soils. They also observed that aspen reached its best development on porous, loamy, humic soils that are rich in minerals.

Growth in Response to Competition

Inter-specific competiton is not generally a problem associated with trembling aspen reproduction. The rapid initial growth rate of trembling aspen suckers easily exceeds that of most other vegetation grown under similar conditions. However, in the case of aspen seedlings, freedom from competing vegetation is essential throughout the first year (Shirley 1941).

Intra-specific competiton causes high mortality and restricts diameter growth and crown development in rapidly growing trembling aspen stands (Kirby *et al.* 1957, Pollard 1971). In a fire origin stand with an estimated site index of 27.4 m at 50 years, Pollard (1971) found a decrease from 31,000 stems per ha at age four to 22,000 stems per ha by age seven.

## Seasonal Photosynthesis of Aspen

The foliage production of aspen is influenced by age. Pollard (1972) found the foliage production of 6-, 15- and 52-year-old trembling aspen stands to be 2600, 2600 and 1500 $kg.ha^{-1}$ respectively. He also found the leaf area index (LAI) of the same stands to be 2.4, 2.9 and 1.6 respectively. Peterson *et al.* (1970) found the LAI of a mixed age aspen stand (66- to 89-year-old) in Alberta to be 1.8.

Late spring frosts have a major influence on total seasonal foliage production (Pollard 1970). If early leaf development is retarded by late spring frosts, the LAI will be small for the remainder of the season. Frost damage to individual stands of trembling aspen is highly variable and can range from nearly complete bud killing to little apparent damage (Cayford *et al.* 1959). Trees with light bud injury can develop normal leaves, but when bud damage is severe, abnormally large widely scattered clusters of leaves are produced.

### Foliage

An understanding of the seasonal translocation patterns of photosynthate within aspen is necessary in order to predict where glyphosate, applied at different times during the growing season, will be distributed within the tree. Although information reguiring the translocation of photosynthates within trembling aspen could not be found in the literature, some information on translocation patterns within other aspen species has been published.

The following information is a summary of the available literature on the seasonal translocation of photosynthate within bigtooth aspen (Populus grandidentata Michx.) and hybrid poplar (Populus tristis x balsamifera cv. Tristis). In mid-May both terminal and axillary buds of both aspens flush (Donnelly 1974). For the first two weeks after bud flush, shoot growth depends primarily on photosynthates stored in the stem in proximity to the breaking bud (Donnelly 1974). As soon as mature leaves develop, photosynthate produced by these leaves becomes the primary source of photosynthate for subsequent shoot growth (Isebrands 1982).

The translocation pattern of photosynthate from a shoot varies with the location of the shoot in the crown and with the time of the season (Figures 3 and 4). The seasonal transport patterns of photosynthate from mature leaves on current terminal shoots differs from the seasonal transport patterns from mature leaves on lateral branches. Before budset, which occurs in late July (Donnelly 1974), photosynthate produced in the mature leaves on the current terminal is primarily translocated acropetally to the expanding current terminal leaves and basipetally to elongating terminal stem and stem internodes. Lesser quantities of photosynthate are translocated to the roots and little photosynthate moves to the newly developing lateral branches (Isebrands 1982).

After budset, the distribution pattern of exported photosynthate changes. The translocation of photosynthate from current terminal leaves to the terminal bud and the roots increases dramatically toward the end of August. By mid-September export of photosynthate to the roots may be as high as 50% of the total quantity translocated within the tree.

The translocation patterns of photosynthate from mature leaves on lateral branches are similar regardless of their position in the crown. Early in the growing season mature leaves on lateral branches contribute photosynthate to the lateral branch itself for branch elongation and growth and to the stem internodes below for diameter growth. As the season progresses the mature leaves on laterals export an increased quantity of photosynthate to the roots just like the current terminal (Isebrands 1982).

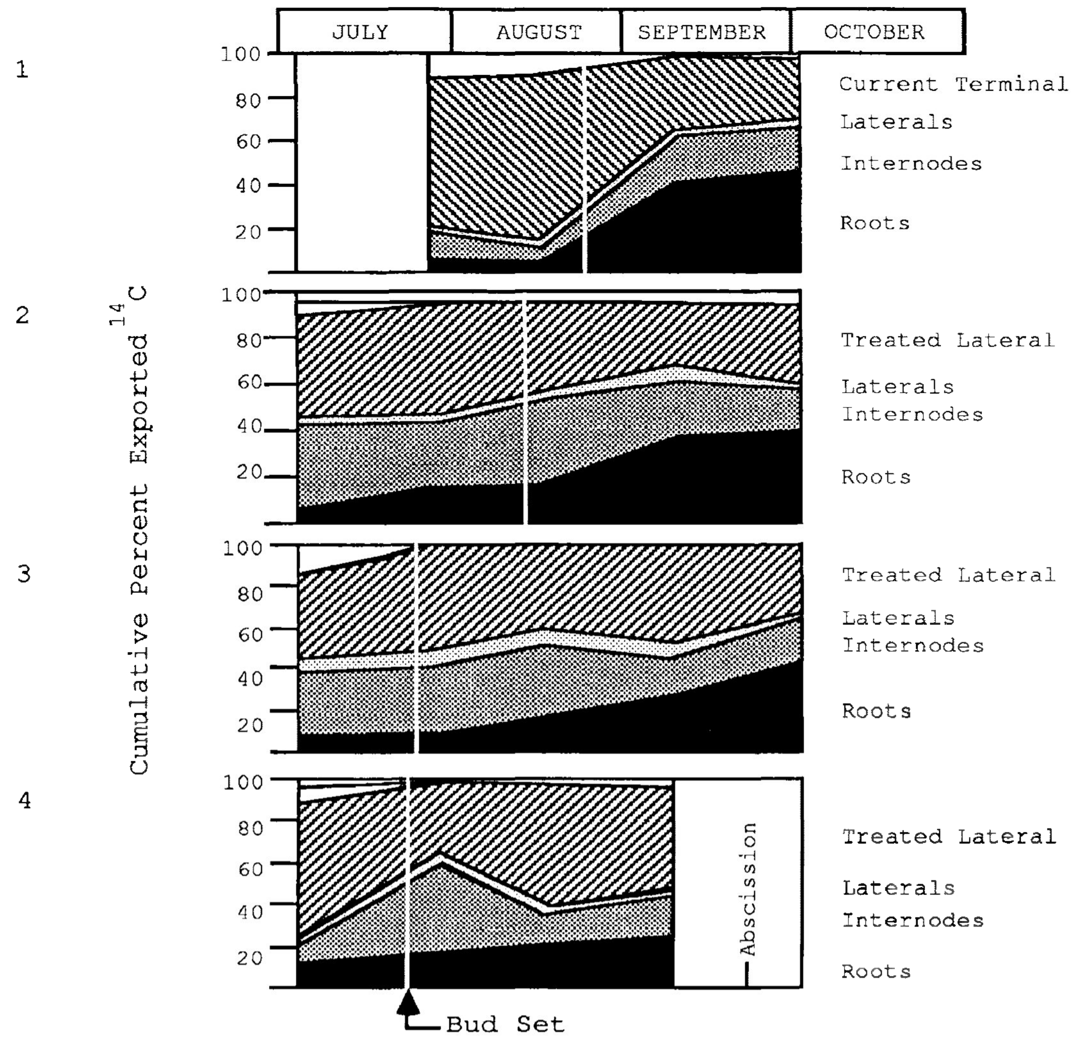



Figure 3. Cumulative per cent of exported $^{14}C$ from mature leaves at four positions within the crown of 2-yr-old intensively cultured P. tristis trees during the course of the season; 1) mature leaves of current terminal shoot, 2) mature leaves of 5th first-order lateral branch from top, 3) mature leaves of middle 5th first-order lateral branch, and 4) mature leaves of 5th first-order branch from the base. The recovery positions are indicated on the right hand side of the graphs (Isebrands 1982).

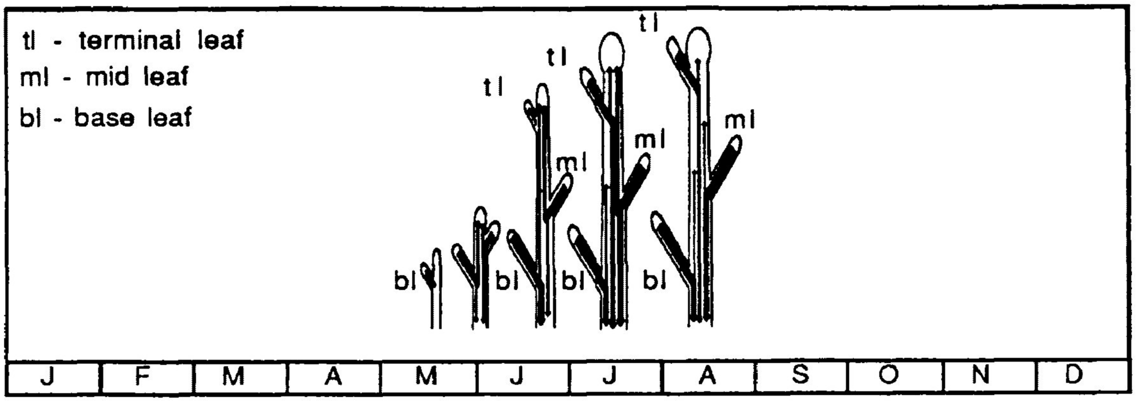



Figure 4. Seasonal translocation of photosynthate within the current terminal shoots of Populus grandidentata (Donnelly 1974).

Bark

Although the annual contribution of bark photosynthesis to the carbohydrate supply of a tree is low, bark photosynthesis nearly equals stem respiration and it could increase the chances of survival of stressed trees after insect defoliation or after a late spring frost (Shepard 1975, Foote and Schaedle 1978, Jones and Schier 1985) or perhaps herbicide applications. The twigs and stems of trembling aspen have a greenish corticular layer just beneath the bark surface which contains chlorophyll (Pearson and Lawrence 1958). The phelloderm and cortical parenchyma cells located in the bark of the stem and branches produce approximately one to two percent of the total carbohydrate supply of an aspen tree (Barr and Potter 1974).

The total amount of $CO_2$ assimilated within the bark of trembling aspen is a function of both light intensity and temperature (Foote and Schaedle 1976, 1978). This is reflected in the seasonal distribution of the total amounts of $CO_2$ assimilated by the bark. Approximately 59% of the total $CO_2$ is assimilated from June through August, 27% from March through May, 10% from September through November and only 4% from December through February (Foote and Schaedle 1978).

**GLYPHOSATE HERBICIDE**

Glyphosate, formerly formulated as Roundup® liquid herbicide, is currently formulated as Vision™ liquid herbicide by the Monsanto Agricultural Products Company. Roundup® and Vision™ have identica ingredients; therefore, all literature pertaining to Roundup® published prior to January of 1987, also applies to Vision™. Roundup® is a relatively non-toxic herbicide that contains 356 $g.L^{-1}$ of the isopropylamine salt of glyphosate together with a surfactant (Franz 1978, W.S.S.A. 1983).

In general, glyphosate is an excellent forestry herbicide for the following reasons: it effectively controls a broad spectrum of weed species including trembling aspen (Polhill 1978, McCormack and Saviello 1981, Sutton 1984); it is poorly absorbed by conifers in the dormant state (Lund-Hoie 1974, 1977, 1980), it is rapidly inactivated by soil (Sprankle *et al.* 1975), and it is relatively non-toxic to mammals, birds, fish, insects and most bacteria (Franz 1978).

## Toxicology

Lethal dose 50% (LD 50) refers to the dosage level of test material that will induce mortality in 50% of experimental animals. Oral (rat) and dermal (rabbit) toxicity levels for both Roundup® and glyphosate are relatively low (LD 50 = 5000 $mg.kg^{-1}$). Roundup® herbicide is less toxic following oral ingestion (rat) than aspirin (LD 50 = 1000 $mg.kg^{-1}$), table salt (LD 50 = 3000 $mg.kg^{-1}$) or caffeine (LD 50 = 192 $mg.kg^{-1}$) (Monsanto 1984).

## Environmental Impact

Glyphosate biodegrades rapidly via soil microorganisms (average half-life = 60 days) under both aerobic and anaerobic conditions. The breakdown of glyphosate takes place primarily by microbial degradation rather than by chemical decomposition (Monsanto 1984). The principal metabolite formed upon the degradation of glyphosate in soil is aminomethylphosphonic acid (AMPA) which is biologically degradable (Rueppel *et al.* 1977).

## Behaviour In Plants

Glyphosate is a non-selective, post-emergent herbicide and is absorbed through foliage and green stem tissues of plants. Glyphosate is readily translocated throughout the aerial and underground parts of most plants. It is generally believed that glyphosate is translocated according to the "source" to "sink" principle (Lund-Hoie 1980). Translocation takes place via the symplastic system and perhaps the apoplast (Ashton and Crafts 1981). Very little is known about the factors that determine the relative amounts of glyphosate translocated in the symplast or apoplast (Casely and Coupland 1985).

Although post-emergent unit activity is high, glyphosate shows no significant pre-emergent effect or residual soil activity even at relatively high rates (e.g. 57 $kg.ha^{-1}$) (Franz 1978). Klingman (1974) found that glyphosate does not harm ungerminated grass seed. Thus, grass can reestablish on a treated area from a residual seed source.

"Glyphosate exerts phytotoxicity by inhibiting the shikimic acid pathway and thus arresting the biosynthesis of aromatic amino acids" (Cole 1985). Action at the shikimic acid pathway and inhibition of the synthesis of aromatic amino acids is unique to glyphosate (Cole 1985). The absence of the shikimic pathway in animals is an important factor in its low animal toxicity (Cole 1985).

Glyphosate does not appear to have an immediate direct effect on respiration, DNA synthesis, RNA synthesis, protein synthesis (Ashton and Crafts 1981) or photosynthesis (Cole 1985).

The susceptibility of different plants can be highly variable and depends upon the leaf penetration and subsequent distribution of the herbicide within the plant (Lund-Hoie 1980). Lack of needle penetration via the waxy cuticle explains, to a large degree, the high level of tolerance shown by conifers (Lehela *et al.* 1972, Lund-Hoie 1980).

The usual phytotoxic symptoms of glyphosate injury to vegetation are gradual wilting and yellowing of the foliage which advances to complete browning of above-ground growth and deterioration of underground plant parts (Mansfield and Fralick 1979). A symptom of glyphosate absorbtion by coniferous species is the shortening of the needles in the tips of the lateral shoots the year after application (Day 1985, pers. com.).

The symptoms usually develop within two to four days with most annual weeds and within seven to ten days with most perennial weeds (Sutton 1978). Under field conditions, symptoms often develop slowly and two- to three-week delays are common (Ashton and Crafts 1981). In woody species, glyphosate is a slow acting herbicide (Lund-Hoie 1980). In general, the full effect or deterioration of the woody tissue should not be expected for one- to two-years after application. For species such as ash (Fraxinus L.) and oak (Quercus L.), the herbicidal processes may continue for up to three years (Lund-Hoie 1980).

## Efficacy in Forest Plantations

Sutton (1985) recommends that the efficacy of herbicide applications be discussed in terms of *herbicidal efficacy* and *silvicultural efficacy*. 'Herbicidal efficacy' is defined as the capacity of a herbicide to cause direct phytotoxic effects in weeds and 'Silvicultural efficacy' is defined as the capacity of a herbicide to promote indirectly positive growth responses in crop trees.

### Herbicidal Efficacy

Glyphosate can be used to control a wide variety of plants; including the following woody plant species: moutain maple, alder (Alnus rugosa (Du Roi) Spreng.), hazel (Corylus cornuta Marsh.), raspberry (Rubus idaeus L.), willow (Salix L.) and aspen (Polhill 1978, Perala 1984, Sutton 1984).

The rate of glyphosate application used to control competing vegetation is critical. According to Lund-Hoie (1980), "Glyphosate has a sharp, clear threshold for effect. This means that if the application approaches a minimum dosage, the result will be either full effect or no effect at all, depending on environmental conditions at the time of spraying". In general, lower concentrations of glyphosate may be more effective for controlling perennials than higher concentrations, because higher concentrations may kill tissue on contact before the herbicide can be translocated into other areas of the plant (Sutton 1978). The susceptibility of several plant species to mid-late August, aerially applied glyphosate is shown in Figure 5. Conifers such as white spruce and balsam fir are relatively tolerant to glyphosate compared to deciduous species such as aspen or willow.

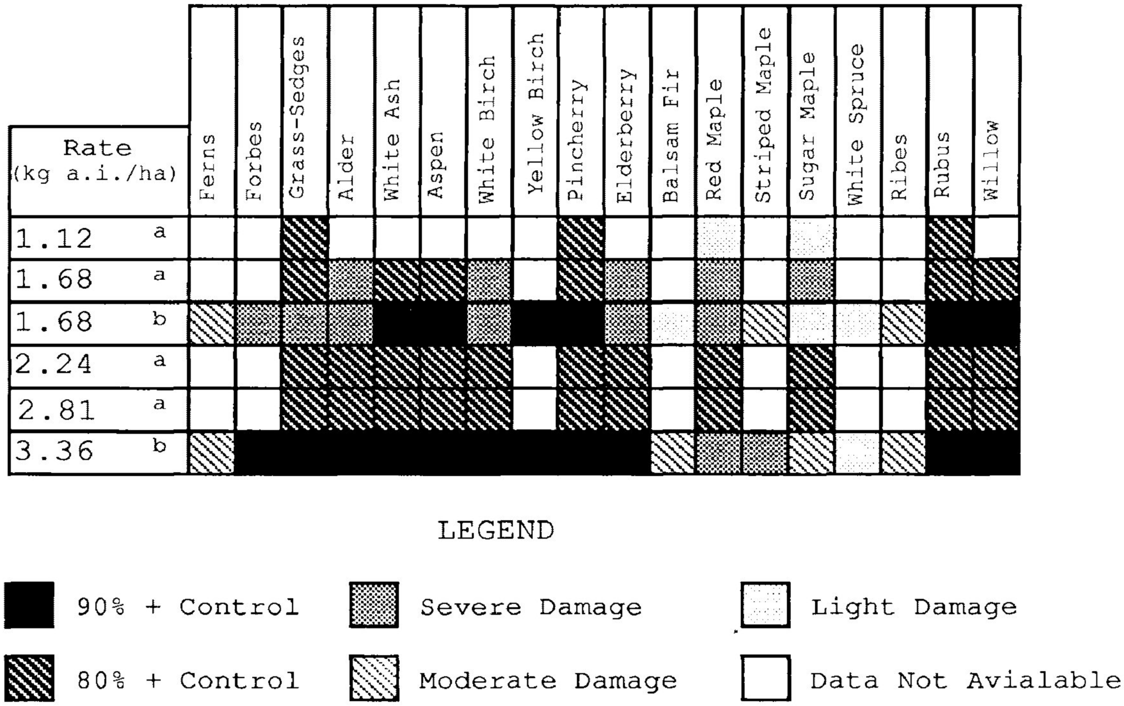



Figure 5. The susceptibility of several northern forest species to mid-late August, aerially applied Roundup® at five application rates (Adapted from: a] Anon. (1985) and b] Newton and Knight (1981)).

The rate of application is critical in attempting to control aspen with glyphosate. Rates of 3 to 6 $L.ha^{-1}$ (1.07 to 2.14 $kg.ha^{-1}$ respectively) are recommended for the control of trembling aspen (Monsanto 1987). Perala (1984) reported that glyphosate applied at between 1.12 and 2.24 $kg.ha^{-1}$ resulted in consistent and effective reductions in aspen biomass and woody stem density. Sutton (1984) found that 2.0 $kg.ha^{-1}$ of ground applied glyphosate gave 95% control of aspen three years after application and 1 $kg.ha^{-1}$ gave 50% control. Lund-Hoie (1975) observed 70, 97, 100 and 100% control (top kill with no regrowth) of European aspen (Populus tremula L.) with 0.25, 0.50, 1.00 and 2.00 $kg.ha^{-1}$ of glyphosate applied from a mist blower at the rate of 120 litres of solution per hectare. Lund-Hoie (1975) also observed that the maximum effect of glyphosate on European aspen applied at 0.50 $kg.ha^{-1}$ did not occur until two years after the application.

The time of glyphosate application used for the control of woody plants does not appear to be as critical as the rate of application as long as the target vegetation is growing vigorously (Sutton 1978). However, mid-summer applications seem to be more effective than spring applications (Andrews *et al.* 1974, Blackmore and Corns 1979). During the mid-summer period most brush species are still photosynthetically active and accumulating food reserves, some of which are translocated to the root systems for storage (Gratowski 1975).

Late season applications may be carried out, provided that no major leaf fall has taken place in undesirable brush and tree species (Monsanto 1987). Perala (1984) found that glyphosate is equally effective for aspen control between August 8 and September 2, or after the accumulation of from 2300 to 2900 Fahrenheit Growing Degree Days over a 40°F threshold. Control of aspen with glyphosate is not reliable after the second week of September in the north central United States (Perala 1984).

The effect of glyphosate applications is not just dependent on the rate and time of application. Factors such as the formulation of the compound, climatic factors, spray drift and the physiological behaviour within the target plant are also important (Lund-Hoie 1980). The salt formulation of glyphosate is susceptible to being washed off by rainfall for a few hours after application due to slow uptake. The amount of glyphosate lost due to rainfall appears to depend on the intensity of the rainfall (Lund-Hoie 1980).

Lund-Hoie (1974) reports that air humidity affects the long term effect of glyphosate but air temperature is relatively unimportant. Optimum conditions for application of glyphosate are air temperatures between 18 and 20°C and as high a relative humidity as possible (Lund-Hoie 1980). He also reports that low temperatures can be compensated for by a high relative humidity, but low relative humidity cannot be compensated for by high temperature.

The herbicidal efficacy of glyphosate is negatively correlated to aircraft speed during application (Barring 1979). High speed helicopter applications (90 to 100 $km.hr^{-1}$) generally require a dose of 1.42 $kg.ha^{-1}$ to obtain equivalent control of <u>Populus tremula</u> L., <u>Rosa</u> L. and <u>Alnus incana</u> Moench. as 0.71 to 1.07 $kg.ha^{-1}$ applied at low speeds (50 to 60 $km.hr^{-1}$). The reason for this difference in application rates is not fully understood, but is most likely related to droplet size (McCormack pers comm. September, 1989).

Wendel and Kochenderfer (1984) recommend that for best control the target species should not be under stress from drought, damage or other factors at the time of application. Healthy active foliage is required to absorb enough chemical for translocation to all parts of the plant at toxic levels (Boyd et al. 1985)

## Silvicultural Efficacy

When applied according to label directions, Vision™ is effective for the release of conifer genera such as Douglas fir (Pseudotsuga Carr.), fir (Abies L.), hemlock (Tsuga (Endl.) Carr.), pine (Pinus L.) and spruce (Picea Dietr.) (Monsanto 1987).

As with herbicidal efficacy, the rate of application is critical. High rates of glyphosate can damage or kill coniferous seedlings (Sutton 1978, Alm 1981), and in particular, white spruce (Young 1979). Young (1979) found that 2.0 $kg.ha^{-1}$ caused moderate damage and 4.0 $kg.ha^{-1}$ caused severe damage to potted white spruce seedlings in a growth chamber study. Indirect damage caused by high rates of glyphosate can also be significant. Very successful control of trembling aspen may result in the increased exposure of white spruce crop trees to both late spring and early fall frosts (Sutton 1985).

The time of glyphosate application is critical in terms of crop damage, because applications made during periods of rapid conifer growth may result in injury to the conifers in the form of tip and/or needle burn (Monsanto 1987). This may be more true for pine than for spruce. Lund-Hoie (1977) reported that in plantations of Norway spruce (*Picea abies* (L.) Karst.), glyphosate can be applied from the beginning of shoot elongation until the target species no longer has vital green leaves. However, in plantations of Scots pine (Pinus sylvestris L.), the application should not start before shoot elongation has ended and the shoots are fully matured. Sutton (1984) found that jack pine could be heavily damaged by mid-July applications of glyphosate at 4.0 $kg.ha^{-1}$, but were relatively unharmed by early September applications made at the same rate. Applications should be avoided during lammas or late season conifer growth (Monsanto 1987). During cold summers, the application of glyphosate in areas where the conifer crop will be exposed to the spray, should be delayed by one to two weeks (Barring 1979). This applies especially to pine regeneration.

In general, maximum control of competing vegetation and the minimum negative effect on conifers can best be obtained by applying glyphosate in the late summer, after bud set and hardening of the current year's growth (Gratowski 1978, Sutton 1978). Monsanto (1985) published an application timing chart for glyphosate herbicide for different uses (Figure 6). This chart presents the final two weeks in August as being the optimum time during the growing season for the application of glyphosate for conifer release.

