POST LOGGING SUCCESSION AND VEGETATION MANAGEMENT WITH HEXAZINONE HERBICIDE IN *Picea glauca* (Moench) Voss - *Populus tremuloides* Michx. FOREST

by

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Abstract

The objectives were: to review the successional behaviour of white spruce (*Picea glauca* (Moench) Voss) - trembling aspen (*Populus tremuloides* Michx.) stands in the literature, to conduct field studies of the successional behaviour of planted white spruce in aspen stands, and to test hexazinone herbicide as a means of modifying the post-logging environment to release white spruce and other conifers.

Five and 13 year old white spruce plantations were selected for study. Fifty square random plots were established in each plantation. Total and mean aspen and white spruce volumes per plot were calculated. Each plantation was stratified into 3 components or "Situation Types" based on aspen density. Five plots were established at both plantations in each of these Types. These "Situation Plots" were circular and selected so that a white spruce tree was located at each plot centre. The central white spruce and the mean aspen tree on each "Situation Plot" were cut down for stem analysis. The number of frost damaged tips per m^2 crown area on each central white spruce tree were calculated.

The mean and total aspen volumes per plot are not related to the white spruce volumes per plot in either plantation. The current annual increment curves of the paired central white spruce and the mean aspen tree from each "Situation Plot" do not show any trends for the 5 year old plantation. Current annual volume increment curves from the 13 year old plantation show that a rapidly growing aspen tree will suppress its white spruce neighbour. The number of frost damaged tips per m^2 white spruce crown area significantly decreases as the number of aspen trees per plot increases at the 5 year old plantation. This relationship was not strong at the 13 year old plantation.

This information is used to make recommendations for releasing white spruce from trembling aspen competition with hexazinone herbicide.

Factorial herbicide trials were established in the field and greenhouse to evaluate the effect of hexazinone herbicide on white spruce and trembling aspen. Trials were also established to evaluate the effect of hexazinone on black spruce (*Picea mariana* (Mill.) B.S.P.), jack pine (*Pinus banksiana* Lamb.), willow (*Salix* spp.) and beaked hazel (*Corylus cornuta* Marsh.). Various hexazinone rates, forms, spacings and spray positions were tested. Hexazinone 'Gridball' pellets and hexazinone concentrated solution (DPX-LX or LE) were the herbicide forms used.

White spruce, black spruce and jack pine were found to be quite tolerant to hexazinone herbicide. Hexazinone did not reduce the survival or height growth of the white spruce significantly except in the greenhouse trial. Jack pine and black spruce were only significantly affected at the highest rates. In the greenhouse trial, the high hexazinone rates applied to the foliage and soil significantly reduced the survival and the foliage dry weight of both white spruce and jack pine. Most rates of hexazinone applied caused a significant reduction in height growth, survival and foliage dry weight of the aspen, willow and hazel.

These results suggest that hexazinone can be used effectively to control weed species in conifer plantations.

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INTRODUCTION

The objectives of this thesis are:

1. to review the successional behaviour of white spruce (*Picea glauca* (Moench) Voss)-trembling aspen (*Populus tremuloides* Michx.)stands in the Great Lakes-St. Lawrence and Boreal Forest Regions in the literature in order to gain an understanding of natural forest succession as a basis for plantation management,

2. to study the successional behaviour of planted white spruce that occurs during the first 13 years after logging in sucker origin trembling aspen stands of the B9 or Superior Section of the Boreal Forest Region (Rowe 1972),

3. to test hexazinone herbicide as a means of modifying the post-logging environment and releasing white spruce, black spruce (Picea mariana (Mill.) B.S.P.), and jack pine (Pinus banksiana Lamb.)from the aspen, willow (Salix spp.), and beaked hazel (Corylus cornuta Marsh.) competition that occurs after logging.

The normal post-wildfire succession of the spruce-aspen forest is modified in two ways: 1. by forest fire suppression and 2. by logging. Naturally, most spruce-aspen stands in the boreal forest are subject to wild-fire every 60 to 100 years (Day and Harvey 1980a). Through forest fire suppression timber that would normally be consumed by fire is available for harvesting.

The boreal forest is subject to the frequent occurrence of fire. Usually the tree species that were present before the fire return after the fire because of adaptations for survival after fire (Methven et al 1975). Logging drastically changes the species composition of the majority of post-logged forest cover types.

Commercial clearcutting is the most common logging system used in the spruce-aspen forest. Spruce and high quality veneer aspen are the more valuable species on today's market. Usually these species are logged leaving the unmerchantable aspen unutilized. Because of this, the spruce seed source is often severely reduced while, in contrast, the aspen seed source and suckers remain. Under normal conditions white spruce trees can be expected to disperse seed abundantly every 4 years for a distance of 100 metres (Fowells 1963). As some clearcuts inspected by the author in northwestern Ontario range up to 800 hectares in size, and as cutting is an annual event, it is obvious that spruce seed will be inadequate to regenerate such large clearcuts.

Natural regeneration of white spruce is best on bare mineral soil (Phelps 1951, LeBarron 1945) or decayed wood (Lees 1972, Day 1963a, Phelps 1948). The slash, duff and litter that are usually present on recently logged sites provide the most unfavorable seedbed for white spruce.

White spruce is normally tolerant to low levels of light, but because of its small size and slow growth during the first few years it is not able to compete with the dense growth of herbacious vegetation, shrubs and understory trees that remain in the absence of fire (Bedell 1948, Row 1955). Such dense and rapidly growing competition may be enough to completely exclude white spruce from a stand that was white spruce-aspen prior to logging.

After logging, aspen reproduces vegetatively by prolific suckering (MacLean 1960). During logging operations the forest stand is severely disturbed; surface litter is often removed and the dark mineral soil increases in temperature; parent aspen trees are often cut and therefore the apical dominance effect is lost. All of these factors contribute to abundant suckering of aspen (Jarvis 1968, Maini and Horton 1966 a and b).

Aspen grows very quickly and it will rapidly overtop and suppress any neighbouring white spruce trees. Aspen competes with white spruce in two ways: 1) Physiologically by reducing the amount of moisture and light available to the spruce and therefore causing diminished white spruce growth, and 2) mechanically by whipping the white spruce crown.

Various methods have been used to reduce aspen competition in white spruce-trembling aspen stands. Mechanical methods such as cutting, breaking or girdling the aspen suckers and prescribed burns in advance of planting have been attempted. Mechanical release treatments are often too expensive to apply in Canada. These treatments usually do not last very long as the aspen will rapidly re-sucker. Prescribed burning, after logging and before planting, may result in increased aspen suckering. It is a technique that requires a great deal of expertise.

Chemical release treatments have generally been used with more success than mechanical release treatments in spruce-aspen stands. Herbicide treatments tend to be quite effective. They are often much faster to apply, require less manpower and are therefore more economical and have longer lasting results than mechanical release treatments (Roe 1953). Chemical treatment prior to mechanical site preparation has also been used successfully.

Low volatile formulations of the phenoxy acetic acids were, until recently, the principal herbicides used in forestry (Romancier 1965 and Haagsma 1968). Herbicides such as 2,4-D and 2,4,5-T must be applied at quite high rates in order to be effective. These rates are often close to the detrimental rate for spruce and pine. The herbicide 2,4,5-T is no longer available for use in forestry since the Ontario Ministry of Natural Resources withdrew it from use in 1980. Controversy over the environmental effects of the phenoxy acetic acids may also result in 2,4-D being taken off the market.

Studies during the 1960's with fenuron were very promising for the control of woody plants (Sutton 1965a and b). Work with fenuron was discontinued in the late 1960's when the herbicide was no longer available from the Dupont

Chemical Company. The forestry market was not large enough to commercially warrant its production.

In the 1970's, none of the herbicides available for forestry even closely approximated the effectiveness of fenuron. Mathews (1970) worked with bromacil and karbutilate as possible substitutes for fenuron. These herbicides were all quite toxic to both white and black spruce seedlings and could not replace fenuron (Mathews 1970). This factor and the bleak future of the phenoxy acetic acids has stimulated interest in research for new herbicides.

Hexazinone is a new triazine herbicide, the chemical structure of hexazinone is shown in Figure 1. Although its mode of action is not clearly understood, it is thought to be a photosynthetic inhibitor that affects the dark release of oxygen (Weed Science Society of America 1979). Much research surrounding hexazinone has taken place in New Zealand and in the loblolly pine (*Pinus taeda* L.) plantations of the southern United States.

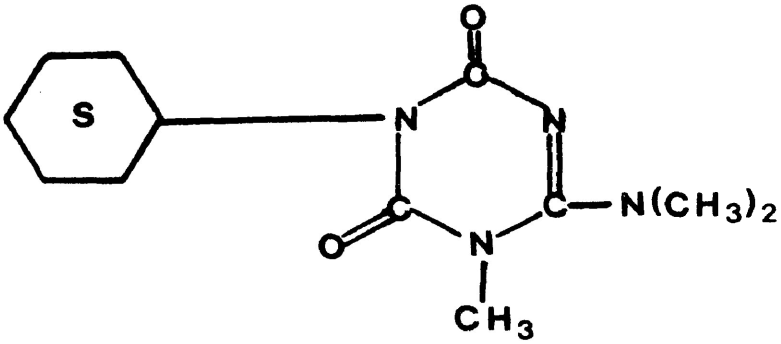


Figure 1. The chemical structure of hexazinone (3-Cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione).

Hexazinone can be applied as a foliar spray, in concentrated solution with a 'Spotton-gun', or in a pellet of 'Gridball' formulation. These different formulations make it possible to apply hexazinone non selectively in a grid pattern with 'Gridballs' or concentrated solution or broadcast as a foliage spray. It can also be applied selectively with 'Gridballs' or concentrated solution applied with a 'Spotton-gun' to individually release trees.

Studies using hexazinone herbicide to reduce competition with white spruce in the Boreal Forest Region were initiated in the Thunder Bay area during 1978 and 1979, (Polhill 1978, Dunsford 1979). These studies have shown that hexazinone is an effective herbicide for controlling aspen and in stands where aspen is providing competition to white spruce regeneration.

This thesis will provide initial information on the post logging succession in white spruce plantations. It also provides recommendations for vegetation management techniques with hexazinone herbicide. In addition to white spruce and trembling aspen, hexazinone trials were also conducted on black spruce, jack pine, willow, and beaked hazel as these species are also important components of the mixedwood forest. Knowledge about the release of white spruce from trembling aspen in the B9 or Superior Section of the Boreal Forest Region (Rowe 1972) should be enhanced by this thesis.

LITERATURE REVIEW

Autecology of White Spruce:

i)Germination and Establishment:

White spruce begins to produce seeds at approximately 30 years of age. Optimum seed production occurs when the trees are 60 years of age or older (Fowells 1965). Good seed crops are produced every 2 to 6 years, with light seed crops in the intervening years (Fowells 1965). Seedfall begins in late August or early Setember and may continue, to a limited extent, through the following winter (Roe 1946). If sufficient wind is available, mature trees can be expected to disperse seed in excess of 300 metres (Rowe 1955). Under calmer conditions, seed dispersal has been observed to be about 100 metres (Fowells 1965).

White spruce seed normally germinates during June, but low air temperature or inadequate moisture may delay germination until July or August (Waldron 1966). Temperature is of the greatest importance in the germination of white spruce seed. Holt (1955) found that white spruce seed will not germinate below or above certain critical temperature limits. White spruce seed will germinate between a minimum temperature of 7°C and a maximum temperature of 29°C (Mork 1938). Rowe (1953b) found a mean air temperature of 7°C during the week prior to white spruce seed germination. Germination began during the first half of July at a mean air temperature of 14°C and it stopped when the mean air temperature reached 12°C during the first week in September (Rowe 1953b). In overmature spruce stands in the foothills of Alberta, low soil temperatures reached beneath the organic layer provided an inhospitable rooting medium for both mature white spruce trees and seedlings (Endean 1972). At low temperatures, root growth is very slow. Endean (1972) feels that this is a major factor limiting regeneration success.

Moisture is often a limiting factor in spruce germination and survival. (Holt 1955 and Day 1963a). Day (1964) found that regeneration after logging is more abundant on moisture retentive seedbeds in moist and shaded microenvironments. The length of the growing season before the onset of drought appears to reduce mortality and this remains true as long as the rate of root extension exceeds the rate of surface drying (Day 1963). Phelps (1948) found that the number of days of drought sufficient to cause seedling mortality varied from 7 to 24. Day (1963b) suggests that abundant and well distributed precipitation is required to ensure good spruce germination on exposed seedbeds.

Insects, fungi, birds and animals may prevent white spruce germination by destroying the seed (Holt 1955).

The presence or absence of a receptive seedbed is a major constraint on the germination and establishment of white spruce. Bare mineral soil is a much better seedbed than the original duff surface of the natural forest floor (LeBarron 1945, Phelps 1951). When the seed makes contact with bare mineral soil during drier periods it can take advantage of water diffused to the soil surface from more moist subsurface soil layers. Duff, litter and moss are easily dried out; this could kill the newly germinating seedlings. The number of white spruce seedlings tends to decrease as litter depth increases (Phelps 1948). Holman (1927) found that a duff layer greater than 5 cm in depth inhibited spruce germination. A scarified seedbed was superior to both a mounded and undisturbed seedbed for spruce regeneration in Alberta (Lees 1963). Crossley (1955) found that baring the mineral soil to coniferous seedfall resulted in increased spruce stocking for 4 years, and the scarified seedbed remained more receptive to spruce germination than the unscarified control for 3 years. Remeasurement of this area in 1961 (Day 1963c) showed that although the seedbed treatment was initially promising, it was not a success. Spruce reproduction on the scarified areas was not significantly different from that on the unscarified controls. Day (1963c) suggests that poor response and growth of spruce regeneration was due to moisture deficiencies and lack of nutrients rather than vegetative competition. Phelps (1948) found that areas where the litter had been removed, either by raking or burning, were more favorable to the establishment and survival of white spruce seedlings than those where the litter had been undisturbed. Fifteen years after logging, regeneration on deep untreated moss was inadequate whereas all of the treated seedbeds (heavy burning, light burning, and stripping to mineral soil) produced satisfactory regeneration from natural seedfall (Parker 1952).

Decayed wood provides a satisfactory seedbed, especially in stands that have not been opened up by logging or fire. Phelps (1948) found that the majority of seedlings germinated on a substratum of rotten wood. Day (1963a) found that spruce germination was significantly better on decayed wood than on mineral soil. He suggests that decayed wood may have special physical or chemical properties that stimulate germination. A rotten log is receptive to conifer seed, conserves moisture and resists colonization of herbaceous vegetation (Lees 1972). Twenty to 30 years are required for wood to decay to the point suitable for spruce germination (Rowe 1955).

Seed size has no effect on either the germination or the survival rate of white spruce, although larger white spruce seeds tend to produce bigger seedlings (Burgar 1964).

White spruce is tolerant, but because of its small size during the first year, it is not able to compete with dense growth of herbacious vegetation, shrubs and understory trees (Bedell 1948, Rowe 1955). According to Phelps (1948), mortality among seedlings is greatest during the first three years after germination. Hall (1979) found that overall white spruce survival after planting was 75% with most of the mortality occuring during the first growing season. Waldron (1966) found that more than 60% of seedlings died before 4 years; survival was greater on disturbed than undisturbed seedbeds. Lees (1970) found that overwinter mortality of white spruce seedlings was greater than growing season mortality. Day (1964) suggests that shade reduces the growth rate of spruce seedlings and that microenvironments most suited to germination and survival may not be best for later developement.

Trenching experiments had no influence on white spruce germination and early survival (Griffith 1931, Ackerman 1957). This indicates that root competition of herbaceous vegetation and the residual stand is not initially an important factor in white spruce germination and initial seedling survival. Day (1970) suggests that root competition from the residual stand does reduce the survival of older seedlings.

Leaf litter has a varying effect on the germination and survival of white spruce. Aspen leaves are very efficient in conserving soil moisture and thus may have a beneficial effect on the germination of white spruce (Cayford and Waldron 1962). Gregory (1966) found that protection of young white spruce seedlings from birch leaf fall increased first year germination and survival and continued to significantly enhance survival through the first 4 growing seasons. Leathery leaves such as those of hard maple (_Acer saccharum_ Marsh.), oak (_Quercus_ spp.), and aspen do more harm than the thinner leaves of birch (_Betula papyrifera_ Marsh.) whose veination causes them to curl and dry (Koroleff 1954). Waldron (1963) found that the heavest period of white spruce seed dispersal preceeded the heaviest period of litter fall by over one month. This could have a significant effect on white spruce regeneration, especially on scarified areas, as more seed would likely come in contact with a favorable seedbed. In stands containing a substantial aspen component, it is possible that leaves flattened by winter snow would be a limiting factor in spruce germination (Waldron 1963).

ii) Growth and Development:

The current annual height increment for white spruce growing free from competition has been found to increase slowly for the first 14 years after planting and then level off (Hambly 1980). These results agree with those of Stiell (1976) who found that the current annual height increment for white spruce increased slowly for the first 10 years after planting and remained uniform from age 15 to 35 depending on site quality. Growth rates start to decline at about 35 years (Stiell and Berry 1973).

Young white spruce stands are very prone to frost damage. White spruce breaks dormancy around June 1, but heavy frosts often occur after this and damage the trees (Rowe 1955). White spruce flushes earlier than black spruce and is therefore more prone to frost damage (Fowells 1965). Spring frosts can cause white spruce to loose new growth, but other buds soon replace this loss (Argetsinger 1957). Cayford et al (1959) found that buds that were well advanced and showing green tips of foliage were often injured or killed by late spring frosts. They suggest that the amount of bud-killing is entirely dependent on the degree of bud swelling. Clements et al (1972) found that unopened buds of white spruce could be damaged by late spring frost even before the buds were ready for flushing. They also found that there was more damage among shorter trees than among taller trees. Sixty-seven per cent of the trees in a 6 year old white spruce plantation were affected (Clements et al 1972). There was more frost damage among open-grown trees than among understory trees (Clements et al 1972).

White spruce is classed as a tolerant species (Baker 1949). When white spruce grows with hardwoods established at the same time, it may fall behind and remain an understory tree (Cayford 1957). The height growth of white spruce seedlings is significantly affected by vegetative competition (Lees 1970). Spruce may become suppressed at an early age and , on stands up to 100 years of age, aspen suppression may reduce white spruce volume by 50% (Cayford 1957).

Rowe (1955) found that old white spruce trees develop extensive shallow root systems from which vertical sinkers descend into the lower soil (Rowe 1955). He suggests that this sometimes gives white spruce an advantage when competing against the deeper rooted hardwoods for moisture from the surface. Wagg (1967) suggests that white spruce will develop this type of root system only on soils with excessive moisture near the surface. He found that white spruce developed an elongated tap root on well-drained uniform textured soils and a restricted tap root on soils with either textural changes between horizons or with compact horizions. White spruce with this type of root system would likely be deeper rooted than hardwoods in the same stand.

In coniferous mixtures, white spruce will reach dominance with balsam fir and jack pine and it will eventually outgrow them. Stands of this type tend to regenerate to balsam fir (Fowells 1965).

Autecology of Trembling Aspen:

i)Germination, Suckering and Establishment:

Trembling aspen is a dioecious tree species with staminate and pistillate catkins usually born on separate trees (Maini 1968). Trembling aspen begins to produce flowers at about 15 years of age (Maini 1968). Flowers develop in April or May before foliation. Pollination is by wind and the fruits ripen in May or June, 4 to 6 weeks after flowering (Fowells 1965). Good seed crops are produced every second or third year (Maini 1968). Seed dispersal takes place a few days after ripening. The light seed can be carried for miles by air currents or else dispersed by water (Fowells 1965).

The establishment of trembling aspen seedlings in nature is rare and is restricted to moist freshly exposed mineral soil (Maini 1960). Horton and Maini (1964) found that when seedbeds were naturally provided with a very abundant quantity of trembling aspen seeds, neither severely nor lightly burned plots produced even a single germinant; the moister scalped plots produced a great many. For adequate aspen reproduction from seed to occur, a favorable seed bed, a good seed crop, and abundant soil moisture are required. This often happens when a fire exposes bare mineral soil during the spring of a good seed year (Zehngraff 1947). Maini (1960) found that the shortage of seedling origin trembling aspen stands in nature is due to: i) short seed viability, ii) presence of a water soluble germination and growth inhibitor in the seed hair, iii) occurrence of unfavorable moisture conditions during seed dispersal on upland sites that aspens usually inhabit, iv) susceptibility of seedlings to high temperatures that occur on soil surfaces blackened by fire, v) susceptibility of seedlings to fungal attack, vi) adverse influence of diurnal temperature fluctuations on initial seedling growth, and vii) unfavorable chemical nature of some substrates on which seedlings are likely to fall.

Usually the suckering of trembling aspen is so profuse that seedlings are excluded. Aspen root suckers grow from 1 to 2 metres per year for the first 5 years; this enables them to dominate the stand early and mechanically whip most competitors (Day and Harvey 1980a).

Asexual, rather than sexual, reproduction is a more important factor in aspen regeneration in the boreal forest. Trembling aspen survives the adverse conditions at the northern and southern limits of its range by asexual reproduction (Maini 1968). Aspen reproduction by formation of adventitious shoots on roots (or suckering) is a common phenomenon (Maini 1960). Maini and Horton (1966a) feel that warm temperature is the main envionmental factor stimulating aspen sucker formation. Maximum incidence and growth of suckers occurred at a temperature of 23°C and declined gradually below and above this temperature (Maini and Horton 1966a). Stenecker (1974a) suggests that the apical dominance of parent tree crowns primarily controls suckering, but that once this effect is broken increased soil temperature promote suckering. Root depth also influences sucker incidence. Most suckers develop from the shallowest portions of the soil, within 5 cm of ground surface or just beneath the organic soil horizions (Jarvis 1965). Suckers usually originate on shallow cordlike roots ranging from 0.5 to 5 cm in thickness (Maini 1960). This could also be a temperature effect as the shallowest portions of the soil horizon also have the highest temperature. Older aspen stands appear to lose the ability to sucker (Rowe 1955).

The abundance of aspen suckers has also been shown to be related to the degree of stand disturbance (Maini and Horton 1966a and 1966b, Jarvis 1968). When a forest stand is severely disturbed, much of the surface litter is removed and the dark mineral soil increases in temperature. Parent aspen trees are often cut and therefore lose apical dominance. For abundant and vigorous suckering, strong light and heat must reach the forest floor (Jarvis 1965).

Suckers originating on a single parent root system remain connected by parent roots even after they have developed their own root system. This connection remains alive until one of the trees dies (Maini 1960). Maini (1968) observed live root connections between two 65 year old aspen trees.

Aspen is very intolerant of shade and grows best under full sunlight (Maini 1968). Maini (1960) found that height growth of aspen suckers was initially faster than that of seedlings. This is thought to be due to the well developed root systems on which suckers originate (Maini 1960, Barnes 1966).

ii)Growth and Development:

Trembling aspen is a small to medium sized tree which, under good conditions, will reach 27 to 30 metres in height and 30 to 60 cm in diameter (Jarvis 1968). As aspen trees get older defect and decay become more prevalent and, for most aspen stands, the rotation age is a pathological rotation (Jarvis 1968). In eastern Canada and the Prairie Provinces, the rotation age for trembling aspen varies from 65 to 80 years (Jarvis 1968). In Ontario, the optimum rotation age for trembling aspen is 53 years (Plonski 1974). Volume growth will still increase substantially after this.

White Spruce-Trembling Aspen Succession and the Influence of Fire

The complicated relationships between white spruce and trembling aspen have been the subject of much dispute since the early twentieth century (Fetherolf 1917, Baker 1918). Fetherolf (1917) regarded aspen as a permanent forest type that occupies a particular ecological niche in the environment and can be replaced by no other species. Baker (1918) more correctly suggested that aspen is a temporary forest type occupying a transitory and subclimax stage in succession. Barnes (1966) feels that, although the aspen community is best classified as temporary in a successional sense, the permanent features of aspen clones should not be overlooked. The aerial parts of trembling aspen are transient, but a given clone can live almost indefinately as long as its root system endures and its suckering ability does not deteriorate (Barnes 1966).

Recent work on aspen spruce succession has shown that trembling aspen either re-suckers or re-seeds abundantly after wildfire. White spruce regenerates less successfully than aspen after wildfires. Because of its rapid early growth, trembling aspen usually dominates white spruce forming a stratified mixture (Day and Harvey 1980a). Highly productive monoculture populations are maintained near the starting point of succession (Dix and Swan 1971). The spruce-aspen forest is not static. It exists in a state of dynamic change, constantly developing, aging and renewing (Rowe 1961).

Many boreal species are adapted to repetitive disturbances of which wildfire is the most important and windthrow least. The outcomes from these disturbances differ from those in more stable environments (Shafi and Yarranton 1973a). In the boreal forest, the evolutionary pressure is probably frequent fire re-occurrence. Most species are perennial, capable of rapid vegetative reproduction and either possess underground reproductive organs or adaptations effective in rapid postfire establishment (Shafi and Yarranton 1973b). Aspen is a good example of a species that, due to rapid asexual reproduction has a tremendous capacity to colonize burns (Jarvis 1965).

White spruce is able to retain a small proportion of the annual seed crop in cones which persist for the better part of a year (Roe 1946, Rowe 1953b). Unless a fire totally destroys the upper part of the tree, these seeds may survive and regenerate the area. Fire may also serve as the stimulus needed to release this seed still held in the cone (Rowe 1953b). This characteristic of white spruce is an adaptation that could help it survive in an ecosystem dominated by fire.

Invariably, the same dominant tree species that were present prior to a fire return immediately after the fire. This implies that cycling by fire rather than by succession is the basic mechanism for renewal in the boreal forest (Methven et al 1975). In northeastern Minnisota, Ohman et al (1973) found that the time elapsed since the last major disturbance, and the type of vegetation present at the time of that disturbance, were important in determining the composition and the structure of present upland communities.

When natural catastrophes are prevented, the spruce-aspen forest eventually becomes decadent (Rowe 1961). Balsam fir (Abies balsamea (L.) Mill.) is a successful invader of the Lake States aspen-birch-fir-spruce communities (Heinselman 1954, Buell and Niering 1957, MacLean 1960). Because of efficient fire suppression techniques, the poplar forests of Quetico Provincial Park in Ontario are developing into decadent stands and they are being invaded by tolerant species such as red maple (Acer rubrum L.) and balsam fir (Woods and Day 1977). Effective fire suppression in the boreal forest of Sweden over the past two centuries has eliminated fire as a rejuvenating factor in the forests of that country (Zackresson 1977).

Rowe and Scotter (1973) suggest that, without fire, the forest becomes more and more homogeneous; the long-lived white spruce replaces pine, aspen, balsam poplar (Populus balsamifera L.) and birch. Results of other studies do not agree with this. Day and Harvey (1980a) found that the forest becomes less homogeneous as the time since the last wildfire increases. On Isle Royale, fir is a very prominent species and it is suggested that, in the absence of fire, it will maintain a dominate role and white spruce reproduction will become scanty (Heinselman 1973). White spruce has difficulty reproducing on an undisturbed forest floor (MacLean 1960). Observations in the uplands of the lower

Mackenzie River Valley, N.W.T., suggest that the open spruce forest eventually dies out if fire is excluded to be replaced by an almost tundra-like condition; white spruce seedlings are not able to germinate on the dense lichen mat that develops in these areas in the absence of fire (Strang 1972).

Conifer reinvasion after a fire depends on site characteristics, intensity of the burn, and chance factors that determine which species becomes established on the site (Severson and Thilenius 1976). Fire may favor white spruce regeneration by modifying the seedbed (Wagg 1964). Holt (1955) found that fire caused a decrease in litter depth, humus depth, root competition and shade by other vegetation; it caused an increase in soil moisture supply and soil temperature. All of these factors aid in white spruce regeneration, but as the texture and depth of the humus layer increased, the beneficial effects of burning decreases (Holt 1955). Ackerman (1957), on the other hand, found that the removal of organic matter by burning had an adverse effect upon spruce germination and survival. In the Alberta foothills, prescribed burning at economic and safe levels did not produce a significant reduction in the organic layor or a large increase in the soil temperature on the site tested (Endean and Johnstone 1974).

On burned ground, in an open cut-over stand, the period of maximum white spruce germination was delayed at least 1 1/2 months (Rowe 1952). This is likely a moisture deficiency effect. Reeder and Jurgensen (1979) found that fire induced water repellency in the forest soils of upper Michigan especially those soils with white pine (Pinus strobus L.), red pine (Pinus resinosa Ait.) and trembling aspen litter. The nonwettable properties of these soils generally decreased rapidly over time (Reeder and Jurgensen 1979).

The effect of fire on the vegetative reproduction of aspen is complicated. In general, the abundance of aspen suckers increases if the area is burned (Maini and Horton 1966b). Conversely, a very intense burn could kill the aspen roots and thus be used as a means of controlling aspen suckers. In practise, this is an inefficient method of controlling aspen suckering as it is difficult to maintain the intense burning and persistent smouldering necessary to kill the shallow aspen roots that have the potential to sucker (Horton and Maini 1964, Horton and Hopkins 1965). Schier and Campbell (1978) found that a high burn intensity increased the depth at which suckers were initiated, possibly because of increased soil temperature and killing of the roots near the soil surface. According to Shirley (1931 and 1932) light burning stimulates aspen suckering by the increased heat absorption of the blackened soil surface. A prescribed burn during the first dormant season following logging can be used to promote poplar regeneration (Perala 1974a); two or more prescribed burns in the spring of the year before growth begins reduce the abundance of suckering by aspen and can be used to eliminate aspen from an area (Buckman and Blankenship 1965).

Post Logging Spruce-Aspen Succession

Clear felling of trees results in rapid decomposition of litter on the forest floor; the surface and topsoil layers begin to mineralize and severe erosion may occur on steep slopes (Zhukov 1976). According to Wright (1976), many of the effects of a clear cut are similar to those of a fire except that while only a small fraction of the nutrient capital of the forest is lost during a forest fire, logging can severely deplete the available nutrient supply. This would likely only be true in complete biomass harvesting. Traditional harvesting methods leave large amounts of residue wood and slash behind.

Logging often reduces the chances of effective spruce regeneration by opening the canopy and allowing prolific growth of herbs and shrubs. This increases the competition of the forest floor. On the Peace and Slave River lowlands, lesser vegetation became more luxuriant with each succeeding year following logging; shrubs provided complete coverage after five years resulting in unfavorable seedbed conditions for spruce regeneration (Wagg 1964). Old trees which would have decayed to provide seedbeds are removed during logging operations and the ground is scarified only along haul trails (Rowe 1955). Surveys showed that, after normal logging operations in Manitoba, white spruce regeneration was not sufficient to provide for future well-stocked stands (Haig 1962). Haig 1962 modified the seed supply by clearcutting in strips and by shelterwood cutting; he modified the seedbed conditions by site preparing with the Athens plough and with a bulldozer blade. Excellent regeneration was obtained in these treated areas.

Holt (1955) found that cutover areas "matured" after 10 years, when the humus layer suddenly began to shrink away and spruce started geminating on the area. Spruce regeneration is still very poor on cutover areas however. Pogue (1946) found that in British Columbia, white spruce restocking will not satisfy the barest minimum requirements even 120 years after cutting.

After a cutover, aspen sprouts prolifically (MacLean 1960). Vegetative reproduction of aspen is most vigorous the first year following clearcut (Horton and Maini 1964). Some studies show that a greater number of suckers are produced if logging is done during the dormant season (Stoeckler and Macon 1956). In other experiments, more suckers were produced after summer logging (Maini and Horton 1966b, Bella and DeFranceschi 1972). Regardless of cutting season, initial differences in numbers of suckers diminsh with age and practically disappear by six years of age (Bella and DeFranceschi 1972). Suckering is generally poor on areas where dense ground vegetation or slash exist at the time of cutting (Maini and Horton 1966a and 1966b, Bella and DeFranceschi 1972). Complete cleacutting appears to produce the most abundant sprout regeneration of aspen (Stoeckler and Macon 1956, Schier and Smith 1979).

Silviculture in Post-Logged White Spruce-Aspen Forests

i)White Spruce Plantations - Their Establishment and Performance:

The survival and later growth of young white spruce plantations is best on areas that have received some form of site preparation treatment. Stiell (1958) suggested that white spruce should be planted in furrows. He found that white spruce seedling survival was best when the trees were planted in open ploughed furrows, possibly because of the removal of ground competition and better soil-moisture relationships (Stiell 1955). Waldron (1964) found that white spruce transplants suffered the highest mortality on undisturbed plots and the lowest on scalped plots. This reflected the intensity of vegetative competition on the plots. The undisturbed plots had the greatest vegetative competition and the scalped plots the least. Ten years after planting, white spruce transplant survival remained highest on the scalped plots (Waldron 1964). Dobbs (1976) found that both white spruce seedlings and transplants grew better on scarified plots than on unscarified plots. Mullin (1973) found that post-planting cultivation during the first and second year after planting of old field white spruce plantations more than doubled the survival rate over that of the control plantations which had been cultivated only once prior to planting.

Generally, large white spruce nursery stock tend to survive and grow better than small white spruce nursery stock (Dobbs 1976). Brace (1964) found that white spruce nursery stock greater than 15 cm in height grew better than white spruce nursery stock less than 15 cm in height.In contrast, Waldron (1964) found that 2+3 white spruce nursery stock had greater mortality during the first year after planting than 2+2 white spruce nursery stock on plots which had been disced and scalped. Possibly the removal of the protective plant cover from around these large transplants resulted in increased evapotranspiration stress. The smaller transplants were better able to withstand this stress (Waldron 1964).

White spruce transplants tend to have higher survival and better growth rates than white spruce seedlings (Mullin 1966). Mullin (1975) found that, 5 years after planting, 2+2 white spruce transplants were growing well while 2+0 white spruce seedlings were still growing poorly. Seedlings at the 2+0 stage are less efficient than transplants in overcoming competing herbacious vegetation (Stiell 1955). Hall (1979) found that white spruce seedlings which were grown for 1 or 2 seasons in transplant beds grew better than those which grew only in seedbeds and these larger seedlings maintained their height advantage over the small ones in the plantation 5 years after planting.

When Dobbs (1976) compared different sizes of white spruce nursery stock grown on scarified and unscarified plots, he found that large stock on untreated plots outperformed small stock on treated plots. This could possibly indicate a potential "trade-off" in certain situations between nursery stock size and site preparation.

The method of planting tends to have a varying influence on the growth and development of white spruce plantations. Brace (1964) experimented with 3 planting methods. In the first two methods the seedling roots were placed in a horizontal plane close to the soil surface. The third method was the conventional wedge method that places the roots vertically. After 9 growing seasons, there were no significant differences in the survival and growth of white spruce due to planting method (Brace 1964). Mullin (1966) experimented with the wedge, slit, cone and T methods of planting. He found that the T method resulted in the lowest survival. The cone method showed no benefit in terms of survival or growth and he suggested that it be disgarded because of its greater cost. Of the two more standard methods, the wedge gave higher survival rates and better growth than the slit method (Mullin 1966b). He found that competition of other plant species on the site had much more influence than planting method on the growth of the plantation.

Improper planting with any method can result in a great deal of mortality in young white spruce plantations. Lyons (1925) suggested that a tree that is improperly planted is started into its plantation life seriously handicapped.

Stiell (1958) found that poor planting was a major problem in many plantations. Seedling mortality during the first few years can often be attributed to poor planting (Stiell 1955). Hughes (1978) found that mortality in white spruce plantations during the first year after planting could be mainly attributed to poor quality seedlings and planting methods.

The greatest mortality of white spruce plantations occurs during the first 4 years after planting (Stiell 1958). One of the most important reasons for this early mortality is vegetative competition. Stiell (1955 and 1958) found that dense grass, young aspen and birch suckers and sprouts from intolerant hardwoods resulted in considerable young white spruce mortality. Mullin (1969), in a greenhouse trial, found that competition from black spruce, grass and hard maple reduced the growth of white spruce at all levels of moisture tested. Stiell (1958) found that while dense grass, herbacious vegetation and scattered brush may cause initial seedling mortality, if the seedlings survive later growth is not reduced. White spruce growth is reduced when seedlings are planted under full overhead cover such as tall bracken fern, dense brush, suckers or a closed hardwood canopy (Stiell 1958). Early invasion by hardwoods did not decrease height growth, but did decrease diameter growth (Stiell 1958). Cunningham (1953) found that white spruce plantations at Grand "Mere" Quebec planted between 1924 and 1932 were unable to compete with volunteer red maple, balsam fir, white birch and aspen. He felt that these stands were no longer valuable as a pulpwood crop (Cunningham 1953). Stiell (1958) suggested that cover which provides side shade to white spruce but does not check height growth may have an early protective value on exposed sites.

White spruce mortality in older plantations can result from mutual competition. Stiell (1955) feels that this is usually not important until the plantation is 30 years of age or older. Mortality from mutual competition is a factor of stocking level and height (Stiell 1976). Mortality will begin in a plantation established at 1.2 x 1.2 m spacing before the stand is 6 m. tall, but not until the height is 12 m. if the initial spacing is 2.4 x 2.4 m. (Stiell 1976). Subordinant white spruce trees are tolerant however, and they can survive long after the crown has closed in over them (Stiell 1955).

Another important reason for early white spruce plantation mortality is poor soil and moisture conditions (Stiell 1958). Stiell (1958) found that white spruce plantations usually take twice as long to reach merchantable size on coarse shallow soils than on soils with adequate moisture. White spruce plantations grow best on moist tills of loamy sand and sandy loam, moist lacustrine silt loams with silt and clay bands, fresh interbanded windblown and waterlain sandy loam and fine sand (Stiell 1955). Fresh and moist sites were generally most favourable to white spruce, but the more moist the site the greater the tendency for suppression and mortality from invading alders and hardwoods before the spruce was well established (Stiell 1955). In a greenhouse study, Mullin (1969) found that the best growth of white spruce was achieved at the highest moisture level, in which the pots were cyclically raised to a drip-point twice weekly and permitted to dry by evapotranspiration between water additions. Gagnon (1961) found that, in a 31 year old plantation, mean annual ring width was closely related to the mean monthly precipitation during June, July and August of the preceeding year. This relationship was evident for the past 18 years (Gagnon 1961).

Mortality in young white spuce plantations can also result from drought, frost heaving, exposure, late season planting with active stock or planting with poor or overgrown stock and browse by wild animals (Stiell 1958). Frost damage can cause a reduction in growth rate especially in depressions and on level ground between slopes (Stiell 1955). This damage ceases with full crown closure of the stand (Stiell 1955).

Initial growth of young white spruce plantations is very variable (Stiell 1958). Perhaps this is due to the varying capacity of growth of individuals in an average lot of stock (Stiell 1955). Generally, white spruce plantations grow very slowly during the first few years after planting. Seedlings often take several years after planting to assume a rapid or even a reasonable rate of height growth (Stiell 1976). This early period of minimal height growth, if prolonged, is often described as growth check. Mullin (1964) found that growth check reduced the leader length of white spruce by about 50% the first year after outplanting. He suggested that growth check is mainly due to competition from other species on the site (Mullin 1966b).

Stiell and Berry (1973) found that the time required for planted white spruce trees to reach breast height varied from 6 to 12 years in white spruce plantations at the Petawawa Forest Experiment Station. This was independant of site. As it is difficult to predict early growth rates, site index curves for planted white spruce cannot be reliably extended below about 15 years (Stiell 1976). Hambley (1980) found that current annual height increment for planted white spruce in northern Ontario leveled off at age 15 years to an average of 32 cm/year. Height growth starts to decline between 25 and 35 years (Stiell 1976). At the Petawawa Forest Experiment Station, white spruce plantations, dominant height growth between 45 to 50 years was still about 30 cm/year on the best sites (Stiell and Berry 1973).

ii) Stand Conversion:

The effect of site quality may be important in the development of defects in second growth aspen stands (Kemperman et al 1976). When aspen is growing on poor sites, conversion to other species is the only sound and economical long term approach (Bissinger 1965). Stoeckler (1948) suggests that conversion planting should be concentrated on the coarser textured soils which do not reproduce as rapidly or easily to more valuable species.

A shelterwood system is superior to a seed tree system in the mixedwood forest for securing white spruce regeneration after logging. Lees (1970) found that scarification under a spruce-aspen shelterwood provided a receptive seedbed and the residual stand provided an adequate natural seed supply for white spruce regeneration . By removing 30% of the commercial basal area in a uniform shlterwood felling, Day (1970) found that both the abundance and growth of spruce seedlings and fir were significantly increased. A shelterwood system provides abundant seed and adequate environments for white spruce germination and growth that are not subject to excessive heating and drying.

Waldron (1961) found that seeding white spruce in scalps at the base of aspen resulted in higher germination than seeding white spruce in either the humus layer or in moss and in higher survival than seeding in scalps between the aspen trees. He suggests that planting 2+0 nursery stock in scalps at the base of aspen might be a useful method of introducing white spruce into aspen stands. The cost would be less than that of planting between the aspen with larger stock and seedling mortality resulting from burial by leaf litter would be less than that if the scalps were seeded.

iii)Mechanical Release of White Spruce from Aspen Competition:

As aspen grows much more rapidly than white spruce, young suckers may quickly overtop white spruce seedlings of the same age. The aspen overstory has a very detrimental effect on the growth and productivity of the white spruce beneath (Lees 1970). In todays market, white spruce is a more valuable species than trembling aspen therefore silvicultural practices are usually aimed at encouraging white spruce reproduction and growth.

White spruce will respond to release at advanced stages, but most benefit will be realized early in life (Stenecker 1963). Lees (1966) found that the greatest response to release occurred in the 20 to 40 year age class. Thompson (1949) found that 20 to 30 year old white spruce and balsam fir showed considerably more diameter growth when released from competing white birch, red maple (*Acer rubrum* L.), and yellow birch (*Betula alleghaniensis* Britton). When overtopping hardwoods were removed from a 45 year old mixedwood stand, Daly (1950) found that diameter and volume growth of the conifers was stimulated. White spruce in the 70 to 80 year age class is too old to significantly respond to release (Stenecker 1974b). The recuperative powers of young spruce are usually not affected by competition from aspen and, given an opportunity, spruce will respond favorably to release (Ontkean and Smithers 1959). Johnstone (1978) found that the first 5 years after logging, residual white spruce trees experienced a delayed release in volume and diameter increment and a decline in height increment. This indicates that the trees are unable to benefit from the decreased competition until their crowns have expanded (Johnstone 1978).

Various methods have been used to reduce aspen competition in white spruce-trembling aspen stands. Plice and Hedden (1931) found girdling to be quite effective in releasing spruce from an overstory of aspen and other hardwoods. Clarke (1940) recorded rapid increases in conifer diameter growth after hardwoods in the stand were girdled. Girdling appears to be a good method of eliminating aspen competition from a site (Schier and Smith 1979).

Buckman and Blankenship (1965) suggest that prescribed burns, prior to planting or seeding white spruce, can be used to remove aspen competition. Kill (1970) found that while a spring prescribed burn did initially remove the aspen and other hardwoods in a spruce-aspen stand, vigorous sucker growth and abundant herbaceous vegetation in the following years created an unfavorable seedbed for the establishment of spruce seedlings. Perala (1974b) found that infrequent burning weather, low flammability of aspen, and prolific aspen suckering made prescribed burning a poor tool to convert a good aspen site to conifers.

Problems do exist with these various mechanical release treatments and prescribed burning. Mechanical release treatments are often too expensive to apply in Canada and they do not last very long because the aspen will rapidly re-sucker. Prescribed burning requires a great deal of expertise and serious accidents can occur if proper precautions are not taken.

iv) Chemical Release of White Spruce from Aspen Competition:

Herbicides have been used in an attempt to release white spruce from trembling aspen in spruce-aspen stands. Herbicide treatments tend to be quite effective. They are often much faster, have longer lasting results and are more efficient than mechanical release treatments (Roe 1953).

Chemical control of undesirable forest vegetation is often regarded as a fairly recent post-war tool, but herbicides have been used since the late 1920's to control woody plants in the Lake States. Sodium arsenite, other arsenicals, sodium chlorate, ammonium thiocyanate and 27% diesal oils are some of the older herbicides that proved to be reasonably effective (Rudolf and Watt 1956). These materials were either expensive in the quantities needed, or hazardous to use (Roe 1953, Rudolph and Watt 1956).

Since World War II, many new herbicides have been developed. Low volatile formulations of the phenoxy acids were, until recently, the principal herbicides used in forestry (Romancier 1965, Haagsma 1968). These herbicides are effective in many, but not all, forestry situations. Light foliar applications of 2,4-D and 2,4,5-T ester sprays will damage the new growth of most conifers (Arend 1965). The herbicide 2,4,5-T is effective against a much broader spectrum of species than 2,4-D (Sutton 1969). Aerial spraying of 2,4-D has been found to be quite effective in killing overmature trembling aspen (Pratt 1966), but 2,4,5-T is generally more toxic to this species (Roe 1953). MCPA is another phenoxy herbicide; it is more effective than 2,4,5-T on some species and less effective on others (Roe 1953). Since 1980, 2,4,5-T has not been licensed for use in forestry in Canada. Controversy over the environmental effects of the phenoxy herbicides may also result in the removal of 2,4-D for forestry use.

Dinitro herbicides have been used for brush control (Roe 1953). These herbicides kill leaves quickly, but their action is less residual than that of the phenoxy herbicides and their use is followed by considerable resprouting (Roe 1953). The dinitro herbicides have a high mammalian toxicity, leave a permanent stain on clothing and skin, and are inflammable under certain conditions (Roe 1953).

Quaite (1953) used ammonium sulfamate to eliminate aspen. This chemical is non selective and will kill desirable species as well as undesirable species (Roe 1953). It is also costly to use due to the large amounts that are needed to produce the desired results (Roe 1953). Ammonium sulphamate is highly corrosive with hygroscopic crystals (Weed Science Society of America 1979). This makes both storage and handling of the chemical extremely difficult.

Site preparation with paraquat and simazine resulted in continuing significant increases in height growth for planted white spruce three years after initial weed control treatments (Sutton 1975 a and b). Weed control significantly conserved soil moisture and gave highly significant increases in foliage nutrient concentrations (Sutton 1975 a and b). The fertility effect, rather than soil moisture conservation, was the principal cause for increases in white spruce height incement.

Results of studies during the 1960's with pelleted fenuron were very promising for the control of woody plants. Sutton (1965a) found that fenuron could be used to rehabilitate overmature mixedwood by underplanting groups of white spruce in herbicide treated plots. After a 10 year interval, it may be necessary to again release these trees from competition (Sutton 1974). Fenuron was safely applied at planting time to vegetation competing with white spruce (Sutton 1965b). Fenuron was also used non-selectively in a grid pattern to control both conifers and hardwoods; it could be applied selectively to release conifers from hardwood competition (Sutton 1967). Work with fenuron was discontinued in the late 1960's when the herbicide was no longer available from the Dupont Chemical Company.

