**University of Alberta**

# Competitive effects of woody and herbaceous vegetation in a young boreal mixedwood stand

**by**

**Cosmin Dumitru Man** ©

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# Abstract

The influence of aspen and herbaceous/grass vegetation on light, soil moisture, air temperature, soil temperature, soil nitrogen availability and white spruce growth was measured as part of a large, long-term experiment established near Whitecourt, Alberta in 2002. During the 2004 and 2005 growing seasons, I examined the effects of treatments designed to control only woody or complete vegetation on leaf area index (LAI) of both the woody and herbaceous components and relationships between leaf area index of these components and light, soil moisture, air temperature, soil temperature, soil nitrogen availability or spruce growth. Results indicate that controlling only woody vegetation resulted in rapid expansion of the herbaceous layer. Spot control, involving controlling all vegetation within a 2-m radius, while leaving 3 m of untreated between treated spots, is a promising alternative to classical broadcast treatments for establishing spruce in a mixedwood stand, at least for first 3 years after establishment.

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# Chapter 1. General Introduction

Mixedwood forests dominated by trembling aspen (*Populus tremuloides* Michx) and white spruce (*Picea glauca* [Moench] Voss) (Rowe 1972) occupy about 15 million ha and represent almost one third of the productive forest sites in the Prairie Provinces (Brace Forest Services 1992; Navratil et al. 1994). These forests are mainly found on moraine or lacustrine luvisols, in cold and moist climates (CCEA 2004). The major species found in mixedwood stands in western Canada are white spruce and aspen (Lieffers et al. 1996), while in eastern Canada white spruce is frequently substituted by balsam fir (Kneeshaw and Bergeron 1998). The presence of an aspen component in a stand may contribute to stand health, productivity, amelioration of frost and other problems, biodiversity, and long-term sustainability (Comeau 1996, Man and Lieffers 1999a).

Due to the increasing economic importance and harvesting of aspen in western Canada, its place in natural succession, its potential role in sustainable management of boreal forest ecosystems, and its importance in wildlife habitat, there is a growing interest in finding ways to manage mixedwood stands to achieve various objectives. However, growing mixedwood stands, compared with monocultures, creates several challenges for foresters. One of the key factors in managing mixedwood stands is to find a balance between the unfavorable effects of deciduous competition on conifers and the beneficial effects of aspen on nutrient availability, microclimate, insect and disease damage, and biodiversity (Comeau et al. 1999a). Moreover, sustainable management of mixedwood forests requires a clear understanding of succession and the critical phases at which foresters might manipulate stands to effectively achieve stated objectives (Lieffers et al. 2003). Therefore, practical regeneration strategies are needed to reproduce the temporal, spatial, compositional, and structural diversity of mixedwood forests and sustain the values they support on our landscape (Pitt et al. 2005).

One of the most critical periods in the development of mixedwood stands occurs immediately during and after establishment. Since treatments applied in this period will influence future stand development, it is critical to assure proper conditions for establishment of young spruce seedlings. This will likely involve use of site preparation and vegetation management treatments.

### 1.1. Characteristics of boreal mixedwoods

The nature and structure of boreal mixedwood forests results from the combined effects of several factors, including disturbances (mainly wildfire), ecological variability of the land base on which the disturbances take place, and differences in autoecology of the component species (Chen and Popadiuk 2002). Western boreal mixedwood forests are comprised of three major types of stands: aspen dominated, spruce dominated, or mixtures of the two (Lieffers and Beck 1994).

There is no single, universal definition of what constitutes a mixedwood forest. MacDonald (1996) defines a boreal mixedwood site as an area that shows climatic, topographic and edaphic conditions capable of sustaining mixedwood stands. In other areas, a mixedwood stand is often defined as a stand that has recognizable components of at least 2 species, and is typically defined based on each component species contributing at least 20% to the total stand volume or canopy composition (Voicu 2004). At young stages, the plant community may include substantial numbers of small white spruce or balsam fir growing in the understory, but where basal area, volume, or cover are not currently sufficient to meet these criteria.

Mixedwood forests develop as a consequence of natural succession. Following the harvesting of mixedwood stands, trembling aspen regenerates vigorously and dominates the early stages of subsequent development (Thorpe 1992). Complementary to aspen, white spruce grows slowly during the early stages of development and usually does not become dominant in the canopy until much later (Lieffers and Beck 1994). Several studies indicate a potential reduction in conifer growth (primarily due to reduced light) and whipping damage from hardwood species (Lees 1966; Thorpe 1992; MacIsaac and Navratil 1996).

Stand dynamics in boreal mixedwoods depend on interactions between and among species, interactions between species and site, and the nature of disturbance and its impact on stand development (Andison and Kimmins 1999). Changes in mixedwood stands over time frequently include changes in species composition (Chen and Popadiouk 2002), with stand development being strongly influenced by the type, intensity, and timing of disturbances, stand and site conditions, biotic factors (i.e. insects), and adjacent stands on the site, as well as by the consequences of those disturbances for seedbeds, seed production, competition, survival, growth, and tree mortality (Andison and Kimmins 1999; Chen and Popadiouk 2002).

Burton et al. (2003) summarized some of the main characteristics of boreal forest:

➢ Cold continental climate with severe winters, a short growing season, and cold soils;

➢ Forests dominated by relatively few species of softwoods (i.e. spruce, pine, and fir) and hardwoods (i.e. aspen, birch, and alder);

➢ Slow tree growth that results in strong wood with a large range of commercial utilization, as well as slow decomposition rates resulting in strong nitrogen limitations to plant productivity;

➢ Distinct cycles of natural disturbance and succession dominated by wildfire and insect outbreaks.

Due to the rapid and generally abundant regeneration of aspen on mixedwood sites, the frequent lack of replacement species (due to lack of a white spruce seed source or suitable seedbed conditions) or premature arrival of fire disturbances (Rowe 1961; Peterson and Peterson 1992), mixedwood stands may not always follow the classical patterns of succession. Other species also establish in the early stages following harvesting or fire. These include various herbaceous species such as fireweed (*Epilobium angustifolium* L.), grasses (*Calamagrostis canadensis* (Michx.) Beauv.) , *Elymus* L. species, and shrubs (beaked hazel (*Corylus cornuta* Marsh.), wild raspberry (*Rubus idaeus* L,), green alder (*Alnus crispa* (Ait.) Pursh), willow (*Salix* L. species) etc.) (Peterson and Peterson 1992).

Throughout much of western Canada in the first half of the 20th century, mixedwood stands were harvested to remove large white spruce for lumber (Lieffers and Beck 1994; Andison and Kimmins 1999). The same approach was adopted in the eastern boreal, where the management of mixedwood stands involved extracting the valuable softwood or hardwood species. By the 1970's, it appears that harvesting had resulted in a reduction in white spruce present in the boreal forest compared to what may have been present prior to 1880 (Prevost 1996). This phase was followed by a period when the more desirable spruce was promoted as opposed to aspen (aspen being considered as non-merchantable) by trying to convert mixedwood stands to softwood stands (MacDonald 1996; Cumming and Armstrong 2001). However, as technological developments enabled the utilization of aspen and poplar (MacDonald 1996; Cumming and Armstrong 2001), the conversion to softwood stands came into question (Andison and Kimmins 1999). In addition, conversion was often unsuccessful and expensive due to persistent competition from trembling aspen and grasses (Lieffers and Beck 1994). Increasing anxiety among environmentalists due to widespread conversion of mixedwood stands to pure softwoods using herbicides was another key reason for reassessment of the stand conversion strategy (Andison and Kimmins 1999).

### 1.2. Mixtures versus monocultures

There has been an increasing interest in promoting mixedwood stands, in part because the formation of mixed stands is part of natural succession in the boreal landscape. In addition, sustainable forest management in Canada encourages preservation of naturally occurring stand types on the landscape. Some of the beneficial effects of mixedwood stands over pure stands include: higher biodiversity; increased resistance to diseases, insects and frost damage; improved litter decomposition and nutrient cycling; maintenance of soil and site productivity; amelioration of environmental extremes; increased wind stability; and control of other competitors (Kelty 1992; Comeau 1996; MacDonald 1996; Man and Lieffers 1999a; Comeau et al. 1999b; Comeau et al. 2005).

Compared to pure stands, stratified stands made up of species with different light requirements (i.e. shade intolerant species in the upper canopy and shade tolerant species underneath) make better use of site resources, including available light (Kelty 1992; Mielikainen 1996). This can result in higher stand productivity as found in a vertically stratified aspen-conifer mixture (Edgar and Burk 2001; MacPherson et al. 2001).

Mixedwood stands may, under ideal conditions, provide greater yields than pure stands, as suggested by studies in hardwood-hemlock mixtures (Kelty 1992), Douglas-fir and red alder stands (Comeau 1996), birch and conifer stands (Mielikainen 1996), or in mixedwood stands of white spruce and aspen (Wang et al. 1995; Man and Lieffers 1999a). The optimal proportion of hardwoods in a mixedwood stand varies with species (25-50% for birch, 20-40% for red alder) (Comeau 1996, Mielikainen 1996). Total growth rates, as well as yields at rotation age can be greater for mixed-species stands than for pure stands (MacDonald 1996). Greater productivity of mixedwood stands could be the result of adding the growth of white spruce owing to prolonged photosynthetic periods in spring and fall (Constabel and Lieffers 1996) to the potential yield of purely deciduous aspen stands (Man and Lieffers 1999a). However, since aspen and white spruce reach merchantable sizes at different ages, and pathogens often reduce aspen yield after age 80, achieving higher total yield requires management regimes that are designed to capture this additional potential volume. At present there is no clear information on the optimal densities, combinations, or arrangements of aspen and white spruce that are required to obtain maximum yields. However, it is clear that high densities of aspen will slow growth rates of white spruce.

Other advantages of growing mixtures rather than monocultures potentially include:

➢ Greater rates of decomposition and nutrient turnover due to aspen presence (Smith 1962, Pare and Van Cleve 1993, Peterson and Peterson 1996, Bergeron and Harvey 1997)

➢ A protective effect of aspen overstory on air temperature and humidity reducing the risk of frosts and its intensity (Groot and Carlson 1996, Pritchard and Comeau 2004, Voicu 2004)

➢ Reduced competition from other woody and herbaceous species, especially *Calamagrostis,* due to reduced light reaching the understory (Lieffers and Stadt 1994)

➢ Reduced damage caused by wind gusts (Navratil 1996, Man and Lieffers 1999a, Kelty 1992)

➢ Assurance that at least one of the species will survive due to increased compensatory growth (Debyle 1991, Kelty 1992)

➢ Increased stability for the industry as a whole (MacDonald 1996)

➢ Increased aesthetic value of landscapes (Comeau 1996)

➢ Better habitat for wildlife and protection of watersheds by offering a greater diversity of species in the understory (Comeau 1996, MacDonald 1996)

➢ Economic advantages, such as reduced regeneration cost, accelerated regeneration of the site, and a greater diversity of products (Lieffers and Beck 1994)

Technical advancements make mixedwoods more appealing to the forest industry now that the capability exists to process the component species into a broader range of products. At the same time, the availability of pure conifer stands is decreasing, while mixedwood stands have emerged as an important, low cost source of fiber close to mills (MacDonald 1995).

Silviculture treatments such as mechanical site preparation and herbicide application can be effective for establishing spruce stands at reasonable costs. However, depending on the management strategy adopted, spruce establishment on a mixedwood site can be costly ($450-900/ha MSP (mechanical site preparation) and $700-$1000/ha planting (Comeau et. al. 2005)), while establishment of aspen requires no additional costs. Without follow-up tending, up to two-thirds of spruce plantations may revert to mixedwood or broadleaf stands (Brace and Bella 1988). The economics of stand tending has also shifted in favor of mixedwoods (MacDonald 1995), but depending on the management strategy, more entries in the stand may be required (brushing cost: $250-$1200/ha/entry; manual cutting to reduce aspen densities: $400-$1200/ha/entry (Comeau et. al. 2005). Furthermore, the justification of using herbicides to boost conifer crops has been increasingly difficult to defend as the commercial value of aspen has increased (Beck 1988). All of the above are important factors to consider in setting the direction for management of mixedwood forests.

### 1.3. Competition for resources

Accelerating development of white spruce in young mixedwood plantations requires an understanding of the temporal dynamics of interspecific competition and its influence on factors that control seedling survival and growth. It is important to consider competition within the context of the ecosystems in which it occurs. Competition appears to be most problematic during the first years after planting, with the best volume growth of crop tree seedlings usually being realized when trees are maintained entirely free of competition (Wagner et al 1999).

Competition in mixedwoods is mostly for light, water, and nutrients. Light is widely considered to be the major factor for which competition occurs in forests. Competition for light is generally acknowledged to be of primary importance in young mixedwood stands (Coates and Burton 1999, Comeau and Heineman 2003), the availability of light having a substantial influence on the survival and growth of tree seedlings (Grossnickle 2001). As the basal and leaf area of the overstory develop, light levels below canopy decrease (Comeau. 2001) leading to reductions in the amount of light available to understory trees or other plants. As light availability declines, survival, height, and diameter growth of juvenile spruce also declines (Comeau et al. 1993, Comeau et al. 1999, Tanner et. al. 1996, Lieffers et. al. 2002).

The main factors contributing to the wide range variation of light in mixedwood stands are: total leaf area, live crown height, spatial distribution of the trees, sun angle, sky conditions, tree species (Messier 1996), site, age and density (Comeau et al. 2002). The more leaf area in overstory, the less light can penetrate it and reach the understory plant community which, in case of young mixedwood plantations, can include white spruce as one of the crop species. Light penetration through canopy increase with increasing size of gaps, width of strips and distance from edges (Groot and Carlson 1996, Pritchard and Comeau 2004, Voicu 2004). Under spruce canopies, light levels are reduced more than under similar aspen canopies. In a mixedwood stand, the presence of more broadleaves means more available light for understory plant community. Due to the fact that the foliage of broadleaves is absent in spring and autumn, the light levels below these canopies are increased and can provide favorable conditions for photosynthesis of understory spruce (Constabel and Lieffers 1996). Understory vegetation also plays an important role in development of seedlings, as shrub and herb layers may be very vigorous under older aspen stands with the leaf area of the understory sometimes exceeding that of the overstory (Lieffers et al. 1999).

Several studies (Eis 1981, Carter and Klinka 1992, Coates et al. 1994, Lieffers and Stadt 1994, Chen 1997) indicate limiting values for light levels in order for spruce seedlings to survive. The conclusion is that below 10-15% of full sunlight white spruce seedlings cannot survive. Between 60 and 85% light is required for these seedlings to grow at about 70% of their maximum rate, with optimal height growth being realized at 40% of light (Lieffers and Stadt 1994). However, extended periods of exposure to low light levels increase the probability of mortality (Kobe and Coates 1997).

While it is widely assumed that aspen competes with conifers for light (Burton 1993), there is evidence that competition for water may also occur on some sites (Brand 1991; Coopersmith et al. 2000). Competition for soil moisture typically increases with vegetation density and leaf area index (Mitchell et al. 1993, Petersen et al. 1988). Climatic and site factors will influence the intensity, duration, and temporal pattern of competition for water. Shrubs, forbs, and grasses can comprise substantial cover or leaf area index (LAI) in forest ecosystems, with cover of these understory species generally declining as overstory cover increases (Lieffers and Stadt 1994). Brand (1991) found that competing vegetation could have measurable effects on soil moisture availability in young boreal conifer plantations during some years, especially during dry summers. If seedlings are unable to maintain a favorable internal water balance, growth is reduced, especially when soil moisture declines (Grossnickle et al. 2001). The threshold below which it is believed that white spruce seedlings might experience moisture stress is 20% volumetric water content. In addition to competing for light, water, and nutrients, delayed soil warming resulting from shade and litterfall from *Calamagrostis*, aspen and other vegetation can significantly shorten the growing season for other species in boreal forests (Hogg and Lieffers 1991).

The competitive effects of aspen, grasses and herbaceous vegetation are expected to differ substantially when expressed on the basis of leaf area index, due to differences in resource requirements and utilization (Goldberg and Werner 1983). Bell et al. (2000) found differences between the competitive effects of woody and herbaceous vegetation on jack pine and black spruce growth when evaluated on the basis of percent cover. Comeau et al. (1993) report no differences in the competitive influences of different shrub, forbs and grass species on Engelmann spruce in southern B.C. Effects are likely to vary depending upon resource availability, species, climate and other factors. Further study is required to evaluate the relative competitive effects of grass and aspen in young spruce and mixedwood plantations in the boreal forest.

### 1.4. Vegetation management

Vegetation management involves manipulation of the rate and course of forest succession to accelerate achievement of a forest with the desired composition and structure. Therefore, in order to achieve forest management objectives, controlling aspen and herbaceous vegetation in a mixedwood stand and thus competition, may be beneficial.

Since many critical factors influence the establishment and early growth of planted white spruce on upland sites in the boreal forest, substantial effort is often invested in the control of hardwood competition in coniferous plantations in western Canada (Ehrentaut and Branter 1990). These factors include:

- Frost damage relating to Chinook events and summer frost
- Competition from aspen, balsam poplar and white birch for light and water
- Competition from *Calamagrostis canadensis* and other vegetation, and
- Cold soil temperatures, which are made worse by grass and other vegetation cover
- Wet soils

A number of studies indicate potential reductions in conifer growth as a result of competition (primarily for light) and leader whipping damage from aspen (Lees 1966, Yang 1991, Morris and MacDonald 1991, MacIsaac and Navratil 1996). Site preparation and brushing treatments, which reduce competition from aspen and other broadleaved trees, can provide substantial increases in growth of white spruce (e.g., Lees 1966, Biring et al. 1999, Biring and Hays-Byl 2000, Jobidon 2000) and result in increases in spruce yield, shortening of rotation lengths, or acceleration of achievement of merchantable diameters. In the context of increasing interest in mixedwoods, it is critical both for scientists and forest managers to find suitable and effective strategies for managing such dynamic and diverse ecosystems as boreal mixedwood forests.

Trembling aspen generally increases in abundance following clear cutting because of its aggressive root suckering after disturbance. Usually reaching maturity at 60 years of age, it is considered a potential competitor to white spruce for many years. Although it is moderately shade tolerant, white spruce may not establish or survive under closed aspen or *Calamagrostis* canopies, particularly when light levels are below 8% (Lieffers and Stadt 1994). While growing mixedwood stands may be desirable, creating valuable and healthy mixedwood stands may require significant silvicultural investment that exceeds efforts required to establish and maintain aspen or conifer stands, as well as an obligation to perform the necessary silvicultural operations. These operations include mechanical site preparation techniques adapted to the site conditions to improve conifer establishment (Lieffers and Beck 1994), early and mid-rotation thinning, and modified harvesting to protect advance regeneration (MacDonald 1996).

The primary objective of site preparation would be to create microsites which would favor the establishment and growth of the desired species. In spruce plantations, the most common treatments used for site preparation are mounding or disk-trenching and vegetation management. Mounding or disk-trenching is also commonly used to provide both suitable microsites and early vegetation control around spruce. Annually, in Canada site preparation and release treatments are used on approximately 290 000 ha (30 000 ha in Alberta, 60 000 ha in British Columbia) (National forestry database, url: http://nfdp.ccfm.org/). Vegetation management treatments include use of herbicides (triclopyr ester (Release®), glyphosate - (Vision®)), or cutting ("brushing") treatments. . Triclopyr ester is used to control aspen and other woody species and glyphosate is used to control aspen, grass and herbaceous vegetation. Each year in Canada, herbicides are being applied on an area that exceeds 170 000 ha (30 000ha in Alberta, 24 000ha in British Columbia) (National forestry database, url: http://nfdp.ccfm.org/). Biring and Hays-Byl (2000) found that glyphosate treatment had a measurable effect on white spruce growth and on aspen and shrub density. This treatment increases conifer survival and yield and reduces conifer rotation length. However, there are concerns about the impacts of herbicide treatments on stand composition. Biring and Has-Byl (2000) indicate that, 10 years after herbicide treatment, deciduous densities will be less than 1500 sph (stems per hectare), and that the deciduous component will be largely birch and balsam poplar. Other studies (Biring et al. 1999, Pitt and Bell 2005) indicate the same concern of not achieving a mixedwood stand after application of broadcast vegetation management treatments.

It is widely accepted that vegetation control is needed to overcome the strong competitive effects of the other components of the plant community that are not considered crop species. Since the treatments being used to control competition generate concerns about future stand structure, spot treatments might be used to achieve these objectives. Another aspect of the competition is that removal or reduction of the woody component often results in significant increases in grass (i.e. *Calamagrostis*) or herbaceous vegetation (Comeau, pers. comm.) which could have negative effects on the growth of young seedlings. Therefore, action must be taken to overcome competition from both woody and herbaceous vegetation, since controlling only one of the components can accomplish little in terms of spruce response.

On prepared sites, using the available techniques described above, white spruce is typically planted at densities of 1100 to 1600 sph. Annually, in Canada, approximately 400 000 ha are planted (38 000 ha in Alberta, 160 000 ha in British Columbia).

### *1.4.1. Juvenile Tending*

To maintain the mixedwood structure of stands, Prevost (1996) suggests that pre-commercial thinning should be applied during the first 15 years after disturbance. Until the 1980's, harvesting was usually followed by little management in terms of regenerating the harvested area in boreal mixedwood forests. This was the direct result of the low commercial timber volume per hectare, regeneration problems, small log sizes, and poor economics perceived with harvesting boreal mixedwood forests (Andison and Kimmins 1999). In the 1980's concern developed as a result of reports of declining conifer volume and an associated increase in the abundance of deciduous stands across the landscape. This led to widespread attempts to convert both young and mature deciduous dominated stands to coniferous stands. In the 1990's, changes in forest economics worldwide and the development of oriented strandboard and pulp industries utilizing aspen and poplar led to increased interest in the utilization and management of mixedwood forests. Increased demand for timber products, new developments in wood processing, a more ecological-based management philosophy, as well as a better understanding of forest ecosystems and loss of timber supplies at global level (Lieffers and Beck 1994; Andison and Kimmins 1999), made the management of boreal mixedwood forests more attractive.

In a young spruce-aspen mixedwood stand, there are both aspen and white spruce that require relatively high light levels to grow. On the other hand, larger openings can induce damage such as frost, or competition from *Calamagrostis*. To address these problems, there are a number of possible ways to manage young mixedwood stands (Lieffers et al. 1999; Comeau and Mihajlovich 2001; Pitt et al. 2005; Comeau et al. 2005), which include:

1) Manipulating aspen densities to provide conditions that improve survival and growth of spruce. This involves increasing light levels by reducing aspen density. The final result will be a vertically stratified mixture of aspen and white spruce, with spruce occupying a codominant position in the canopy;

2) Treating areas around individual conifers and removing competition within a desired radius. Mechanical or chemical removal of all vegetation within a 1-2 m radius seems to significantly improve white spruce survival and growth. This will create a vertically stratified mixture of aspen and white spruce, with spruce occupying diverse positions in the canopy;

3) Treating patches or clusters of conifers, while leaving a portion of the stand untreated. This option involves removing aspen from the spruce patches. This will result in a horizontally stratified mixture of aspen and white spruce, where spruce can take advantage of the potential nursing influences of aspen, while getting adequate light levels for sustained growth, depending on patch sizes. However, because of the typical slow initial growth of white spruce, it might be necessary to control competition for an extended period of time (Sutton 1986).

### 1.5. Objectives

My study was part of a larger, long-term experiment established at Judy Creek, near Whitecourt, Alberta in 2002 by Dr. Phil Comeau, Dr. Doug Pitt, Mr. Milo Mihajlovich, and Mr. Dan MacIsaac. This long-term study is examining the combined effects of early woody and herbaceous vegetation control and subsequent manipulation of aspen density on the dynamics and growth of a mixedwood stand in central Alberta, and includes an examination of the effects of duration of herbaceous control on spruce performance. The study has two components: 1) a response surface component; and, 2) reference treatments or an alternative practices component. In the response surface component, the objective is to evaluate the effects of duration of herbaceous control within a 2 m radius of each of 400 white spruce per hectare (0, 2, and 3 years), with spacing of the aspen component of the plot to a range of densities (400, 800, 1200, 2000 stems per ha, and natural (i.e., unthinned)) in the selected plots (spacing treatments will be applied in 2007). In all response surface plots, woody vegetation has been controlled within a 2 m radius of the planted spruce using applications of triclopyr ester. Herbaceous control is being achieved using foliar applications of glyphosate herbicide for the specified number of years.

Five reference treatments represent selected alternative practices: a) untended mixedwood plantation (i.e., spruce planted and aspen allowed to regenerate naturally and left untended); b) mixedwood plantation with control of grass and herbaceous vegetation only; c) pure spruce plantation with control of all competition; d) spruce plantation with control of woody competition only, and e) untended aspen. In the reference treatment plots, spruce were planted at 2.5 m spacing (1600 trees/ha) and treatments were applied to the entire plot. Woody-only vegetation control is being achieved with triclopyr ester and glyphosate is being used to provide control of both herbaceous and woody vegetation. Herbaceous-only vegetation control, while leaving the woody tree layer undamaged, was initially attempted using a directed foliar application of glyphosate. However, due to evidence of some damage to the small aspen in 2003, hand weeding was used in 2004 and 2005. In the future, directed spot applications of glyphosate will be used to provide control of the herbaceous layer, which is now small relative to the aspen. This treatment is expected to have little impact on the aspen which is now over 3.0 m in height.

The objectives of my study were to examine effects of selected treatments on: 1) vegetation development, particularly LAI and root surface area; 2) major factors and resources influencing spruce growth (light, soil moisture, soil nitrogen availability, air temperature and soil temperature); and, 3) growth of planted white spruce.

For the studies presented in this thesis, a series of 5 treatments in 2004 and 6 treatments in 2005 were chosen. The treatments are:

- CCB – Complete Control Broadcast, in which all the vegetation within the plot has been controlled using glyphosate
- CCR – Complete Control Radial, in which all the vegetation within a 2 m radius around each spruce seedling was controlled using glyphosate. Note that in 2005, this treatment was divided in 2 ((a) Complete Control Radial

for 2 years – CCR2 and (b) Complete Control Radial for 3 years – CCR3, respectively) according to the number of years of complete vegetation control within the 2 m radius

- N – No control (untreated) which is an untended mixedwood plantation
- WCB – Woody Control Broadcast, which is a pure spruce plantation with control of woody competition only using triclopyr ester
- WCR – Woody Control Radial, in which woody vegetation within a 2 m radius around the spruce seedling is being controlled using triclopyr ester and in later years clipping.

This thesis is organized as follows:

Chapter 2 – Materials and methods, which presents detailed explanations of the methods and techniques used for this study. This section is divided into several subsections which describe the methods used for measuring competing vegetation and their use of available resources and thus the influence on seedlings growth. A study site history and detailed description of statistical analyses used are also provided;

Chapter 3 – Results and discussion, in which the main findings and conclusions are being presented for competing vegetation, and resource availability;

Chapter 4 – Results and discussion, in which the main findings and conclusions are being presented for spruce seedlings growth;

Chapter 5 – Conclusions, in which the conclusion of the entire study are presented along with practical applications and suggestions for further research.

**1.6. References**

Alberta Forest Products Association. Url: http://www.albertaforestproducts.ca/. Last visit December 1, 2005.

Andison, D.W., and Kimmins, J.P 1999. Scaling up to understand British Columbia's boreal mixedwoods. Environ. Rev. 7:19-30.

Beck, J.A. 1988. Symposium summary. J.K. Samoil (editor) IN: Management and utilization of northern mixedwoods. Proc. Symp. 11-14 Apr 1988, Edmonton, AB. Can. For. Serv., Edmonton, AB, North. For. Centre, Inf. Rep. NOR-X-296, pp.145-146.

Beckingham, J.D., and Archibald, J.H. 1996. Field guide to ecosites of northern Alberta. Can. For. Ser. Special Report 5. 412 pp.

Bell, F.W., Ter-Mikaelian, M.T., and Wagner, R.G. 2000. Relative competitiveness of nine early-successional boreal forest species associated with planted jack pine and black spruce seedlings. Can. J. For. Res. 30: 790-800.

Bergeron, Y., and Harvey, B. 1997. Basing silviculture on natural ecosystem dynamics:an approach to the southern boreal mixedwoods of Quebec. For. Ecol. Manage. 92:235-242.