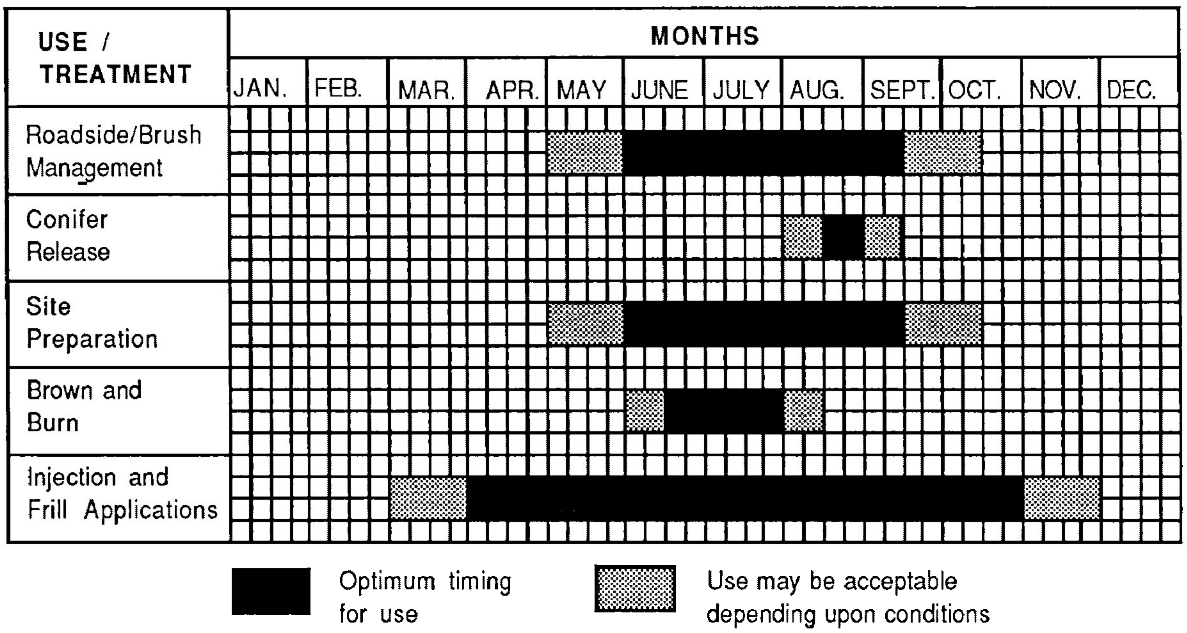



Figure 6. Application timing chart for glyphosate herbicide (Monsanto 1985).

Lund-Hoie (1974) observed that coniferous species like Norway spruce have a high degree of tolerance to glyphosate when the application is delayed until after the end of shoot growth. Direct damage to spruce from the aerial application of glyphosate in mid- to late-August may be negligible as can be seen in Figure 5.

## METHODOLOGY

The objectives of the study were met by conducting three trials that involved: 1) the aerial application of glyphosate at three rates, 2) the ground application of glyphosate at three rates at three periods of time during the growing season, and 3) the evaluation of the resuckering potential of aspen sprayed in the ground trial. All trials were established within a white spruce plantation located in the Porcupine Provincial Forest of the Mixedwood Section (B.18a) of western Manitoba (Lat. 52$^{o}$ 20'N, Long. 101$^{o}$ 40'W). The study area was burned-over in May 1980, site prepared with a disc trencher (TTS-350) in September 1981 and hand planted in late-May 1982 with 3+0 white spruce seedlings from Pineland Forestry Nursery at Hadashville, Manitoba. A regeneration survey conducted in July, 1983 confirmed that approximately 90% of the planted white spruce survived.

The methodology involved with each trial is discussed in detail below.

### TRIAL 1 - THE EFFECT OF AERIAL SPRAYING ON THE SURVIVAL AND GROWTH OF OUTPLANTED 3+0 WHITE SPRUCE AND ASPEN COMPETITION

This trial was initiated as a Manitoba Department of Natural Resources silvicultural project, but was modified in order to monitor the effects of three rates of glyphosate. It is important to note that a fully replicated conventional experimental design was not layed out. The size of area required to conduct a such a trial on an operational scale would have been greater than the size of the plantation.

In July 1984, three 4.8 ha spray plots were demarcated in the white spruce plantation. Nine 0.04 ha sample sub-plots were located at random within each plot and measured to assess the abundance and condition of the planted white spruce and trembling aspen competition. In 1985, six 4.8 ha spray plots were demarcated near those established in 1984 (Figure 7). As in 1984, nine 0.04 ha sample plots were located at random within each plot and measured as before. The layout of the sample plots within each of the nine spray plots is shown in Appendix A.

Three rates of glyphosate were applied aerially in both 1984 and 1985 in cooperation with the Forestry Branch of the Manitoba Department of Natural Resources. In 1984, one plot was aerially sprayed at each rate (0.00 [Control], 0.90 and 1.60 $kg.ha^{-1}$) on August 22 with a Bell 206 helicopter. In 1985, two plots were sprayed at each of three rates (0.0 [Control], 0.93 and 1.99 $kg.ha^{-1}$) on August 19 with a Bell G-4 helicopter. Table 1 presents the spray equipment used in the 1984 and 1985 spray programmes and the weather conditions at the time of spray and for the following week after spray.

Table 1. Description of spray equipment and weather conditions for the aerial spray programs.

| Parameter | August 22,1984 | August 19,1985 |
|---|---|---|
| Helicopter | Bell-206 Jet Ranger | Bell G-4 |
| Average Flying Speed | 84 km/h | 80 km/h |
| Average Flying Height | 23 m | 23 m |
| Swath Width | 25 m | 15 m |
| Tank Pressure | 50 p.s.i. | 37 p.s.i. |
| Boom Length | 12.9 m | 12.9 m |
| Nozzle System | 22 | 29 |
| Nozzle # | 4664 | 4664 |
| Orfice # | D5 | D8 |
| Core # | 25 | 25 |
| Orfice Diameter | 1.9 mm | 3.2 mm |
| Temperature at Time of Spray | 0 °C - morning | 3 °C - morning<br>12 °C - evening |
| Wind Speed | 0 km/h | 4-7 km/h |
| Relative Humidity | N.A. | 47% |
| Average Noon Temp. At Hart Mountain For One Week After Application | 19 °C | 15 °C |
| Number of Days Before Measurable Rainfall | 12 | 2 |

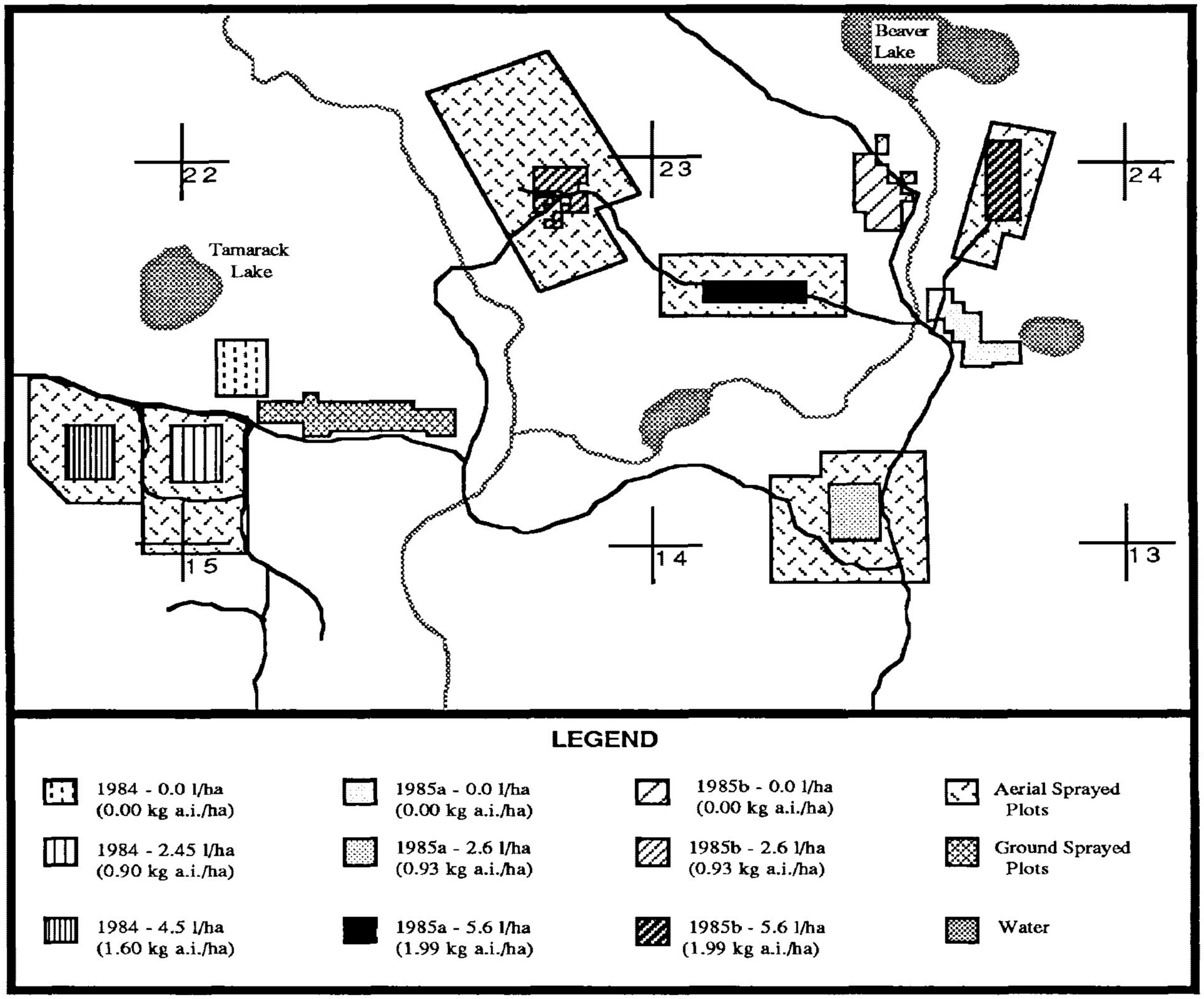



Figure 7. Layout of the aerial spray and ground spray plots in Township 39, Range 29 of the Western Region of Manitoba.

Pre-spray measurements made on the ten white spruce closest to each of the 0.04 ha sub-plots included the 1981, 1982, 1983 and 1984 annual height increment, the basal diameter for the 1984 spray areas, the 1981 to 1985 annual height increment and the 1985 basal diameter for the 1985 spray areas.

As many of the white spruce had been planted deeper than the root collar diameter (RCD) and had developed adventitious roots prior to the 1984 measurements, basal diameter measurements, at ground level, were made rather than RCD measurements.

Post-spray measurements carried out on the white spruce in the 1985 and 1986 growing seasons included survival, percentage of terminal buds browsed by snowshoe hares, percentage of terminal buds damaged by frost, number of multiple leaders, annual height increments and basal diameter of the white spruce.

The stem volume for the white spruce was estimated for individual trees based on the formula for the volume of a right cone:

$$\text{Stem Volume} = 1/3\ \pi\ r^2 \times ht$$

where:
r = basal radius (cm), and
ht = total stem height (cm).

Pre-spray measurements made on the trembling aspen in the 0.04 ha sub-plots included the number of trembling aspen stems per sub-plot by height and diameter classes and the branch diameters at point of foliation of three aspen stems and mean basal area per sub-plot.

Post-spray measurements carried out on the aspen within the 0.04 ha sub-plots in the 1985 and 1986 growing seasons included: a) the number of aspen stems by diameter, height and morphological condition classes and b) branch diameters at point of foliation of the three aspen stems of mean basal area per sub-plot (to estimate change in foliage dry weight).

The health of the aspen was recorded in accordance with the following coding classes:

| Code No. | Morphological Code |
|---|---|
| 1 | - Dead (buds and inner bark dry). |
| 2 | - Inner bark alive (green) buds dead. |
| 3 | - Inner bark alive (green), buds broken but leaf development minimal. |
| 4 | - Inner bark alive (green), buds broken, leaves developed but show signs of herbicide damage. |
| 5 | - Inner bark alive (green), foliage shows no signs of herbicide damage. |

Two methods were used to monitor aspen foliage biomass. First, trees within each of the height and diameter classes in morphological condition codes 4 or 5 were randomly selected from the sprayed and unsprayed sites. The oven dry weight (ODW) of the foliage was measured and regressed against the height and the basal area of the trees from which the foliage was obtained. Low correlations for oven dry weight of the foliage with the independent variables height and diameter for the sprayed areas prevented the development of a regression model to estimate the foliage for each individual tree on the field sub-plots.

Second, oven dry weight of the aspen foliage per hectare was attempted using the point of foliation method (Harvey 1981). The ODW of foliage supported by branches was measured and regressed against the diameter of the branch at the point of contact with the bole of the tree. Diameters of all branches on the three trees of mean basal area per sub-plot were measured to estimate foliage dry weight per hectare.

The condition of all branches on the three aspen of mean basal area within each plot was recorded in accordance to the four coding classes described below. Dead branches were not recorded. The four morphological health codes are:

| Code No. | | Morphological Condition |
|---|---|---|
| 1 | - | Buds dead. |
| 2 | - | Buds broken, leaves did not develop. |
| 3 | - | Buds broken, leaves developed but showed signs of herbicide damage. |
| 4 | - | Buds broken, leaves show no signs of herbicide damage. |

Sprayed and non-sprayed branches were collected in the fall of 1985 and only non-sprayed foliage was collected in mid-summer of 1986. The foliage was dried at 100$^{o}$C for 24 hours and the oven dry weight was measured. The oven dry weight of the foliage was regressed against the branch's basal area.

## TRIAL 2 - THE EFFECT OF SIMULATED AERIAL SPRAYING ON THE SURVIVAL AND GROWTH OF OUTPLANTED 3+0 WHITE SPRUCE AND ASPEN COMPETITION.

A complete randomized design with two factors, three glyphosate spray rates (0.0 [Control], 0.5 and 1.0 kg.ha$^{-1}$), and three application times in relation to the phenological state of the white spruce (late-spring steady state [July 16], early dormancy development transitional state [August 5] and dormancy development transitional state [August 22]) was established in 1985 in the same white spruce plantation as the aerial spray trials.

In this trial there are three replications of each of the nine treatment combinations on a total of twenty-seven 10 x 140 m [0.14 ha] plots. Each 0.14 ha plot contains five 4 x 5 m (0.002 ha) sub-plots. Three of these sub-plots were randomly chosen for use in this study and one was randomly chosen for use in Trial 3. Table 2 presents the time of application and the volumes of water and glyphosate applied to each of the 27 plots. Figure 8 presents the layout of the plots and sub-plots for trials 2 and 3. The glyphosate herbicide was applied from a Model #4F Research and Development backpack sprayer which was used to simulate aerial spraying.

The pre- and post-spray attributes of the trembling aspen competition and the planted white spruce were measured as described in trial 1. Pre-spray measurements made on the ten white spruce closest to the centre point of the 0.04 ha plots included: a) the 1981, 1982, 1983, 1984 and 1985 annual height growth and b) the 1985 basal diameter.

Post-spray measurements made on the white spruce in 1986 included: survival, percentage of terminal shoots browsed by snowshoe hares, percentage of terminal buds damaged by frost, annual height increments and basal diameter increments. Post-spray measurements made on the white spruce in 1987 included: survival, annual height increment and basal diameter increment. The spruce volume was monitored according to the methods detailed in trial 1.

Table 2. Rate and time of glyphosate application for the ground spray trial.

| TREATMENT (REPLICATION) | FIELD PLOT | DATE OF APPLICATION | GLYPHOSATE ($kg.ha^{-1}$) | WATER ($L.ha^{-1}$) | SPRAY TIME | Rainfall < 1 h (*) |
|---|---|---|---|---|---|---|
| 1 (1) | 09 | 16/07/85 | 0.0 | 0.0 | N/A | |
| 1 (2) | 17 | 16/07/85 | 0.0 | 0.0 | N/A | |
| 1 (3) | 21 | 16/07/85 | 0.0 | 0.0 | N/A | |
| 2 (1) | 10 | 16/07/85 | 0.5 | 47.7 | morning | |
| 2 (2) | 15 | 16/07/85 | 0.5 | 42.2 | morning | |
| 2 (3) | 18 | 16/07/85 | 0.5 | 54.4 | morning | |
| 3 (1) | 06 | 16/07/85 | 1.0 | 37.4 | morning | |
| 3 (2) | 23 | 16/07/85 | 1.0 | 40.9 | morning | |
| 3 (3) | 26 | 14/07/85 | 1.0 | 53.8 | evening | * |
| 4 (1) | 02 | 05/08/85 | 0.0 | 0.0 | N/A | |
| 4 (2) | 03 | 05/08/85 | 0.0 | 0.0 | N/A | |
| 4 (3) | 05 | 05/08/85 | 0.0 | 0.0 | N/A | |
| 5 (1) | 04 | 05/08/85 | 0.5 | 44.2 | morning | |
| 5 (2) | 07 | 05/08/85 | 0.5 | 42.8 | morning | |
| 5 (3) | 08 | 05/08/85 | 0.5 | 42.8 | morning | |
| 6 (1) | 24 | 05/08/85 | 1.0 | 50.8 | morning | |
| 6 (2) | 25 | 05/08/85 | 1.0 | 53.7 | morning | |
| 6 (3) | 27 | 04/08/85 | 1.0 | 46.4 | evening | |
| 7 (1) | 01 | 25/08/85 | 0.0 | 0.0 | N/A | |
| 7 (2) | 13 | 25/08/85 | 0.0 | 0.0 | N/A | |
| 7 (3) | 19 | 25/08/85 | 0.0 | 0.0 | N/A | |
| 8 (1) | 11 | 25/08/85 | 0.5 | 43.7 | morning | |
| 8 (2) | 14 | 25/08/85 | 0.5 | 43.7 | morning | |
| 8 (3) | 20 | 25/08/85 | 0.5 | 46.4 | morning | |
| 9 (1) | 12 | 25/08/85 | 1.0 | 60.8 | morning | |
| 9 (2) | 16 | 21/08/85 | 1.0 | 44.1 | morning | * |
| 9 (3) | 22 | 21/08/85 | 1.0 | 43.5 | morning | * |

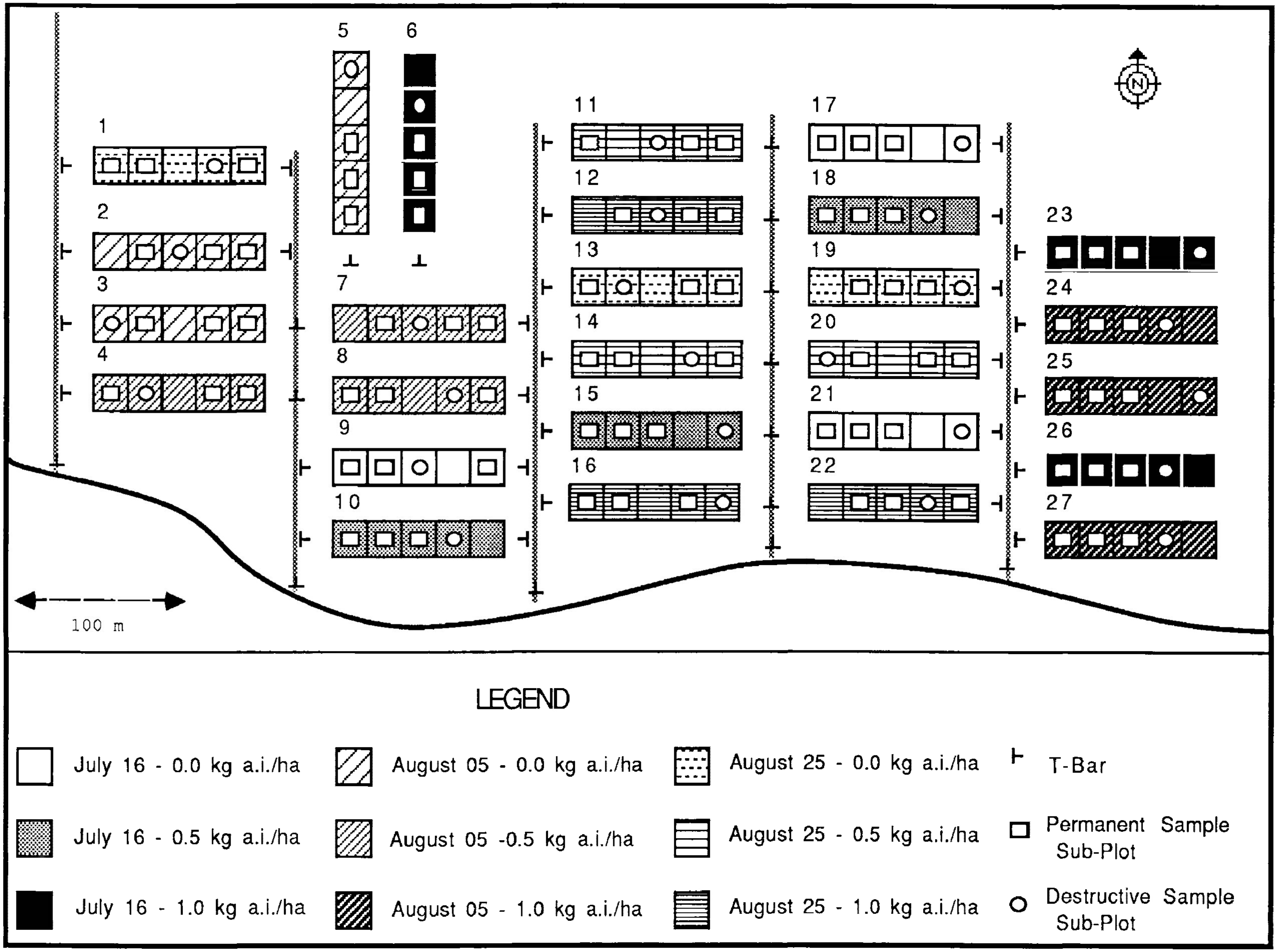



Figure 8: Layout of plots and sub-plots for trials 2 and 3.

Pre-spray measurements made on trembling aspen in the 0.04 ha plots included the number of trembling aspen stems by height and diameter classes and the branch diameters of the three aspen of approximately mean basal area per sub-plot.

Post-spray measurements made on the trembling aspen in the 1986 growing season included the number of aspen stems by diameter, height and morphological condition classes and branch diameters at point of foliation of the three aspen stems of mean basal area per sub-plot (to estimate change in foliage dry weight). In the 1987 growing season only the number of aspen stems by diameter and morphological condition classes was recorded. The condition and foliage biomass were monitored as detailed in trial 1.

The data were summarized by calculating plot means and standard deviations to determine if the samples were statistically sound and to become familiar with any trends. The effect of rainfall and high initial kill of the trembling aspen precluded the use of treatments involving 1.0 $kg.ha^{-1}$ in further analyses. Residual data were checked for normality using RANKIT plots and for homogeneity using Bartlett's test. Pearson correlation was used to determine the linear correlation between pairs of variables. Significant differences were determined by covariance analysis. All data were analyzed using SPSSX programmes on the VAX 11/780.

**TRIAL 3 - TOXICOLOGY STUDY ON ASPEN ROOT CUTTINGS**

This trial was completed in conjunction with trial 2. Refer to trial 2 for experimental design and plot layout. The sub-plots for this trial are referred to as 'destructive sub-plots'. These were randomly selected from the two remaining subplots in trial 2. The layout of the destructive sub-plots is presented in Figure 8.

The six aspen stems closest to the centre of each of the destructive sub-plots with root systems large enough to excise a 10.0 cm long root cutting were selected for sampling in May of 1986. The root system of each of the aspen stems was excavated and the 10.0 cm root segment closest to the stem was excised. Care was taken during root excavation because the outer layer of bark could be easily damaged and root segments with injured bark usually fail to form suckers (Eliasson 1971b). Lateral roots were excised from the cuttings for the sake of uniformity.

To reduce the incidence of disease, sharp clean tools were used to cut the parent root and to remove lateral roots. All cuttings were scrubbed clean with a soft brush and then dipped in a fungicide solution (5 ml of Captan 50W $L^{-1}$ of water).

The root cuttings were packed in moist peat moss and transported to the Lakehead University greenhouse on May 28, 1985. They were stored at approximately 2 $^{o}$C in a walk-in freezer until they were planted.

On May 30, 1985 the root cuttings were planted horizontally in a peat, perlite, vermiculite mixture (3:2:1 ratio) at a depth of 1.0 cm in individual plastic containers. The containers measured 10.0 x 10.0 x 9.0 cm. The containers were randomly placed in flats in an unheated polyurethane greenhouse and watered lightly on a daily basis.