Mathews (1970) worked with bromacil and karbutilate as possible substitutes for fenuron. These herbicides were all quite toxic to both white and black spruce seedlings and were not acceptable replacements for fenuron.

Glyphosate is a new herbicide that shows some potential for use in forestry. Noste and Phipps (1978) found that white spruce seedling survival and diameter were greater on plots treated with glyphosate to reduce competition. The results of Blackmore and Corns (1979) do not concur with this. They found that white spruce growth was depressed in glyphosate treated strips. Polhill (1978) found that glyphosate applied at 3.3 kg ai/ha caused minor damage to approximately 25% of the white spruce shoots the year following herbicide application. Sutton (1978) found that glyphosate was highly effective in killing trembling aspen, white birch and beaked hazel; pin cherry (*Prunus pensylvanica* L. f.) resprouted with moderate vigor. Mean second year white spruce height increment was greater in the glyphosate than in the non-herbicide treated plots (Sutton 1978).

The use of Hexazinone Herbicide in Forestry

During the 1970's none of the herbicides available for forestry closely approximated the effectiveness of fenuron. This factor and controversy about the environmental effects of the phenoxy acetic acids in forestry have stimulated interest in research on new herbicides.

Hexazione is a new triazine herbicide. Although its mode of action is not clearly understood, it is thought to be a photosynthetic inhibitor that affects the dark release of oxygen (Weed Science Society of America 1979). Hexazinone can be applied as a foliar spray, in concentrated solution with a 'spotton-gun' or in pelleted formulation.

Much research about hexazinone has taken place in New Zealand in _Pinus radiata_ D. Don plantations (Bowers and Porter 1975 and 1977, Coackly and Moor 1977). Radiata pine is tolerant to hexazinone applied as foliage spray, up to rates of 7.2 kg ai/ha, but this tolerance decreases during the period of maximum spring flush (Bowers and Porter 1975 and 1977). The best control of grasses, bracken, wattle and broom is obtained when hexazinone is applied as a foliage spray during the period of active weed growth (Coackly and Moor 1977).

Hexazinone has been used in the loblolly pine plantations of the southern states (South et al 1976, O'Laughlin et al 1976, Nelson et al 1977, Fitzgerald and

Fortson 1977, Turner 1979, Parker 1979, Newbold 1979, Hamilton 1979, Dudley and Nelson 1979). Hexazinone applied as a post emergent foliar spray has been found to be toxic to young loblolly pine at rates as low as 0.56 kg ai/ha (South et al 1976). Nelson et al (1977) found that hexazinone applied as a pre-emergent herbicide treatment at rates of 0.56 kg ai/ha and 1.12 kg ai/ha provided adequate weed control without damaging young loblolly pine seedlings. O'Laughlin et at (1976) found that hexazinone was highly effective as a foliar treatment, but that dosages should not exceed 1.12 to 2.24 kg ai/ha. These discrepancies between suitable herbicide application rates are likely due to variation in site conditions. Herbicide applications should be made during the late summer otherwise considerable pine mortality will occur (O'Laughlin et al 1976). Activated charcoal root coatings of pine seedlings will absorb hexazinone and reduce pine phytotoxicity (Fitzgerald and Fortson 1979).

In North Carolina, aerial applications of hexazinone at rates from 1.1 to 3.4 kg ai/ha resulted in good to moderate weed control on 307 out of 355 hectares (Dudley and Nelson 1979).

Hexazinone can be selectively applied with pellet formulations to avoid crop species and control the competing species. Hexazinone as 10% active ingredient pellets applied in a circular band 1 metre away from the bole of red (Quercus falcata Michx.) and post (Quercus stellata Wangenh.) oaks at a rate of 0.42 g.ai./2.5 cm. diameter resulted in 89% defoliation 18 weeks after treatment. When hexazinone pellets were placed approximately 1 metre away from loblolly pine seedlings, no phytotoxicity was observed (Parker 1979). Hamilton (1979) found that, on sandy soils hexazinone "Gridballs" applied at rates of 5.6 to 11.2 kg.ai./ha provided adequate control to susceptible species; on heavy clays and poorly drained soils, 22.4 kg ai/ ha provided adequate control. Invariably, dead pines were affected by a "Gridball" which fell within 0.31 metres of the pine's root collar (Hamilton 1979). According to Turner (1979), 6.0 to 22.4 kg.ai/ha hexazinone "Gridball" formulation will provide satisfactory control of most hardwoods for both site preparation and pine release. Spot treatment of hexazinone followed by a prescribed burn can be used for site preparation, and hexazinone also effectively kills weeds in southern pine stands (Newbold 1979).

In northern England and Scotland, weed control with hexazinone applied as a foliage spray in April and May resulted in better height increment in spruce and pine than hexazinone applied at other times of the year (Jones 1978). This suggests that competition should be removed before the conifers flush (Jones et al. 1980). March and May applications of hexazinone at rates of 1.5 to 1.8 kg ai/ha provide better control of both grasses and broadleaved weeds than August applications (Jones et al 1980). Spruce should not be treated with the herbicide until the new growth has hardened off (Jones 1978), but pines are tolerant to hexazinone rates of 3.6 kh ai/ha applied during the flushing period (Jones et al 1980). As hexazinone is little affected by high soil organic matter, it could be useful on sites of second cropping where there is a lot of surface litter (Jones 1978, Jones et al 1980).

In Arkansas, hexazinone was found to control hickories (Carya spp.) and white oak (Quercus alba L.) very effectively when it was applied as an injection (Kossuth et. al. 1978).

Mature red pine (Pinus resinosa Ait.) is quire tolerant to hexazinone, but the tolerance range on newly planted seedlings is small (Wiltrout and Holt 1978).

Studies using hexazinone herbicide for woody brush control and to control competion with white spruce were initiated in the boreal forest in 1978 and 1979 (Polhill 1978, Dunsford 1979). Hexazinone applied at rates of 1.2 and 2.4 kg ai/ha, is an effective herbicide for controlling aspen on recent cutovers that have regenerated to aspen brush, and in stands where aspen is providing competion to white spruce regeneration (Dunsford 1979). Hexazinone pellets, if placed in proper configiration to avoid white spruce roots, could be very effective in controlling competition in spruce plantations (Polhill 1978).

SECTION I

THE POST LOGGING SUCCESSIONAL BEHAVIOUR OF PLANTED WHITE SPRUCE IN SUCKER ORIGIN TREMBLING ASPEN STANDS.

In order to properly manage forest stands, it is important to understand the dynamic relationships that exist between the crop trees and their competitors. This section provides an investigation on post logging succession in two young white spruce plantations of different age classes.

Methods

i. Study Areas:

White spruce plantations of two age classes, young sapling (5 years), and young pole (13 years) with heavy aspen competition were chosen for study. These plantations are located north of Thunder Bay in the B9 or Superior Section of the Boreal Forest Region (Rowe 1972) and in Site Region 3W (Hills 1961).

Plantation 1 is located approximately 65 kilometres north of Thunder Bay on Highway 800 close to the junction of the Wolf River Rd. at $49^{0}45'$ N lat. and $89^{0}00'$ W long

(Appendix (App.) A, Figure A1). The area was cut over in 1966. It was site prepared with a light prescribed burn and planted to white spruce in 1967. The area has since become infested with brush and weed trees, primarily aspen, which are competing with the white spruce crop. Many of the white spruce are suffering from severe frost damage. The site is gently rolling and is a very shallow sandy loam till over bedrock, typical of the ground moraine deposits in the region (Zoltai 1965). The hillocks are probably drought prone in dry growing seasons. Sphagnum spp. growing from overmoist depressions in the bedrock will trap and hold moisture in the hollows during wet seasons.

Plantation 2 is located approximately 25 kilometres from the junction of Highway 800 along the Wolf River Rd., close to Anders Lake at $49^{o}00'$ N lat. and $89^{o}15'$ W long (App. A, Figure A2). The area was cut over during the winters of 1972, 1973, and 1974. It was site prepared with barrels and planted to white spruce in 1975. The area has since become heavily infested with brush and weed trees, primarily aspen, which are competing with the white spruce crop. Some of the white spruce are suffering from frost damage. The site is a shallow sandy loam till over bedrock that is well aerated and is dry to fresh all year.

ii. Stand Description Plots:

In both plantations, fifty square plots were randomly located. The size of the plot was varied depending on the size of the trees as described on page 55 under 'Situation Plots'. Larger trees exert a competitive influence over a larger area than smaller trees. In Plantation 1, the plot size chosen was 8m x 8m (area = $64m^2$). In Plantation 2, the plot size chosen was 3m x 3m (area = $9m^2$). This would compensate for the reduced number of large aspen stems per hectare in the older plantation.

A modification of the Christian and Perry (1953) type classification (Day 1968) was used to describe the vegetation on each plot. The vegetation was classified as follows.

1. It was divided into three layers, T, S and F where T= Tree Layer, S=Shrub Layer and F=Field Layer. For example, T^6 would mean a Tree Layer averaging 6 metres in height.

2. The percentage area covered by the foliage of each layer was estimated and recorded. For example, $S^{0.5}20$ indicates a Shrub Layer of 0.5 metres in height that has a foliage surface covering of 20% of the area.

3. The standard tree symbols developed by Day (1967) were used to describe the 2 major species present in the Tree and Field Layers and the 3 major species present in the Shrub Layer. For example, $T^{15}_{POt}10$ indicates a Tree Layer composed of 15 metre aspen that has a foliage surface covering 10% of the area.

This information was used to construct diagrams of the plantations to schematically depict conditions on plots with high, medium and low tree density.

On each plot the following list of measurements were taken of the aspen and the white spruce.

1. Diameter: The diameter above butt swell (5% of the total height up to 4 metres) was measured. The trees were tallied according to 1 cm diameter classes .

2. Height: The heights of 3 randomly selected trees of each 1 cm diameter class were measured.

3. Density and Frequency

The diameters of 5 randomly selected aspen and white spruce trees from both plantations were measured at 1 metre intervals up each tree. In Plantation 1, which ranged from 0 to 14 cm. in diameter, a 1 cm. diameter class was used. In Plantation 2, which ranged from 0 to 4 cm. in diameter, a 0.25 cm. diameter class was used. These values were used to calculate the volume of each tree using Smalian's formula (Husch et al. 1972). This information was used to construct regressions that related diameter above butt swell to volume for the aspen and spruce in both plantations (App. B, Figures B1, B2, B3, and B4). The volume/diameter data were fitted using transformed and corrected (Baskerville 1972) regressions of the form $Y=aX^b$. The total and mean volumes of aspen and white spruce on each plot were calculated using these regression equations.

The cruise data were compiled and aspen density per plot frequency distributions were plotted. These distributions were used to stratify the plots into three Situation Types: close, medium and wide spacing according to their aspen density (Table 1).

Table 1. The Three Situation Types Defined At Plantations 1 And 2.

SITUATION	SPACING	# OF ASPEN TREES / PLOT
I	Wide	0-9
II	Medium	10-19
III	Close	>20 (max. 40)

This information was used to construct graphs relating the total volume of spruce per plot to the total volume of aspen per plot, the mean volume of spruce per plot to the mean volume of aspen per plot, and the mean volume of spruce per plot to the total volume of aspen per plot for each Situation Type.

iii) Situation Plots:

The term 'Situation' is used to describe the interrelationships between a planted white spruce tree and the aspen that surrounds it. For example, a short suppressed white spruce surrounded by tall dense aspen would be in a very different situation from a similar aged medium height intermediate spruce surrounded by tall sparse aspen. In each plantation, randomly selected 'Situations' were evaluated and stratified into the same three classes described in Table 1.

Each Situation Plot was circular with a white spruce located at the centre. The average ratio of the height of the white spruce to the plot diameter was 1:3. Therefore, the situation plot diameter was 9m (area =63.62 m^2) on Plantation 1, and 3m (area = 7.07m^2) on Plantation 2. The area of the circular Situation Plots was similar to that of the square plots used for the Stand Description. Five of each of the 3 Situation Types were measured on both plantations.

In each Situation Plot, the following measurements were taken.

1. Height: The total heights of all aspen and white spruce trees were measured.

2. Diameter: The diameters above butt swell (5% of the height up to 4 metres) of all aspen and white spruce trees were measured.

3. Frost Damaged Tips: The number of frost damaged tips on the central white spruce was estimated.

4. Crown Height: The crown height of the central white spruce tree was measured.

5. Crown Width: The crown width of the central white spruce tree was measured.

An aspen tree close to the mean diameter of each plot and the white spruce located at each plot centre were cut down for destructive sampling. The bole of each tree was sectioned into 0.25 m lengths and 2 cm thick disc samples were taken and frozen for later stem analysis.

The crown areas of the central white spruce trees were estimated using Equation 1. This equation calculates the area of a curved surface of a cone. The number of white spruce frost damaged tips per m^2 crown area on the central white spruce trees were calculated and plotted against the number of aspen trees on each Situation Plot. This information was used to construct regressions relating the number of white spruce frost damaged tips per m^2 crown area to the aspen density per Situation Plot.

Equation 1 $A=2/3\pi rh$

A=crown area

r=crown radius

h=crown height

iv) Stem Analysis

The geometric mean radius of each disc was established. The geometric rather than the arithmetic mean radius was used as the geometric mean radius is the true mean radius of a ellipse (Equation 2)

Equation 2 $R=(d_1 x d_2)/2$

R=geometric mean radius

d_1=largest diameter

d_2=perpendicular bisector of the largest diameter

The ring widths along 2 mean radii for each disc were measured with a calibrated hand lens. The geometric mean ring width was calculated for each year along these two radii. These values were used for analysis.

Mean periodic sheath volume increments were calculated for the aspen and the spruce using Smalian's formula. This information was used to construct growth curves for each tree.

Results

The results from the two plantations are presented individually.

Plantation 1:

The results of the Christian and Perry (1953) type classification for plots with high, medium and low tree densities are shown in Figure 2. Per cent cover does not add up to 100% on plots where there was a lot of bare ground or rotting wood.

The total white spruce volume per plot/total aspen volume per plot is obviously not well related (Figure 3). Regression equations were not computed. The mean white spruce volume per plot/mean aspen volume per plot (Figure 4), and the mean white spruce volume per plot/total aspen volume per plot (Figure 5) are also not well related. Thus, the volume of aspen per plot does not seem to affect the volume of white spruce.

There is also no relationship between the Situation Types (shown by dot shape in Figures 3, 4 and 5) and the volume of white spruce. The white spruce crop trees were found to have the same range of volumes in all Situations

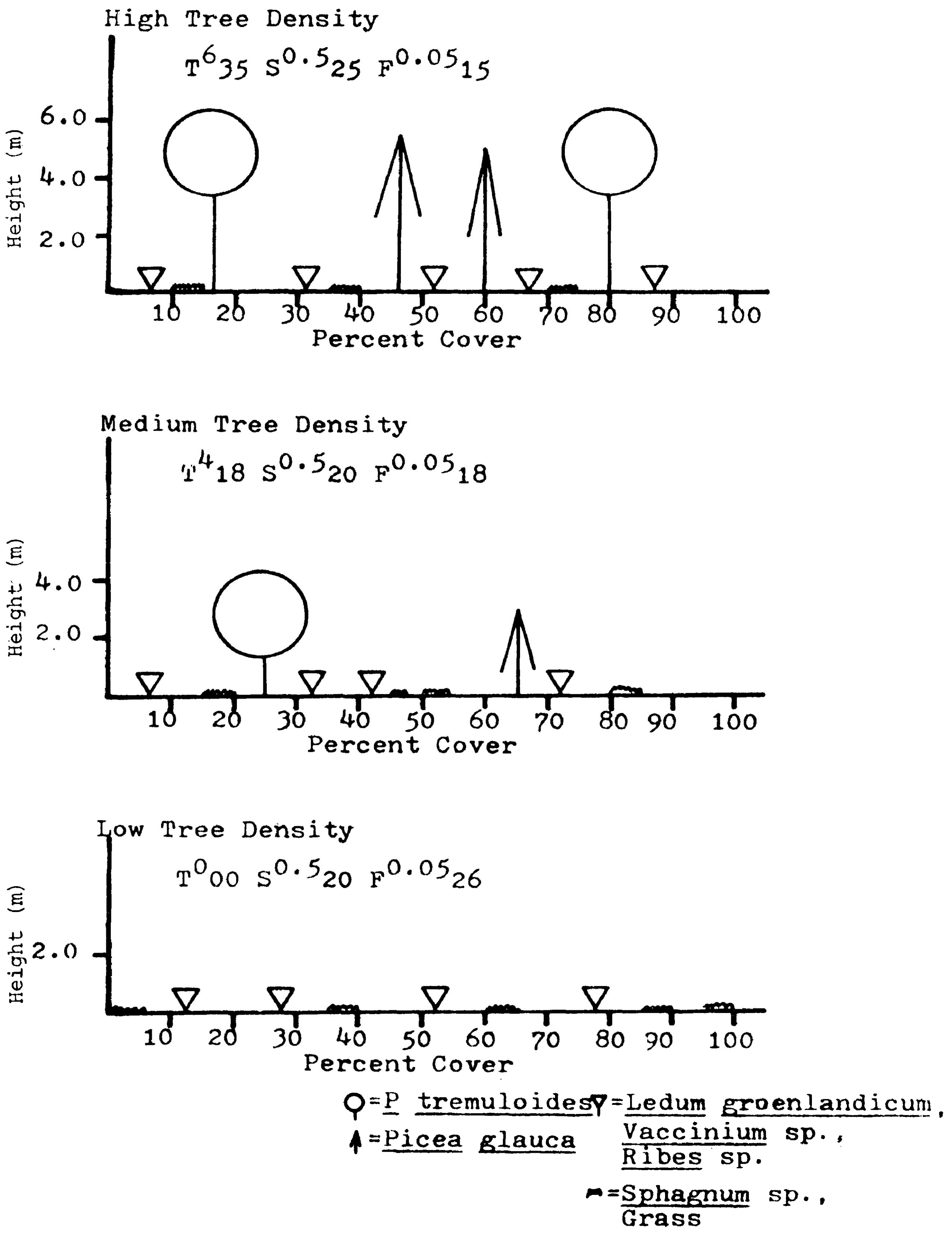


Figure 2. Schematic description of plots with high, medium and low tree density at Plantation 1 .

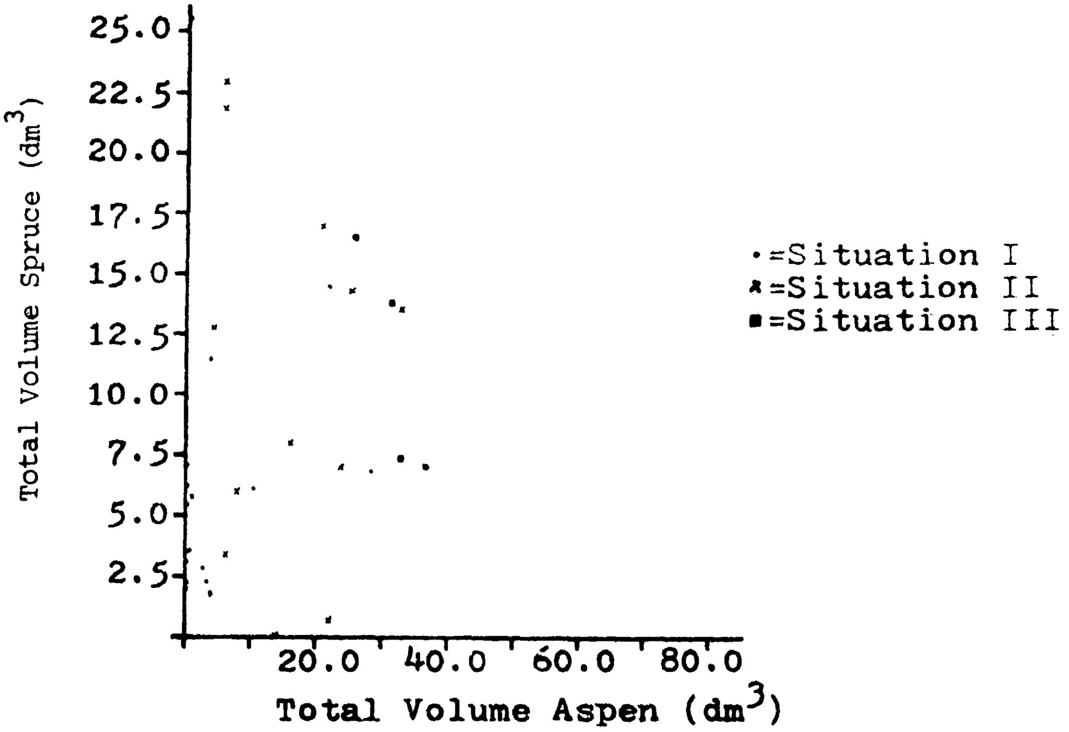


Figure 3. Total volume of spruce per plot vrs. total volume of aspen per plot at Plantation 1.

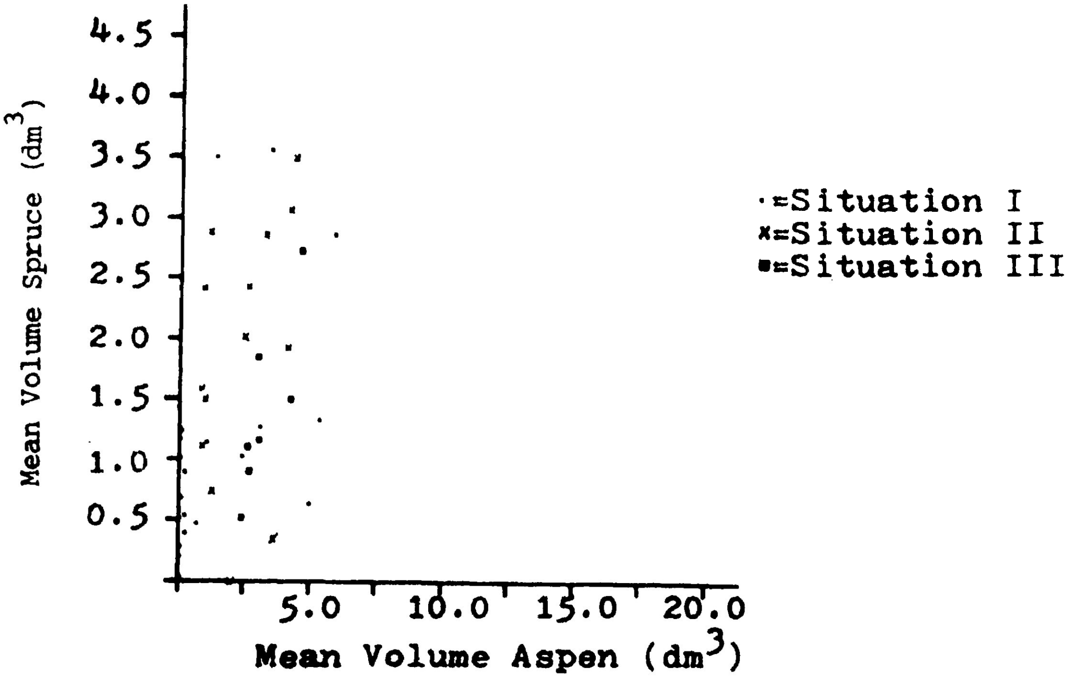


Figure 4. Mean volume of spruce per plot vrs. mean volume of aspen per plot at Plantation 1 .

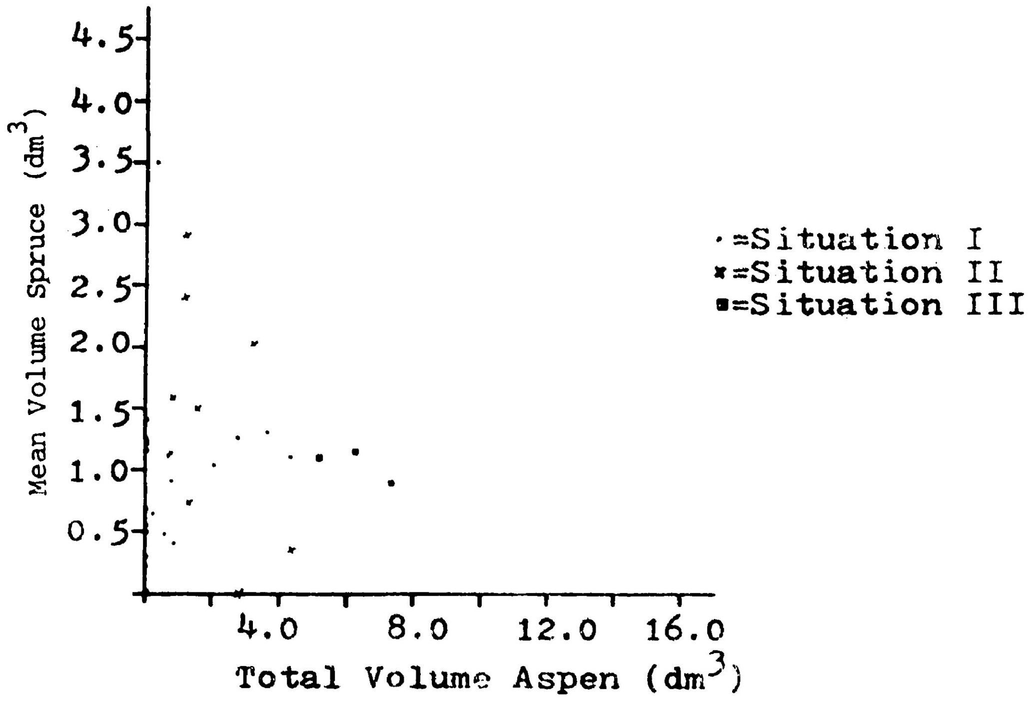


Figure 5. Mean volume of spruce per plot vrs. total volume of aspen per plot at Plantation 1.

regardless of the spacing or volume of the competing aspen.

As the number of aspen trees per plot increases, the number of white spruce frost damaged tips per m^2 crown area on the centrally located white spruce from each circular Situation Plot decreases (Figure 6). Situation Types II and III (shown by dot shape in Figure 6) with close and medium aspen spacing had lower numbers of white spruce frost damaged tips per m^2 crown area the than Situation Type I with wide aspen spacing. The regression of number of white spruce frost damaged tips per m^2 crown area (Y) plotted against the number of aspen trees per plot (X) was not significant (App. D, Table D1). The best fitting regression is given in Equation 3 and Figure 6.

Equation 3. $Y=10.13+21.09/X$

$R^2=0.25$

Figures 7, 8, 9, 10, 11, and 12 show the volume growth curves calculated from stem analysis for the aspen and white spruce from the circular Situation Plots.

There is a slight trend for white spruce in Situation Type I plots (0-9 aspen trees per plot) to put on more volume growth per year than the white spruce on Situation

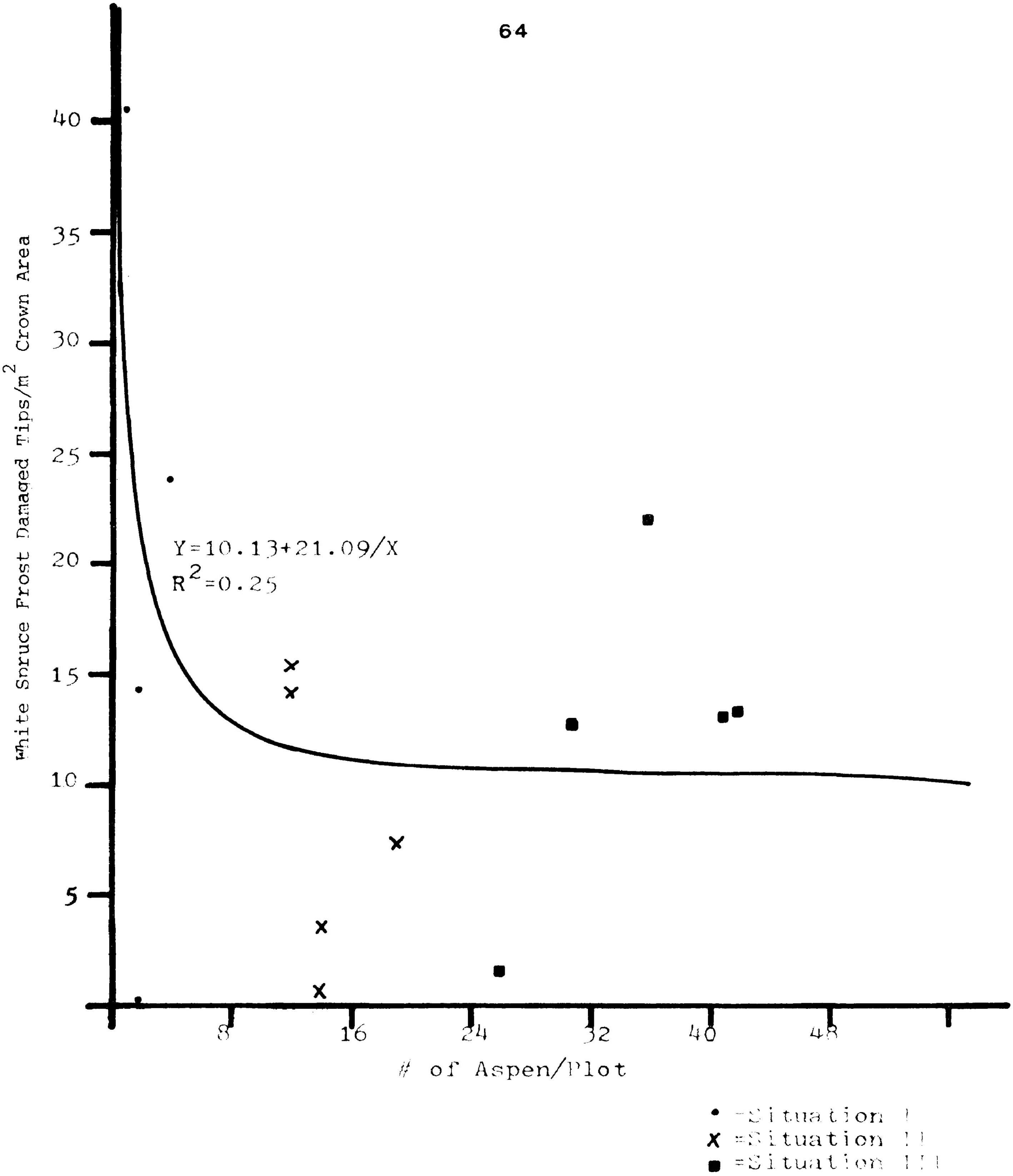


Figure 6. White spruce frost damaged tips per unit crown area vrs. number of aspen trees per plot at Plantation 1

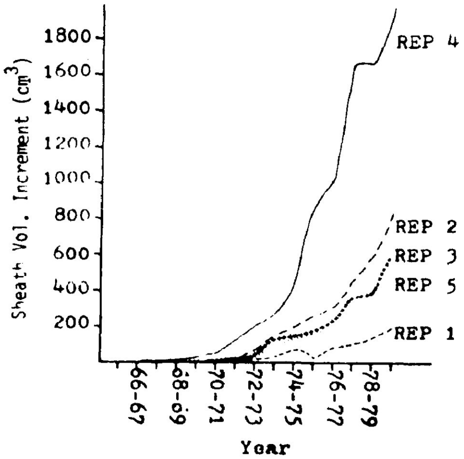


Figure 7 . Plantation 1 - The growth curves for white spruce on Situation Type I plots.

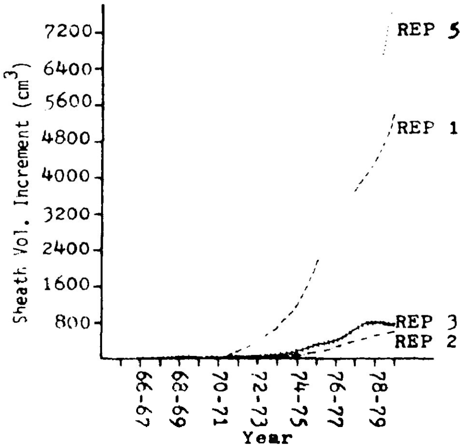


Figure 8 . Plantation 1 - The growth curves for aspen on Situation Type I plots.

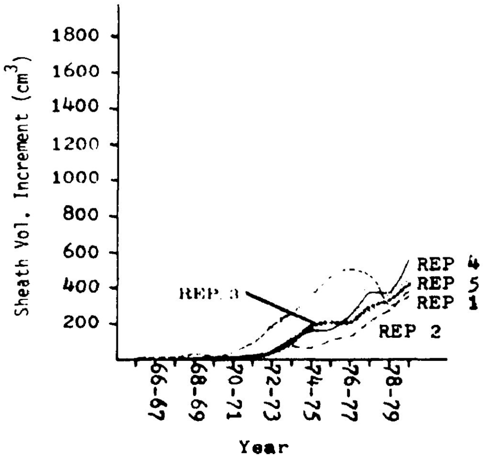


Figure 9 . Plantation 1 - The growth curves for white spruce on Situation Type II plots.

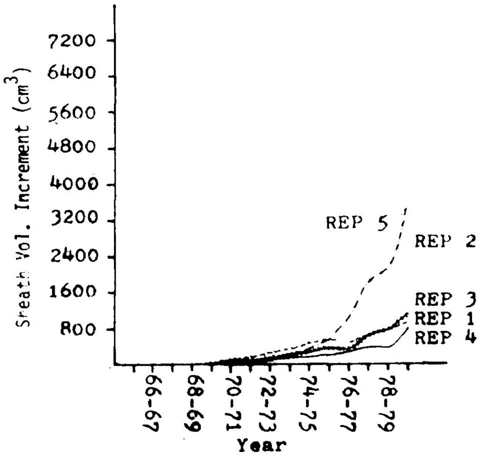


Figure 10. Plantation 1 - The growth curves for aspen on Situation Type II plots.

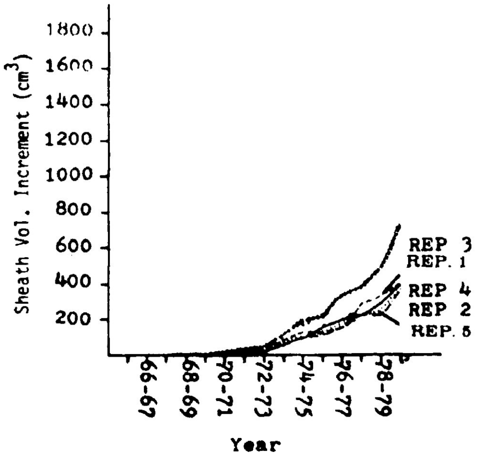


Figure 11. Plantation 1 - The growth curves for white Spruce on Situation Type III plots.

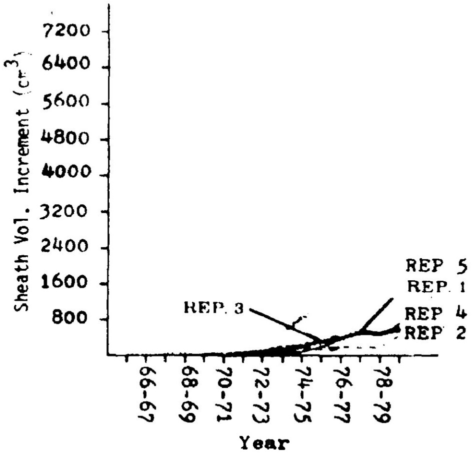


Figure 12. Plantation 1 - The growth curves for aspen on Situation Type III plots.

Type III Plots (> 20 aspen trees per plot), but there is much overlap between the growth curves from these two Situation Types (Figures 7 and 11). There is also a trend for some of the widely spaced aspen on Situation Type I Plots to grow better than the closely spaced aspen on Situation Type III Plots, but again there is overlap between the growth curves from these two Situation Types (Figures 8 and 12). Both the aspen and the white spruce on Situation Type II Plots (10 - 19 aspen trees per plot) grew much the same as the aspen and the white spruce on the Situation Type III Plots (Figures 9 and 10).

When the volume growth of the white spruce is compared to the volume growth of the aspen for the paired aspen and spruce on each Situation Type, a few trends appear.

The white spruce sampled on Situation Type I, Replication 4 was the fastest growing white spruce. It was not paired with an aspen as there were no aspen trees on that plot. The second fastest growing white spruce was in Replication 2. It was paired with a very slow growing mean aspen tree (Figures 7 and 8). Similarly, Replications 5 and 1 had the two slowest growing white spruce trees. These were paired with the two fastest growing aspen trees (Figures 7 and 8).

The trends between volume growth of aspen and volume growth of white spruce were not as clear for Situation Type II (10 - 19 aspen trees per plot). Again though, the two fastest growing aspen coincided with two of the slower growing white spruce (Figures 9 and 10). The two slowest growing aspen were paired with the two fastest growing spruce (Figures 9 and 10). The aspen and white spruce on Replication 3 grew intermediately when compared to the other trees (Figures 9 and 10).

The results are even more erratic for Situation Type III (> 20 aspen trees per plot) but they still follow the same general pattern. The fastest growing aspen on Replication 5 coincides with one of the slower growing white spruce. (Figures 11 and 12). One of the slower growing aspen on Replication 3 coincides with the fastest growing white spruce (Figures 11 and 12).

Plantation 2:

The results of the Christian and Perry (1953) type classification for plots with high, medium and low tree densities are shown in Figure 13.

The total white spruce volume per plot/total aspen volume per plot is obviously not well related (Figure 14). Regression equations were not computed. The mean white

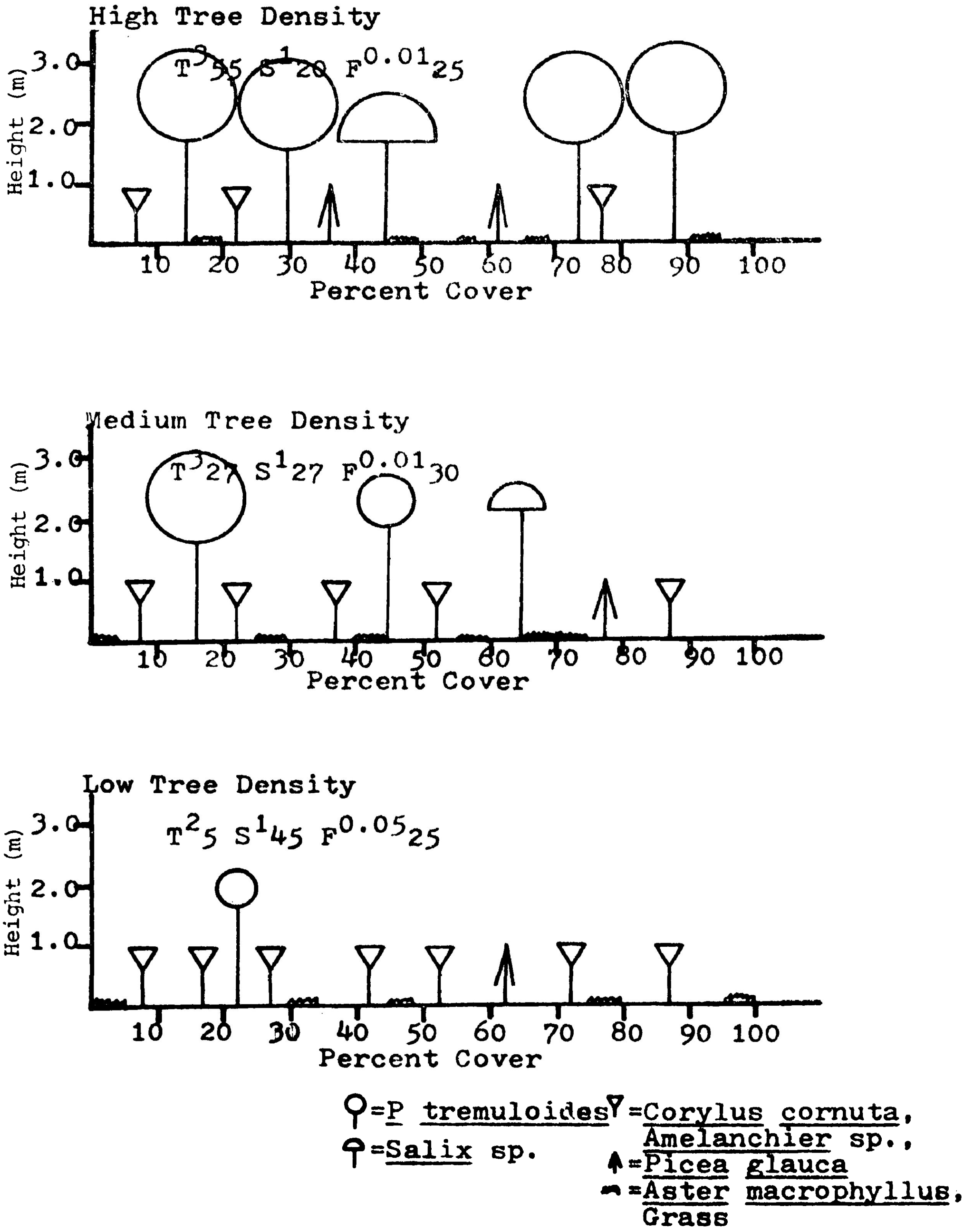


Figure 13 . Schematic description of plots with high, medium and low tree density at Plantation 2.

spruce volume per plot/mean aspen volume per plot (Figure 15) and the mean white spruce volume per plot/total aspen volume per plot (Figure 16) are also not well related. As at Plantation 1, the volume of aspen per plot does not seem to affect the volume of white spruce.

There is also no relationship between the Situation Types (shown by dot shape in Figures 14, 15 and 16) and the volume of white spruce. As at Plantation 1, the white spruce crop was found to have the same range of volumes in all situations regardless of the spacing or volume of the competing aspen.

As the number of aspen trees per plot increases the number of white spruce frost damaged tips per m^2 crown area on the centrally located white spruce from each circular Situation Plot decreases (Figure 17). Situation Types II and III (shown by dot shape in Figure 17) with close and medium aspen spacing had lower numbers of white spruce frost damaged tips per m^2 crown area than Sitution Type I with wide spacing. This relationship was more pronounced than that of Plantation 1. The regression of number of white spruce frost damaged tips per m^2 crown area (Y) plotted against the number of aspen trees per plot (X) was highly significant ($P=0.01$) (App. D, Table D2). The best fitting regression is given in Equation 4 and Figure 17.