Biring, B.S. and W. Hays-Byl. 2000. Ten-year conifer and vegetation responses to glyphosate treatment in the SBSdw3. B.C. Ministry of Forests, Research Branch. Victoria. Extension Note 48. url: http://www.for.gov.bc.ca/hfd/pubs/Docs/En/En48.htm

Biring, B.S., Hays-Byl, W.J. and Hoyles, S.E. 1999. Twelve-year conifer and vegetation responses to discing and glyphosate on a BWBSmw backlog site. B.C. Ministry of Forest, Research Branch, Victoria. Working Paper 43.

Brace Forest Service 1992. Protecting white spruce understories when harvesting aspen. For.Can. and For. Lands Wildl., Alta. For. Serv. Edmonton, Alta Canada-Alberta Partnership Agreement in For. Rep.No.102. Prog. Rep.38 pp.

Brace, L.G., and Bella, I. E. 1988. Understanding the understory: dilemma and opportunity. J.K. Samoil (editor) In: Management and utilization of northern mixedwoods. Proc. Symp. 11-14 Apr 1988, Edmonton, AB. Can. For. Serv., Edmonton, AB, North. For.Centre, Inf. Rep. NOR-X-296, pp.69-86.

Brand, D.G. 1991. The establishment of boreal and sub-boreal conifer plantations: an integrated analysis of environmental conditions and seedling growth. Forest Science 37: 68-100.

Burton P.J., Messier, C., Weetman, G.F., Prepas, E.E, Adamowicz, W.L., and Tittler, R. 2003. The current state of boreal forestry and the drive to change. Chapter1. In Towards Sustainable Management Of the Boreal Forest. Edited by P.J. Burton, C.Messier, D.W.Smith, and W.L. Adamowicz. NRC Research Press, Otawa, Ontario, Canada. pp. 1-40.

Burton, P.J. 1993. Some limitations inherent to static indices of plant competition. Can. J. For. Res. 23: 2141-2152.

Carter, R.E., Klinka, K., 1992. Variation in shade tolerance of Douglas-fir, western hemlock and western redcedar in coastal British Columbia. For. Ecol. Manag. 55, 87-105.

Cater, T.C., and Chapin F.S. III. 2000. Differential effects of competition or microenvironment on boreal tree seedling establishment after fire. Ecology, 81(4), pp. 1086-1099.

CCEA Canadian Council on Ecological area. 2004. Some descriptive biophysical characteristics of Canada's marine and terrestrial ecozones. Available at http://www.ccea.org/ecozones/stats/biochar.html [visited October, 18, 2005]

Chen H.Y.H., and Popadiouk, R.V. 2002. Dynamics of North American boreal mixedwoods. Environ. Rev. 10:137-166.

Chen, H.Y.H., 1997. Interspecific responses of planted seedlings to light availability in interior British Columbia: survival, growth, allometric patterns, and specific leaf area. Can. J. For. Res. 27, 1383-1393.

Coates, K.D., Burton, P.J., 1999. Growth of planted tree seedlings in response to ambient light levels in northwestern interior cedar-hemlock forests of British Columbia. Can. J. For. Res. 29, 1374-1382.

Coates, K.D., Haeussler, S., Linderburgh, S., Pojar, R., Stock, A.J., 1994. Ecology and Silviculture of interior spruce in British Columbia. FRDA Report 220. BC Ministry of Forestry and Forestry Canada, Victoria, BC, 182 pp.

Comeau, P.G. 1996 Why mixedwoods? In Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors).B.C. Min. For., Research Branch., Victoria. Land Manage. Handbk. 36. pp.1-7

Comeau, P.G. 2001. Relationships between stand parameters and understory light in boreal aspen stands. Journal of Ecosystems and Management 1(2): 103–110.

Comeau, P.G., and Heineman, J.L. 2003. Predicting understory light microclimate from stand parameters in young paper birch (Betula papyrifera marsh.) stands. For. Ecol. Manage. 180:303-315.

Comeau, P.G., and Mihajlovich, M. 2001. Summary of breakout session #1 of vegetation management in boreal mixedwoods. Managing spruce-aspen mixtures. Bernier D, R.A. Campbell, D. Cloutier (editors) In: Vegetation management of boreal mixedwoods. Abstracts of a workshop. Extracted from proceedings of the 2001 National meeting-expert committee on weeds. Nov 25-28,2001, Quebec City, Quebec, Canada.

Comeau, P.G., Biring, B.S., and Harper, G.J. 1999. Conifer response to brushing treatments: a summary of Brithish Columbia data. B.C. Min. For., Research Branch, Victoria. Extension note 41. 12 pp.

Comeau, P.G., Braumandl, T.F., and Xie, C-Y. 1993. Effects of overtopping vegetation on light availability and growth of Engelmann spruce (*Picea engelmannii*) seedlings. Can. J. For. Res. 23: 2044-2048.

Comeau, P.G., Kabzems, R., McClarnon, J., Heineman, J.L. 2005. Implications of selected approaches for regenerating and managing western boreal mixedwoods. Forestry-Chronicle. 81(4): 559-574

Comeau, P.G., Wang, J., Letchford, T., and Coopersmith, D. 1999a. Effects of spacing paper-birch-mixedwood stands in central British Columbia. B.C. Min. For., Research Branch, Victoria. Extension note 29. 7 pp.

Constabel, A.J., and Lieffers, V.J. 1996. Seasonal patterns of light transmission through boreal mixedwood canopies. Can. J. For. Res. 26:1008-1014.

Coopersmith, D., Sagar, B. and Thompson, D. 2000. Ten year results of the Bear Mountain Mixedwood Trial (EP 1077): The effect of overtopping aspen canopies on white spruce seedling growth and seedling microclimate. In Forest Research Note #PG-23.

Cumming, S.G., and Amstrong, G.W. 2001. Divided land base and overlapping forest tenure in Alberta, Canada: A simulation study exploring costs of forest policy. For. Chron. 77:501-508.

Debyle, N.V. 1991. Integrated use in mixedwood forests-a challenge. In Northern mixedwood '89. Proc. Symp. Sept 12-14, 1989, Fort St.John, B.C. Shortreid A. (editor), For Can., Victoria, B.C. FRDA Rep. No.164. pp. 60-64.

Edgar, C.B., and Burk, T. E. 2001. Productivity of aspen forests in northeastern Minnesota, U.S.A., as related to stand composition and canopy structure. Can. J. For. Res. 31:1019-1029.

Ehrentaut, G. and Branter, K. 1990. Vegetation management by manual and mechanical means in Alberta boreal forests. For. Chron. 66:366-368

Eis, S. 1981. Effect of vegetative competition on regeneration of white spruce. Can. J. For. Res. 11: 1-8.

Goldberg, D.E. and Werner, P.A.. 1983. Equivalence of competitors in plant communities A null hypothesis and a field experimental approach. Amer. J. Bot. 70: 1098-1104.

Groot, A., Carlson, D.W. 1996. Influence of shelter on night temperatures, frost damage, and bud break of white spruce seedlings. Canadian Journal of Forest Research. 26(9): 1531-1538.

Grossnickle, S.C. et al. 2001. Ecophysiological Principles. In Regenerating the Canadian Forest: Principles and Practice for Ontario (Markham, Ont.: Fitzhenry & Whiteside).

Hogg, E.H. and Lieffers, V.J. 1991. The impact of *Calamagrostis canadensis* on soil thermal regimes after logging in northern Alberta. Can. J. For. Res. 21: 387-394.

Jobidon, R. 2000. Density-dependent effects of northern hardwood competition on selected environmental resources and young white spruce (*Picea glauca*) plantation growth, mineral nutrition, and stand structural development – a 5-year study. Forest Ecol. Manage. 130:77-97.

Kelty, M.J. 1992. Comparative productivity of monocultures and mixed species stands. In The ecology and silviculture of mixed-species forests. Kelty M.J., B.C.Larson, and C.D.Oliver (editors) Kluwer Academic Publishers. Netherlands. pp.125-141

Kneeshaw, D.D., and Bergeron, Y. 1998. Canopy gap characteristics and tree replacements in the southeastern boreal forest. Ecology 79:783-794.

Kobe, R.K., Coates, K.D. 1997. Models of sapling mortality as a function of growth to characterize interspecific variation in shade tolerance of eight tree species of northwestern British Columbia. Canadian Journal of Forest Research. 27(2): 227-236.

Lees, J.C.1966.Release of white spruce from aspen competition in Alberta's spruce-aspen forest. Dept. Forest. Public. No.1163. 16 pp.

Lieffers, V. J., and Beck, J.A. Jr. 1994. A semi-natural approach to mixedwood management in the prairie provinces. For. Chron. 70:260-264.

Lieffers, V.J., and Stadt, K.J. 1994. Growth of understory Picea galuca, Calamagrostis Canadensis, and Epilobium angustifolium in relation to overstory light transmission. Can. J. For. Res. 24:1193-1198.

Lieffers, V.J., Macmillan, R.B, MacPherson, D.,Branter, K., and Stewart, J. 1996. Semi-natural and intensive sivicultural systems for the boreal mixedwood forests. For. Chron. 72:286-292.

Lieffers, V.J., Messier, C., Burton, P.J., Ruel, J.-C., and Grover, B.E. 2003. Nature-based silviculture for sustaining a variety of boreal forest values. Chapter 13. In Towards Sustainable Management of the Boreal Forest. Edited by P.J. Burton, C.Messier, D.W.Smith, and W.L. Adamowicz. NRC Research Press, Otawa, Ontario, Canada. pp. 481-530.

Lieffers, V.J., Messier, C., Stadt, K.J., Gendron, F., and Comeau, P.G. 1999. Predicting and managing light in the understory of boreal forests. Can. J. For. Res. 29:796-811.

Lieffers, V.J., Pinno, B.D. and Stadt, K.J. 2002. Light dynamics and free-to-grow standard in aspen-dominated mixedwood forest. For. Chron. 78:137-145.

MacDonald, G.B. 1995. The case for boreal mixedwood management: An Ontario perspective. For. Chron.71:725-733.

MacDonald, G.B. 1996. Mixedwood management research and practice in Ontario. In Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors).B.C. Min. For., Research Branch., Victoria. Land Manage. Handbk. 36. pp.102-113.

MacIsaac, D.A., and Navratil, S. 1996. Competition dynamics in juvenile boreal hardwood-conifer mixtures. In Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors).B.C. Min. For., Research Branch., Victoria. Land Manage. Handbk. 36. pp.23-34

MacPherson, D.M., Lieffers, V.J., and Blenis, P.V. 2001. Productivity of aspen stands with and without a spruce understory in Alberta's boreal mixedwood forests. For. Chron. 77:351-356.

Man, R., and Lieffers, V.J. 1999a. Are mixtures of aspen and white spruce more productive than single species stands? For. Chron. 75:505-513.

Man, R., and Lieffers, V.J. 1999b. Effects of shelterwood and site preparation on microclimate and establishment of white spruce seedlings in aboreal mixedwood forest. For. Chron. 75:837-844.

Messier, C. 1996. Managing light and understorey vegetation in boreal and temperate broadleaf-conifer forests. In Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors).B.C. Min. For., Research Branch., Victoria. Land Manage. Handbk. 36. pp.59-81.

Mielikainen, K. 1996. Approaches to managing birch-dominated mixed stands in Findland. In Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors).B.C. Min. For., Research Branch., Victoria. Land Manage. Handbk. 36. pp.8-14.

Mitchell, R.J., Zutter, B.R., Green, T.H., Perry, M.A. and Gjerstad, D.H. 1993. Spatial and temporal variations in competitive effects on soil moisture and pine response. Ecol. Appl. 3: 167-174.

Morris, D.M. and MacDonald, G.B. 1991. Development of a competition index for young conifer plantations established on boreal mixedwood sites. For. Chron. 67: 403-410.

Navratil, S. 1996. Silvicultural systems for managing deciduous and mixedwood stand with white spruce undertsorey. In Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors).B.C. Min. For., Research Branch., Victoria. Land Manage. Handbk. 36. pp.35-46.

Navratil, S., Brace, L.G., Sauder, E.A., and Lux, S. 1994. Silvicultural and harvesting options to favor immature white spruce and aspen regeneration in boreal mixedwoods. Can. For. Ser. NOR-X-337, 78 pp.

Pare D., and Van Cleve, K.1993. Soil nutrient availability and relationship with above ground biomass production of postharvest upland white spruce sites in interior Alaska. Can. J. For. Res. 23:1223-1232.

Petersen, T.D., Newton, M. and Zedaker, S.M. 1988. Influence of Ceanothus velutinus and associated forbs on the water stress and stemwood production of Douglas-fir. Forest Science 34: 333-343.

Peterson, E.B., and Peterson, N.M. 1992. Ecology,managementg, and use of aspen and balsam polar in the prairie provinces Can. For. Ser, North. For. Center, Alta, Special report 1, 252 pp.

Pitt, D.G., Bell, F.W. 2005. Juvenile response to conifer release alternatives on aspen-white spruce boreal mixedwood sites. Part I: Stand structure and composition. Forestry Chronicle. 81(4): 538-547.

Pitt, D., Comeau, P., Mihajlovich, M., MacIsaac, D. 2005. Effects of herbaceous vegetation control and aspen stem density on boreal mixedwood stand development. Partners Report – 2004 field season. Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. (http://www.forestresearch.ca/product_catalogue/reports.htm, RP-026)

Prevost, M 1996. Mixedwood management research and practice in Quebec. IN Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors). B.C. Min. For. Res., Victoria, pp.97-101.

Pritchard, J.M., Comeau, P.G. 2004. Effects of opening size and stand characteristics on light transmittance and temperature under young trembling aspen stands. Forest Ecology and Management. 200(1/3): 119-128.

Robinson, D. E., Wagner, R. G., Bell, W. F. and Swanton, C. J. 2001 – Photosynthesis, nitrogen-use efficiency, and water-use efficiency of jack pine seedlings in competition with four boreal forest plant species. Can. J. For. Res. 31: 2014-2025.

Rowe, J.S. 1961. Critique of some vegetation concepts as applied to forests of northwestern Alberta. Can. J. Bot. 39:1008-1017.

Rowe, J.S. 1972. Forest regions of Canada. Can. For. Serv. Publication No.1300, 172 pp.

Smith D.M. 1962. The practice of silviculture. 7th edition. John Wiley & Sons, Inc., New York, 578 pp.

Sutton, R.F. 1986. Hexazinone Gridballs applied with concurrent underplanting of white spruce in boreal mixedwood: 7-year results. For. Chron. 62:226-231.

Tanner, D., Delong C.S., and Eastham, A. 1996. Investigations of Planting White Spruce under a Trembling Aspen Canopy. In Silviculture of temperate and boreal broadleaf-conifer mixtures. Edited by P.G. Comeau and K.D. Thomas. BC Ministry of Forests, Victoria. Land Management Handbook no. 36. pp. 114-121.

Thorpe, J.P. 1992. Patterns of diversity in the boreal forest. In The ecology and silviculture of mixed-species forests. M.J. Kelty, B.C.Larson, and C.D.Oliver (editors) Kluwer Academic Publishers. Netherlands pp.65-79.

Voicu, M.F. 2004. Gradients in microclimate and spruce growth adjacent to young aspen stands. MSc Thesis, University of Alberta, Faculty of Graduate Studies and Research, Edmonton, Alberta.

Wagner, R.G., G.H. Mohammed, and T.L. Noland. 1999. Critical period of interspecific competition for northern conifers associated with herbaceous competition. Can. J. For. Res. 29: 890-897.

Wang, J.R., Comeau, P.G., and Kimmins, J.P. 1995. Simulation of mixedwood management of aspen and white spruce in northeastern British Columbia. Water Air Soil Pollut. 82:171-178.

Yang, R.C. 1991. Growth of white spruce following release from aspen competition: 35 year results. The Forestry Chronicle 67(6):706-711.

# Chapter 2. Materials and Methods

## 2.1. Study site description and problem statement

My study was conducted as a part of the long term Judy Creek Mixedwood Experiment underway 30 km northeast of Whitecourt Alberta, on lands licensed to Blue Ridge Lumber (1981) Ltd. This project was initiated by Dr. Doug Pitt, Dr. Phil Comeau, Mr. Milo Mihajlovich, and Mr. Dan MacIsaac in 2002, as described in Pitt et al. (2005).

### *2.1.1. History and characteristics of the site*

The following information regarding the history and characteristics of the site has been summarized from Pitt et al. (2005). The study was established in 2002, following harvesting of a 75 years old trembling aspen (*Populus tremuloides* Michx) dominated stands with small components of lodgepole pine (*Pinus contorta* Dougl. ex. Loud.) and balsam poplar (*Populus balsamifera* L.) scattered throughout. Average basal area of the stand was 33 $m^2$/ha, with a mean DBH (diameter at breast height) of 26.5 cm and a stand height of 23.5 m. Coarse woody debris (over 10 cm in diameter) was removed from the site during May 2002, and resulting piles were burned in December 2002, just after the first snowfall. Plots were installed and tree positions pinned, consistent with study protocols, in late June 2002. The site was planted on June 27-28, 2003, with 2+0 PSB 412 white spruce container stock. At the time of planting, these trees averaged 18.6 cm in height, 3.5 mm in stem diameter, 7.5 cm in crown diameter, and 0.62 $cm^3$ in stem volume (assuming conical form). No differences were detected among treatments with respect to initial tree sizes ($p > 0.47$).

Soils across the site tend to be luvisols, with parent material consisting of ablation till. There is a rounded cobble layer at about 25 – 40 cm, indicating post – glacial fluvial action. Soils are generally mesic and fine-textured, with texture ranging between silty loam and clay, with a bulk density for first 20 cm of 1.14 (lower in the first 10 cm and higher in the next 10 cm). Some plots have a sandy loam veneer over silty clay loam.

### *2.1.2. Problem statement*

The focus of the study reported in this thesis is the influence of aspen versus herbaceous/grass vegetation effects on light, soil moisture, and soil nitrogen availability, and the subsequent effects of these factors on spruce growth. Treatment effects on leaf area index and relationships between leaf area index of the major vegetation components ((a) aspen or (b) herbs and grasses) and light, soil moisture, nitrogen availability or spruce growth are also being examined.

Questions:

- Do woody and herbaceous layers have similar effects on resource (light, soil moisture and soil nitrogen) availability during the first 3 years after regeneration?

- Is spruce growth related to changes in resource availability resulting from vegetation management treatments?

The null hypotheses to be tested are as follows:

- Competitive effects of woody and herbaceous layers do not have different influences on resource (light, soil moisture and soil nitrogen) availability and consequently on spruce growth

- Vegetation management treatments do not influence resource availability and subsequent spruce growth is not being affected by these changes

### *2.1.3. Study design*

For my study, I used selected treatments that reflect different levels of vegetation control (untreated, removal of woody vegetation only, and removal of all vegetation) (Table 2.1, and Figure 2.1). Since the work was conducted during early years of this study, there are no differences between the 2 and 4 year duration treatments in 2004, but in 2005 the 4 year duration had received 3 years of control and consequently it was necessary to distinguish it from the 2 year duration treatment in 2005. In addition, spacing of aspen is not a factor in my study, since this treatment will not be applied until 2007.

The components of the study that I worked with were treated as a completely randomized experimental design with at least 3 replicate plots for each treatment. The vegetation treatments (5 in all in 2004, 6 in all in 2005) are treated as fixed effects and the plots as random effects. The response variables used in this study vary with the question being addressed, but generally include soil moisture, air and soil temperature, light (diffuse non-interceptance or DIFN), and soil nitrogen availability. The independent variables are treatment and leaf area index (LAI) of aspen and herbaceous and grass vegetation. Relationships between annual spruce growth (root collar diameter and height during the first three years after planting) and light, soil moisture and soil N are also examined. Extraneous variables include microsite quality, microclimate variation, topography, and extreme weather events (i.e. winter injury). For my study I selected 8 spruce seedlings in each selected plot (4 seedlings located at measurement plot corners and one tree from the middle of each edge row).

### 2.2. Competing vegetation

For the purpose of this study, every component of vegetation (woody and herbaceous) was considered to be potentially competitive with white spruce seedlings. To characterize competing vegetation above and below ground, three variables were measured in 2004 and 2005. The variables are: leaf area index – LAI (the amount of vertically projected leaf area per $m^2$ of ground surface), root surface area, and root dry weight.

LAI-2000 plant canopy analyzers (Li-Cor Inc., Lincoln, NB) were used to measure leaf area index during 2004 and 2005 growing seasons. These measurements were taken at 5 cm above the ground (with matching open sky readings). LAI-2000 measurements were taken with an 180° view restrictor on the sensor, and with the sensor head being oriented west in the morning and east in the afternoon to avoid having the sensor pointing towards the sun. These measurements were taken at the 8 selected seedlings (in all plots listed in Table 2.1.) with the LAI-2000 sensor positioned outside of the dripline of the seedling and pointing away from the seedling (to avoid including the seedling leaf area in the measurement). During 2004, these measurements were performed every week, from May 11 until August 30, and then every 2 weeks until the end of September. In 2005, the measurements were taken every 2 weeks throughout the growing season.

In radial treatment plots, an additional LAI-2000 measurement was collected in untreated vegetation areas located between the 2 m treated circle around each planted spruce seedling. These additional measurements were used to examine differences between these untreated portions of the radial treatment plots and the completely untreated (N) plots.

In midsummer (July 28, 2004 and July 26, 2005) leaf area index of overstory and understory at these 8 selected seedlings (in all plots listed in Table 2.1.) was measured by taking an additional sensor reading above the shrub/forb/grass understory layer (most of the times this was equal to the top of the herbaceous layer). The reading above the shrub/forb/grass understory layer was used as a measurement of aspen LAI, with understory LAI being calculated as the difference between the reading taken at 5 cm height and the aspen LAI. All 5 rings of the LAI-2000 sensor were used to calculate the final values for Leaf area index and light (DIFN). Some restrictions were applied to avoid "bad readings": i) avoid measuring between 11.30 AM and 2.00 PM when the sun is high in the sky; ii) avoid measuring in foggy or rainy weather; and, iii) avoid measuring when there is a thick, low cloud layer(iii).

To characterize root surface area and root dry weight, 72 soil cores were collected in each of the summers of 2004 and 2005. A SS Soil Sampler Heavy Duty Short with Foot Assist (Star Quality Samplers, Edmonton, Alberta) (d = 1 inch = 2.54 cm) (approximately 100 $cm^3$ each soil sample collected) was used to collect 1 sample next to each of 4 spruce in each plot listed in Table 2.1. In each plot, the 20 cm depth samples were extracted 1m west from the spruce seedling in the middle of each edge row. In reference treatments, trees adjacent to the datalogger and sensor installations were sampled. The soil samples were sealed in plastic bags, labelled, and frozen for later processing. In the lab, the roots were extracted, using the following technique:

1) The soil sample was washed through a 1 mm sieve with a gentle stream of warm water;

2) Roots were separated from the remaining materials (charcoal, gravel, twigs, pieces of decaying wood etc.) using tweezers;

3) The surface area of the resulting root sample was measured by scanning (Epson Expression 1680 scanner) and analysis of the pictures with WinRhizo (Regent Instruments INC, Montreal, v.2002c) computer software; and,

4) Dry weights were obtained after drying samples at 70 $^{o}$C for 48 hours.

The data obtained as described above, was used for statistical analysis, as described in section 2.5.

### 2.3. Resource availability

Microclimate variables were monitored with sensors for air and soil temperature and volumetric water content, attached to dataloggers during both 2004 and 2005 growing seasons. In each of the 11 selected response surface plots (Tables 2.1.) one CS616 soil moisture probe was installed 1 m south of one randomly selected spruce and one CS616 soil moisture probe was installed in the untreated vegetation between spruce (Figure 2.2.). Air temperature sensors (unshielded chromel-constantan thermocouples) were installed at 1.5 m and 0.3 m height, 1 m east of the one selected spruce in each of these plots. A soil temperature sensor was installed at 20 cm depth 1 m north of the same seedling. In addition, an air temperature sensor was installed at 30 cm height and a soil temperature probe at 20 cm depth next to the soil moisture sensor installed in the untreated vegetation area. In 2005, sensors were installed in two additional plots (1 and 36) to increase the number of replicates in each treatment.

In each of the 9 selected reference treatment plots (Table 2.1) one CS616 soil moisture probe was installed 1 m south of one randomly selected spruce (Figure 2.3.). Air temperature sensors (unshielded chromel-constantan thermocouple) were installed at 1.5 m and 0.3 m height, 1 m east of the one selected spruce. A soil temperature sensor was installed at 20 cm depth 1 m north of the seedling.

In the attempt to increase the sample size, soil moisture content was also measured using a portable Hydrosense soil moisture (TDR) probes, with 20 cm rods at 14 day intervals during 2004 and 2005 growing seasons. These measurements were taken within 10 cm of the existing CS616 soil moisture probes (1 m S of the seedling), and 1 m N, E and W of the selected seedlings in each selected plot. Due to poor correlations between these Hydrosense measurements and CS616 probe, this was abandoned.

A climate station was installed adjacent to the southeast corner of plot 25 (Figure 2.4). PPFD (Photosynthetic Photon Flux Density which has units of quanta (photons) per unit time per unit surface area) is being measured using a quantum sensor (K&Z) mounted on the top of the 10 m tall tower, air temperature and relative humidity are being measured using a CS500 temperature and relative humidity probe mounted at 8 m height on the tower, precipitation are being measured using a TE525 tipping bucket rain gauge. Air temperature is also being measured at 1.5 m, and 8 m height using fine wire unshielded thermocouples.

Campbell Scientific CR10x 2Mb dataloggers were attached to all sensors. Soil moisture sensors (CS616 probes) were read once each hour and hourly and daily minima and maxima values were stored. Air and soil temperature sensors were scanned at 300 seconds (5 minutes) intervals and hourly minima, maxima and mean and daily minima and maxima values were stored. PPFD was measured at 5 minute intervals and hourly minima, maxima and mean values were stored.

To test for nitrogen contents in leaves and branches of vegetation components, a total of 12 clip plots were established in 2004. Three clip plots (2.5 m x 2.5 m each) were randomly selected for each of the 3 treatments (radial complete control, radial and broadcast woody control) across the whole site. Additionally, 3 more clip plots were randomly selected in untreated vegetation areas. The vegetation was clipped and separated into seven groups: 1) Aspen, 2) Tall Shrubs (> 1.5 m), 3) Low Shrubs (< 1.5 m), 4) Herbs, 5) Grasses, sedges and rushes, 6) *Calamagrostis canadensis,* and, 7) other deciduous. For all groups leaves were detached from stems and branches. Additionally, for aspen, stems were separated from branches. For each group, a sample of leaves was collected and pressed in a plant press. These pressed leaves were returned to the lab and scanned to determine leaf area and then dried and weighed to determine specific leaf area ($cm^2/g$) (in the end, these weights were added to the final sample weights). Analysis of nitrogen concentration was completed at the Natural Resources Analytical Lab in the Department of Renewable Resources, at the University of Alberta, using the wet digestion technique (sulphuric acid + hydrogen peroxide).

To characterize treatment effects on soil nitrogen availability in 2005, PRS™ probes (Western AG Innovations Inc., Saskatoon, Canada) were used. The PRS™ probes consist of an ion-exchange resin membrane (IEM) which facilitates the measurement of inorganic nitrogen ($NH_4^+$-N and $NO_3^-$-N) among other nutrients existing in the soil. Before insertion into soil, the probes (both anion- and cation-exchange) were regenerated as described in Hangs et al. (2004): (1) shaken three successive times in 0.5 mol/L $NaHCO_3$ for 4 hours to be saturated with sodium ($Na^+$) and bicarbonate ($HCO_3^-$), respectively; (2) shaken in 0.01 mol/L ethylene-diaminetetraacetate (EDTA) for four hours to allow the adsorption of micronutrients, in particular polyvalent metal cations such as Al, Fe, Mn, Cu, and Zn; (3) rinsed with deionized water. In each of the 20 plots listed in Table 2.1, during the 2005 growing season, four anion and four cation probes were installed (1 m west from selected white spruce) to measure the amount of available nitrogen during a total of four 4 week periods starting in early-May, early-June, late-June and late-July. After 4 weeks in the ground, the probes were removed from the ground, washed with deionized water, sealed in Ziploc® bags and sent to Western AG Innovations Inc., Saskatoon, Canada for further analysis, as detailed by Hangs et.al. (2004): (1) elution of adsorbed ions for analytical measurement of N, using 1 mol/L KCl (Johnson et.al. 2001) for one hour in order to remove ≥95% of the adsorbed ions from the IEM (Duarte 2002); (2) determined inorganic N ($NH_4^+$-N and $NO_3^-$-N) colorimetrically using a Technicon Autoanalyzer II (TIC 1977); (3) $NO_3^-$-N slightly modified by addition of NaOH to $NH_4Cl$ reagent (bringing the pH at 8.5) to neutralize the sample solution before its entry into the Cd-reduction column (Western Ag Labs, 2003).