The root cuttings were transported back to the spray site on June 26, 1985. They were grown outside and watered on a daily basis. During periods of stormy weather they were covered with a tarpulin to prevent damage.

The root suckers were harvested on July 18, 50 days from the time of potting. The total number of suckers initiated and the top height of the dominant suckers for each root cutting were recorded. All the aspen suckers initiated by an individual root cutting were then dried at 100 $^{o}$C for 24 hr and weighed.

Plot means and standard deviations were calculated for all response variables. Rainfall and the high initial kill associated with 1.0 $kg.ha^{-1}$ of glyphosate precluded the use of treatments involving 1.0 $kg.ha^{-1}$ from further analyses. Data from remaining treatments were checked for normality using RANKIT plots and for homogeneity using Bartlett's test. The number of suckers initiated followed a Poisson distribution and required transformation. The square root of 'the number of suckers initiated plus one' as recommended by both Greig-Smith (1964) and Steel and Torrie (1980) was used. Further analysis of the number of suckers was conducted using the transformed version of this variable. Top height, oven dry weight and the transformed number of suckers approached normality and were homoscedastic. The linearity between the three variables was determined using Pearson correlations.

All variables were then analyzed using univariate analysis of variance. Maximum information could only be achieved by analyzing the three response variables as separate entities. Each of the three response variables is influenced by different factors. The number of suckers initated is more closely related to hormone levels and ratios than to root carbohydrate reserves (Schier and Johnston 1971). The top height of the tallest sucker is more dependent upon photosynthate produced by the leaves than on reserve carbohydrates and the oven dry weight is dependent upon both the reserve carbohydrate from the parent root system and photosynthate produced by the leaves.

# RESULTS

First year post-spray results of the 1984 and 1985 aerial spray trial and 1985 ground spray trial and second year post-spray results of the 1984 aerial and 1985 ground spray trials are presented in two sections: 1) silvicultural efficacy and 2) herbicidal efficacy.

## SILVICULTURAL EFFICACY: EFFECT OF GLYPHOSATE ON THE WHITE SPRUCE CROP

The effect of glyphosate on the white spruce crop trees was monitored using survival; snowshoe hare browsing; frost damage; multiple leadering and height, root collar diameter and volume growth. The majority of these factors were influenced by the application of glyphosate. The results of the 1984 and 1985 aerial spray trial will be presented first followed by the results of the 1985 ground spray trial.

### Trial 1 - The Effect of Aerial Spraying on the Survival and Growth of Outplanted 3+0 White Spruce and Aspen Competition

The following observations are based on a small number of samples on which statistical analysis was not feasible. Trends rather than significant differences are presented.

Survival of the white spruce did not appear to be influenced by the application of glyphosate. Survival ranged from 92 to 100 % (Table 3) with approximately equal amounts of mortality occurring in both the control and sprayed plots. No test of significance between the means was carried out.

The percentage of terminal shoots browsed by snowshoe hare did not appear to be related to either the year or rate of glyphosate application. The percentage of terminal shoots browsed in 1986 ranged from zero to nine per cent (Table 3). Although a higher percentage of browsing occurred within the control plots, a small amount of browsing also occurred within the sprayed plots.

The degree of frost damage to the terminal shoots was directly influenced by the rate of application of glyphosate. The amount of frost damage to the spruce on individual plots ranged from 39 to 97 %

(Table 3) with the greatest amount of frost damage associated with the highest glyphosate application rate. White spruce within the 1984 sprayed plots received slightly more frost damage than the spruce within the 1985 plots. The difference, in terms of frost damage to the terminal shoots, between the highest rate of application and the controls for the plots sprayed in 1984 and 1985 was 33 and 25 %, respectively.

In both the 1984 and 1985 sprayed plots the amount of multiple leadering increased with the rate of glyphosate applied (Table 3). The greatest number of multiple leaders was associated with the highest glyphosate application rate.

Table 3. Influence of the aerial application of glyphosate on the per cent survival, per cent of terminal shoots browsed by snowshoe hares, per cent of terminal shoots damaged by frost and average number of multiple leaders of the white spruce crop.

| Treatment | | Survival 1986 (%) | Rabbit Browsed 1986 (%) | Frost Damage 1986 (%) | Average Number of Terminal Shoots in 1986 |
|---|---|---|---|---|---|
| 1984 | 0.00 $kg.ha^{-1}$ | 92 | 0 | 64 | 1.7 |
| | 0.90 $kg.ha^{-1}$ | 97 | 1 | 80 | 1.9 |
| | 1.60 $kg.ha^{-1}$ | 97 | 1 | 97 | 2.6 |
| 1985a | 0.00 $kg.ha^{-1}$ | 99 | 9 | 62 | 1.5 |
| | 0.93 $kg.ha^{-1}$ | 98 | 1 | 46 | 1.6 |
| | 1.99 $kg.ha^{-1}$ | 100 | 1 | 70 | 2.7 |
| 1985b | 0.00 $kg.ha^{-1}$ | 99 | 2 | 39 | 0.9 |
| | 0.93 $kg.ha^{-1}$ | 100 | 0 | 70 | 1.4 |
| | 1.99 $kg.ha^{-1}$ | 99 | 4 | 80 | 1.4 |
| 1985 average | 0.00 $kg.ha^{-1}$ | 99 | 6 | 50 | 1.2 |
| | 0.93 $kg.ha^{-1}$ | 99 | 1 | 58 | 1.5 |
| | 1.99 $kg.ha^{-1}$ | 99 | 3 | 75 | 2.0 |

Annual and cumulative height growth of the white spruce were negatively affected by the removal of the trembling aspen overstory. The controls in both the 1984 and 1985 spray plots had the greatest cumulative height growth in 1986, followed by the moderate and then the highest spray rate. In the 1984 trial, there was less than a one per cent difference in height between the control and the 1.60 $kg.ha^{-1}$ spray rate and even less of a difference between the control and the 0.90 $kg.ha^{-1}$ rate. However, in the 1985 trial, there was a 20 % difference in cumulative height growth between the control and the 1.99 $kg.ha^{-1}$ rate. This difference may be due in part to the greater pre-spray height of the spruce in the control plots and more frost damage occurring in the sprayed plots. A very small difference in height existed between the moderate and high spray rate in both the 1984 and 1985 trials.

The mean annual height increments and cumulative height growth from 1981, the final year that the stock was in the nursery, to 1986 for the 1984 and 1985 aerial spray trials are presented in Table 4. The mean annual height increments for all plots, including the controls, were characterized by relatively large increments in 1981, small in 1982 and 1983, large in 1984 and 1985 and small increments again in 1986. In 1981 the spruce were growing under ideal conditions in the Hadashville nursery. In the spring of 1982, they were outplanted and appeared to have suffered from planting 'check' for two growing seasons. In the fall of 1985 or early spring of 1986, a heavy frost may have also damaged the terminal buds.

The root collar diameter and volume of the white spruce were positively influenced by the application of glyphosate. The greatest gains in both basal diameter and volume growth were generally associated with the highest application rate of glyphosate with the exception of the 1985b plots (Table 5). In 1986, spruce within the 0.90 and 1.60 $kg.ha^{-1}$ plots of the 1984 spray sites had approximately 129 and 134 per cent greater basal diameters and 148 and 176 per cent greater volumes respectively than spruce within the control. Spruce within the 0.93 and 1.99 $kg.ha^{-1}$ plots of the 1985 spray sites had on average approximately five and two per cent smaller basal diameters and 23 and 21 per cent smaller volumes respectively than spruce within the control.

Table 4. Mean annual height increment and cumulative height growth of the white spruce from 1981 to 1986 by treatment for the aerial spray trials.

| Treatment | Statistic | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|
| | | (cm) | | | | | |
| <u>1984</u> | | | | | | | |
| 0.00 kg.ha$^{-1}$ | Increment | 10.4 | 4.6 | 5.3 | 11.2 | 9.4[1] | 6.6[2] |
| | Cumulative | 10.4 | 15.0 | 20.4 | 31.5 | 41.0 | 47.6 |
| 0.90 kg.ha$^{-1}$ | Increment | 10.1 | 4.4 | 5.6 | 11.0 | 8.9[1] | 6.2[2] |
| | Cumulative | 10.1 | 14.5 | 20.1 | 31.1 | 40.0 | 46.2 |
| 1.60 kg.ha$^{-1}$ | Increment | 9.9 | 4.3 | 4.9 | 11.5 | 10.5[1] | 3.9[2] |
| | Cumulative | 9.9 | 14.2 | 19.1 | 30.6 | 41.1 | 45.0 |
| <u>1985a</u> | | | | | | | |
| 0.00 kg.ha$^{-1}$ | Increment | 10.7 | 3.9 | 5.1 | 9.1 | 10.7 | 10.51 |
| | Cumulative | 10.7 | 14.6 | 19.7 | 28.8 | 39.5 | 50.0 |
| 0.93 kg.ha$^{-1}$ | Increment | 9.6 | 4.9 | 4.6 | 8.4 | 7.8 | 5.6[1] |
| | Cumulative | 9.6 | 14.4 | 19.1 | 27.4 | 35.2 | 40.8 |
| 1.99 kg.ha$^{-1}$ | Increment | 9.5 | 4.1 | 5.0 | 8.8 | 10.5 | 7.4[1] |
| | Cumulative | 9.5 | 13.6 | 18.6 | 27.4 | 37.9 | 45.3 |
| <u>1985b</u> | | | | | | | |
| 0.00 kg.ha$^{-1}$ | Increment | 9.4 | 4.3 | 5.3 | 11.6 | 12.6 | 9.4[1] |
| | Cumulative | 9.4 | 13.6 | 18.9 | 30.5 | 43.0 | 52.4 |
| 0.93 kg.ha$^{-1}$ | Increment | 8.7 | 4.2 | 3.9 | 7.7 | 9.3 | 8.6[1] |
| | Cumulative | 8.7 | 12.9 | 16.8 | 24.5 | 33.8 | 42.4 |
| 1.99 kg.ha$^{-1}$ | Increment | 11.0 | 4.5 | 3.8 | 7.0 | 7.4 | 3.4[1] |
| | Cumulative | 11.0 | 15.5 | 19.3 | 26.3 | 33.7 | 37.1 |
| <u>1985-Average</u> | | | | | | | |
| 0.00 kg.ha$^{-1}$ | Increment | 10.0 | 4.2 | 5.2 | 10.3 | 11.6 | 10.0[1] |
| | Cumulative | 10.0 | 14.1 | 19.3 | 29.6 | 41.3 | 51.2 |
| 0.90 kg.ha$^{-1}$ | Increment | 9.2 | 4.5 | 4.3 | 8.0 | 8.5 | 7.1[1] |
| | Cumulative | 9.2 | 13.7 | 17.9 | 26.0 | 34.5 | 41.7 |
| 1.99 kg.ha$^{-1}$ | Increment | 10.3 | 4.3 | 4.4 | 7.9 | 9.0 | 5.4[1] |
| | Cumulative | 10.3 | 14.6 | 19.0 | 26.8 | 35.8 | 41.2 |

[1] - first year post-spray increment
[2] - second year post-spray increment

Table 5. Mean annual and cumulative basal diameter measurements and volume estimates of the white spruce by glyphosate treatment for the aerial spray trials.

| Treatment | Statistic | Basal Diameter | | | Stem Volume | | |
|---|---|---|---|---|---|---|---|
| | | 1984 | 1985 | 1986 | 1984 | 1985 | 1986 |
| | | cm | | | $cm^3$ | | |
| 1984 | | | | | | | |
| 0.00 $kg.ha^{-1}$ | Increment | - | 0.2[1] | 0.2[2] | - | 3.6[1] | 6.2[2] |
| | Cumulative | 0.5 | 0.7 | 0.9 | 2.6 | 6.2 | 12.4 |
| 0.90 $kg.ha^{-1}$ | Increment | - | 0.3[1] | 0.3[2] | - | 5.2[1] | 10.8[2] |
| | Cumulative | 0.5 | 0.8 | 1.1 | 2.4 | 7.6 | 18.3 |
| 1.60 $kg.ha^{-1}$ | Increment | - | 0.3[1] | 0.3[2] | 2.6 | 6.9[1] | 12.2[2] |
| | Cumulative | 0.5 | 0.8 | 1.2 | 2.6 | 9.5 | 21.8 |
| 1985a | | | | | | | |
| 0.00 $kg.ha^{-1}$ | Increment | - | - | 0.2[1] | - | - | 5.1[1] |
| | Cumulative | - | 0.6 | 0.8 | - | 4.7 | 9.8 |
| 0.93 $kg.ha^{-1}$ | Increment | - | - | 0.2[1] | - | - | 5.6[1] |
| | Cumulative | - | 0.6 | 0.8 | - | 3.9 | 9.5 |
| 1.99 $kg.ha^{-1}$ | Increment | - | - | 0.3[1] | - | - | 8.7[1] |
| | Cumulative | - | 0.6 | 0.9 | - | 4.3 | 13.0 |
| 1985b | | | | | | | |
| 0.00 $kg.ha^{-1}$ | Increment | - | - | 0.2[1] | - | - | 7.3[1] |
| | Cumulative | - | 0.7 | 0.9 | - | 7.1 | 14.4 |
| 0.93 $kg.ha^{-1}$ | Increment | - | - | 0.2[1] | - | - | 5.9[1] |
| | Cumulative | - | 0.6 | 0.8 | - | 3.2 | 9.1 |
| 1.99 $kg.ha^{-1}$ | Increment | - | - | 0.2[1] | - | - | 3.1[1] |
| | Cumulative | - | 0.5 | 0.7 | - | 2.9 | 6.0 |
| 1985-average | | | | | | | |
| 0.00 $kg.ha^{-1}$ | Increment | - | - | 0.2[1] | - | - | 6.2[1] |
| | Cumulative | - | 0.7 | 0.9 | - | 5.6 | 12.1 |
| 0.93 $kg.ha^{-1}$ | Increment | - | - | 0.2[1] | - | - | 5.7[1] |
| | Cumulative | - | 0.6 | 0.8 | - | 3.6 | 9.3 |
| 1.99 $kg.ha^{-1}$ | Increment | - | - | 0.2[1] | - | - | 5.9[1] |
| | Cumulative | - | 0.6 | 0.8 | - | 3.6 | 9.5 |

1 - first year post-spray increment
2 - second year post-spray increment

**Trial 2 - The Effect of Simulated Aerial Spraying on the Survival and Growth of Outplanted 3+0 White Spruce and Aspen Competition.**

The white spruce crop was not directly injured by glyphosate at any of the times or rates of application tested. Survival ranged from 98 to 100 % (Table 6). None of the mortality that occurred was directly attributable to the application of glyphosate.

The percentage of terminal shoots browsed by snowshoe hare in the winter of 1985/86 ranged from zero to ten per cent (Table 6). The percentage of browsed shoots was not directly related to either the time nor the rate of glyphosate application. All of the browsing occurred within seven of the 27 sample plots (Figure 9). All of these plots were associated with areas that had above average densities of aspen.

The most common form of injury to the white spruce crop was associated with frost damage to the terminal shoots. The amount of frost damage ranged from 49 to 73 % (Table 6). As with the aerial spray trial, the highest damage was associated with the highest spray rate and the lowest damage with the controls.

The amount of multiple leadering is believed to have been an indirect result of the frost damage. Analysis of variance indicated that the number of terminal shoots per spruce as measured in 1986 were significantly increased by the rate of glyphosate application (Appendix C-1). Neither the time nor the time by rate interaction were significantly different at the 95 % level of confidence.

The pattern of height increment over time for this trial was very similar to that of the aerial spray trial. The mean annual height increments in all plots were relatively high in 1981, low in 1982 and 1983, the first two years after outplanting, then increased dramatically in 1984 and decreased again in 1985. Both the mean height and cumulative height growth of the 1986 to 1987 growing seasons were positively influenced by the removal of the trembling aspen competition (Table 7).

The analysis of the cumulative height growth data for the 1985, 1986 and 1987 growing seasons are presented in Appendix C-2,3 and 4. Analysis of variance of the cumulative height growth in 1985 indicated that there was a significant difference (95 % level of confidence) between times of application. This significant difference was not reflected in the analysis of the 1986 nor the 1987 data. The effect of rainfall and high initial kill of the trembling aspen precluded the use of treatments involving the 1.0 $kg.ha^{-1}$ rate in further analyses. The inclusion of the treatments involving the 1.0 $kg.ha^{-1}$ rate would have created an unbalanced, incomplete design. This would have meant the analysis of treatments with only two replications.

Analysis of covariance on the cumulative height in 1986, using the 1985 cumulative height as a covariate, showed no significant differences between treatments.

Table 6. Influence of the ground applications of glyphosate on the per cent survival, per cent of terminal shoots browsed by snowshoe hares, per cent of terminal shoots damaged by frost and average number of multiple leaders of the white spruce crop.

| Treatment | | Survival 1986 (%) | Rabbit Browsed 1986 (%) | Frost Damage 1986 (%) | Average Number of Terminal Shoots in 1986 |
|---|---|---|---|---|---|
| 0.0 $kg.ha^{-1}$ | | | | | |
| | July 16 | 100 | 4 | 49 | 1.3 |
| | August 5 | 99 | 0 | 57 | 1.8 |
| | August 25 | 100 | 3 | 54 | 1.7 |
| 0.5 $kg.ha^{-1}$ | | | | | |
| | July 16 | 100 | 0 | 64 | 2.0 |
| | August 5 | 98 | 0 | 72 | 2.1 |
| | August 25 | 100 | 3 | 57 | 1.9 |
| 1.0 $kg.ha^{-1}$ | | | | | |
| | July 16 | 98 | 0 | 66 | 1.7 |
| | August 5 | 100 | 10 | 58 | 1.4 |
| | August 25 | 100 | 3 | 73 | 2.1 |
| Average | | | | | |
| | 0.0 $kg.ha^{-1}$ | 100 | 3 | 53 | 1.6 |
| | 0.5 $kg.ha^{-1}$ | 99 | 1 | 64 | 2.0 |
| | 1.0 $kg.ha^{-1}$ | 99 | 4 | 66 | 1.7 |

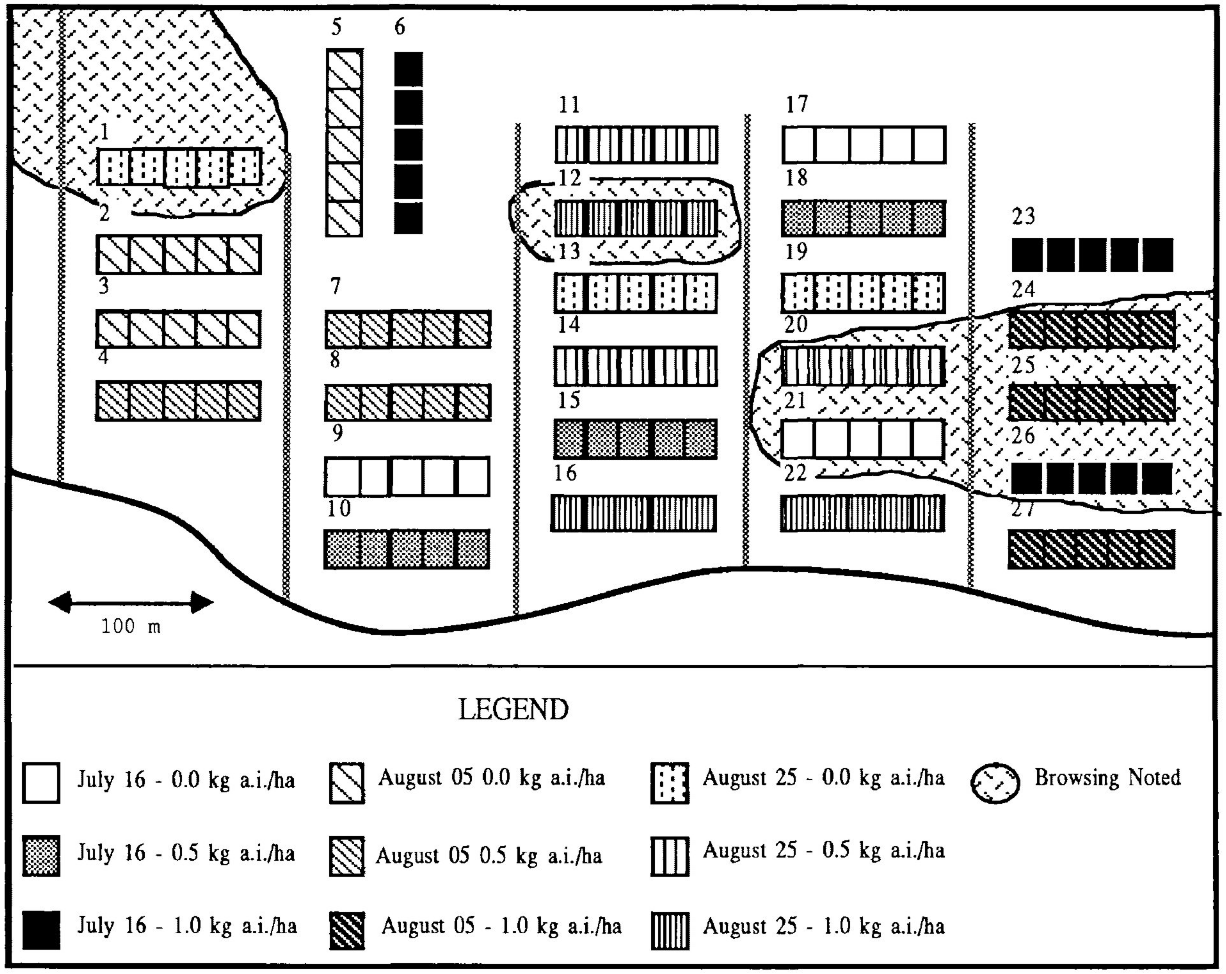



Figure 9. Location of plots in which browsing by snowshoe hare of the white spruce's terminal shoots was noted in August of 1986.

Analysis of covariance on the cumulative height in 1987, using the 1985 cumulative height as a covariate, showed that the application of 0.5 $kg.ha^{-1}$ of glyphosate significantly increased the height growth of the white spruce (Appendix C-4). This equates to an average increase of 4.0 cm in height growth after two growing seasons. Neither the time of application nor the time by rate interaction showed significant differences between the cumulative height measurements of the different treatments. Although the 1.0 $kg.ha^{-1}$ rate was not tested to determine if it was significantly different from the 0.5 $kg.ha^{-1}$ rate, it is doubtful that a difference in average cumulative height of less than 1.0 cm after two growing seasons would constitute a significant difference.