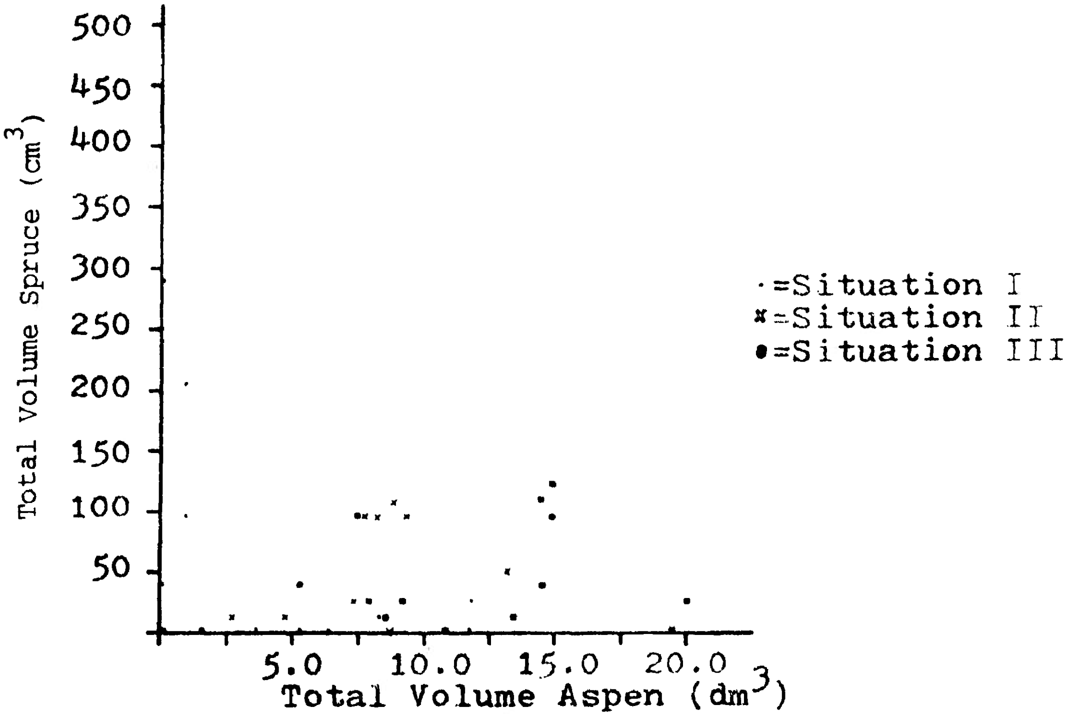


Figure 14. **Total volume of spruce per plot vrs. total volume of aspen per plot at Plantation 2.**

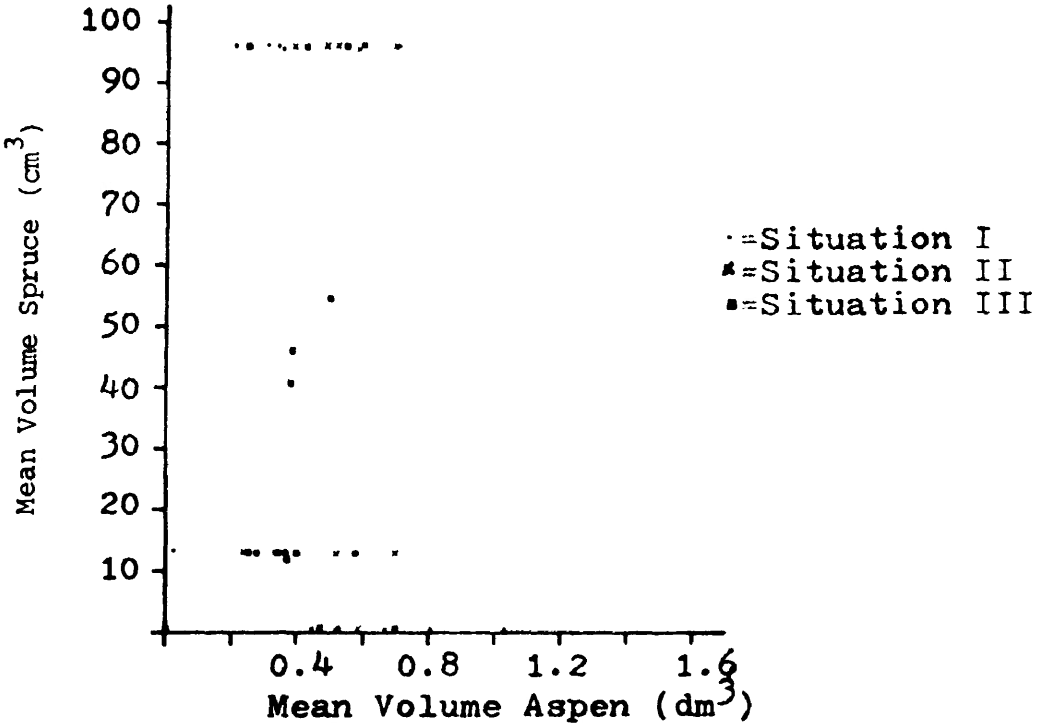


Figure 15 . **Mean volume of spruce per plot vrs. mean volume of aspen per plot at Plantation 2.**

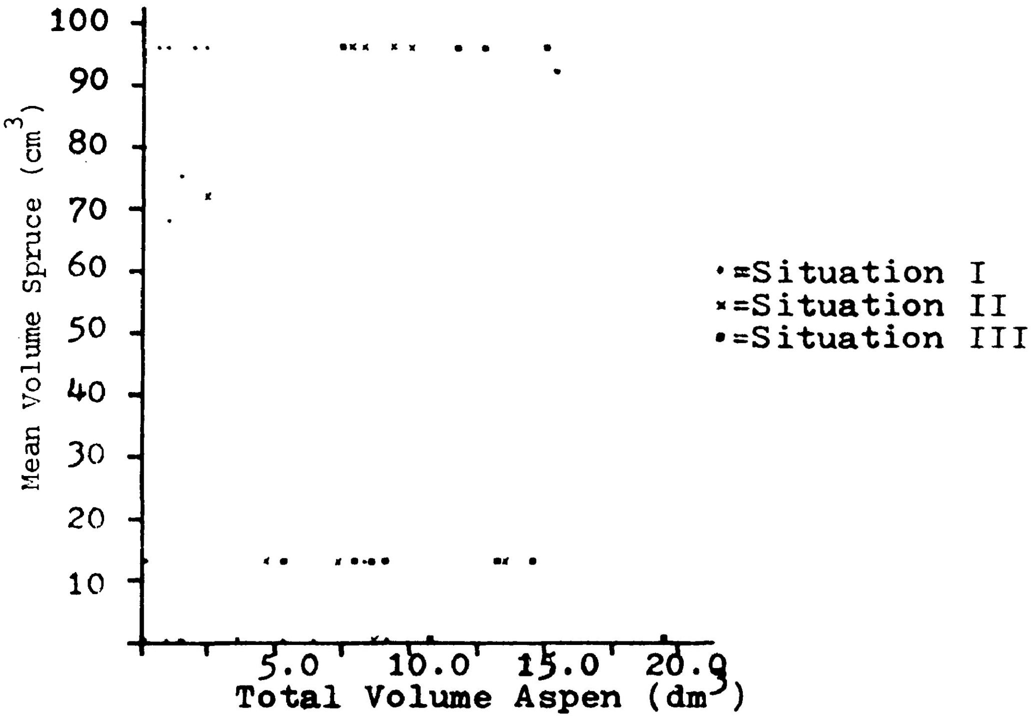


Figure 16. **Mean volume of spruce per plot vrs. total volume of aspen per plot at Plantation 2.**

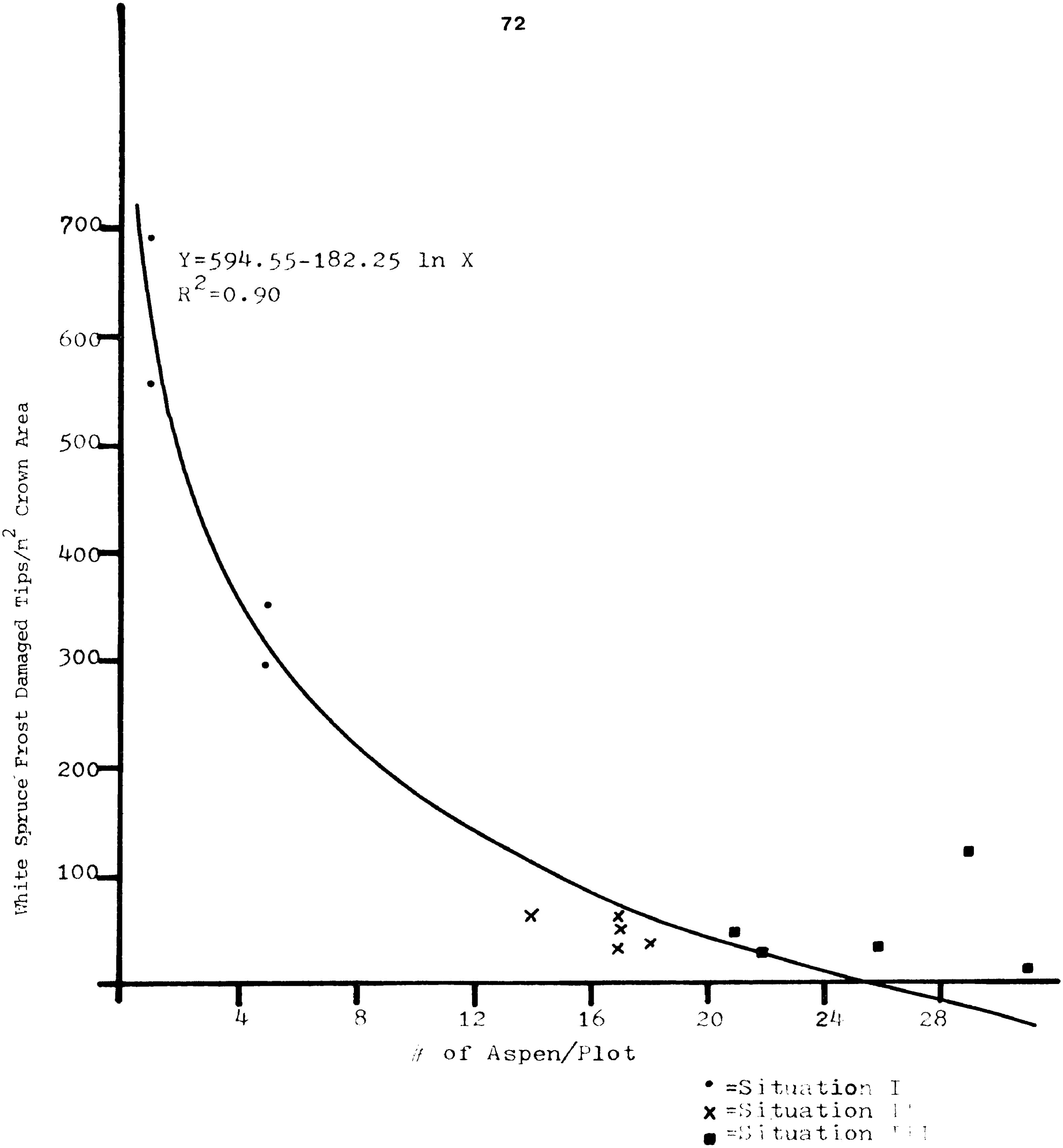


Figure 17. White spruce frost damaged tips per unit crown area vrs. number of aspen trees per plot at Plantation 2.

Equation 4. $Y=594.55-182.25\ln X$

$R^2=0.90$

Figures 18, 19, 20, 21, 22, and 23 show the volume growth curves calculated from stem analysis for the aspen and white spruce from the circular Situation Plots.

The white spruce on all three Situation Types put on roughly the same volume growth per year (Figures 18, 20 and 22). The aspen volume growth was erratic for all three Situation Types (Figures 19, 21 and 23).

Unlike the results at Plantation 1, when the volume growth of the white spruce is compared to the volume growth of the aspen for paired trees from each situation plot, there do not appear to be any trends. Often a fast growing aspen is paired with a fast growing spruce as in Situation Type II, Replication 3 (Figures 20 and 21) and Situation Type III, Replication 1 (Figures 22 and 23). A fast growing aspen may be paired with a slow growing spruce as in Situation Type I, Replication 5 (Figures 18 and 19). In Situation Type II, Replication 2 (Figures 20 and 21), a slow growing aspen is paired with a slow growing spruce. In Situation Type I, Replication 3 (Figures 18 and 19) a slow growing aspen is paired with a fast growing spruce. There

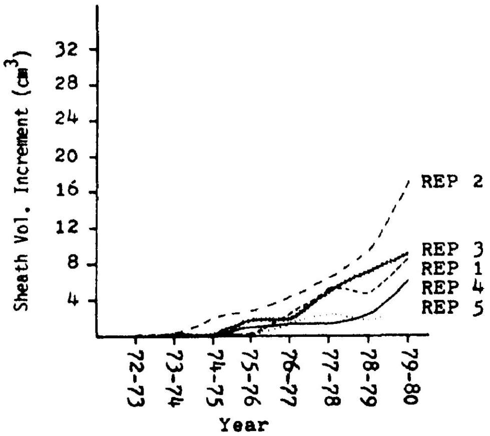


Figure 18. Plantation 2 - The growth curves for white spruce on Situation Type I plots.

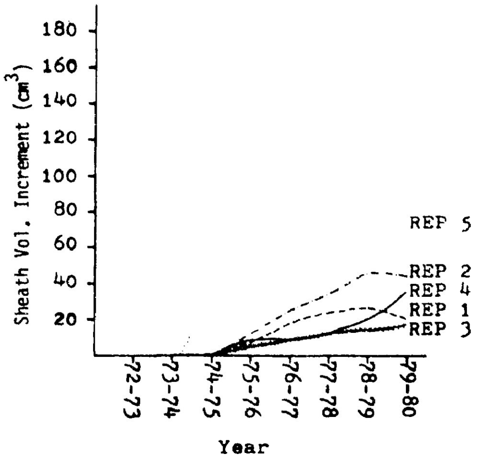


Figure 19. Plantation 2 - The growth curves for aspen on Situation Type I plots.

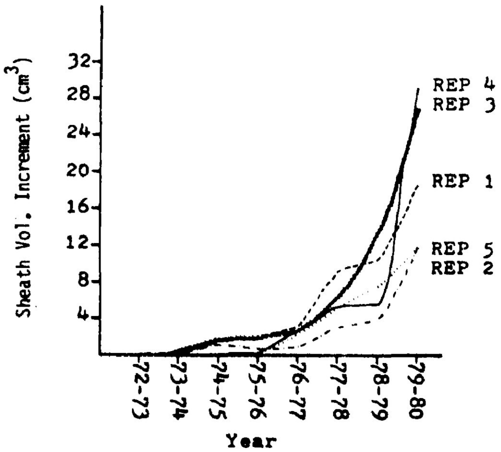


Figure 20. Plantation 2 - The growth curves for white spruce on Situation Type II plots.

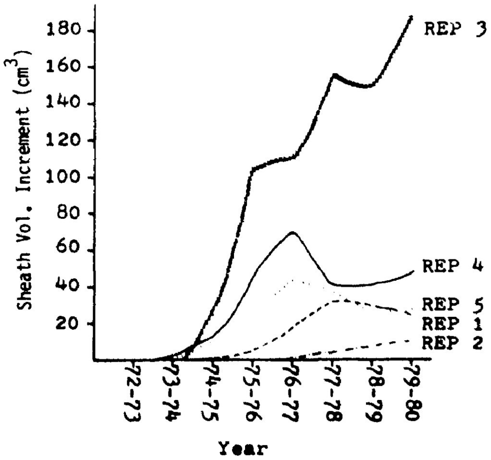


Figure 21. Plantation 2 - The growth curves for aspen on Situation Type II plots.

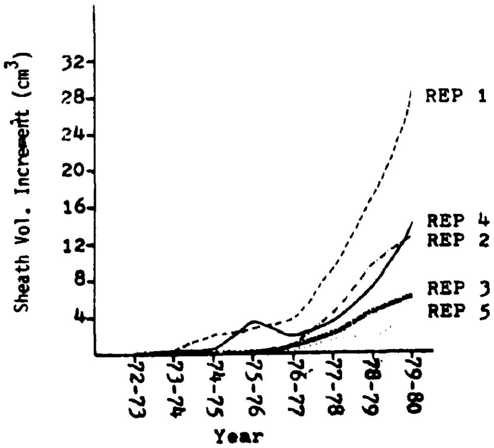


Figure 22. Plantation 2 - The growth curves for white spruce on Situation Type III plots.

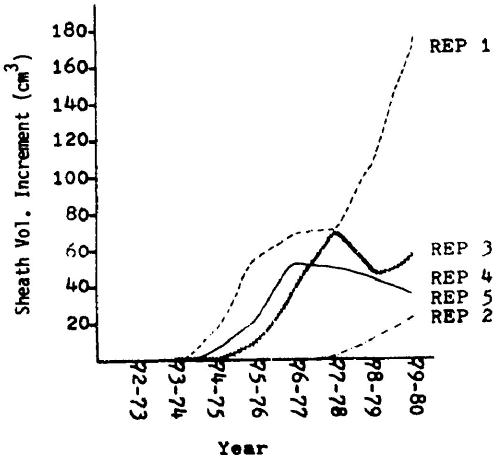


Figure 23. Plantation 2 - The growth curves for aspen on Situation Type III plots.

appears to be no relationship between the volume growth of the aspen and the volume growth of the white spruce.

SECTION II

FIELD AND GREENHOUSE TRIALS WITH HEXAZINONE HERBICIDE

Six trials with hexazinone herbicide were undertaken in order to determine if hexazinone could be used to effectively control competition in conifer plantations, to remove unwanted brush, and to eliminate a residual stand of poor quality mature aspen. A greenhouse trial was also undertaken to determine the effect of hexazinone on various crop and weed species grown under controlled conditions. The titles, and dates of initiation and evaluation of these six trials are outlined in Table 2.

Table 2. Outline of the Hexazinone Herbicide Trials

HERBICIDE TRIAL	DATE INITIATED	DATE(S) EVALUATED
1. The Brush Control Trials		
Location 1	Early June 1978	Early August 1978 and Mid. July 1979
Location 2	Late June 1978	Mid. August 1978 and Early August 1978
Location 3	Late July 1978	Mid. August 1979
2. The Seedling Survival Trials		
White Spruce	Mid June 1979	Late August 1979 and
Black Spruce	Mid June 1979	Late October 1980
3. The Crop Tree Trials		
White Spruce	Early July 1979	Early September 1980
White Spruce	Early July 1979	Late August 1980
Black Spruce	Early July 1979	Early September 1980
Jack Pine	Early July 1979	Early September 1980
4. The Weed Tree and Brush Trials		
Trembling Aspen	Mid July 1979	Late August 1980
Willow	Mid July 1979	Early September 1980
5. The Mature Aspen Trial	Late August 1979	Early September 1980
6. The Greenhouse Trials		
Jack Pine	Mid February 1980	Early May 1980
White Spruce	Mid February 1980	Early May 1980
Aspen	Mid February 1980	Early May 1980
Hazel	Mid February 1980	Early May 1980

Methods

1. The Brush Control Trials:

Randomized block field trials were established at three locations in old cutovers in 1978 (Dunsford 1979). These trials are situated approximately 80 kilometres west of Thunder Bay close to the junction of Highways 17 and 11 near Shabaqua Corners in Goldie Township. This area is within the B9 or Superior Section of the Boreal Forest Region (Rowe 1972) and in Site Region 4W (Hills 1961). The exact location of these trials is shown in App. A, Figures A3 and A4.

The three locations were chosen to illustrate various silvicultural problems.

Location 1 was cut over during 1974 to 1975. The area was not site prepared and it has subsequently regenerated to dense weed tree and brush species. No conifer crop is present (Table 3 and Figure 24).

Location 2 was cut over in 1969. It was site prepared in 1971 with a V plough to cut the larger trees and to separate the slash (Myles 1978). Sharkfin barrels were dragged behind the plough. These break through the slash and rip into the soil surface layers and root mat (Smith

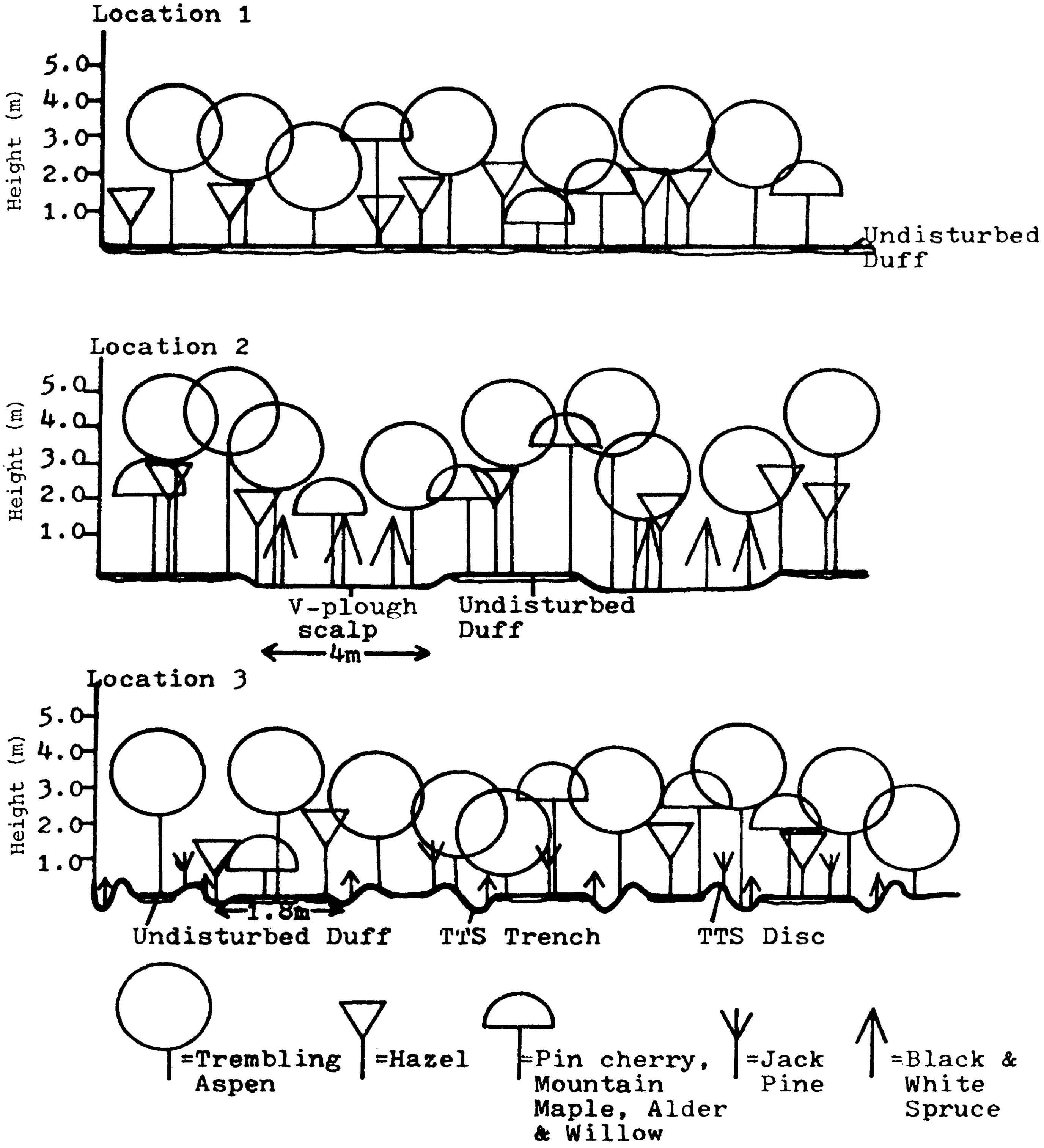


Figure 24. Schematic description of Locations 1,2 and 3.

1979). This area was planted with white spruce in May 1972. It has since become heavily infested with weed tree and brush species which are competing with the white spruce crop (Table 3 and Figure 24).

Location 3 was cut over on several occasions between 1962 to 1970. It was aerially seeded in 1972 with jack pine. Jack pine regeneration was very poor. In 1976 the area was site prepared with a TTS disc trencher. The trencher is a row scarifier which operates on the same principle as the agricultural disc harrow. It cuts into the soil, turning up two equidistant furrows (Myles 1978, Smith 1979, and Murray 1980).

In 1977 Location 3 was planted with white and black spruce. Conifer regeneration is still very poor at this location. A few scattered jack pine and white spruce trees are present, but these are seriously suppressed by dense weed trees and brush (Table 3 and Figure 24).

Table 3. Stand History and Description of Locations 1,2 and 3.

LOCATION	DATE OF CUTOVER	DATE AND TYPE OF SITE PREPARATION	DATE PLANTED, HEIGHT AND SPECIES OF CROP	HEIGHT AND SPECIES OF WEED TREE AND BRUSH IN ORDER OF IMPORTANCE
1	1974-1975	none	none	Trembling Aspen (2.5 to 4.5m)= Hazel (1 to 2.5m)>Mountain Maple=Alder= Willow=Pin Cherry
2	1969	1971-Vblade corridors and barrels	1972-White Spruce (1.5m)	Trembling Aspen (3.5 to 5.5m) Hazel (2.0 to 3.0)>Mountain Maple=Alder= Willow=Pin Cherry
3	1962-1970	1976-TTS disc trencher	1972 aerially seeded with Jack Pine (1.0 to 1.5m) 1977 White and Black Spruce (0.5m)	Trembling Aspen (2.5 to 4.5m)> Hazel (1 to 2.5m)=Mountain Maple=Alder Willow=Pin Cherry

The hexazinone herbicide trials were set up in the field as described in Table 4.

Table 4. Description of the Hexazinone Herbicide Trials at Locations 1,2 and 3.

LOCATION	DATE APPLIED	HEXAZINONE FORM	PLOT SIZE (m)	DATE ASSESSED IN 1978	DATE ASSESSED IN 1979
1	Early June 1978	DPXLE and Gridballs	15x15	Early August 1978	Mid. July 1979
2	Late June 1978	DPXLE and Gridballs	20x20	Mid. August 1978	Early August 1979
3	Late July 1978	DPXLX and Gridballs	20x20	----	Mid. August 1979

The experimental design was a 2 x 5 factorial superimposed on a randomized block design. Each field trial was composed of 30 plots (3 blocks x 2 forms x 5 rate and spacing of herbicide treatments) (Table 5).

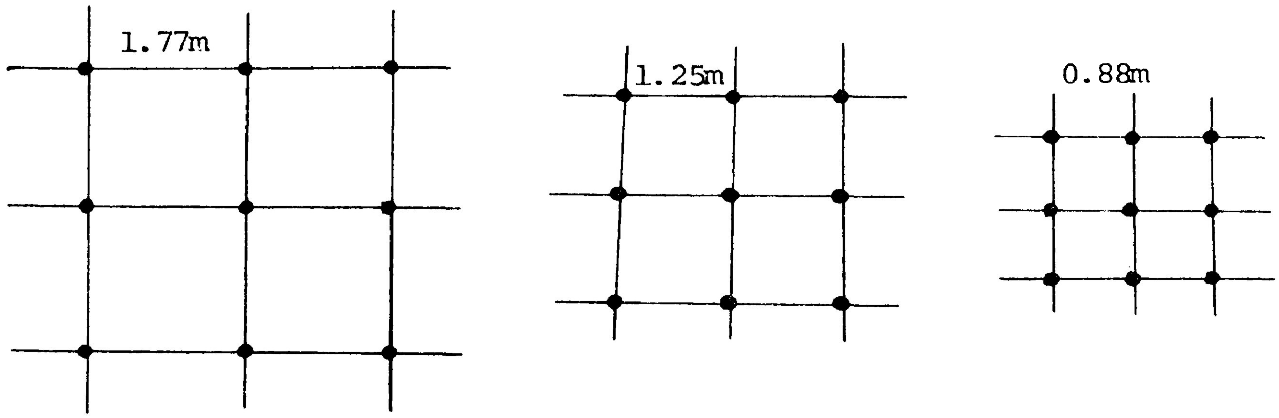
Table 5. The Hexazinone Herbicide Treatments Applied in the Brush Control Trials.

TREATMENT NUMBER	HEXAZINONE FORM	APPLICATION METHOD	RATE (kg ai/ha)	SPACING (mxm)
1	Liquid	10 ml. of	0.0	nil
2	(DPX-LE[1])	diluted	1.2	1.77
3	" "	solution	1.2	1.25
4	" "	applied by	2.4	1.25
5	" "	spotton-gun	2.4	0.88
6	Solid	Gridballs	(nil) 0.0	nil
7	" "	applied	(2cc.) 1.2	1.77
8	" "	by	(1cc.) 1.2	1.25
9	" "	hand	(2cc.) 2.4	1.25
10	" "		(1cc.) 2.4	0.88

[1] Note: The trial at Location 3 was treated with DPX-LX.

There were two treatments in the primary factor: hexazinone concentrated liquid (DPX 3674-LE or LX) solutions and hexazinone 'Gridballs' (DPX 3674-A). DPX-LE was used at Locations 1 and 2; DPX-LX was used at Location 3.

There were five different rate and spacing treatments in the secondary factor. The two rates of application (1.2 and 2.4 kg ai./ha) were achieved by varying the spacing interval between 'spot' applications of hexazinone as shown in Figure 25.



S:	1.77	1.25		0.88
R:	1.20	1.20	2.40	2.40
#:	3,200	6,400	6,400	12,800
R/S:	0.3750	0.1875	0.3750	0.1875

scale: 0m 1m 2m

S = spacing (m^2)
R = rate (kg ai/ha)
\# = number of spots per ha
R/S = rate per spot (g ai)

Figure 25. Schematic description of the rate and spacing treatments.

Hexazinone is a 'spot' applied herbicide. A spot of concentrated solution or a 'Gridball' pellet is applied to the soil surface. The herbicide is thought to move outward from this spot in a manner similar to that described in

Figure 26.

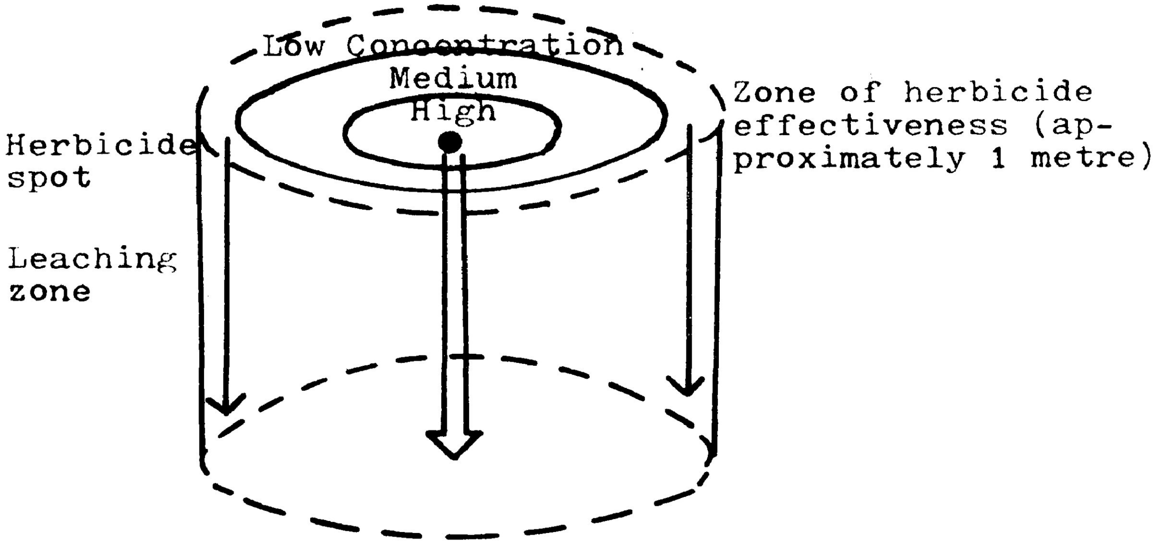


Figure 26. Schematic description of the zone of effectiveness around a hexazinone spot.

Locations 1 and 2 were evaluated twice, once during August 1978 (Dunsford 1979), and once during July and August 1979. Location 3 was evaluated for the first time during August 1979. The 10 trembling aspen trees randomly chosen by Dunsford (1979) on each plot at Locations 1 and 2 were re-evaluated during July and August 1979. Ten aspen trees per plot at Location 3 were randomly designated for evaluation in August 1979.

The following measurements of the selected aspen trees were made on each plot.

1. Condition Code: The effect of the various hexazinone treatments on the aspen was evaluated by assigning a subjective condition code (Table 6) to each of the 10 selected aspen trees on each plot.

2. Height: The total height of each tree in metres was measured.

3. Diameter: The diameter in centimetres above butt swell (5% of the total tree height up to 4 metres) was measured.

Foliage dry weight was estimated using the branch diameter at point of foliation method. The diameters at point of foliation of all branches carrying live foliage were measured. The branch diameters were recorded in five diameter classes, 1 to 3, 4 to 6, 7 to 9, 10 to 12 or 13 to 15 mm using the Branch Diameter Guide shown in Figure 27. Foliage dry weight in grams was estimated for individual branches using the regression equation established by Dunsford(1979). These values were summed for each tree. The total foliage dry weight per plot was divided by 10 to obtain the average foliage dry weight in grams per tree on each plot.

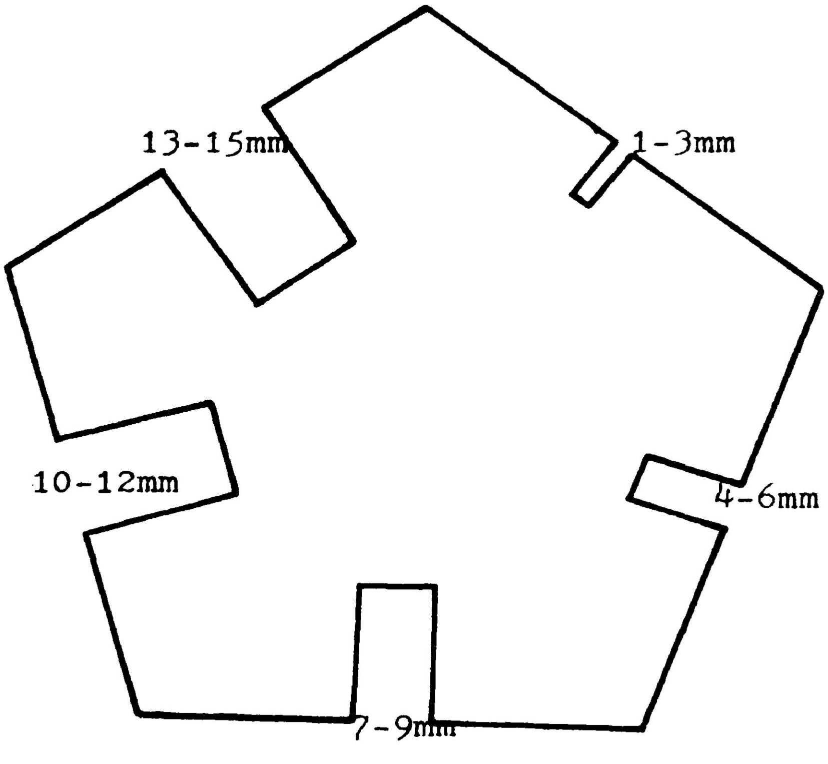


Figure 27. The branch diameter guide.

The regression curve established by Dunsford (1979) (Equation 5) was a logarithmic transformation, therefore the method outlined by Baskerville (1972) was used to correct it (Equation 6). Logarithmic transformations tend to skew the variance when the derived equation is retransformed back into original values. This can result in underestimates of up to 20 per cent (Baskerville 1972) if the residual mean square is high.

Equation 5 $\quad FDW = 0.1816X^{2.0791}$ $\quad$ uncorrected curve

Equation 6 $\quad FDW = 0.1816X^{2.0791} \times e^{0.007165}$ $\quad$ corrected curve

FDW = foliage dry weight in grams

X = branch diameter at point of foliation in mm.

It was decided to continue to use data based on the uncorrected curve (Equation 5) in all analysis as the initial analysis of results (Dunsford 1979) was carried out using the uncorrected curve, and as the effect of correction was minimal (Figure 28). Equation 1 would provide the best comparison between analysis of 1978 data with 1979 data.

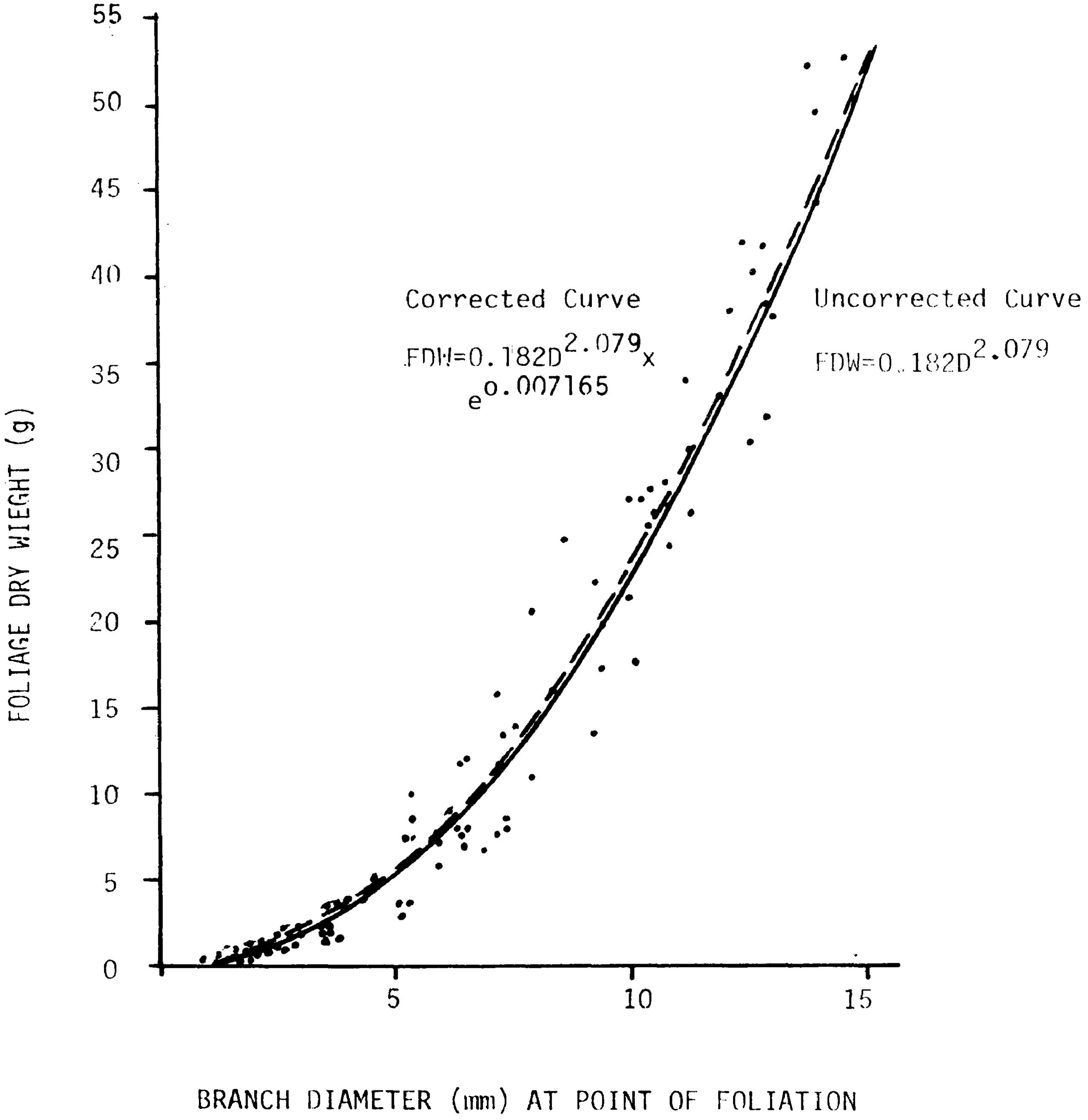


Figure 28.The plotted points show actual foliage dry weight (FDW) and branch diameter at point of foliation (D).

Table 6. The Subjective Condition Code Used to Describe the Condition of the Aspen.

CONDITION	CODE
healthy (no damage or defoliation)	0
1-25% brown and defoliated	1
26-50% " "	2
51-75% " "	3
76-99% " "	4
dead	5

2. The Seedling Survival Trials:

In June 1979, Replications 1 and 2 of The Brush Control Trial - Location 3 were hand planted with 1 1/2 + 1 1/2 white spruce and black spruce and 2+0 jack pine nursery stock in three 2 x 5 factorial randomized block field trials. The purpose of this trial was to determine the effect of hexazinone applied in 1978 on nursery stock planted one year after herbicide application.

Each 2 x 5 factorial field trial was composed of 2 herbicide forms x 5 herbicide rate - spacings x 2 replications x 20 trees/replication = 400 trees. A description of the treatments can be found in Table 5.

The three species were planted on each plot in Replications 1 and 2 (Figure 29). Replication 3 was not planted because of time constraints.

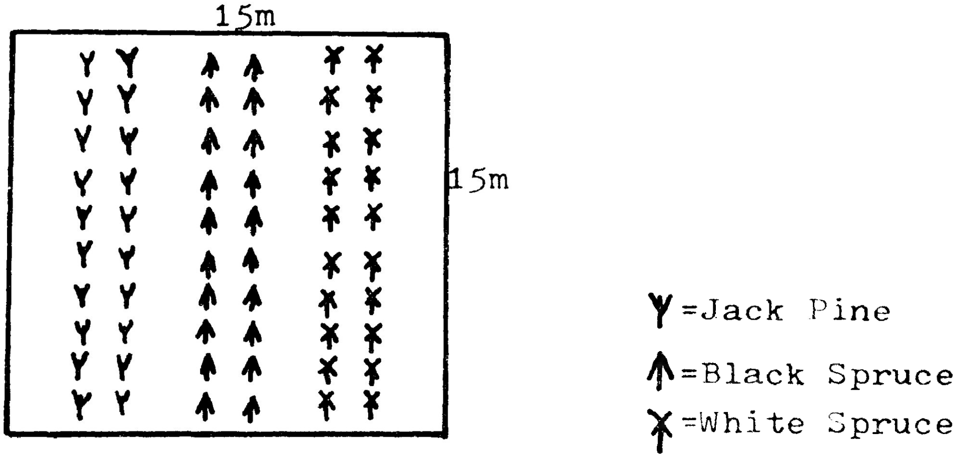


Figure 29 .Planting layout of a single plot in the Seedling Survival Trial.

During the fall of 1979, three months after planting, the seedlings were assessed. The trees were assigned the same subjective condition described in the Brush Control Trials (Table 6) and per cent survival was measured. Height increment of the established seedlings was measured, but rabbit damage invalidated this assessment.

The seedlings were re-assessed during October 1980. The trees were again assigned a subjective condition code, and per cent survival and height increment were re-measured. The 1980 results were used in all analysis. These results, taken a full growing season after planting, would probably provide the first results showing initial growth response to release from aspen competition.

Many of the jack pine seedlings on both control and hexazinone treated plots died during the year after planting, and as a light covering of snow on the ground made it virtually impossible to find these seedlings in 1980, measurement of the jack pine was discontinued.

3. The Crop Tree Trials:

Four 3^2 factorial randomized block field trials were established in June and July 1979 to determine if hexazinone had a detrimental effect on the crop trees shown in Table 7.

Table 7. Species and Height of Trees in the Four Crop Tree Hexazinone Herbicide Trials.

TRIAL #	CROP SPECIES	HEIGHT (m)
i	White Spruce	1.50
ii	White Spruce	0.30
iii	Black Spruce	0.30
iv	Jack Pine	1.75

These trials are situated close to the Brush Control Trials. The exact location of these trials is shown in App. A, Figures A3, A4, and A5.

Each 3^2 factorial field trial was composed of 3 herbicide rates x 3 herbicide spacings x 3 replications x 5 trees per replication = 135 trees (Table 8).

Table 8. The Hexazinone Herbicide Treatments Applied in the Crop Tree Trials.

TREATMENT #	HEXAZINONE RATE (g ai/spot)	SPACING (m)
1	0	1.5
2	0	1.0
3	0	0.5
4	0.1875	1.5
5	0.1875	1.0
6	0.1875	0.5
7	0.3750	1.5
8	0.3750	1.0
9	0.3750	0.5

The two rates of hexazinone (0.1875 g. ai/spot and 0.3750 g. ai/spot) were chosen as this is the equivalent amount of herbicide that would be applied with a 1 cc or a 2 cc hexazinone 'Gridball'. Figure 26 shows how the herbicide applied as a 'spot' is thought to migrate through the soil.

Hexazinone concentrated liquid (DPX 3674-LX) was used rather than hexazinone 'Gridballs'. The concentrated liquid form is faster acting than the 'Gridball' form because the hexazinone in the latter is included in a slowly disintegrating clay ball. Thus the field results with hexazinone concentrated liquid would be more readily apparent and would have more severe effects on the crop trees.

Two 'spots' of hexazinone were applied on both sides of each tree as shown in Figure 30.

During the summer of 1979, 100 branches were collected from each species on sites adjacent to the test sites. These branches were selected to represent the overall range of branch diameters for each species equally. The branch diameters at point of foliation and the foliage dry weight of each branch were determined. Line and curvilinear regressions were formulated to determine the relationship between branch diameter at point of foliation and foliage dry weight (App. C, Figures C1, C2, C3, and C4).

As described in the Brush Control Trials, the condition code, height and diameter of each tree were measured prior to herbicide treatment.

The Crop Tree Trials were evaluated during August and September 1980. The trees were again assigned a subjective condition code, per cent survival was measured, and the total height and the diameter above butt swell of each tree was measured. Height growth of the trees was determined by subtracting the total height in 1979 from the total height in 1980.

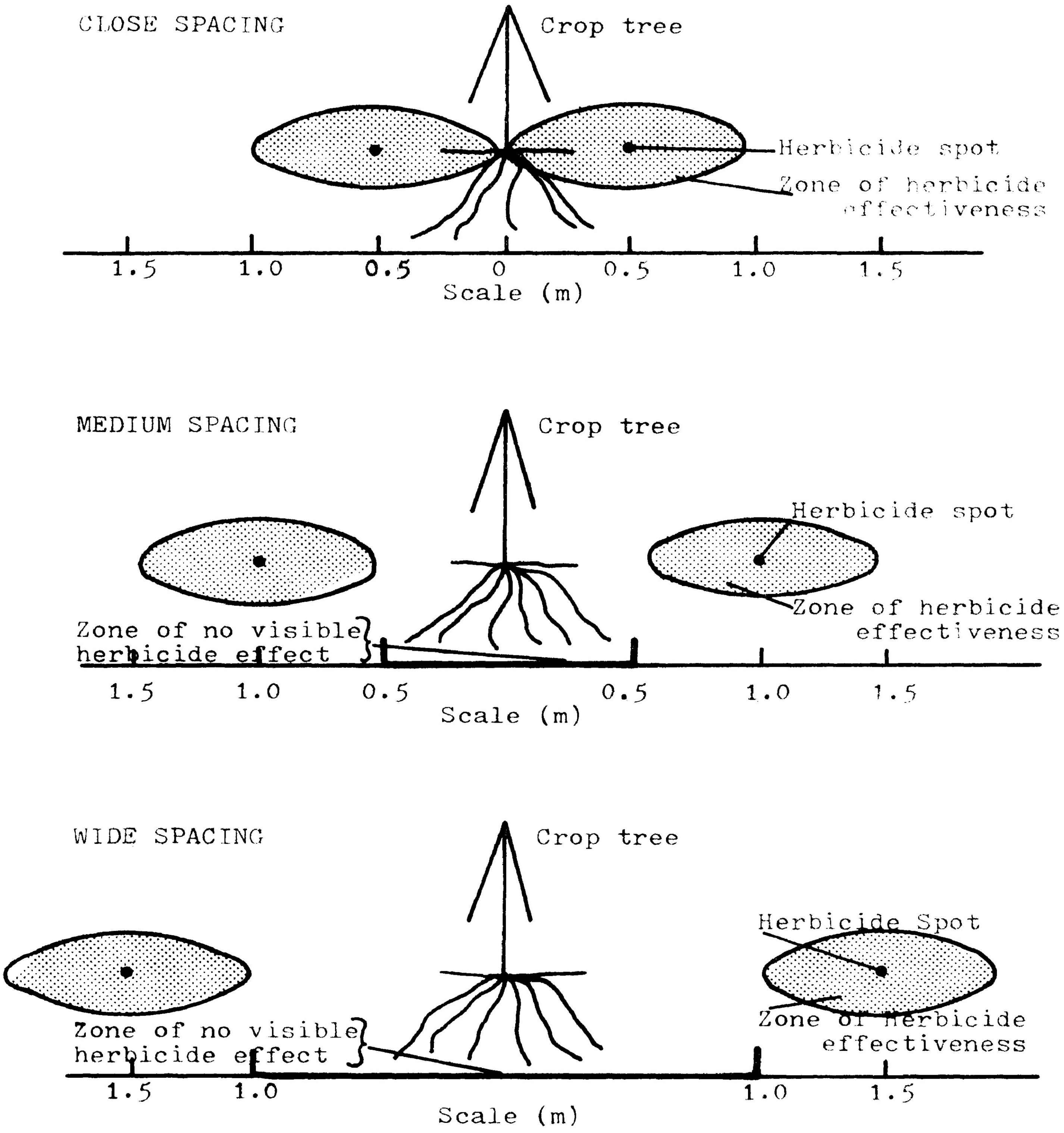


Figure 30. Schematic description of the hexazinone spacing treatments.

The regression equations relating branch diameter at point of foliation to foliage dry weight were not used to estimate the foliage dry weight of the trees. Due to the amount of time that had elapsed since herbicide treatment, any herbicide affected trees were dead while the rest remained healthy. This result limited the usefulness of the branch diameter at point of foliation method and it was discontinued.

4. The Weed Tree and Brush Trials:

Two randomized block field trials were established in July 1979 to determine if hexazinone had a detrimental effect on the weed tree and brush species shown in Table 9 .

Table 9. Species and Height of the Trees in the Two Weed Tree and Brush Hexazinone Herbicide Trials.

TRIAL #	WEED TREE OR BRUSH SPECIES	HEIGHT (m)
i	Aspen	4.0
ii	Willow	3.0

These trials are situated close to the Brush Control Trials. The exact location of these trials is shown in App. A, Figures A3 and A4.

The methods used for each trial are presented individually.

i. Aspen Weed Tree Trial

The Aspen Weed Tree Trial was a 3 x 4 factorial randomized block design. There were 3 herbicide rates x 4 herbicide spacings x 3 replications x 5 trees per replication = 180 trees (Table 10).