Available light (% transmittance), also known as DIFN (diffuse non-interceptance), was measured with LAI-2000 plant canopy analyzer, as detailed in section 2.2.

### 2.4. Tree measurement

To document patterns in height and diameter growth of spruce seedlings, root collar diameter (RCD) and height of the 8 randomly selected spruce seedlings (in all 26 plots highlighted in Figure 2.1.) were measured every two weeks during 2004 and 2005 growing seasons. RCD was measured using calipers, and height using a standard measuring tape. The trees chosen to be measured were trees in each of the plot corners and the trees located in middle of each edge row, as described above. If any of these trees were dead, other trees within the edge rows were chosen.

Many additional measurements are being collected for the Judy Creek Mixedwood Experiment, and include annual measurement of a larger sample of planted spruce in each plot, as well as a sample of aspen (Pitt et al. 2005). These data are not included in this thesis.

### 2.5. Statistical analysis

Statistical analysis was completed using SAS software (SAS Institute, Cary, NC). Analysis of variance (ANOVA) was used to examine treatment effects on response variables, based on a completely randomized experimental design with replications ($n \geq 3$). Planned (a priori) contrasts (Table 2.2) were used to compare woody control to complete control (averaging over control *method*), broadcast control to radial control (averaging over *type* of vegetation control), the interaction between the *type* of vegetation control and the *method* of control, and "untreated" to the average effect of the vegetation treatments. In addition, in 2005, planned contrasts were used to compare effects of two versus three years of radial complete control. These contrasts offer useful information regarding the differences between radial and broadcast treatments, between controlled and uncontrolled vegetation, and between woody control and complete control of vegetation treatments.

Data provided by the dataloggers were used to calculate hours above or below certain thresholds as follows:

- For air and soil temperature:
    - MaxM5C – No of hours with maximum hourly temperatures over 5°C;
    - MinL5C – No of hours with minimum hourly temperatures below 5°C;
    - AverL5C – No of hours with average hourly temperatures below 5°C;
    - MinL0C – No of hours with minimum hourly temperatures below 0°C;
    - MinLn4C – No of hours with minimum hourly temperatures below -4°C.
- For volumetric water content (VWC):
    - Less20 – No of hours with VWC below 20%;
    - Less25 – No of hours with VWC below 25%;
    - Less30 – No of hours with VWC below 30%;

To characterize treatment effects on soil nitrogen availability for the entire 2005 growing season, the total nitrogen extracted from probe membranes was used as the response variable. Midsummer's leaf area index (LAI) and light (DIFN) were tested for treatment effects, both in 2004 and 2005 growing seasons. RCD (root collar diameter), height, and HDR (height to diameter ratio) were used to characterize treatment effects on spruce growth for an entire season and for both growing seasons (summed growth during whole study period). For characterizing seasonal patterns in spruce growth, initial RCD was used as covariate. Competition below ground was tested using root surface area and dry weight as response variables.

Correlation analysis was used to explore simple relationships between soil moisture and LAI, between N availability and LAI, between root surface area or dry weight and LAI, and between these variables and spruce growth. Multiple non-linear regression analyses was used to examine relationships between a) spruce growth and b) soil moisture availability, soil nitrogen availability, light availability (inverse of LAI), LAI, air temperature and soil temperature. To determine whether the coefficients for herbaceous LAI were different those for from woody LAI t-tests were used. Problems using soil moisture were encountered, since none of the variables (growing degree hours below certain thresholds) presented above were significant in terms of treatment effects, since both 2004 and 2005 were relatively wet growing seasons. However, soil moisture wasn't monitored in previous years. Multiple regression analysis was used to examine relationships between N availability and both aspen and herbaceous LAI.

The main findings are presented in chapters 3 and 4 of this paper.

**2.6. References**

Beckingham, J.D., Corns, I.G.W., Archibald, J.H. 1996. Field guide to ecosites of west-central Alberta. Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent., Edmonton, AB. Spec. Rep. 9.

Coopersmith, D., and E. Hall. 1999. Experimental project 1077 – The Siphon Creek mixedwood trial: The use of a simple height-to-diameter ratio to predict the growth success of planted white spruce seedlings beneath aspen canopies. British Columbia Ministry of Forests, Forest Research Note PG-17. 10 *p.*

Duarte, N. 2002. nitrogen form and availability measured with ion exchange resin in a loblolly pine stand on the coastal plain of North Carolina. M. Sc. Thesis, Department of Soil Science, North Carolina State University, Raleigh, N.C.

Hangs, R.D., Greer, K.J., Sulewski C.A. 2004. The effect of interspecific competition on conifer seedling growth and nitrogen availability measured using ion-exchange membranes. Canadian Journal of Forest Research 34: 754-761.

Johnson, D.W., Hungate, B.A., Dijkstra, P., Hymus, G., and Drake, B. 2001. Effects of elevated carbon dioxide on soils in a Florida scrub oak ecosystem. J. Environ. Qual. 30: 501-507.

Pitt, D., Comeau, P., Mihajlovich, M., MacIsaac, D. 2005. Effects of herbaceous vegetation control and aspen stem density on boreal mixedwood stand development. Partners Report – 2004 field season. Canadian Forest Service, Great

Lakes Forestry Centre, Sault Ste. Marie, ON. (http://www.forestresearch.ca/product_catalogue/reports.htm, RP-026).

TIC (Technicon Instrument Corporation). 1977. Individual/simultaneous determinations of nitrogen and (or) phosphorus in BD acid digest: industrial method No. 329-74W. TIC, Tarrytown, N.Y.

Western Ag Labs Ltd. 2003. Standard operating procedures. Colometric determination of nitrogen: nitrate and nitrite. Western Ag Labs Ltd., Saskatoon, Sask.

Table 2.1. Plots selected for measurements with fixed sensors attached to dataloggers.
Note: dataloggers and CS616 probes were installed in 2005 in plots 1 and 36; there is no difference between CCR2 and CCR3 in 2004, being the 2nd growing season.

| Treatment | Plots |
|---|---|
| Broadcast Complete Control (CCB) | 11, 29, 32 |
| Radial Complete Control 2 years (CCR2) | 7, 12, 13 |
| Radial Complete Control 3 years (CCR3) | 1, 18, 20, 27 |
| Broadcast Woody Control (WCB) | 10, 16, 34 |
| Radial Woody Control (WCR) | 5, 25, 36, 38 |
| Broadcast No Control (untreated) (N) | 4, 33, 35 |

Table 2.2. Planned contrasts
CCB – Broadcast Complete Control; CCR – Complete Control Radial; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| 2004 | | | | | |
|---|---|---|---|---|---|
| **Contrast** | **Mixedwood (WCR)** | **Mixedwood (CCR)** | **Pure (WCB)** | **Pure (CCB)** | **Pure, no control (N)** |
| **Treated vs. untreated** | 1 | 1 | 1 | 1 | -4 |
| **Mixedwood vs. Pure** | 1 | 1 | -1 | -1 | 0 |
| **WC vs. CC** | 1 | -1 | 1 | -1 | 0 |
| **Interaction** | 1 | -1 | -1 | 1 | 0 |

| 2005 | | | | | | |
|---|---|---|---|---|---|---|
| **Contrast** | **Mixedwood (WCR)** | **Mixedwood (CCR2)** | **Mixedwood (CCR3)** | **Pure (WCB)** | **Pure (CCB)** | **Pure, no control (N)** |
| **Treated vs. untreated** | 1 | 1 | 1 | 1 | 1 | -5 |
| **Mixedwood vs. Pure** | 2 | 2 | 2 | -3 | -3 | 0 |
| **WC vs. CC** | 3 | -2 | -2 | 3 | -2 | 0 |
| **CCR2 vs. CCR3** | 0 | 1 | -1 | 0 | 0 | 0 |
| **Interaction** | 3 | -2 | -2 | -2 | 3 | 0 |

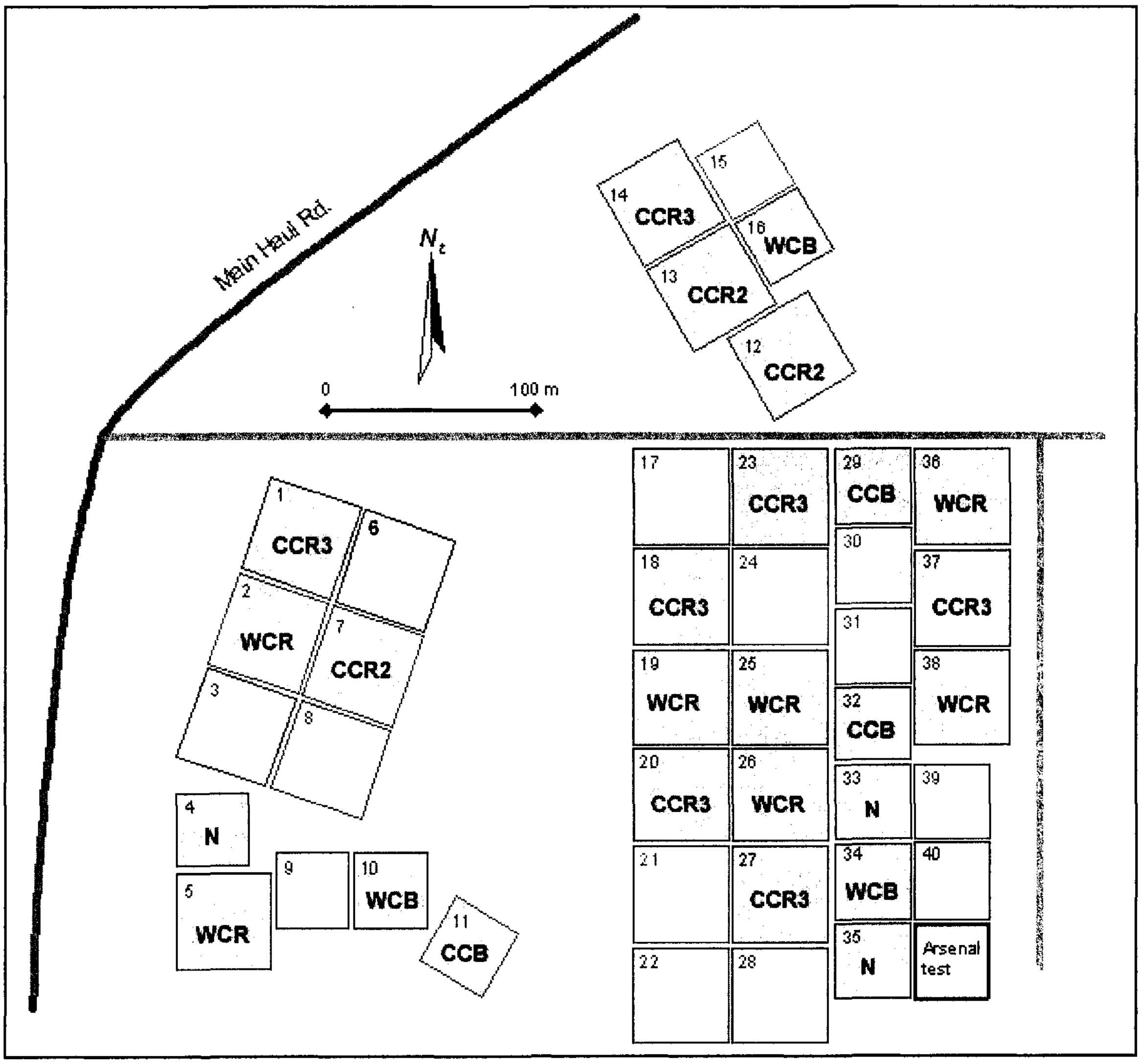



Figure 2.1. Treatment randomization (The highlighted plots represent the ones in my study). CCB – Broadcast Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control. (from Pitt et al. 2006).

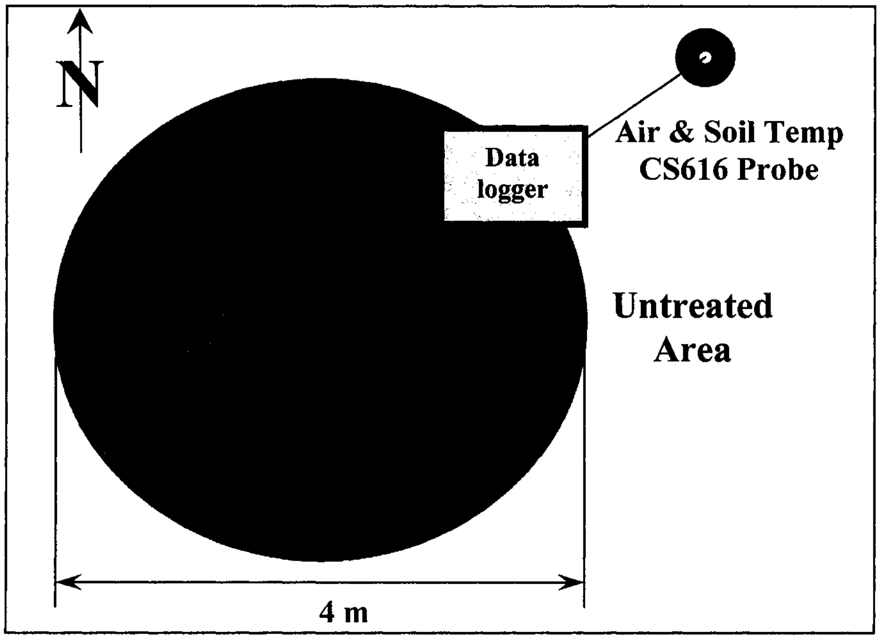


Figure 2.2. Schematic representation of datalogger installation in response surface treatment plots

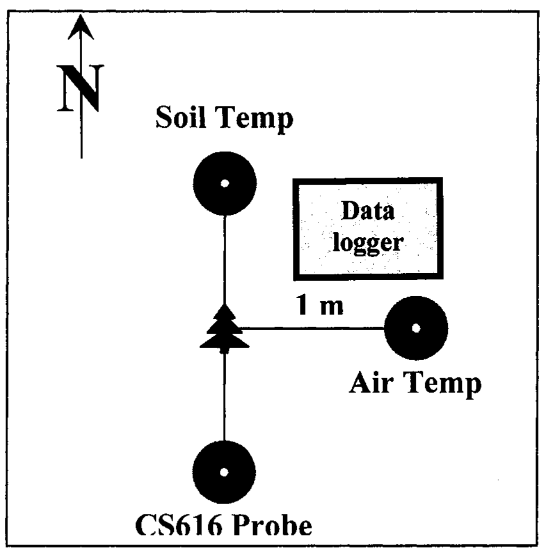
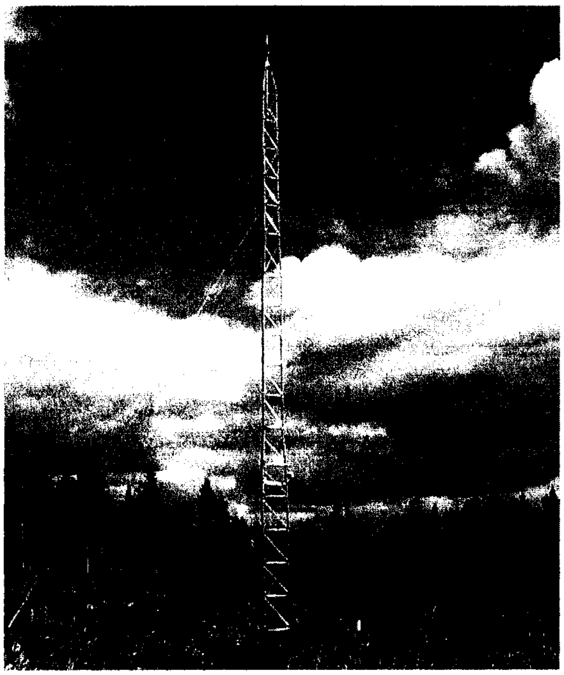
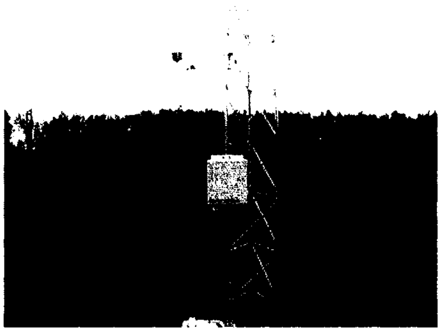


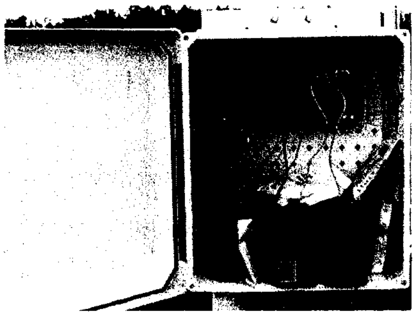
Figure 2.3. Schematic representation of datalogger installation in reference treatment plots



Tower installation - Judy Creek, Whitecourt, Alberta



Tower details - datalogger box and CS500 temperature and humidity sensor with 42303 radiation shield



Tower details - datalogger box

Figure 2.4. Climate station at Judy Creek, Whitecourt, Alberta

# Chapter 3. Competing vegetation and resource availability

In this chapter, treatment effects on competing vegetation and resource availability are presented and discussed. This includes the variables measured during 2004 and 2005 growing seasons: leaf area index, root dry weight and surface area, air and soil temperature, volumetric water content, light, and nitrogen availability.

## 3.1. Competing vegetation

For a better understanding of the vegetation effects, the following has been extracted from Pitt et al. (2006):

> "Total untreated vegetation cover on the site increased from an average of just over 20% in the year pre-treatment, to more than 70% by the end of the second growing season (Figure 3.1.). Cover remained relatively unchanged through the third growing season. In the reference plots, herbaceous control, woody control, and complete vegetation control reduced total cover through the third growing season to 30%, 63%, and 38%, respectively. *Calamagrostis* in the woody control plots and *Epilobium* in the complete control plots (Figure 3.2.) elevated total cover values above what might be expected in these plots, given their respective treatment regimes. In the radial treatments, total cover was reduced to about 50% in woody-only and 2-year complete vegetation removal plots and to below 40% in 3-year complete vegetation control plots. Aspen

continues to dominate the woody community on this site and its cover and stem density values clearly characterize the different treatments (Figure 3.2.).

Over time, in untreated plots, dominance has shifted to sarsaparilla and dewberry (*Rubus pubescens*), with other species occurring in a dominant cover positions less frequently. Complete vegetation removal, either in broadcast or radial treatments, caused a shift in dominance towards *Epilobuim* species, fireweed in year 2 and northern willow herb (*Epilobuim watsonii*) in year 3. This is likely due to the glyphosate treatments used in these plots and the relatively late timing of application in years 1 and 2."

### *3.1.1. Leaf Area Index*

In 2004, leaf area index (LAI) reached its maximum values in the untreated control plots (no treatment) in mid-July (July 18), with little increase in LAI occurring between May 11 and June 02 (Figure 3.3). In the complete control plots, LAI increased over the course of the summer, reaching a maximum towards the end of August. LAI was the highest for untreated (no treatment) and lowest for complete control (broadcast and radial) with "woody control" (broadcast and radial) between the two. The statistical analysis (Table 3.1) for midsummer LAI (July 20$^{th}$, 2004), showed an overall treatment effect ($p$<0.01), with untreated plots having higher LAI than treated plots ($p$<0.01) and woody control having higher LAI than complete control treatments ($p$<0.01). In 2005, LAI (Figure 3.4) followed similar trends to those observed in 2004, but with more vigorous development early in the growing season, indicated by LAI values exceeding 1 $m^2/m^2$ 2 weeks earlier in 2005 than in 2004.

On July 9th, 2005, a hail storm resulted in a substantial reduction in overstory leaf area (mostly aspen) (approximately one third of the leaf area was lost). It appears that the effect of the hailstorm on grass (*Calamagrostis*) LAI was minor. Following the hailstorm, aspen leaf area did not fully recover during the growing season. The fact that LAI values of plots with radial complete vegetation control are higher than plots with broadcast complete vegetation control results from the LAI-2000 sensor measuring vegetation which is beyond the 2 m treatment radius (use of the 5th ring results in measurements being collected within a radius of approximately 2.5 m). In addition, branches of aspen are beginning to grow into the 2 m treatment radius.

Following completion of the last treatment in 2004 for plots with 2 years radial complete vegetation control, LAI increased in comparison to the other 2 treatments involving complete control (broadcast and 3 years radial). Grass LAI continued to increase in 2005 in the broadcast woody control treatment from 2 $m^2/m^2$ in 2004 to over 3 $m^2/m^2$ in 2005, while overstory LAI (mostly aspen) remained close to 3 $m^2/m^2$ in both 2004 and 2005 (prior to the hailstorm).

Statistical results (Table 3.1.) showed that overall, there was a treatment effect on midsummer LAIs (July 28th, 2005) ($p$<0.01). The planned contrasts revealed greater LAIs in untreated plots than in the treated ($p$<0.01), and that removal of woody vegetation using triclopyr allowed expansion of the grass layer and, thus, greater LAI compared with complete vegetation control (both radial and broadcast) ($p$<0.01). In 2005, LAI differed between radial and broadcast treatments ($p<0.01$). In addition, in 2004, the interaction between treatments was not significant ($p=0.5201$), while in 2005, this interaction is significant ($p=0.0021$) (Table 3.1., Figure 3.5.). This suggests that the effects of the *type* of vegetation controlled (woody vs. complete) were not consistent across treatment *methods* (radial vs. broadcast), the colonization of *Calamagrostis* where woody component was removed, increasing LAI.

Table 3.2 summarizes statistical results for 2005, for leaf area index separated by vegetation components: a) overstory, represented mostly by aspen, and b) understory represented mostly by herbaceous layer. Since results were similar in 2004, I present results only for 2005 in this thesis. For both vegetation layers, treatments reduced LAI ($p<0.01$). The planned contrasts suggest that for both vegetation components, leaf area index in untreated plots (no treatment) was different than in all other treatments ($p<0.05$). Differences between radial and broadcast treatments and between woody and complete control treatments ($p<0.01$), were also detected. The interaction ($p=0.01$) suggests that the massive presence of grass layer due to woody component removal is higher for broadcast application of treatment (Figure 3.6.). The analysis didn't show any differences between 2 and 3 years of complete vegetation control in 2005.

Fluctuations in leaf area index (total, overstory and understory) over time are consistent with findings of Pitt et al. (2006) in terms of changes in species and their cover. Pre-treatment *Aster* species accounted for 37% of dominant forb cover, followed by sarsaparilla (*Aralia nudicaulis*, 23%), fireweed (*Epilobium angustifolium*, 15%), strawberry (*Fragaria virginiana*, 11%), and northern bluebell (*Mertensia paniculata*, 5%). Over time, in untreated plots, dominance has shifted to sarsaparilla and dewberry (*Rubus pubescens*), with the other species occurring in dominant cover positions less frequently. Complete vegetation removal, either in broadcast or radial treatments, caused a shift in dominance towards *Epilobuim* species, fireweed in year 2 and northern willow herb (*Epilobuim watsonii*) in year 3. This is likely due to the glyphosate treatments used in these plots and the relatively late timing of application in years 1 and 2. In broadcast-treated plots, secondary species tended towards woodland horsetail (*Equisetum sylvaticum*), heart-leaved arnicolus (*Arnicus cordifolia*), and bunchberry (*Cornus canadensis*). In radial complete vegetation removal plots, many of the species found in the untreated plots occurred outside the treated radii, secondary to the *Epilobium* species within. Woody-only and herbaceous-only control resulted patterns of dominance similar to those of the untreated plots, greatly reduced cover values being the largest difference between these two groups.

### *3.1.2. Root dry weight and surface area*

In both 2004 and 2005 growing seasons, vegetation control treatments reduced root surface area and root dry weight ($p$<0.05) (Table 3.3). The complete control treatment reduced the amount of roots (in terms of weight and surface area), and the removal of only woody vegetation resulted in an increase in root weight ($p$<0.01 for both seasons). In 2004, radial treatment reduced root surface area and dry weight more than broadcast application ($p$<0.05), while in 2005 this difference was not observed ($p$>0.05).

The interaction (Figure 3.7) in 2004 showed an increase in total root surface area for WCB, while WCR had less total root surface area than the untreated. In 2005, this interaction was not visible ($p>0.05$) due to the increase of root surface area in both N and WCR treatments. No differences between 2 and 3 years of vegetation control were detected for root surface area.

The highest values for root surface area were recorded WCB treatment, and in terms of root dry weight for N. Results from 2004 suggest that for a 1 ha area where all the woody vegetation is controlled, the amount of roots expected to be found to a 20 cm depth would be approximately 79,757 $m^2$/ha, weighing about 207 kg/ha. Without vegetation control, the amount of roots would be approximately 51,412 $m^2$/ha, weighing about 233 kg/ha.

In 2005, the root weight and surface area for complete control (broadcast and both radial treatments) and woody control broadcast treatments show similar trends to those observed in 2004. However, values for the untreated and woody control radial treatments were larger in 2005 than in 2004. The highest value for root surface area was again found in the woody control broadcast and for root dry weight for N. This difference between treatment effects on surface area and weight is a reflection of the fact that roots of the grass and herbaceous species are generally much smaller in size and root systems are more fibrous than for woody species. Consequently, the ratio of surface area to weight is much greater for grasses and herbs than for woody species. The results from 2005 suggest that where all the woody vegetation is controlled the amount of roots to 20 cm depth would be approximately 81,042 $m^2$/ha or about 191 kg/ha. In comparison, with no vegetation control, the amount of roots would be approximately 65,507 $m^2$/ha or 264 kg/ha. Regression equations relating root surface area to leaf area index provided weak (<0.6) coefficients of determination (*r*).

As observed for LAI, these results indicate that controlling only woody vegetation, even in case of radial treatments, can lead to expansion of the forb and grass layer (especially *Calamagrostis*) root systems. The numbers presented in this section, suggest that we can expect values for root surface area as high as 80,000 $m^2$ /ha (woody control) and root dry weights as high as 260 kg/ha (in the untreated).

### 3.2. Resource availability

Results from measurement of soil moisture, air and soil temperature, nitrogen availability and light in the selected treatment plots are presented in this section. The important relationships between some of the variables above are also presented.

#### *3.2.1. Volumetric water content*

Seasonal trends in soil volumetric water content (VWC) for 2004 and 2005 (Figures 3.8 and 3.9) indicate that there were no hours with treatment average soil moisture below 20%, due to the fact that both 2004 and 2005 were relatively wet years. Precipitation measured on site during the period from May to September was 930 mm in 2004 and 690 mm in 2005, with precipitation being well distributed during the growing season (Figures 3.10 and 3.11). When soil moisture is below 15%, growth of spruce seedlings is likely to be seriously reduced, while some reduction in spruce growth can be expected for soil moisture values below 25% (Grossnickle 2000). During both 2004 and 2005, there were plots in which CS616 sensors recorded values below 20% for more than 100 hours during an entire season (plot11-CCB, plot33-N, plot10-WCB, plot25-WCR in 2004 and plot35-N, plot10-WCB, plot25-WCR in 2005). This indicates that there is a high variability between plots over relatively small distances (60-100 m) in terms of soil moisture, with this variation potentially masking treatment effects.

Statistical results (Table 3.4) showed no treatment effects for all soil moisture variables analyzed ($p>0.05$). The interaction for hours with volumetric water content below 30% in 2005 ($p=0.02$) (Figure 3.12) suggests that the exposed soil in broadcast treatment may be drying faster, due to evapotranspiration and migration of water on exposed soils, rather than use of water by surrounding vegetation. No differences between 2 and 3 years of vegetation control were detected for soil moisture in 2005.

Possible relationships between volumetric water content and leaf area index of vegetation components were explored without success ($r<0.4$, $p>0.9$). It appears that the high values for volumetric water content recorded during both 2004 and 2005 growing seasons resulted in little or no effect of treatments or vegetation cover on soil moisture.