Table 7. The mean annual height increment and cumulative growth of the white spruce from 1981 to 1987 by glyphosate treatment for the ground spray trial.

| Treatment | Statistic | 1981 | 1982 | 1983 | 1984 (cm) | 1985 | 1986[1] | 1987[2] |
|---|---|---|---|---|---|---|---|---|
| **0.0 kg.ha$^{-1}$** | | | | | | | | |
| July 16 | Increment | 9.3 | 4.4 | 4.9 | 8.7 | 7.8 | 5.9 | 10.3 |
| | Cumulative | 9.3 | 13.7 | 18.6 | 27.3 | 35.1 | 41.0 | 51.4 |
| August 5 | Increment | 9.9 | 4.2 | 4.4 | 8.5 | 8.1 | 5.8 | 11.8 |
| | Cumulative | 9.9 | 14.1 | 18.5 | 27.0 | 35.1 | 41.0 | 52.8 |
| August 25 | Increment | 10.1 | 4.8 | 5.6 | 10.7 | 9.4 | 6.7 | 10.8 |
| | Cumulative | 10.1 | 15.0 | 20.5 | 31.2 | 40.6 | 47.3 | 58.1 |
| **0.5 kg.ha$^{-1}$** | | | | | | | | |
| July 16 | Increment | 9.8 | 4.1 | 4.5 | 9.4 | 8.5 | 7.0 | 16.8 |
| | Cumulative | 9.8 | 13.9 | 18.4 | 27.8 | 36.3 | 43.3 | 60.1 |
| August 5 | Increment | 9.3 | 4.3 | 5.0 | 8.8 | 8.0 | 4.7 | 12.7 |
| | Cumulative | 9.3 | 13.6 | 18.7 | 27.4 | 35.3 | 40.1 | 52.8 |
| August 25 | Increment | 9.7 | 4.7 | 5.3 | 9.6 | 8.7 | 7.3 | 15.9 |
| | Cumulative | 9.7 | 14.4 | 19.7 | 29.4 | 38.1 | 45.4 | 61.3 |
| **1.0 kg.ha$^{-1}$** | | | | | | | | |
| July 16 | Increment | 10.0 | 4.4 | 4.2 | 9.3 | 8.3 | 5.8 | 13.9 |
| | Cumulative | 10.0 | 14.4 | 18.6 | 27.9 | 36.1 | 41.9 | 55.8 |
| August 5 | Increment | 9.8 | 4.5 | 5.2 | 9.7 | 9.0 | 7.8 | 16.0 |
| | Cumulative | 9.8 | 14.3 | 19.5 | 29.2 | 38.3 | 46.1 | 62.1 |
| August 25 | Increment | 9.7 | 4.4 | 4.5 | 9.9 | 9.6 | 6.0 | 14.5 |
| | Cumulative | 9.7 | 14.1 | 18.6 | 28.6 | 38.2 | 44.1 | 58.6 |
| **Average** | | | | | | | | |
| 0.0 kg.ha$^{-1}$ | Increment | 9.8 | 4.5 | 5.0 | 9.3 | 8.4 | 6.2 | 11.0 |
| | Cumulative | 9.8 | 14.2 | 19.2 | 28.5 | 36.9 | 43.1 | 54.1 |
| 0.5 kg.ha$^{-1}$ | Increment | 9.6 | 4.4 | 4.9 | 9.3 | 8.4 | 6.4 | 15.1 |
| | Cumulative | 9.6 | 14.0 | 18.9 | 28.2 | 36.6 | 42.9 | 58.1 |
| 1.0 kg.ha$^{-1}$ | Increment | 9.8 | 4.4 | 4.6 | 9.6 | 9.0 | 6.5 | 14.8 |
| | Cumulative | 9.8 | 14.3 | 18.9 | 28.5 | 37.5 | 44.0 | 58.8 |

[1] - first year post-spray increment
[2] - second year post-spray increment

Both the basal diameter and the stem volume were positively influenced by the removal of the trembling aspen competition. In 1987 the spruce in the 0.5 $kg.ha^{-1}$ and 1.0 $kg.ha^{-1}$ sprayed plots had an average of 21 and 35 % larger cumulative basal diameter measurements respectively than spruce in control plots (Table 8). An analysis of variance of the pre-spray basal diameter data did not indicate significant differences at the 95 % level of confidence between treatments (Appendix C-5).

Analysis of covariance on the first and second year post-spray data (Appendix C-6 and 7 respectively) indicated that the application of 0.5 $kg.ha^{-1}$ of glyphosate significantly increased the basal diameter of the white spruce. Neither the times nor the time by rate interactions were significantly different at the 95 % level of confidence.

The change in mean stem volume of the spruce in the nine treatment combinations over time is presented in Table 8. The spruce in plots which received the highest application rates of glyphosate have the greatest volumes and the controls have the lowest volumes. In 1987 the spruce in the 0.5 $kg.ha^{-1}$ and 1.0 $kg.ha^{-1}$ sprayed plots had an average stem volume of 155 and 195 % greater volumes respectively than the spruce in control plots.

Analysis of variance of the pre-spray stem volume measurements did not indicate significant differences at the 95 % level of confidence between treatments (Appendix C-8). Analysis of covariance on the first and second year post-spray volume data (Appendix C-9 and 10 respectively) showed that the application of 0.5 $kg.ha^{-1}$ of glyphosate significantly increased the volume of the white spruce. The application times were significantly different (95 % level of confidence) in 1986 but not in 1987 and the time by rate interactions were significantly different (95 % level of confidence) in 1987 but not in 1986.

Table 8. The mean annual and cumulative basal diameter measurements and volume estimates of white spruce by glyphosate treatment for the 1985 ground spray trial.

| Treatment | Statistic | Basal Diameter 1985 | 1986[1] | 1987[2] | Stem Volume 1985 | 1986[1] | 1987[2] |
|---|---|---|---|---|---|---|---|
| | | ---------cm--------- | | | ----------$cm^3$--------- | | |
| 0.0 $kg.ha^{-1}$ | | | | | | | |
| July16 | Increment | - | 0.2 | 0.1 | - | 2.7 | 3.3 |
| | Cumulative | 0.6 | 0.8 | 0.9 | 3.2 | 5.9 | 9.2 |
| August 5 | Increment | - | 0.2 | 0.2 | - | 3.2 | 6.6 |
| | Cumulative | 0.6 | 0.8 | 1.0 | 3.9 | 7.1 | 13.7 |
| August 25 | Increment | - | 0.2 | 0.1 | - | 4.2 | 6.0 |
| | Cumulative | 0.6 | 0.8 | 0.9 | 4.5 | 8.7 | 14.7 |
| 0.5 $kg.ha^{-1}$ | | | | | | | |
| July 16 | Increment | - | 0.3 | 0.2 | - | 6.6 | 11.4 |
| | Cumulative | 0.7 | 1.0 | 1.2 | 4.2 | 10.8 | 22.2 |
| August 5 | Increment | - | 0.2 | 0.2 | - | 3.8 | 7.7 |
| | Cumulative | 0.6 | 0.8 | 1.0 | 3.4 | 7.1 | 14.8 |
| August 25 | Increment | - | 0.3 | 0.2 | - | 6.5 | 11.4 |
| | Cumulative | 0.6 | 0.9 | 1.1 | 3.7 | 10.2 | 21.5 |
| 1.0 $kg.ha^{-1}$ | | | | | | | |
| July 16 | Increment | - | 0.3 | 0.2 | - | 6.6 | 12.9 |
| | Cumulative | 0.6 | 0.9 | 1.1 | 3.8 | 10.3 | 23.3 |
| August 5 | Increment | - | 0.4 | 0.2 | - | 8.5 | 11.2 |
| | Cumulative | 0.6 | 1.0 | 1.2 | 4.1 | 12.5 | 23.7 |
| August 25 | Increment | - | 0.4 | 0.3 | - | 7.9 | 15.3 |
| | Cumulative | 0.6 | 1.0 | 1.3 | 4.2 | 12.1 | 27.4 |
| Average | | | | | | | |
| 0.0 $kg.ha^{-1}$ | Increment | - | 0.2 | 0.1 | - | 3.4 | 5.3 |
| | Cumulative | 0.6 | 0.8 | 0.9 | 3.9 | 7.3 | 12.6 |
| 0.5 $kg.ha^{-1}$ | Increment | - | 0.3 | 0.2 | - | 5.6 | 10.1 |
| | Cumulative | 0.6 | 0.9 | 1.1 | 3.8 | 9.4 | 19.5 |
| 1.0 $kg.ha^{-1}$ | Increment | - | 0.4 | 0.3 | - | 7.6 | 12.7 |
| | Cumulative | 0.6 | 1.0 | 1.2 | 3.9 | 11.6 | 24.2 |

1 - first year post-spray increment
2 - second year post-spray increment

## HERBICIDAL EFFICACY: EFFECT OF GLYPHOSATE ON TREMBLING ASPEN COMPETITION

The following results include the influence of glyphosate on the survival, height and basal area growth and on the oven-dry weight of the foliage. The results of the foliage regression prediction equations are presented prior to the results of the aerial and ground spray trials. The results of the applications of glyphosate on trembling aspen in the 1984 and 1985 aerial spray trials are followed by the results of the 1985 ground spray trials and the 1986 root cutting trial.

### Foliage Prediction Equations

Regression equations were developed to predict aspen foliage dry weight of the trembling aspen. Both the foliage weight vs stem measurements and the foliage weight vs branch diameter measurements provided regression equations with high pre-spray and very low post-spray correlation coefficients.

#### Foliage Dry Weight vs Stem Measurements

The pre- and post-spray regression models to predict foliage oven-dry weight of aspen on sprayed and non-sprayed sites were developed using basal caliper at a height of 0.3 m and total stem height measurements (Table 9). The $Log_{10}$ transformations of basal diameter at 0.3 m from the base of the stem and of basal area were the best predictors of the foliage dry weight per tree. The addition of tree height to the regression equations once diameter or basal area had been entered did not significantly improve the regression equations.

All post-spray regressions had very low correlation coefficients and can not be used to accurately predict post-spray foliage. Due to the low post-spray correlation coefficients of the 1985 data, post-spray data were not collected in 1986. Further statistical analyses were carried out on the basal area measurements rather than foliage dry-weight estimates.

Table 9. Regression equations to predict foliage oven-dry weights from stem measurements of aspen from sprayed and non sprayed sites.

| Age | Treatment | Regression Equation | n | $R^2$ | SEE |
|---|---|---|---|---|---|
| Six | Control | ODW = -29.46 + 29.87 x Ht | 71 | 0.61 | 22.76 |
| | | ODW = -22.76 + 30.91 x Dia | 71 | 0.65 | 19.06 |
| | | ODW = 0.82 + 10.08 x Ba | 71 | 0.74 | 16.72 |
| | | ODW = 7.93 + 2.34 x (Ba x Ht) | 71 | 0.72 | 17.32 |
| | | Log10(ODW) = 0.64 + 2.07 x Log10 (Ht) | 71 | 0.56 | 0.39 |
| | | Log10(ODW) = 0.89 + 1.71 x Log10 (Dia) | 71 | 0.65 | 0.35 |
| Six | Sprayed | ODW = -0.86 + 3.01 x Ht | 115 | 0.15 | 4.98 |
| | | ODW = -1.38 + 4.07 x Dia | 115 | 0.26 | 4.67 |
| | | ODW = 1.21 + 1.64 x Ba | 115 | 0.27 | 4.63 |
| | | ODW = 2.17 + 1.53 x (Ba x Ht) | 115 | 0.23 | 4.74 |
| | | Log10(ODW) = 0.13 + 1.16 x Log10 (Ht) | 115 | 0.20 | 0.47 |
| | | Log10(ODW) = 0.26 + 1.13 x Log10 (Dia) | 115 | 0.25 | 0.45 |
| Seven | Control | ODW = -12.33 + 8.55 x Ht | 60 | 0.65 | 7.44 |
| | | ODW = -6.44 + 7.52 x Dia | 60 | 0.68 | 7.12 |
| | | ODW = 0.73 + 1.83 x Ba | 60 | 0.77 | 6.00 |
| | | ODW = 3.57 + 1.11 x (Ba x Ht) | 60 | 0.74 | 6.42 |
| | | Log10(ODW) = -0.27 + 2.57 x Log10 (Ht) | 60 | 0.81 | 0.25 |
| | | Log10(ODW) = 0.27 + 1.72 x Log10 (Dia) | 60 | 0.74 | 0.29 |

Where:

ODW = Aspen foliage dry weight (g),
Ht = Total height (m) of the aspen stem,
Dia = Basal caliper (cm) at 0.3 m from the stem's base, and
Ba = Basal area ($cm^2$) at 0.3 m from the stem's base.

Foliage Dry Weight vs Branch Diameter

Pre- and post-spray regression curves were also developed for the aspen foliage using the point of foliation method (Harvey 1981) on the sprayed and unsprayed sites (Table 10). Like the foliage dry weight vs stem measurement curves regression models with high correlation coefficients were developed for the pre-spray data, but not for the post-spray data. Transformations did not significantly improve the post-spray regression models.

Low correlation coefficients between oven-dry weight of the foliage and the independent variable (branch basal area for the sprayed areas) prevented the development of a reliable regression model to predict the foliage on each of the three trees of mean basal area on all the sample sub-plots. Since the foliage for each sample sub-plot could not be accurately estimated, the total dry weight of the foliage per hectare was not calculated.

Table 10. Regression equations to predict foliage oven-dry weights from branch diameter measurements of aspen from sprayed and non sprayed sites.

| Age | Treatment | Regression Equation | n | $R^2$ | SEE |
|---|---|---|---|---|---|
| Five | Control | ODW =-5.70 + 0.66 x Br | 191 | 0.73 | 4.61 |
| | | Log10 (ODW) = 1.10 + 2.48 x Log10 (BA) | 191 | 0.94 | 0.24 |
| Six | Control | ODW =-0.93 + 6.04 x Br | 329 | 0.68 | 1.13 |
| | | Log10 (ODW) = 0.62 + 1.50 x Log10 (BA) | 329 | 0.73 | 0.27 |
| Six | Sprayed | ODW = 0.01 + 0.78 x Br | 146 | 0.23 | 0.38 |
| | | Log10 (ODW) =-0.28 + 1.07 x Log10 (BA) | 146 | 0.30 | 0.45 |
| Seven | Control | ODW =-0.97 + 2.14 x Br | 97 | 0.83 | 0.58 |
| | | Log10 (ODW) =-0.14 + 0.03 x Log10 (BA) | 97 | 0.86 | 0.26 |

Where:

ODW = Aspen foliage dry weight (g),
Br = Branch diameter at point of contact with the bole of the aspen sapling (mm), and
BA = Basal area ($mm^2$) of the branch at point of contact with the bole of the aspen sapling.

**Trial 1 - The Effect of Aerial Spraying on the Survival and Growth of Outplanted 3+0 White Spruce and Aspen Competition**

The following observations are based on a small number of samples on which statistical analysis was not feasible. Due to the variabilty within the aspen, approximately twice as many samples would be required for statistical analysis purposes. Trends rather than significant differences are presented.

The morphological condition codes of the trees of mean basal area were monitored from 1984 to 1986 within the 1984 aerial spray trial. The change in the morphological condition codes of aspen on the 0.90 and 1.60 $kg.ha^{-1}$ sites from 1985 to 1986 are presented in Figures 10 and 11 respectively. No aspen from codes 1, 2 or 3 showed signs of recovery, most died or at least showed signs of continued health reduction. Aspen labelled as code 4 in 1985, from the 0.90 kg.ha$^{-1}$ rate, showed some signs of recovery. In 1986, approximately 20 % of the 1985 code 4 aspen were classified as code 5, 40 % as code 4, 20 % as code 3 and 20 % as code 1.

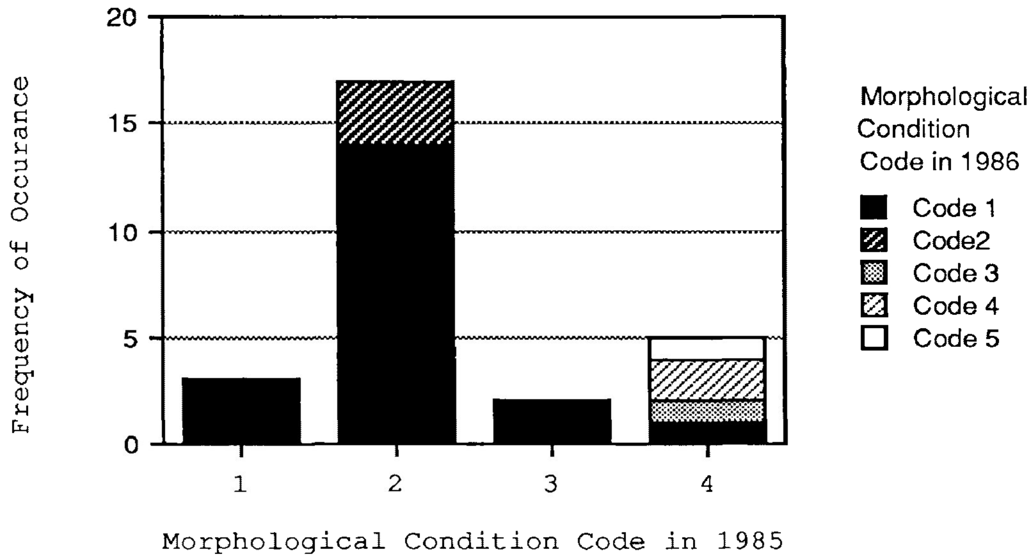



Figure 10. The change in morphological condition code of the 27 mean basal area trees in the 1984 (0.90 kg.ha$^{-1}$) spray area from the 1985 (X axis) to the 1986 (Y axis) growing season.

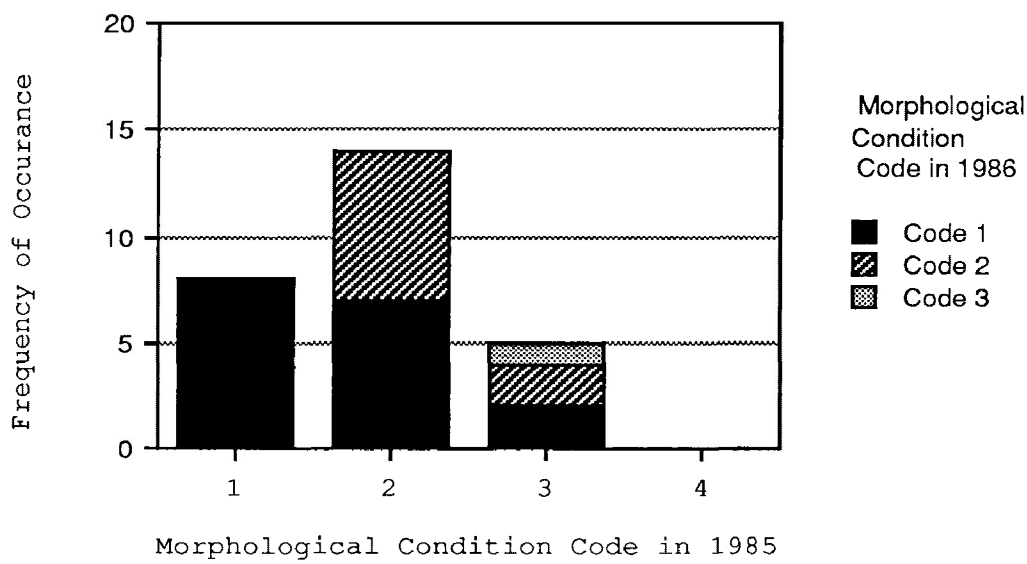



Figure 11. The change in morphological condition code of the 27 mean basal area trees in the 1984 (1.60 kg.ha$^{-1}$) spray area from the (X axis) to the 1986 (Y axis) growing season.

The number of foliated trembling aspen per hectare is highly influenced by the application of glyphosate (Table 11). At the end of the second year following the application of glyphosate, in the 1984 trial, 1.60 $kg.ha^{-1}$ provided marginally better control of trembling aspen than 0.90 kg a.i.ha. The 1.60 $kg.ha^{-1}$ application rate affected the health of 100% and killed 70% of the aspen and the 0.90 $kg.ha^{-1}$ rate affected 96% and killed 62% of the aspen.

Within the 1985 aerial spray trial, both 0.93 and 1.99 $kg.ha^{-1}$ applications damaged 100% of the aspen, but the 1.99 $kg.ha^{-1}$ rate killed twice the number of trembling aspen per hectare as the 0.93 $kg.ha^{-1}$ rate. The per cent mortality of aspen on sites with low densities of overstory residual dead standing aspen (1985a data) was approximately four times higher than that of aspen under relatively high densities of overstory aspen (1985b data).

The per cent distribution of the basal area per hectare of trembling aspen by morphological condition code following the aerial application of glyphosate (Table 12) is very similar to the per cent distribution of the number of aspen per hectare by morphological condition code. In the 1984 trial, an obvious decrease in the health of the sprayed aspen can be seen by comparing the 1985 data to the 1986 data. The high defoliation that occurred in 1985 was followed by a high mortality rate in 1986.

The 1985a data were collected from areas with relatively low overstory residual aspen and the 1985b data were collected from areas of relatively high overstory residual aspen. A substantially different basal area distribution pattern by morphological condition code between the 1985a and the 1985b data can be observed in Table 12. The basal area distribution patterns for the 0.93 and 1.99 $kg.ha^{-1}$ are similar within the 1985a data and within the 1985b data. Less than two per cent mortality was observed in the aspen on the 1984, 1985a and 1985b control plots.

Table 11. The per cent distribution of aspen by morphological condition code after the aerial application of three rates of glyphosate.

| Year and Rate of Application | | Year Measured | Morphological Condition Code 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|---|---|
| 1984 | 0.00 $kg.ha^{-1}$ | 1984 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 2 | 0 | 0 | 0 | 98 | 100 |
| | 0.90 $kg.ha^{-1}$ | 1984 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1985 | 22 | 51 | 14 | 13 | 0 | 100 |
| | | 1986 | 62 | 23 | 4 | 6 | 4 | 100 |
| | 1.60 $kg.ha^{-1}$ | 1984 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1985 | 25 | 50 | 22 | 3 | 0 | 100 |
| | | 1986 | 70 | 20 | 4 | 6 | 0 | 100 |
| 1985a | 0.00 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 1 | 0 | 0 | 0 | 99 | 100 |
| | 0.93 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 41 | 30 | 22 | 7 | 0 | 100 |
| | 1.99 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 70 | 19 | 10 | 1 | 0 | 100 |
| 1985b | 0.00 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 0.93 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 11 | 8 | 18 | 55 | 7 | 100 |
| | 1.99 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 21 | 28 | 49 | 2 | 0 | 100 |
| 1985 Average | | | | | | | | |
| | 0.00 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 1 | 0 | 0 | 0 | 99 | 100 |
| | 0.93 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 26 | 19 | 20 | 31 | 4 | 100 |
| | 1.99 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 46 | 23 | 30 | 1 | 0 | 100 |

Table 12. The per cent distribution of the basal area of trembling aspen by morphological condition code after the aerial application of three rates of glyphosate.

| Year and Rate of Application | | Year Measured | Morphological Condition Code 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|---|---|
| 1984 | 0.00 $kg.ha^{-1}$ | 1984 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 1 | 0 | 0 | 0 | 99 | 100 |
| | 0.90 $kg.ha^{-1}$ | 1984 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1985 | 19 | 56 | 12 | 13 | 0 | 100 |
| | | 1986 | 59 | 27 | 3 | 8 | 3 | 100 |
| | 1.60 $kg.ha^{-1}$ | 1984 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1985 | 22 | 55 | 20 | 3 | 0 | 100 |
| | | 1986 | 63 | 26 | 5 | 6 | 0 | 100 |
| 1985a | 0.00 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 0.93 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 40 | 26 | 22 | 12 | 0 | 100 |
| | 1.99 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 64 | 22 | 13 | 1 | 0 | 100 |
| 1985b | 0.00 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 1 | 0 | 0 | 0 | 99 | 100 |
| | 0.93 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 7 | 5 | 14 | 65 | 9 | 100 |
| | 1.99 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 16 | 30 | 52 | 2 | 0 | 100 |
| 1985 Average | | | | | | | | |
| | 0.00 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 1 | 0 | 0 | 0 | 99 | 100 |
| | 0.93 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 23 | 16 | 18 | 39 | 4 | 100 |
| | 1.99 $kg.ha^{-1}$ | 1985 | 0 | 0 | 0 | 0 | 100 | 100 |
| | | 1986 | 40 | 26 | 33 | 1 | 0 | 100 |

**Trial 2 - The Effect of Simulated Aerial Spraying on the Survival and Growth of Outplanted 3+0 White Spruce and Aspen Competition**

Correlation analysis indicated that the trembling aspen variables (number per plot, basal area per plot and total stem height) were highly correlated at a statistically significant level ($P<0.05$). Since the aspen variables are inter-correlated, analysis of one of them was sufficient for practical purposes. Further analysis was based upon the basal area since it is a function of the number of stems per hectare and the stem diameter and is also highly correlated with foliage oven-dry weight prior to the application of glyphosate. The effect of rainfall and high initial kill of the trembling aspen precluded the use of treatments involving the 1.0 $kg.ha^{-1}$ rate in further analyses. The inclusion of the treatments involving the 1.0 $kg.ha^{-1}$ rate would have created an unbalanced, incomplete design.

Mortality within the control and spray plots increased form 1986 to 1987. The percentage of dead aspen in the control, 0.5 and 1.0 $kg.ha^{-1}$ plots was <1, 11 and 40 % in 1986 and 7, 28, and 71 % in 1987 respectively. In 1987 the percentage of aspen showing no signs of herbicide damage in the control, 0.5 and 1.0 $kg.ha^{-1}$ was 93, 62 and 22% respectively (Table 13).

The per cent distribution of the number of aspen per hectare and the basal caliper by morphological condition code are presented in Tables 13 and 14 respectively. Table 13 which gives the distribution of the number of aspen compares almost exactly with Table 14 which gives the per cent distribution of basal area.

The analysis of the basal area data for the 1985, 1986 and 1987 growing seasons are presented in Appendix C-11, 12 and 13, respectively. Analysis of variance of the basal area measurements made in 1985 indicated that there were no significant differences at the 95 per cent level of confidence between treatments. Analysis of covariance on the basal area in 1986 and 1987, using the 1985 basal area as a covariate, showed significant differences, at the 95 and 99 per cent level of confidence respectively, between application rates.