Table 10. The Hexazinone Herbicide Treatments Applied in the Aspen Weed Tree Trial.

TREATMENT NUMBER	HEXAZINONE RATE (g ai/spot)	SPACING (m)
1	0	2.0
2	0	1.5
3	0	1.0
4	0	0.5
5	0.1875	2.0
6	0.1875	1.5
7	0.1875	1.0
8	0.1875	0.5
9	0.3750	2.0
10	0.3750	1.5
11	0.3750	1.0
12	0.3750	0.5

As explained in the Crop Tree Trials, the two rates of hexazinone chosen were 0.1875 g ai/spot and 0.3750 g ai/spot. Figure 26 shows how the herbicide 'spot' is thought to migrate through the soil.

The widest herbicide spacing (2.0 m) was included in this trial because of the wide spreading root system of aspen and its resulting sensitivity to hexazinone.

As explained in the Crop Tree Trials, hexazinone concentrated liquid (DPX 3674-LX) was the herbicide form used for all treatments.

Two 'spots' of hexazinone were applied on both sides of each tree similar to the manner described in Figure 30.

As described in the Crop Tree Trials, 100 branches were collected from aspen on a site adjacent to the test site. Line and curvilinear regressions were formulated to determine the relationship between branch diameter at point of foliation and foliage dry weight (App. C, Figure C5).

As described in the Brush Control Trials, the condition code, height and diameter of the aspen trees were measured prior to herbicide treatment.

The Aspen Weed Tree Trial was evaluated during August 1980. The trees were again assigned a subjective condition code, per cent survival was measured, and the total height and the diameter above butt swell of each tree was re-measured. Height growth of the trees was determined by subtracting the total height in 1979 from the total height in 1980.

As discussed in the Crop Tree Trials, the regression equations relating branch diameter at point of foliation to foliage dry weight were not used to estimate the foliage dry weight of the trees.

ii. Willow Brush Trial

The Willow Brush Trial was a 3^2 factorial randomized block design. There were 3 herbicide rates x 3 spot numbers x 3 replications x 5 bushes per replication = 135 bushes (Table 11).

Table 11. The Hexazinone Herbicide Treatments Applied in the Willow Brush Trial.

Treatment Number	Hexazinone Rate (g ai/spot)	Number of Spots/Bush
1	0	1
2	0	2
3	0	4
4	0.1875	1
5	0.1875	2
6	0.1875	4
7	0.3750	1
8	0.3750	2
9	0.3750	4

As explained in the Crop Tree Trials, the two rates of hexazinone chosen were 0.1875 g ai/spot and 0.3750 g ai/spot. Figure 26 shows how the herbicide 'spot' is thought to migrate through the soil.

As explained in the Crop Tree Trials, hexazinone concentrated liquid (DPX 3674-LX) was again used for all treatments.

Willow, due to its clumpy growth habit was not treated with different herbicide spacings. Instead, it was treated with either 1, 2 or 4 hexazinone spots at the base of each shrub as shown in Figure 31.

As explained in the Crop Tree Trials, 100 branches were collected from willow on a site adjacent to the test site. Line and curvilinear regressions were formulated to determine the relationship between branch diameter at point of foliation and foliage dry weight (App. C,Figure C6).

The following measurements were made on each shrub prior to herbicide treatment.

1. Condition code: The same subjective condition code described in the Brush Control Trials (Table 6) was assigned to each tree.

2. Height: The overall height of each shrub in metres was measured.

3. Number of Main Stems: The number of live main stems for each shrub was counted.

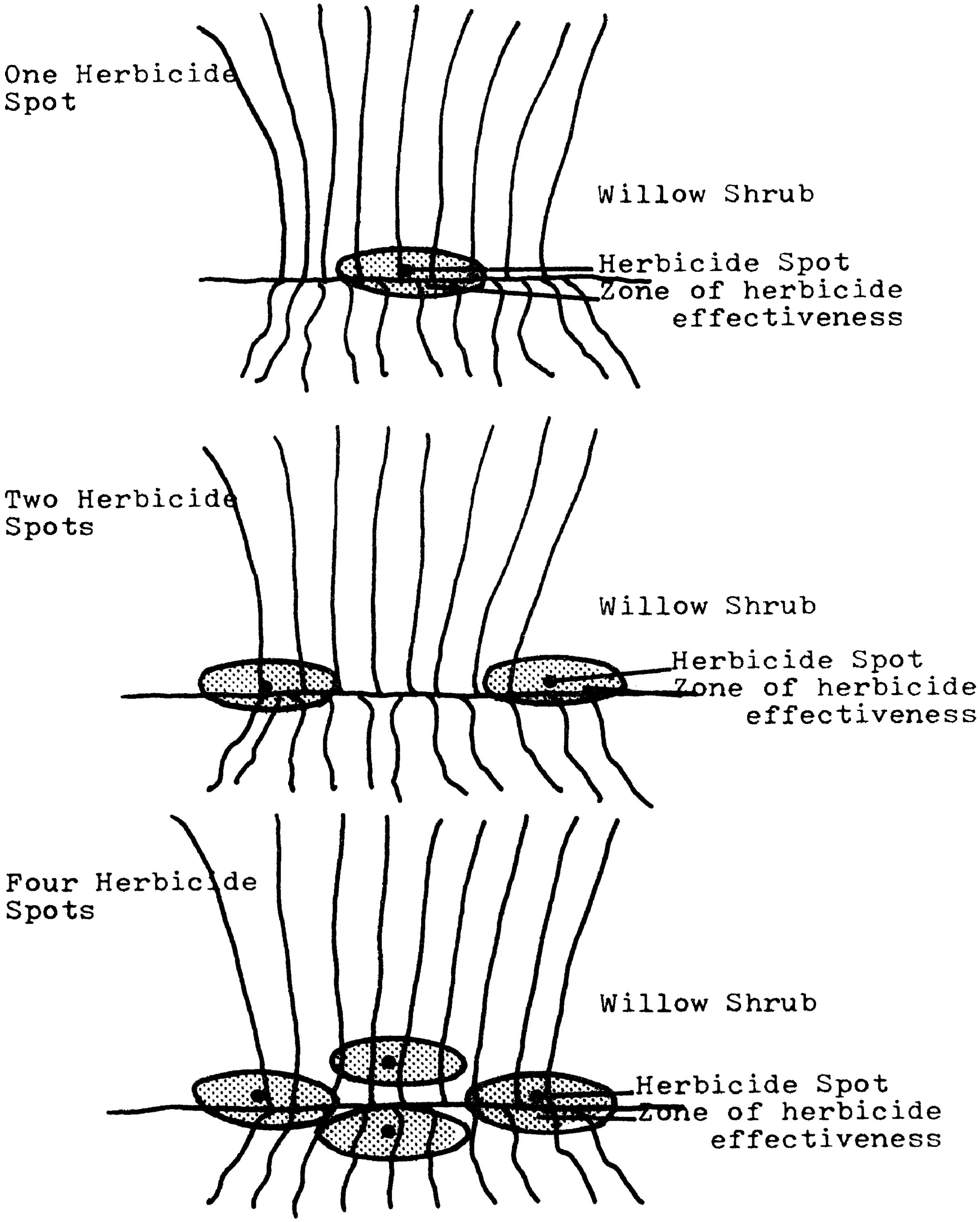


Figure 31. Schematic description of the hexazinone spot placements.

The Willow Brush Trial was evaluated in September 1980. The trees were again assigned a subjective condition code, per cent survival was measured, the overall height was measured and the number of live stems for each shrub was re-counted. Total stem growth of each shrub was determined by subtracting the overall height in 1979 from the overall height in 1980 and multiplying this value by the number of live stems in 1980.

As discussed in the Crop Tree Trials, the regression equations relating branch diameter at point of foliation to foliage dry weight were not used to estimate the foliage dry weight of the shrubs.

5. The Mature Aspen Trial:

A field trial was established in August 1979 to evaluate the effect of hexazinone on mature aspen trees. This trial is situated close to the Brush Control Trials. The exact location of this trial is shown in App. A, Figure A3.

An initial cruise was made of the stand. The trees were divided into three diameter classes based on diamater at breast height measurements. The three diameter classes are shown in Table 12.

Table 12. The Three Diameter Classes in the Mature Aspen Trial.

DIAMETER CLASS	DBH (cm)
S	<12.0
M	12.1-16.0
L	>16.1

The experimental design was a 2 x 4 x 3 factorial randomized block design. There were two herbicide forms x 4 herbicide rates x 3 diameter classes x 3 replications x 3 trees per replication = 216 trees (Table 13).

Table 13. The Hexazinone Herbicide Treatments Applied in the Mature Aspen Trial.

TREATMENT NUMBER	FORM	RATE (# of spots X g ai/spot)	DIAMETER CLASS
1	Liquid	0	L
2	"	0	M
3	"	0	S
4	"	2x3.750	L
5	"	2x3.750	M
6	"	2x3.750	S
7	"	4x3.750	L
8	"	4x3.750	M
9	"	4x3.750	S
10	"	6x3.750	L
11	"	6x3.750	M
12	"	6x3.750	S
13	Solid	0	L
14	"	0	M
15	"	0	S
16	"	2x3.750	L
17	"	2x3.750	M
18	"	2x3.750	S
19	"	4x3.750	L
20	"	4x3.750	M
21	"	4x3.750	S
22	"	6x3.750	L
23	"	6x3.750	M
24	"	6x3.750	S

Hexazinone concentrated liquid (DPX-3674 LX) and hexazinone 'Gridballs' were the two herbicide forms used. The hexazinone rates (0.3750 g ai/spot x 0,2,4 or 6 spots) were chosen as 0.3750 g equals amount of active ingredient that would be applied with a 2 cc 'Gridball'. This would allow comparison between the effectiveness of the two herbicide forms. Figure 26 shows how the herbicide applied as a spot is thought to migrate through the soil.

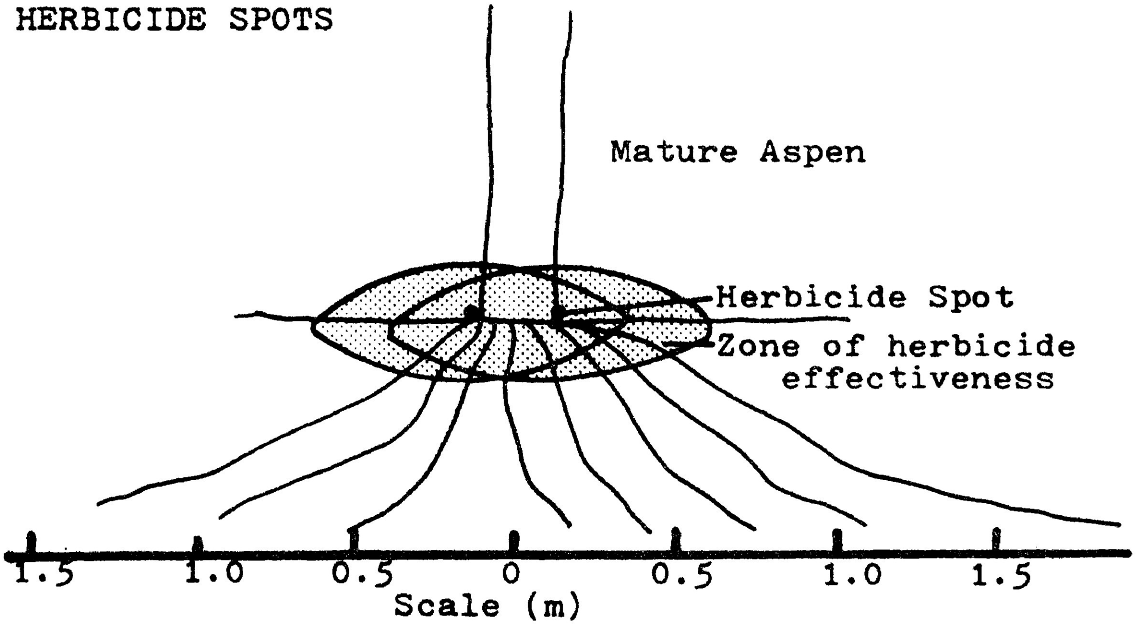
The hexazinone 'spots' were applied around the base of each tree as shown in Figure 32.

The Mature Aspen Trial was evaluated during August 1980. The trees were assigned a subjective condition code (Table 14) and per cent survival was measured.

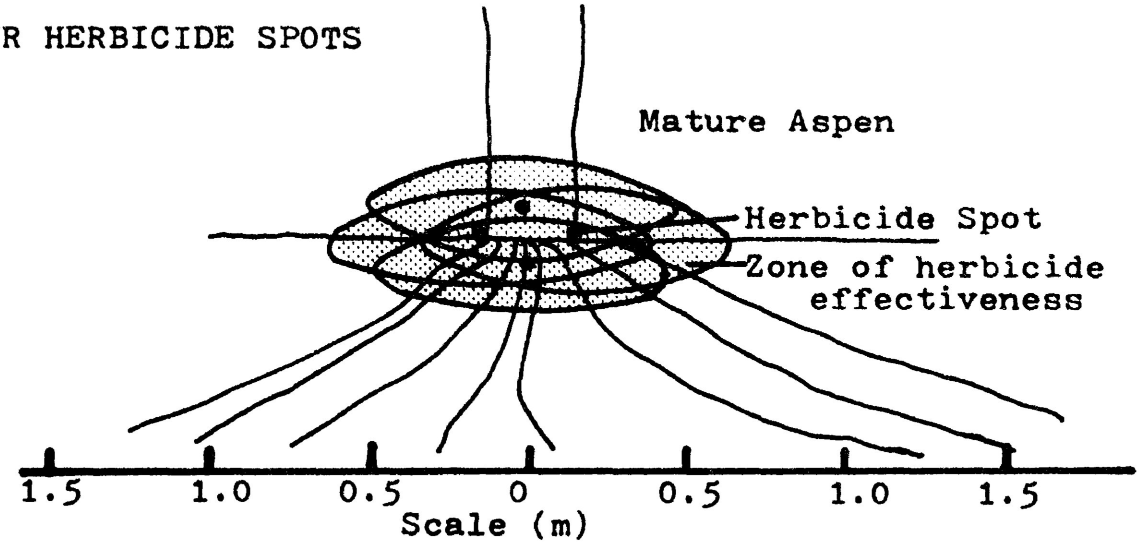
Table 14. The Subjective Condition Code Used to Evaluate the Mature Aspen Trial.

CONDITION CODE	AMOUNT OF DAMAGE
1	Healthy
2	Moderate Damage
3	Dead

TWO HERBICIDE SPOTS



FOUR HERBICIDE SPOTS



SIX HERBICIDE SPOTS

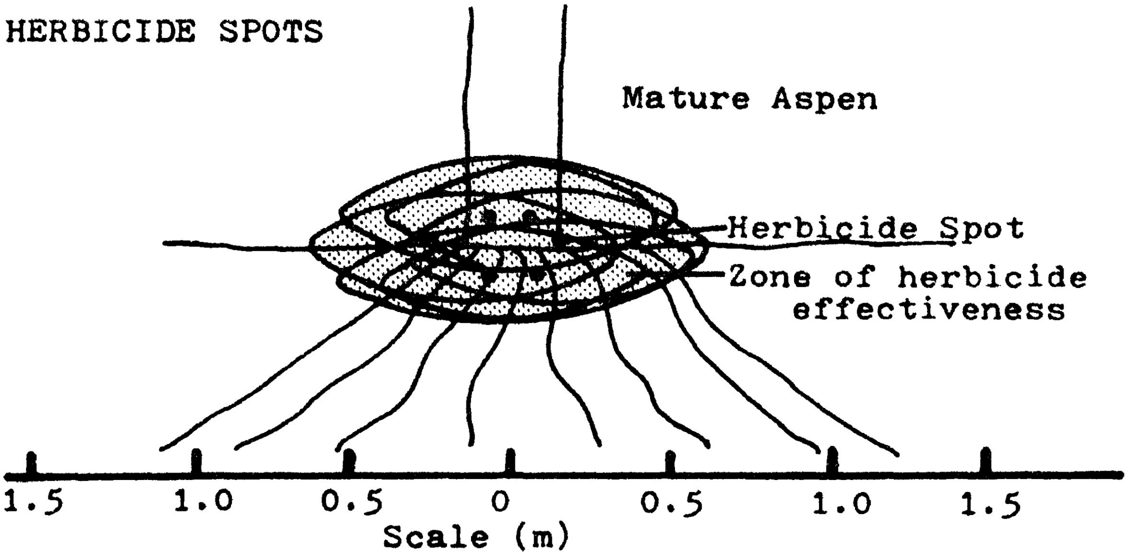


Figure 32. Schematic description of the hexazinone spot treatments.

6. The Greenhouse Trials:

Randomized block trials were established in the Lakehead University Greenhouse in November 1979 to evaluate the effect of hexazinone on four crop and weed species. The crop species tested were jack pine and white spruce; the weed tree and brush species tested were aspen and hazel. Both crop and weed species were grown under controlled conditions. The methods used for the crop and weed species are discussed separately.

i. Jack Pine and White Spruce Crop Tree Greenhouse Trials:

The root collar diameters of one hundred each of 1 1/2 + 1 1/2 white spruce and 2+0 jack pine nursery stock were measured. To minimize size variation and potential experimental error, seedlings within 10% of the mean root collar diameter were selected for study. These seedlings were potted and grown in the Lakehead Univesity Greenhouse for two months prior to hexazinone application. They were initially placed in a cold house maintained at an average temperature of 12°C. The temperature was gradually increased to 20°C over a period of 4 weeks. The trees were then moved into the large Lakehead University Greenhouse, maintained at an average temperature of 22°C, and placed under Gro Lux and Cool White lights. At this point, the roots had started to regenerate and the buds were beginning to flush. After 4 weeks, in February 1980, when the newly flushed shoots had completed elongation and had hardened off, they were treated with hexazinone herbicide.

The experimental design was a 4 x 2 factorial randomized block design. These were 4 herbicide rates x 2 spray positions x 3 replications x 5 trees per replication = 120 trees (Table 15).

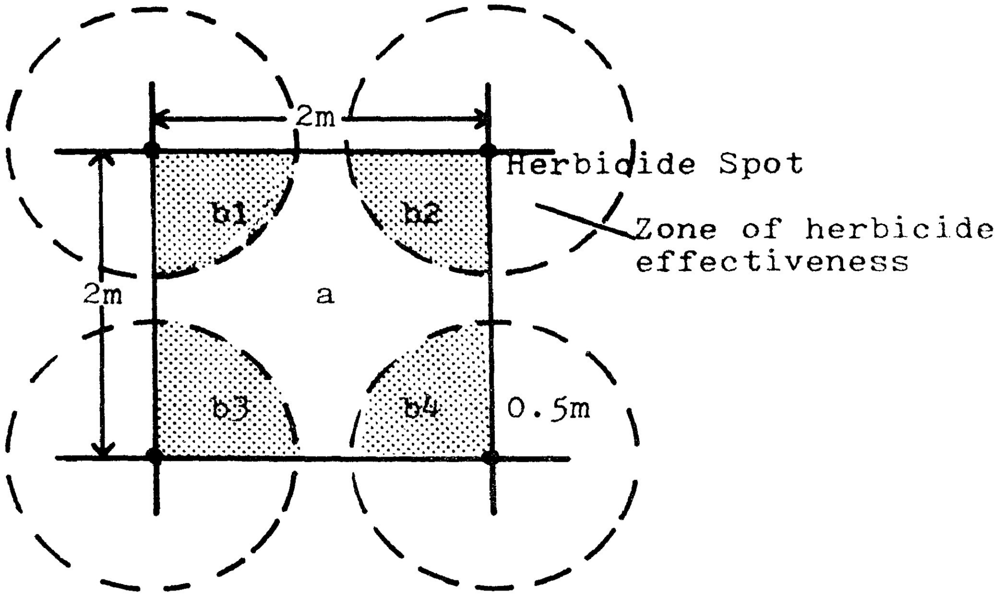
Table 15. The Hexazinone Herbicide Treatments Applied in the Jack Pine and White Spruce Crop Tree Greenhouse Trials.

TREATMENT NUMBER	RATE (g ai/4m^2)	TARGET AREA
1	0	Foliage
2	2.04	"
3	4.08	"
4	8.16	"
5	0	Foliage + Soil
6	2.04	" "
7	4.08	" "
8	8.16	" "

The four rates of hexazinone applied to the potted crop and weed species were designed to simulate the concentration of hexazinone that results from spot applications made in a grid pattern in the field (Figure 33). In grid pattern applications the concentration of hexazinone in each spot within the grid is much higher than the average application rate in kilograms per hectare because only a fraction of the area is affected by the herbicide. The rates of hexazinone applied in this study were 0, 2.04, 4.08 and 8.16 g ai/4m^2. These are equivalent to the within treated spot rates when 0, 1, 2 and 4 kg ai/ha are applied in a grid pattern in the field (Figure 33). Figure 26 shows how the herbicide spot is thought to migrate through the soil.

The rate of spray was controlled by placing the potted trees in a 4 metre square and spraying a preweighed quantity of a suspension of hexazinone in water evenly over the area with a 'Beauty Mist' sprayer.

The hexazinone was applied by two methods: 1) to the foliage alone and 2) to the foliage and soil. In 1) the soil in each pot was covered with cardboard discs and the foliage was sprayed. In 2) the soil was uncovered and both the foliage and soil were sprayed. Both jack pine and white spruce do not often show damage from hexazinone herbicide. The two methods of spray application were chosen to determine if hexazinone applied directly to the roots and foliage would be more damaging than hexazinone applied to



Area a = 2 x 2 = $4m^2$

Area b_{1-4} = 4 x 0.25 r^2 = $0.785m^2$

1Kg ai/ha grid application=1x4/0.785=5.1Kg ai/ha spot rate

2Kg ai/ha grid application=2x4/0.785=10.2Kg ai/ha spot rate

4Kg ai/ha grid application=4x4/0.785=20.4Kg ai/ha spot rate

5.1Kg ai/ha = 2.04 g ai/$4m^2$

10.2Kg ai/ha = 4.08 g ai/$4m^2$

20.4Kg ai/ha = 8.16 g ai/$4m^2$

Figure 33. The relationship between spot and grid application rates of hexazinone herbicide.

the foliage alone.

As described in the Crop Tree Trials, hexazinone concentrated liquid (DPX 3674-LX) was the herbicide form used in all treatments.

The following measurements of the jack pine and white spruce were made prior to hexazinone application.

1. Condition Code: The same subjective condition code described in the Brush Control Trial (Table 6) was assigned to each tree.
2. Total Height
3. Root Collar Diameter

The jack pine and white spruce were evaluated twice during February and March 1980 when the trees were again assigned a subjective condition code. The final evaluation was in May 1980. The trees were assigned a subjective condition code, per cent survival was measured and all green foliage was oven-dried and weighed.

ii. Aspen and Hazel Weed Tree and Brush Greenhouse Trials

Aspen root cuttings and hazel root-stem cuttings were potted and grown in the large Lakehead University Greenhouse, maintained at an average temperature of 22 °C, under Gro-Lux and Cool White lights for two months prior to hexazinone application. When the shoots were fully flushed, the aspen and hazel cuttings were treated with hexazinone herbicide.

The experimental design was a randomized complete block design. There were 4 herbicide rates x 3 replications x 5 trees per replication = 60 weed trees or brush (Table 16).

Table 16. The Hexazinone Herbicide Treatments Applied in the Aspen and Hazel Weed Tree and Brush Greenhouse Trials.

TREATMENT NUMBER	RATE (g ai/4m^2)
1	0
2	2.04
3	4.08
4	8.16

As described in the Jack Pine and White Spruce Greenhouse Trials, the four rates of hexazinone applied in these trials were 0, 2.04, 4.08 and 8.16 g ai/4m^2. The rate of spray was controlled by placing the potted trees in a 4 metre square and spraying evenly over the area with a 'Beauty Mist' sprayer.

The hexazinone was applied using only the second method, foliage and soil, described in the Jack Pine and White Spruce Greenhouse Trials. As both aspen and hazel are quite sensitive to hexazinone herbicide and would likely be damaged by hexazinone applied either to the roots or to the foliage and roots, only one method was used.

As described in the Crop Tree Trials, hexazinone concentrated liquid (DPX 3674-LX) was the herbicide form used for all treatments.

The following measurements of the aspen and hazel were made prior to hexazinone application:

1. Condition Code: The same subjective condition code described in the Brush Control Trials (Table 6) was assigned to each tree.

2. Total Shoot Height.

3. Number of Shoots.

The aspen and hazel were evaluated twice during February and March 1980 when the trees were again assigned a subjective condition code. The final evaluation was in May 1980. The trees were assigned a subjective condition code, per cent survival was measured and all green foliage was oven-dried and weighed.

Statistical Analyses of the Hexazinone Herbicide Trials

Analyses of variance (ANOV) or covariance analyses (COVAR) (Steele and Torrie 1960) were generally used to show the significance of the differences between the treatments in the herbicide trials (Table 17). Preliminary analysis (Prelim. Anal.) (Jeffers 1959) was used to determine whether a detailed analysis by ANOV or COVAR was needed.

Values for per cent survival were transformed using the arcsin method (Steele and Torrie 1960). These transformed values were used in all such analyses.

When ANOV or COVAR showed that there were significant differences between treatments, a Student-Newman-Keul's test (S-N-K test) (Steele and Torrie 1960) was applied. When ANOV was used actual treatment means were compared to determine the significance of the differences between individual treatment means. When COVAR was used, adjusted treatment means were compared.

Table 17. The Statistical Analyses Used in the Hexazinone Herbicide Trials.

HERBICIDE TRIAL	ANALYSIS	PARAMETER(S)	COVARIATE (if applicable)
1) The Brush Control Trials	COVAR	estimated foliage dry weight	Index of tree stem volume (tree diameter (cm) x total height (cm)). 1978 values were used for Locations 1 and 2; 1979 values were used for Location 3.
2) The Seedling Survival Trials	ANOV	i) height increment ii) transformed % survival	
3) The Crop Tree and 4) The Weed Tree and Brush Trials	COVAR	height growth (total stem growth for willow)	Index of tree stem volume (tree diameter (cm) x total height (cm)) for white and black spruce, jack pine and aspen. Overall height x # of main stems for willow. 1979 values were used for all species.
	ANOV	transformed % survival	
5) The Mature Aspen Trial	ANOV	transformed % survival	
6) The Greenhouse Trials			
i) Jack Pine and White Spruce	ANOV	i) transformed % survival ii) foliage dry weight	
ii) Hazel and Aspen	ANOV	transformed % survival	
	COVAR	foliage dry weight	Total shoot length at time of spraying.

Results

The results of the hexazinone herbicide trials are discussed in the same order as in the Methods section.

1. The Brush Control Trials:

The results of the three Locations are presented individually.

i. Location 1:

At Location 1, differences in the foliage dry weights of the aspen over the range of hexazinone treatments were highly significant (P=0.01, COVAR, App. E, Table E1). Plots receiving both liquid and solid hexazinone forms applied at high rates both spacings, and those recieving low rates of hexazinone applied at close spacing, had significantly lower aspen foliage dry weights than the two control plots (S-N-K test, App. E, Table E2).

When the two hexazinone forms were considered as an individual factor, differences in the foliage dry weights of the aspen were non-significant (COVAR, App. E, Table E1).

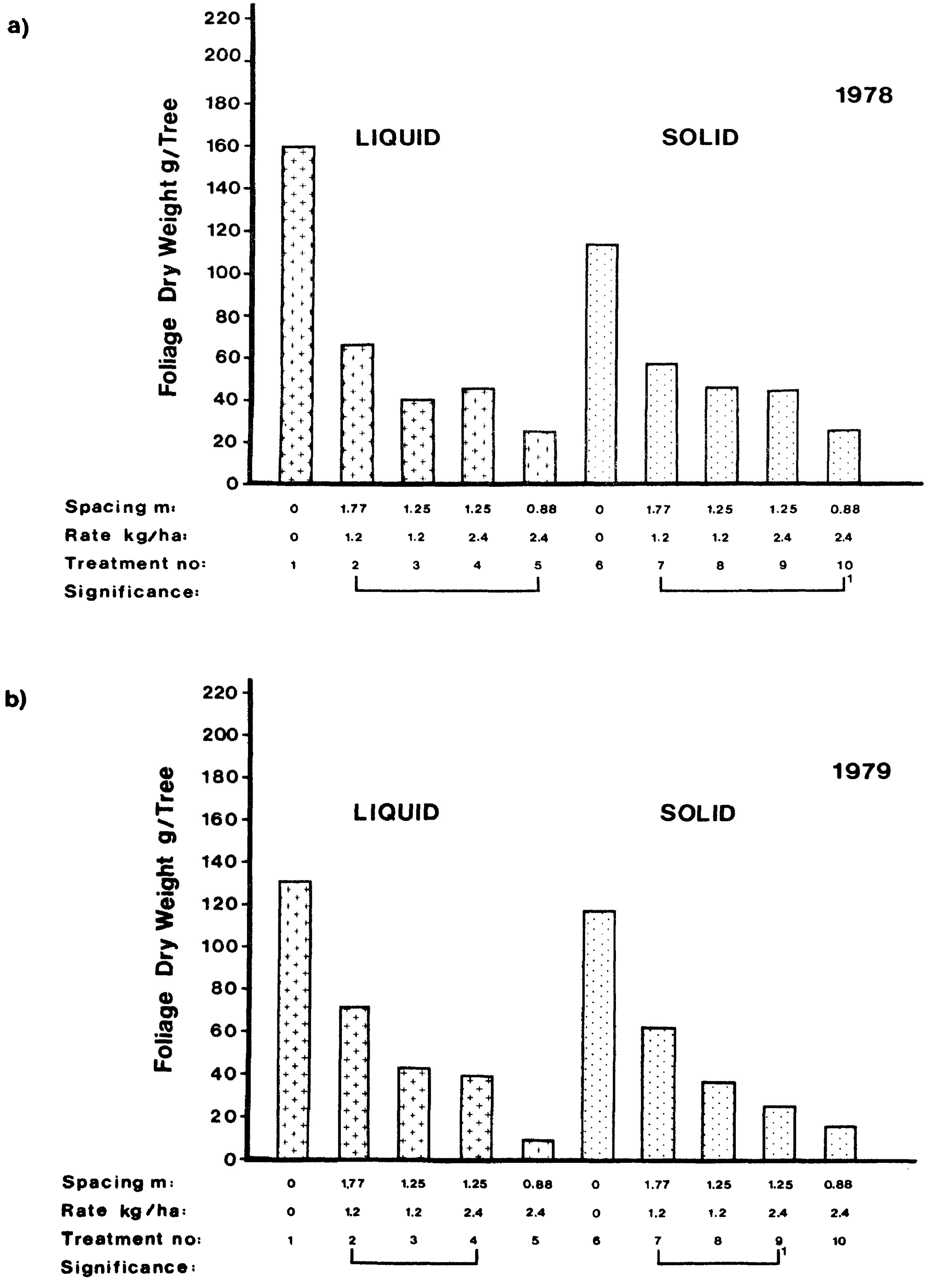
When the rate and spacing treatments were considered as an individual factor, differences in the foliage dry weights of the aspen were highly significant (P=0.01, COVAR, App. E, Table E1). The control plots had significantly higher aspen foliage dry weights than most of the hexazinone treated plots (S-N-K test, Figure 34 b). The hexazinone treated plots had progressively less foliage as herbicide rate increased and spacing decreased (Figure 34 b).

Both forms of hexazinone applied at all rates and spacings reduced the foliage dry weight of the trembling aspen over both years that the trial was measured (Figures 34 a and b).

As spacing decreased and rate increased, more defoliation occurred and the condition of the aspen was reduced (Figure 35). The form of hexazinone used caused little difference in effectiveness (Figure 35).

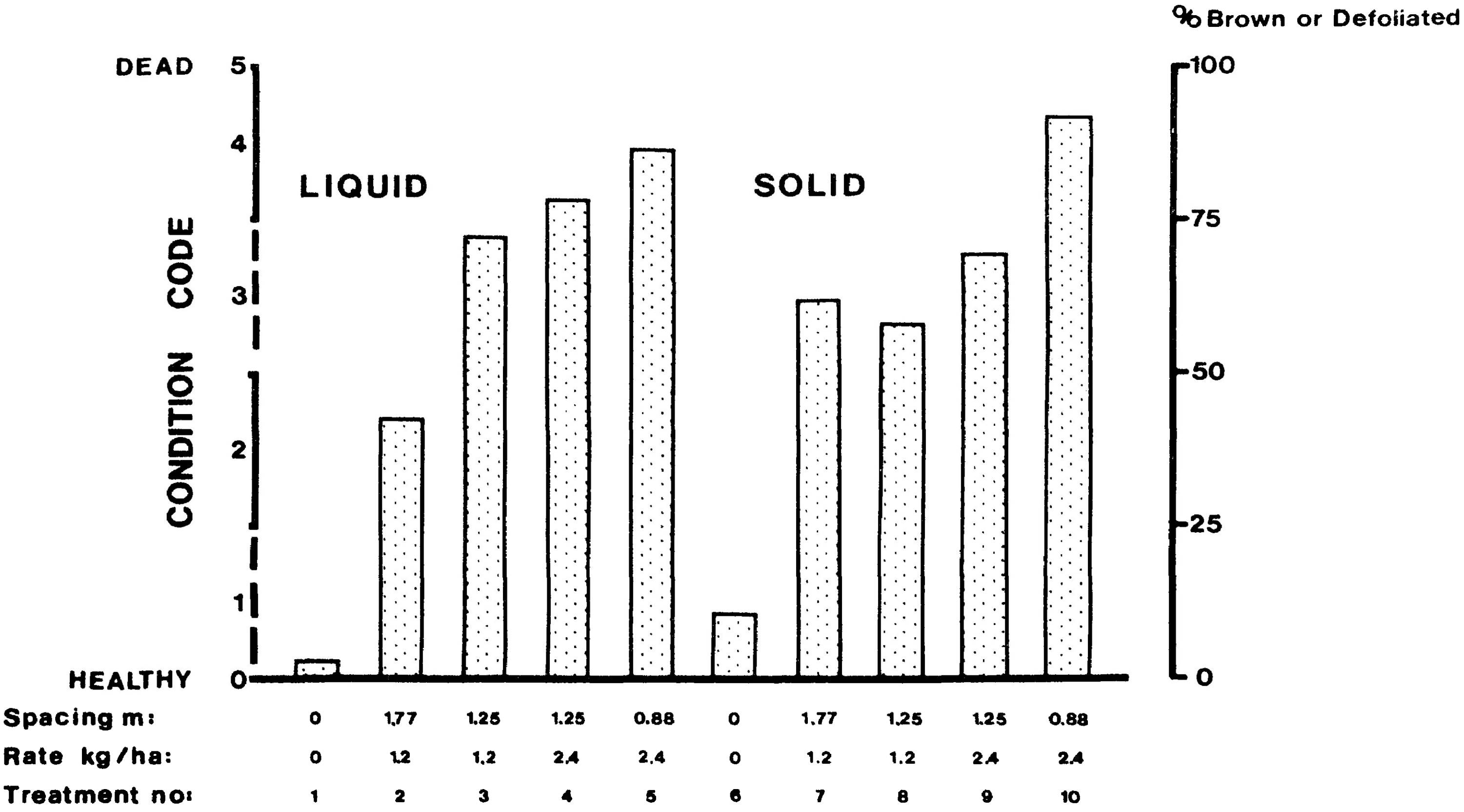
ii. Location 2:

At Location 2, differences in the foliage dry weight of the aspen over the range of hexazinone treatments were highly significant (P=0.01, COVAR, App. E, Table E3). The hexazinone treated plots had significantly lower foliage dry weights than the two control plots (S-N-K test, App. E,



Fiqure 34 The predicted foliage dry weights adjusted by covariance analysis of the aspen at Location 1

[1] Note: Rate and spacing treatments within each herbicide form that were not significantly different (P=0.05) are joined by a line



Fiqure 35 The condition code of the aspen at location 1 in 1979

Table E4).

When the two hexazinone forms were considered as an individual factor, differences in the foliage dry weights of the aspen were non-significant (COVAR, App. E, Table E3).

When the rate and spacing treatments were considered as an individual factor, differences in the foliage dry weights of the aspen were highly significant (P=0.01, COVAR, App. E, Table E3). The control plots had significantly higher aspen foliage dry weights than the hexazinone treated plots (S-N-K test, Figure 36 b).

At Location 2, results were similar to those at Location 1 (Figures 36 a and b). Hexazinone applied at all rates and spacings reduced the foliage dry weight of the trembling aspen over both 1978 (Dunsford 1979) and 1979.

As spacing decreased and rate increased, more defoliation occurred and the condition of the aspen was reduced (Figure 37). The form of hexazinone used caused little difference in effectiveness (Figure 37).

iii. Location 3:

At Location 3, differences in the foliage dry weight of the aspen over the range of hexazinone treatments were highly significant (P=0.01, COVAR, App. E, Table E5).

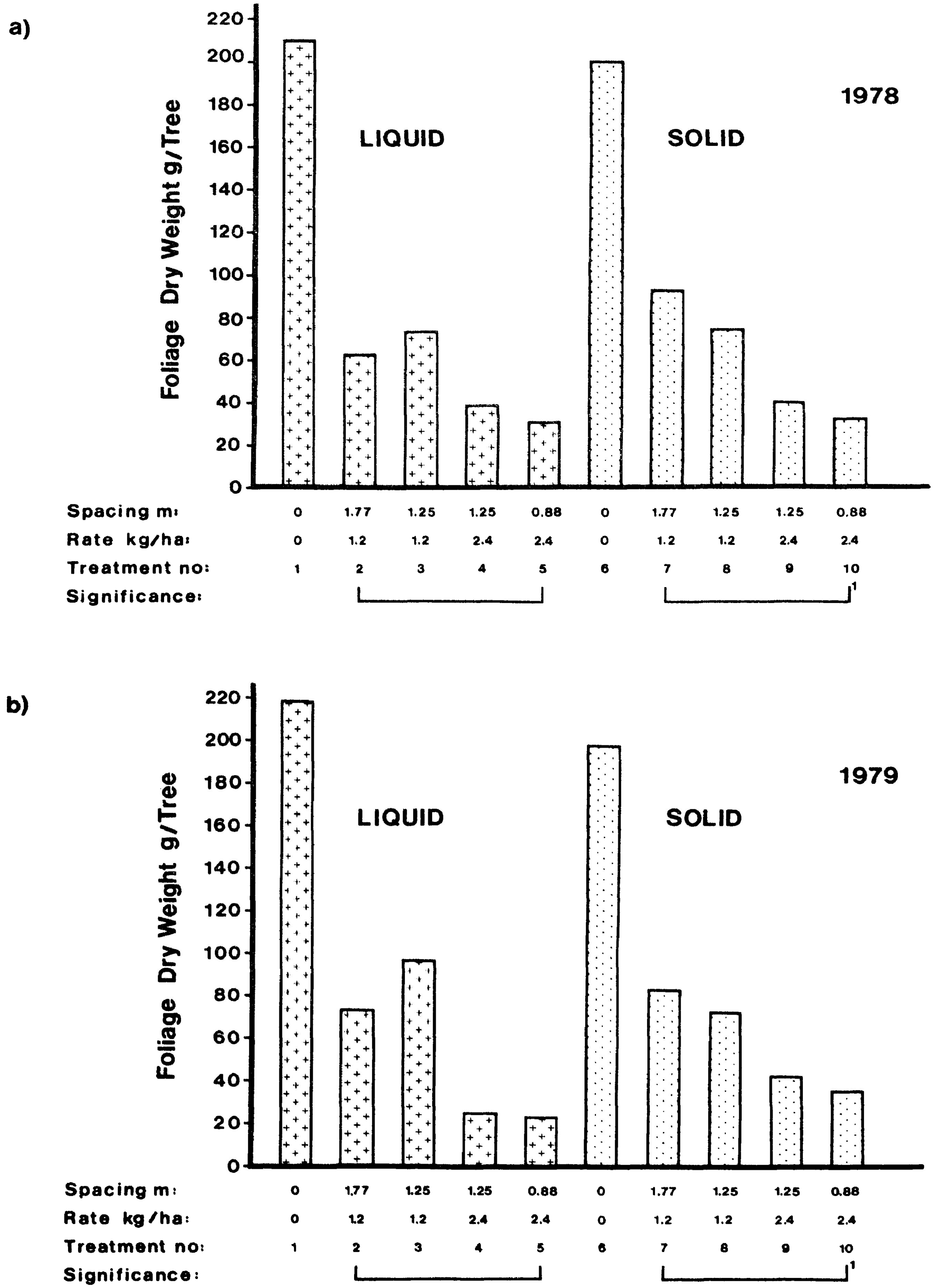
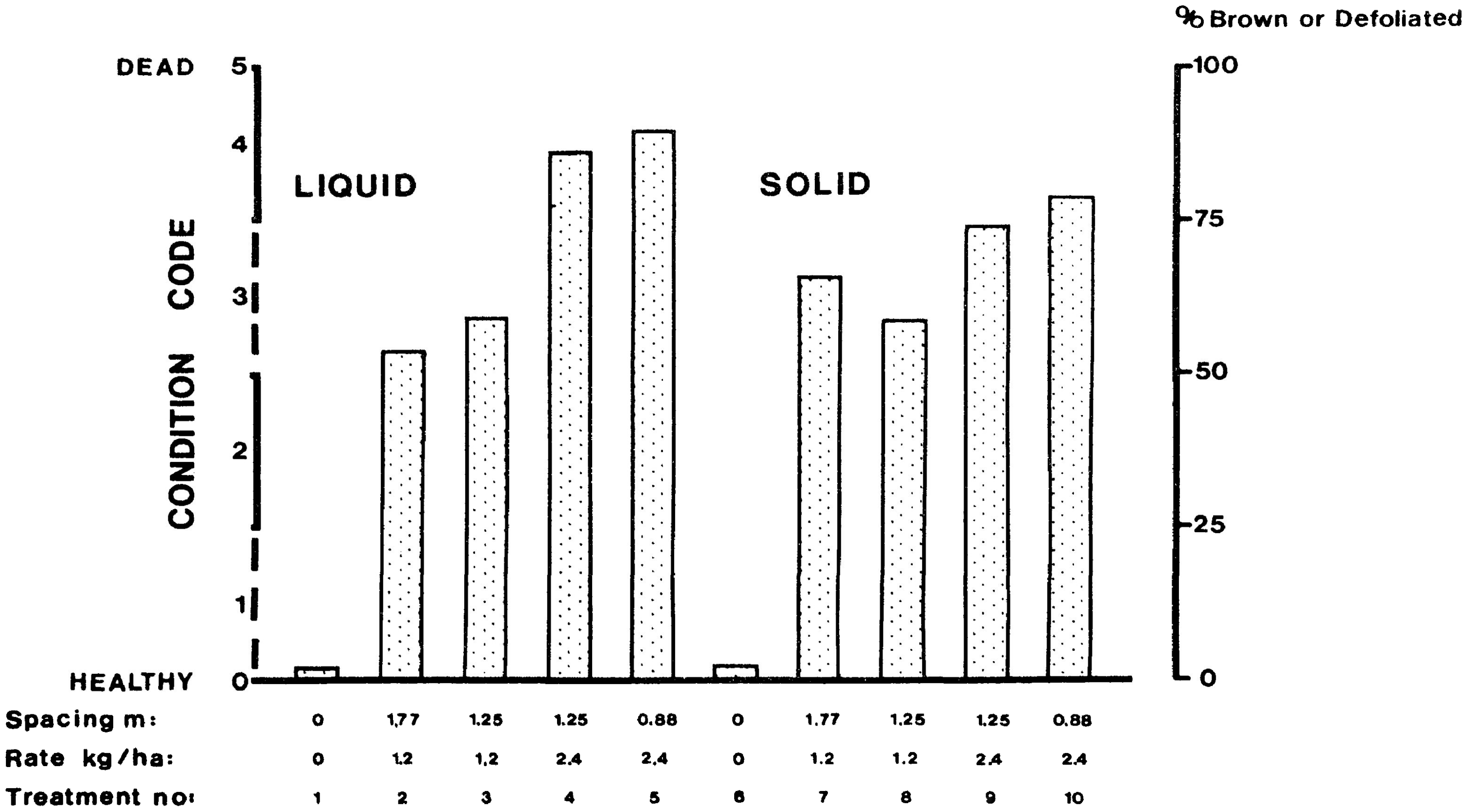


Figure 36 The predicted foliage dry weights adjusted by covariance analysis of the aspen at Location 2

[1] Note: Rate and spacing treatments within each herbicide form that were not significantly different (P=0.05) are joined by a line



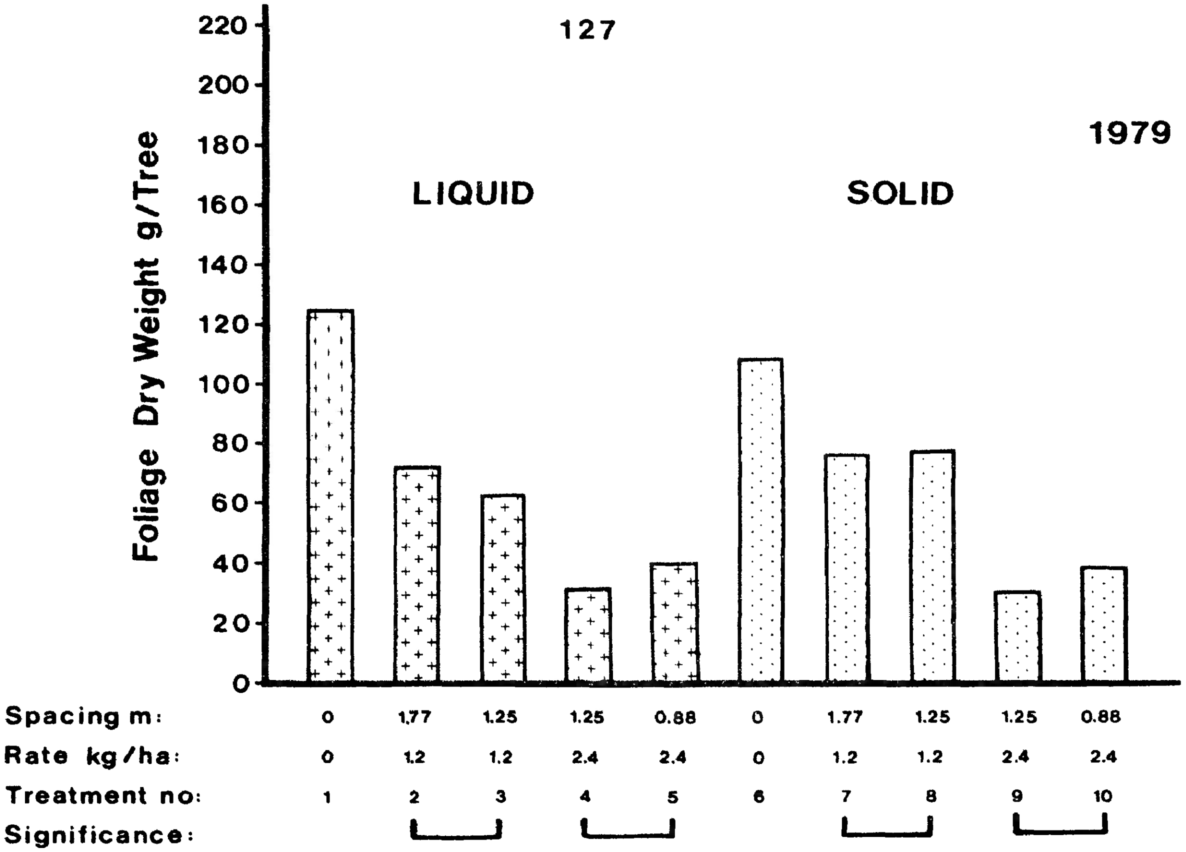
Fiqure 3 7 The condition code of the aspen at location 2 in 1979

Plots receiving both liquid and solid hexazinone forms applied at high rate, both spacings had significantly lower aspen foliage dry weights than most of the other plots (S-N-K test, App. E, Table E6). Plots receiving hexazinone applied at low rate, both spacings had significantly lower aspen foliage dry weights than one of the control plots (S-N-K test, App. E, Table E6).