For both growing seasons, the correlations between the roving sensor (Hydrosense TDR) used to increase the sample size in terms of volumetric water content, and CS616 probe attached to datalogger, were weak (Figures 3.13a and 3.13b). Therefore, the data provided by Hydrosense TDR probe was abandoned.

### *3.2.2. Air temperature*

Seasonal trends in air temperatures at 30 cm height during 2004 and 2005 are shown in Appendix I. They illustrate the occurrence of late and early frost events during both growing seasons. These frost events may cause damage to the leader, buds and branches of spruce seedlings and, ultimately, reduce their growth. However, the effects of growing season frost on seedling growth (root collar diameter and height) could not be isolated from the effects of other factors.

Several studies (Spittlehouse and Stathers 1990; Orcutt and Nilsen 1996; Grossnickle 2000) suggest that extensive periods of exposure of young spruce to air temperature below $0^{\circ}C$ could have damaging effects to conifer seedlings. Therefore, three thresholds for air temperature were selected: -4, 0 and $5^{\circ}C$.

In both the 2004 and 2005 growing seasons, treatments did not have an effect on the number of hours during the growing season (May 08 to September 29, 2004 and May 08 to September 19, 2005) ($p>0.05$) with air temperatures at 30 cm below -4 °C (Table 3.5). Furthermore, none of the contrasts were significant ($p>0.05$). For 2005, the differences between radial and broadcast treatments ($p=0.05$) and between woody and complete vegetation control ($p=0.05$) are weak. This is likely related to the increase of the amount of vegetation (LAI) in woody control treatment plots due to expansion of the grass layer (mostly *Calamagrostis*).

The results also show that overall, in 2004, there were more hours with air temperature at 30 cm height below $-4^{\circ}C$, than in 2005. The seasonal trends (Appendix I) show that for 2004 these low temperatures have been recorded at the very beginning and end of season. Frost during these periods is unlikely to cause damage to the spruce seedlings.

Trends for air temperature at 150 cm height during the 2004 and 2005 growing season (Appendix I) illustrate fewer growing season frost events than were detected at 30 cm height. At 150 cm height, the number of hours above or below threshold temperatures in 2004 and 2005 (Table 3.6) do not show striking differences between treatments. However, statistical analysis (Table 3.6), reveals differences between treatments for hours with maximum above 5°C in 2004 ($p$=0.04), hours with minimum below -4°C in 2004 ($p$=0.02), and hours with average below 5°C in 2005 ($p$=0.04). In the case of hours with minimum below -4°C in 2004, the differences between least squares means are very small (2 hours), and probably have little biological significance.

Planned contrasts (Table 3.6) indicate that, in 2004, for all variables (except growing degree hours for minimum below -4°C), untreated (no treatment) was different ($p$<0.05) from all other treatments, more hours being recorded below 5°C and less above 5°C. The presence of vegetation in relative large amounts (LAI > 3 $m^2/m^2$, section 3.1.) in untreated (no treatment) plots, combined with slower aspen growth in controlled plots (Pitt et al. 2005), had an impact on growing degree hours for air temperature at 150 cm height. However, it only takes a small amount of aspen cover above sensors to influence air temperatures. The only significant interaction in 2004, regarding air temperature at 150 cm height (Figure 3.14), was recorded in the case of growing degree hours for minimum below -4°C ($p$=0.01), but as stated earlier, the difference between treatments is small, with potentially little biological significance. However, this interaction suggests that in broadcast woody control plots, the effect of lower temperatures may last longer due to the presence of a dense grass layer. The presence of woody vegetation (even in the winter) can have a moderating effect on air temperatures around overtopped spruce seedlings. In addition, in 2005, for the same variable, no hours below -4°C were recorded, suggesting that, if there was a strong treatment effect in 2004, in 2005 it may have dissipated. In 2005, the planned contrast analysis (Table 3.6) showed the same trends as in 2004, with no treatment differences for all variables (except hours with maximum above 5°C, and hours with minimum below -4°C). For any of the air temperature variables analyzed in 2005, no differences were detected between 2 and 3 years of vegetation control ($p$>0.05).

Possible relationships between leaf area index of vegetation components and hours with air temperature below or above the thresholds used could not be established, or the correlation coefficients were too low ($r$<0.3, $p$>0.05). However, the results suggest that compared with woody vegetation, the grass layer may have slightly more influence on air temperature, being associated with increased the number of hours below 5°C.

During the winter of 2004/2005 (September 30, 2004 to May 02, 2005), substantial variation in air temperature at 30 cm height was recorded (Figure 3.15) particularly during January, February and March. Between November 1, 2004 and March 31, 2005 there were more than 70 days with snow cover below 15 cm. (Pitt et al. 2006). As a result, the spring revealed many spruce with winter injury and brown needles, in some cases this resulted in death of the top of the tree, although trees generally recovered over the subsequent growing season. Mortality averaged 8.8% across the experiment, with no significant differences between treatments ($p$=0.12) (Pitt et al. 2006). However, specific contrasts revealed higher rates of mortality in the broadcast treatments compared to the radial treatments ($p = 0.04$) and in the broadcast-woody treatments compared to the broadcast-complete control treatments ($p = 0.02$). The highest mortality was observed in broadcast woody-only control (16.0%) and the lowest mortality was observed in untreated plots (2.7%) (Pitt et al. 2006).

The results presented suggest that the presence of vegetation (controlled by treatments) on the site has a strong influence on air temperature variation, with overtopping vegetation cover providing reduced winter injury. This is demonstrated by the 2005 air temperature results, which showed no significant difference at 150 cm height, probably due to a better mixing with the overlying atmosphere at this level. The expansion of grass layer (mostly *Calamagrostis*) and its behavior as an insulating layer (Hogg and Lieffers 1991) in broadcast woody control plots had a major impact on the fluctuation of air temperature at 30 cm height.

### *3.2.3. Soil temperature*

Soil temperature trends at 20 cm depth, for the 2004 growing season (Appendix I) showed no values recorded below 0°C. Treatments did not have an effect on hours above 5°C ($p$=0.52) in 2004 (Table 3.7). This can be explained by the fact that in the second growing season after establishment (2004), the vegetation (or forest floor) had not yet developed sufficiently to cause soil temperature differences between treatments. In 2005, the soil temperature trends (Appendix I) show temperatures lower than 0°C in early May. The analysis of number of days required to pass 5°C in 2005 (Table 3.7), showed an overall non-significant treatment effect ($p$=0.15), but with the highest number of days for the broadcast woody control treatment. The planned contrasts revealed a difference between the radial and broadcast methods ($p$=0.02).

Vegetation control treatments in 2005, increased the number of hours with maximum temperatures above 5°C ($p$=0.01) when all vegetation was controlled, and reduced it in the case of woody-only vegetation control. This is also shown by the planned contrast between woody and complete vegetation control ($p$=0.03), with the number of hours being higher in radial compared with broadcast treatments ($p$=0.01). No differences were detected between 2 and 3 years of vegetation control ($p$>0.05).

Possible relationships between LAI of vegetation components and hours with soil temperature above 5°C could not be established, or the correlation coefficients were too low. However, as in case of air temperature, the results suggest that the grass layer has slightly more influence on soil temperature, compared with woody vegetation.

The temperatures below 0°C recorded in early May in woody control broadcast plots suggest the influence of the grass layer (mostly *Calamagrostis*), on soil warming in early spring. Once the vegetation is sufficiently developed on the site, it has a strong negative effect on soil temperature, leading to delays in warming of the soil, especially for broadcast woody control plots, due to the abundant presence of grass layer (in the spring grass forms a thick and dense layer on the soil due to the weight of snow), and to the lack of insulating vegetation and forest floor in the complete control plots.

### *3.2.4. Nitrogen availability*

The statistical results (Table 3.8) for nitrogen found in leaves of vegetation components (aspen, grasses, forbs, low and tall shrubs) in 2004, revealed no treatment effects and no significant planned contrasts ($p \geq 0.10$). However, the least squares means suggest that somewhat more nitrogen may be stored in aspen leaves than in grass leaves. This, in turn, may reflect lower available soil N in untreated areas compared with vegetation controlled areas. Soil nitrogen availability was highest in the broadcast complete control treatment in April of 2005, and declined through the balance of the 2005 growing season (Figure 3.16). Statistical analysis (Table 3.9) shows that, overall, vegetation treatments increased soil nitrogen availability ($p$=0.01). The planned contrasts (Table 3.9) showed that broadcast application of treatments (broadcast vs. radial) ($p$=0.01) and complete control of vegetation (woody vs. complete control) ($p$=0.01) increased soil nitrogen availability. The interaction ($p$=0.01) (Figure 3.17) indicates much stronger increases in soil nitrogen with broadcast complete control compared to radial complete control. No differences were detected between 2 and 3 years of vegetation control ($p$>0.05) in 2005.

Soil nitrogen variation during the season of 2005, was highly related to the amount of vegetation present (Figure 3.18). A strong non-linear relationship between leaf area (herbaceous and woody) and total nitrogen availability was obtained ($R^2 = 0.7164$). The coefficients of this equation suggest that herbaceous LAI might have a stronger negative effect on soil nitrogen availability than the overstory LAI. However, a t-test indicates that the slopes do not differ significantly between overstory and herbaceous.

Hangs et al. (2004) suggested that soil nitrogen availability might be influenced by volumetric water content. In this regard, relationships between soil nitrogen availability and volumetric water content (hours with VWC below and above 20%) have been explored (both monthly and for the entire season). The results suggest that, in case of this study, volumetric water content was not related to soil nitrogen availability. Relationships between soil temperature and soil nitrogen availability were also examined without success.

These results suggest that soil nitrogen availability may be strongly influenced by both the amount and type of vegetation present on the site, as driven by the vegetation control treatments. Complete broadcast vegetation control resulted in an increase in soil nitrogen availability, while partial or less aggressive treatments did not appear to alter soil nitrogen availability. Vegetation is probably influencing soil nitrogen availability through its effects on soil temperature and nitrogen uptake and immobilization in living vegetation, as shown by the results of nitrogen found in leaves in 2004.

### *3.2.5. Light availability*

Light (DIFN) trends for 2004 and 2005 are illustrated in Figures 3.19 and 3.20. In 2004 light levels were lowest in untreated (no treatment) and highest in complete control (broadcast and radial), while woody control was between the two. Starting from mid June for untreated (no treatment) and beginning of July for woody control (broadcast and radial) until mid September, the light levels were below 40%, which represent substantially less than optimal conditions for spruce seedling growth (Lieffers and Stadt, 1994). For short periods, in the case of untreated (no treatment) light levels reached values below 15%, which is the limit below which spruce seedlings cannot survive (Eis 1981; Carter and Klinka 1992; Coates et al. 1994; Lieffers and Stadt 1994; Chen 1997).

Statistical analysis (Table 3.10) of midsummer light levels (DIFN) in 2004 (July 20$^{th}$, 2004), showed positive effects of vegetation treatment application ($p<0.01$), N having the lowest light levels, compared with all other treatments ($p<0.01$), while complete vegetation control had a stronger effect on increasing the light ($p<0.01$). The least squares means for N in midsummer were below 15%.

Light levels in 2005 (Figure 3.20), followed the same trends as in 2004, only with lower light levels being reached earlier in 2005. The hailstorm in mid July, affected leaf area index (see section 3.1.1.), and resulted in an increase in light levels (which had dropped below 10% prior to the hailstorm).

Statistical analysis (Table 3.10) of midsummer 2005 light levels (DIFN) showed vegetation treatment application had a positive effect on light availability ($p<0.01$). The planned contrasts, showed that N was lower than all other treatments (*p*<0.01). Differences between broadcast and radial methods (*p*=0.02) and between woody and complete control of vegetation (*p*<0.01) were also detected. The interaction (Figure 3.21) (*p*=0.01) suggests that light reaching the spruce seedlings increases with increasing level (amount and radius) of vegetation control. Controlling only parts of the vegetation (i.e. woody vegetation) is not a suitable solution, since this option favours the expansion of the grass layer, and, at this stage, spruce seedlings are below the grass layer. Thus, in these environments, light levels reaching spruce seedlings are low (below 40%) and affect their growth. The interaction (Figure 3.21) also suggests that radial treatments may provide reasonable light levels for spruce growth. Differences in light levels between different periods of vegetation control (2 vs. 3 years in this case) are also evident in 2005 (p<0.01).

As indicated earlier in this chapter, controlling vegetation reduced LAI and, thus, increases light availability. Removal of only woody species resulted in an increase in grass layer (*Calamagrostis*) cover and LAI which significantly reduced light levels available for spruce growth.

### 3.3. Discussion

Results from my study indicate that vegetation management treatments reduced LAI and root surface area and that the amount of vegetation present on the site, expressed in terms of LAI and root surface area, had a significant effect on resource availability (light, soil N availability, air and soil temperature), the apparent influence of herbaceous vegetation being more significant than woody vegetation.

The competitive effects of aspen, grasses, and forbs are expected to differ substantially when expressed on the basis of leaf area index, due to differences in resource requirements and utilization between these layers and between species (Goldberg and Werner 1983). Several studies document the negative competitive effects of woody and herbaceous vegetation on conifer growth (Coates and Burton 1999, Bell et al. 2000, Coopersmith et al. 2000, Grossnickle 2001), and report that there is a significant difference between component layers or species (woody and herbaceous vegetation). In contrast, Comeau et al. (1993) showed no difference between woody and herbaceous layers in their study. Lopushinsky and Klock (1990) also found no difference in competitiveness between species in the herbaceous layer.

The influence of competing vegetation, expressed in terms of LAI, on soil moisture was unexpectedly insignificant, possibly due to the abundance and relatively uniform distribution of precipitation during the years of study. This contrasts with findings of other studies (Brand 1991, Allen and Wentworth 1993, Örlander et al. 1996, Petersen et al.1998, Nilsson and Örlander 1999, Coopersmith et al. 2000, Grossnickle et al. 2001, Watt et al. 2004, Harper et al. 2005), which show a significant positive effect of treatments which reduce cover or LAI on soil moisture. Some studies suggest that changes in abundance of vegetation are not always associated with increased soil moisture (e.g. Robberecht et al. 1983, Zutter et al. 1986, Richards and Caldwell 1987). The few sensors that have recorded measurable periods of drought, suggested that when dry periods do occur, competition is likely to be most apparent in treatments where only the woody vegetation was removed (broadcast more than radial), followed by untreated (no treatment) areas. This is consistent with the suggestions of other studies (Mitchell et al. 1993, Petersen et al. 1988). The poor correlation between the roving and fixed sensors for measuring volumetric water content, suggested that the variability in terms of soil moisture in forest soils is high with both spatial and temporal heterogeneity being important (Brand 1991, Mitchell et al. 1993, Grossnickle et al. 2001). Pitt et al. (2006) reported treatment effects for the sister study established in Timmins, Ontario.

The seasonal trends in LAI and light (DIFN) were consistent with the level of vegetation control provided by the treatments. In this study, vegetation LAI was highest in untreated (no treatment) areas, while complete control of vegetation (both radial and broadcast) severely reduced it. LAI variation strongly influenced light availability for spruce seedlings (Eis 1981, Carter and Klinka 1992, Coates et al. 1994, Lieffers and Stadt 1994, Chen 1997); the more vegetation being controlled, the more light becoming available for spruce seedlings. The absence of foliage in early spring and fall, as suggested by LAI trends in both growing seasons, provided favourable conditions for spruce seedlings to increase their size (Constabel and Lieffers, 1996). This is also consistent with the findings of other studies mentioned in this chapter.

Soil nitrogen availability was strongly correlated with LAI, but weakly correlated with root surface area or root dry weight. These results are consistent with other studies (Hangs et al. 2004, Orlander et al. 1996, Switzer and Nelson 1972, Hough 1982), which showed that removal of all competing vegetation increases soil nitrogen availability.

However, the rapid expansion of grass LAI creates a sink for soil nitrogen (Emmet et al. 1991, Fahey et al. 1991), with this layer being more competitive for soil nitrogen than the woody vegetation (Matsushima, 2005). Over time, as vegetation amounts increase, it is believed that soil nitrogen availability will decrease (Allen et al. 1990). Other studies (Landhäuser et al. 1996, Powelson and Lieffers 1992, Landhäuser and Lieffers 1994) also show a dependence of *Calamagrostis canadensis* growth on soil nutrients, particularly nitrogen (Hangs et al. 2003).

The variation of air temperature on the site was driven mostly by the amount of vegetation, expressed in terms of leaf area index. This is consistent with results from other studies (e.g. Groot and Carlson 1996, Groot et al. 1997, Grossnickle 2000, Pritchard and Comeau 2004, Voicu and Comeau 2006), which showed the influence of vegetation presence on air and soil temperature. In broadcast woody controlled areas, the variation of air temperature at 30 cm height was strongly influenced by the amount of grass (*Calamagrostis*) present, and thus the isolator behavior of grass (Hogg and Lieffers 1991) could have a damaging effect on spruce seedlings.

It seems that the herbaceous vegetation did not have the same protective benefits as woody vegetation during winter injury of 2004/2005; the seedlings in radial treatments being better protected by surrounding vegetation which was less than one tree length away (Groot and Carlson 1996, Groot et al. 1997, Pritchard and Comeau 2004, Voicu and Comeau 2006). Moreover, in early spring, the herbaceous vegetation formed a thick and dense layer on the soil surface and caused delays in soil warming, while the soil temperatures increased more rapidly in spring in plots that were not covered by dry grass.

It is expected that, along with development of grass layer (increasing LAI), the trend that has been observed during these first 3 years (more grass on the site, longer delays in warming the soil), may lead to even longer (and perhaps significant) delays in warming the soil in early spring on areas where broadcast woody control of vegetation has been performed.

The LAI trends presented suggest that treatment application reduced the amount of vegetation accordingly. This is consistent with other studies (e.g. Comeau et al. 1993, Comeau et al. 1999, Tanner et al. 1996, Lieffers et al. 2002). Removal of woody vegetation only, resulted in expansion of the grass layer (*Calamagrostis*), especially in the case of a broadcast application, and thus the amount of vegetation present in understory exceeded that present in the overstory (Hogg and Lieffers 1991, Lieffers et al. 1999). In concert with changes in LAI, root surface area of competing vegetation was significantly influenced by treatment application, the colonization of herbaceous vegetation being most spectacular. Several studies (Powelson and Lieffers 1992, MacDonald and Lieffers 1993, Landhäuser and Lieffers 1999) showed that after harvesting, *Calamagrostis canadensis* tends to colonize a site due to soil exposure to light and higher temperatures, thus stimulating rhizomatous growth from existing clones prior to disturbance (Ahlgren 1960, Dyrness and Norum 1983). Larger and more dominant trees contribute disproportionately to total below ground biomass (Le Goff and Ottorini 2001, Richardson et al. 2003), aspen lateral roots being concentrated in the upper 20 cm of soil (Pregitzer and Friend 1996). The results from my study support the theory that large numbers of suckers (in untreated areas) and their high leaf area (Barnes 1966) support a large underground biomass (DesRochers and Lieffers 2001). Also, hormonal activity (i.e., apical dominance) of *Calamagrostis canadensis* (Rogan and Smith 1976, Landhäuser and Lieffers 1999), and aspen (Farmer 1962, Schier 1975) played an important role in variation of root surface area and clonal activity of these species. The larger values for root surface area in the case of herbaceous vegetation could also be explained by their lighter weight and larger surface areas, compared with woody roots. The results from this study showed a weaker relationship between root surface area and leaf area index, compared with DesRochers and Lieffers (2001), who documented a strong relationship between leaf area index and live root biomass.

Application of glyphosate (Vision®) for controlling all vegetation or triclopyr (Release®) for controlling woody vegetation is generally most effective when treatments are applied during the first few years after planting (Blackmore and Corns 1979, Freedman et al. 1993, Wagner 1999, Harper et al. 2005). Glyphosate treatments often increase seedling survival (Freedman et al. 1993, Biring et al. 2003). However, caution is needed when glyphosate is applied, since it may lead to development of pure or nearly pure conifer stands, in place of mixedwood stands (Biring et al. 1999; Biring and Has-Byl 2000, Pitt and Bell 2005). In this regard, spot treatments might be useful for creating mixedwood stands, as suggested by the underlying experiment (Pitt et al. 2006).

The results of the present study showed that vegetation management treatments can be used to manipulate vegetation characteristics (LAI and root surface area), which ultimately lead to effects on resources (light, soil moisture, soil N availability, air and soil temperature) available to crop tree seedlings. A 2-m radius of complete vegetation control around spruce seedlings seems to provide a favorable early environment for white spruce, in relation to improved light levels and reduced competitive effects of the grass layer. Differences between 2 and 3 years of vegetation control weren't showed by this study. It appears that different vegetation components (overstory and understory) are not competing for same resources. However, since aspen height growth is likely to exceed that of spruce for at least 25 years, and aspen crowns are likely to expand into the 2-m radius spots where the spruce are located, further treatments may be required to provide optimal growing conditions for these seedlings.

### 3.4. References

Ahlgren, C.E. 1960. Some effects of fire on reproduction and growth of vegetation in northeastern Minnesota. Ecology 41: 431–445.

Allen, H.L., and Wentworth, T.R. 1993. Vegetation control and site preparation affect patterns of shoot elongation for 3-year-old loblolly pine. Can. J. For. Res. 23: 2110-2115.

Barnes, B.V. 1966. The clonal growth habit of American aspens. Ecology, 47: 439–447.

Bell, F.W., Ter-Mikaelian, M.T., and Wagner, R.G. 2000. Relative competitiveness of nine early-successional boreal forest species associated with planted jack pine and black spruce seedlings. Can. J. For. Res. 30: 790-800.

Biring, B.S. and W. Hays-Byl. 2000. Ten-year conifer and vegetation responses to glyphosate treatment in the SBSdw3. B.C. Ministry of Forests, Research Branch.

Victoria. Extension Note 48. url: http://www.for.gov.bc.ca/hfd/pubs/Docs/En/En48.htm

Biring, B.S., Hays-Byl, W.J. and Hoyles, S.E. 1999. Twelve-year conifer and vegetation responses to disking and glyphosate on a BWBSmw backlog site. B.C. Ministry of Forest, Research Branch, Victoria. Working Paper 43.

Blackmore, D.G., and Corns, W.G. 1979. Lodgepole pine and white spruce establishment after glyphosate and fertilizer treatments on grassy cutover forest land. For. Chron. 55: 102-105.

Brand, D.G. 1991. The establishment of boreal and sub-boreal conifer plantations: an integrated analysis of environmental conditions and seedling growth. Forest Science 37: 68-100.

Carter, R.E., Klinka, K., 1992. Variation in shade tolerance of Douglas-fir, western hemlock and western redcedar in coastal British Columbia. For. Ecol. Manag. 55, 87-105.

Chen, H.Y.H., 1997. Interspecific responses of planted seedlings to light availability in interior British Columbia: survival, growth, allometric patterns, and specific leaf area. Can. J. For. Res. 27, 1383-1393.

Coates, K.D., Burton, P.J., 1999. Growth of planted tree seedlings in response to ambient light levels in northwestern interior cedar-hemlock forests of British Columbia. Can. J. For. Res. 29, 1374-1382.

Coates, K.D., Haeussler, S., Linderburgh, S., Pojar, R., Stock, A.J., 1994. Ecology and Silviculture of interior spruce in British Columbia. FRDA Report 220. BC Ministry of Forestry and Forestry Canada, Victoria, BC, 182 pp.

Comeau, P.G., and Heineman, J.L. 2003. Predicting understory light microclimate from stand parameters in young paper birch (Betula papyrifera marsh.) stands. For. Ecol. Manage. 180:303-315.

Comeau, P.G., Biring, B.S., and Harper, G.J. 1999. Conifer response to brushing treatments: a summary of Brithish Columbia data. B.C. Min. For., Research Branch, Victoria. Extension note 41. 12 pp.

Comeau, P.G., Braumandl, T.F., and Xie, C-Y. 1993. Effects of overtopping vegetation on light availability and growth of Engelmann spruce (*Picea engelmannii*) seedlings. Can. J. For. Res. 23: 2044-2048.

Constabel, A.J., and Lieffers, V.J. 1996. Seasonal patterns of light transmission through boreal mixedwood canopies. Can. J. For. Res. 26:1008-1014.

Coopersmith, D., Sagar, B. and Thompson, D. 2000. Ten year results of the Bear Mountain Mixedwood Trial (EP 1077): The effect of overtopping aspen canopies on white spruce seedling growth and seedling microclimate. In Forest Research Note #PG-23.

DesRochers, A., and Lieffers, V.J. 2001. Root biomass of regenerating aspen (*Populus tremuloides*) stands of different densities in Alberta.

Dyrness, C.T. and Norum, R.A. 1983. The effects of experimental fires on black spruce forest floors in interior Alaska. Can. J. For. Res. 13: 879–893.

Eis, S. 1981. Effect of vegetative competition on regeneration of white spruce. Can. J. For. Res. 11: 1-8.

Emmet, B.A., Anderson, J.M., and Hornung, M. 1991. The control of dissolved nitrogen losses following two intensities of harvesting in a Sitka spruce forest (N. Wales). Forest Ecology and Management 41: 65-80.

Fahney, T.J., Hill, M.O., Stevens, P.A., Hornung, M., and Rowland, P. 1991. Nutrient accumulation in vegetation following conventional and whole-tree harvest of Sitka spruce plantations in North Wales. Forestry 64: 271-88.

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

Freedman, B., Morash, R., and MacKinnon, D. 1993. Short-term changes in vegetation after silvicultural spraying of glyphosate herbicide onto regenerating clearcuts in Nova Scotia, Canada. Can. J. For. Res. 23: 2300-2311.

Goldberg, D.E. and Werner, P.A.. 1983. Equivalence of competitors in plant communities A null hypothesis and a field experimental approach. Amer. J. Bot. 70: 1098-1104.

Groot, A., Carlson, D.W. 1996. Influence of shelter on night temperatures, frost damage, and bud break of white spruce seedlings. Canadian Journal of Forest Research. 26(9): 1531-1538.

Groot, A., Carlson, D.W., Fleming, R.L., Wood, J.E., 1997. Small openings in trembling aspen forest: microclimate and regeneration of white spruce and trembling aspen.

Nat. Res. Can. Can. For. Serv. Great Lake Forestry Centre, Sault Ste. Marie, Ont. NODA/NFP Technical Report TR-47, 25 pp.

Grossnickle, S.C. 2000.Ecophysiology of northern spruce species. The performance of planted seedlings. NRC Research Press, Ottawa, Ontario, Canada.

Grossnickle, S.C. et al. 2001. Ecophysiological Principles. In Regenerating the Canadian Forest: Principles and Practice for Ontario (Markham, Ont.: Fitzhenry & Whiteside).

Hangs, R.D., Greer, K.J., Sulewski C.A. 2004. The effect of interspecific competition on conifer seedling growth and nitrogen availability measured using ion-exchange membranes. Canadian Journal of Forest Research 34: 754-761.

Hangs, R.D., Knight, D., and Van Rees, K.C.J. 2003. nitrogen uptake characteristics for roots of conifer seedlings and common boreal forest competitor species. Can. J. For. Res. 33: 156-163.

Harper, G.J., Comeau, P.G., and Biring, B.S. 2005. A comparison of Herbicide and Mulch Mat treatments for reducing grass, herb, and shrub competition in the BC Interior Douglas-fir zone – ten year results. WJAF 20(3): 167-176.

Hogg, E.H. and Lieffers, V.J. 1991. The impact of *Calamagrostis canadensis* on soil thermal regimes after logging in northern Alberta. Can. J. For. Res. 21: 387-394.

Hough, W.A. 1982. Phytomass and nutrients in the understory and forest floor of slash/longleaf pine stands. For. Sci. 28: 359-372.

Landhäuser, S.M., and Lieffers, V.J. 1994. Competition between *Calamagrostis canadensis* and *Epilobium angustifolium* under different soil temperature and nutrient regimes. Can. J. For. Res. 24: 2244-2250.

Landhäuser, S.M., and Lieffers, V.J. 1999. Rhizome growth of Calamagrostis canadensis into mounds created for tree seedling establishment. New Forests 18: 245–262.

Landhäuser, S.M., Stadt, K.J., Lieffers, V.J., and McNabb, D.H. 1996. Rhizome growth of *Calamagrostis canadensis* in response to soil nutrients and bulk density. Can. J. Plant Sci. 76: 545-550.