Table 13. The per cent distribution of aspen by morphological condition code after the ground application of three rates of glyphosate at three times during the growing season.

| Rate and Time of Application | Year Measured | Morphological Condition Code 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|---|
| <u>0.0 kg.ha$^{-1}$</u> | | | | | | | |
| July 16 | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 1987 | 11 | 0 | 0 | 0 | 89 | 100 |
| August 5 | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 1987 | 0 | 0 | 0 | 0 | 100 | 100 |
| August 25 | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 1987 | 9 | 0 | 0 | 0 | 91 | 100 |
| <u>0.5 kg.ha$^{-1}$</u> | | | | | | | |
| July 16 | 1986 | 17 | 8 | 8 | 63 | 4 | 100 |
| | 1987 | 27 | 2 | 0 | 4 | 67 | 100 |
| August 5 | 1986 | 6 | 2 | 9 | 59 | 24 | 100 |
| | 1987 | 15 | 0 | 0 | 9 | 76 | 100 |
| August 25 | 1986 | 10 | 20 | 36 | 31 | 3 | 100 |
| | 1987 | 43 | 4 | 4 | 7 | 42 | 100 |
| <u>1.0 kg.ha$^{-1}$</u> | | | | | | | |
| July 16 | 1986 | 43 | 14 | 14 | 28 | 1 | 100 |
| | 1987 | 60 | 3 | 2 | 13 | 22 | 100 |
| August 5 | 1986 | 24 | 9 | 20 | 34 | 14 | 100 |
| | 1987 | 52 | 1 | 1 | 3 | 43 | 100 |
| August 25 | 1986 | 53 | 38 | 7 | 2 | 0 | 100 |
| | 1987 | 100 | 0 | 0 | 0 | 0 | 100 |
| <u>Average</u> | | | | | | | |
| 0.0 kg.ha$^{-1}$ | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 1987 | 7 | 0 | 0 | 0 | 93 | 100 |
| 0.5 kg.ha$^{-1}$ | 1986 | 11 | 10 | 18 | 51 | 10 | 100 |
| | 1987 | 28 | 2 | 1 | 7 | 62 | 100 |
| 1.0 kg.ha$^{-1}$ | 1986 | 40 | 20 | 14 | 21 | 5 | 100 |
| | 1987 | 71 | 1 | 1 | 5 | 22 | 100 |

Table 14. The per cent distribution of the basal area of aspen by morphological condition code after the ground application of three rates of glyphosate at three times during the growing season.

| Rate and Time of Application | Year Measured | Morphological Condition Code 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|---|
| 0.0 kg.ha$^{-1}$ | | | | | | | |
| July 16 | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 1987 | 11 | 0 | 0 | 0 | 89 | 100 |
| August 5 | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 1987 | 0 | 0 | 0 | 0 | 100 | 100 |
| August 25 | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 1987 | 8 | 0 | 0 | 0 | 92 | 100 |
| 0.5 kg.ha$^{-1}$ | | | | | | | |
| July 16 | 1986 | 17 | 8 | 8 | 63 | 4 | 100 |
| | 1987 | 18 | 2 | 0 | 4 | 76 | 100 |
| August 5 | 1986 | 6 | 2 | 9 | 59 | 23 | 100 |
| | 1987 | 3 | 0 | 0 | 8 | 89 | 100 |
| August 25 | 1986 | 10 | 20 | 36 | 31 | 3 | 100 |
| | 1987 | 37 | 5 | 4 | 8 | 46 | 100 |
| 1.0 kg.ha$^{-1}$ | | | | | | | |
| July 16 | 1986 | 43 | 14 | 14 | 28 | 1 | 100 |
| | 1987 | 62 | 4 | 2 | 8 | 24 | 100 |
| August 5 | 1986 | 17 | 10 | 19 | 43 | 11 | 100 |
| | 1987 | 48 | 2 | 1 | 2 | 47 | 100 |
| August 25 | 1986 | 46 | 45 | 8 | 1 | 0 | 100 |
| | 1987 | 100 | 0 | 0 | 0 | 0 | 100 |
| Average | | | | | | | |
| 0.0 kg.ha$^{-1}$ | 1986 | 0 | 0 | 0 | 0 | 100 | 100 |
| | 1987 | 6 | 0 | 0 | 0 | 94 | 100 |
| 0.5 kg.ha$^{-1}$ | 1986 | 11 | 10 | 18 | 51 | 10 | 100 |
| | 1987 | 20 | 2 | 1 | 7 | 70 | 100 |
| 1.0 kg.ha$^{-1}$ | 1986 | 36 | 23 | 13 | 24 | 4 | 100 |
| | 1987 | 70 | 2 | 1 | 3 | 24 | 100 |

Although the application times were not significantly different, the greatest control was achieved with the late August sprays. Early-August applications provided the least control of the trembling aspen competition. The mid-July, early August and late August applications of 0.5 $kg.ha^{-1}$ damaged 95, 77 and 98% of the aspen in 1986, respectively (Table 14). For the same application times the 1.0 $kg.ha^{-1}$ rate damaged 99, 86 and 100%, respectively. The August 25 application of 1.0 $kg.ha^{-1}$ was the only treatment that killed 100 % of the aspen (Figure 12).

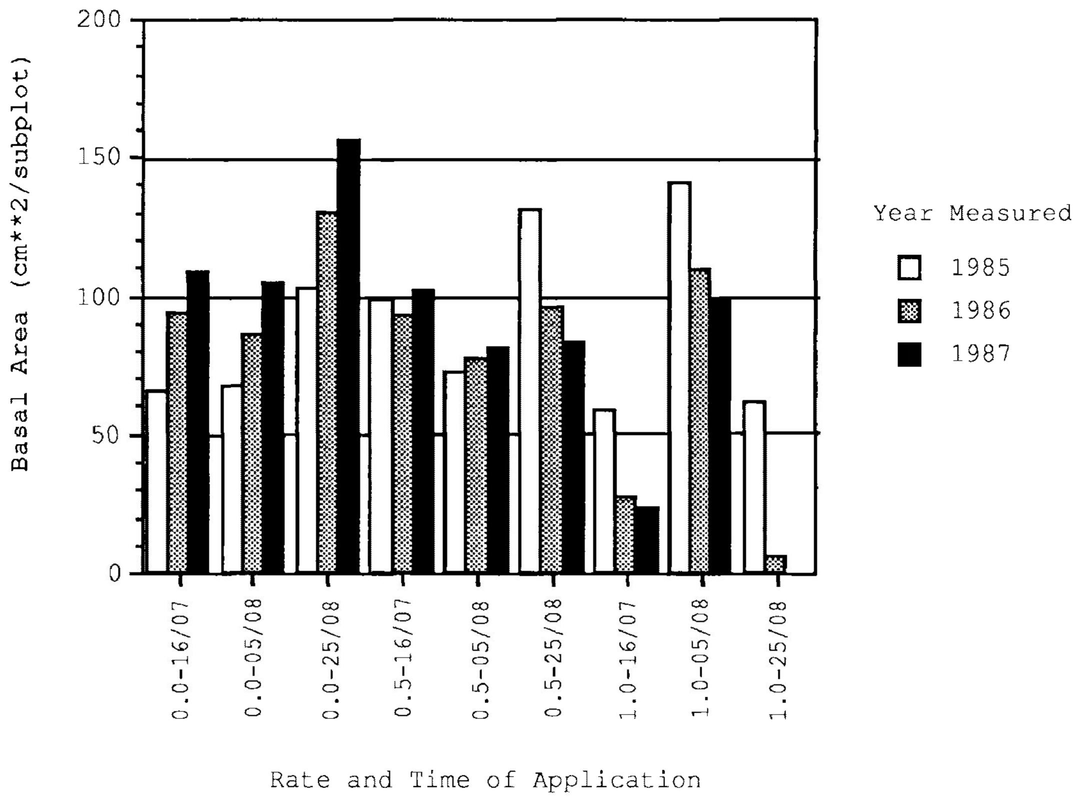



Figure 12. Influence of the rate and time of glyphosate application on the mean basal area of trembling aspen from 1985 to 1987.

**Trial 3 - Toxicology Study on Aspen Root Cuttings**

Correlation coefficients relating the number, oven-dry weight and dominant height of the aspen suckers indicated that the three variables were intercorrelated (Table 15). Based on biological reasons, each variable was analyzed individually.

Table 15. Correlation matrix for aspen suckers.

| | Number | Oven-Dry Weight | Dominant Height |
|---|---|---|---|
| Number | 1.0000 | | |
| Oven-Dry Weight | 0.6873* | 1.0000 | |
| Dominant Height | 0.4387* | 0.8529* | 1.0000 |

* - Siginficant at the 95 % level of confidence

The average number of suckers initiated per root cutting was influenced by rate of glyphosate application and, to a much lesser degree, time of glyphosate application (Figure 13). The 1.0 $kg.ha^{-1}$ rate eliminated all resuckering of aspen at both the mid-July and late-August spray periods. A small amount of resuckering occurred at the mid-August period of application. With the 0.5 $kg.ha^{-1}$ rate, the mid-July and mid-August sprays initiated slightly more suckers than the late-August spray. Small differences occurred between the number of suckers initiated by the aspen sprayed with 0.5 $kg.ha^{-1}$ of glyphosate and the controls. In general, the aspen sprayed with 0.5 $kg.ha^{-1}$ initiated a greater number of suckers than the aspen in the controls.

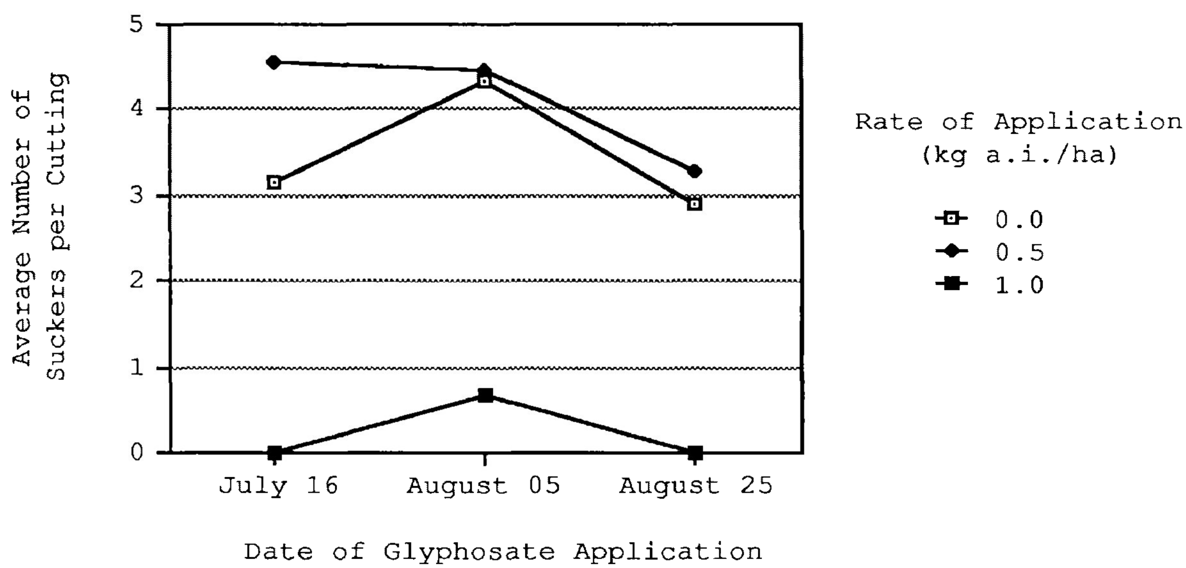



Figure 13. Influence of the rate and time of glyphosate application on the average number of aspen suckers initiated per root cutting.

An analysis of variance between the 0.0 and 0.5 kg.ha$^{-1}$ rates determined that there were no significant differences between the application times nor the application rates in terms of the number of suckers initiated per root cutting (Appendix C-14).

The height of the dominant suckers was also influenced by the rate and time of glyphosate application. The rate of application had a far greater impact on the height growth of the aspen suckers than the time of application (Figure 14). Since the 1.0 kg.ha$^{-1}$ rate eliminated all resuckering of aspen at both the mid-July and late-August spray times, no height growth was recorded for these treatment combinations. New suckers from the aspen sprayed with 1.0 kg.ha$^{-1}$ of glyphosate in mid-August produced rather stunted height growth.

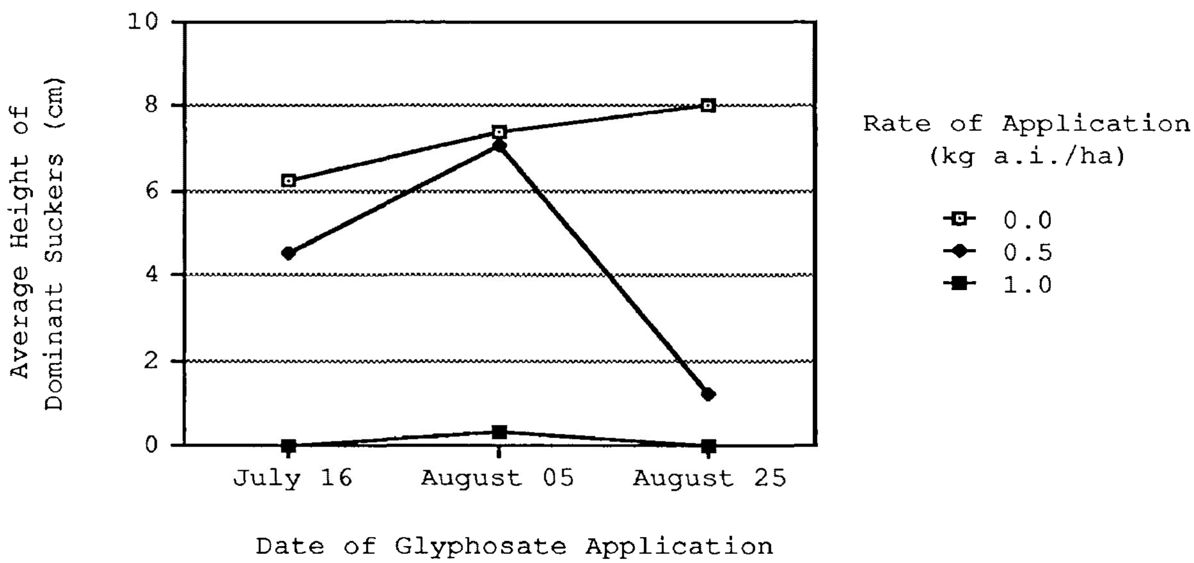



Figure 14. Influence of the rate and time of glyphosate application on the height growth of dominant suckers.

An analysis of variance of the height of the dominant suckers determined that there were significant differences between the time, rate and time by rate interactions (Appendix C-15). From a Student-Newman- Keul's test (Steel and Torrie 1980) it was determined that 0.5 kg.ha$^{-1}$ applied on August 25 was significantly different from the other five treatment combinations (Appendix C-16). The July 16 application did not provide significantly better control of the aspen than the August 5 application. In general, the height growth of the aspen suckers in the July 16 and August 5 applications of glyphosate at 0.5 kg.ha$^{-1}$ were not significantly different from the height growth of the aspen in the controls.

The stem-foliage oven-dry weight of the aspen suckers was also influenced by the time and rate of glyphosate application. An oven-dry weight was not recorded for both the mid-July and late-August spray times at the 1.0 $kg.ha^{-1}$ rate, because no resuckering occurred within these treatment combinations. New suckers from the aspen sprayed with 1.0 $kg.ha^{-1}$ of glyphosate in mid-August were rather small with very low oven-dry weights (Figure 15).

An analysis of variance on the control and 0.5 $kg.ha^{-1}$ data indicated that there was a significant difference between the rate and time by rate interaction in terms of the stem-foliage oven-dry weight of the aspen suckers (Appendix C-17). The results of a Student-Newman-Keul's test determined that 0.5 $kg.ha^{-1}$ applied on August 25 was significantly different from the other five treatments tested (Appendix C-18).

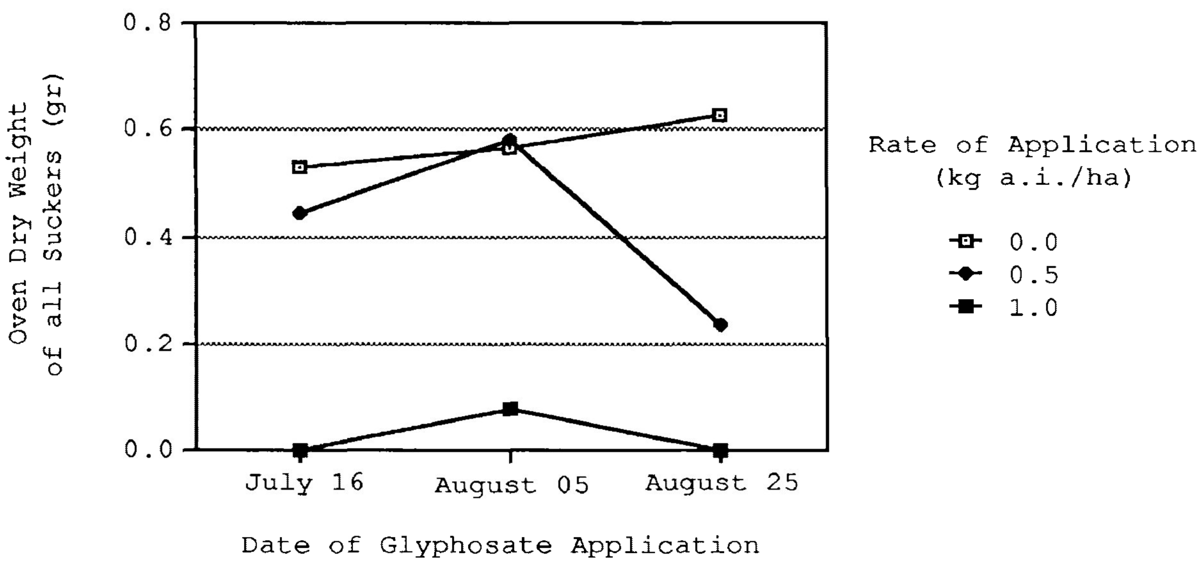



Figure 15. Influence of the rate and time of glyphosate application on the average oven-dry weight of all suckers initiated per root cutting.

# DISCUSSION

The results of the aerial and ground spray trials are those of the first and second year and should be considered as preliminary. Although insufficient time has elapsed for the trials to show a full response, the ground and aerial treatments already show trends which may be proven valid by future measurements.

Assessments of operational herbicide applications have commonly been based upon the percentage kill of the competing vegetation. Although this is an important measure of response, the primary objective of herbicide use is not simply to remove the competing vegetation from a particular site but to improve the growth of the crop.

Since the crop response is of primary concern, the silvicultural efficacy will be presented first followed by the herbicidal efficacy.

## SILVICULTURAL EFFICACY

The results of this research are consistent with those reported by Monsanto (1985). The optimum time to apply glyphosate for white spruce release in Manitoba occurs in mid-late August after the buds have set and during the time when there is relatively little shoot growth. Figure 16 provides a summary of the phenology of white spruce in relation to the optimum spray window for glyphosate. This type of one page summary diagrams by species, if developed for localized areas, may prove useful to forest vegetation managers.

In general, white spruce showed a positive growth response within two growing seasons after the application of glyphosate in both the aerial and the ground spray trials. Although relatively small gains in height increment were realized, the greatest gains were related to diameter and volume increments. Spruce within sprayed plots had up to 195 % greater cumulative volumes, within two seasons following release, than spruce within controls.

Less than one per cent of the white spruce died during the study period. No injury to the white spruce crop on either the aerial or the ground sprayed areas could be directly attributed to the glyphosate applications. This may be a result of the relatively high tolerance level of white spruce to glyphosate. Newton and Knight (1979) report that white spruce will tolerate aerially applied glyphosate in mid-late August at a rate of up to 3.36 $kg.ha^{-1}$ with negligible damage. This same rate of application would result in greater than 90% control of the trembling aspen competition (Newton and Knight 1981).

Although mortality related to snowshoe hare browsing was expected to occur, only one of the 1620 spruce measured was killed by hares during the study period. Browsing of terminal shoots by snowshoe hare contributed, in part, to height growth differences between treatments. In the winter of 1985/1986, approximately 2.2 per cent of the terminal shoots were browsed by snowshoe hares. Snowshoe hare browsing was not directly related to method, year, rate or time of glyphosate application, but rather to the general environment surrounding a spray plot. For example, the control plot within the aerial spray trial, which received the greatest amount of browsing, was within approximately 75 m of an area where logging of residual aspen for fuelwood took place in the winter of 1985/86. Trampling of the young aspen saplings during the winter harvesting operations is believed to have created a more favourable feeding area for the hares and attracted a relatively higher population of hares to this particular site.

There are two possible reasons why significant damage by snow shoe hare was not observed. The hare population was small during the period of study and the spruce were probably buried by snow during the winter months.

Severe browsing of conifers by snowshoe hare is generally associated with areas that have, or areas in close proximity to, a heavy brush or aspen cover during the winter months of years with peak hare populations. Shirley (1941), Aldous and Aldous (1944), Rowe (1955), Sutton (1984) and Drew (1988) have all reported detrimental effects of the snowshoe hare on young conifers under a cover of shrubs or trembling aspen. Since snowshoe hare do not dig through snow to obtain food, damage during the winter months is generally limited to conifers that have not been buried by snow. Snowshoe hare populations peak approximately every ten years and severe damage to conifer crops is generally associated with these peaks. Since the last peak in the ten year snowshoe hare population cycle occurred in 1980 in the Porcupine Mountain Provincial Forest, the next peak in the snowshoe hare population is most likely to occur around 1990, the same time when the fifth year post-spray data is to be collected.

Since white spruce is not free of significant browsing by snowshoe hare until it is approximately two metres high (Peterson 1988), the author speculates that the full influence of the snowshoe hare population will be realized from the 1990 measurements.

Since the spruce within the study areas are still relatively small they may also be subject to competition from grasses and herbs (Figure 17). Visual observations indicate that grass and herb competition can increase substantially within two years after the removal of the aspen competition. Very little competition existed during the first post-spray season, within the 1984 aerially sprayed areas, but large quantities of grass and herbs had become established by the second post-spray season.

For these reasons it is very important to obtain the fifth year data before making any final conclusions on the silvicultural efficacy of the application of glyphosate for the release of white spruce from trembling aspen competition.

The most common response of the white spruce to frost injury, in both the aerial and ground sprayed areas, was multiple leadering. This is believed to have been the result of a severe frost during the period of needle primordia initiation in late-August of 1985 or a severe spring frost prior to bud flush in 1986. The greatest amount of multiple leadering was associated with the areas that received the highest application rates in both the aerial and ground spray trials. These areas were relatively free from aspen competition. Within the ground spray trial the increased exposure generally resulted in greater multiple leadering and significantly greater height growth.

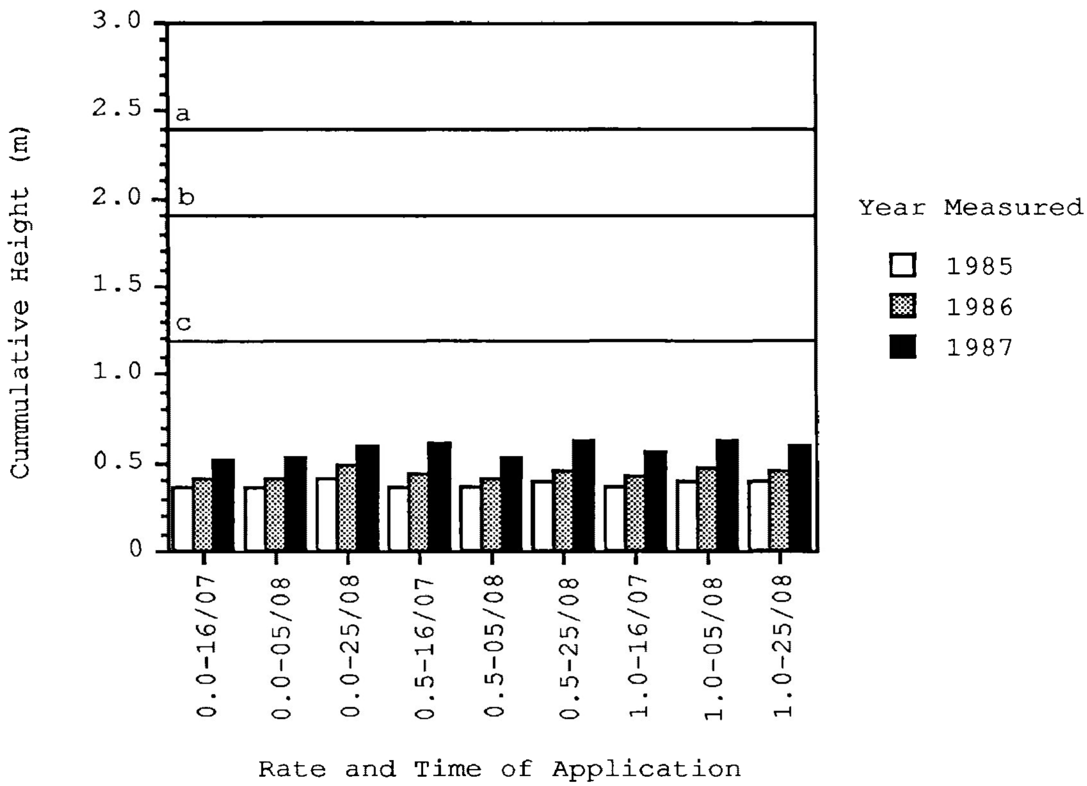



Figure 17. Influence of the application of glyphosate at three rates and three times on cumulative height growth and the relationship between the cumulative height growth and a) the height at which white spruce is most likely to respond from a single manual cleaning b) the height at which white spruce becomes relatively free of significant browsing by snowshoe hare and c) the height at which white spruce becomes relatively free of competition from Canada bluejoint (Adapted from Peterson 1988).