When the two hexazinone forms were considered as an individual factor, differences in the foliage dry weights of the aspen were non-significant (COVAR, App. E, Table E5).

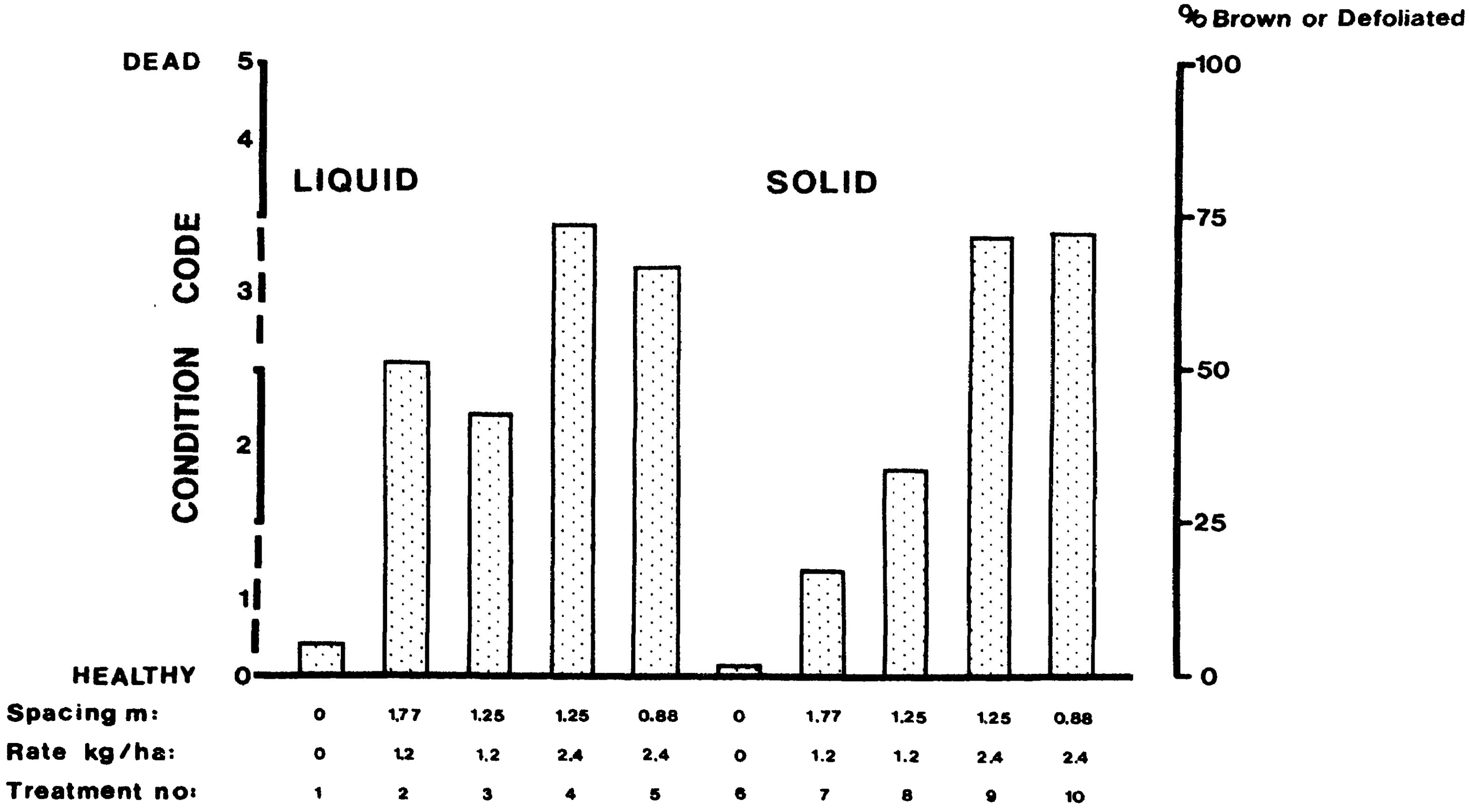
When the rate and spacing treatments were considered as an individual factor, differences in the foliage dry weights of the aspen were highly significant ($P=0.01$, COVAR, App. E, Table E5). The control plots had significantly higher foliage dry weights than the hexazinone treated plots (S-N-K test, Figure 38). Plots receiving the high hexazinone rate had significantly lower aspen foliage dry weights than plots recieving the low hexazinone rate (S-N-K test, Figure 38).

At Location 3, results were similar to those at Locations 1 and 2 (Figure 38). Hexazinone applied at all rates and spacings reduced the foliage dry weight of the aspen.



Fiqure38 The predicted foliage dry weights adjusted by covariance analysis of the aspen at Location 3

[1] Note: Rate and spacing treatments within each herbicide form that were not significantly different (P=0.05) are joined by a line



Fiqure 39 The condition code of the aspen at location 3 in 1979

As the hexazinone spacing decreased and the rate increased, more defoliation occurred and the condition of the aspen was reduced (Figure 39). The form of hexazinone used caused little difference in effectiveness (Figure 39).

2. The Seedling Survival Trials:

The results of the seedling survival trials are presented by species.

i.White Spruce:

In the white spruce study, there were significant differences between hexazinone treatments in height increment (P=0.05, ANOV, App.E Table E7). Treatment 6 (the solid control) resulted in significantly less height increment than Treatment 9 (solid form applied at 2.4 kg/ha and 1.25 metre spacing) (S-N-K test, App. E, Table E8).

When the two forms of hexazinone were considered as an individual factor, differences in height increment were non-significant (ANOV, App. E, Table E7).

When the rate and spacing treatments were considered as an individual factor, differences in height increment were highly significant (P=0.01, ANOV, App. E, Table E7). The control and the low rate of hexazinone applied at 1.25 m.

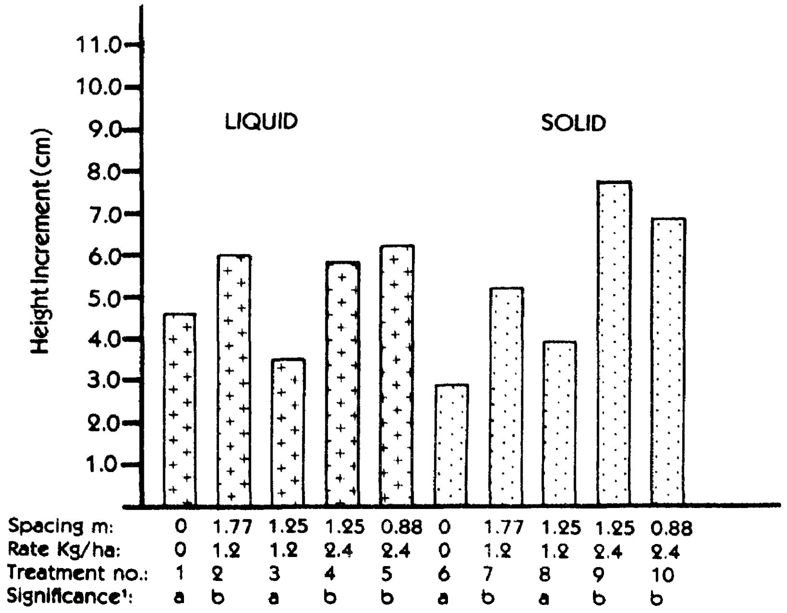


Figure 40. The height increment of the White Spruce Seedling Survival Trial.

[1] Note: Rate and spacing treatments within each herbicide form that were not significantly different (P=0.05) are assigned the same letter.

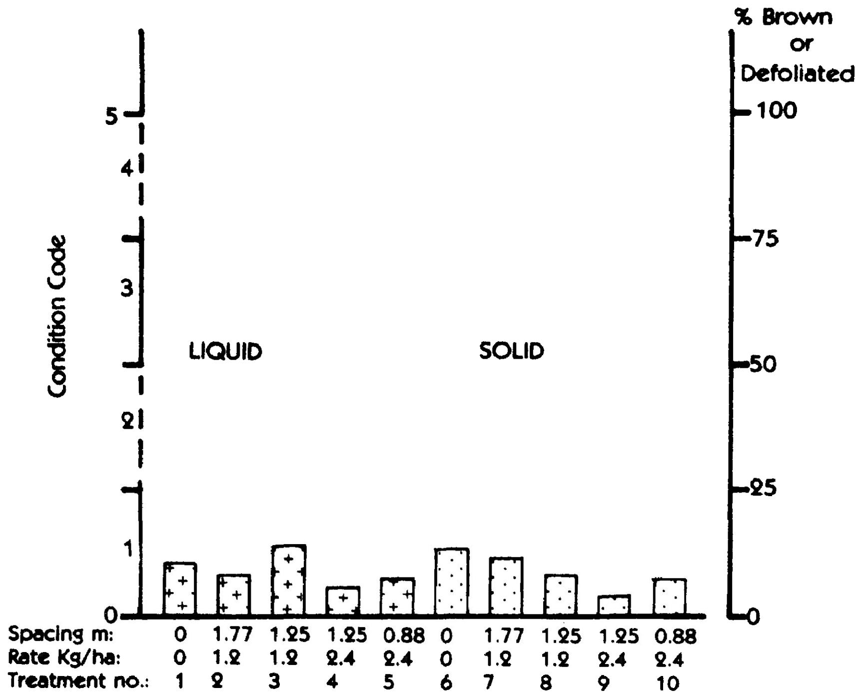


Figure 41. The condition code of the White Spruce Seedling Survival Trial.

spacing resulted in significantly lower height increments than the three other rate and spacing treatments (S-N-K test, Figure 40).

Differences in the transformed per cent survival values over the range of hexazinone treatments were non-significant (Prelim. Anal.).

The white spruce trees were all quite healthy and did not appear to be damaged by the hexazinone applied in 1978 (Figure 41).

ii.Black Spruce:

In the black spruce study, there were no significant differences in the height increment over the range of hexazinone treatments (ANOV, App. E, Table E9). There were also no significant differences in the transformed per cent survival values over the range of hexazinone treatments (ANOV, App. E, Table E10).

There do not appear to be any trends in the effect of the hexazinone applied in 1978 on the condition of the black spruce trees planted in 1979 (Figure 42).

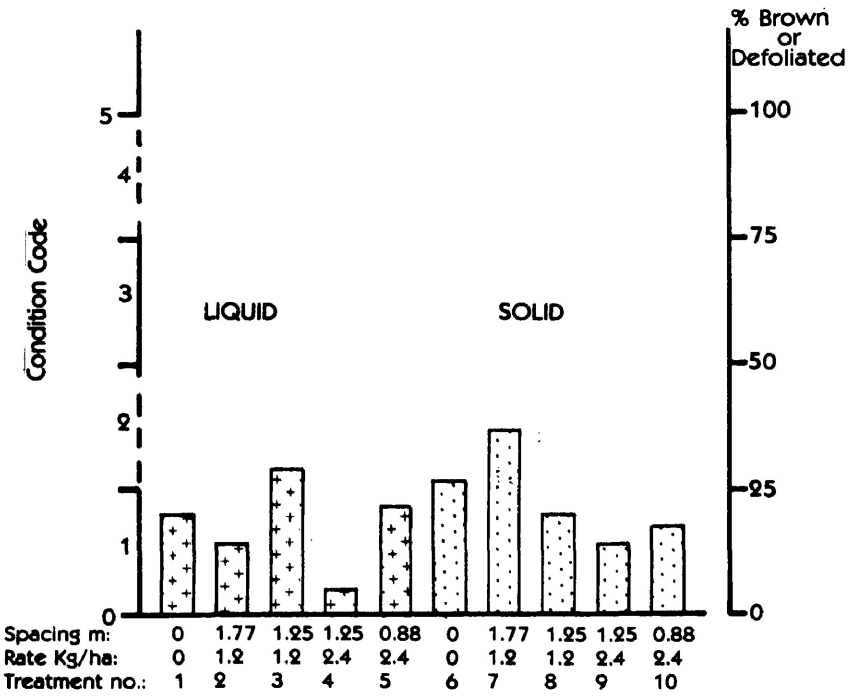


Figure 42. The condition code of the Black Spruce Seedling Survival Trial.

3. The Crop Tree Trials:

The results of each crop tree trial are presented individually.

i. White Spruce (1.5 Metre) Crop Tree Trial

Differences in the white spruce height growth over the range of hexazinone rate and spacing treatments were non significant (Prelim. Anal.). There were also no significant differences between the transformed per cent survival values over the range of hexazinone rate and spacing treatments (ANOV, App. E, Table E11).

The white spruce trees were all quite healthy and were not damaged by the hexazinone treatments (Figure 43).

ii. White Spruce (0.5 Metre) Crop Tree Trial

Differences in the white spruce height growth over the range of hexazinone rate and spacing treatments were non-significant (Prelim. Anal.). There were also no significant differences between the transformed per cent survival values over the range of hexazinone rate and spacing treatments (ANOV, App. E, Table E12).

The white spruce trees were all quite healthy and they were not damaged by the hexazinone treatments (Figure 44).

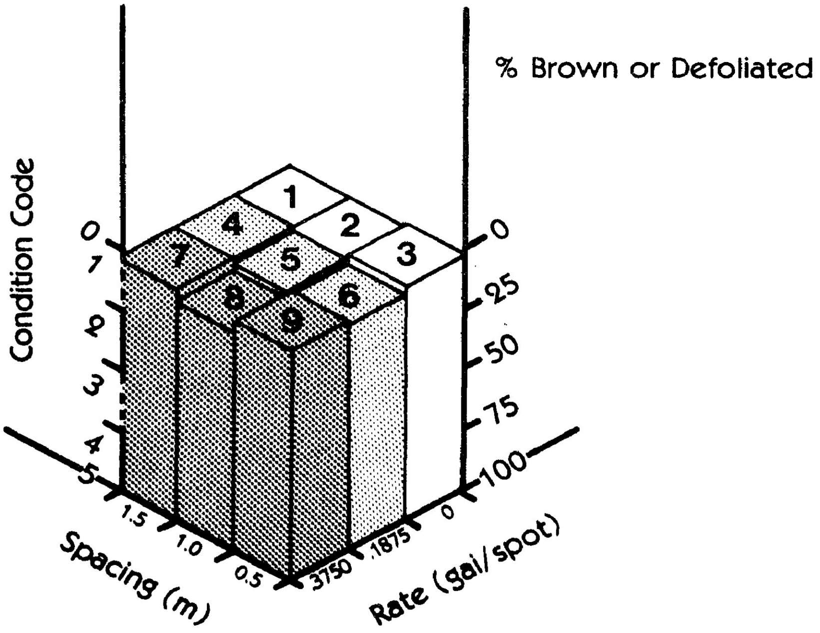


Figure 43. The condition code of the White Spruce (1.5 Metre) Crop Tree Trial.

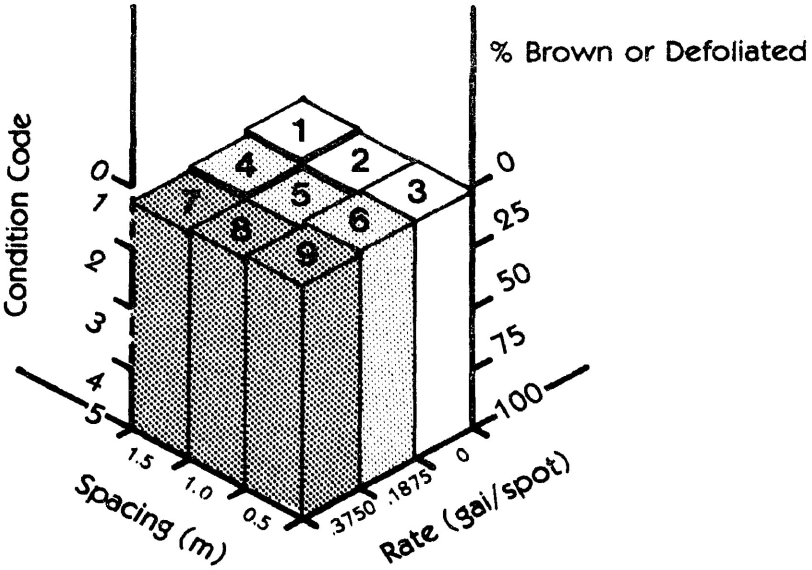


Figure 44. The condition code of the White Spruce (0.5 Metre) Crop Tree Trial.

iii. Black Spruce Crop Tree Trial

Differences in the black spruce height growth over the range of hexazinone rate and spacing treatments were non significant (Prelim. Anal.).

Differences in the transformed per cent survival values over the range of hexazinone rate and spacing treatments were highly significant (P=0.01, ANOV, App. E, Table E13). Treatment 9, the high hexazinone rate applied at the close spacing, caused significantly greater mortality than any of the other treatments (S-N-K test, Figure 45).

When the hexazinone rates were considered as an individual factor, differences between the transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E13). The high hexazinone rate caused significantly greater mortality than the control or low hexazinone rate (S-N-K test, Figure 45).

When the hexazinone spacings were considered as an individual factor, differences between the transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E13). The close hexazinone spacing caused significantly greater mortality than the medium or wide hexazinone spacings (S-N-K test, Figure 45).

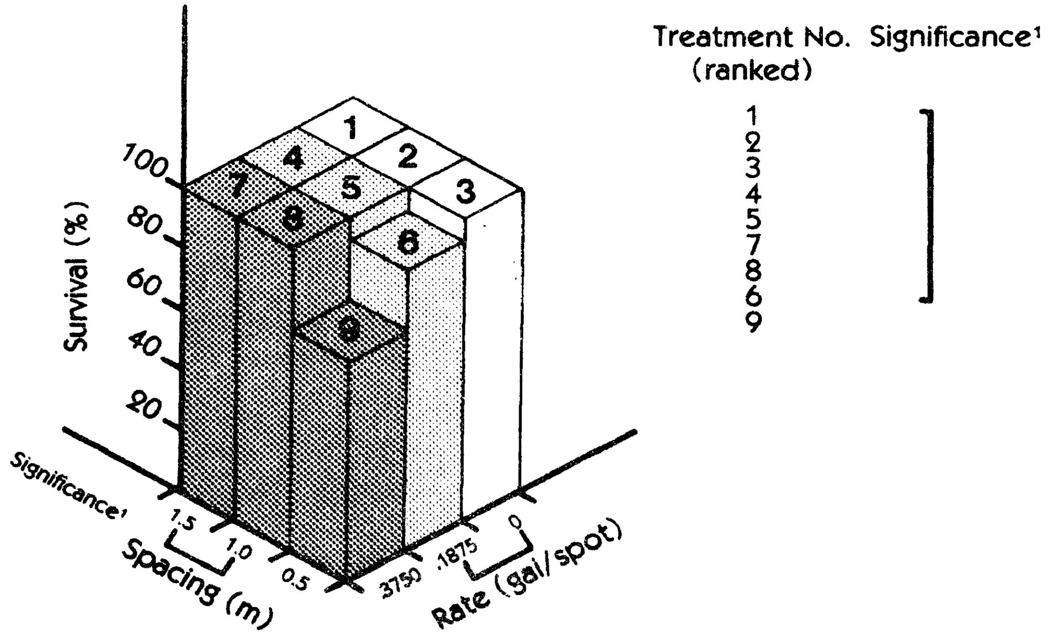


Figure45. The survival (%) of the Black Spruce Crop Tree Trial.

[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

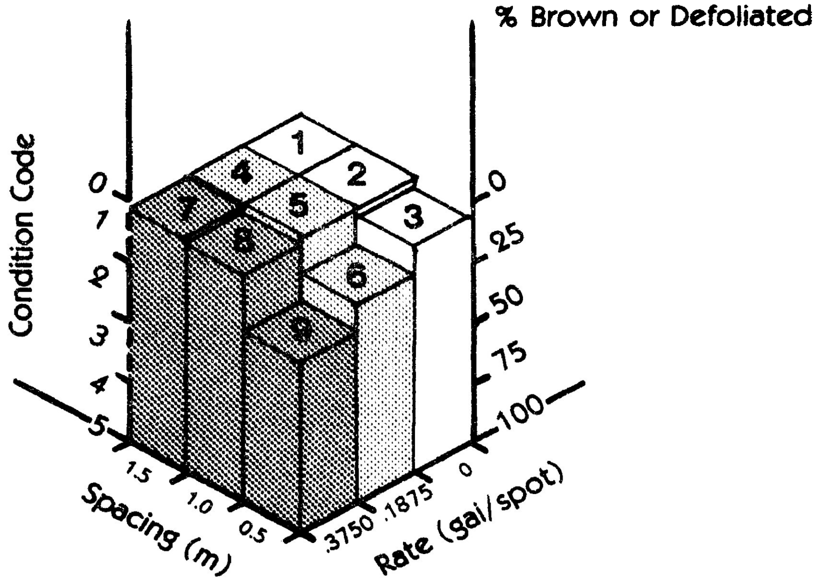


Figure46. The condition code of the Black Spruce Crop Tree Trial.

As the spacing decreased and the hexazinone rate increased, the condition of the black spruce trees declined (Figure 46).

iv. Jack Pine Crop Tree Trial

An analysis of covariance showed that there were significant differences between hexazinone treatments in jack pine height growth (P=0.05, App. E, Table E14). However, the rather discriminating S-N-K test showed that these differences were not significant and therefore treatment differences were taken to be non-significant (Figure 47).

When the hexazinone rates and the hexazinone spacings were considered as individual factors, there were no significant differences in height growth (COVAR, App. E, Table E14, Figure 47).

Differences in the transformed per cent survival values over the range of hexazinone rate and spacing treatments were significant (P=0.05, ANOV, App. E, Table E15). Treatment 9 the high hexazinone rate applied at the close spacing, caused significantly greater mortality than most of the other treatments (S-N-K test, Figure 48).

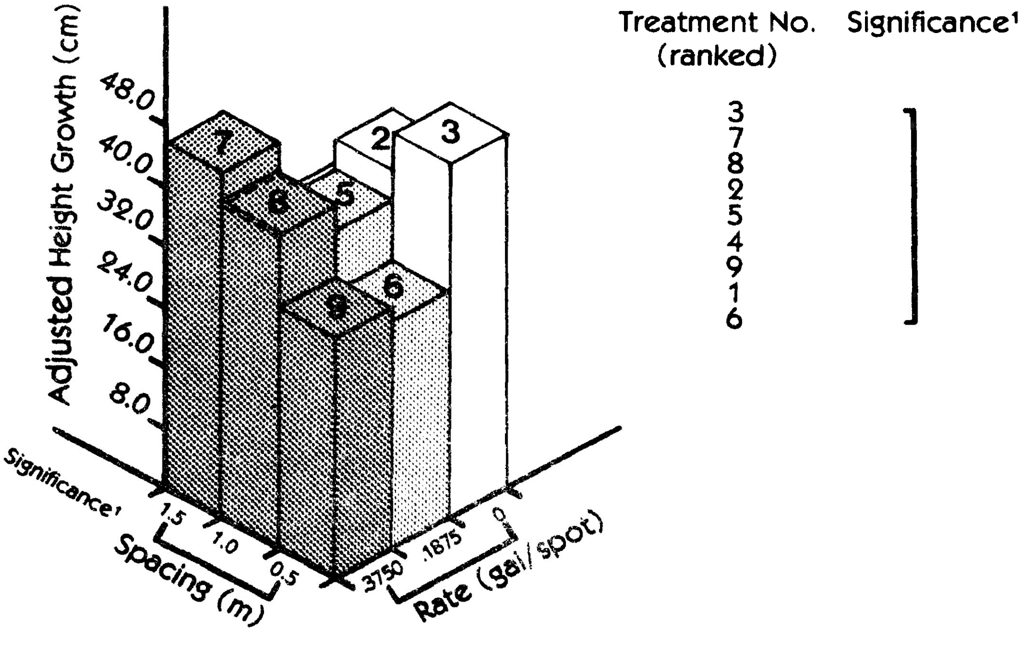


Figure 47. The height growth of the Jack Pine Crop Tree Trial adjusted by covariance analysis.

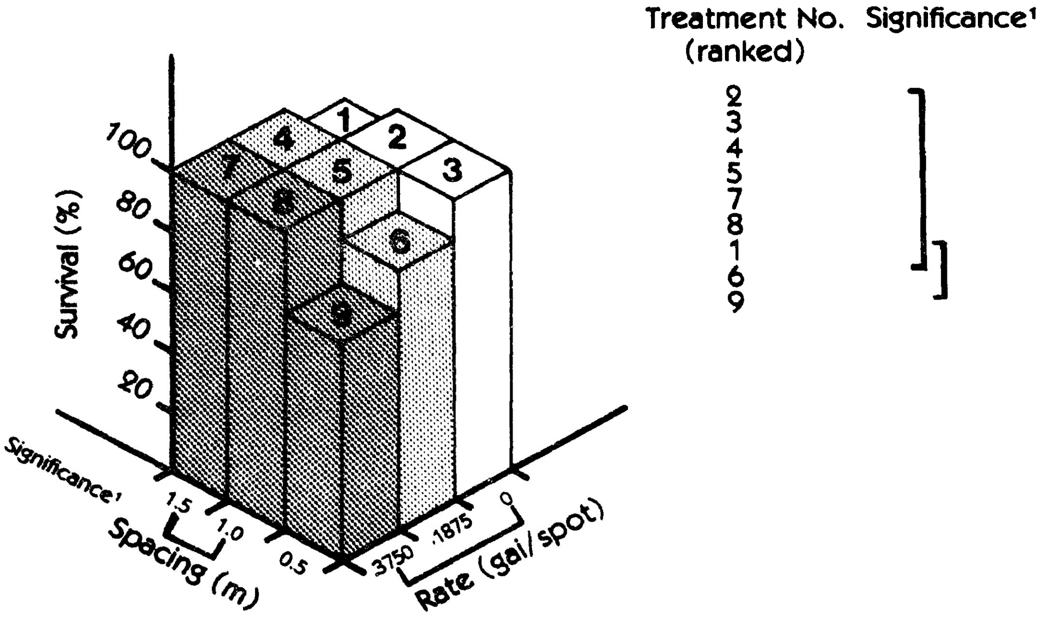


Figure 48. The survival (%) of the Jack Pine Crop Tree Trial.

[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

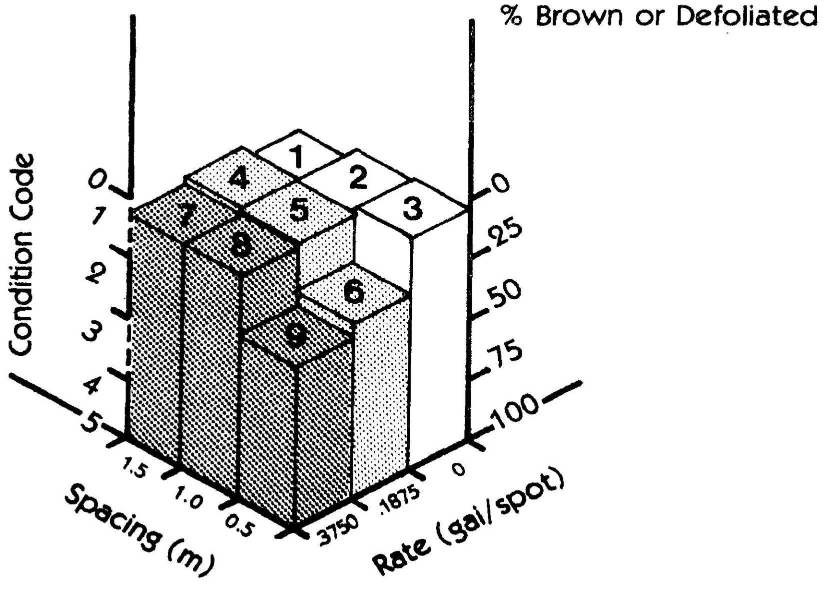


Figure 49. The condition code of the Jack Pine Crop Tree Trial.

When the hexazinone rates were considered as an individual factor, there were no significant differences in transformed per cent survival values (ANOV, App. E, Table E15 and Figure 48).

When the hexazinone spacings were considered as an individual factor, differences between the transformed per cent survival values were significant (P=0.05, ANOV, App. E, Table E15). The close hexazinone spacing caused significantly greater mortality than the medium or wide hexazinone spacings (S-N-K test, Figure 48).

As the hexazinone rate increased and the spacing decreased, the condition of the jack pine trees declined (Figure 49).

4. The Weed Tree and Brush Trials:

The results of both weed tree and brush trials are presented individually.

i. Aspen Weed Tree Trial

In the Aspen Weed Tree Trial, differences in the height growth over the range of hexazinone rate and spacing treatments were highly significant (P=0.01, COVAR, App. E,

Table E16). Treatments 8 and 12 (hexazinone applied at the closest spacing at both the low and high rates) resulted in significantly less height growth than some of the controls (S-N-K test, Figure 50).

When the hexazinone rates were considered as an individual factor, differences in height growth were highly significant (P=0.01, COVAR, App. E, Table E16). Both the low and high hexazinone rates resulted in significantly less height growth than the control (S-N-K test, Figure 50).

When the hexazinone spacings were considered as an individual factor, differences in height growth were significant (P=0.05, COVAR, App. E, Table E16). The closest spacing resulted in significantly less height growth than the other three spacing treatments (S-N-K test, Figure 50).

Differences in the transformed per cent survival values over the range of hexazinone rate and spacing treatments were highly significant (P=0.01, ANOV, App. E, Table E17). Treatments 8 and 12 (hexazinone applied at the closest spacing at both the low and high rates) caused significantly greater mortality than some of the control treatments (S-N-K test, Figure 51).

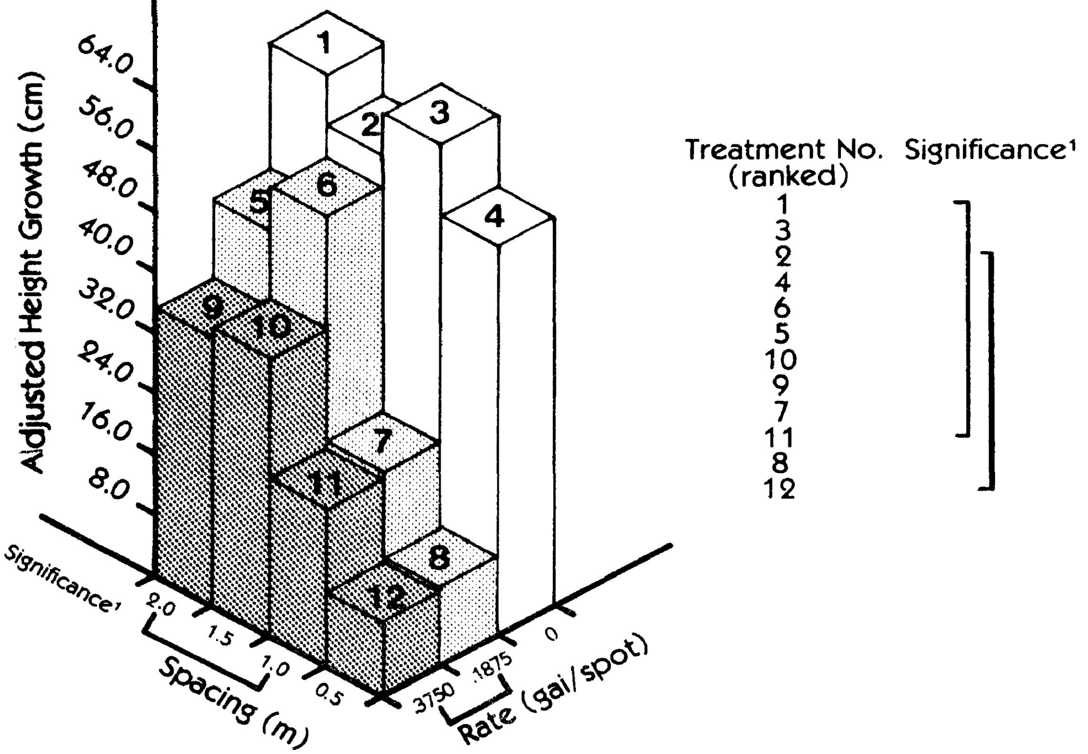


Figure 50. The height growth of the Aspen Weed Tree Trial adjusted by covariance analysis.

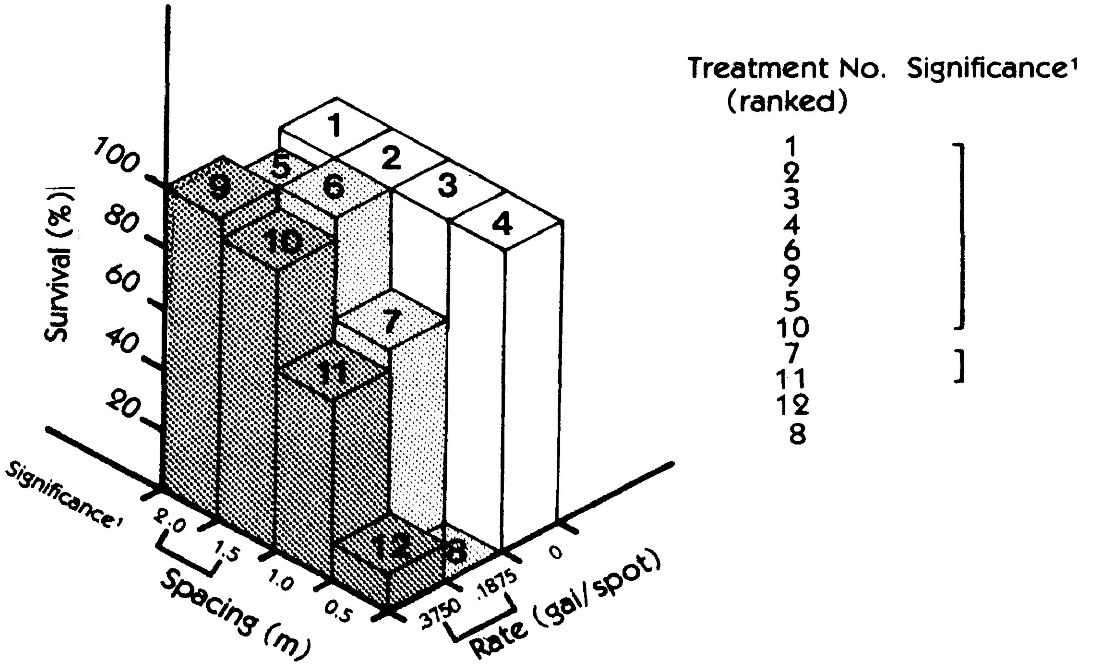


Figure 51. The survival (%) of the Aspen Weed Tree Trial.

[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

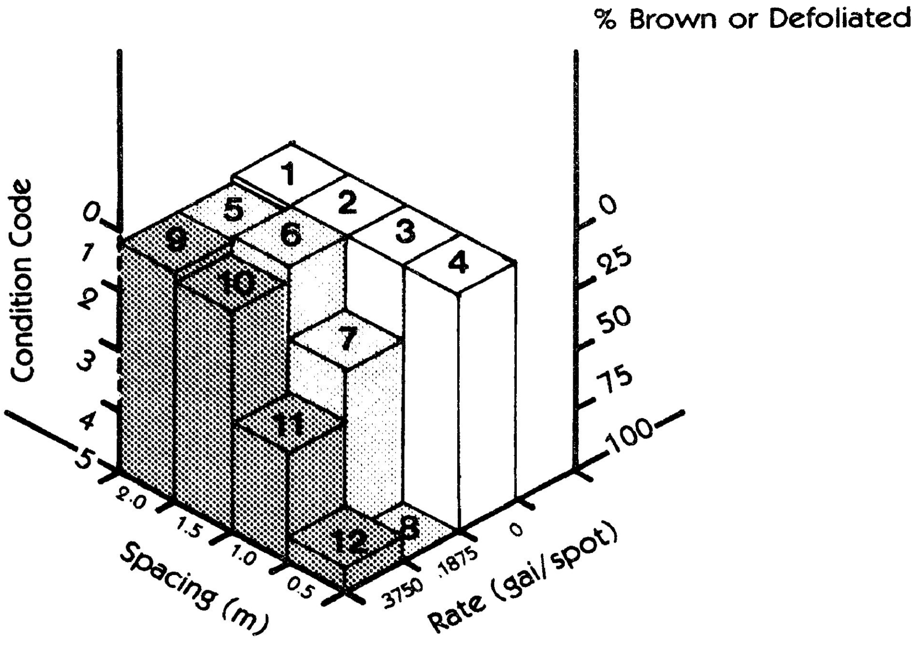


Figure 52. The condition code of the Aspen Weed Tree Trial.

When the hexazinone rates were considered as an individual factor, differences between the transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E17). Both the low and the high hexazinone rates caused significantly greater mortality than the control (S-N-K test, Figure 51).

When the hexazinone spacings were considered as an individual factor, differences between the transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E17). The two closest spacings were significantly different from each other, the closest spacing causing the greatest mortality. The two closest spacings both caused significantly greater mortality than the two widest spacings (S-N-K test, Figure 51).

As the hexazinone rate increased and the spacing decreased, the condition of the aspen trees declined (Figure 52).

ii. Willow Brush Trial.

In the Willow Brush Trial, differences in the total stem growth over the range of hexazinone rate and spacing treatments were highly significant (P=0.01, COVAR, App. E, Table E18). One of the control treatments resulted in significantly more total stem growth than any of the other treatments (S-N-K test, Figure 53).

When the hexazinone rates were considered as an individual factor, differences in the total stem growth were highly significant (P=0.01, COVAR, App. E, Table E18). Both the low and high hexazinone rates resulted in significantly less total stem growth than the control (S-N-K test, Figure 53).

When the number of hexazinone spots applied was considered as an individual factor, there were no significant differences in total stem growth (COVAR, App. E, Table E18 and Figure 53).

Differences in the transformed per cent survival values over the range of hexazinone rate and spacing treatments were highly significant (P=0.01. ANOV, App. E, Table E19). Treatment 9 (high rate - 4 herbicide spots) caused significantly greater mortality than any of the other treatments (S-N-K test, Figure 54). Treatments 6, 7 and 8 (low rate - 4 hexazinone spots, high rate - 1 hexazinone spot and high rate - 2 hexazinone spots) caused significantly greater mortality than the three controls and treatments 4 and 5 (low rate - 1 hexazinone spot and low rate - 2 hexazinone spots) (S-N-K test, Figure 54).

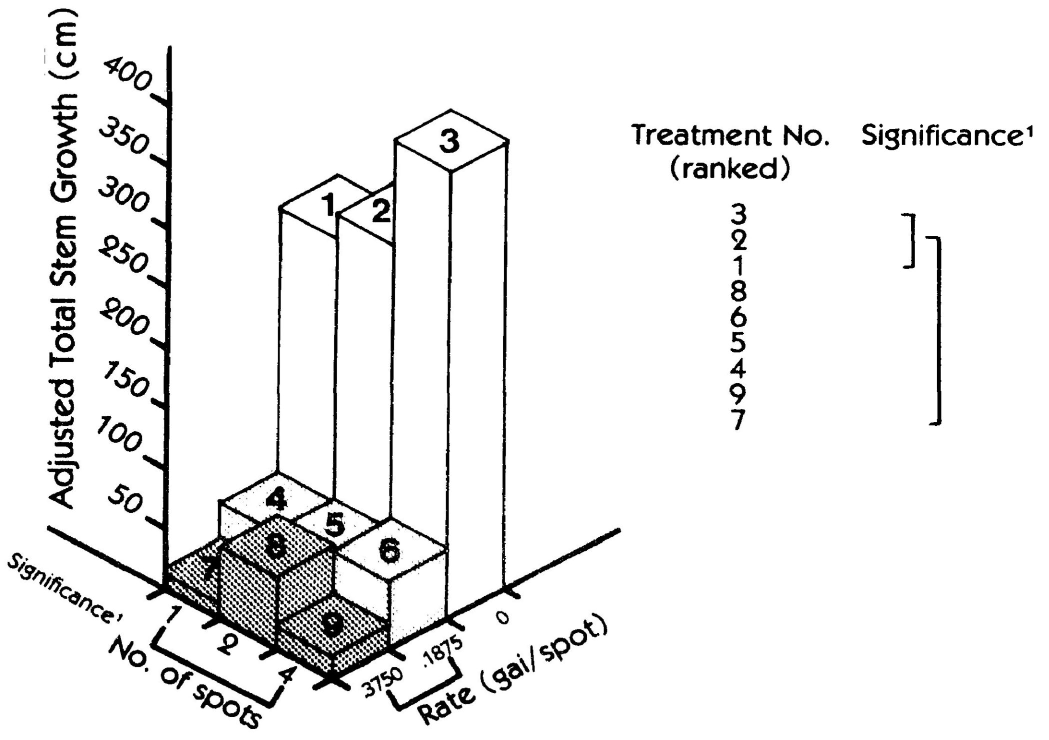


Figure 53. The total stem growth of the Willow Brush Trial adjusted by covariance analysis.

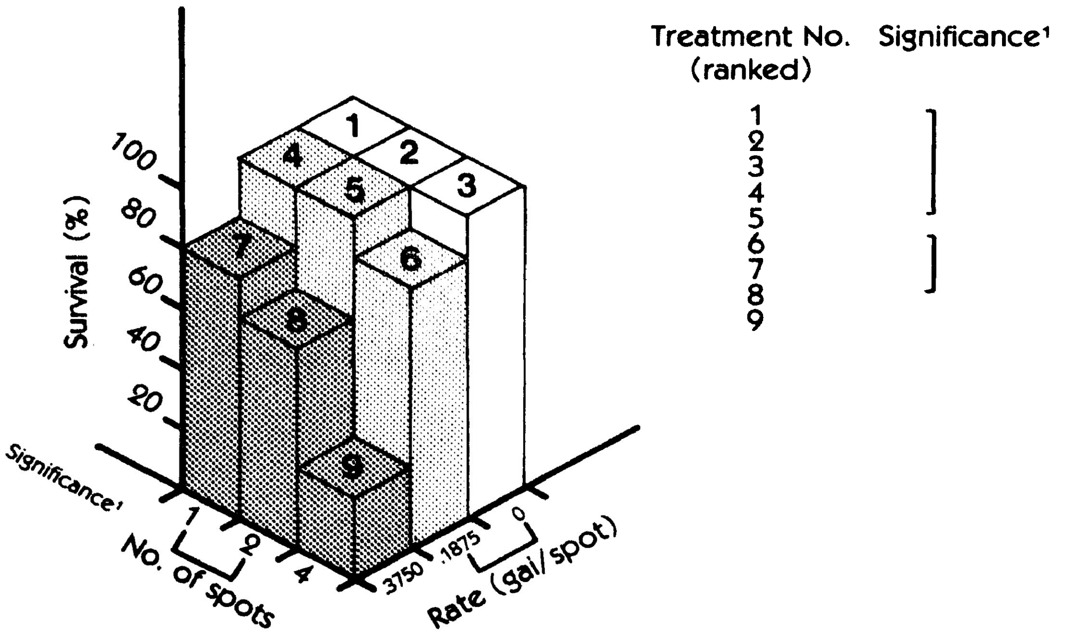


Figure 54. The survival (%) of the Willow Brush Trial

[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

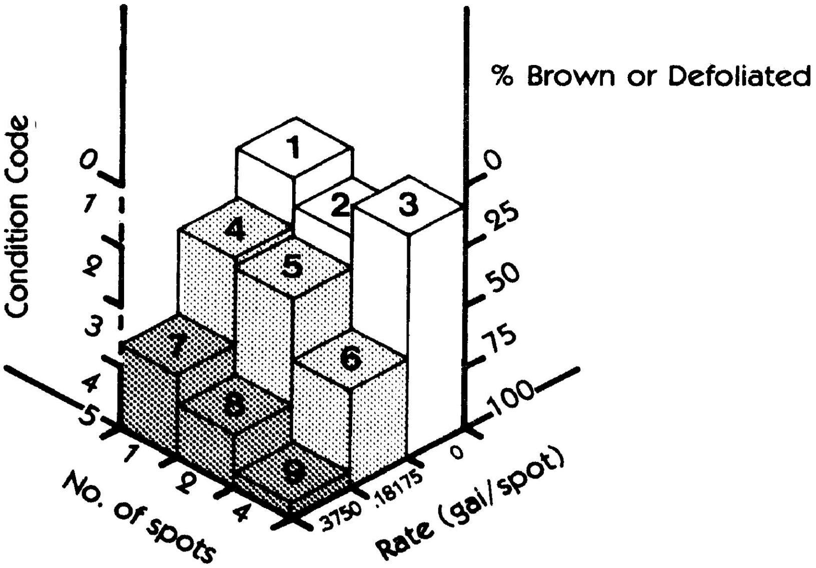


Figure 55. The condition code of the Willow Brush Trial

When the hexazinone rates were considered as an individual factor, differences between transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E19). The high hexazinone rate caused significantly greater mortality than the low hexazinone rate or the control (S-N-K test, Figure 54).

When the number of hexazinone spots applied was considered as an individual factor, differences between transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E19). Shrubs receiving 4 herbicide spots suffered significantly greater mortality than those receiving 1 or 2 herbicide spots (S-N-K test, Figure 54).

Differences in the transformed per cent survival values between the replications were significant (P=0.05, ANOV, App. E, Table E19). Replication 3 had significantly lower transformed per cent survival values than Replication 1 (S-N-K test).