Le Goff N., Ottorini J.-M., Root biomass and biomass increment in a beech (*Fagus* sylvatica L.) stand in North-East France, Ann. For. Sci. 58 (2001) 1–13.

Lieffers, V.J., and Stadt, K.J. 1994. Growth of understory Picea galuca, Calamagrostis Canadensis, and Epilobium angustifolium in relation to overstory light transmission. Can. J. For. Res. 24:1193-1198.

Lieffers, V.J., Messier, C., Stadt, K.J., Gendron, F., and Comeau, P.G. 1999. Predicting and managing light in the understory of boreal forests. Can. J. For. Res. 29:796-811.

Lieffers, V.J., Pinno, B.D. and Stadt, K.J. 2002. Light dynamics and free-to-grow standard in aspen-dominated mixedwood forest. For. Chron. 78:137-145.

Lopushinsky, W., and Klock, G.O. 1990. Soil water use by *Ceanothus velutinus* and two grasses. US Department of Agriculture, Forest Service, Pacific Northwest Research Station. Rsearch note PNW-RN-496.

MacDonald, S.E., and Lieffers, V.J. 1993. Rhizome plasticity and clonal foraging of *Calamagrostis canadensis* in response to habitat heterogeneity. The Journal of Ecology 81(4): 769-776.

Matsushima, M. 2005. Effects of Canada bluejoint grass competition, N fertilization, and litter layer removal on soil N processes and tree growth. MSc Thesis, University of Alberta, Faculty of Graduate Studies and Research, Edmonton, Alberta.

Mitchell, R.J., Zutter, B.R., Green, T.H., Perry, M.A. and Gjerstad, D.H. 1993. Spatial and temporal variations in competitive effects on soil moisture and pine response. Ecol. Appl. 3: 167-174.

Nilsson, U., and Lee Allen, H. 2003. Short and long term effects of site preparation, fertilization and vegetation control on growth and stand development of planted loblolly pine. Forest Ecology and Management 175: 367-377.

Nilsson, U., and Örlander, G. 1999. Water uptake by planted *Picea abies* in relation to competing field vegetation and seedling rooting depth on two grass-dominated sites in southern Sweden. Scand. J. For. Res. 14: 312-319.

Orcutt, D.M., and. Nilsen, E.T. 1996. The physiology of plants under stress.v2. John Wiley & Sons, Inc. New York.

Örlander, G., Nilsson, U., and Hällgren, J-E. 1996. Competition for water and nutrients between ground vegetation and planted *Picea abies*. N.Z.J. For. Sci. 26 (1/2): 99-117.

Petersen, T.D., Newton, M. and Zedaker, S.M. 1988. Influence of *Ceanothus velutinus* and associated forbs on the water stress and stemwood production of Douglas-fir. Forest Science 34: 333-343.

Pitt, D., Comeau, P., Mihajlovich, M., MacIsaac, D. 2006. Effects of herbaceous vegetation control and aspen stem density on boreal mixedwood stand development. Partners Report – 2005 field season. Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. (http://www.forestresearch.ca/product_catalogue/reports.htm, report RP-029)

Pitt, D.G., Bell, F.W. 2005. Juvenile response to conifer release alternatives on aspen-white spruce boreal mixedwood sites. Part I: Stand structure and composition. Forestry Chronicle. 81(4): 538-547.

Powelson, R.A., and Lieffers, V.J. 1992. Effects of light and nutrients on biomass allocation in *Calamagrostis canadensis*. Ecography 15: 31-36.

Pregitzer, K.S. Friend, A.L., 1996. The structure and function of *Populus* root systems. In: Stettler, R.F., Bradshaw, H.D., Heilman, P.E., Hinkley, T.M. (Eds.), The Biology of *Populus* and its Implications for Management and Conservation. NRC Research Press, Ottawa, Ontario, pp. 331–354.

Pritchard, J.M., Comeau, P.G. 2004. Effects of opening size and stand characteristics on light transmittance and temperature under young trembling aspen stands. Forest Ecology and Management. 200(1/3): 119-128.

Richards, J. H., and Caldwell, M. M. 1987. Hydraulic lift: substantial nocturnal water transport between soil layers by *Artemesia tridenta* roots. Oecologia (Berlin) 73:486-489.

Richardson, A.D., Statland, C.B., and Gregoire T.J. 2003. Root biomass distribution under three cover types in a patchy *Pseudotsuga menziesii* forest in western Canada. Ann. For. Sci. 60: 469–474.

Robberecht, R., Mahall, B. E., and Nobel, P. S. 1983. Experimental removal of intraspecific competitors – effects on water relations and productivity of a desert bunchgrass, *Hilaria rigida*. Oecologia (Berlin) 60:21-24.

Rogan, P.G. and Smith, D.L. 1976. Experimental control of bud inhibition in rhizomes of *Agropyron repens* (L.) Beauv. Z. Pflanzenphysiol. Bd. 78: 113–121.

Schier, G.A. 1975. Deterioration of aspen clones in the middle Rocky Mountains. USDA For. Serv. Res. Pap. INT-170.

Spittlehouse, D.L. and R.J. Stathers 1990. Seedling microclimate. B. C. Min. For., Victoria. Land Manage. Rep. No. 65. 28 pp.

Switzer, G.L., and Nelson, L.E. 1972. Nutrient accumulation and cycling in loblolly pine (*Pinus taeda* L.) plantation ecosystems: The first twenty years. Soil Sci. Soc. Amer. Proc. 36:143-147.

Tanner, D., Delong C.S., and Eastham, A. 1996. Investigations of Planting White Spruce under a Trembling Aspen Canopy. In Silviculture of temperate and boreal broadleaf-conifer mixtures. Edited by P.G. Comeau and K.D. Thomas. BC Ministry of Forests, Victoria. Land Management Handbook no. 36. pp. 114-121.

Voicu, M.F., and Comeau, P.G. 2006. Microclimatic and spruce growth gradients adjacent to young aspen stands. Forest Ecology and Management 221: 13–26.

Watt, M.S., Kimberley, M.O., Richardson, B., Whitehead, D., and Mason, E.G. 2004. Testing a juvenile tree growth model sensitive to competition from weeds, using *Pinus radiata* at two contrasting sites in New Zealand. Can. J. For. Res. 34: 1985-1992.

Zutter, B.R., Glover, G.R., and Gjerstad, D.H. 1986. Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. Forest Science 32: 882-899.

Table 3.1. Statistical results for LAI (leaf area index) in midsummer of 2004 (July 20) and 2005 (July, 28).

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

<table>
<tr><th>Variable</th><th>Total mean</th><th>RMSE</th><th>Treat</th><th>LS Mean</th><th>F</th><th>p</th></tr>
<tr><td rowspan="5">LAI 2004 ($m^2m^{-2}$)</td><td rowspan="5">1.42</td><td rowspan="5">0.75</td><td>CCB</td><td>0.65</td><td rowspan="5">56.25</td><td rowspan="5"><0.01</td></tr>
<tr><td>CCR</td><td>0.55</td></tr>
<tr><td>N</td><td>3.11</td></tr>
<tr><td>WCB</td><td>1.97</td></tr>
<tr><td>WCR</td><td>1.68</td></tr>
<tr><td colspan="7">Planned Contrasts LAI 2004</td></tr>
<tr><td colspan="5">Treated vs. Untreated (No treatment vs. all treatments)</td><td>124.65</td><td><.01</td></tr>
<tr><td colspan="5">Mixedwood vs. Pure (Radial vs. Broadcast)</td><td>1.91</td><td>0.16</td></tr>
<tr><td colspan="5">Woody Control vs. Complete Control</td><td>72.1</td><td><.01</td></tr>
<tr><td colspan="5">Interaction</td><td>0.42</td><td>0.52</td></tr>
<tr><td rowspan="6">LAI 2005 ($m^2m^{-2}$)</td><td rowspan="6">1.45</td><td rowspan="6">0.78</td><td>CCB</td><td>0.15</td><td rowspan="6">63.57</td><td rowspan="6"><0.01</td></tr>
<tr><td>CCR2</td><td>0.68</td></tr>
<tr><td>CCR3</td><td>0.35</td></tr>
<tr><td>N</td><td>2.71</td></tr>
<tr><td>WCB</td><td>3.12</td></tr>
<tr><td>WCR</td><td>1.74</td></tr>
<tr><td colspan="7">Planned Contrasts LAI 2005</td></tr>
<tr><td colspan="5">Treated vs. Untreated (No treatment vs. all treatments)</td><td>74.85</td><td><.01</td></tr>
<tr><td colspan="5">Mixedwood vs. Pure (Radial vs. Broadcast)</td><td>25.17</td><td><.01</td></tr>
<tr><td colspan="5">Woody Control vs. Complete Control</td><td>213.28</td><td><.01</td></tr>
<tr><td colspan="5">2 vs. 3 years (CCR2 vs. CCR3)</td><td>2.26</td><td>0.13</td></tr>
<tr><td colspan="5">Interaction</td><td>9.78</td><td>0.01</td></tr>
</table>

Table 3.2. Statistical results for overstory (LAIo) and understory (LAIh) leaf area index on July 28, 2005.

CCB – Broadcast Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | P |
|---|---|---|---|---|---|---|
| LAIo ($m^2m^{-2}$) | 0.24 | 0.16 | CCB | 0.08 | 143.01 | <0.01 |
| | | | CCR2 | 0.07 | | |
| | | | CCR3 | 0.11 | | |
| | | | N | 1.07 | | |
| | | | WCB | 0.07 | | |
| | | | WCR | 0.10 | | |
| LAIh ($m^2m^{-2}$) | 1.21 | 0.76 | CCB | 0.07 | 53.4 | <0.01 |
| | | | CCR2 | 0.60 | | |
| | | | CCR3 | 0.23 | | |
| | | | N | 1.64 | | |
| | | | WCB | 3.04 | | |
| | | | WCR | 1.64 | | |
| **Planned Contrasts LAIo** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 714.13 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0.29 | 0.59 |
| Woody Control vs. Complete Control | | | | | 0.02 | 0.87 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 0.82 | 0.36 |
| Interaction | | | | | 0.01 | 0.91 |
| **Planned Contrasts LAIh** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 9.53 | 0.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 27.52 | <.01 |
| Woody Control vs. Complete Control | | | | | 223.92 | <.01 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 3.00 | 0.01 |
| Interaction | | | | | 10.38 | 0.01 |

Table 3.3. Statistical results for root surface area and dry weight during the growing seasons of 2004 (May 08 – September 29) and 2005 (May 03 – September 19).
CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **Root Surface Area 2004 ($cm^2$)** | 87.06 | 30.54 | **CCB** | 68.88 | 27.06 | <.01 |
| | | | **CCR** | 50.92 | | |
| | | | **N** | 102.82 | | |
| | | | **WCB** | 159.31 | | |
| | | | **WCR** | 89.50 | | |
| **Root Dry Weight 2004 (g)** | 0.29 | 0.15 | **CCB** | 0.30 | 9.35 | <.01 |
| | | | **CCR** | 0.17 | | |
| | | | **N** | 0.46 | | |
| | | | **WCB** | 0.41 | | |
| | | | **WCR** | 0.23 | | |
| **Planned Contrasts Root Surface Area 2004** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 1.2 | 0.27 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 28.31 | <.01 |
| Woody Control vs. Complete Control | | | | | 61.15 | <.01 |
| Interaction | | | | | 9.88 | 0.01 |
| **Planned Contrasts Root Dry Weight 2004** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 13.31 | 0.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 13.8 | 0.01 |
| Woody Control vs. Complete Control | | | | | 3.92 | 0.05 |
| Interaction | | | | | 0.27 | 0.60 |

Table 3.3. – continued

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **Root Surface Area 2005 ($cm^2$)** | 109.67 | 48.30 | **CCB** | 66.50 | 10.08 | <.01 |
| | | | **CCR2** | 78.18 | | |
| | | | **CCR3** | 72.53 | | |
| | | | **N** | 131.01 | | |
| | | | **WCB** | 162.08 | | |
| | | | **WCR** | 147.50 | | |
| **Root Dry Weight 2005 (g)** | 0.36 | 0.20 | **CCB** | 0.26 | 2.51 | 0.03 |
| | | | **CCR2** | 0.26 | | |
| | | | **CCR3** | 0.35 | | |
| | | | **N** | 0.52 | | |
| | | | **WCB** | 0.38 | | |
| | | | **WCR** | 0.37 | | |
| **Planned Contrasts Root Surface Area 2005** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 2.87 | 0.09 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 1.47 | 0.23 |
| Woody Control vs. Complete Control | | | | | 46.97 | <.01 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 0.09 | 0.76 |
| Interaction | | | | | 0.05 | 0.82 |
| **Planned Contrasts Root Dry Weight 2005** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 9.22 | 0.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0 | 0.94 |
| Woody Control vs. Complete Control | | | | | 2.39 | 0.12 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 1.21 | 0.27 |
| Interaction | | | | | 0.07 | 0.79 |

Table 3.4. Statistical results for volumetric water content (VWC) during the growing seasons of 2004 (May 08 – September 29) and 2005 (May 03 – September 19).
CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|---|
| **VWC 2004 (hours)** | Hours Below 20% | 155.94 | 405.55 | **CCB** | 62.7 | 0.96 | 0.46 |
| | | | | **CCR** | 0.0 | | |
| | | | | **N** | 465.3 | | |
| | | | | **WCB** | 41.3 | | |
| | | | | **WCR** | 366.3 | | |
| | Hours Below 25% | 481.38 | 774.78 | **CCB** | 494.7 | 1.04 | 0.42 |
| | | | | **CCR** | 7.7 | | |
| | | | | **N** | 607.0 | | |
| | | | | **WCB** | 746.0 | | |
| | | | | **WCR** | 1025.3 | | |
| | Hours Below 30% | 1204.38 | 1265.96 | **CCB** | 2141.0 | 1.17 | 0.36 |
| | | | | **CCR** | 480.3 | | |
| | | | | **N** | 1092.0 | | |
| | | | | **WCB** | 1088.7 | | |
| | | | | **WCR** | 1944.0 | | |
| **Planned Contrasts Hours Below 20% (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 1.81 | 0.20 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.36 | 0.55 |
| Woody Control vs. Complete Control | | | | | | 0.62 | 0.44 |
| Interaction | | | | | | 0.78 | 0.39 |
| **Planned Contrasts Hours Below 25% (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.01 | 0.93 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.06 | 0.80 |
| Woody Control vs. Complete Control | | | | | | 2.3 | 0.15 |
| Interaction | | | | | | 0.84 | 0.37 |
| **Planned Contrasts Hours Below 30% (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.16 | 0.69 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.35 | 0.56 |
| Woody Control vs. Complete Control | | | | | | 0.09 | 0.76 |
| Interaction | | | | | | 3.39 | 0.08 |

Table 3.4. – Continued

| Variable | | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|---|
| VWC 2005 (hours) | Hours Below 20% | 95.10 | 315.51 | CCB | 6.0 | 1.05 | 0.42 |
| | | | | CCR2 | 0.0 | | |
| | | | | CCR3 | 0.0 | | |
| | | | | N | 58.0 | | |
| | | | | WCB | 474.3 | | |
| | | | | WCR | 71.8 | | |
| | Hours Below 25% | 543.05 | 942.62 | CCB | 747.0 | 1.01 | 0.44 |
| | | | | CCR2 | 0.0 | | |
| | | | | CCR3 | 0.0 | | |
| | | | | N | 321.3 | | |
| | | | | WCB | 1039.7 | | |
| | | | | WCR | 1134.3 | | |
| | Hours Below 30% | 1044.95 | 1154.26 | CCB | 2135.7 | 1.81 | 0.17 |
| | | | | CCR2 | 584.7 | | |
| | | | | CCR3 | 4.5 | | |
| | | | | N | 606.7 | | |
| | | | | WCB | 1103.0 | | |
| | | | | WCR | 1897.0 | | |
| **Planned Contrasts Hours Below 20% (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.07 | 0.79 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 1.81 | 0.19 |
| Woody Control vs. Complete Control | | | | | | 2.98 | 0.10 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 0.00 | 1.00 |
| Interaction | | | | | | 0.58 | 0.46 |
| **Planned Contrasts Hours Below 25% (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.2 | 0.66 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 1.15 | 0.30 |
| Woody Control vs. Complete Control | | | | | | 3.19 | 0.09 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 0.00 | 1.00 |
| Interaction | | | | | | 1.6 | 0.22 |
| **Planned Contrasts Hours Below 30% (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.55 | 0.46 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 1.81 | 0.20 |
| Woody Control vs. Complete Control | | | | | | 1.06 | 0.32 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 0.43 | 0.52 |
| Interaction | | | | | | 6.39 | 0.02 |

Table 3.5. Statistical results for air temperature at 30 cm height during the growing seasons of 2004 (May 08 – September 29) and 2005 (May 03 – September 19).
CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|---|
| **Air Temp 30cm 2004 (hours)** | hours for minimum below -4°C | 51.55 | 15.44 | **CCB** | 41.66 | 2.22 | 0.12 |
| | | | | **CCR** | 47.17 | | |
| | | | | **N** | 59.33 | | |
| | | | | **WCB** | 72.00 | | |
| | | | | **WCR** | 42.00 | | |
| **Planned Contrasts Hours for minimum below -4°C (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.77 | 0.39 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 2.16 | 0.16 |
| Woody Control vs. Complete Control | | | | | | 2.28 | 0.15 |
| Interaction | | | | | | 4.53 | 0.05 |
| **Air Temp 30cm 2005 (hours)** | hours for minimum below -4°C | 3.77 | 6.37 | **CCB** | 0.66 | 2.66 | 0.07 |
| | | | | **CCR2** | 1.66 | | |
| | | | | **CCR3** | 1.33 | | |
| | | | | **N** | 2.00 | | |
| | | | | **WCB** | 16.00 | | |
| | | | | **WCR** | 1.00 | | |
| **Planned Contrasts Hours for minimum below -4°C (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.28 | 0.60 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 4.34 | 0.05 |
| Woody Control vs. Complete Control | | | | | | 4.69 | 0.05 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 0.00 | 0.95 |
| Interaction | | | | | | 2.68 | 0.12 |

Table 3.6. Statistical results for air temperature at 150 cm height during the growing seasons of 2004 (May 08 – September 29) and 2005 (May 03 – September 19).
CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|---|
| **Air Temperature 150cm 2004 (hours)** | Hours for maximum above 5°C | 3030.88 | 17.68 | **CCB** | 3048.00 | 3.34 | 0.04 |
| | | | | **CCR** | 3031.00 | | |
| | | | | **N** | 3002.00 | | |
| | | | | **WCB** | 3026.67 | | |
| | | | | **WCR** | 3046.67 | | |
| | Hours for minimum below 5°C | 673.83 | 36.00 | **CCB** | 646.67 | 2.49 | 0.09 |
| | | | | **CCR** | 675.50 | | |
| | | | | **N** | 720.00 | | |
| | | | | **WCB** | 687.00 | | |
| | | | | **WCR** | 638.33 | | |
| | Hours for minimum below 0°C | 154.88 | 23.33 | **CCB** | 138.00 | 2.28 | 0.11 |
| | | | | **CCR** | 157.17 | | |
| | | | | **N** | 183.33 | | |
| | | | | **WCB** | 161.33 | | |
| | | | | **WCR** | 132.33 | | |
| | Hours for minimum below -4°C | 19.27 | 1.15 | **CCB** | 18.33 | 3.80 | 0.02 |
| | | | | **CCR** | 20.33 | | |
| | | | | **N** | 18.33 | | |
| | | | | **WCB** | 20.33 | | |
| | | | | **WCR** | 18.00 | | |
| **Planned Contrasts Hours for maximum above 5°C (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 10.24 | 0.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.02 | 0.87 |
| Woody Control vs. Complete Control | | | | | | 0.09 | 0.77 |
| Interaction | | | | | | 3.75 | 0.07 |
| **Planned Contrasts Hours for minimum below 5°C (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 6.41 | 0.02 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.26 | 0.61 |
| Woody Control vs. Complete Control | | | | | | 0.01 | 0.93 |
| Interaction | | | | | | 3.97 | 0.06 |
| **Planned Contrasts Hours for minimum below 0°C (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 5.90 | 0.03 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.15 | 0.70 |
| Woody Control vs. Complete Control | | | | | | 0.00 | 0.95 |
| Interaction | | | | | | 3.65 | 0.07 |
| **Planned Contrasts Hours for minimum below -4°C (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 1.55 | 0.23 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.07 | 0.79 |
| Woody Control vs. Complete Control | | | | | | 0.07 | 0.79 |
| Interaction | | | | | | 12.07 | 0.01 |

Table 3.6. – Continued

| Variable | | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|---|
| **Air Temperature 150cm 2005 (hours)** | Hours for maximum above 5°C | 3091.94 | 263.97 | **CCB** | 3175.33 | 1.03 | 0.44 |
| | | | | **CCR2** | 3167.67 | | |
| | | | | **CCR3** | 2780.00 | | |
| | | | | **N** | 3104.33 | | |
| | | | | **WCB** | 3155.00 | | |
| | | | | **WCR** | 3169.33 | | |
| | Hours for minimum below 5°C | 396.83 | 67.08 | **CCB** | 349.00 | 2.52 | 0.08 |
| | | | | **CCR2** | 408.67 | | |
| | | | | **CCR3** | 350.00 | | |
| | | | | **N** | 507.00 | | |
| | | | | **WCB** | 413.00 | | |
| | | | | **WCR** | 353.33 | | |
| | Hours for minimum below 0°C | 33.66 | 14.56 | **CCB** | 22.00 | 2.37 | 0.10 |
| | | | | **CCR2** | 30.67 | | |
| | | | | **CCR3** | 32.00 | | |
| | | | | **N** | 55.00 | | |
| | | | | **WCB** | 41.67 | | |
| | | | | **WCR** | 20.67 | | |
| | Hours for minimum below -4°C | 0 | 0 | **CCB** | 0.00 | - | - |
| | | | | **CCR2** | 0.00 | | |
| | | | | **CCR3** | 0.00 | | |
| | | | | **N** | 0.00 | | |
| | | | | **WCB** | 0.00 | | |
| | | | | **WCR** | 0.00 | | |
| **Planned Contrasts Hours for maximum above 5°C (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.01 | 0.93 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.82 | 0.38 |
| Woody Control vs. Complete Control | | | | | | 0.76 | 0.40 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 3.23 | 0.09 |
| Interaction | | | | | | 0.99 | 0.34 |
| **Planned Contrasts Hours for minimum below 5°C (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 9.71 | 0.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.09 | 0.77 |
| Woody Control vs. Complete Control | | | | | | 0.16 | 0.70 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 1.15 | 0.30 |
| Interaction | | | | | | 1.24 | 0.28 |
| **Planned Contrasts Hours for minimum below 0°C (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 7.73 | 0.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 0.28 | 0.60 |
| Woody Control vs. Complete Control | | | | | | 0.15 | 0.70 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 0.01 | 0.91 |
| Interaction | | | | | | 3.07 | 0.10 |

Table 3.7. Statistical results for soil temperature at 20 cm depth during the growing seasons of 2004 (May 08 – September 29) and 2005 (May 03 – September 19).
CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|---|
| **Soil Temp 20 cm depth 2004 (hours)** | Hours for maximum above 5°C | 3259.72 | 54.16 | **CCB** | 3234.67 | 0.83 | 0.52 |
| | | | | **CCR** | 3269.17 | | |
| | | | | **N** | 3284.33 | | |
| | | | | **WCB** | 3221.67 | | |
| | | | | **WCR** | 3279.33 | | |
| **Planned Contrasts Hours for maximum above 5°C (2004)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 0.92 | 0.35 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 2.48 | 0.13 |
| Woody Control vs. Complete Control | | | | | | 0.00 | 0.96 |
| Interaction | | | | | | 0.16 | 0.69 |
| **Soil Temp 20 cm depth 2005 (hours)** | Hours for maximum above 5°C | 3174.77 | 57.55 | **CCB** | 3115.33 | 4.38 | 0.01 |
| | | | | **CCR2** | 3228.33 | | |
| | | | | **CCR3** | 3241.00 | | |
| | | | | **N** | 3215.33 | | |
| | | | | **WCB** | 3066.67 | | |
| | | | | **WCR** | 3182.00 | | |
| **Planned Contrasts Hours for maximum above 5°C (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 1.79 | 0.20 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 17.29 | 0.01 |
| Woody Control vs. Complete Control | | | | | | 5.41 | 0.03 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 0.07 | 0.79 |
| Interaction | | | | | | 0.98 | 0.34 |
| **No of days to pass 5°C 2005 (days)** | | 3.77 | 3.24 | **CCB** | 5.00 | 1.96 | 0.15 |
| | | | | **CCR2** | 1.00 | | |
| | | | | **CCR3** | 2.67 | | |
| | | | | **N** | 2.00 | | |
| | | | | **WCB** | 8.33 | | |
| | | | | **WCR** | 3.67 | | |
| **Planned Contrasts No of days to pass 5°C (2005)** | | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | | 1.08 | 0.31 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | | 6.11 | 0.02 |
| Woody Control vs. Complete Control | | | | | | 3.32 | 0.09 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | | 0.40 | 0.54 |
| Interaction | | | | | | 0.04 | 0.84 |

Table 3.8. Statistical results for nitrogen found in leaves (aspen, tall shrubs (> 1.5 m), low shrubs (< 1.5 m), herbs, grasses, sedges and rushes, *Calamagrostis canadensis,* and, other deciduous) (N2004) in the growing season of 2004 (May 08 – September 29).

CCR – Radial Complete Control; N – No Treatment (Untreated); WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **N2004 ($g/m^2$)** | 3.27 | 4.67 | **CCR** | 2.65 | 2.41 | 0.14 |
| | | | **N** | 3.95 | | |
| | | | **WCB** | 2.73 | | |
| | | | **WCR** | 3.73 | | |
| **Planned Contrasts N2004** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 3.35 | 0.10 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0.75 | 0.41 |
| Woody Control vs. Complete Control | | | | | 1.20 | 0.30 |
| Interaction | | | | | 0.75 | 0.41 |

Table 3.9. Statistical results for soil nitrogen availability during the growing season of 2005 (May 03 – September 19).

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **N2005 ($\mu g/10cm^2/year$)** | 91.25 | 45.47 | **CCB** | 311.66 | 9.73 | 0.01 |
| | | | **CCR2** | 83.00 | | |
| | | | **CCR3** | 61.50 | | |
| | | | **N** | 29.33 | | |
| | | | **WCB** | 50.67 | | |
| | | | **WCR** | 38.75 | | |
| **Planned Contrasts N2005** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 4.45 | 0.05 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 15.3 | 0.01 |
| Woody Control vs. Complete Control | | | | | 12.8 | 0.01 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 0.22 | 0.64 |
| Interaction | | | | | 13.47 | 0.01 |

Table 3.10. Statistical results for light (DIFN) in the midsummer of 2004 (July 20) and 2005 (July 28).