The decrease in height increment of the white spruce in 1985 and 1986, compared to the 1984 height increment, for both the aerial and the ground trial can be attributed to poor growing conditions during the 1985 growing season. The 1985 growing season was relatively cold and may not have been particularly favourable for either height growth nor needle primordia initiation. Since shoot elongation is partially dependent upon the quantity of bud primordia formed in the previous growing season, damage to the terminal bud apex by frost is believed to have been the primary cause of the relatively low height increment in 1986.

The root collar diameter and volume of the white spruce were positively influenced by the removal of the aspen competition. The relative increase in cumulative volume of the control and ground sprayed plots from 1985 to 1987 is shown in Figure 18. The effects were not directly attributable to the application of the glyphosate but rather to the resulting modifications made to the micro-environment of the spruce.

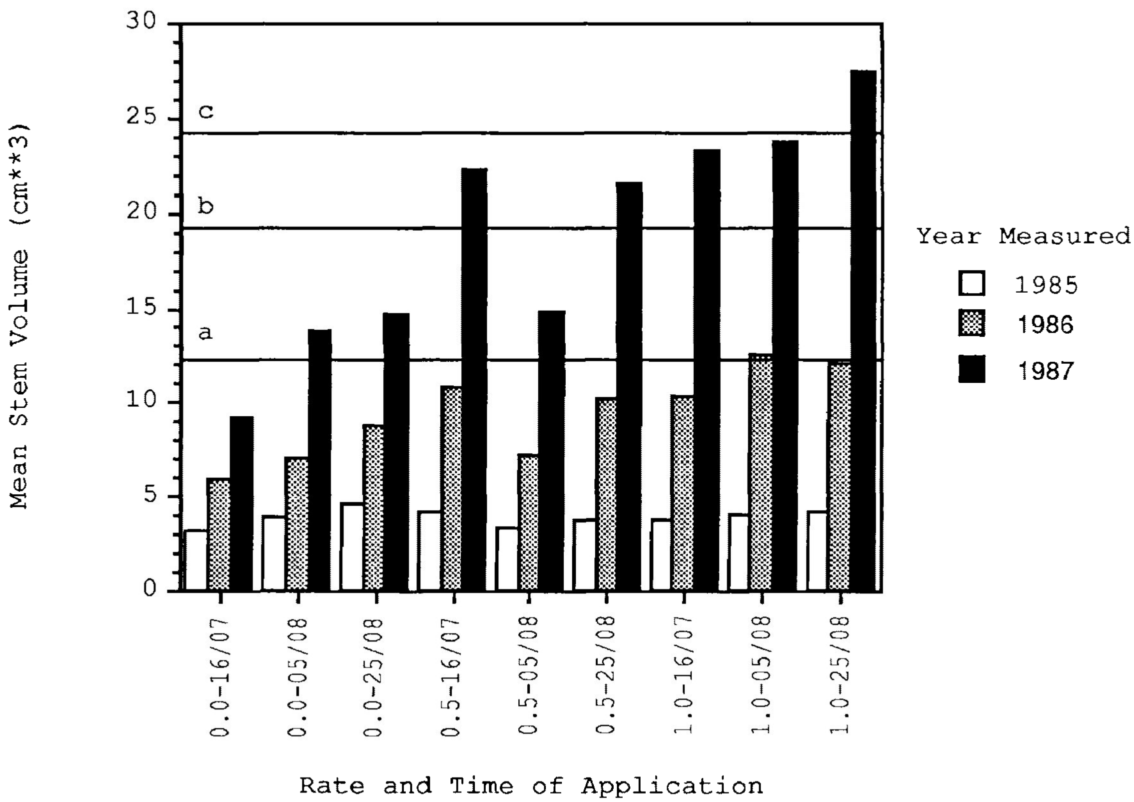



Figure 18. White spruce cumulative volumes from 1985 to 1987 for the ground spray trial. The lines labelled as a, b and c represent the average volumes, for the control, 0.5 kg.ha$^{-1}$ and 1.0 kg.ha$^{-1}$ plots respectively, at the end of the 1987 growing season.

## HERBICIDAL EFFICACY

The per cent kill and the resuckering potential of aspen was influenced by both the rate and the time of glyphosate application. In general, the rate of application was more critical than the time of application. An application rate of 1.0 kg.ha$^{-1}$ applied to the aspen in mid- to late- August provided the best overall herbicidal efficacy. Lund-Hoie (1975) found that autumn applications of 0.5 $kg.ha^{-1}$ of ground applied glyphosate are sufficient to control aspen competition in Norway spruce plantations. In this study the 1.0 and 0.5 kg.ha-1 rates applied in late August killed 100 and 51 per cent of the aspen respectively two year following application. The 51 per cent kill was sufficient to provide short term volume gains for the white spruce, but future 'whipping' from the residual aspen may become a problem. This is speculative at this time and futher measurements are required to verify this point.

The resuckering potential of aspen treated with 0.5 $kg.ha^{-1}$ of glyphosate was relatively high compared to 1.0 $kg.ha^{-1}$. The resuckering potential was dependent upon the time of application during the growing season. Higher resuckering potential was expressed by aspen following glyphosate application made in mid-July or early August than late August. This variation in seasonal susceptibility to glyphosate is believed to be a function of seasonal translocation patterns of carbohydrates to the root system. Higher quantities of carbohydrates are translocated to the root system in late-August than in either mid-July or early-August.

The results of this research are consistent with those found by Lund-Hoie (1975 and 1980). Lund-Hoie (1975 and 1980) reported that glyphosate is a slow acting herbicide and requires two or more years to have a full effect on woody plants such as European aspen. The results of the 1984 aerial spray trial and the 1985 ground spray trial show that at least two years is required before glyphosate has a full effect on trembling aspen competition.

The results are also consistent with those of Lund-Hoie (1980) in terms of the effect of rainfall. The slow uptake of the salt formulation of glyphosateby the aspen foliage makes it susceptible to being washed off by rainfall for the first three to six hours after application. Monsanto Canada Inc. is in the process of developing surfactants for glyphosate (Vision™) which will increase the rate of absorption of Vision™ by foliage and therefore decrease the effects of rainfall (Roy Maki, pers. commun., 1987).

The results of this research are also consistent with the application timing chart published by Monsanto Canada Inc. (1985). The application timing chart indicates that the first two weeks of August may be acceptable for the application of glyphosate, depending upon conditions, for use in conifer release. In the ground spray trial of this project, mid-August applications of glyphosate provided the poorest overall control of trembling aspen competiton. This may be due to the phenological condition of trembling aspen at this time. The author believes that trembling aspen is in the process of bud set at this time. This is the time of bud set for P. tristis (Figure 19). If this is the case, then the primary carbohydrate 'sinks' at this period of time would be the buds. Quantities of glyphosate applied at this time would then be translocated to the buds instead of basipetally to the stem and the roots. From Figure 19 one can see that the translocation of photosynthate to the roots of P. tristis increases dramatically after the completion of bud set. In this study the application of glyphosate at low rates in mid-August resulted in mainly code 4 trembling aspen which may have the potential for recovery in the ensuing growing season. Glyphosate applied at low rates, approximately 0.5 $kg.ha^{-1}$, in mid-August has an effect on the formation of leaf primordia in the season of application but the effect is not severe enough to kill the tree.

The dead standing aspen have a strong, negative influence on the first year effects of glyphoste on the aspen. The 1985 aerial applications were made under wind conditions of approximately 7 $km.hr^{-1}$. There was a 48 per cent difference in per cent kill of aspen in the 1985a (light overstory) and the 1985b (heavy overstory) 1.99 $kg.ha^{-1}$ plots one year after application. Since the glyphosate was released 60 m above the target vegetation, a fair portion of the herbicide could have been intercepted by the branches and boles of the dead standing aspen due to the horizontal displacement caused by a cross wind. This may account for a large portion of the lower herbicidal efficacy of the 1985 spray as compared to the 1984 spray.

Although strong correlations were found between the pre-spray basal diameter of the trembling aspen and its associated foliage oven dry weight, very poor post-spray correlations were found. Possible reasons why the post spray basal area to foliage oven dry weight regressions were so poor are as follows:

1) unevenness of spray application caused by drift,

2) overtopping aspen or dead standing aspen, and

3) differential susceptibility of aspen clones to glyphosate damage.

## RECOMMENDATIONS

To obtain an optimum level of both silvicultural and herbicidal efficacy, I recommend that the herbicide glyphosate be applied at approximately 1.0 $kg.ha^{-1}$ in mid- to late-August to release white spruce in the B.18a of Manitoba. Since 1.0 $kg.ha^{-1}$ can provide 100 per cent kill of the aspen under ideal conditions, rates between 0.5 and 1.0 $kg.ha^{-1}$, should be considered if high aspen kill is not desirable. Such circumstances may include frost pockets.

Glyphosate is a slow acting herbicide on trembling aspen; therfore, the best evaluations of herbicidal efficacy occurs somewhere between two and five years after the application of glyphosate (Dr. M. McCormack pers. com. Fall, 1989). Two years are required if low application rates are used. This time is required in order to ensure a complete kill of the aspen root system and a response by the white spruce.

Possible strategies for better herbicidal efficacy where standing residual timber exists may be: to cut the residual timber prior to spraying, to spray under very low wind speed (perhaps less than 4 $km.h^{-1}$), or to conduct ground applications.

Research should be carried out to evaluate the phenological development cycle of trembling aspen. Understanding of the seasonal photosynthate translocation patterns within trembling aspen would result in better control using glyphosate.

## LITERATURE CITED

Aldous, C.M. and S.E. Aldous. 1944. The snowshoe hare - A serious enemy of forest plantations. J. For. 42:88-94.

Alm, A.A. 1981. Glyphosate and 2,4-D application over red pine seedlings with hand held equipment. Sch. For., Univ. Minn., Res. Note No. 276. 4 pp.

Andrews, O.N. Jr. et al. 1974. Glyphosate control of railway right-of-way vegetation in the southeast. Proc. South. Weed Sci. Soc. 27:251-258.

Anon. 1985. Forestry Field Handbook. Nova Scotia Dept. Lands For., Field Handb. 25 pp.

Ashton, F.M. and A.S. Crafts. 1981. Mode of Action of Herbicides. John Wiley and Sons, Inc., Toronto. 525 pp.

Baker, F.S. 1949. A revised tolerance table. J. For. 47:179-181.

Baldwin, H.I. 1931. The period of height growth in some north-eastern conifers. Ecol. 12: 655-689.

Barr, M.L. and L.D. Potter. 1974. Chlorophyll and carotinoids in aspen bark (Populus tremuloides). Southwestern Nat. 19:147-154.

Barring, U. 1979. Results of country-wide trials in forestry-trials into aerial application of glyphosate and triclopyr amine. pp. 82-93 *in* Weeds and weed control, Part 1. 20th Swedish Weed Conf., Uppsala, Sweden, Jan. 31 - Feb. 2, 1979.

Bell, F.W. 1983. Comparative reproduction from male and female trembling aspen (Populus tremuloides Michaux.) root cuttings. B.Sc.For. Thesis, Sch. For., Lakehead Univ., Thunder Bay, Ont. 49 pp.

Bickerstaff, A, W.L. Wallace and F. Evert. 1981. Growth of forests in Canada. Part 2: A quantitative description of the land base and the mean annual increment. Environ. Can., Can. For. Serv., Inf. Rep. PI-X-1. 125 pp.

Blackmore, D.G. and Wm.C. Corns. 1979. Lodgepole pine and white spruce establishment after glyphosate and fertilizer treatment of grassy cutover forest land. For. Chron. 55:102-105.

Boyd, R.J., D.L. Miller, F.A. Kidd and C.P. Ritter. 1985. Herbicides for forest weed control in the Inland Northwest: A summary of effects on weeds and conifers. U.S.D.A. For. Serv., Gen. Tech. Rep INT-195. 63 pp.

Brace, L.G. and I.E. Bella. 1988. Understanding the understory: Dilemma and opportunity. pp. 69-86. *in* Samoil, J.K. (ed). Management and utilization of northern mixedwoods. Govern. Can., Can. For. Serv., Inf. Rep. NOR-X-296. 163 pp.

Brinkman, K.A. and E.I. Roe. 1975. Quaking aspen: Silvics and management in the Lake States. U.S.D.A. For. Serv., Agric. Handb. No. 486. 52 pp.

Campbell, R.A. 1988. Report on herbicide use for timber management in Ontario. pp. 194-244. *in* Ontario Ministry of Natural Resources, Class Environmental Assessment for Timber Management on Crown Lands in Ontario, MNR Witness Statement of Evidence Panel XII Maintenace: Tending, Vol.1.

Cannell, M.G.R. and L.J. Sheppard. 1982. Seasonal changes in the frost hardiness of provenances of Picea sitchensis in Scotland. For. 55:137-153.

Carmean, W.H. and J.T. Hahn. 1981. Revised site index curves for balsam fir and white spruce in the Lake States. U.S.D.A. For. Serv., Res. Note NC-269. 4 pp.

Casely, J.C. and D. Coupland. 1985. Environmental and plant factors affecting glyphosate uptake, movement and activity. pp. 92-123 *in* Grosshard, E. and D. Atkinson. (eds). The Herbicide Glyphosate. Butterworths. Toronto. 490 pp.

Cayford, J.H. 1957. Influence of the aspen overstory on white spruce growth in Saskatchewan. Can. Dept. North. Aff. Natn. Resour., For. Br., For. Res. Div., Tech. Note No. 58. 12 pp.

Cayford, J.H., V. Hildahl, L.D. Nairn and P.H. Wheaton. 1959. Injury to trees from winter drying and frost in Manitoba and Saskatchewan in 1958. For. Chron. 35:282-290.

Cheng, W.W. 1947. The anatomical properties of selected Populus clones. Ph.D. dissertion, Iowa State Univ. 232 pp.

Clements, J.R., J.W. Fraser and C.W. Yeatman. 1971. Frost damage to white spruce buds. Can. J. For. Res. 2:62-63.

Cole, D.J. 1985. Mode of action of glyphosate - A literature analysis. pp. 48-74 pp. *in* E. Grosshard and D. Atkinson (eds.) The Herbicide Glyphosate. Butterworths, Toronto. 490 pp.

Day, R.J. 1985. Basic seedling physiology: Essential information for producing and planting nursury stock. *in* Proc. Northern Silviculture Committee Interior Spruce Symp., Prince George, British Columbia. 29 pp.

Dobbs, R.C. 1972. Regeneration of white and engelman spruce: A literature review with special reference to the British Columbia Interior. Can. Dep. Environ., Can. For. Serv., Pacific For. Res. Cen., Inf. Rep. BC-X-69. 77 pp.

Donnely, J.R. 1974. Seasonal changes in photosynthate transport within elongating shoots of Populus grandidentata. Can. J. Bot. 52:2547-2559.

Drew, T.J. 1988. Managing white spruce in Alberta's Mixedwood Forest: The dilemma. pp. 35-40. *in* Samoil, J.K. (ed). Management and utilization of northern mixedwoods. Govern. Can., Can. For. Serv., Inf. Rep. NOR-X-296. 163 pp.

Einspahr, D.w. and M.K. Benson. 1968. Management of aspen on 10- to 20 year rotations. J. For. 66:557-560.

Eis, S. 1967. Establishment and early development of white spruce in the interior of British Columbia. For. Chron. 43:174-177.

Eliasson, L. 1971a. Growth regulators in Populus tremula. II. Effect of light on inhibitor content in root suckers. Physiol. Plant. 24:205-208.

Eliasson, L. 1971b. Growth regulators in Populus tremula. III. Variation of auxin and inhibitor level in roots in relation to root sucker formation. Physiol. Plant. 25:118-121.

Expert Committee on Weeds. 1984. Research report. Western Canada Section Meeting, Dec. 3-6, 1984, Winnipeg, Man.

Farmer, R.E. Jr. 1962. Aspen root sucker formation and apical dominance. For. Sci. 8:403-410.

Farmer, R.E. Jr. 1963. Effect of light intensity on growth of Populus tremuloides cuttings under two temperature regimes. Ecol. 44:409-411.

Fitzpatrick, J.M. and J.V. Stewart. 1968. The poplar resource and its challenge to Canadian forestry. pp. 214-239 *in* J.S. Maini and J.H. Cayford (eds.). Growth and utilization of poplars in Canada. Can. Dept. For. and Rural Dev., Publ. 1250. 257 pp.

Foote, K.C. and M. Schaedle. 1976. Physiological characteristics of photosynthesis and respiration in stems of Populus tremuloides Michx. Plant Physiol. 58:91-94.

Foote, K.C. and M. Schaedle. 1978. The contribution of aspen bark photosynthesis to the energy balance of the stem. For. Sci. 24:569-578.

Franz, J.F. 1978. Glyphosate and related chemistry. pp. 139-147 *in* Geissbuhler, H. (ed.). Advances in Pesticide Science. Part 2. Pergamon Press, Toronto. 835 pp.

Fraser, D.A. 1962. Apical and radial growth of white spruce (Picea glauca (Moench) Voss) at Chalk River, Ontario, Canada. Can. J. Bot. 40:659-668.

Froning, K. 1972. An appraisal of recent plantations in forests of the Prairie Provinces. Dep. Environ., Can. For. Serv., Inf. Rep. NOR-X-31.

Glerum, C. 1982. Frost hardiness and dormancy in conifers. pp. 37-46 *in* Northeastern Area Nurserymen's Conf. Nova Scotia Dept. Lands For., Nova Scotia.

Gratowski, H. 1975. Silvicultural use of herbicides in the Pacific Northwestern forests. U.S.D.A. For. Serv., Gen. Tech. Rep. PNW-77. 48 pp.

Gratowski, H. 1978. Herbicides for shrub and weed control in western Oregon. U.S.D.A. For. Serv., Gen. Tech. Rep. PNW-37. 44 pp.

Greig-Smith, P. 1964. Quantitative plant ecology. Butterworths & Co., London. 256 pp.

Gross, H.L. 1983. Injuries to terminal shoots cause multiple- leadered nursery seedlings. Environ. Can., Can. For. Serv., Inf. Rep. O-X-347. 12 pp.

Gross, H.L. 1985. Multiple-leadered trees compare favourably with single-leadered trees in field performance tests of nursery stock. Environ. Can., Can. For. Serv., Inf. Rep. O-X-363. 10 pp.

Haeussler, S. and D. Coates. 1986. Autecological characteristics of selected species that compete with conifers in British Columbia: A literature review. Canada/British Columbia, Economic and Regional Development Agreement. FRDA Rep. 001. 180 pp.

Haig, R.A. 1959. Reforestation by planting 1918-30, Riding and Duck Mountains, Manitoba and Saskatchewan. Dep. Nor. Aff. Nat. Res., For. Br., Mimeo.

Haig, R.A. 1962. Regeneration in Manitoba. For. Chron. 38:74-78.

Harvey, E.M.F. 1981. Post logging succession and vegetation management with hexazinone herbicide in Picea glauca (Moench) Voss - Populus tremuloides Mich. forest. M.Sc.F. thesis, Sch. For., Lakehead Univ, Thunder Bay, ON., 247 pp.

Hofstra, G., C. McLeod, D. Keefer and J. Ensing. 1982. Causes of multileadering- natural or cultural. Ont. Min. Nat. Resour., Nurserymen's Meeting, Thunder Bay, Ont.

Horton, K.W. and J.S. Maini. 1964. Aspen reproduction: Its characteristics and control. Can. Dept. For., Mono. No. 64-0-12. 85 pp.

Isebrands, J.G. 1982. Toward a physiological basis of intensive culture of poplar. pp. 81-90 *in* Proc. of the Tech. Assoc. of the Pulp and Paper Industry. Res. and Dev. Div. Conf., Asheville, NC. Aug. 29 - Sept. 1.

Jarvis, J.M., G.A. Steneker, R.M. Waldron and J.C. Lees. 1966. Review of silvicultural research in white spruce and trembling aspen cover types in the Mixedwood Forest Section Boreal forest Region Alberta - Saskatchewan - Manitoba. Can. Dept. For. Rural Dev., For. Br., Dept. Publ. No. 1156. 29 pp.

Johnson, H.J. 1973. An evaluation of scarification and direct seeding in Alberta. Environ. Can., For. Serv., Inf. Rep. NOR-X-71. 27 pp.

Johnson, H.J. 1986. The release of white spruce from trembling aspen overstoreys: A review of available information and silvicultural guidelines. Canada Manitoba For. Econ. and Regional Dev. Agreement., Manitoba Dept. Nat. Resour., For. Br. 109 pp.

Jones, J.R. and G.A. Schier. 1985. Growth. pp. 19-24 *in* DeByle, N.V. and R.P. Winokur (eds.). Aspen: Ecology and Management in the Western United States. U.S.D.A. For. Serv., Gen. Tech. Rep. RM-119. 283 pp.

Kabzems, A. 1952. Stand dynamics and development in the mixedwood forest. For. Chron. 28:7-22.

Kagis, I. 1952. Some problems in mixedwood stands. For. Chron. 28:6-18.

Keith, L.B., J.R. Cary, O.J. Ronstad and M.c. Brillingham. 1984. Demography and ecology of a declining snowshoe hare population. Wildl. Monogr. 90:43.

Kemperman, J.A. 1978. Sucker-root relationship in aspen. For. Res. Note No. 12, 4 pp.

Kirby, C.L. 1962. The growth and yield of white spruce - aspen stands in Saskatchewan. Sask. Dept. Nat. Resour., For. Br., Tech. Bull. No. 4. 58 pp.

Kirby, C.L., W.S. Bailey and J.G. Gilmour. 1957. The growth and yield of aspen in Saskatchewan. Sask. Dept. Nat. Resour., For. Br., Tech. Bull. No. 3. 67 pp.

Klingman, D.L. 1974. Germination of grass seed placed on soil before or after spraying with glyphosate. Proc. Northeastern Weed Sci. Soc. 28:406.

Kroes, G. 1979. The effect of clone, root diameter and time of year on suckering of Populus tremuloides Michaux. B.Sc.F. Thesis, Sch. For., Lakehead Univ., Thunder Bay, ON. 38 pp.

Lees, J.C. 1966. Release of white spruce from aspen competition in Alberta's spruce-aspen forest. Can. Dept. For., For. Res. Br., Pub. No. 1163. 16 pp.

Lees, J.C. 1967. Release of white spruce from aspen competition in Alberta's spruce-aspen forest. Can., Dep. Environ., For. Res. Br. Publ. 1163. 16 pp.

Lees, J.C. 1970. Natural regeneration of white spruce under spruce-aspen shelterwood, B-18a Forest Section, Alberta. Dep. Fish. For., Can. For. Serv., Publ. No. 1274. 14 pp.

Lehela, A., R.J. Day and Z. Koran. 1972. A close up of the stomatal regions of white spruce and jack pine. For. Chron. 48:32-34.

Logan, K.T. 1969. Growth of tree seedlings as affected by light intensity IV: Black spruce, white spruce, balsam fir, eastern white cedar. Dept. Environ., Can. For. Serv., Pub. 1256. 12 pp.

Lund-Hoie, K. 1974. Norwegian experiences concerning herbicides for the control of weeds in forest plantations. pp. K6-K7 *in* Weeds and weed control, Part 1. Proc. of the 15th Swedish Weed Conference. Lantbrukshogskolan, Uppsala, Sweden.

Lund-Hoie, K. 1975. N-phosphonomethylglycine (glyphosate), an alternative to the phenoxy acids for the control of unwanted plant species in forest plantations in Norway. pp. 490-491 *in* Proc. Inter. Cong. Plant Prot., Part 2, Rep. and Inf., Sec. 3, Chemical Control.

Lund-Hoie, K. 1976. The correlation between tolerance of Norway spruce to glyphosate and uptake, distribution and metabolism of the herbicide in the spruce plants. Agric. Coll., Norway, Sci. Rep. 55: NR21. 25 pp.