As the hexazinone rate increased and the number of herbicide spots increased, the condition of the willow shrubs declined (Figure 55).

5. The Mature Aspen Trial

Differences in the mature aspen transformed per cent survival values over the range of hexazinone treatments were highly significant (P=0.01, ANOV, App. E, Table E20). The small and medium diameter classes receiving 4 and 6 hexazinone spots suffered significantly greater mortality than the control treatments or the large diameter classes receiving 2 hexazinone spots (S-N-K test, App. E, Table E21). As the tree diameter decreased and the number of hexazinone spots increased, the per cent survival of aspen tended to decrease.

When the two hexazinone forms were considered as an individual factor, there were no significant differences between transformed per cent survival values (ANOV, App. E, Table E20).

When the hexazinone rates were considered as an individual factor, differences between transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E20). All of the hexazinone rate treatments were significantly different from each other, the highest rates causing the greatest mortality (S-N-K test, Figure 56).

When the diameter classes were considered as an individual factor, differences between transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E20). The small and medium diameter classes

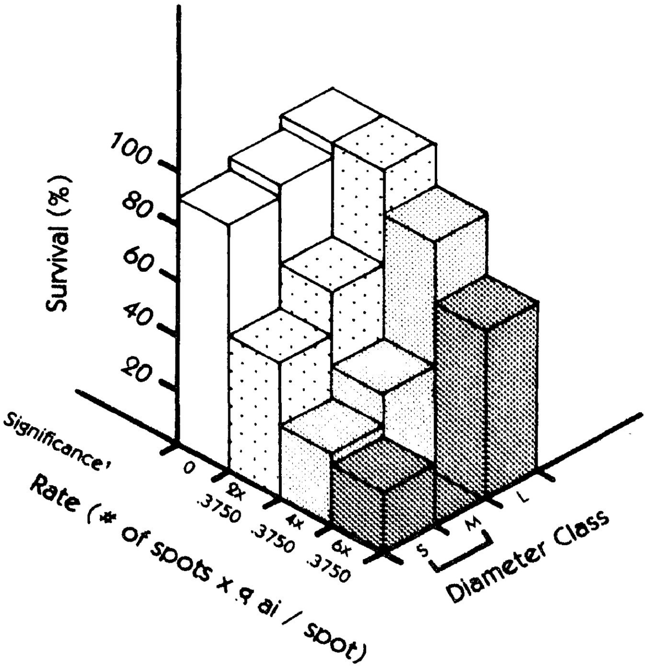


Figure 56. The survival (%) of the Mature Aspen Trial. The solid and liquid treatments applied at the same rate to trees of the same diameter class are combined.

[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

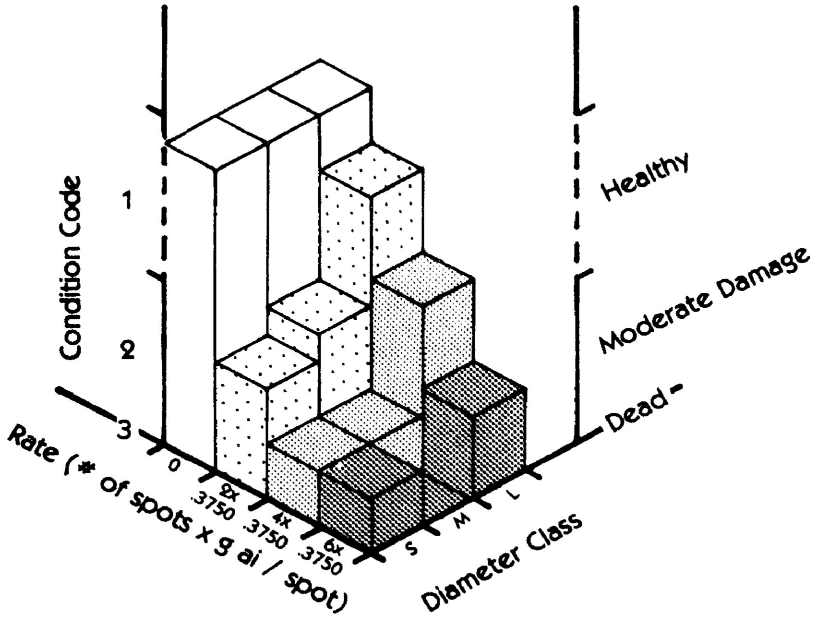


Figure 57. The condition code of the Mature Aspen Trial. The solid and liquid treatments applied at the same rate to trees of the same diameter class are combined.

suffered significantly greater mortality than the large diameter classes (S-N-K test, Figure 56).

As the hexazinone rate increased and the diameter class decreased, the condition of the mature aspen trees declined (Figure 57).

6. The Greenhouse Trials:

The results of each greenhouse trial are presented individually.

i. Jack Pine:

Differences in the jack pine transformed per cent survival values over the range of hexazinone rate and position treatments were highly significant (P=0.01, ANOV, App. E, Table E23). Treatments 4, 6 and 7 (hexazinone applied to foliage at 8.16 g ai/4m^2 and hexazinone applied to foliage and soil at rates of 2.04 and 4.08 g ai/4m^2) caused significantly greater mortality than treatments 1, 2, 3 and 5 (hexazinone applied to foliage at rates of 0, 2.04 and 4.08 g ai/4m^2 and hexazinone applied to foliage and soil at 0 g ai/4m^2) (S-N-K test, Figure 58). Treatment 8

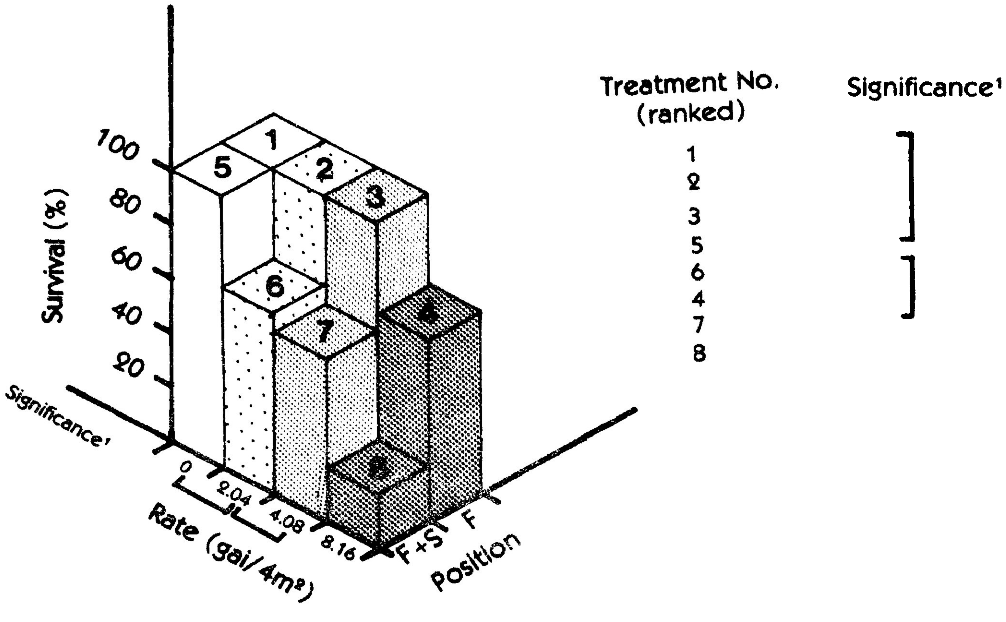


Figure 58. The survival (%) of the Jack Pine Greenhouse Trial.

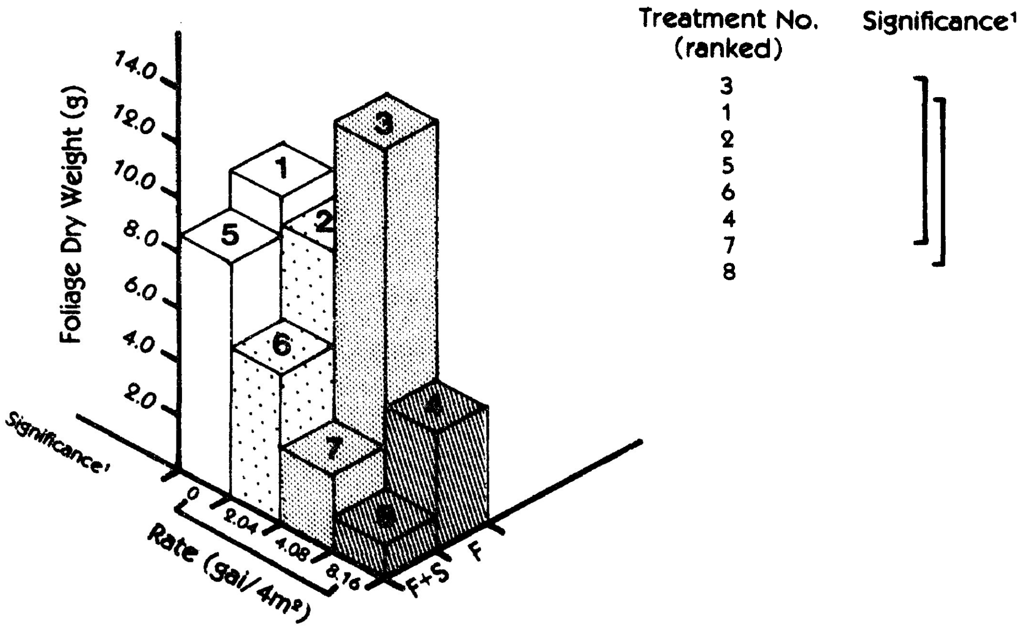


Figure 59. The actual foliage dry weight of the Jack Pine Greenhouse Trial.

[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

(hexazinone applied to foliage and soil at 8.16 g ai/4m^2) caused significantly greater mortality than any of the other treatments (S-N-K test, Figure 58).

When the hexazinone rates were considered as an individual factor, differences between the transformed per cent survival values were highly significant ($P=0.01$, ANOV, App. E, Table E23). The highest hexazinone rate (8.16 g ai/4m^2) caused significantly greater mortality than the other three hexazinone rates (S-N-K test, Figure 58). The 4.08 g ai/4m^2 rate caused significantly greater mortality than the controls (S-N-K test, Figure 58).

When hexazinone was applied at the foliage and soil position, jack pine survival was significantly less than when hexazinone was only applied at the soil position ($P=0.01$, ANOV, S-N-K test, App. E, Table E23. Figure 58).

Differences in foliage dry weights over the range of hexazinone rate and position treatments were significant ($P=0.05$, ANOV, App. E, Table E22). Treatment 8 (hexazinone applied to foliage and soil at 8.16 g ai/4m^2) resulted in significantly lower foliage dry weight than treatment 3 (hexazinone applied to foliage at 4.08 g ai/4m^2) (S-N-K test, Figure 59).

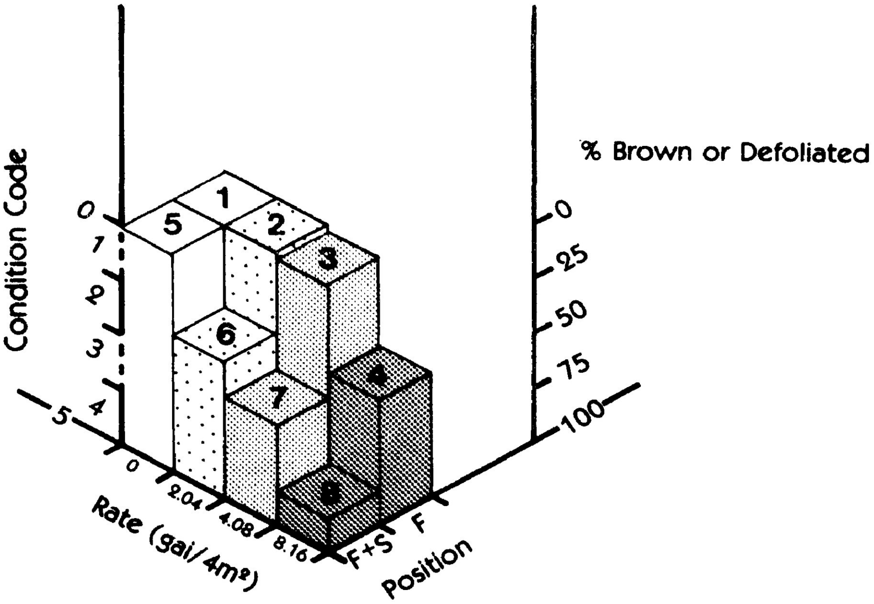


Figure 60 The condition code of the Jack Pine Greenhouse Trial.

When the hexazinone rates were considered as an individual factor, there were no significant differences in foliage dry weights (ANOV, App. E, Table E22 and Figure 59).

When hexazinone was applied at the foliage and soil position, jack pine foliage dry weight was significantly less than when hexazinone was only applied at the soil position ($P=0.05$, ANOV, S-N-K test, App.E, Table E22, Figure 59).

As the hexazinone rate increased and the position changed from foliage to foliage and soil, the condition of the jack pine trees declined (Figure 60).

ii. White Spruce

Differences in the white spruce transformed per cent survival values over the range of hexazinone rate and position treatments were highly significant ($P=0.01$, ANOV, App. E, Table E25). Treatments 7 and 8 (hexazinone applied to foliage and soil at rates of 4.08 and 8.16 g ai/4m^2) caused significantly greater mortality than any of the other treatments (S-N-K test, Figure 61). The two controls had significantly higher transformed per cent survival values than most of the other treatments (S-N-K test, Figure 61).

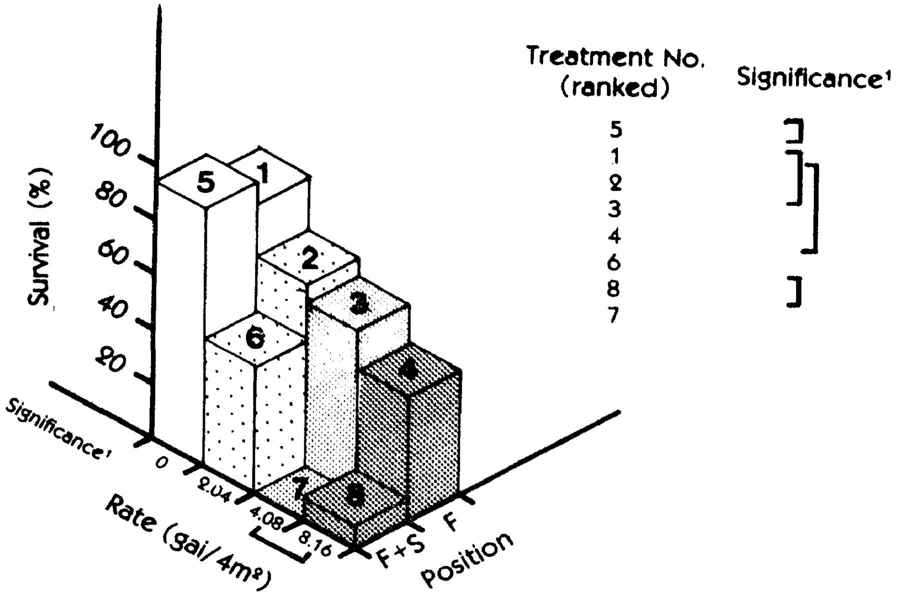


Figure 61. The survival (%) of the White Spruce Greenhouse Trial.

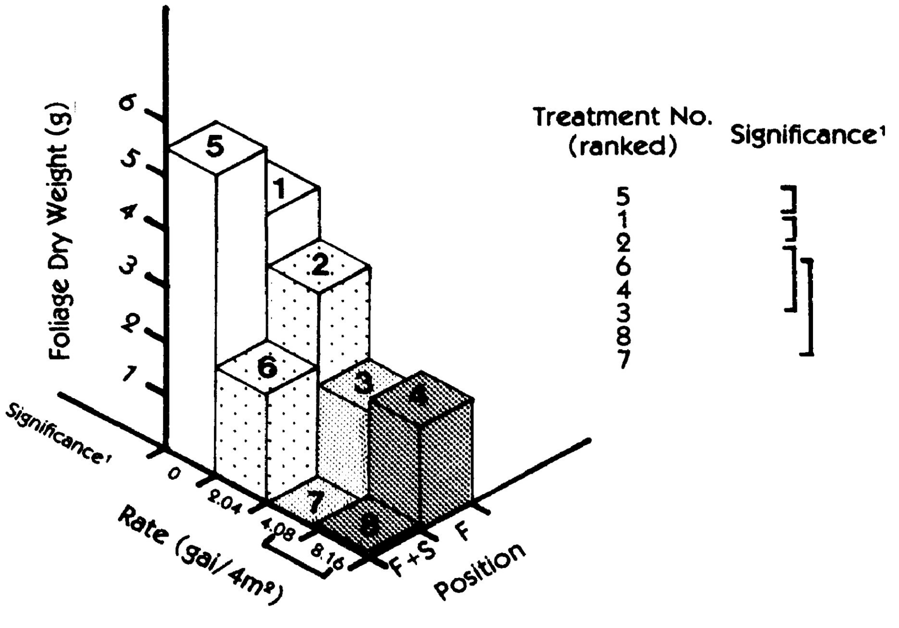


Figure 62. The actual foliage dry weight of the White Spruce Greenhouse Trial.

[1] Note: Treatments that were not significantly different (P=0.0s) are joined by a line.

When the hexazinone rates were considered as an individual factor, differences between the transformed per cent survival values were highly significant (P=0.01, ANOV, App. E, Table E25). The two highest rates (4.08 and 8.16 g ai/4m^2) caused significantly greater mortality than the other two rates (S-N-K test, Figure 61). The 2.04 g ai/4m^2 rate caused significantly greater mortality than the controls (S-N-K test, Figure 61).

When hexazinone was applied at the foliage and soil position, white spruce survival was significantly less than when hexazinone was only applied at the soil position (P=0.01, ANOV, S-N-K test, App. E, Table E 25, Figure 61).

Differences in the white spruce foliage dry weights over the range of hexazinone rate and position treatments were highly significant (P=0.01, ANOV, App. E, Table E24). The two control treatments resulted in significantly higher foliage dry weights than most of the other treatments (S-N-K test, Figure 62). Treatment 2 (hexazinone applied to foliage at 2.04 g ai/4m^2) resulted in significantly higher foliage dry weights than treatments 7 and 8 (hexazinone applied to foliage and soil at rates of 4.08 and 8.16 g ai/4m^2) (S-N-K test, Figure 62).

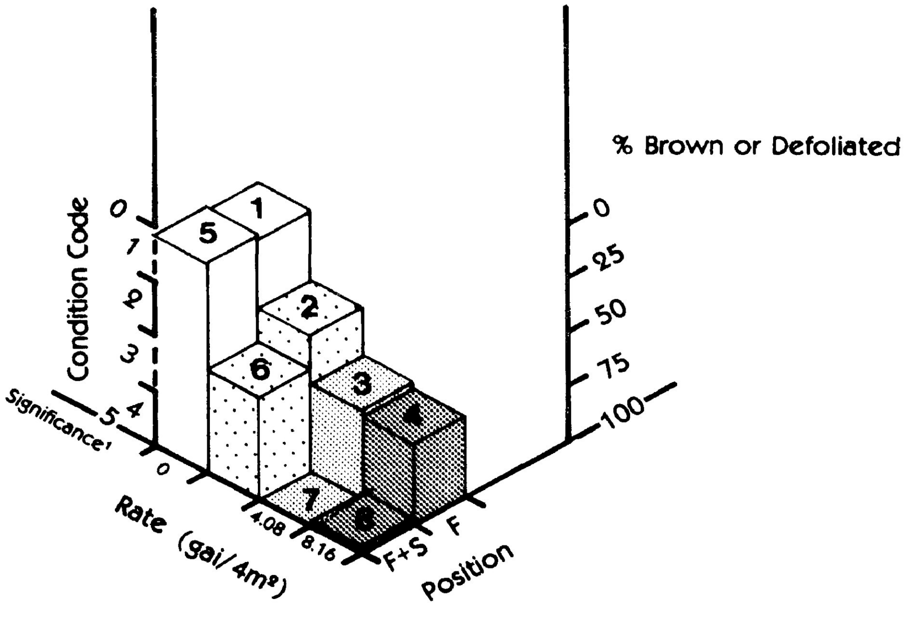


Figure 63. The condition code of the White Spruce Greenhouse Trial.

When the hexazinone rates were considered as an individual factor, differences in foliage dry weights were highly significant (P=0.01, ANOV, App. E, Table E24). The two highest rates (4.08 and 8.16 g ai/4m^2) resulted in significantly lower foliage dry weights than the controls or the 2.04 g ai/4m^2 rate (S-N-K test, Figure 62). The 2.04 g ai/4m^{2}rate resulted in significantly lower foliage dry weights than the controls (S-N-K test, Figure 62).

When hexazinone was applied at the foliage and soil position, white spruce foliage dry weight was significantly less than when hexazinone was only applied at the soil position (P=0.05, ANOV, S-N-K test, App. E, Table E24, Figure 62).

As the hexazinone rate increased and the spray position changed from foliage to foliage and soil, the condition of the white spruce trees declined (Figure 63).

iii. Aspen

Differences in the aspen transformed per cent survival values over the range of hexazinone rate treatments were highly significant (P=0.01, ANOV, App. E, Table E26). The control resulted in significantly higher transformed per cent survival values than any of the other treatments (S-N-K test, Figure 64).

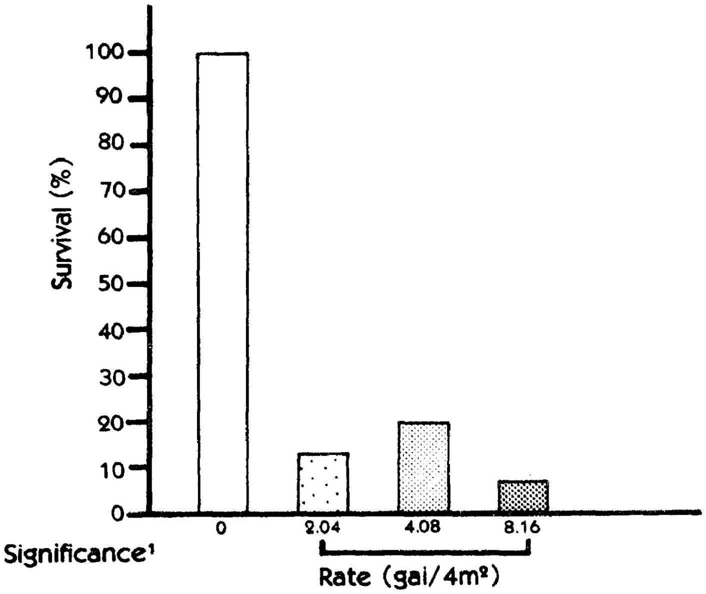


Figure 64. The survival (%) of the Aspen Greenhouse Trial.

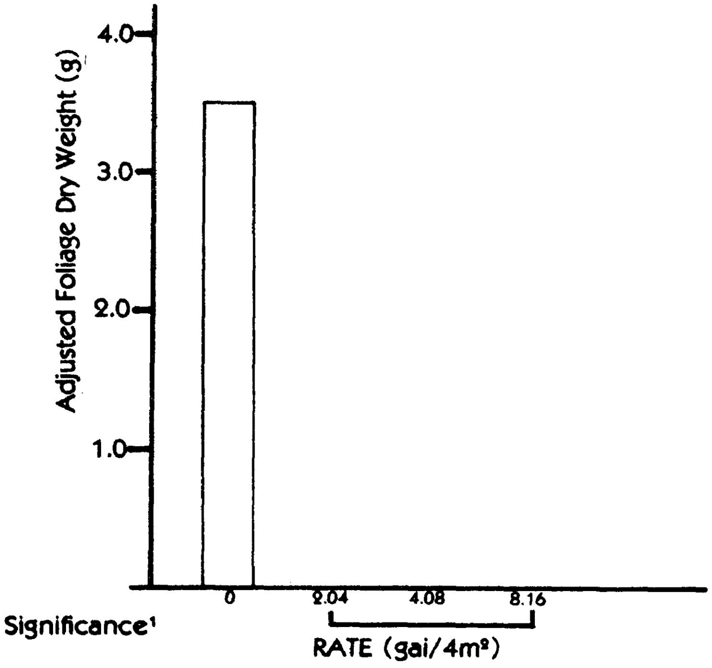


Figure 65. The foliage dry weight of the Aspen Greenhouse Trial adjusted by covariance analysis.

[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

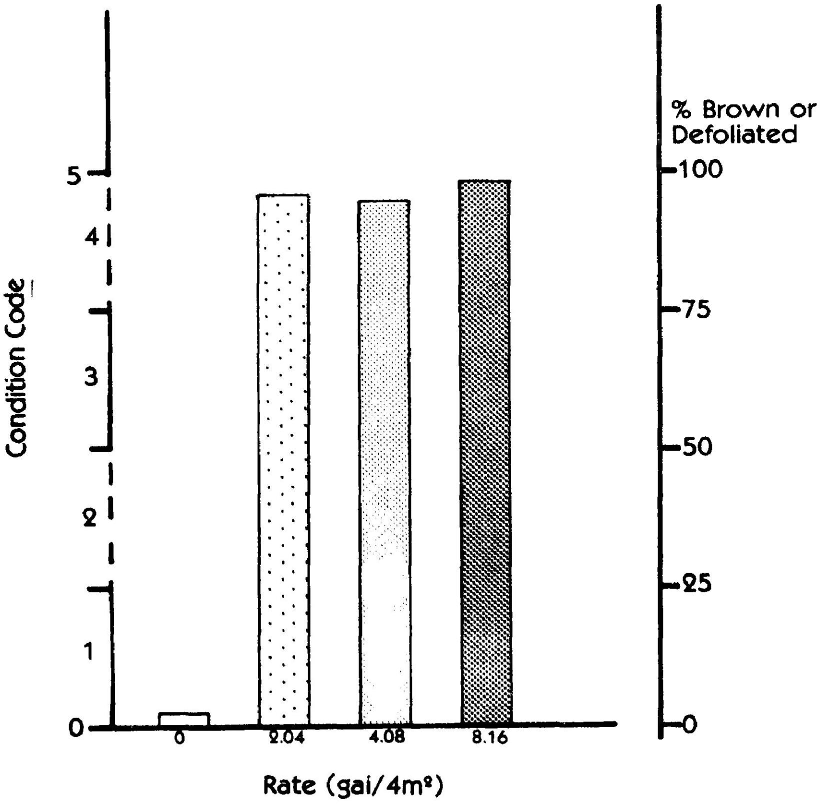


Figure 66. The condition code of the Aspen Greenhouse Trial.

Differences in the foliage dry weights over the range of hexazinone rate treatments were highly significant (P=0.01, COVAR, App. E, Table E27). The control resulted in significantly higher foliage dry weights than any of the other treatments (S-N-K test, Figure 65).

As the hexazinone rate increased the condition of the aspen declined (Figure 66).

iv. Hazel

Differences in the hazel transformed per cent survival values over the range of hexazinone rate treatments were highly significant (P=0.01, ANOV, App. E, Table E28). The control resulted in significantly higher transformed per cent survival values than any of the other treatments (S-N-K test, Figure 67).

Differences in the hazel foliage dry weights over the range of hexazinone treatments were highly significant (P=0.01, COVAR, App. E, Table E29). The control resulted in significantly higher foliage dry weights than any of the other treatments (S-N-K test, Figure 68).

As the hexazinone rate increased the condition of the hazel declined (Figure 69).

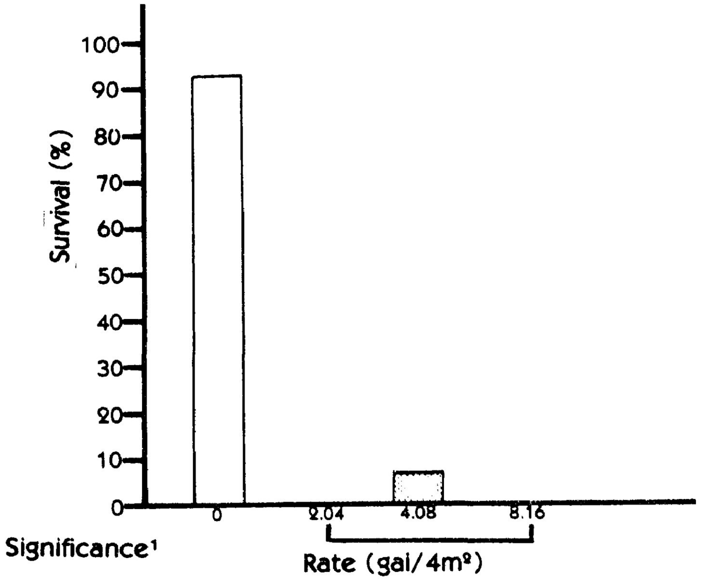


Figure 67. The survival (%) of the Hazel Greenhouse Trial.

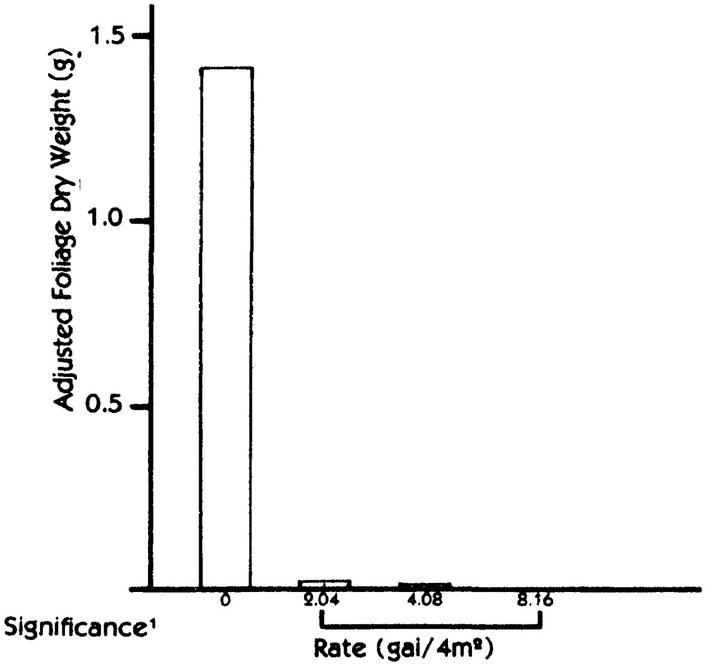


Figure 68. The foliage dry weight of the Hazel Greenhouse Trial adjusted by covariance analysis.

[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

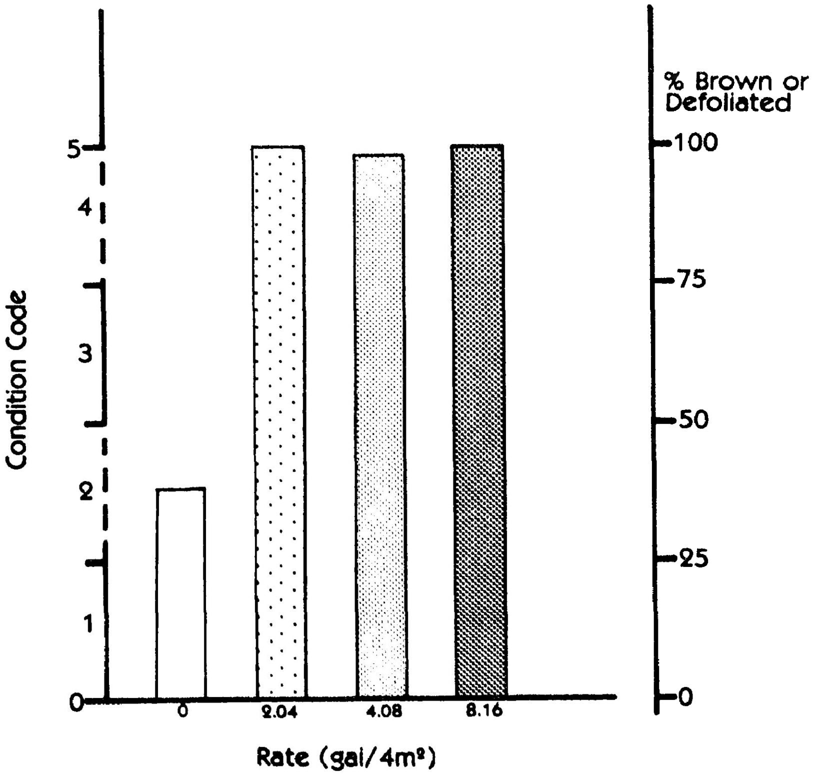


Figure 69. The condition code of the Hazel Greenhouse Trial.

DISCUSSION

The discussion is presented in two sections in the same sequence used previously. The first section deals with the post-logging successional behaviour of planted white spruce in sucker origin aspen stands from 0 to 13 years after logging. It is necessary to be aware of the relationships that exist between white spruce and aspen in young white spruce plantations before any silvicultural release treatments or weeding prescriptions can be made. The second section discusses the results of the field and greenhouse trials with hexazinone herbicide.

SECTION I

THE POST-LOGGING SUCCESSIONAL BEHAVIOUR OF PLANTED WHITE SPRUCE IN SUCKER ORIGIN TREMBLING ASPEN STANDS

The volume of aspen per plot appears not to affect the volume of white spruce at either Plantation 1 or Plantation 2 (Figures 3, 4, 5, 14, 15 and 16). Plots which had few or many aspen trees contained white spruce with a similar range of volumes. This could be due to a number of factors. It is likely that variations in site and microclimate on each plot masked the relationship between white spruce and aspen volumes. Possibly multi-variate analysis using ground frost incidence, soil depth and water relations as additional factors would have eliminated this variation.

In Plantation 2 (5 years old), frost damage to white spruce is related to the density of trembling aspen (Figure 17). White spruce trees that were surrounded by many aspen trees had less frost damage than those that were surrounded by few aspen trees. This relationship is not strong for Plantation 1 (13 years old). These results concur with those of Clements et al. (1972) who found that more frost damage occured among shorter trees than among taller trees and more damage occured among open grown trees than among protected trees. Steill (1955) found that frost damage ceased with full crown closure of the stand.

The current annual volume increment curves for the centrally located white spruce and the aspen tree of mean diameter on each circular situation plot are erratic in some cases, but certain trends do exist (Figures 7, 8, 9, 10, 11, 12, 18, 19, 20, 21, 22 and 23). The volume growth of white spruce is not affected by the density of aspen in either plantations (Figures 7, 9, 11, 18, 20 and 22). The white spruce on plots with a few widely spaced aspen trees are growing just as well as white spruce on plots with dense aspen competition.

The growth in volume of the aspen trees of mean diameter is also not affected by the density of aspen per plot (Figures 8, 10, 12, 19, 21 and 23). The current annual volume increment curves for the aspen at Plantation 2 are very erratic (Figures 19, 21 and 23). These erratic growth curves could have been aggravated by inaccurate counting and measuring of growth rings. Trembling aspen is a diffuse porous wood with annual rings that are extremely difficult to see. Kirby (1953) found that 87% of aspen ring counts he made in the field were inaccurate.

When the current annual volume increment curves for the paired centrally located white spruce and the mean aspen trees on each plot are compared, certain trends become apparent at Plantation 1 (Figures 7, 8, 9, 10, 11 and 12). Fast growing spruce trees are usually found with slow growing aspen trees; slow growing spruce trees are usually found with fast growing aspen trees; intermediate growing spruce trees are usually found with intermediate growing aspen trees. It appears that a fast growing aspen tree will suppress its white spruce neighbor. These relationships do not exist at Plantation 2. According to Hambley (1980), the current annual height increment of planted white spruce increases very slowly to a maximum when the trees are about 14 years of age. The total height of planted white spruce increases very little for the first 10 years; after this the trees begin to grow rapidly (Stiell 1976, Hambley 1980). If volume growth can be expected to follow the same trends, then it is possible that the white spruce and aspen in Plantation 2 have not yet reached the stage of competition that exists at Plantation 1. Fast growing aspen trees may begin to limit white spruce growth at Plantation 2 as it matures.

Although no actual measurements of mechanical damage were taken, whipping of the white spruce crowns by competing aspen trees was observed in both Plantations. Repeated years of mechanical abrasion between the aspen and white spruce crowns will damage the form and will probably decrease the value of the white spruce crop. Dead or broken branches provide access to various pathogens that could kill the white spruce prematurely. White spruce crowns that are limited in size by the competing aspen are no longer able to photosynthesize as efficiently and the growth rate of the tree is reduced.

There are 1,458 aspen trees per hectare on Plantation 1 and 13,333 aspen trees per hectare on Plantation 2. As a young sucker origin aspen stand increases in age, intraspecific competition results in the death of many suckers and a decrease in the number of suckers per hectare. A regression equation was established from Plonski's (1974) relationship between number of aspen trees per hectare and age for Site Class 2 aspen. It was extapolated into the younger age classes. It was found that the number of aspen trees per hectare decreased from 59,524 at 8 years to 6,553 at 15 years. If the growth rate of white spruce is not reduced during the 10 year period after planting, release treatments should be postponed. Fewer aspen stems would have to be treated after this point in time. It is more efficient to control a small number of larger competitors than a large number of small competitors.

The results of this study agree with those of Hambley (1980). She found that response to release was best in older (15 year old) stands. She was of the opinion that these stands had already been left too long and the growth rate was reduced by the time release treatment ocurred. Younger stands did not suffer suppression and their response to release was not as great. Stands should be released prior to a reduction in growth rate (Hambley 1980). Johnstone (1978) suggests that white spruce trees are unable to benefit from decreased competition until their crowns have expanded. This emphasises the need to release a white spruce stand from competition before the growth rate is suppressed.

The results of this study suggest that Plantation 2 (5 years old) should be released before it reaches the age of Plantation 1 (13 years old). Plantation 1 is begining to show the effects of reduced white spruce volume growth due to competition by rapidly growing aspen trees. The white spruce trees in this plantation appear to be above the line of frost damage and would likely not suffer too much if the overtopping aspen canopy was partially removed. The white spruce trees on Plantation 2 are not suffering reduced volume growth because of aspen competition and trees which are growing under an aspen canopy are benefitting because of the protection from frost damage. Postponing release treatments in Plantation 2 for a few years until the number of aspen trees per hectare has decreased would be a sound procedure both ecologically and economically.

SECTION II
FIELD AND GREENHOUSE TRIALS WITH HEXAZINONE HERBICIDE

1. The Brush Control Trials:

Hexazinone, placed in a grid pattern, can be used very effectively to control brush. Figures 34a and 34b and 36a and 36b show that both forms of hexazinone applied at all rates and spacings reduced the foliage dry weight of the aspen during 1978 (Dunsford 1979) and 1979 at Locations 1 and 2. There was a reduction in foliage dry weight on the hexazinone treated plots from 1978 to 1979 (Figures 34a and b and 36a and b). Trees that were partially killed in 1978 were completely dead by 1979. There was also a reduction in the foliage dry weight on the control plots at Location 1 from 1978 to 1979. Hexazinone was observed to kill trees along sucker lines in the treated plots. Sometimes these sucker lines extended into the control plots and these trees died during 1979.

The branch diameter at point of foliation method is both an efficient and effective way to estimate foliage dry weight. Figures 34a and b and 36a and b show that the results over both 1978 (Dunsford 1979) and 1979 do not differ to any great extent. The branch diameter at point of foliation method provides an objective system for evaluating the condition and health of young trees. It could be an extremely valuable technique for evaluating the effectiveness of herbicide control of perennial woody weeds.

Figure 38 shows that hexazinone effectively reduced the foliage dry weight of the aspen at Location 3. Location 1 and 2 were treated with hexazione herbicide during early June and late June 1978; Location 3 was not treated until late July 1978. This late season application of hexazinone herbicide was not as effective in reducing the aspen competition. The effects of hexazinone at Location 3 did not appear until after foliation (mid June) 1979. The herbicide was applied after the active growing season at Location 3. Much of it had likely leached out of the rooting zone by the following spring.

Although there were no significant differences between the aspen foliage dry weights for plots treated with liquid or solid hexazinone formulations, liquid hexazinone appears to control the aspen better. In the 'Gridball' formulation, the hexazinone is contained within a slowly disintegrating clay ball. Abundant precipitation is needed to release the active herbicide ingredient. In plots treated with 'Gridballs', it is likely that the herbicide was not released until after the active growing season. Much of it would have leached out of the aspen rooting zone by the following spring and therefore it was not as effective.

2. The Seedling Survival Trials:

The results of the seedling survival trials suggest that conifer crops are not affected by hexazinone if they are planted the year after the herbicide is applied. White spruce seedlings grew better on plots receiving the higher rates of hexazinone (Figure 40). This suggests that the white spruce are responding favorably to release from competition. The black spruce grew well and had high survival rates regardless of the rate of hexazinone applied the year before. Many of the jack pine seedlings died on both the control and the hexazinone treated plots. This suggests that the jack pine were suffering from some cause other than hexazinone phytotoxicity. Evaluation of the white and black spruce seedlings should be carried out for a few more years in order to establish relationships between the degree of release from competition and volume growth of the conifers.

3. The Crop Tree Trials:

Hexazinone can be used effectively in spot applications to selectively release conifers from overtopping hardwood competition. White spruce is extremely tolerant to hexazinone herbicide. Even the highest rate applied at the closest spacing to both the 1.5 m and the 0.5 m white spruce did not cause a reduction in height growth. Black spruce and jack pine are more sensitive than white spruce to hexazinone herbicide. Hexazinone applied at the highest rate and the closest spacing reduced the per cent survival of these two species (Figures 45 and 48). The other herbicide rates did not cause any damage. These results do not agree with those of Jones (1978) and Jones et al.

(1980) who found that spruce was less tolerant to hexazinone than pine. They were working with Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Norway spruce (*Picea abies* (L.) Karst.), lodgepole pine (*Pinus contorta* Dougl.), Scots pine (*Pinus sylvestris* L.), and Corsican pine (*Pinus nigra* var. *maritima* Arnold). Possibly these species react differently to hexazinone than white and black spruce and jack pine. Studies in New Zealand have shown that radiata pine is extremely tolerant to hexazinone (Bowers and Porter 1975 and 1977, Coackly and Moor 1977).

Hexazinone spot applications of up to 0.3750 g ai/spot can safely be applied to with 0.5 m of a white spruce tree. Hexazinone spot applications of 0.3750 g ai/spot should not be applied any closer than 1.0 m to black spruce and jack pine, but spot applications of 0.1875 g ai/spot can safely be applied to with 0.5 m of these two species.

If hexazinone had damaged the conifers to a greater extent, the regressions established by the branch diameter at point of foliation method (App. C, Figures C1, C2, C3, and C4) could have been used to estimate the amount of herbicide damage to the trees. There were few partially defoliated trees in this trial however, and this limited the usefulness of the branch diameter at point of foliation method.

4. Weed Tree and Brush Trials:

Hexazinone will effectively control aspen and willow.

Hexazinone applied at most rates and spacings reduced the height growth of immature aspen (Figure 50). This was mainly a result of increased mortality (Figure 51). Most aspen trees were either completely killed by the herbicide, or else they survived with little apparent damage.

The herbicide spacing was a more important factor in aspen control than the hexazinone rate. Aspen is extremely sensitive to hexazinone and both the low and high rates significantly reduced the per cent survival over that of the controls (Figure 51). There were no significant differences between the two hexazinone rates applied. Hexazinone applied at the low rate will both effectively control aspen and economize on herbicide expenditure .

The two closer spacings were much more effective in reducing aspen per cent survival than the two wider spacings (Figure 51). Even though aspen has a wide spreading root system, the herbicide spot application should not be placed farther than 1 metre from the tree to ensure complete kill.

Willow is less sensitive to hexazinone than aspen. The high hexazinone rate resulted in significantly less total stem growth than the low rate or the controls (Figure 53).

The high hexazinone rate applied with 4 spot applications resulted in greater mortality than the other treatments (Figure 54). Unlike the aspen, willow was often only partially damaged by the herbicide and its condition was reduced (Figure 55). This means that some of the willow roots still remain alive and they will probably resucker in later years. Herbicide applications may have to be repeated in a few years to control willow. Only one application is needed to control aspen.

App. E, Table E19 shows that there were significant differences between replications in the willow transformed per cent survival values at P=0.05. This could possibly be explained by site variation in the field. It is difficult to maintain uniform conditions in a large field trial.

As most herbicide affected aspen trees died and the rest remained healthy, there was no need to use the regression established by the branch diameter at point of foliation method (App. C, Figure C5) to estimate herbicide damage. The branch diameter at point of foliation method (App. C, Figure C6) could have been used to estimate the amount of herbicde damage to the partially killed willow.

5. The Mature Aspen Trial

Hexazinone can be used to eliminate an overstory of residual mature aspen trees. Figures 56 and 57 show that both solid and liquid forms of hexazinone will reduce an overstory of residual mature aspen trees. The higher rates are more effective. Large diameter trees are more difficult to kill than trees of small or medium diameters. The herbicide was applied in this trial during late August 1979. As discussed in the Brush Control Trials, a June or an early July hexazinone appication would likely have been more effective. Logging practises in northern Ontario often leave mature poor quality aspen trees. The roots of these trees are stimulated to sucker by the increased soil temperatures and stand disturbances that accompany logging operations. By eliminating the residual parent mature aspen trees, possibly these suckers will be killed by hexazinone which is translocated along the parent root system. Less hexazinone is needed to kill a few residual mature aspen trees than would be needed to kill each individual sucker.

6. The Greenhouse Trials:

Hexazinone will damage young conifer seedlings if it is sprayed directly on the foliage. Jack pine is slightly more tolerant to foliage treatment of hexazinone than white spruce. High rates of hexazinone do reduce the per cent survival, foliage dry weight and condition of both species

(Figures 58, 59, 60 and 61, 62, 63). Both species are damaged more by hexazinone applied to the foliage and soil than by hexazinone applied to the foliage alone. Hexazinone is absorbed more effectively through the root system. By applying hexazinone to the foliage and soil, the tree is, in effect, coming in contact with more herbicide than it would if hexazinone was applied to the foliage alone.

As discussed in the Methods section, the hexazinone rates applied in this trial simulate the concentrations of hexazinone that result form spot application made in a grid pattern in the field. As a hexazinone spot (either "Gridball" or concentrated solution formulation) would not likely be applied directly on top of a conifer seedling, rates of this magnitude would not normally be sprayed directly on a seedling. Results from loblolly pine plantations in the Southern United States suggest that hexazinone applied as a broadcast foliage spray at rates of 0.56 kg ai/ha and 1.12 kg ai/ha will not damage conifer seedlings (Nelson et al. 1976). The 2.04 g. ai/4m^2 rate did not significantly reduce the per cent survival or the foliage dry weight of the jack pine over the control. This rate is equivalent to a 1 kg ai/ha broadcast application rate (Figure 33). White spruce was slightly damaged by this rate, but the damage was significantly less than that which resulted from herbicide applications at the two higher rates.