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **Light (DIFN) 2004 (fraction)** | 0.49 | 0.18 | **CCB** | 0.71 | 63.85 | <.01 |
| | | | **CCR** | 0.73 | | |
| | | | **N** | 0.11 | | |
| | | | **WCB** | 0.30 | | |
| | | | **WCR** | 0.37 | | |
| **Planned Contrasts Light (DIFN) (2004)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 100.66 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 1.69 | 0.19 |
| Woody Control vs. Complete Control | | | | | 121.38 | <.01 |
| Interaction | | | | | 0.39 | 0.5 |
| **Light (DIFN) 2005 (fraction)** | 0.51 | 0.13 | **CCB** | 0.89 | 141.06 | <.01 |
| | | | **CCR2** | 0.64 | | |
| | | | **CCR3** | 0.81 | | |
| | | | **N** | 0.16 | | |
| | | | **WCB** | 0.21 | | |
| | | | **WCR** | 0.37 | | |
| **Planned Contrasts Light (DIFN) (2005)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 211.04 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 5.07 | 0.02 |
| Woody Control vs. Complete Control | | | | | 447.74 | <.01 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 21.01 | <.01 |
| Interaction | | | | | 11.18 | 0.01 |

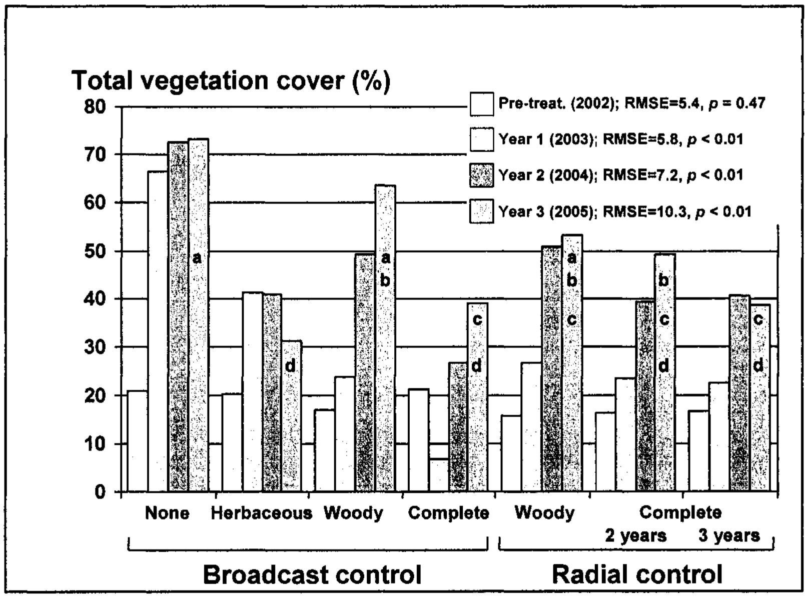



Figure 3.1. Total vegetation cover over time on the site. Treatments are grouped as *reference* [broadcast control = none ($n$=6); herbaceous-only ($n$=3); woody-only ($n$=3); and complete ($n$=3)] and *response-surface* [radial = woody-only ($n$=9) and complete 2 years ($n$=7) or 3 years ($n$=9). Means with the same letter do not differ in year 3 ($\alpha$=0.05, Tukey's HSD) (from Pitt et al. 2006).

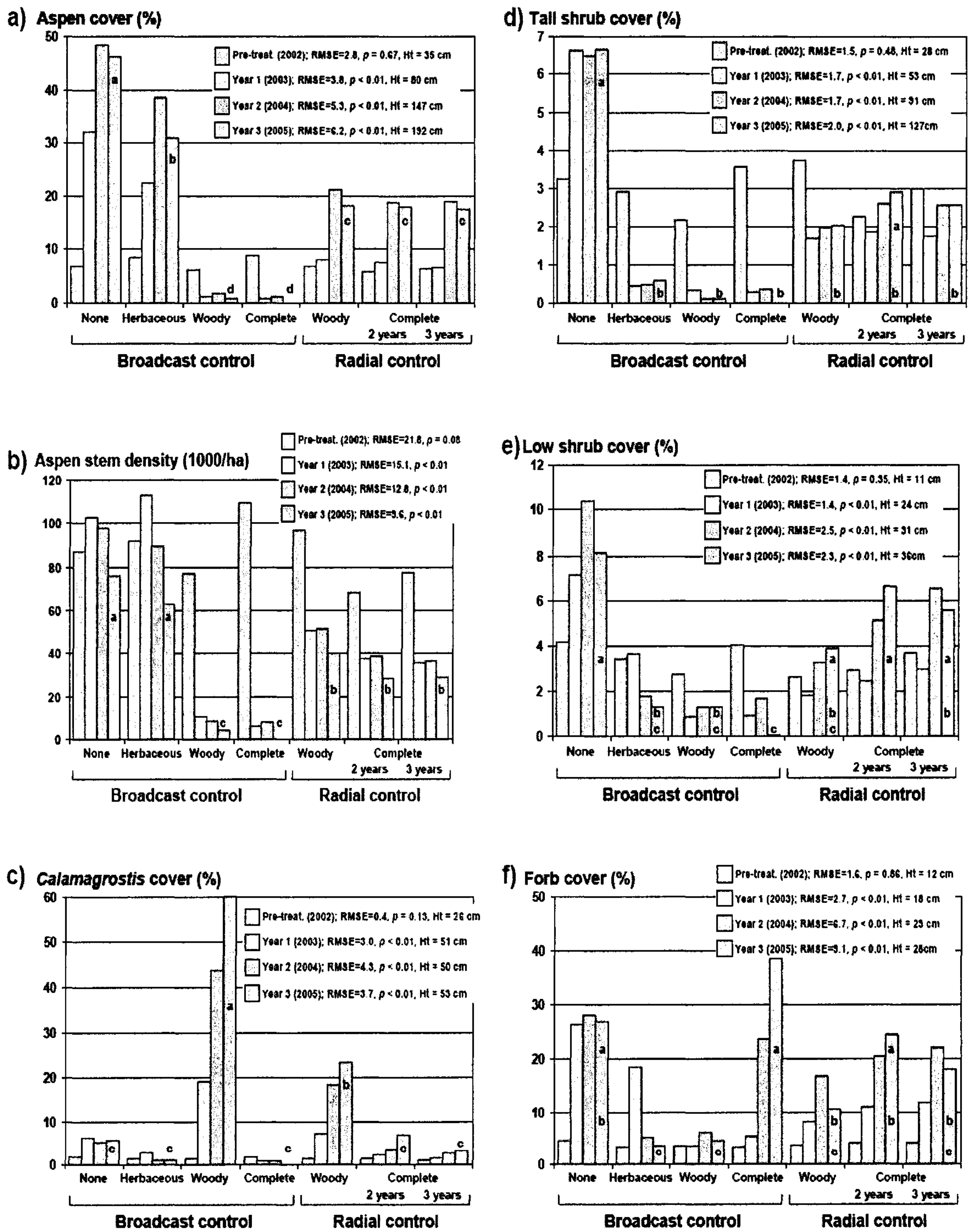



Figure 3.2. Vegetation cover for major vegetation groups over time on the AB site.
Treatments are grouped as *reference* [broadcast control = none ($n$=6); herbaceous-only ($n$=3); woody-only ($n$=3); and complete ($n$=3)] and *response-surface* [radial = woody-only ($n$=9) and complete 2 years ($n$=7) or 3 years ($n$=9). Means with the same letter do not differ in year 3 ($\alpha$=0.05, Tukey's HSD). (from Pitt et. al. 2006).

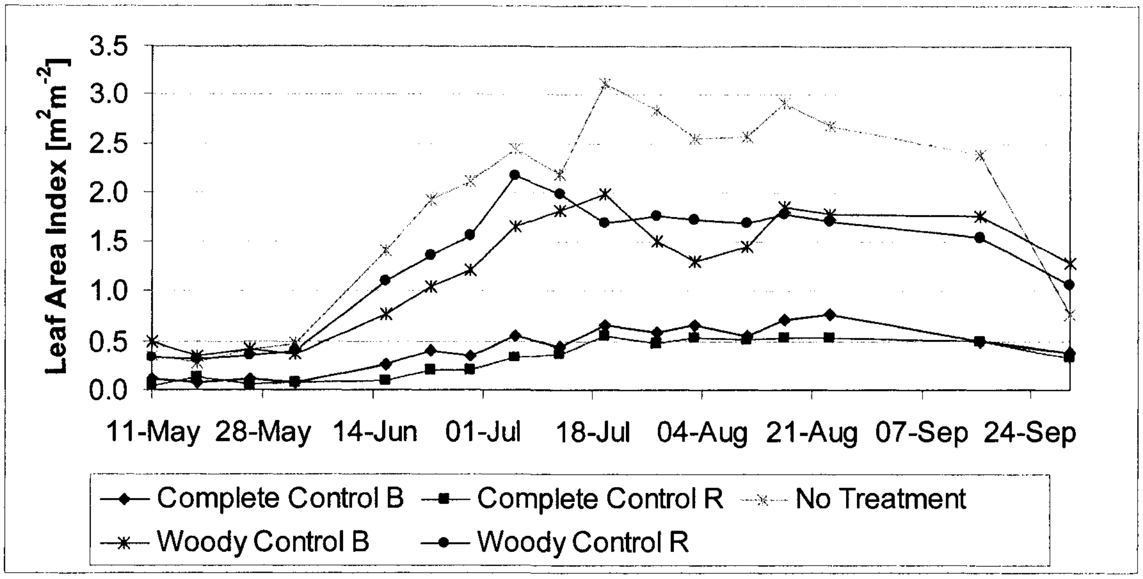



Figure 3.3. Leaf Area Index seasonal trends from May11 – September 30, 2004. R – Radial; B – Broadcast.

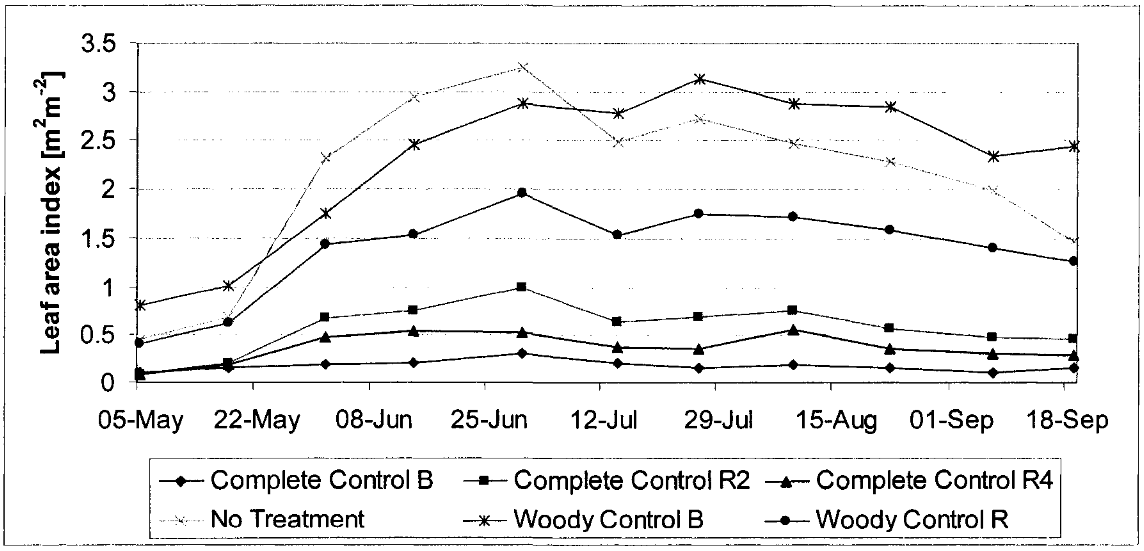



Figure 3.4. Leaf Area Index seasonal trends from May 05 – September 19, 2005. R2 – radial 2 years control; R4 – radial 3 years control; B – broadcast.

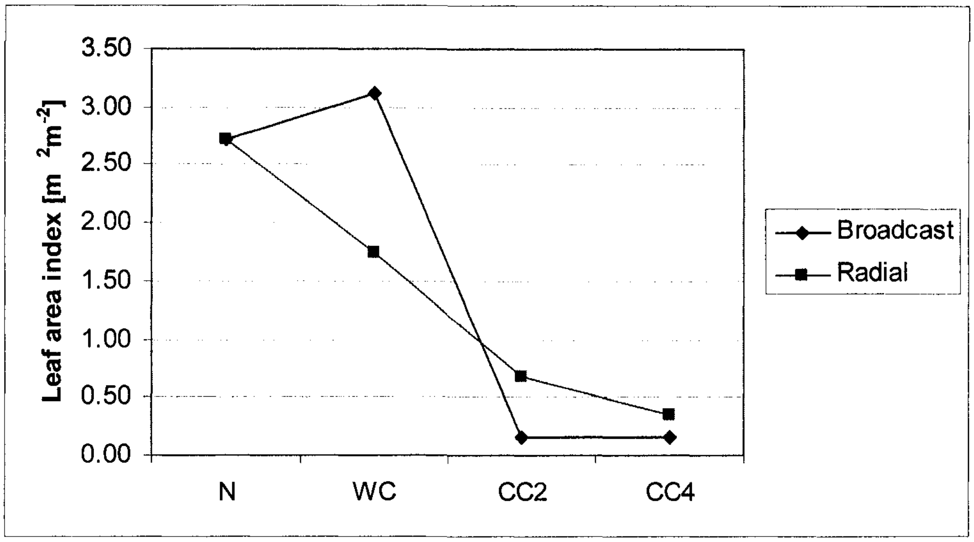



Figure 3.5. Leaf Area Index interaction in July 28, 2005. N – No treatment; WC – Woody Control; CC2 – Complete control 2 years; CC4 – Complete Control 3 years.

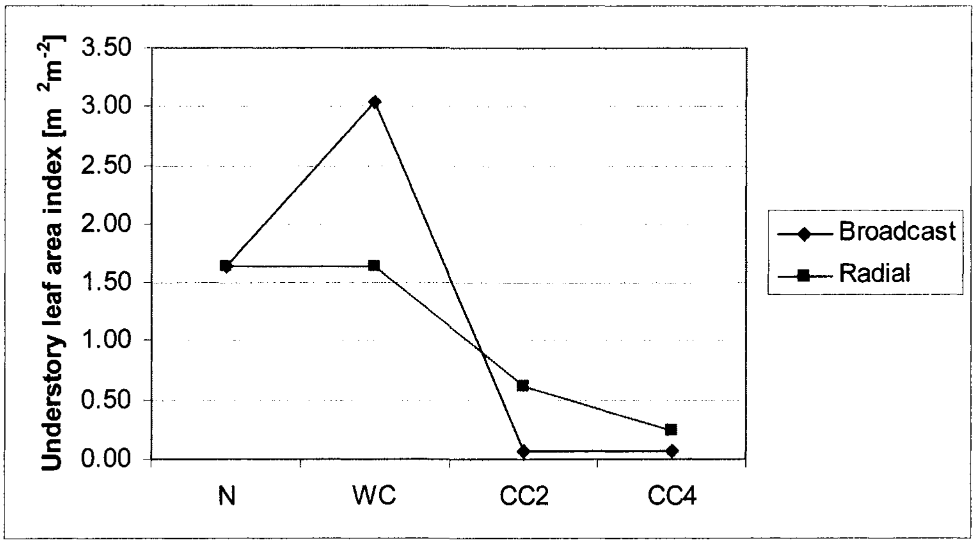



Figure 3.6. Understory Leaf Area Index interaction in July 28, 2005. N – No treatment; WC – Woody Control; CC2 – Complete control 2 years; CC4 – Complete Control 3 years.

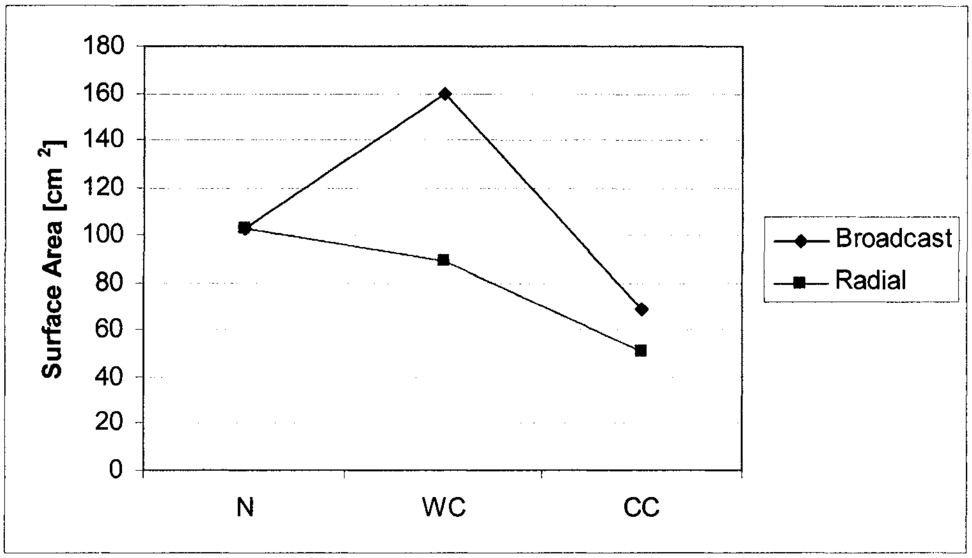



Figure 3.7. Root surface area interaction in 2004. N – No treatment; WC – Woody Control; CC – Complete control.

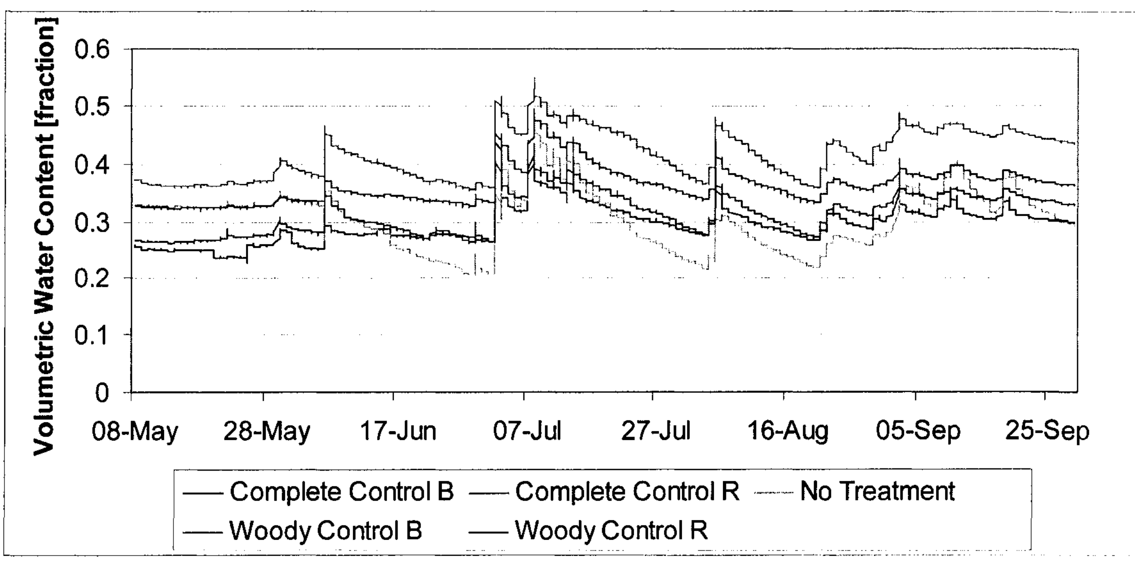



Figure 3.8. Trends for volumetric water content (VWC) during the growing season of 2004 (May 08 – September 29). R – Radial; B – Broadcast.

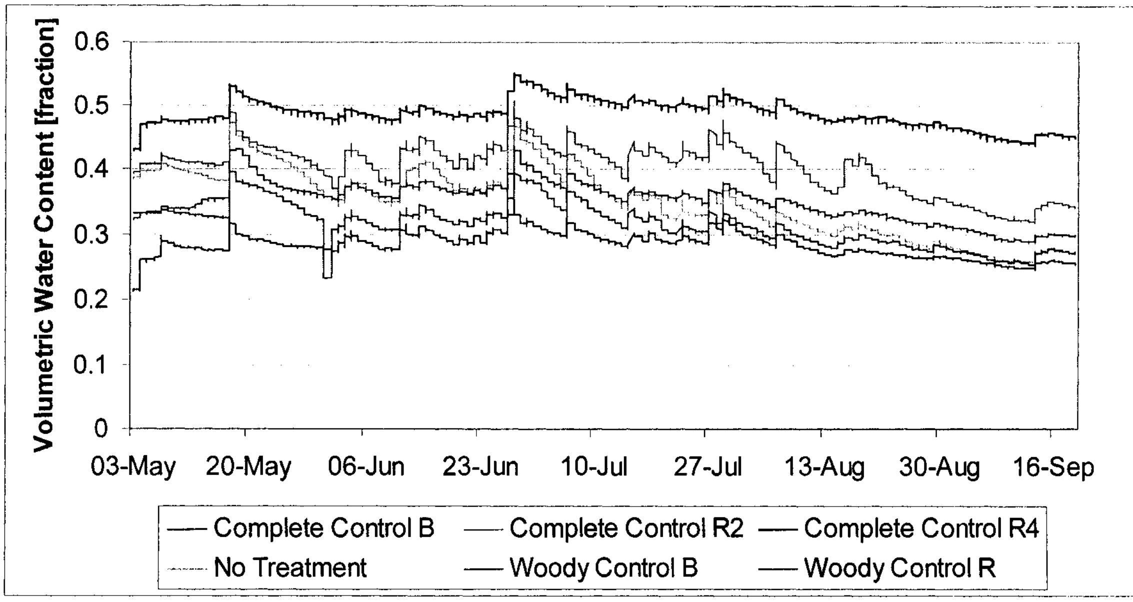



Figure 3.9. Trends for volumetric water content (VWC) during the growing season of 2005 (May 03 – September 19). R2 – radial 2 years control; R4 – radial 3 years control; B – broadcast

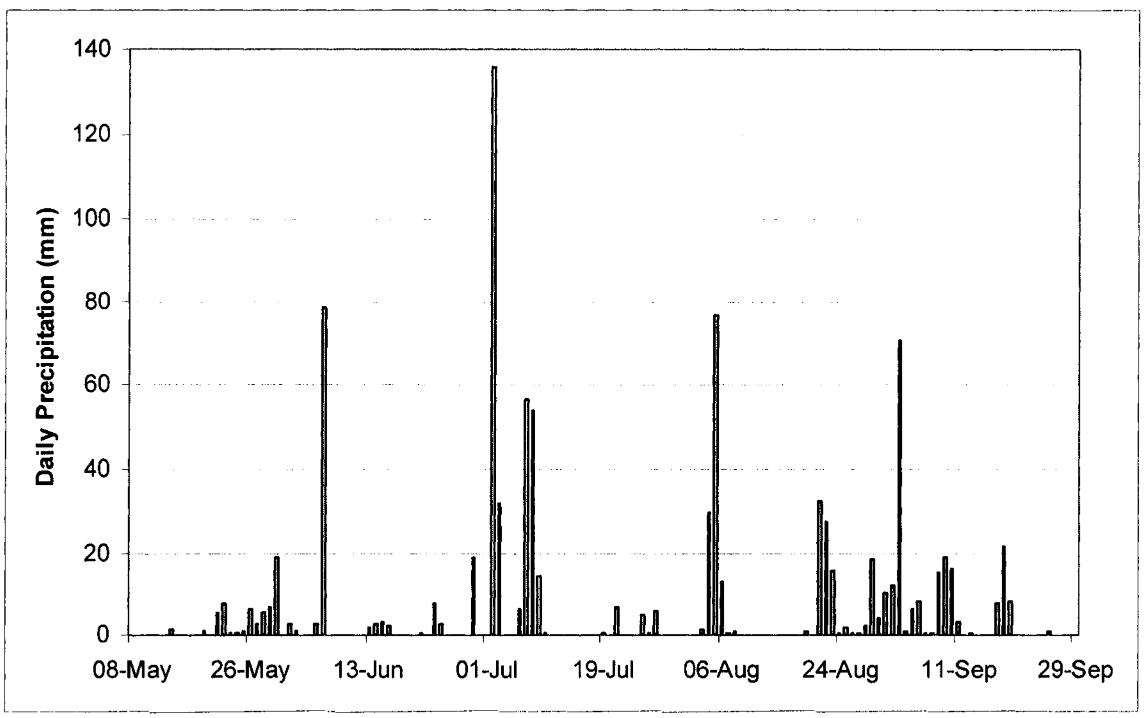



Figure 3.10. Daily precipitation during the growing season of 2004 (May 08 – September 29).

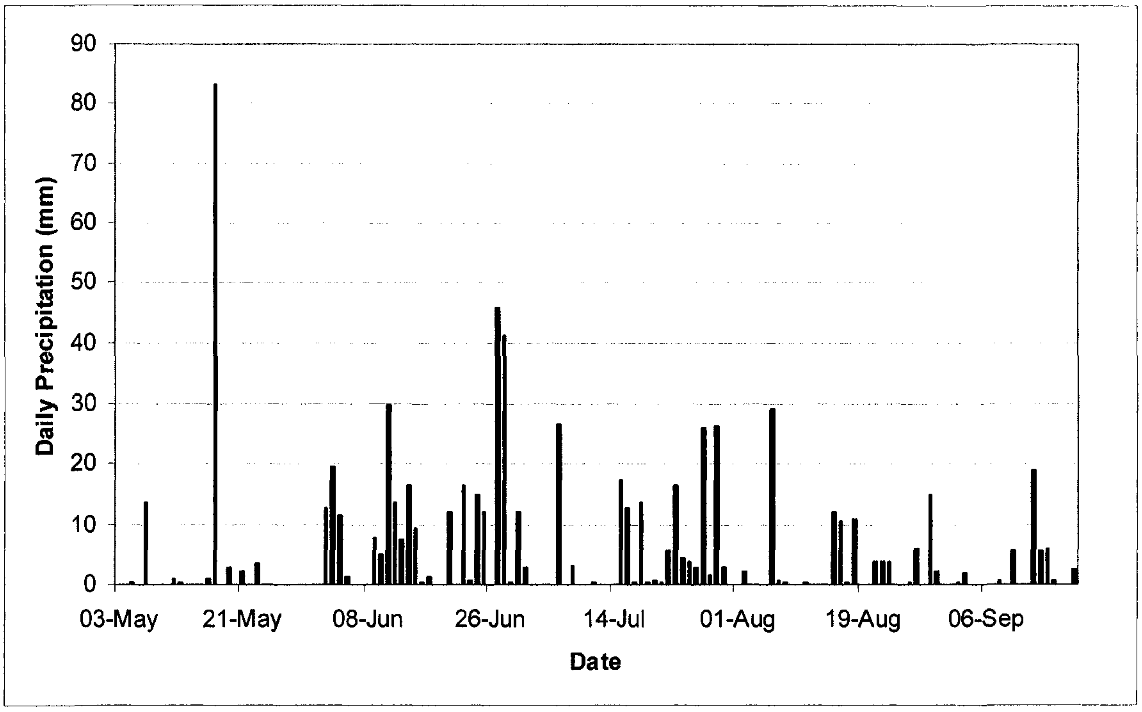



Figure 3.11. Daily precipitation during the growing season of 2005 (May 03 – September 19).

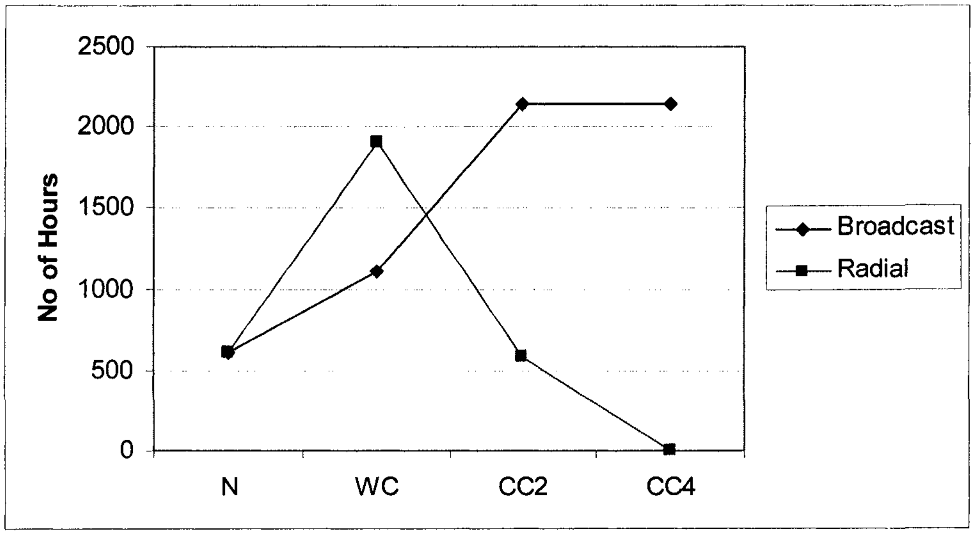



Figure 3.12. Volumetric water content (hours below 30%) interaction in 2005. N – No treatment; WC – Woody control; CC2 – Complete control 2 years; CC4 – Complete Control 3 years.