Lund-Hoie, K. 1977. Weeds and weed control. Proc. 18th Swedish Weed Conference, Agric. Coll. Sweden, Uppsala. January 27-28, 1977. 1 p.

Lund-Hoie, K. 1980. The impact of helicopter application of glyphosate on the management of Norwegian forest plantations. pp. 73-82 *in* Proc. Weed Control in Forestry Conf., Univ. Nottingham, England, April 1-2,1980.

MacLeod, W.K. and A.W. Blyth. 1955. Yield of even-aged, fully stocked spruce-poplar stands in Northern Alberta. Can. Dept. Nthn. Aff. Natn. Resources, For. Br., For. Res. Div., Tech. Note No. 18. 33 pp.

Maini, J.S. 1968a. The relationship between the origin of adventitious buds and the orientation of Populus tremuloides root cuttings. Bull. Ecol. Soc. Amer. 49: 81-82.

Maini, J.S. 1968b. Silvics and ecology of Populus in Canada. pp. 20-69 *in* J.S. Maini and J.H. Cayford (eds.). Growth and utilization of polars in Canada. Can. Dept. For. Rural Dev., Publ. 1250. 257 pp.

Maini, J.S. and K.W. Horton. 1966. Vegetative propagation of Populus spp. I. Influence of temperature on formation and initial growth of aspen suckers. Can. J. Bot. 44:1181-1189.

Malik, N. and W.H. Vanden Born. 1986. Use of herbicides in forest management. Govn. Can., Can. For. Serv., Inf. Rep. NOR-X-282. 18 pp.

Mansfield, C.F. and H.J. Fralick. 1979. Using the Micron Herbi 77 for weed control in decidous landscape stock. O.M.N.R. Nursery Notes No. 58. 5 pp.

McCormack, M.L. and T.B. Saviello. 1981. Glyphosate and triclopyr mixtures to control forest brush. Proc. Northeastern Weed Sci. Soc. 35:218.

Miller, R.S.B. 1958. Interim report on herbicide experiments allied to project RC-17. ON. Min. Nat. Resour. Unpub. Rep. 33 pp.

Monsanto. 1980. Roundup herbicide bulletin No. 1 - Toxicology and environmental review. Monsanto Agricultural Products Company, St. Louis, Mo. 3 pp.

Monsanto. 1984. Roundup® : Herbicide bulletin. Monsanto Canada Ltd. 6 pp.

Monsanto. 1985. Roundup® in forestry. Monsanto Canada, Inc. 9 pp.

Monsanto. 1987. Vision™ in forestry. Monsanto Canada, Inc. 10 pp.

Mullin, R.E. 1964. Reduction in growth of white spruce after outplanting. For. Chron. 40:488-493, 502.

Newton, M. and F.B. Knight. 1981. Handbook of Weed Control and Insect Control Chemicals for Forest Resource Managers. Timber Press, Beaverton, Oregon. 213 pp.

Nienstaedt, H. 1957. Silvical characteristics of white spruce. Lake States For. Expt. Stn, St. Paul, Minn. 23 pp.

Nienstaedt, H. 1966. Dormancy and dormancy release in white spruce. For. Sci. 12:374-384.

Nienstaedt, H. 1982. White spruce in the Lake States. pp. 142-167.in Proceedings of the artificial regeneration of conifers in the Upper Great Lakes Region, Oct. 26-28, Green Bay, WI.

Nienstaedt, H. 1985. Inheritance and correlations of frost injury, growth, flowering, and cone characteristics in white spruce, _Picea glauca_ (Moench) Voss. Can. J. For. Res. 15:498-504.

Nienstaedt, H. and A. Teich. 1972. Genetics of white spruce. U.S.D.A. For. Serv., Res. Pap. WO-15. 24 pp.

Owens J.N., M. Molder and H. Langer. 1977. Bud development in _Picea glauca_. I. Annual growth cycle of vegetative buds and shoot elongation as they relate to date and temperature sums. Can. J. Bot. 55:2728-2745.

Owens J.N. and M. Molder. 1976. Bud development in Sitka spruce. I. Annual growth cycle of vegetative buds and shoot. Can. J. Bot. 54:313-325.

Pearson, L.C. and D.B. Lawrence. 1958. Photosynthesis of aspen bark. Amer. J. Bot. 45:383-387.

Perala, D.A. 1978. Aspen sucker production and growth from outplanted root cutting. U.S.D.A. For. Serv., North Cent. For. Expt. Stn., Res. Note NC-242. 4 pp.

Perala, D.A. 1984. Using glyphosate herbicide in converting aspen to conifers. U.S.D.A. For. Serv., North Cent. For. Expt. Stn., Res. Pap. NC-259. 5 pp.

Peterson, E.B., Y.H. Chan and J.B. Cragg. 1970. Above-ground standing crop, leaf area and caloric value of an aspen clone near Calgary, Alberta. Can. J. Bot. 48:1459-1469.

Phelps, V.H. 1948. White spruce reproduction in Manitoba and Saskatchewan. Can. Dept. of Mines Resour, Mines For. Serv. Br., Dominion For. Serv., Silv. Res. Note No. 86. 32 pp.

Polhill, B.E. 1978. A herbicide trial for plantation release in the Thunder Bay District. B.Sc.F. Thesis., Sch. For., Lakehead Univ. Thunder Bay, ON. 26 pp.

Pollard, D.F.W. 1970. Leaf area development on different shoot types in a young aspen stand and its effect upon production. Can. J. Bot. 48:1801-1804.

Pollard, D.F.W. 1971. Mortality and annual changes in distribution of above-ground biomass in an aspen sucker stand. Can. J. For. Res. 1:262-266.

Pollard, D.F.W. 1972. Above-ground dry matter production in three stands of trembling aspen. Can. J. For. Res. 2:27-33.

Pollard, D.F.W. 1973. Provenance variation in phenology of needle initiation in white spruce. Can. J. For. Res. 3:589-593.

Pollard, D.F.W. 1974. Bud morphogenesis of white spruce Picea glauca seedlings in a uniform environment. Can. J. Bot. 52:1569-1571.

Pollard, D.F.W. and T.K. Logan. 1977. The effect of light intensity, photoperiod, soil moisture potential, and temperature on bud morphogenesis in Picea species. Can. J. For. Res. 7:415-421.

Radvanyi, A. 1987. Snowshoe hare and forest plantations: A literature review and problem analysis. Agric. Can., Can. For. Serv., North. For. Cent., Edmonton, Alberta., Inf. Rep. NOR-X-290. 17 pp.

Rauscher, H.M. 1984. Growth and yield of white spruce plantations in the Lake States (a literature review). USDA For. Serv., Res. Pap. NC-253. 46 pp.

Rennie, D.A., W.A. Klassen, W.A. Fuller and E.H. Kennett. 1985. Report on the task force on use of herbicides in forest management. Report prepared for the Dep. Parks and Renewable Resour. Govern. Sask., Saskatoon, Sask. 180 pp.

Rowe, J.S. 1955. Factors influencing white spruce reproduction in Manitoba and Saskatchewan. Can. Dept. North. Aff. Natl. Resour., For. Res. Div., Tech. Note 3. 27 pp.

Rowe, J.S. 1972. Forest Regions of Canada. Can. Dep. Environ., Can. For. Serv., Pub. No. 1300. 172 pp.

Rueppel, M.L., B.B. Brightwell, J. Schaefer and J.T. Marvel. 1977. Metabolism and degredation of glyphosate in soil and water. J. Agric. and Food Chem. 25:517-523.

Samish, R.M. 1954. Dormancy in woody plants. Am. Re. Plant Physiol. 5:183-204.

Sayn-Wittgenstein, L. 1961. Phenological aids to species identification on air photographs. Can. Dept. For., For. Res. Br., Tech. Note No. 104. 26 pp.

Sandburg, D. and A.E. Schneider. 1953. The regeneration of aspen by suckering. Minn. For. Notes. No. 24. 2 pp.

Schier, G.A. 1973a. Origin and development of aspen root suckers. Can. J. For. Res. 3:45-53.

Schier, G.A. 1973b. Seasonal variation in sucker production from excised roots of Populus tremuloides and the role of endogenous auxin. Can. J. For. Res. 3:459-461.

Schier, G.A. 1975. Deterioration of aspen clones in the middle Rocky Mountains. U.S.D.A. For. Serv., Res. Pap. INT-179. 14 pp.

Schier, G.A. 1978.Variation in suckering capacity amoung and within lateral roots of an aspen clone. U.S.D.A. For. Serv., Res. Note INT-241. 6 pp.

Schier, G.A. and R.S. Johnston. 1971. Clonal variation in total non-structural carbohydrates of trembling aspen roots in three Utah areas. Can. J. For. Res. 1: 252-255.

Schier, G.A. and J.C. Zasada. 1973. Role of carbohydrate reserves in the development of root suckers in Populus tremuloides. Can. J. For. Res. 3:243-250.

Shepard, R.K., Jr. 1975. Radial distribution of corticular photosynthate in stems of big tooth and trembling aspen. For. Sci. 21:370-372.

Shirley, H.L. 1941. Restoring conifers to aspen lands in the lake States. U.S.D.A. For. Serv., Tech. Bull. 763. 36 pp.

Smith, H. and N.P. Kefford. 1964. The chemical regulation of the dormancy phases of bud development. Amer. J. Bot. 51:1002-1012.

Sprankle, P., W.F. Meggitt and D. Penner. 1975. Absorption mobility and microbial degredation of glyphosate in soil and water. Weed Sci. 23:229-234.

Starr, G.H. 1971. Propagation of aspen trees from lateral roots. J. For. 69:866-867.

Steel, R.G. and J.H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach, 2nd ed. McGraw-Hill Book Co., Toronto. 633 pp.

Steneker, G.A. 1963. Results of a 1936 release cutting to favour white spruce in a 50-year-old white spruce-aspen stand in Manitoba. Can. Dep. For., For. Res. Br., Publ. No. 1005. 17 pp.

Steneker, G.A. 1967. Growth of white spruce following release from trembling aspen. Can. Dep. For. Rural Dev., For. Br., Dep. Publ. No. 1183. 16 pp.

Steneker, G.A. 1972. The size of trembling aspen (<u>Populus tremuloides</u> Michx.) clones in Manitoba. Can. J. For. Res. 3:472-478.

Steneker, G.A. 1974. Factors affecting the suckering of tembling aspen. For. Chron. 50:32-34.

Steneker, G.A. 1976. Guide to the silvicultural management of trembling aspen in the prairie provinces. Environ. Can., Can. For. Serv., Int. Rep. NOR-X-164. 6 pp.

Steneker, G.A. and Wall. 1970. Aspen clones: Their significance and recognition. Can. For. Serv., For. Res. Lab., Liason Note MS-L-8. 10 pp.

Steneker, G.A. and M.A. Walters. 1971. The effect of root length upon the suckering of trembling aspen. Dep. Fish and For., Can. For. Serv., Inf. Rep. A-X-46. 11 pp.

Stephens, G.R. Jr. 1965. Accelerating early height growth of white spruce. J. For. 63:671-673.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics a biometrical approach. (2nd ed.). McGraw-Hill Book Comp., Toronto. 633 pp.

Stiell, W.M. 1976. White spruce: Artificial regeneration in Canada. Environ. Can., Can. For. Serv., Inf. Rep. FMR-X-85. 275 pp.

Stiell, W.M. and A.B. Berry. 1973. Development of unthinned white spruce plantations to age 50 at Petawawa Forest Experiment Station. Dep. Environ., Can. For. Serv. Pub. No.1317. 18 pp.

Stoeckeler, J.H. 1938. Soil adaptability of white spruce. J. For. 36:1145-1147.

Stoeckeler, J.H. 1965. Spring frost damage in young forest plantings near La Crosse, Wisconsin. J. For. 63:12-14.

Sutton, R.F. 1969. Silvics of white spruce (Picea glauca (Moench) Voss). Can. Dept. Fish. For., For. Br. Pub. No. 1250. 57 pp.

Sutton, R.F. 1975. Nutrition and growth of white spruce outplants: Enhancement by herbicidal site preparation. Can. J. For. Res. 5:217-223.

Sutton, R.F. 1978. Glyphosate herbicide: An assessment of forestry potential. For. Chron. 54:24-28.

Sutton, R.F. 1984. Plantation establishment in the Boreal Forest: Glyphosate, hexazinone, and manual weed control. For. Chron. 60:283-289.

Sutton, R.F. 1985. Vegetation management in Canadian forestry. Environ. Can., Can. For. Serv., Inf. Rep. 0-X-369. 34 pp.

Teich, A.H. and M.J. Holst. 1974. White spruce limestone ecotypes. For. Chron. 50:110-111.

Tew, R.K. 1970. Root carbohydrate reserves in vegetative reproduction of aspens. For. Sci. 16:318-320.

Thrower, J.S. 1986. Estimating site quality from early height growth of white spruce and red pine plantations in the Thunder Bay area. M.Sc.F. thesis, Sch. For., Lakehead Univ, Thunder Bay, ON., 143 pp.

Vaartaja, O. 1957. Photoperiodic response in seedlings of northern tree species. Can. J. Bot. 35: 132-138.

Vogt, R.A. and G.S. Cox. 1970. Evidence for the hormonal control of stump sprouting by oak. For. Sci. 16:165-171.

Wendel, G.W. and J.N. Kochenderfer. 1984. Aerial release of Norway spruce with Roundup® in the Central Appalachians. North. J. Appl. For. 2:29-32.

Winton, L.L. 1964. Cessation of dormancy in white spruce. Minn. For. Res. Notes. No. 155. 2 pp.

Wright, J.W., H. Nienstaedt, W.A. Lemmien, J.N. Bright, M.W. Day and R.L. Sajdak. 1977. Better white spruce for Michigan. Mich. State Univ., Agric. Expt. Stn., East Lansing, Res. Rep. 316. 8 pp.

W.S.S.A., 1983. Herbicide handbook of the Weed Science Society of America (5th Ed.). Weed Sci. Soc. Amer. Champaign, Illinois. 515 pp.

Young, W.D. 1979. The effect of glyphosate on potted 3+0 white spruce seedlings varies with rate of application, phenological development and environment. B.Sc.F. Thesis, Sch. For., Lakehead Univ, Thunder Bay, Ont. 30 pp.

Zufa, L. 1971. A rapid method for vegetative propagation of aspens and their hybrids. For. Chron. 47:36-39.

# APPENDIX A

## MAPS SHOWING THE LAYOUT OF SUBPLOTS WITHIN THE 1984 AND 1985 AERIAL PLOTS

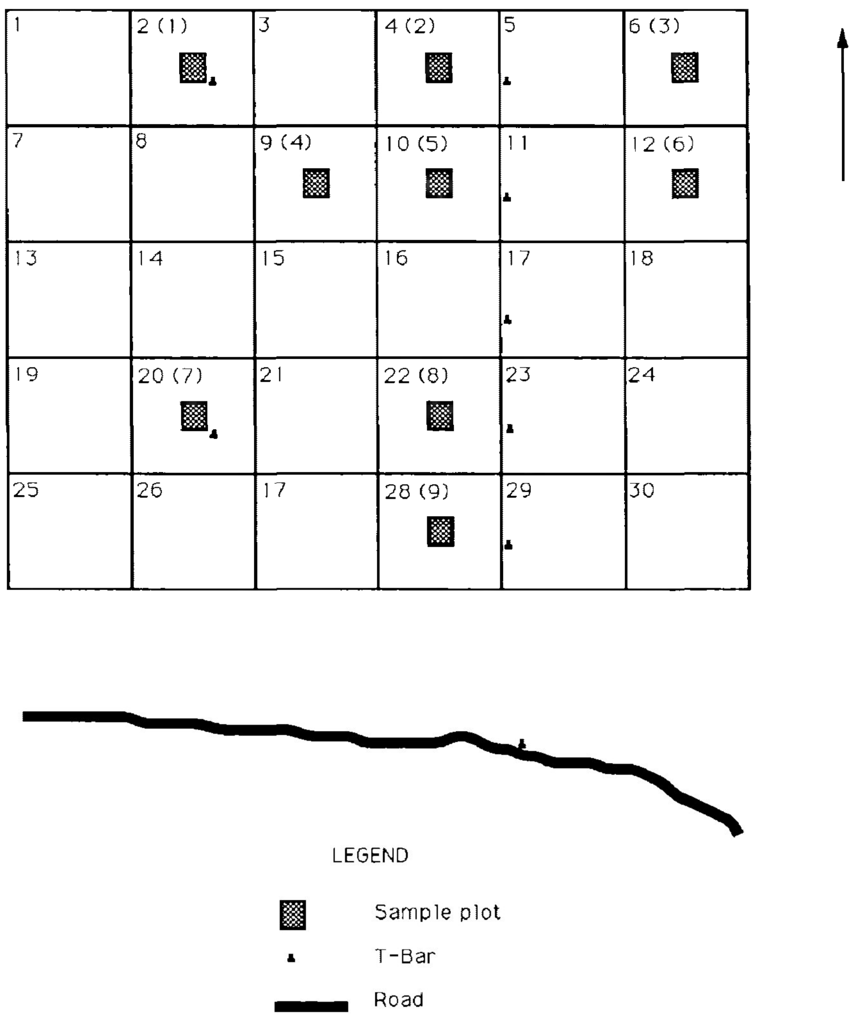



Figure 1. Layout of subplots within the aerial plot 1984 (0.00 kg a.i. $ha^{-1}$)

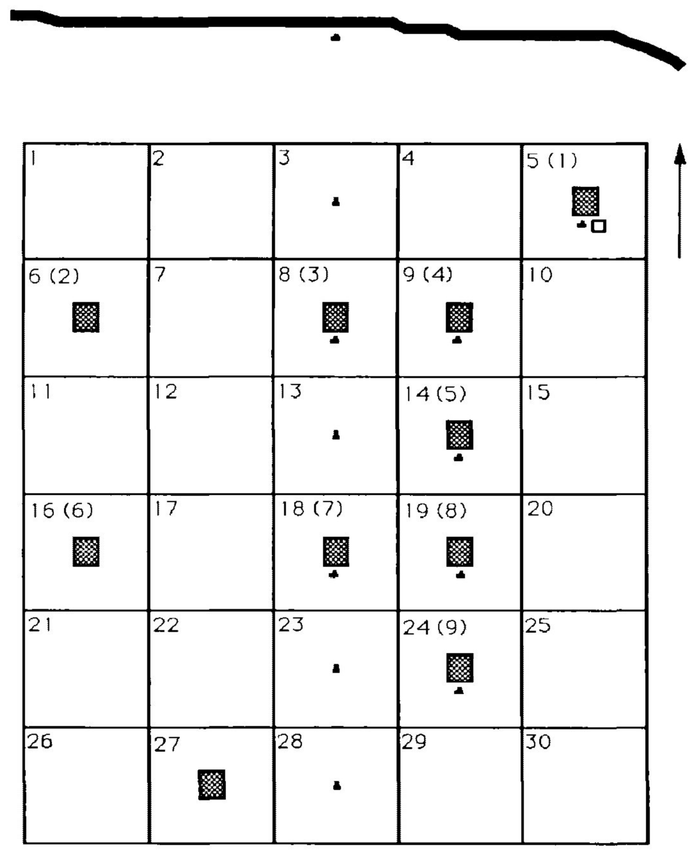



Figure 2. Layout of subplots within the aerial plot 1984 (0.90 kg a.i. $ha^{-1}$)

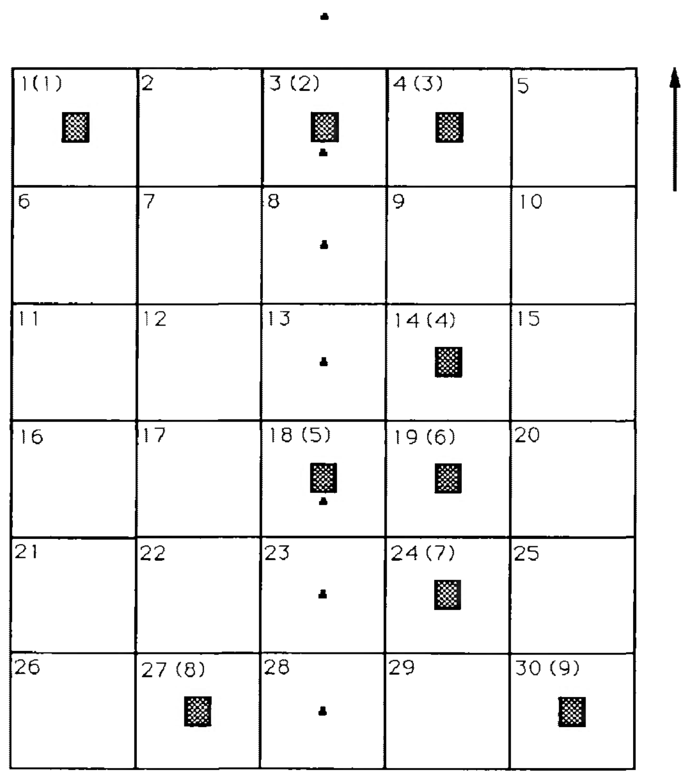



Figure 3. Layout of subplots within the aerial plot 1984 (1.60 kg a.i. $ha^{-1}$)

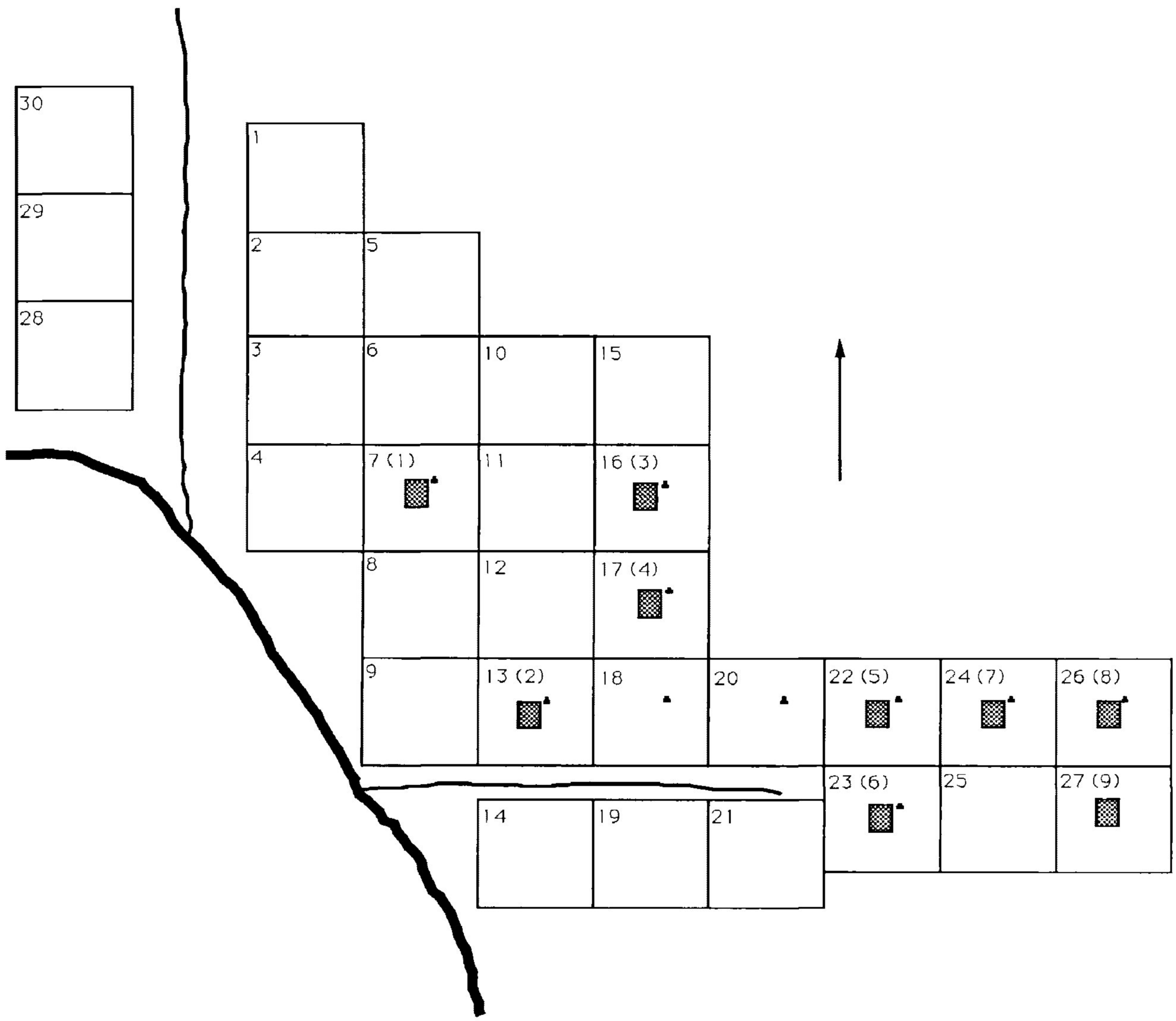



Figure 4. Layout of subplots within the aerial plot 1985a (0.00 kg a.i. $ha^{-1}$)