Aspen was effectively controlled by all three of the applied herbicide rates (Figure 64, 65, and 66). Almost 100% aspen kill resulted from all of the rates. Aspen is extremely sensitive to hexazinone. During this trial, vapor drift from some of the treated aspen killed some nearby untreated aspen.

Hazel was also very effectively controlled by all three of the applied herbicide rates (Figures 67, 68, and 69). Almost 100% hazel kill resulted from all three rates. Some live leaf buds were found upon close examination of hazel that were severlely damaged. These buds may sprout and, given time, the hazel may recover.

Aspen and hazel are both very sensitive to hexazinone, but hazel does have the ability to recover whereas aspen is completely killed. In stands where there is dense hazel, competition, conifer crop trees may have to be released more than once.

CONCLUSION

Young white spruce plantations should be released from aspen competition prior to a reduction in volume growth. This usually occurs sometime between 8 and 15 years after planting. However, it is neither necessary nor desirable to completely remove the aspen canopy as white spruce will initially benefit from the frost protection offered by a light aspen canopy.

Aerial spraying with 2,4-D is the most common method used today to release white spruce from aspen competition. Such treatments are often ineffective resulting in deformed aspen and seriously reducing the future merchantable value of the aspen component of the stand. If the aerial spray treatment is effective, it may completely open up the stand by removing the protective aspen canopy and the white spruce could suffer from frost damage.

Prior to the development of hexazinone herbicide, hand release was the only feasible method available to selectively release white spruce from aspen competition. The herbicides 2,4-D and 2,4,5-T were sometimes applied in frills by the hack and squirt method. Although this was considered to be an improvement over hand release, it was still not entirely satisfactory as in both cases re-suckering tended to occur. Both hand release and hack and squirt were very time consuming and inefficient. It is difficult to use hand release treatments in 8 to 15 year old plantations as the aspen component is quite large in diameter and it is hard to break or cut. To release a white spruce plantation prior to this is an ecologically unsound procedure as very young white spruce are severely damaged by frost and benefit from the protection of a light overtopping canopy. In addition, the number of aspen stems per hectare is very large in a young stand making hand release very labor intensive and time consuming. The number of aspen suckers rapidly decreases as the stand matures.

Hexazinone herbicide provides a promising method of selectively releasing white spruce from aspen competition. It is easy to apply, it will destroy large diameter competitors and it will kill entire sucker lines of very young aspen. Conifers are very tolerant to hexazinone and it can be effectively used to release white spruce, black spruce and jack pine from many of the weed tree and brush species common in the boreal forest.

THE USE OF HEXAZINONE FOR WEED CONTROL IN SITE PREPARATION, PLANTATION ESTABLISHMENT AND PLANTATION TENDING IN THE BOREAL FOREST

Hexazinone herbicide is a very powerful silvicultural tool that can be used to kill deciduous weed species and to release conifer crops in the boreal forest. It is not yet licensed for forestry in Canada, but this herbicide has been used considerably in radiata pine plantations in New Zealand and in longleaf pine plantations in the southern United States. This user guide discusses the use of 'Gridball' and concentrated solution formulations of hexazinone (DPX-LE and DPX-LX). Foliage broadcast sprays are not discussed as these have been found to be damaging to conifers in the southern pine plantations (South et al 1976) and cause minimal damage to conifers in the boreal forest (Polhill 1978).

Field Conditions	Rate and Method of Hexazinone Application	Comments
1) Site preparation of a 5 to 10 year old cutover. Conifer regeneration is non-existent and the area has heavily regenerated to weed tree and brush species primarily aspen, hazel, willow and alder between 2.0 to 4.5 metres in height.	Apply 2.4 kg.ai./ha hexazinone spots of concentrated solution (DPX-LX) with a 'Spotton-gun'[1] or 'Gridballs'[2] in a grid pattern. This treatment will be most effective if hexazinone spots of 0.1875 g.ai/spot[3] DPX-LX or 1 cc. 'Gridballs' are placed at 0.88 m. spacing. A less satisfactory option is hexazinone spots of 0.3750 g.ai/spot[4] DPX-LX or 2 cc. 'Gridballs' placed at 1.25 m. spacing.	If willow, hazel or alder are present, the herbicide should be applied directly to their roots. Three to 4 spots of 0.3750 g.ai/spot DPX-LX or 3 to 4 2 cc. 'Gridballs' should be used. Aspen root systems are completely killed by hexazinone applied in a grid pattern and only one herbicide application will be needed. The other species will either be killed or severely set back provided their roots are treated. Conifers can be planted with no damage in hexazinone treated plots the year after herbicide application.

[1] Note: A 'Spotton-gun' is a plunger type squirt gun dispenser for hexazinone herbicide. It is calibrated in cc. or ml. to squirt the desired amount of herbicide. It is attached to a backpack which holds the concentrated hexazinone and water solution.

[2] Note: In the 'Gridball' formulation, the hexazinone active ingredient is contained within a clay ball. A 2 cc. 'Gridball' contains 0.3750 g.ai hexazinone; a 1 cc. 'Gridball' contains 0.1875 g.ai hexazinone.

[3] Note: 25% ai DPX-LX contains 239.65 g.ai hexazinone/l. To apply 4 cc. spots of DPX-LX each spot containing 0.1875 g.ai hexazinone, hexazinone should be mixed according to the following ratio: 50 cc. hexazinone to 206 cc. water. This will be enough concentrated solution to apply 64 4 cc. spots of 0.1875 g.ai/spot DPX-LX.

[4] Note: To apply 4 cc. spots of DPX-LX each spot containing 0.3750 g.ai hexazinone, hexazinone should be mixed according to the following ratio: 100 cc. hexazinone to 156 cc. water. This will be enough concentrated solution to apply 64 4 cc. spots of 0.3750 g.ai/spot DPX-LX.

Field Conditions	Rate and Method of Hexazinone Application	Comments
2) Contemporanious application at planting time. Hexazinone can be applied concurrently with planting to control competition.	Apply 3 spots of 0.3750 g.ai/spot DPX-LX or 3 2 cc. 'Gridballs' in a triangular pattern 0.50 m. from each white spruce seedling and 1.0 m. from each jack pine and black spruce seedling. If mechanized planting is being undertaken, hexazinone could be applied at the time of planting by a hopper fed system of distribution.	Although no studies have been undertaken on contemporanious Hexazinone application at the time of planting, the results of Dunsford (1979) and Day and Harvey (1980) suggest that young conifers are extremely tolerant to hexazinone. Jack pine and black spruce are more sensitive to hexazinone than white spruce and care should be taken to avoid herbicide contact with the roots of these species. When seedlings are placed in hollows or at the bottom of slopes, lower hexazinone concentrations should be applied.
3) Tending of young plantations that need individual release from hardwood competition.	Apply spots of 0.3750 g.ai/spot DPX-LX or 2 cc. 'Gridballs' close to the competition. One or 2 spots will control aspen; 3 to 4 spots may be needed for willow,hazel or alder. If the competition is extremely close to the crop trees, the herbicide can be placed up to 1.0 m. away from aspen and 0.50 m. away from willow, hazel or alder. Higher herbicide concentrations may be needed in this case.	Jack pine and black spruce are more sensitive to hexazinone than white spruce. Hexazinone spots of 0.3750 g.ai/spot should not be placed closer than 0.5 m. from white spruce or 1.0 m. from jack pine or black spruce. Spots of 0.1875 g.ai/spot can be placed within 0.25 m. of white spruce and as close as 0.50 m. from jack pine or black spruce. Often plantations will benefit from a spot release where broadcast release would be costly (in terms of herbicide expenditure) and wasteful. Young white spruce (3.5 m.) is very frost sensitive and will benefit from a light covering of aspen or other weed species. Normally, it

Field Conditions	Rate and Method of Hexazinone Application	Comments
		should not be released until it is well established (between 6 and 15 years after planting). It should only be released from competition that is mechanically interfering with its crown. Older white spruce may be more completely released. Jack pine and black spruce are not particularly frost sensitive and may be released from competition at any time.
4) Removal of mature residual aspen trees between 12 and 16 cm. DBH.	Apply 4 or 6 spots of 0.3750 g.ai/spot DPX-LX or 2 cc. 'Gridballs' at the base of each tree.	Large diameter trees require more herbicide and are more difficult to kill than small diameter trees. Often logging practises in northern Ontario leave mature poor quality aspen trees. The roots of these trees are stimulated to sucker after logging. These suckers will be killed by hexazinone which is translocated along the parent root system. Less herbicide is needed to kill a few residual mature aspen trees than would be needed to kill each individual sucker. If utilization of aspen improves and more aspen are cut, it may be possible to treat the recently cut aspen stumps with hexazinone and either prevent suckering or kill the surrounding suckers in the same manner.

Additional Comments:

1) Although the results of Dunsford (1979) and Day and Harvey (1980) show that there are no significant differences between the effectiveness of liquid and solid hexazinone formulations, upon observation the liquid formulation appears to be slightly more effective than the solid. The solid formulation is still quite effective however and, due to its ease of application, may be the preferred formulation, especially when untrained personnel are involved in herbicide applications.

2) Hexazinone applications are best made just before the period of active growth. They may also be made during the period of active weed growth provided there is sufficient precipitation to break down the 'Gridballs' and leach in the hexazinone. Applications made in mid-July and later in the season may not be effective in the year of application. They may be effective the next year, but herbicidal activity is reduced.

3) Hexazinone will completely kill the root system of trembling aspen. When willow, alder or hazel competition is present, hexazinone applications may have to be repeated as the root systems of these species may not be completely killed by hexazinone.

4) The rates of hexazinone given in this user guide may vary depending on the soil texture, amount of precipitation and age and stage of development of the competition.

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APPENDIX A

Maps showing exact locations of Plantations 1 and 2 and the Hexazinone Herbicide Trials.

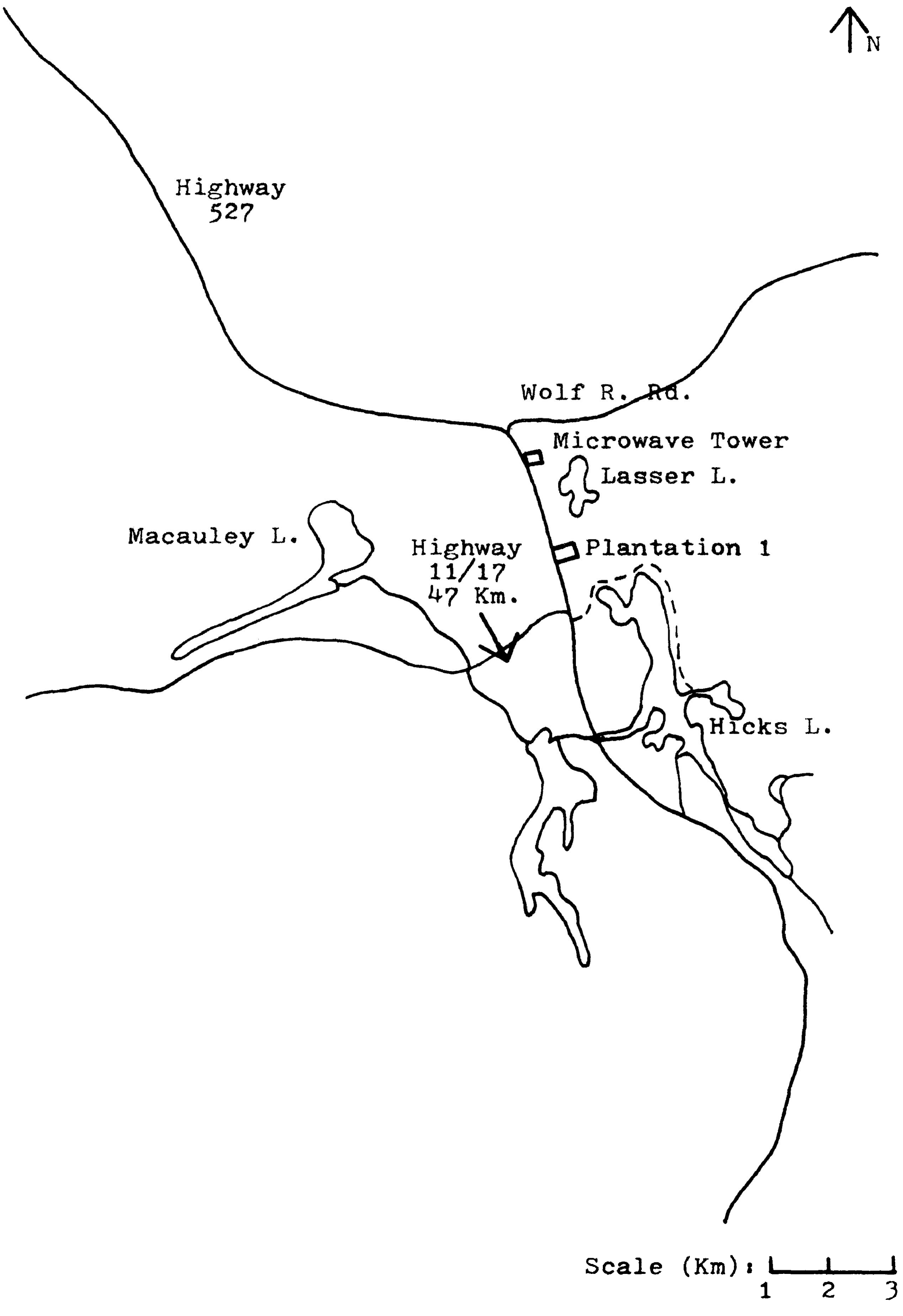

Figure A1. The location of Plantation 1 relative to Highway 527 and the Wolf River Road.

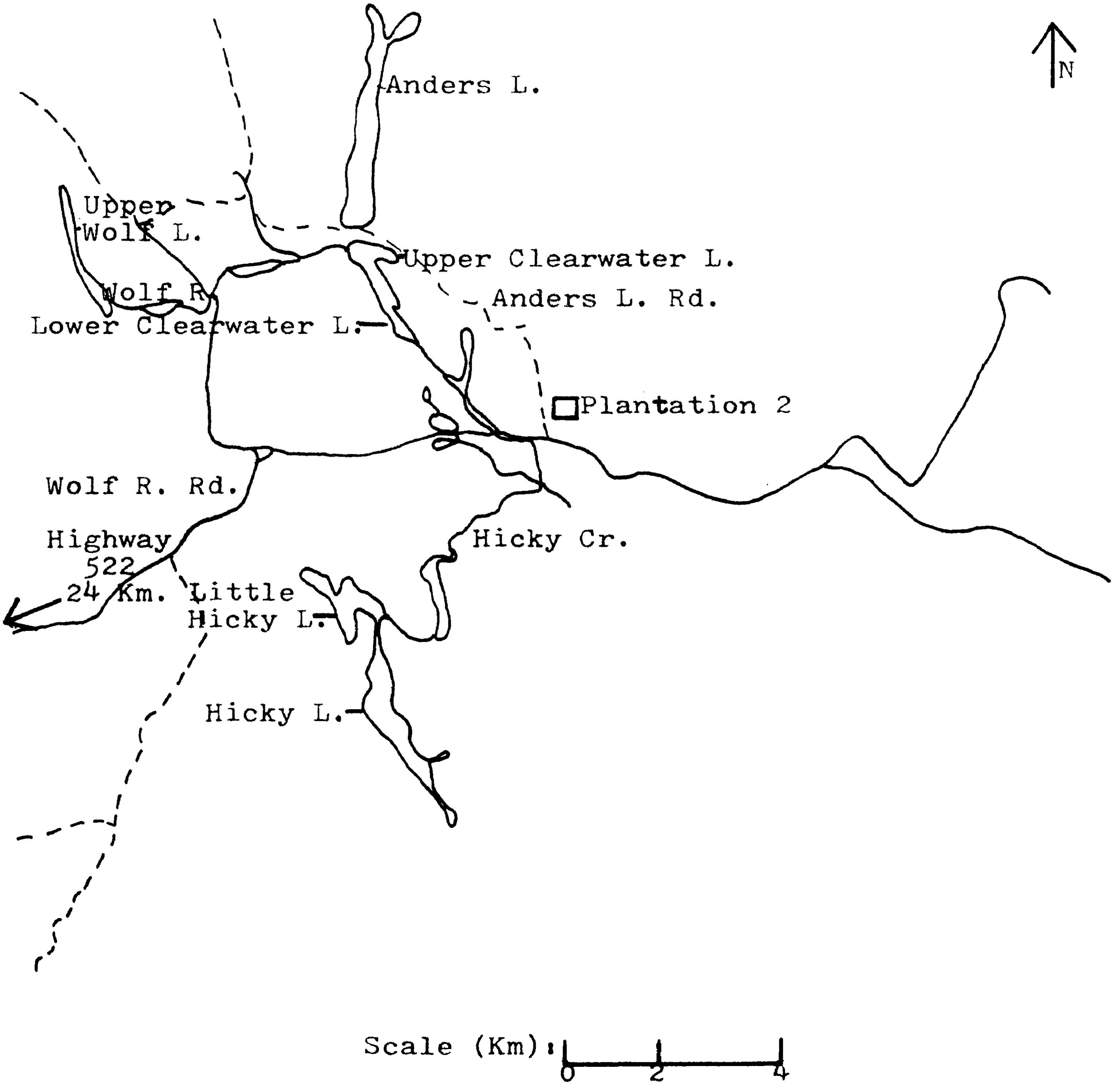

Figure A2. The location of Plantation 2 relative to the Wolf River Road and Anders Lake.

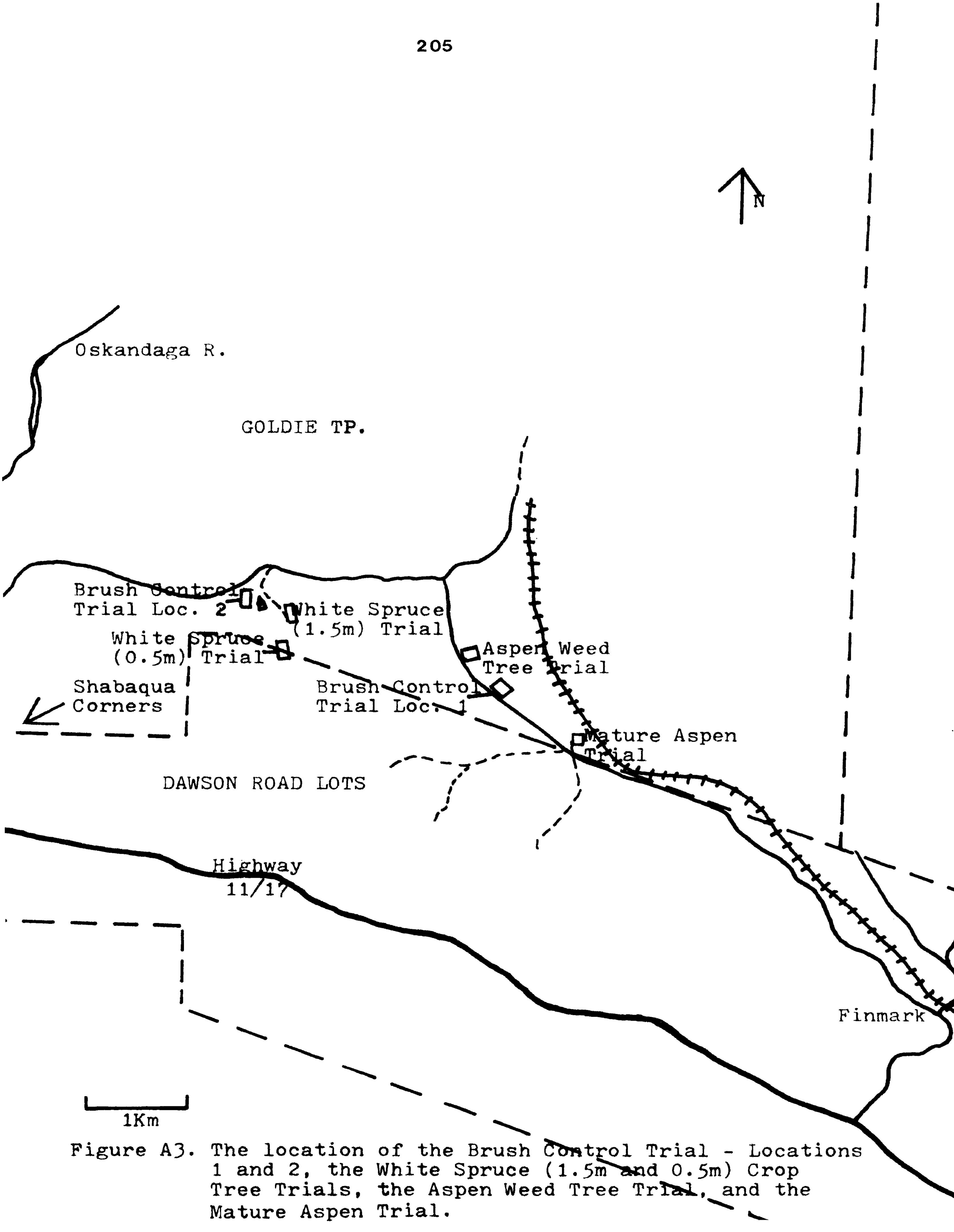

Figure A3. The location of the Brush Control Trial - Locations 1 and 2, the White Spruce (1.5m and 0.5m) Crop Tree Trials, the Aspen Weed Tree Trial, and the Mature Aspen Trial.

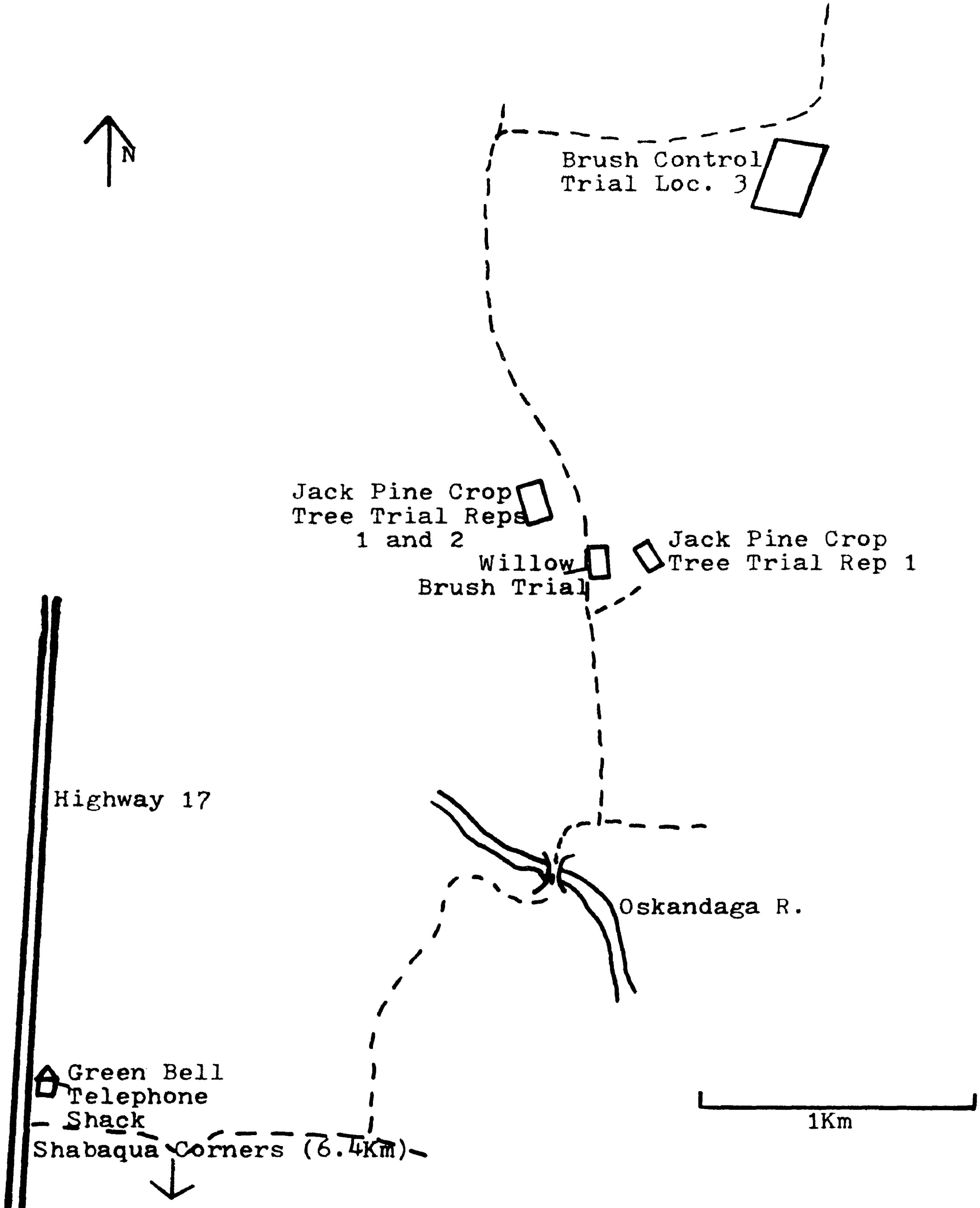

Figure A4. The location of the Brush Control Trial - Location 3, the Jack Pine Crop Tree Trial, and the Willow Brush Trial.

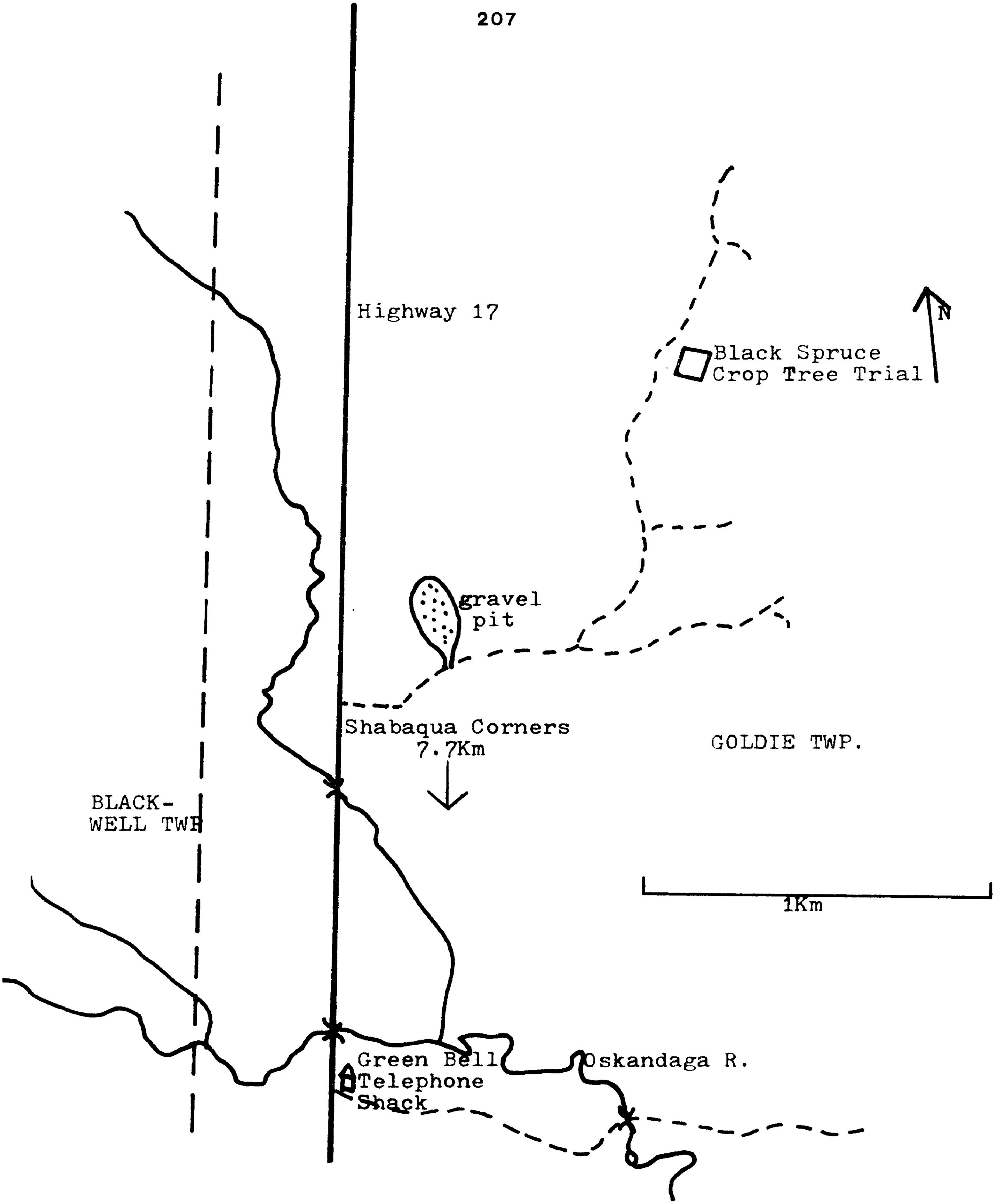

Figure A5. The location of the Black Spruce Crop Tree Trial.

APPENDIX B

Regressions relating diameter above butt swell to volume for the aspen and the white spruce at Plantations 1 and 2.

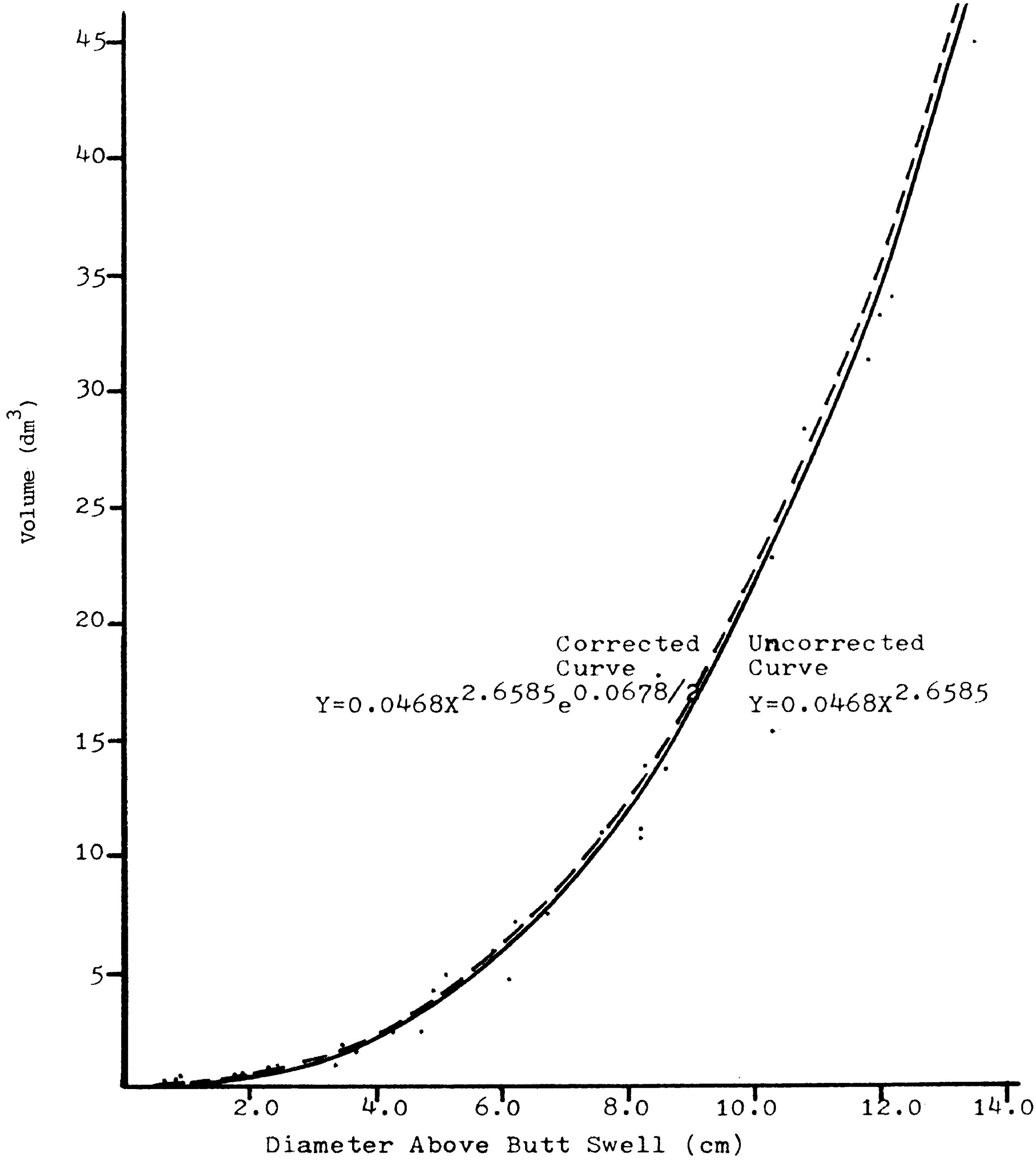

Figure B1. Points plotted represent diameter above butt swell and volume of aspen at Plantation 1.

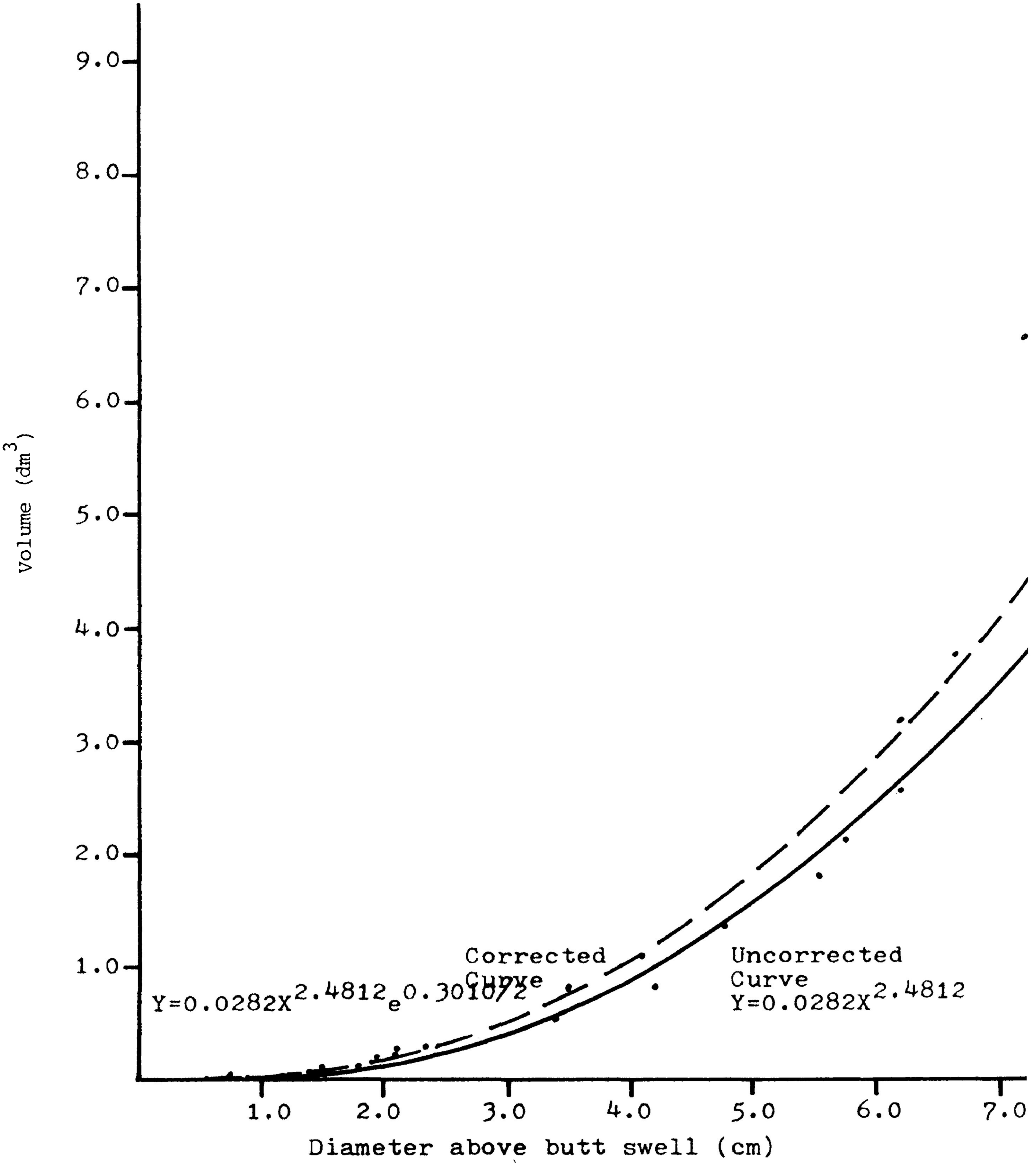

Figure B2. Points plotted represent diameter above butt swell and volume of white spruce at Plantation 1.

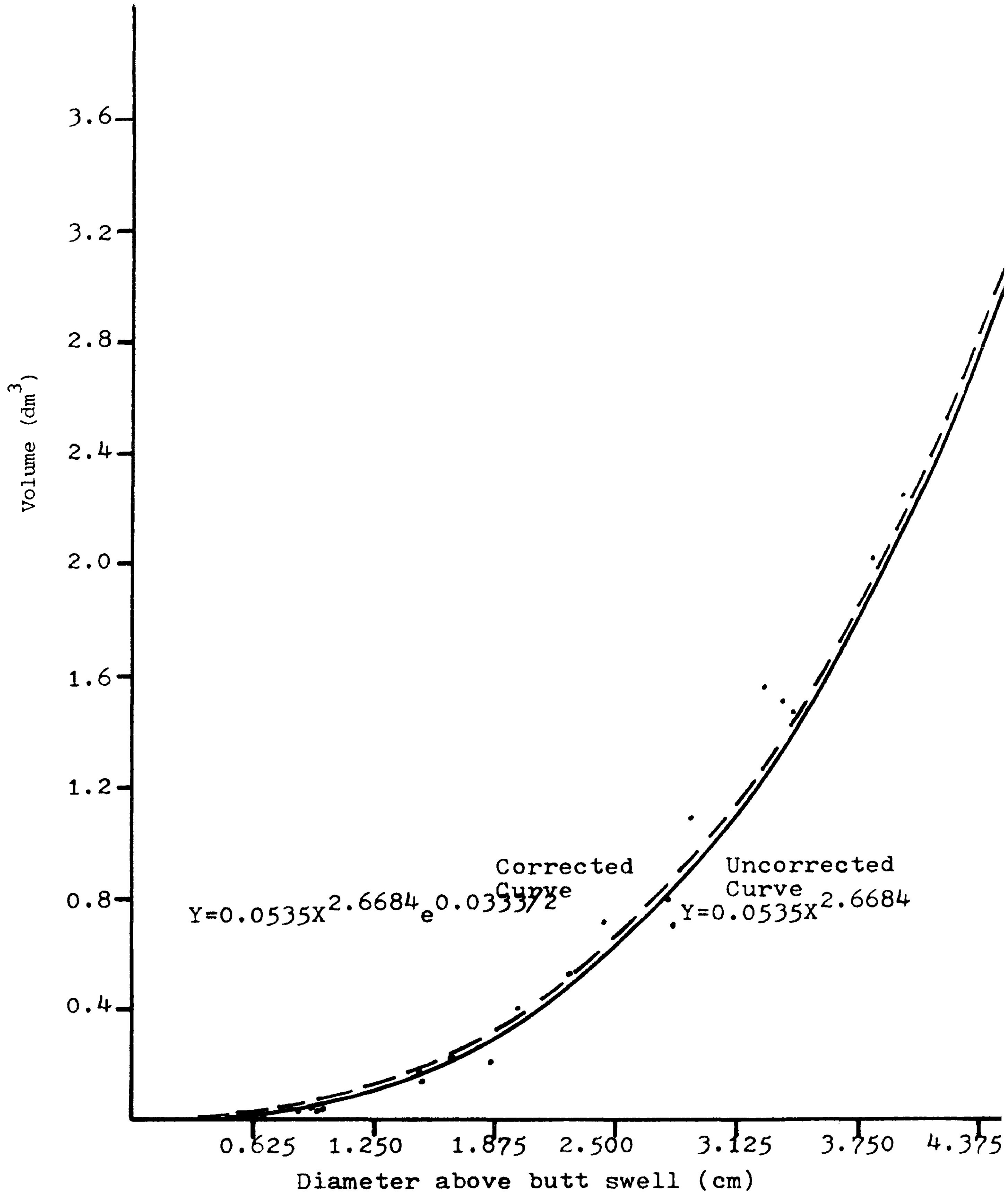

Figure B3. Points plotted represent diameter above butt swell and volume of aspen at Plantation 2.

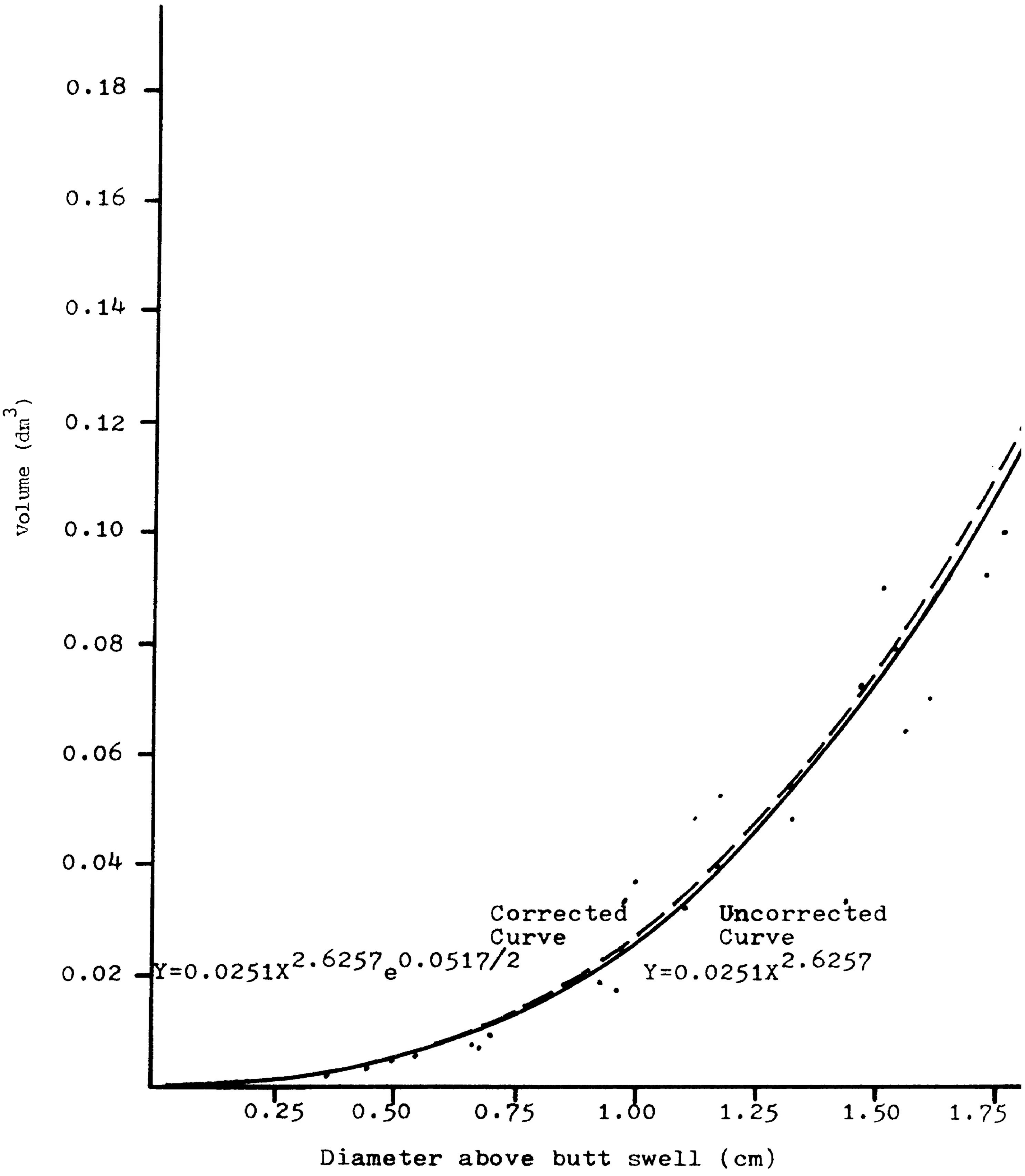

Figure B4. Points plotted represent diameter above butt swell and volume of white spruce at Plantation 2.

APPENDIX C

Regression curves relating foliage dry weight to branch diameter at the point of foliation.