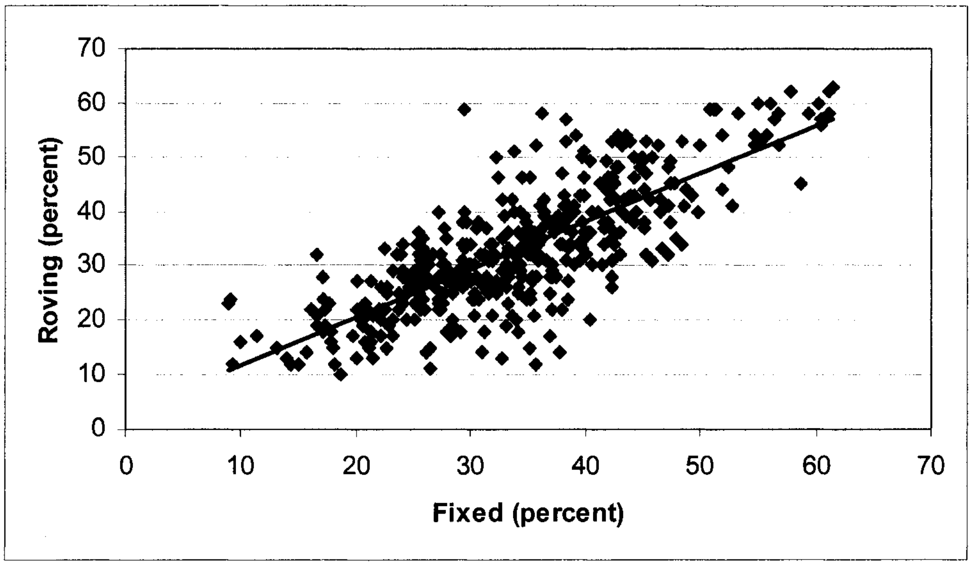



Figure 3.13a. Correlation between roving (Hydrosense TDR) and fixed (CS616) volumetric water content sensors in the growing season of 2004 (May 08 – September 29). The line showed is described by the equation: $Roving = 0.8803 \cdot Fixed + 2.9325$. $r$ = 0.7822, $n$ = 288.

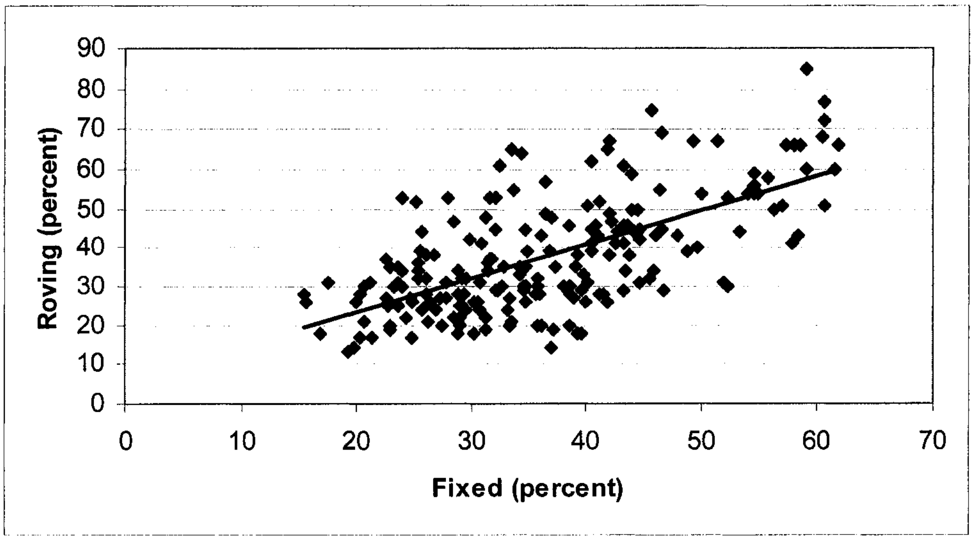



Figure 3.13b. Correlation between roving (Hydrosense TDR) and fixed (CS616) volumetric water content sensors in the growing season of 2005 (May 03 – September 19). The line showed is described by the equation: $Roving = 0.8753 \cdot Fixed + 5.8035$. $r$ = 0.6531, $n$ = 208.

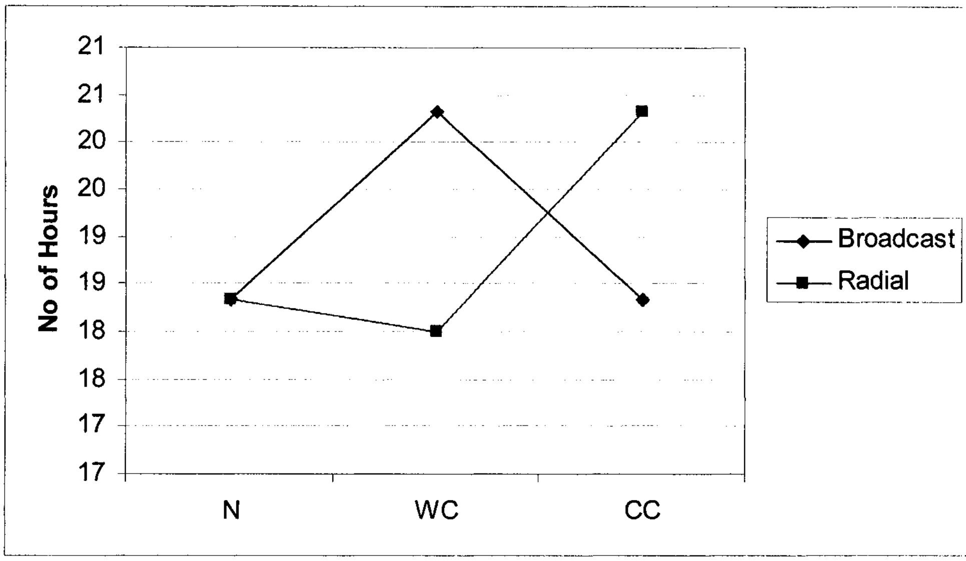



Figure 3.14. Hours for minimum below -4°C interaction in 2004. N – No treatment; WC – Woody control; CC – Complete control.

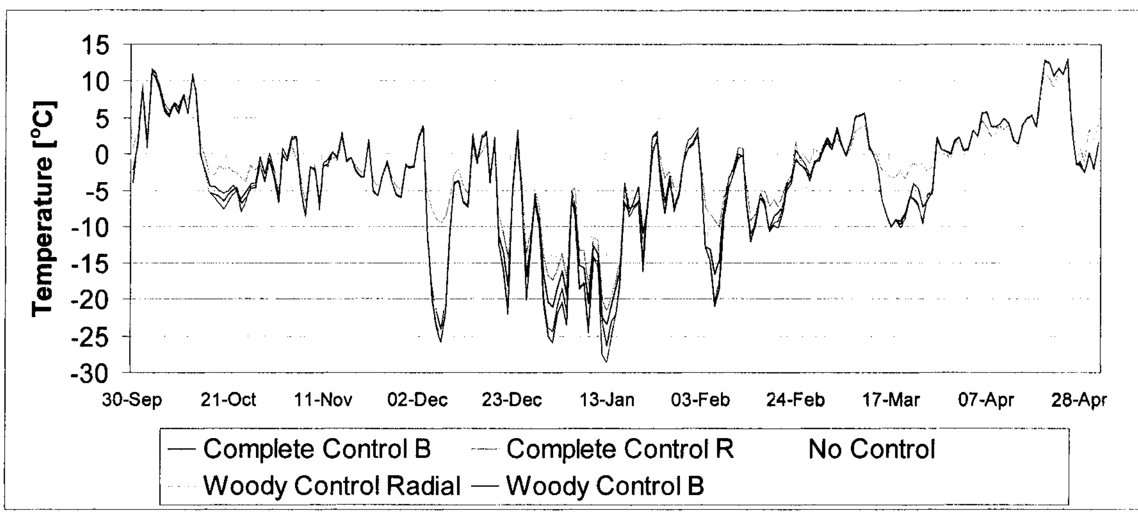



Figure 3.15. Trends for air temperature at 30 cm height during the 2004/2005 winter (September 30, 2004 to May 02, 2005). B – broadcast; R – radial.

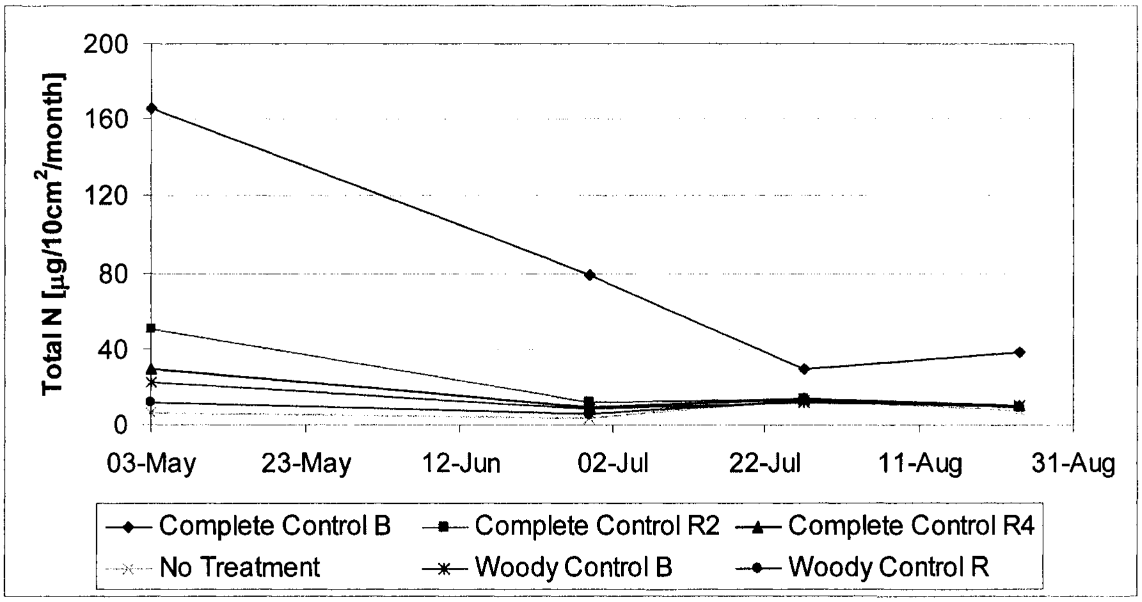



Figure 3.16. Trends for soil nitrogen availability during the growing season of 2005 (May 03 – September 19). B – Broadcast; R2 – Radial 2 years; R4 – Radial 3 years.

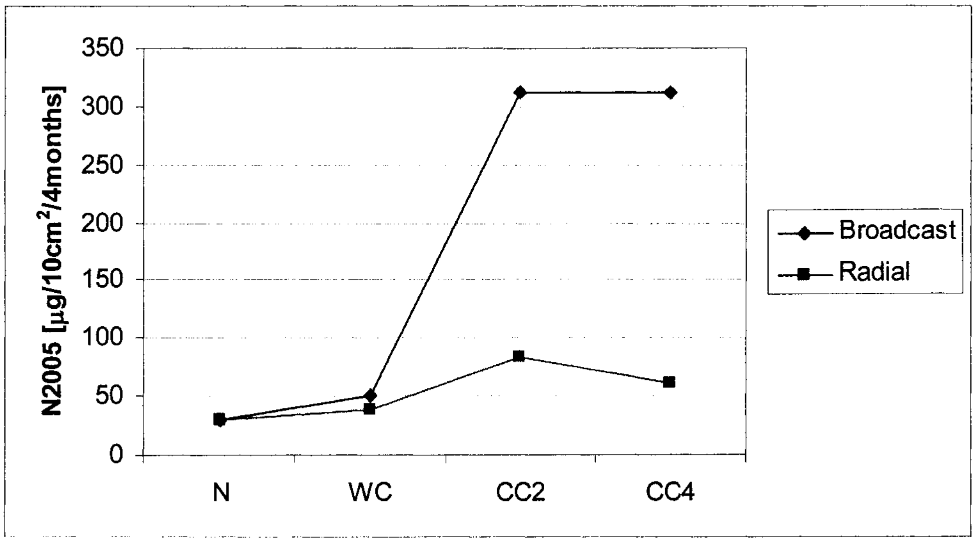



Figure 3.17. Soil nitrogen availability (N2005) interaction during the growing season of 2005 (May 03 – September 19). N – No treatment; WC – Woody control; CC2 – Complete control 2 years; CC4 – Complete control 3 years.

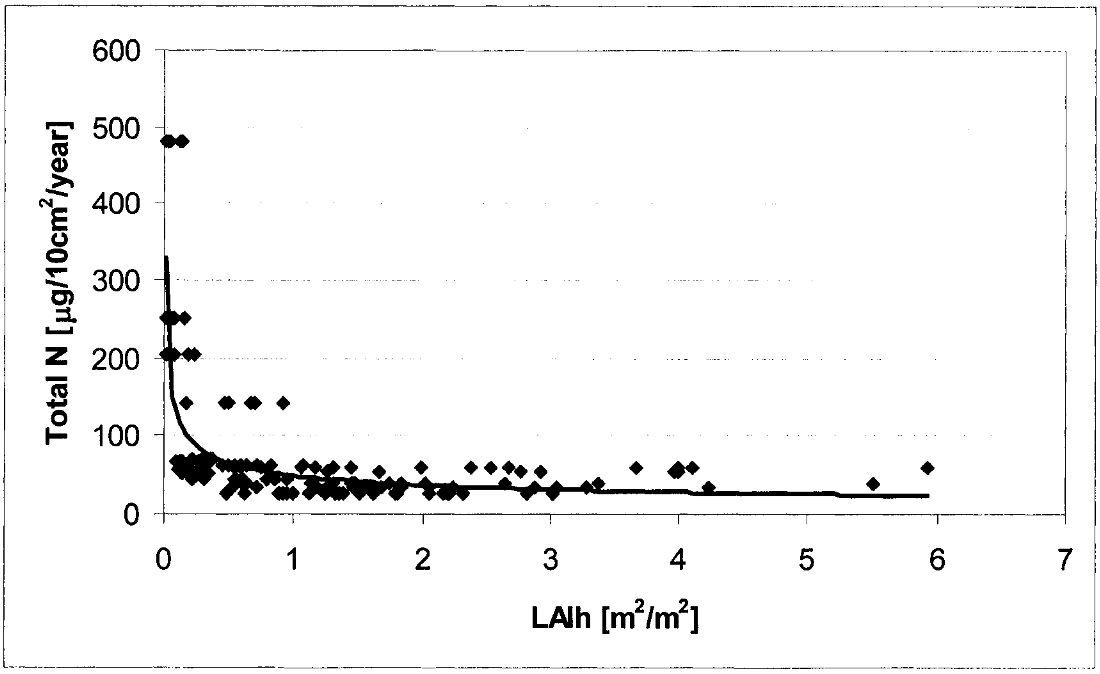



Figure 3.18. Relationship between herbaceous vegetation Leaf Area Index (LAIh) and total nitrogen availability in 2005. The line shows the relationship described by the equation: $N = 80.3618 \cdot LAIo^{0.1543} \cdot LAIh^{-0.4521}$, N – nitrogen availability, LAIo – overstory LAI, LAIh – herbaceous vegetation LAI. $\mathbf{R^2 = 0.7164}$, RMSE = 77.3770, $n$ = 148. For the line shown, LAIo = 0.26 m²/m² (average value).

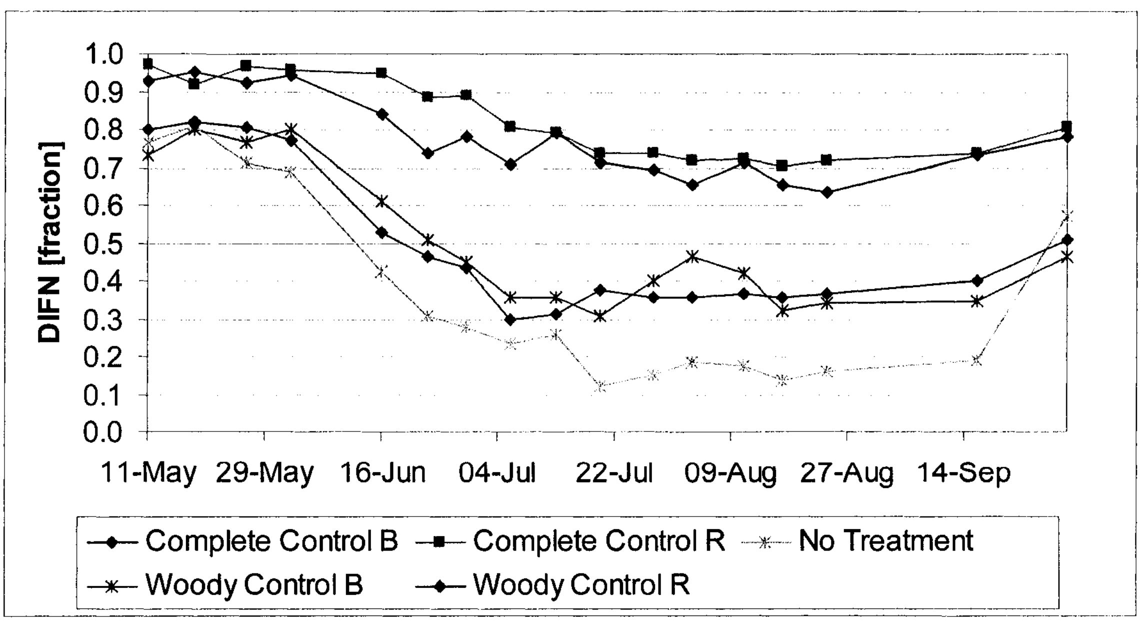



Figure 3.19. Light (DIFN) seasonal trends during the growing season of 2004 (May 08 – September 29). B – Broadcast; R – Radial.

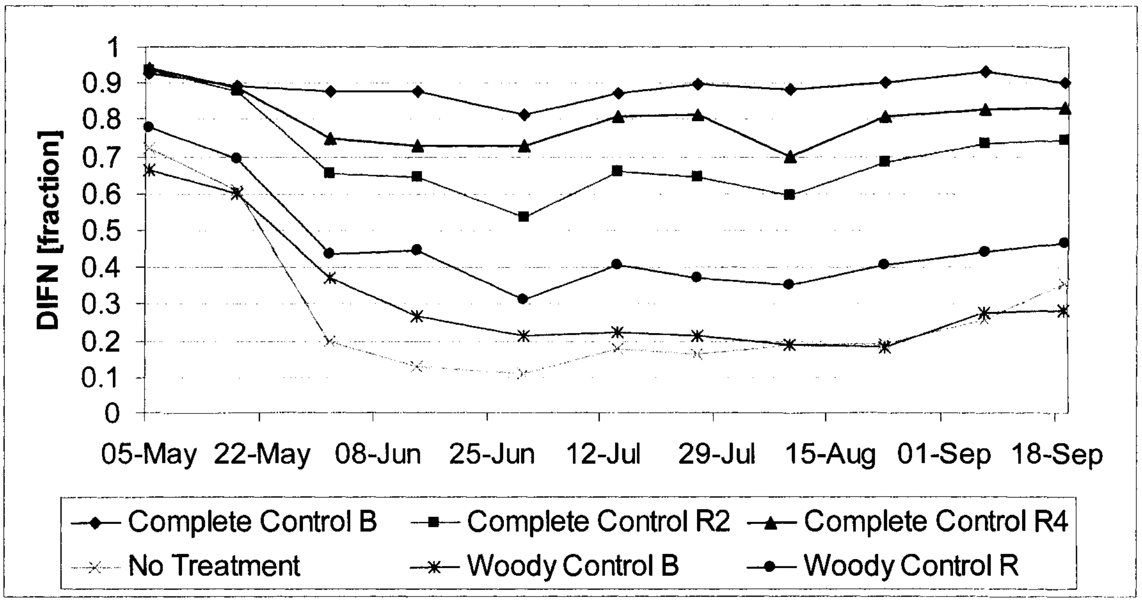



Figure 3.20. Light (DIFN) seasonal trends during the growing season of 2005 (May 03 – September 19). B – Broadcast; R2 – radial 2 years control; R4 – radial 3 years control.

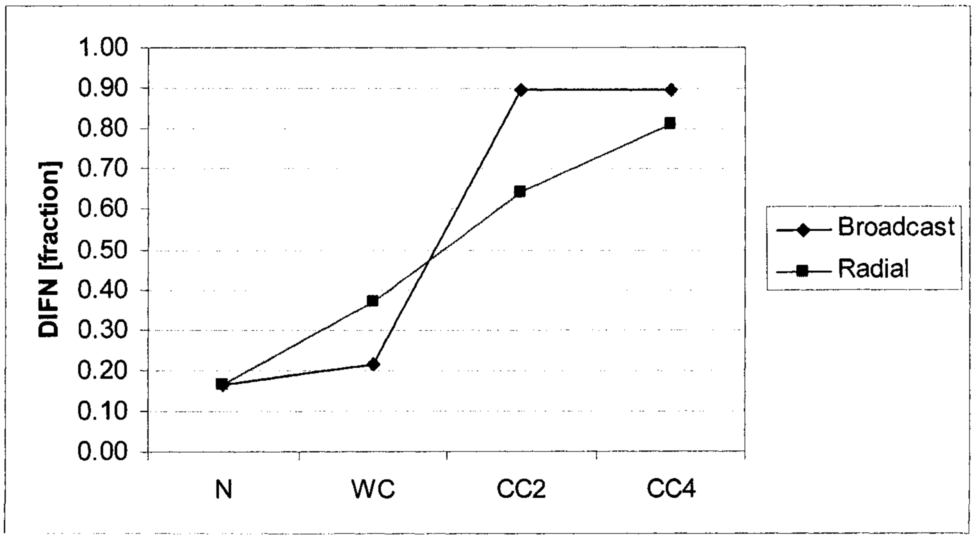



Figure 3.21. Light (DIFN) interaction in midsummer of 2005 (July 28). N – No treatment; WC – Woody control; CC2 – Complete control 2 years; CC4 – Complete control 3 years.

# Chapter 4. Spruce seedling growth

In this chapter, results from measurement of spruce seedling growth responses to treatments applied in this study are presented and discussed. Response variables measured include root collar diameter, height, stem volume index, HDR (height to diameter ratio), and relationships between spruce growth and resource availability.

## 4.1. Root collar diameter (RCD) increment

The seasonal trend of root collar diameter (RCD) growth in 2004 (Figures 4.1 and 4.2.) suggests a relatively continuous rate of growth throughout the summer, with a large increase during the first half of July. It appears that diameter growth ceased by the end of September. Statistical analysis (Table 4.1) showed that vegetation treatments increased the size of RCD ($p<0.01$), with a mean growth increment throughout 2004 of 2.7 mm. The planned contrasts showed that the untreated situation doesn't allow for very rapid growth at young stages ($p<0.01$). It appears that removal of all vegetation had a more positive effect on seedling growth than removal of woody vegetation only ($p<0.01$). This suggests that root collar diameter growth was highest in plots were the competitive effects of surrounding vegetation were least (i.e. complete control of vegetation, both radial and broadcast). Analysis of seasonal data (Table 4.2, and Figure 4.2) in which initial RCD was used as a covariate, showed a significant increase in RCD growth ($p<0.05$) for the following periods: 7 – 18 May, 2 June – 27 July, and 10 – 24 August 2004.

The seasonal trend of root collar diameter (RCD) growth in 2005 (Figures 4.3 and 4.4) suggests a relatively continuous rate of growth through the summer, but with high variation between the measuring times. This variability might be caused by error associated with the measurement of such small diameter seedlings, or by variation in growing conditions through the summer.

As in 2004, the highest growth rate was recorded in the complete vegetation control treatments (both broadcast and radial), and the lowest growth rates in untreated plots. It appears that the cover of vegetation in untreated plots had a strong effect on root collar diameter. Statistical results (Table 4.1) showed that the vegetation treatments increased overall RCD ($p<0.01$), with an overall growth increment of 2.0 mm per year (less than in 2004). As in 2004, planned contrasts indicated that the untreated scenario is least suitable for fast growth ($p<0.01$), while removal of all vegetation resulted in the most ($p<0.01$). No difference between 2 and 3 years of vegetation control was observed ($p=0.49$). The seasonal analysis (Table 4.2, Figure 4.4) in which initial RCD was used as a covariate, showed significant increments on RCD growth ($p<0.05$) for the following periods: 17 May – 2 June, 14 – 28 June, and 9 – 23 August 2005. This suggests, as in the previous year, three windows of opportunity for spruce seedlings to significantly increase their diameters (early May, mid-June and late August).

For the analysis of growth over the cumulative study period (2 years), the data set was reduced due to some dead trees, or trees with dead leaders found at the end of 2005 growing season. Therefore, from the total sample size of 208 trees, 200 were used in the analysis of 2004 growing season, 158 in 2005 and 178 in the analysis of growth for both growing seasons. The smaller database for 2005 can be explained by the fact that some trees had less than 0.01 mm increment, thus they were removed from the dataset.

The statistical analysis for total RCD growth over the two growing seasons (Table 4.3), revealed similar trends to those observed in 2004 and 2005; vegetation treatment effects increasing RCD ($p<0.01$). The best growth was recorded in the complete vegetation control (both broadcast and radial) treatments with no significant difference between broadcast and radial application ($p=0.44$). Diameter increment was lower in the untreated than in all other treatments ($p<0.01$). RCD increment (2004 and 2005) was also affected by the amount of vegetation controlled (woody vs. complete), with removal of only woody resulting in less growth than complete vegetation removal ($p<0.01$). However, no difference between 2 and 3 years of vegetation control has been noticed ($p=0.37$).

Multiple non-linear regressions (Figures 4.5 and 4.6) were used to examine relationships between root collar diameter (RCD) increment and leaf area index of vegetation components (overstory and understory, at this stage, being mostly represented by the herbaceous layer). Initial size of seedlings was also included in the regression model to account for variation in initial size. These equations, using LAI as the independent variables, explain approximately 50% of variation in seedling growth. T-test analysis between coefficients (Table 4.4) showed no difference in 2004, while in 2005 overstory leaf area index had a significantly ($p<0.05$) stronger negative influence on spruce growth.

Results suggest that removal of woody vegetation alone was not sufficient to release seedlings from competition and result in diameter growth responses in 2005. In 2004, cover and LAI of the grass and herb layer were lower and may not have been sufficient to counteract the benefits of woody vegetation removal. It also appears that radial treatments are beneficial for spruce seedlings growth in terms of root collar diameter.

### 4.2. Height increment

During 2004 height increment occurred during a 4 week period, beginning in mid-June (Figures 4.7 and 4.8). The best growth was realized in complete control treatment (both radial and broadcast) and untreated (no treatment) plots, but the trends for all treatments follow the same pattern, with lowest increment occurring in the woody control treatment. The statistical analysis (Table 4.5) showed an overall increase in height ($p$<0.01), with an average increment for 2004 of 7.6 cm/year. The planned contrasts showed that the amount of vegetation controlled (woody vs. herbaceous) had an impact on height increment in 2004 ($p$<0.01), while the area of application (radial vs. broadcast) didn't have any effect ($p$=0.65). Height increment, however, was higher in complete control than in the woody control in 2004.

Due to the winter injury damage during the winter of 2004/2005 (see chapter 3, air temperature), and other adverse effects, the spruce seedlings affected by this were removed from the analysis of height. Therefore, for the 2005 growing season, only healthy trees were used for height growth analysis.

Seasonal trends in height growth for 2005 (Figures 4.9 and 4.10) are similar to those for 2004, with an actual increment during a 4 week period beginning in late May (3 weeks earlier than in 2004). The best rate in height growth was realised in complete control treatment (both broadcast and radial) plots, but the trends for all treatments followed the same pattern, with lowest increment occurring in the woody control treatment (radial). The statistical results (Table 4.5) showed that height increment wasn't affected by vegetation treatment application in 2005 ($p$=0.44), the average of height increment being 9.9 cm/year (higher than in previous year). The least square means, showed that lowest increment was recorded in the untreated (no treatment), while woody control treatment realised almost the same heights as the complete control treatment. The planned contrasts suggested that treatment had no effect on spruce height increment in 2005 ($p$>0.05). In addition, 2 or 3 years of vegetation control didn't make a difference in the 3$^{rd}$ growing season ($p$=0.73).

Statistical analysis (Table 4.6) of cumulative growth (for entire 2-year study period) showed an overall increase in height ($p$=0.01) with an average height increment over a 2 year period of 16.4 cm. The planned contrasts suggested that the *type* of the vegetation controlled (woody vs. complete) had a greater impact on height increment, than the *method* of application (radial vs. broadcast), but both were statistically non-significant ($p$>0.05). The interaction (Figure 4.11) ($p$ = 0.01) suggested that height increment was dependant both on *type* of vegetation controlled and *method* of treatment application, the most suitable scenario being complete control radial treatment. Possible relationships between height and leaf area index or light (DIFN) were explored without success ($r<0.1$, $p>0.05$). However, the analysis revealed the fact that herbaceous layer has a slightly stronger potential affect on height increment. After 3 growing seasons, no differences were detected between 2 and 3 years of vegetation control ($p=0.72$).