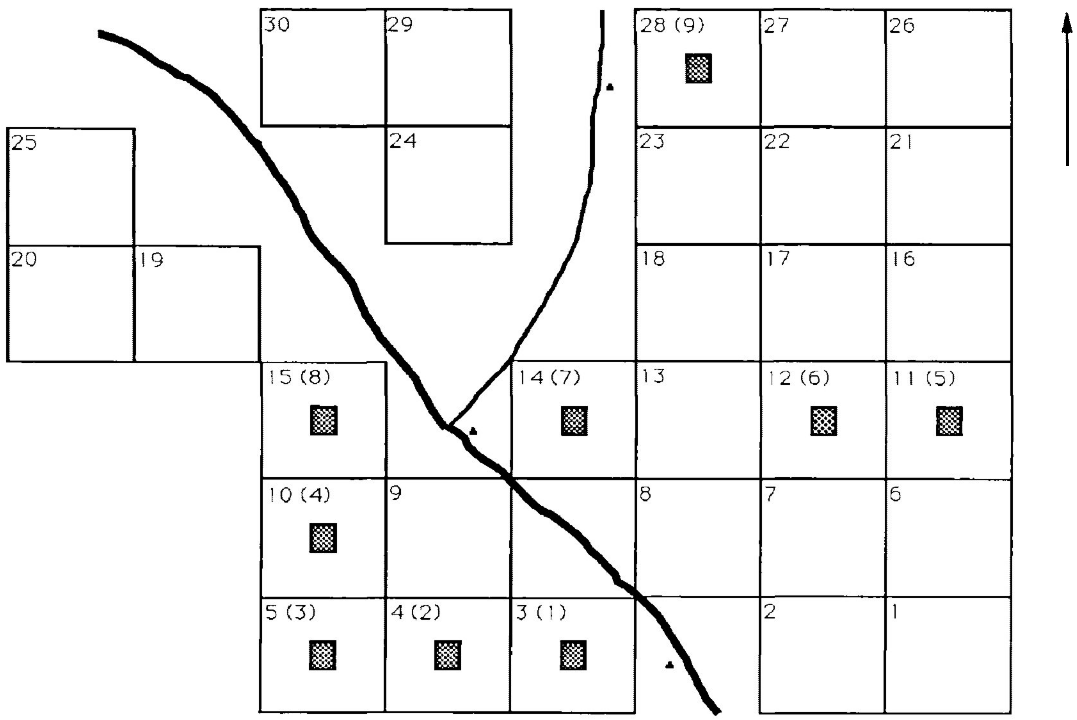



Figure 5. Layout of subplots within the aerial plot 1985a (0.93 kg a.i. $ha^{-1}$)

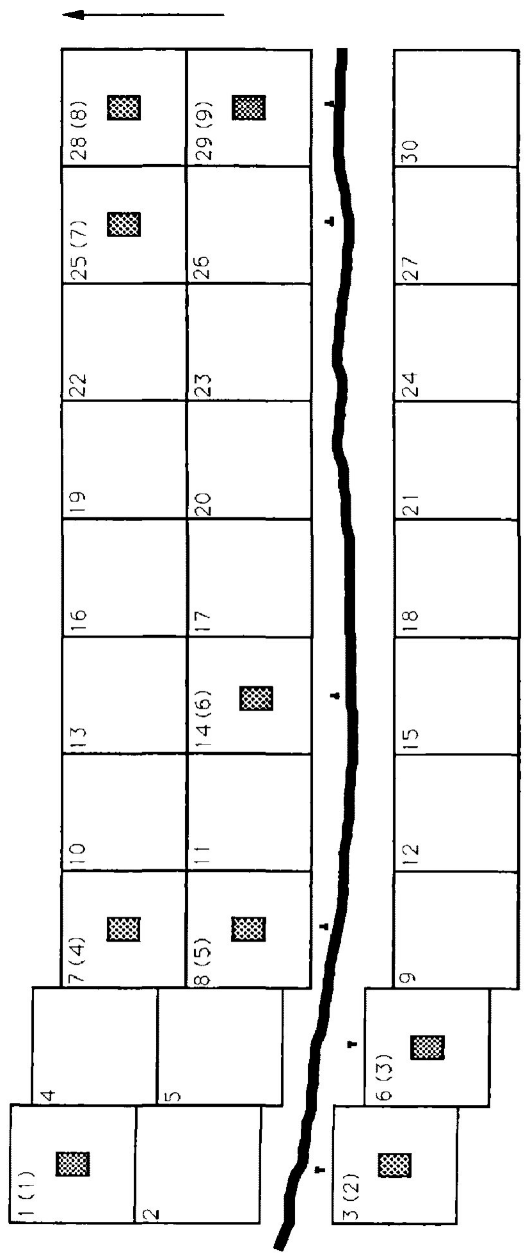



Figure 6. Layout of subplots within the aerial plot 1984 (1.99 kg a.i. $ha^{-1}$)

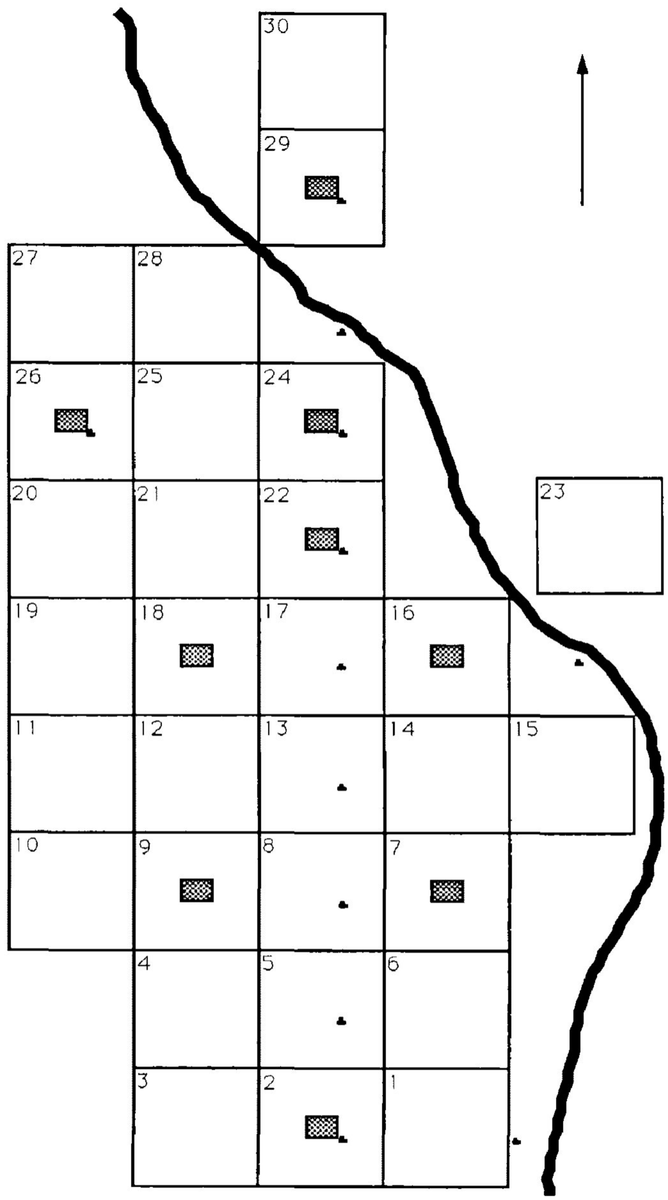



Figure 7. Layout of subplots within the aerial plot 1985b (0.00 kg a.i. $ha^{-1}$)

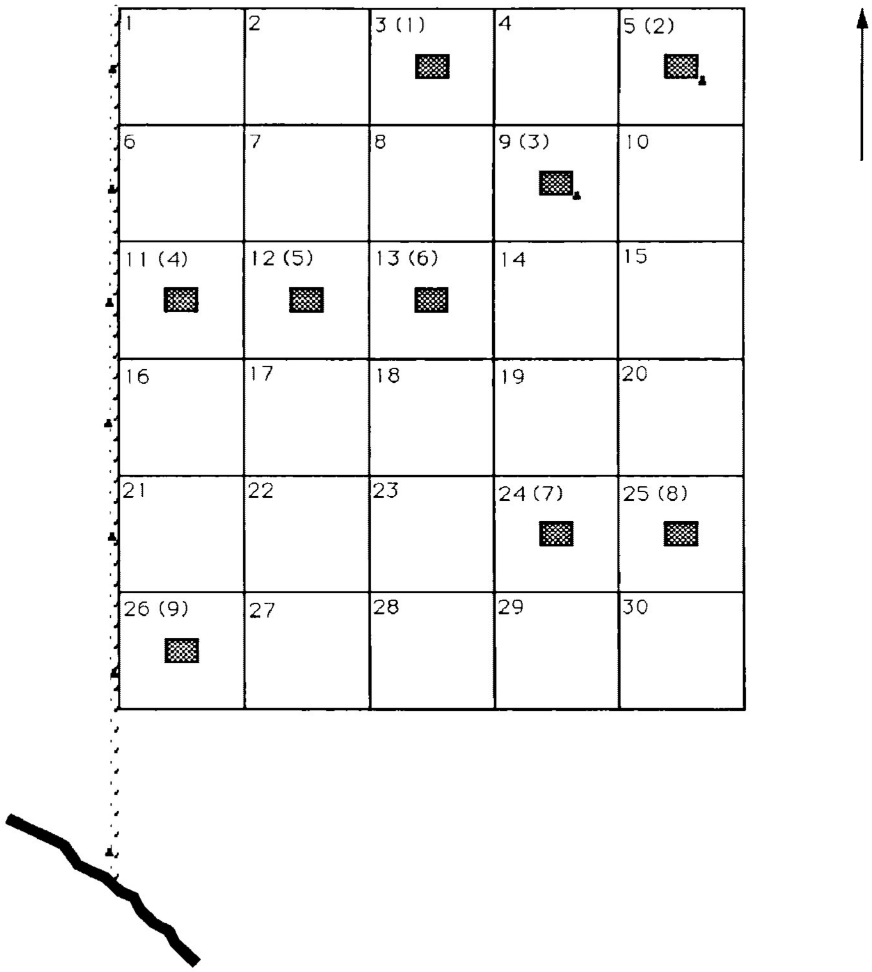



Figure 8. Layout of subplots within the aerial plot 1985b (0.93 kg a.i. $ha^{-1}$)

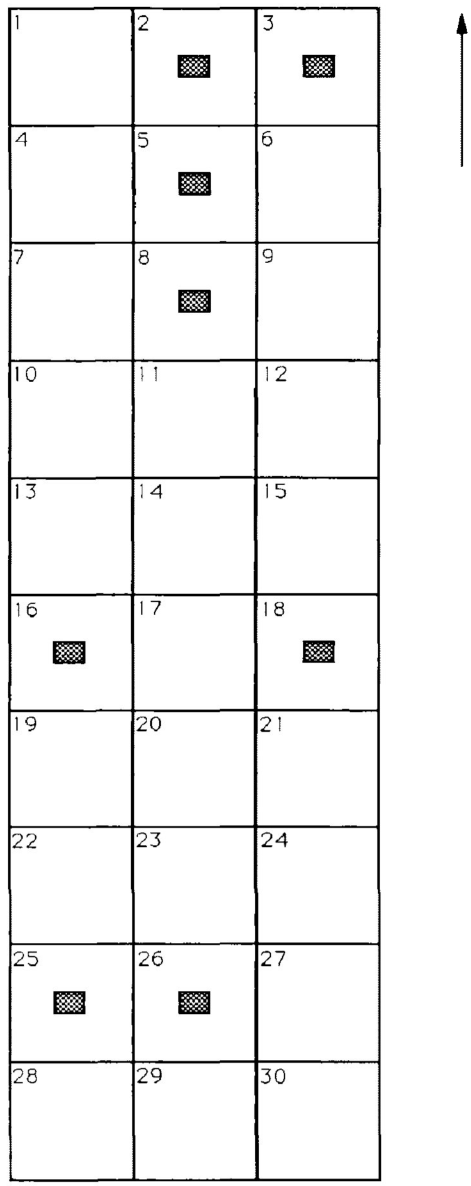



Figure 9. Layout of subplots within the aerial plot 1985b (1.99 kg a.i. $ha^{-1}$)

# APPENDIX B

## DESCRIPTION OF SOILS WITHIN THE 1984 AERIAL PLOTS

Appendix B-1: Results of soil analysis of soils collected from the 1984 spray trial.

| SPRAY RATE (kg a.i./ha) | HORIZON | DEPTH | TEXTURE (cm) | pH | ORGANIC CONTENT (%) |
|---|---|---|---|---|---|
| 0.00 | LFH | 2-0 | | | |
| | Ahe | 0-7 | loamy sand | 5.9 | 0.018 |
| | Bt | 7-13 | sandy clay loam | 5.9 | 0.033 |
| | Bm | 13-47 | loamy sand | 7.0 | 0.020 |
| | C | $47^{+}$ | sandy loam | 7.3 | 0.016 |
| 0.90 | LFH | 6-0 | | | |
| | Ahe | 0-10 | sandy loam | 5.5 | 0.025 |
| | Bt | 10-29 | sandy clay loam | 5.5 | 0.031 |
| | Bm | 29-50 | loamy sand | 7.3 | 0.016 |
| | C | $50^{+}$ | sandy loam | 7.4 | 0.017 |
| 1.60 | LFH | 5-0 | | | |
| | Ahe | 0-9 | loamy sand | 5.2 | 0.015 |
| | Bt | 9-33 | sandy clay loam | 5.2 | 0.016 |
| | Bm | 33-54 | sandy loam | 6.7 | 0.017 |
| | C | $54^{+}$ | sandy loam | 7.3 | 0.013 |

# APPENDIX C

## STATISTICAL ANALYSES OF WHITE SPRUE AND TREMBLING ASPEN VARIABLES

Appendix C-1: Analysis of variance on number of white spruce terminal shoots.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 0.70 | 0.35 | 1.16 | 0.35 | NS |
| Rate | 1 | 2.00 | 2.00 | 6.61 | 0.02 | * |
| Time by Rate | 2 | 0.57 | 0.29 | 0.95 | 0.42 | NS |
| Error 1 | 12 | 3.64 | 0.30 | | | |
| Total | 17 | 6.91 | | | | |

NS - Not significantly different at the 95 % level of confidence.
** - Significantly different at the 95 % level of confidence.

Appendix C-2: Analysis of variance of white spruce cumulative height at the end of the season of glyphosate application.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 177.72 | 88.86 | 4.80 | 0.029 | * |
| Rate | 1 | 1.53 | 1.53 | 0.08 | 0.778 | NS |
| Time by Rate | 2 | 33.08 | 16.54 | 0.89 | 0.435 | NS |
| Error 1 | 12 | 222.25 | 18.52 | | | |
| Total | 17 | 434.58 | | | | |

NS - Not significantly different at the 95% level of confidence.
* - Significantly different at the 95% level of confidence.

Appendix C-3: Analysis of covariance of white spruce cumulative height at the end of the first post-spray growing season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 21.12 | 10.56 | 1.51 | 0.263 | NS |
| Rate | 1 | 0.50 | 0.50 | 0.07 | 0.793 | NS |
| Time by Rate | 2 | 11.60 | 5.80 | 0.83 | 0.462 | NS |
| Regression | 1 | 214.30 | 214.30 | 30.64 | 0.000 | ** |
| Error 1 | 11 | 76.93 | 6.99 | | | |
| Total | 17 | 324.45 | | | | |

NS - Not significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-4: Analysis of covariance of white spruce cumulative height at the end of the second post-spray growing season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 47.09 | 23.55 | 0.76 | 0.489 | NS |
| Rate | 1 | 270.60 | 270.60 | 8.77 | 0.013 | * |
| Time by Rate | 2 | 152.19 | 76.09 | 2.47 | 0.130 | NS |
| Regression | 1 | 419.21 | 419.21 | 13.58 | 0.004 | ** |
| Error 1 | 11 | 339.50 | 30.86 | | | |
| Total | 17 | 1228.59 | | | | |

NS - Not significantly different at the 95% level of confidence.
* - Significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-5: Analysis of variance of white spruce basal diameter at the end of the season of glyphosate application.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 0.00 | 0.00 | 0.00 | 0.997 | NS |
| Rate | 1 | 0.00 | 0.00 | 0.12 | 0.734 | NS |
| Time by Rate | 2 | 0.05 | 0.03 | 3.42 | 0.067 | NS |
| Error 1 | 12 | 0.09 | 0.01 | | | |
| Total | 17 | 0.14 | | | | |

NS - Not significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-6: Analysis of covariance of white spruce basal diameter at the end of the first post-spray growing season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 0.03 | 0.02 | 3.93 | 0.051 | NS |
| Rate | 1 | 0.16 | 0.16 | 38.33 | 0.000 | ** |
| Time by Rate | 2 | 0.02 | 0.01 | 2.42 | 0.135 | NS |
| Regression | 1 | 0.09 | 0.09 | 21.60 | 0.001 | ** |
| Error 1 | 11 | 0.05 | 0.00 | | | |
| Total | 17 | 0.35 | | | | |

NS - Not significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-7: Analysis of covariance of white spruce basal diameter at the end of the second post-spray growing season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 0.02 | 0.01 | 2.02 | 0.179 | NS |
| Rate | 1 | 0.52 | 0.52 | 98.38 | 0.000 | ** |
| Time by Rate | 2 | 0.04 | 0.02 | 3.74 | 0.058 | NS |
| Regression | 1 | 0.27 | 0.27 | 51.11 | 0.000 | ** |
| Error 1 | 11 | 1.12 | 0.01 | | | |
| Total | 17 | 1.97 | | | | |

NS - Not significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-8: Analysis of variance of white spruce stem volume at the end of the season of glyphosate application.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 2.41 | 1.21 | 0.59 | 0.570 | NS |
| Rate | 1 | 0.21 | 0.21 | 0.10 | 0.757 | NS |
| Time by Rate | 2 | 8.93 | 4.46 | 2.18 | 0.156 | NS |
| Error 1 | 12 | 24.58 | 2.05 | | | |
| Total | 17 | 36.13 | | | | |

NS - Not significantly different at the 95% level of confidence.

Appendix C-9: Analysis of covariance of white spruce stem volume at the end of the first post-spray growing season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 22.32 | 11.16 | 3.97 | 0.050 | * |
| Rate | 1 | 72.36 | 72.36 | 25.74 | 0.000 | ** |
| Time by Rate | 2 | 13.63 | 6.82 | 2.42 | 0.134 | NS |
| Regression | 1 | 60.38 | 60.38 | 21.48 | 0.001 | ** |
| Error 1 | 11 | 30.92 | 2.81 | | | |
| Total | 17 | 199.61 | | | | |

NS - Not significantly different at the 95% level of confidence.
* - Significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-10: Analysis of covariance of white spruce stem volume at the end of the second post-spray growing season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 28.25 | 14.12 | 1.42 | 0.283 | NS |
| Rate | 1 | 748.60 | 748.60 | 75.22 | 0.000 | ** |
| Time by Rate | 2 | 125.12 | 62.56 | 6.29 | 0.015 | * |
| Regression | 1 | 442.92 | 442.92 | 44.50 | 0.000 | ** |
| Error 1 | 11 | 109.48 | 9.95 | | | |
| Total | 17 | 1454.37 | | | | |

NS - Not significantly different at the 95% level of confidence.
* - Significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-11: Analysis of variance of aspen basal area at the end of the pre-spray season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 21368.32 | 10684.16 | 3.03 | 0.086 | NS |
| Rate | 1 | 6554.04 | 6554.04 | 1.86 | 0.198 | NS |
| Time by Rate | 2 | 1938.51 | 969.26 | 0.27 | 0.764 | NS |
| Error 1 | 12 | 42299.44 | 3524.95 | | | |
| Total | 17 | 72160.31 | | | | |

NS - Not significantly different at the 95 % level of confidence

Appendix C-12: Analysis of covariance of aspen basal area at the end of the first post-spray growing season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 124.49 | 62.25 | 0.03 | 0.968 | NS |
| Rate | 1 | 9365.92 | 9365.92 | 4.89 | 0.049 | * |
| Time by Rate | 2 | 3800.87 | 1900.43 | 0.99 | 0.401 | NS |
| Regression | 1 | 16667.61 | 16667.61 | 8.71 | 0.013 | * |
| Error 1 | 11 | 21058.31 | 1914.39 | | | |
| Total | 17 | 51017.20 | | | | |

NS - Not significantly different at the 95% level of confidence.
* - Significantly different at the 95% level of confidence.

Appendix C-13: Analysis of covariance of aspen basal area at the end of the second post-spray growing season.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 351.23 | 175.62 | 0.08 | 0.925 | NS |
| Rate | 1 | 26830.23 | 26830.23 | 12.03 | 0.005 | ** |
| Time by Rate | 2 | 12192.85 | 6096.42 | 2.73 | 0.109 | NS |
| Regression | 1 | 15634.28 | 15634.28 | 7.01 | 0.023 | * |
| Error 1 | 11 | 24541.31 | 2231.03 | | | |
| Total | 17 | 79549.90 | | | | |

NS - Not significantly different at the 95% level of confidence.
* - Significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-14: Analysis of variance for number of aspen suckers.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 2.57 | 1.28 | 1.17 | 0.343 | NS |
| Rate | 1 | 0.00 | 0.00 | 0.00 | 0.955 | NS |
| Time by Rate | 2 | 0.50 | 0.25 | 0.23 | 0.799 | NS |
| Error 1 | 12 | 13.14 | 1.10 | 1.46 | 0.153 | NS |
| Error 2 | 90 | 67.31 | 0.75 | | | |
| Total | 107 | 83.52 | | | | |

NS - Not significantly different at the 95% level of confidence.

Appendix C-15: Analysis of variance for height of dominant aspen suckers.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 134.80 | 67.06 | 4.09 | 0.044 | * |
| Rate | 1 | 233.79 | 233.79 | 14.26 | 0.003 | ** |
| Time by Rate | 2 | 210.51 | 105.25 | 6.42 | 0.013 | * |
| Error 1 | 12 | 196.80 | 16.40 | 1.35 | 0.206 | NS |
| Error 2 | 90 | 1093.89 | 12.15 | | | |
| Total | 107 | 1869.79 | | | | |

NS - Not significantly different at the 95% level of confidence.
* - Significantly different at the 95% level of confidence.
** - Significantly different at the 99% level of confidence.

Appendix C-16: Results of Student-Newman-Keul's tests of significance for height of dominant aspen suckers.

| Time | Aug.25 | Jul.16 | Jul.16 | Aug.5 | Aug.5 | Aug.25 |
|---|---|---|---|---|---|---|
| Rate($kg.ha^{-1}$) | 0.5 | 0.5 | 0.0 | 0.5 | 0.0 | 0.0 |
| Mean (cm) | 1.19 | 4.53 | 6.23 | 7.09 | 7.42 | 8.01 |
| Significance | | --- | --- | --- | --- | |
| | | | --- | --- | --- | --- |

Appendix C-17: Analysis of variance for stem-foliage oven-dry weight of aspen suckers.

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Square | F Ratio | Significance of F | |
|---|---|---|---|---|---|---|
| Time | 2 | 0.37 | 0.18 | 1.98 | 0.18 | NS |
| Rate | 1 | 0.64 | 0.64 | 6.84 | 0.02 | * |
| Time by Rate | 2 | 0.82 | 0.41 | 4.38 | 0.04 | * |
| Error 1 | 12 | 1.12 | 0.09 | 1.62 | 0.10 | NS |
| Error 2 | 90 | 5.20 | 0.06 | | | |
| Total | 107 | 8.15 | | | | |

NS - Not significantly different at the 95% level of confidence
* - Significantly different at the 95% level of confidence

Appendix C-18: Results of Student-Newman-Keul's tests of significance for oven-dry weight of aspen suckers.

| Time | Aug.25 | Jul.16 | Jul.16 | Aug.5 | Aug.5 | Aug.25 |
|---|---|---|---|---|---|---|
| Rate($kg.ha^{-1}$) | 0.5 | 0.5 | 0.0 | 0.5 | 0.0 | 0.0 |
| Mean (g) | 0.24 | 0.44 | 0.53 | 0.57 | 0.58 | 0.63 |
| Significance | | --- | --- | --- | --- | --- |