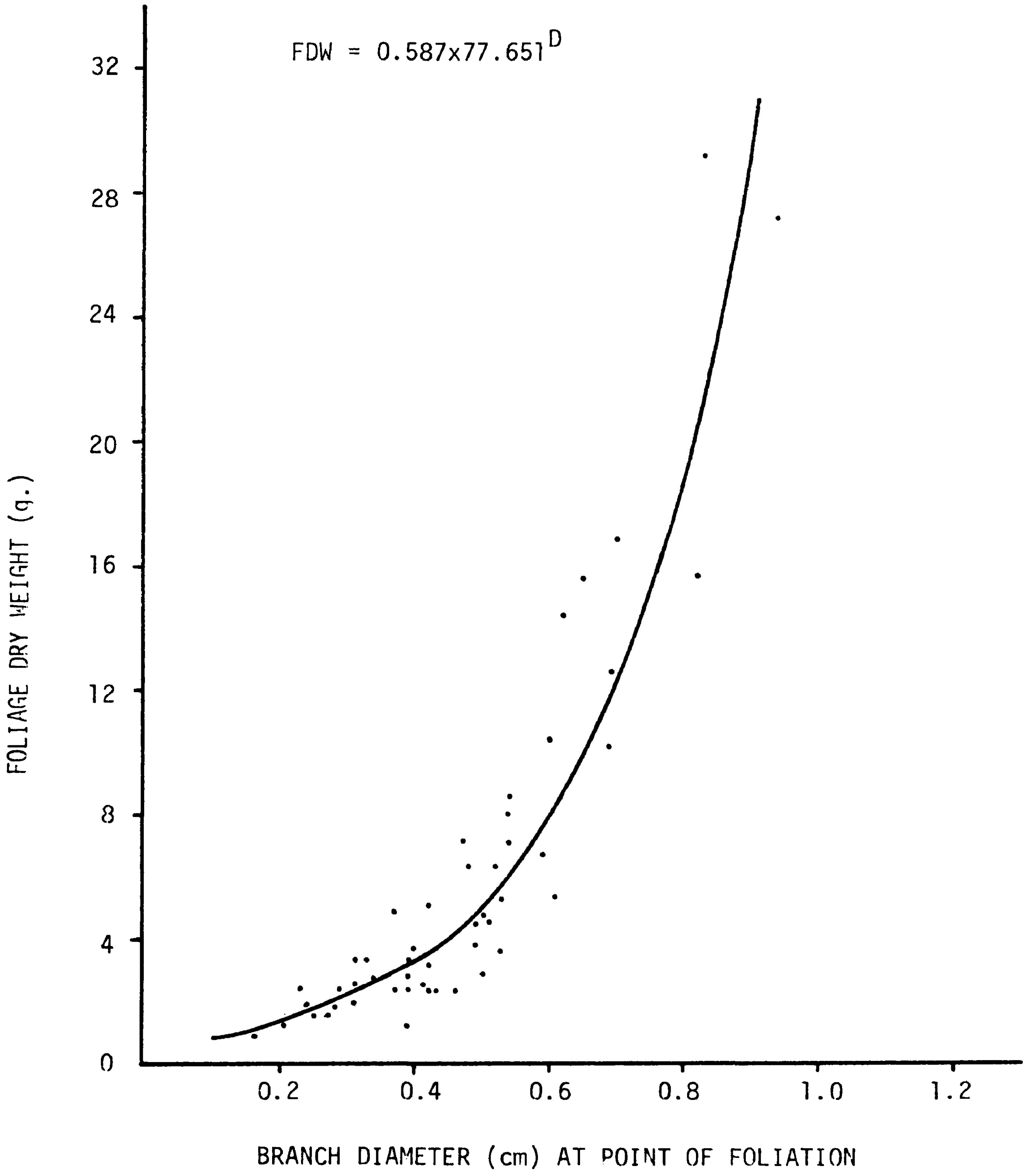

Figure C1. Points plotted represent branch diameter and foliage dry weight of *Picea glauca*.

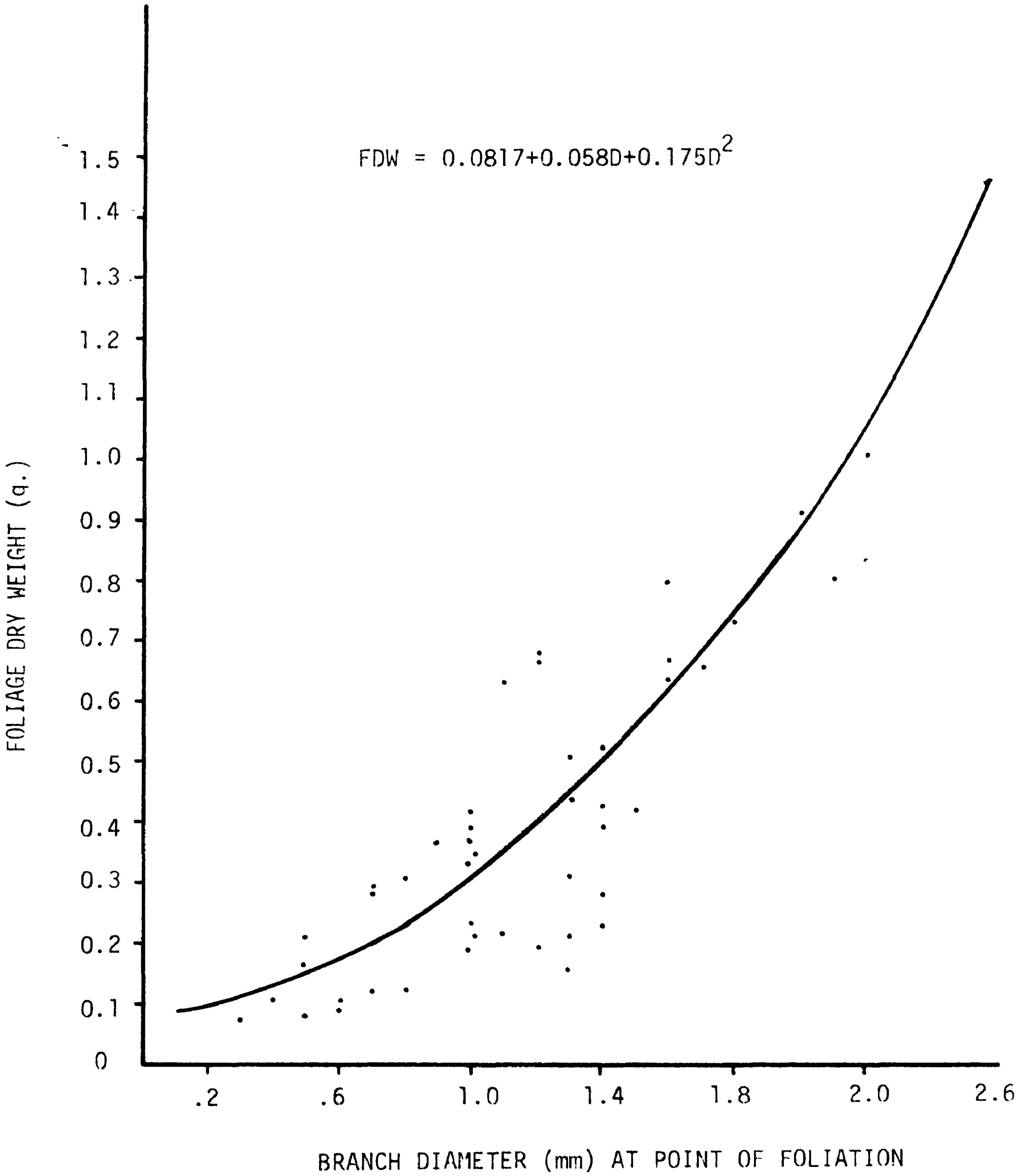

Figure C2. Points plotted represent branch diameter and foliage dry weight of *Picea glauca*.

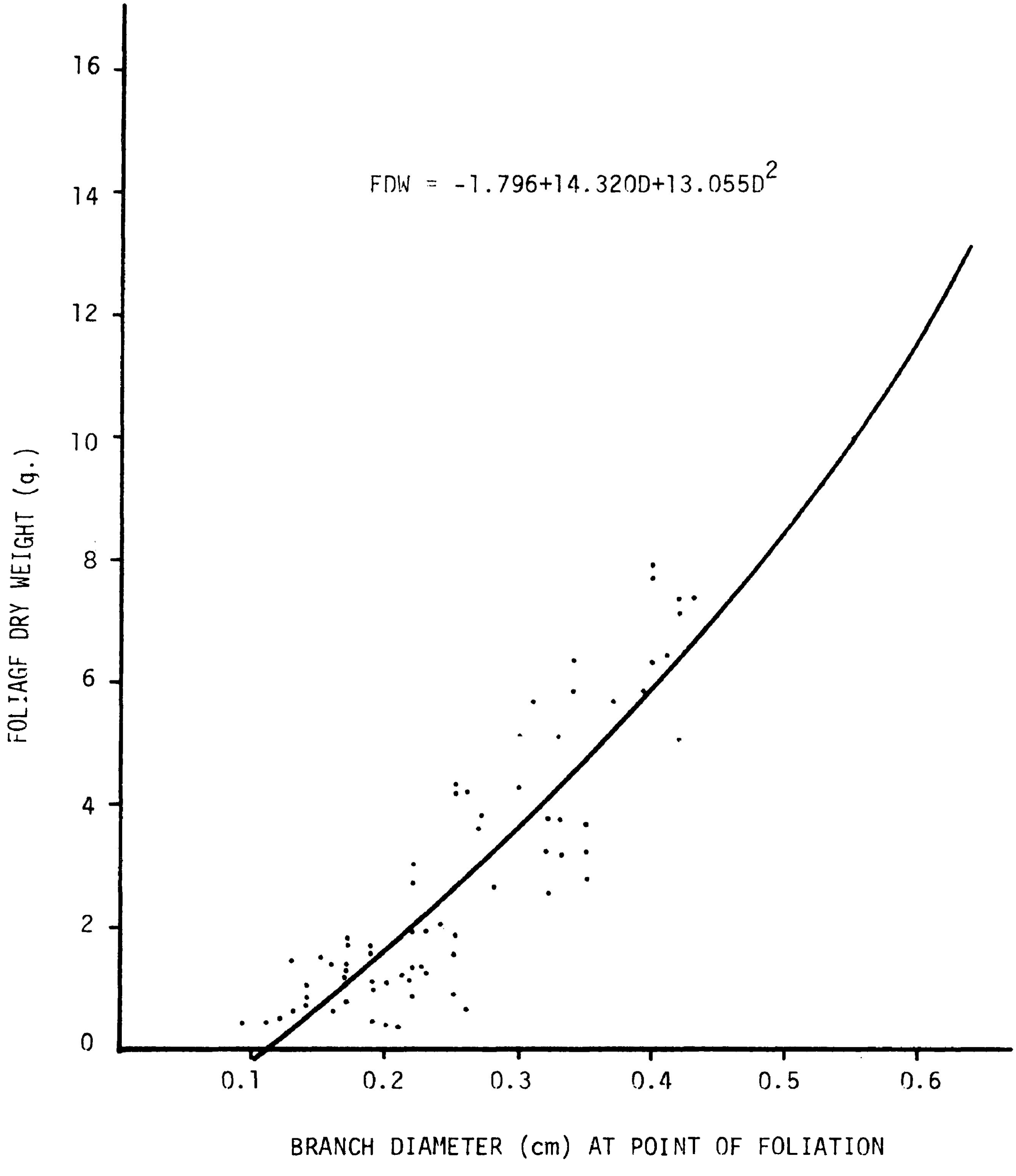

Figure C3. Points plotted represent branch diameter and foliage dry weight of *Picea mariana*.

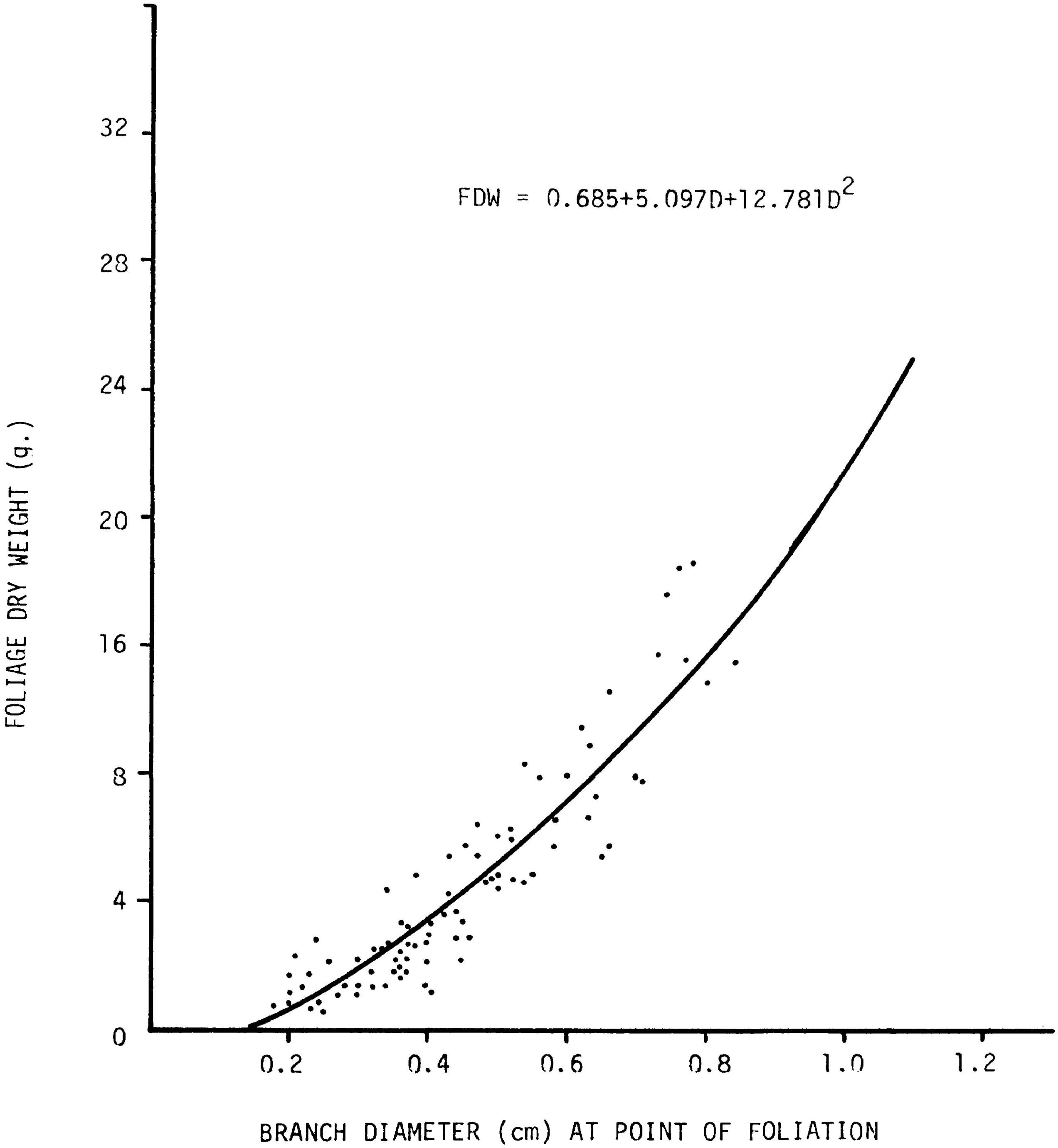

Figure C4. Points plotted represent branch diameter and foliage dry weight of *Pinus banksiana*.

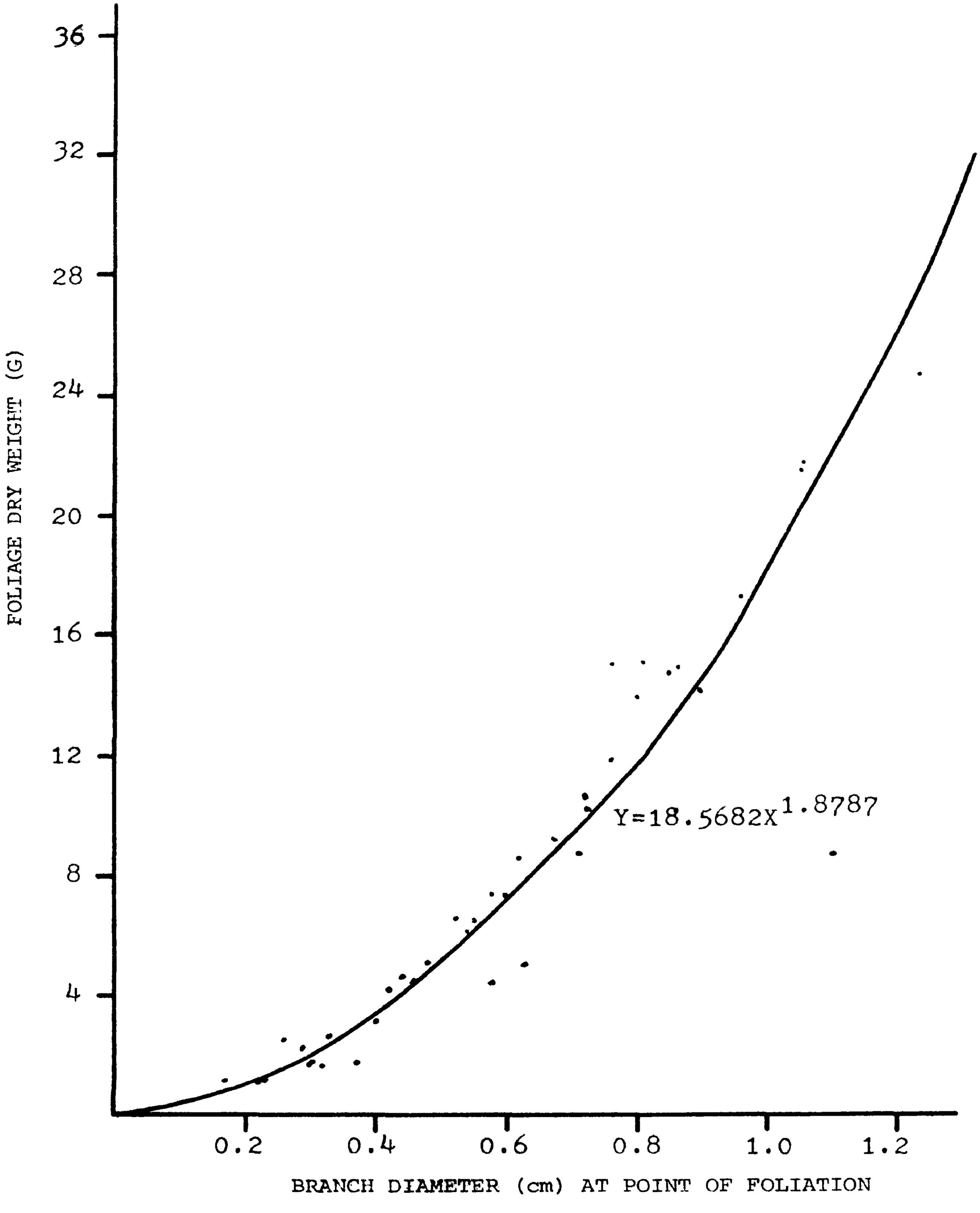

Figure C5. Points plotted represent branch diameter (X) and foliage dry weight (Y) of Populus tremuloides.

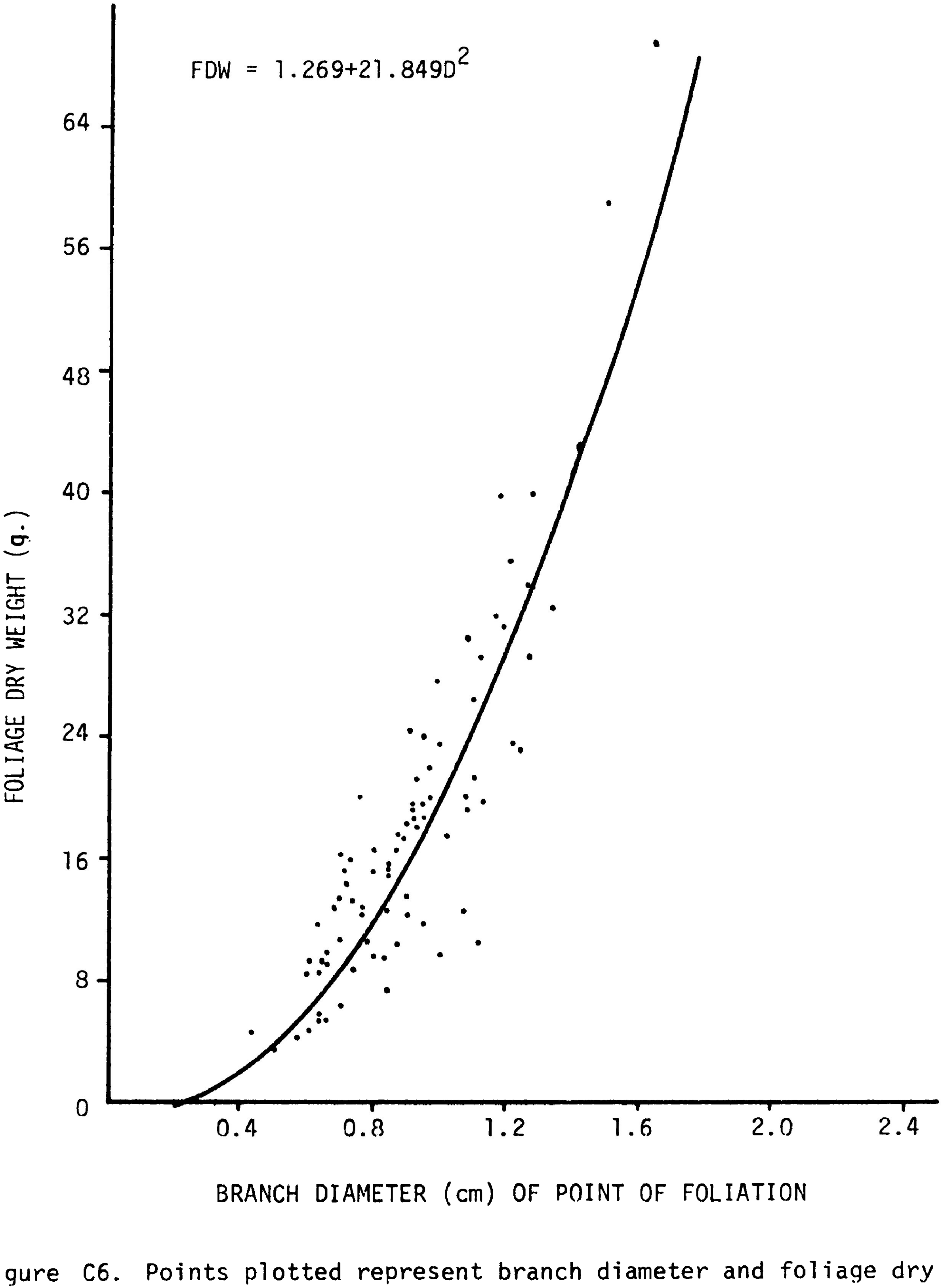

Figure C6. Points plotted represent branch diameter and foliage dry weight of *Salix* ssp.

APPENDIX D

Analysis of variance of the regressions relating number of frost damaged tips per unit white spruce crown area to number of aspen trees per plot for Plantations 1 and 2.

Table D1: White Spruce Frost Damaged Tips per Unit Crown Area vrs. Number of Aspen Trees / Plot at Plantation 1.

Anova of Regression

Source of Variation	df	SS	MS	VR
Reg. Y - X	1	467.3335	467.3335	4.2935 N.S.
Residual	13	1,415.024	108.848	
Total about $\bar{y}$	14	1,882.3575		

Table D2. White Spruce Frost Damaged Tips per Unit Tree Crown Area vrs. Number of Aspen Trees / Plot at Plantation 2.

Anova of Regression

Source of Variation	df	SS	MS	VR
Reg Y - X	1	576,325.8	576,325.8	122.1406 **[1]
Residual	13	61,341.076	4,178.5443	
Total about $\bar{y}$	14	637,666.88		

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[1] Note: ** means significant differences at P = 0.01

APPENDIX E

Analysis of variance, analysis of covariance, and Student-Newman-Keul's test tables for the Hexazinone Herbicide Trials.

Table E1: Analysis of Covariance: Location 1, Estimated Mean Foliage Dry Weight per Tree in Grams

		Sums of Products			For Adjusted Values			
Source of Variation	df	Σx^2	Σxy	Σy^2	df	SS	MS	F
Total	29	13,407,132.34	347,684.00	61,684.07				
Blocks	2	2,160,677.51	1,866.18	3,465.42				
Treatments	9	5,051,358.62	324,197.76	47,813.96				
Ma (forms)	1	139,946.7	8,245.18	485.78				
Mi (rates + spac.)	4	4,717,600.66	308,880.67	46,754.20				
MaMi	4	1,193,811.26	7,071.92	573.99				
Error	18	6,195,096.21	21,620.05	10,404.69	17	10,329.24	607.60	
Treat. + Error	27	11,246,454.83	345,817.81	58,218.66	26	47,585.09	1,830.20	
Forms + Error	19	6,335,042.91	29,865.22	10,890.47	18	10,749.68	597.20	
R + S + Error	22	10,912,696.87	330,500.72	57,158.89	21	57,073.64	2,717.79	
F X R & S + Error	22	6,388,907.47	28,691.97	10,978.68	21	10,849.83	516.66	
Blocks + Error	20	8,355,773.72	23,486.23	13,870.11	19	13,804.09	726.53	
Treatments Adjusted					9	37,255.85	4,139.54	6.81**[1]
Forms Adjusted					1	420.44	420.44	N.S.
R & S Adjusted					4	46,744.40	11,686.10	19.23**[1]
T X R & S Adjusted					4	520.59	130.15	N.S.
Blocks Adjusted					2	3,474.85	1,737.43	2.86 N.S.

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[1] Note: ** means significant differences at P = 0.01

Table E2: Predicted Foliage Dry Weights for all Hexazinone Treatments at Location 1.

Herbicide Treatment (ranked)	1	6	2	7	3	4	8	9	10	5
Form	Liquid	Solid	Liquid	Solid	Liquid	Liquid	Solid	Solid	Solid	Liquid
Rate (kg/ha)	0	0	1.2	1.2	1.2	2.4	1.2	2.4	2.4	2.4
Spacing (m)	0	0	1.77	1.77	1.25	1.25	1.25	1.25	0.88	0.88
Predicted FDW (g/tree)	133.63	118.29	71.42	60.12	42.23	40.80	35.41	26.83	14.51	71.33
Adjusted Predicted FDW (g/tree)	131.07	116.39	72.31	61.36	43.71	39.11	36.82	26.61	15.19	8.02
Significance[1]										

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[1] Note: Treatments that were not significantly different (P=0.05) are joined by a line.

Table E3: Analysis of Covariance: Location 2, Estimated mean foliage dry weight per tree in grams.

		Sums of Products			For Adjusted Values			
Source of Variation	df	$\sum x^2$	$\sum xy$	$\sum y^2$	df	SS	MS	F
Total	29	52,711,167.73	1,364,689.80	184,854.99				
Blocks	2	7,600,867.36	251,660.66	8,414.25				
Treatments	9	21,316,212.33	744,449.18	145,584.65				
Ma (forms)	1	1,807,518.35	22,322.13	275.67				
Mi (rates + spac.)	4	12,661,450.81	685,479.35	143,480.00				
MaMi	4	6,847,243.17	36,647.70	1,828.98				
Error	18	23,794,088.04	368,579.96	30,856.08	17	25,146.63	1,479.21	
Treat. + Error	27	45,110,300.37	1,113,029.14	176,440.73	26	148,978.40	5,729.94	
Form + Error	19	25,601,606.39	390,902.09	31,131.75	18	25,163.20	1,397.96	
R + S + Error	22	36,455,538.85	1,054,059.31	174,336.08	21	143,859.48	6,850.45	
F X R & S + Error	22	30,641,331.21	405,227.66	32,685.06	21	27,325.98	1,301.24	
Blocks + Error	20	31,394,955.40	620,240.62	39,270.33	19	27,016.82	1,421.94	
Treatments Adjusted					9	123,831.77	13,759.09	9.30**[1]
Forms Adjusted					1	16.57	16.57	N.S.
R X S Adjusted					4	118,712.85	29,678.21	20.06**[1]
F X R & S Adjusted					4	2,179.35	544.83	N.S.
Blocks Adjusted					2	1,870.19	935.10	N.S.

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[1] Note: ** means significant differences at P = 0.01

Table E4: Predicted foliage dry weights for all treatments at Location 2.

Herbicide Treatment (ranked)	1	6	3	7	2	8	9	10	4	5
Form	Liquid	Solid	Liquid	Solid	Liquid	Solid	Solid	Solid	Liquid	Liquid
Rate (kg/ha)	0	0	1.2	1.2	1.2	1.2	2.4	2.4	2.4	2.4
Spacing (m)	0	0	1.25	1.77	1.77	1.25	1.25	0.88	1.25	0.88
Predicted FDW (g/tree)	225.08	200.43	93.79	72.53	62.75	106.56	43.54	24.85	24.91	11.08
Adjusted Predicted FDW (g/tree)	218.40	196.94	96.82	82.08	73.75	72.67	41.55	35.67	24.02	23.57
Significance[1]	└──	──┘	└──	────	────	────	────	────	────	──┘

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[1] Note: Treatments that were not significantly different (P = 0.05) are joined by a line.

Table E5: Analysis of Covariance: Location 3, Estimated mean foliage dry weight per tree in grams.

Source of Variation	df	Sums of Products $\sum x^2$	$\sum xy$	$\sum y^2$	For Adjusted Values df	SS	MS	F
Total	29	30,862,611.84	631,749.10	48,414.67				
Blocks	2	1,225,405.60	13,356.59	1,306.44				
Treatments	9	7,550.061.87	365,296.16	36,489.08				
MA (forms)	1	102,163.84	1,043.10	10.67				
Mi (Rates + Spac.)	4	4,432,732.80	336,140.62	35,499.17				
MaMi	4	3,015,165.20	28,112.44	979.24				
Error	18	22,087,143.00	253,096.34	10,619.15	17	7,718.92	454.05	
Treatment + Error	27	29,637,205.00	618,392.50	47,108.23	26	34,205.22	1,315.59	
Form + Error	19	22,189,307.00	254,139.44	10,629.82	18	7,719.10	428.84	
R & S + Error	22	26,519,876.00	589,236.96	46,118.32	21	33,026.25	1,572.68	
F X R & S + Error	22	25,102,309.00	281,208.78	11,598.39	21	8,448.15	402.29	
Block + Error	20	23,312,549.97	266,452.93	11,925.59	19	8,880.14	467.38	
Treatment Adjusted					9	26,486.30	2,942.92	6.48**[1]
Forms Adjusted					1	0.18	0.18	N.S.
R & S Adjusted					4	25,307.33	6,326.83	13.93**[1]
F X R & S Adjusted					4	729.23	183.31	N.S.
Blocks Adjusted					2	1,161.22	580.61	1.28 N.S.

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[1] Note: ** means significantly different at P = 0.01

Table E6: Predicted foliage dry weight for all Hexazinone treatments at Location 3.

Herbicide Treatment (ranked)	1	6	8	7	2	3	5	10	4	9
Form	Liquid	Solid	Solid	Solid	Liquid	Liquid	Liquid	Solid	Liquid	Solid
Rate (kg/ha)	0	0	1.2	1.2	1.2	1.2	2.4	2.4	2.4	2.4
Spacing (m)	0	0	1.25	1.77	1.77	1.25	0.88	0.88	1.25	1.25
Predicted FDW (g/tree)	138.27	114.87	74.14	76.75	67.22	71.75	33.43	35.56	29.91	33.30
Adjusted Predicted FDW (g/tree)	126.73	111.56	78.82	77.69	71.09	64.61	41.34	39.38	33.47	30.51
Significance[1]	└────	────┘	└────	────────	────────	────┘	└────	────────	────────	────┘

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[1] Note: Treatments that were not significantly different are joined by a line.

Table E7: Analysis of Variance of the White Spruce Seedling Survival Trial - Shoot Elongation

Source of Variation	df	SS	MS	VR	
Replications	1	3.29	3.29	2.67	N.S.
Treatments	9	44.01	4.89	3.98*[1]	
Forms	1	0.21	0.21		N.S.
Rates + Spacing	4	37.89	9.47	7.70**[2]	
F X R & S	4	5.91	1.48	1.20	N.S.
Error	9	11.08	1.23		
Total	19	58.38			

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[1] Note: * means significant differences at $P = 0.05$

[2] Note: ** means significant differences at $P = 0.01$

Table E8: White Spruce Seedling Survival Trial
- Shoot Elongation for all Hexazinone Treatments

Herbicide Treatment (ranked)	9	10	5	2	4	7	1	8	3	6
Form	Solid	Solid	Liquid	Liquid	Liquid	Solid	Liquid	Solid	Liquid	Solid
Rate (kg/ha)	2.4	2.4	2.4	1.2	2.4	1.2	0	1.2	1.2	0
Spacing (m)	1.25	0.88	0.88	1.77	1.25	1.77	0	1.25	1.25	0
Shoot Elongation per tree (cm)	7.74	6.77	6.17	6.00	5.81	5.24	4.06	3.90	3.50	2.91
Significance [1]	—	—	—	—	—	—	—	—	—	
		—	—	—	—	—	—	—	—	—

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[1] Note: Treatments that were not significantly different (P = 0.05) are joined by a line.

Table E9: Analysis of Variance of the Black Spruce Seedling Survival Trial - Shoot Elongation

Source of Variation	df	SS	MS	VR
Replications	1	15.95	15.95	1.79 N.S.
Treatments	9	110.53	12.28	1.38 N.S.
Forms (ma)	1	0.51	0.51	N.S.
Rates + Spacing (Mi)	4	68.30	17.07	1.91 N.S.
F X R & S	4	41.72	10.43	1.17 N.S.
Error	9	80.28	8.92	
Total	19	206.77		

Table E10: Analysis of Variance of the Black Spruce Seedling Survival Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	1	208.34	208.34	2.18 N.S.
Treatments	9	1,175.86	130.65	1.37 N.S.
Forms (Ma)	1	5.95	5.95	N.S.
Rates + Spacing (M)	4	362.80	90.70	N.S.
F X R & S	4	307.11	201.78	2.11 N.S.
Error	9	860.67	95.63	
Total	19	2,244.87		

Table E11: Analysis of Variance of the White Spruce (1.5m) Crop Tree Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	52.25	26.13	1.00 N.S.
Treatments	8	209.02	26.13	1.00 N.S.
Rate (Ma)	2	52.25	26.13	1.00 N.S.
Spacing (Mi)	2	52.25	26.13	1.00 N.S.
R X S	4	104.52	26.13	1.00 N.S.
Error	16	418.03	26.13	
Total	26	679.31		

Table E12: Analysis of Variance of the White Spruce (0.5m) Crop Tree Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	52.25	26.12	N.S.
Treatments	8	365.78	45.72	N.S.
Rate (Ma)	2	209.02	104.51	1.88 N.S.
Spacing (Mi)	2	52.25	26.13	N.S.
R X S	4	104.51	26.13	N.S.
Error	16	888.32	55.52	
Total	26	1,306.36		

Table E13: Analysis of Variance of the Black Spruce Crop Tree Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	39.22	19.61	N.S.
Treatments	8	2,554.30	319.29	9.49**[1]
Rate (Ma)	2	502.31	251.16	7.47**[1]
Spacing (Mi)	2	1,047.38	523.69	15.57**[1]
R X S	4	1,004.61	251.15	7.47**[1]
Error	16	538.09	33.63	
Total	26	3,131.61		

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[1] Note: ** means significant differences at P = 0.01

Table E14: Covariance Analysis of the Jack Pine Crop Tree Trial
- Mean Tree Height Growth

Source of Variation	df	Sums of Products $\sum x^2$	$\sum xy$	$\sum y^2$	For Adjusted Values df	SS	MS	VR
Total	26	476,291.69	-5,103.27	1,899.31				
Blocks	2	165,707.72	-5,682.81	231.07				
Treatments	8	173,009.48	1,270.55	979.10				
Rate (Ma)	2	120,246.88	2,182.21	175.02				
Spacing (Mi)	2	10,779.18	- 833.06	98.21				
R X S	4	41,983.42	- 78.60	705.87				
Error	16	137,574.48	- 691.01	689.15	15	685.68	45.71	
Treatments + Error	24	310,583.96	579.54	1,668.25	23	1,667.17	72.49	
Rate + Error	18	257,821.36	1,491.20	864.17	17	855.55	50.33	
Spacing + Error	18	148,353.66	-1,524.07	787.36	17	771.70	45.39	
R X S + Error	20	179,557.90	- 769.61	1,395.02	19	1,391.72	73.25	
Block + Error	18	303,282.20	-6,373.82	920.22	17	768.27	46.25	
Treatments Adjusted					8	981.49	122.69	2.68^{*1}
Rate Adjusted					2	169.87	84.94	1.86 N.S.
Spacing Adjusted					2	86.02	43.01	N.S.
R X S Adjusted					4	706.04	176.51	3.86^{*1}
Block Adjusted					2	82.59	41.30	N.S.

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[1] Note: * means significant differences at $P = 0.05$

Table E15: Analysis of Variance of the Jack Pine Crop Tree Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	502.31	251.15	2.74 N.S.
Treatments	8	2,301.48	287.69	3.14*[1]
Rates (Ma)	2	149.67	74.84	N.S.
Spacing (Mi)	2	1,072.85	536.42	5.86*[1]
R X S	4	1,078.96	269.74	2.95 N.S.
Error	16	1,464.27	91.52	
Total	26	4,268.05		

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[1] Note: * means significant differences at P = 0.05

Table E16: Analysis of Covariance of the Aspen Weed Tree Trial
- Mean Tree Height Growth

Source of Variation	df	Sums of Products Σx^2	Σxy	Σy^2	For Adjusted Values df	SS	MS	VR
Total	35	71,464,782.52	696,419.71	23,288.87				
Replications	2	3,941,806.30	-21,262.25	190.78				
Treatments	11	22,647,512.04	480,924.26	16,535.27				
Rate (Ma)	2	4,242,247.20	166,084.76	8,609.80				
Spacing (Mi)	3	9,924,362.10	235,954.58	5,863.57				
R X S	6	8,480,902.70	78,884.92	2,061.90				
Error	22	44,875,464.00	236,757.69	6,562.82	21	5,313.71	253.03	
Treatment + Error	33	67,522,976.00	717,681.95	23,098.09	32	15,470.06	483.44	
Rate + Error	24	49,117,711.00	402,842.45	15,172.62	23	11,868.68	516.03	
Spacing + Error	25	54,799,826.00	472,712.27	12,426.39	24	8,348.70	347.86	
R X S + Error	28	53,356,367.00	315,642.61	8,624.72	27	6,757.46	250.28	
Blocks + Error	24	48,817,270.49	215,495.45	6,753.60	23	5,802.33	252.28	
Treatments Adjusted					11	10,156.35	923.30	3.65**[1]
Rate Adjusted					2	6,554.97	3,277.49	12.95**[1]
Spacing Adjusted					3	3,034.99	1,011.66	4.00*[2]
R X S Adjusted					6	1,443.75	240.63	N.S.
Blocks Adjusted					2	488.62	244.31	N.S.

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[1] Note: ** means significant differences at P = 0.01

[2] Note: * means significant differences at P = 0.05

Table E17: Analysis of Variance of the Aspen Weed Tree Trial
- Percent Survival (Arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	42.97	21.48	N.S.
Treatments	11	32,543.19	2,958.47	36.81**[1]
Rate (Ma)	2	8,127.65	4,063.82	50.56**[1]
Spacing (Mi)	3	15,839.96	5,279.99	65.70**[1]
R X S	6	8,575.58	1,429.26	17.78**[1]
Error	22	1,768.20	80.37	
Total	35	34,354.35		

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[1] Note: ** means significant differences at P = 0.01

Table E18: Analysis of Covariance of the Willow Brush Trial
- Total Stem Growth per Shrub

Source of Variation	df	Sums of Products Σx^2	Σxy	Σy^2	For Adjusted Values df	SS	MS	VR
Total	26	77,471,259.77	1,473,542.19	646,668.27				
Replications	2	999,708.67	-112,658.50	16,787.22				
Treatments	8	19,629,105.21	560,113.25	469,048.71				
Rate (Ma)	2	3,973.56	22,707.32	432,211.06				
Number of Spots (Mi)	2	531,594.05	-47,183.77	4,517.35				
R X N	4	19,093,537.00	584,589.70	32,320.30				
Error	16	56,842,445.00	1,026,087.50	160,832.34	15	142,309.99	9,487.33	
Treatment + Error	24	77,471,259.00	1,586,200.80	629,881.05	23	597,404.06	25,974.09	
Rate + Error	18	57,846,128.00	1,048,794.80	593,043.40	17	574,027.94	33,766.35	
Number + Error	18	58,373,748.00	978,903.73	165,349.69	17	148,933.88	8,760.82	
R X N + Error	20	76,935,691.00	1,610,677.20	193,152.64	19	159,432.52	8,391.19	
Blocks + Error	18	57,842,154.56	913,428.95	177,619.56	17	163,194.91	9,599.70	
Treatment Adjusted					8	455,094.07	56,886.76	6.00**[1]
Rate Adjusted					2	431,717.95	215,858.98	22.75**[1]
Number Adjusted					2	6,623.89	3,311.95	N.S.
R X N Adjusted					4	17,122.53	4,280.63	N.S.
Blocks Adjusted					2	20,884.92	10,442.46	1.10 N.S.

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[1] Note: ** means significant differences at $P = 0.01$.

Table E19: Analysis of Variance of Willow Brush Trial - Percent Survival (Arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	601.10	300.55	4.14*[1]
Treatments	8	10,561.64	1,320.20	18.08**[2]
Rate (Ma)	2	7,778.50	3,889.25	53.25**[2]
Number of Spots (Mi)	2	1,658.09	829.05	11.35**[2]
R X N	4	1,125.05	281.26	3.85*[1]
Error	16	1,168.61	73.04	
Total	26	12,331.35		

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[1] Note: * means significant differences at P = 0.05

[2] Note: ** means significant differences at P = 0.01

Table E20: Analysis of Variance of the Mature Aspen Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	249.89	124.94	N.S.
Treatments	23	65,831.25	2,862.23	6.07**[1]
Form (Ma)	1	1,499.33	1,499.33	3.18 N.S.
Rate (Me)	3	34,811.04	11,603.68	24.59**[1]
Diam.Class (Mi)	2	17,241.82	8,620.91	18.27**[1]
F X R	3	2,947.36	982.45	2.08 N.S.
F X D	2	249.88	124.94	N.S.
R X D	6	5,596.01	932.67	1.98 N.S.
F X R X D	6	3,485.81	580.97	1.23 N.S.
Error	46	21,703.03	471.81	
Total	71	87,784.17		

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[1] Note: ** means significant differences at P = 0.01

Table E21: Mature Aspen Trail
- Actual and Transformed Percent Survival for all Hexazinone Treatments

Herbicide Treatment (ranked)	1	2	3	4	13	16	19	14	17	15	22	7	18	5	10	20	24	9	6	8	21	12	11	23
Form	L	L	L	L	S	S	S	S	S	S	S	L	S	L	L	S	S	L	L	L	S	L	L	S
Rate (# spots X 0.3750 gai)	0	0	0	2	0	2	4	0	2	0	6	4	2	2	6	4	6	4	2	4	4	6	6	6
Diam. Class	L	M	S	L	L	L	L	M	M	S	L	L	S	M	L	M	S	S	S	M	S	S	M	M
Actual Survival (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	88.89	77.78	77.78	77.78	66.67	66.67	55.55	44.44	44.44	44.44	33.33	33.33	33.33	22.22	0	0	0
Transformed Survival (arcsin transformation,	90.00	90.00	90.00	90.00	90.00	90.00	90.00	72.25	71.75	66.51	66.51	50.00	60.00	53.49	41.75	41.75	41.75	36.24	30.00	30.00	23.49	0	0	0
Significance[1]																								

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[1] Note: Treatments that were not significantly different (P = 0.05) are joined by a line.

Table E22: Analysis of Variance of the Jack Pine Greenhouse Trial - Foliage Dry Weight (gram/tree)

Source of Variation	df	SS	MS	VR
Replications	2	25.01	12.50	N.S.
Treatments	7	362.48	51.78	2.78*[1]
Rate (Ma)	3	150.13	50.04	2.69 N.S.
Position (Mi)	1	132.92	132.92	7.13*[1]
R X P	3	79.43	26.48	1.42 N.S.
Error	14	260.90	18.64	
Total	23	648.39		

Table E23: Analysis of Variance of the Jack Pine Greenhouse Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	244.42	122.21	N.S.
Treatments	7	15,185.77	2,169.40	9.23**[2]
Rates (Ma)	3	9,397.41	3,132.47	13.33**[2]
Position (Mi)	1	4,287.22	4,287.22	18.24**[2]
R X P	3	1,501.14	500.38	2.13 N.S.
Error	14	3,290.86	235.06	
Total	23	18,721.05		

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[1] Note: * means significant differences at P = 0.05

[2] Note: ** means significant differences at P = 0.01

Table E24: Analysis of Variance of the White Spruce Greenhouse Trial - Foliage Dry Weight (gram/tree)

Source of Variation	df	SS	MS	VR
Replications	2	2.88	1.44	1.84 N.S.
Treatments	7	78.07	11.15	14.27**[1]
Rate (Ma)	3	63.71	21.24	27.17**[1]
Position (Mi)	1	4.81	4.81	6.15 *[2]
R X P	3	9.55	3.18	4.07 *[2]
Error	14	10.94	0.78	
Total	23	91.89		

Table E25: Analysis of Variance of the White Spruce Greenhouse Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	619.89	309.95	2.20 N.S.
Treatments	7	16,579.69	2,368.53	16.81**[1]
Rate (Ma)	3	10,593.06	3,531.02	25.06**[1]
Position (Mi)	1	2,932.67	2,932.67	20.81**[1]
R X P	3	3,053.96	1,017.97	7.22**[1]
Error	14	1,972.77	140.91	
Total	23	19,172.35		

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[1] Note: ** means significant differences at P = 0.01

[2] Note: * means significant differences at P = 0.05

Table E26: Analysis of Variance of the Aspen Greenhouse Trial - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	384.87	192.44	N.S.
Treatment	3	12,533.89	4,177.96	18.47**[1]
Error	6	1,357.36	226.23	
Total	11	14,276.12		

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[1] Note: ** means significant differences at P = 0.01

Table E27: Analysis of Covariance of the Aspen Greenhouse Trial - Foliage Dry Weight (g/tree)

		Sums of Products			For Adjusted Values			
Source of Variation	df	Σx^2	Σxy	Σy^2	df	SS	MS	VR
Total	11	262.50	42.87	27.21				
Replications	2	180.14	-0.13	0.02				
Treatment	3	68.93	42.98	27.14				
Error	6	13.43	0.01	0.05	5	0.05	0.01	
Treatment + Error	9	82.36	42.99	27.19	8	4.75	0.59	
Replications + Error	8	193.57	-0.12	0.07	7	0.06	0.01	
Treatments Adjusted					3	4.70	1.57	1.57**[1]
Replications Adjusted					2	0.01	0.005	N.S.

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[1] Note: ** means significant differences at P = 0.01

Table E28: Analysis of Variance of the Hazel Greenhouse Trail - Percent Survival (arcsin transformation)

Source of Variation	df	SS	MS	VR
Replications	2	0	0	0
Treatments	3	13,914.49	4,638.16	29.59**[1]
Error	6	940.58	156.76	
Total	11	14,855.07		

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[1] Note: ** means significant differences at P = 0.01

Table E29: Analysis of Covariance of the Hazel Greenhouse Trial
- Foliage Dry Weight (g/tree)

		Sums of Products			For Adjusted Values			
Source of Variation	df	Σx^2	Σxy	Σy^2	df	SS	MS	VR
Total	11	414.69	9.30	4.82				
Replications	2	17.62	0.81	0.09				
Treatments	3	41.35	3.95	4.50				
Error	6	355.71	4.54	0.23	5	0.17	0.03	
Treatment + Error	9	397.06	8.49	4.73	8	4.55	0.57	
Replications + Error	8	373.33	5.35	0.32	7	0.24	0.03	
Treatments Adjusted					3	4.38	1.46	48.67**[1]
Replications Adjusted					2	0.07	0.04	1.17 N.S.

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[1] Note: ** means significant differences at P = 0.01