Analysis of these height increment data indicate that removal of the woody vegetation, without control of the grass and forb layer, may result in reduced height growth of planted spruce, at least during the early establishment years. However, non-lethal injuries to buds, needles and other plant tissues due to winter injury may have resulted in growth reductions, or had other impacts on seedling performance that cannot be isolated from the effects of other factors.

### 4.3. Volume increment

As noted in section 4.1, for the analysis of volume increment, some trees were removed from the data set since they were either dead at the end of the growing season, or had the leader dead, due mostly to the 2004/2005 winter injury. Therefore, for the analysis of growth for both seasons, only 5 trees per plot were used, the total number of observations used being 115.

Statistical results of volume index (assuming cylindrical form) (Table 4.7) showed an overall increase in volume due to treatment application ($p<0.05$) in both 2004 and 2005 growing seasons. In 2004, the lowest increase in volume was recorded in untreated scenario, while in 2005 this effect disappeared, probably due to the fact that RCD increment was reduced overall in favour of height. However, for both years planned contrasts showed greater increments in case of complete vegetation control, compared with only woody vegetation control($p<0.05$). At this stage, 2 or 3 years of vegetation control had same effect on volume variation ($p=0.24$). Since the amount of vegetation present on the site (or controlled) had an impact on RCD and height increment, finding similar treatment effects on volume is not surprising.

Over a 2 year period (the study period) the statistical results for cumulative volume growth (Table 4.8) showed an overall volume increment due to vegetation treatments ($p<0.01$), with an average increment of 4.1 $cm^3$/2 years. In addition, the planned contrasts showed differences between untreated (no treatment) and all other treatments ($p=0.03$) and between woody and complete vegetation control ($p<0.01$). This suggests that highest growth volume rate at this stage of stand development is being realized in plots where complete removal of vegetation has been performed with no difference between radial and broadcast application ($p=0.99$). Possible differences between 2 and 3 years of vegetation control weren't suggested by the analysis ($p=0.30$).

As in the case of RCD, a multiple non-linear regression (Figures 4.12 and 4.13) was fit between volume increment, and leaf area index of vegetation components (overstory and understory – at this stage being mostly represented by the herbaceous layer). Initial size of seedlings has also been used in the regressions to account for the variation in initial size of these seedlings. These equations, using LAI as the independent variables, explain approximately 40% of variation in seedling growth. Only in 2005, overstory leaf area index had a stronger negative effect on volume increment variation, than understory (herbaceous) leaf area index (Table 4.4).

Results from analysis of volume increment suggest that a 2 m radius treatment is sufficient for spruce seedlings to grow at reasonable levels, at least for the first 3 growing seasons.

### 4.4. Height to diameter ratio

Statistical results for HDR (height to diameter ratio) (Table 4.9) showed a decrease due to treatment application ($p<0.01$) in both 2004 and 2005 growing seasons. Planned contrasts showed differences between no treatment and all other treatments and between woody and complete vegetation control ($p<0.05$), for both 2004 and 2005 growing seasons. HDR was higher in the no treatment than treated, and in the woody control compared to the complete control in both years (51.9 in 2004 and 60.6 in 2005). In the 3$^{rd}$ growing season, differences between 2 and 3 years of vegetation control weren't suggested by the analysis ($p=0.51$). This suggests that the amount of vegetation present on the site (or left after treatment application) has an influence on slenderness of trees, and on growth allocation between diameter and height increment of spruce seedlings.

A multiple non-linear regression was fit between HDR and leaf area index of vegetation components in 2004 (Figure 4.14), and in 2005 (Figure 4.15), using initial height as initial measurement of a seedling's growth. This suggested that approximately half of the variation of HDR is explained by variation of leaf area index of vegetation components during the growing season. The impact of leaf area index appears to increase with increasing vegetation, since in 2005, the coefficient of determination (0.6580) was higher than in 2004 (0.4650). However, for both growing seasons t-tests (Table 4.4) did not show differences between vegetation components (overstory vs. understory).

Another multiple non-linear regression was fit between HDR and light (DIFN) (Figure 4.16), using initial height as initial measurement of a seedling's growth. This regression explains approximately half of the variation of HDR, with a stronger relationship obtained in 2005 than in 2004 ($R^2$=0.4014 in 2004, compared with $R^2$=0.6725 in 2005).

Inclusion of other variables (i.e., soil heat sum and volumetric water content) was tested, but these did not increase $R^2$ values. Soil nitrogen availability in 2005 was not included in the model, since as shown in chapter 3, it was strongly related with leaf area index of vegetation components.

## 4.5. Discussion

All growth variables analyzed (RCD, height, and volume increment, and HDR) were influenced by the application of treatments. The highest growth rate was realized when trees were maintained entirely free of competition, as suggested by Wagner et al. (1999). The use of site preparation and application of treatments described in Chapter 2, resulted in an increase in spruce seedling growth, as has also been observed in several other several studies (Lees 1966, Biring et al. 1999, Biring and Hays-Byl 2000, Jobidon 2000). The factor that most affected growth was the increase in the leaf area index of competing vegetation, and thus reduced availability of light (Lees 1966, Yang 1991, Morris and MacDonald 1991, MacIsaac and Navratil 1996). Light levels below 10-15% (Eis 1981; Carter and Klinka 1992; Coates et al. 1994; Lieffers and Stadt 1994; Chen 1997) are known to severely limit spruce growth, in some cases even leading to death. Regression models using leaf area index of vegetation components and light (DIFN) as independent variables explained approximately half of the variation in spruce growth during the first 3 years after establishment. However, only in 2005 did vegetation components have different effects on growth variables analyzed, with overstory having a stronger negative influence than understory.

Vegetation management impacts on growth of crop species has been documented all over the world (e.g. Miller et al. 1991, Lauer et al. 1993, Richardson 1993, Stein 1995, Mason and Milne 1999, Bell et al. 2000, Biring et al. 2003, Miller et al. 2003a, b, Harper et al. 2005, Rose and Rosner 2005, Balandier et al. 2006, Wagner et al. 2006). These studies suggest that controlling vegetation at early stages can significantly improve the growth of crop tree seedlings. Several studies also indicate that herbaceous vegetation can be very competitive in young plantations and that it is sometimes more competitive than woody vegetation during the first few years after planting (Miller et al. 1991, Richardson 1993, Rose et al. 1999, Bell et al. 2000, Miller et al. 2003, Pitt and Bell 2005). Stem diameter growth is generally more sensitive to competition and treatments that reduce competition than height (Miller et al. 1991, Bell et al. 2000). The results of the present study are consistent with the above statements, showing significant improvements in RCD, height and volume increments, 3 years after establishment, with significant differences between treatments, but not between years (2 vs. 3) of vegetation control. However, over time, there may be a shift of competitiveness from the herbaceous to the woody community, as competing woody vegetation increases in size and the spruce grow taller than the grass and extend their root systems more widely (Dyrness 1973, Schonmaker and McKee 1988, Stein 1995, Miller et al. 2003).

HDR variation during study years may have been driven mostly by the available light (DIFN), and thus manipulation of LAI by the treatments applied in this study. As shown by similar studies (Cole and Newton 1987, Hughes and Tappeiner 1990, Biring et al. 2003), HDR increased in response to increasing competition.

Light, soil nitrogen availability, and soil temperature were correlated with variations in seedling growth, but volumetric water content was not (as discussed in Chapter 3). However, some studies (e.g. Petersen et al. 1988, Harper et al. 2005) found that reductions in soil moisture due to competing vegetation had a major impact on Douglas fir growth. Soil nitrogen availability was significantly influenced by treatments application, but with a minor impact on spruce growth. This contrasts with other studies (Örlander et al. 1996, Staples et al. 1999, Robinson et al. 2001, Matsushima 2005) which showed that soil nitrogen is the principal cause for reduction in growth of Norway spruce, white spruce, and jack pine seedlings, during early establishment phase. Clearly, limiting factors will vary by site.

The leaf-off periods in the spring and fall (low LAI values) provided high light in the understory (Constabel and Lieffers, 1996, Man and Lieffers, 1997), with aspen canopies transmitting more light in the fall and autumn (Hutchinson and Matt 1977, Ross et al. 1986, Uemura 1994) and thus providing potential periods for photosynthesis of understory evergreen species (Waring and Franklin 1979, Chabot and Hicks 1982, Lassoie et al. 1983, Young 1985). Understory evergreen species are able to achieve part of their annual carbon fixation during these periods of time (Emmingham and Waring 1977, Waring and Franklin 1979, Harrington et al. 1989), especially in the spring when solar irradiation due to high solar elevation is generally well above the compensation points (Man and Lieffers, 1997).Therefore, two windows of opportunity were created for significant growth of white spruce seedlings at Judy Creek (in early spring and late fall). In 2005, the spring window shifted 2 weeks earlier than in 2004, due probably to earlier warming of soil and lack of night-time frost. This study found significant treatment effects on early spring or late fall growth associated with more frequent freezing temperatures and delays in soil warming (WCB) (Lundmark and Hällgren 1987, Lundmark et al. 1988, Örlander 1993, Man and Lieffers, 1997).

In conclusion, the application of treatments had a major effect on light and soil nitrogen availability, and subsequently on increases in spruce growth. The variation in leaf area index of vegetation components can be used to explain approximately half of the increase in spruce growth, with overstory having a stronger negative effect in the 3rd growing season only. It appears that treatment effects have accumulated since site establishment in 2002. RCD and height growth of white spruce (and thus volume growth and HDR variation) are being significantly influenced by application of treatments and associated changes in resource availability and competitive effects. A 2-m radius of vegetation control around the spruce seedlings appears to offer a suitable environment for spruce growth during these first few years after establishment, but controlling vegetation for only a 2-year period may not be enough, even though my results didn't show differences between 2 and 3 years of vegetation control.

### 4.6. References

Balandier, P., Collet, C., Miller, J.H., Reynolds, P.E, and Zedaker, S.M. 2006. Deigning forest vegetation management strategies based on the mechanisms and dynamics of crop tree competition by neighbouring vegetation. Forestry 79(1): 3-27.

Bell, F.W., Ter-Mikaelian, M.T., and Wagner, R.G. 2000. Relative competitiveness of nine early-successional boreal forest species associated with planted jack pine and black spruce seedlings. Can. J. For. Res. 30: 790-800.

Biring, B.S. and W. Hays-Byl. 2000. Ten-year conifer and vegetation responses to glyphosate treatment in the SBSdw3. B.C. Ministry of Forests, Research Branch. Victoria. Extension Note 48. url: http://www.for.gov.bc.ca/hfd/pubs/Docs/En/En48.htm

Biring, B.S., Comeau, P.G., and Fielder, P. 2003. Long-term effects of vegetation control treatments for release of Englemann spruce from a mixed-shrub community in Southern British Columbia. Ann. For. Sci. 60: 681-690.

Biring, B.S., Hays-Byl, W.J. and Hoyles, S.E. 1999. Twelve-year conifer and vegetation responses to discing and glyphosate on a BWBSmw backlog site. B.C. Ministry of Forest, Research Branch, Victoria. Working Paper 43.

Carter, R.E., Klinka, K., 1992. Variation in shade tolerance of Douglas-fir, western hemlock and western redcedar in coastal British Columbia. For. Ecol. Manag. 55, 87-105.

Chabot, B.F., and Hicks, D.J. 1982. The ecology of leaf life spans. Annu. Rev. Ecol. Syst. 13: 229-259.

Chen, H.Y.H., 1997. Interspecific responses of planted seedlings to light availability in interior British Columbia: survival, growth, allometric patterns, and specific leaf area. Can. J. For. Res. 27, 1383-1393.

Coates, K.D., Haeussler, S., Linderburgh, S., Pojar, R., Stock, A.J., 1994. Ecology and Silviculture of interior spruce in British Columbia. FRDA Report 220. BC Ministry of Forestry and Forestry Canada, Victoria, BC, 182 pp.

Cole, E.C. and Newton, M. 1987. Fifth-year response of Douglas-fir to crowding and nonconiferous competition, Can. J. For. Res. 17: 181-186.

Constabel, A.J., and Lieffers, V.J. 1996. Seasonal patterns of light transmission through boreal mixedwood canopies. Can. J. For. Res. 26: 1008-1014.

Dyrness, C.T. 1073. Early stages of plant succession following logging and burning in the western Cascades of Oregon, Ecology 54: 57-69.

Eis, S. 1981. Effect of vegetative competition on regeneration of white spruce. Can. J. For. Res. 11: 1-8.

Emmingham, W.H., and Waring, R.H. 1977. An index of photosynthesis for comparing forest sites in western Oregon. Can. J. For. Res. 7: 165-174.

Harper, G.J., Comeau, P.G., and Biring, B.S. 2005.A comparison of Herbecide and Mulch Mat treatments for reducing grass, herb, and shrub competition in the BC Interior Douglas-fir zone – ten year results. WJAF 20(3): 167-176.

Harrington, R.A., Brown, B.J., and Reich, P.B. 1989. Ecophysiology of exotic and native shrubs in southern Wisconsin. Oecologia, 80: 356-367.

Hughes, T.F. and Tappeiner, J.C. 1990. Relationship of Pacific madrone sprout growth to productivity of Douglas-fir seedlings and understory vegetation. West. J. Appl. For. 5: 20-24.

Hutchinson, B.A., and Matt, D.R. 1977. The distribution of solar radiation within a deciduous forest. Ecol. Monogr. 47: 185-207.

Jobidon, R. 1992. Measurement of light transmission in young conifer plantations: a new technique for assessing herbicide efficacy. North. J. Appli. For. 9: 17-37.

Jobidon, R. 2000. Density-dependent effects of northern hardwood competition on selected environmental resources and young white spruce (*Picea glauca*) plantation growth, mineral nutrition, and stand structural development – a 5-year study. Forest Ecol. Manage. 130:77-97.

Lassoie, J.P., Dougherty, P.M., Reich, P.B., Hinckley, T.M., Metcalf, C.M., and Dina, S.J. 1983. Ecophysiological investigations of understory eastern red cedar in central Missouri. Ecology, 64: 1355-1366.

Lauer, D.K., Glover, G.R., and Gjerstad, D.H. 1993. Comparison of duration and method of herbaceous weed control on loblolly pine response through midrotation. Can J. For. Res. 23: 2116-2125.

Lees, J.C.1966.Release of white spruce from aspen competition in Alberta's spruce-aspen forest. Dept. Forest. Public. No.1163. 16 pp.

Lieffers, V.J., and Stadt, K.J. 1994. Growth of understory *Picea galuca, Calamagrostis Canadensis,* and *Epilobium angustifolium* in relation to overstory light transmission. Can. J. For. Res. 24:1193-1198.

Lundmark, T., and Hällgren, J.E. 1987. Effects of frost on shaded and exposed spruce and pine seedlings planted in the fields. Can. J. For. Res. 17: 1179-1201.

Lundmark, T., Hällgren, J.E., and Degermark, C. 1988. Effects of summer frost on the gas exchange of field-grown *Pinus sylvestris* L. seedlings. Scand. J. For. Res. 3: 441-448.

MacIsaac, D.A., and Navratil, S. 1996. Competition dynamics in juvenile boreal hardwood-conifer mixtures. In Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors).B.C. Min. For., Research Branch., Victoria. Land Manage. Handbk. 36. pp.23-34

Man, R., and Lieffers, V.J. 1997. Seasonal photosynthetic response to light and temperature in white spruce (*Picea glauca*) seedlings planted under an aspen (*Populus tremuloides*) canopy and in the open. Tree Physiology 17: 437-444.

Mason, E.G., and Milne, P.G. 1999. Effects of weed control, fertilization and soil cultivation on the growth of *Pinus radiata* at midrotation in Canterbury, New Zealand. Can. J. For. Res. 29: 985-992.

Matsushima, M. 2005. Effects of Canada bluejoint grass competition, N fertilization, and litter layer removal on soil N processes and tree growth. MSc Thesis, University of Alberta, Faculty of Graduate Studies and Research, Edmonton, Alberta.

Miller, J.H., Zutter, B.R., Newbold, R.A., Edwards, M.B., and Zedaker, S.M. 2003a. Stand dynamics and plant associates of loblolly pine plantations to midrotation after early intensive vegetation management – a Southeastern United States regional study. South. J. Appl. For. 27(4): 00-00.

Miller, J.H., Zutter, B.R., Zedaker, S.M , Edwards, M.B., and Newbold, R.A. 1991. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. South. J. Appl. For. 15: 169-179.

Miller, J.H., Zutter, B.R., Zedaker, S.M , Edwards, M.B., and Newbold, R.A. 2003b. Growth and yield relative to competition fo loblolly pine plantations to midrotation – a Southeastern United States regional study. South. J. Appl. For. 27(4): 00-00.

Morris, D.M. and MacDonald, G.B. 1991. Development of a competition index for young conifer plantations established on boreal mixedwood sites. For. Chron. 67: 403-410.

Örlander, G. 1993. Shading reduces both visible and invisible frost damage to Norway spruce seedlings in the field. Forestry 66: 27-36.

Örlander, G., Nilsson, U., and Hällgren, J-E. 1996. Competition for water and nutrients between ground vegetation and planted Picea abies. N.Z.J. For. Sci. 26 (1/2): 99-117.

Petersen, T.D., Newton, M. and Zedaker, S.M. 1988. Influence of *Ceanothus velutinus* and associated forbs on the water stress and stemwood production of Douglas-fir. Forest Science 34: 333-343.

Pitt, D.G., and Bell, F.W. 2005. Juvenile response to conifer release alternatives on aspen-white spruce boreal mixedwood sites. Part I: Stand structure and composition. Forestry Chronicle. 81(4): 538-547.

Richardson, B. 1993. Vegetation management practices in plantation forests of Australia and New Zealand. Can. J. For. Res. 23: 1989-2005.

Robinson, D.E., Wagner, R.G., Bell, F.W., and Swanton, C.J. 2001. Photosynthesis, nitrogen-use efficiency, and water-use efficiency of jack pine seedlings in competition with four boreal forest plant species. Can. J. For. Res. 31: 2014-2025.

Rose, R., and Rosner, L.S. 2005. Eighth-year response of Douglas-fir seedlings to area of weed control and herbaceous versus woody weed control. Ann. For. Sci. 62: 481-492.

Rose, R., Ketchum, J.S., and Hanson, D.E. 1999. Three-year survival and growth of Douglas-fir seedlings under various vegetation-free regimes. For. Sci. 45: 117-126.

Ross, M.S., Flanagan, L.B., and La Roi, G.H. 1986. Seasonal and successional changes in light quality and quantity in the understory of boreal forest ecosystems. Can. J. Bot. 64: 2792-2799.

Schoonmaker, P. and McKee, A. 1988. Species composition and diversity during secondary succession of coniferous forests in the western Cascade Mountains of Oregon. For. Sci. 34: 968-979.

Staples, T.E., Van Rees, K.C.J., and van Kessel, C. 1999. nitrogen competition using 15N between early successional plants and planted white spruce seedlings. Can. J. For. Res. 29: 1282-1289.

Stein, W.I. 1995. Ten-year development of Douglas-fir and associated vegetation after different site preparation on coast range clearcuts. USDA For. Serv. Res. Pap. PNW-RP-473.

Uemura, S. 1994. Patterns of leaf phenology in forest understory. Can. J. Bot. 72: 409-414.

Wagner, R.G., G.H. Mohammed, and T.L. Noland. 1999. Critical period of interspecific competition for northern conifers associated with herbaceous competition. Can. J. For. Res. 29: 890-897.

Wagner, R.G., Little, K.M., Richardson, B., and McNabb, K. 2006. The role of vegetation management for enhancing productivity of the world's forests. Forestry 79(1): 57-79.

Waring, R.H., and Franklin, J.F. 1979. The evergreen conifer forest of the Pacific Northwest. Science 9Washington, D.C.), 204: 1380-1386.

Yang, R.C. 1991. Growth of white spruce following release from aspen competition: 35 year results. The Forestry Chronicle 67(6):706-711.

Young, D.R. 1985. Crown architecture, light interception, and stomatal conductance patterns for sympatric deciduous and evergreen species in a forest understory. Can. J. Bot. 63: 2425-2429.

Table 4.1. Statistical results for analysis of root collar diameter (RCD) increment during the growing seasons of 2004 (May 08 – September 29) and 2005 (May 03 – September 19).

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **RCD Increment 2004 [mm/year]** | 2.64 | 1.03 | **CCB** | 3.68 | 27.02 | <.01 |
| | | | **CCR** | 3.19 | | |
| | | | **N** | 1.16 | | |
| | | | **WCB** | 2.13 | | |
| | | | **WCR** | 2.27 | | |
| **Planned Contrasts RCD increment (2004)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 51.67 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 1.01 | 0.31 |
| Woody Control vs. Complete Control | | | | | 48.75 | <.01 |
| Interaction | | | | | 3.25 | 0.07 |
| **RCD Increment 2005 [mm/year]** | 1.99 | 1.13 | **CCB** | 2.46 | 10.83 | <.01 |
| | | | **CCR2** | 2.43 | | |
| | | | **CCR3** | 2.62 | | |
| | | | **N** | 0.75 | | |
| | | | **WCB** | 1.35 | | |
| | | | **WCR** | 1.51 | | |
| **Planned Contrasts RCD increment (2005)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 21.65 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 1.32 | 0.25 |
| Woody Control vs. Complete Control | | | | | 20.81 | <.01 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 0.48 | 0.49 |
| Interaction | | | | | 0.42 | 0.51 |

Table 4.2. Statistical results for analysis of seasonal increments in root collar diameter (RCD). P values indicate results from ANOVA evaluating overall treatment effects on diameter increment during the indicated time period.

| Measurement # | Date | Total Mean [mm] | RMSE | F | *p* |
|---|---|---|---|---|---|
| **2004 (May 08 – September 29)** | | | | | |
| Growth 1 | 18-May-04 | 0.28 | 0.31 | 3.52 | 0.01 |
| Growth 2 | 02-Jun-04 | 0.44 | 0.34 | 0.53 | 0.75 |
| Growth 3 | 14-Jun-04 | 0.25 | 0.77 | 4.53 | 0.01 |
| Growth 4 | 29-Jun-04 | 0.17 | 0.32 | 3.95 | 0.01 |
| Growth 5 | 13-Jul-04 | 0.49 | 0.86 | 4.65 | 0.01 |
| Growth 6 | 27-Jul-04 | 0.42 | 0.83 | 3.00 | 0.01 |
| Growth 7 | 10-Aug-04 | 0.29 | 0.88 | 0.64 | 0.66 |
| Growth 8 | 24-Aug-04 | 0.33 | 0.42 | 2.36 | 0.04 |
| Growth 9 | 06-Sep-04 | 0.09 | 0.20 | 1.47 | 0.20 |
| Growth 10 | 30-Sep-04 | 0.07 | 0.24 | 0.38 | 0.86 |
| **2005 (May 03 – September 19)** | | | | | |
| Growth 1 | 17-May-05 | 0.26 | 0.42 | 1.66 | 0.13 |
| Growth 2 | 02-Jun-05 | 0.12 | 0.43 | 5.76 | <.01 |
| Growth 3 | 14-Jun-05 | 0.17 | 0.43 | 1.43 | 0.20 |
| Growth 4 | 28-Jun-05 | 0.28 | 0.44 | 7.48 | <.01 |
| Growth 5 | 14-Jul-05 | 0.26 | 0.82 | 2.12 | 0.05 |
| Growth 6 | 25-Jul-05 | 0.16 | 0.53 | 1.36 | 0.23 |
| Growth 7 | 09-Aug-05 | 0.16 | 0.68 | 0.79 | 0.57 |
| Growth 8 | 23-Aug-05 | 0.09 | 0.48 | 3.44 | 0.01 |
| Growth 9 | 07-Sep-05 | 0.04 | 0.47 | 0.57 | 0.75 |
| Growth 10 | 19-Sep-05 | -0.03 | 0.48 | 0.67 | 0.67 |

Table 4.3. Statistical results for analysis of root collar diameter (RCD) increment (cumulative for both 2004 and 2005).

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **RCD Increment [mm/2 years]** | 4.30 | 1.69 | **CCB** | 6.49 | 32.06 | <.01 |
| | | | **CCR2** | 5.39 | | |
| | | | **CCR3** | 5.76 | | |
| | | | **N** | 1.63 | | |
| | | | **WCB** | 3.55 | | |
| | | | **WCR** | 3.11 | | |
| **Planned Contrasts RCD increment** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 69.78 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0.59 | 0.44 |
| Woody Control vs. Complete Control | | | | | 60.46 | <.01 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 0.78 | 0.37 |
| Interaction | | | | | 0.1 | 0.74 |

Table 4.4. Results of t-test analysis of regression coefficients.
RCD – root collar diameter; HDR – height to diameter ratio; inc. – increment; LAIo – overstory leaf area index; LAIh – understory (herbaceous) leaf area index

| Variable | $R^2$ | n | $b_1$ (LAIo) | $b_2$ (LAIh) | t | Table T | Significant |
|---|---|---|---|---|---|---|---|
| **2004** | | | | | | | |
| RCD inc. | 0.4972 | 143 | -0.397 | -0.254 | -0.763 | 1.968 | **NO** |
| Volume inc. | 0.4036 | 143 | -0.674 | -0.564 | -0.618 | 1.968 | **NO** |
| HDR | 0.465 | 143 | 0.205 | 0.098 | 0.197 | 1.968 | **NO** |
| **2005** | | | | | | | |
| RCD inc. | 0.4591 | 120 | -0.887 | -0.307 | **-2.999** | 1.969 | **YES** |
| Volume inc. | 0.413 | 120 | -1.958 | -0.555 | **-3.148** | 1.969 | **YES** |
| HDR | 0.658 | 131 | 0.289 | 0.141 | 0.269 | 1.969 | **NO** |

Table 4.5. Statistical results for analysis of height increment during the growing seasons of 2004 (May 08 – September 29) and 2005 (May 03 – September 19).
CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **Height Increment 2004 [cm/year]** | 7.61 | 4.18 | **CCB** | 8.18 | 8.03 | <.01 |
| | | | **CCR** | 8.98 | | |
| | | | **N** | 8.31 | | |
| | | | **WCB** | 6.02 | | |
| | | | **WCR** | 5.77 | | |
| **Planned Contrasts height increment (2004)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 1.79 | 0.18 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0.2 | 0.65 |
| Woody Control vs. Complete Control | | | | | 19.06 | <.01 |
| Interaction | | | | | 0.74 | 0.39 |
| **Height Increment 2005 [cm/year]** | 9.91 | 5.04 | **CCB** | 8.74 | 0.95 | 0.44 |
| | | | **CCR2** | 10.99 | | |
| | | | **CCR3** | 10.56 | | |
| | | | **N** | 8.39 | | |
| | | | **WCB** | 10.32 | | |
| | | | **WCR** | 9.59 | | |
| **Planned Contrasts height increment (2005)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 1.71 | 0.19 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0.61 | 0.43 |
| Woody Control vs. Complete Control | | | | | 0.02 | 0.89 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 0.11 | 0.73 |
| Interaction | | | | | 2.18 | 0.14 |

Table 4.6. Statistical results for analysis of height increment (cumulative for both 2004 and 2005).

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **Height Increment [cm/2 years]** | 16.35 | 7.15 | **CCB** | 16.34 | 3.46 | 0.01 |
| | | | **CCR2** | 18.20 | | |
| | | | **CCR3** | 18.84 | | |
| | | | **N** | 15.57 | | |
| | | | **WCB** | 17.17 | | |
| | | | **WCR** | 13.32 | | |
| **Planned Contrasts Height increment** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 0.54 | 0.46 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0 | 0.98 |
| Woody Control vs. Complete Control | | | | | 3.38 | 0.06 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 0.13 | 0.72 |
| Interaction | | | | | 5.88 | 0.01 |

Table 4.7. Statistical results for analysis of volume increment during the growing seasons of 2004 (May 08 – September 29) and 2005 (May 03 – September 19).

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **Volume Increment 2004 [$cm^3$/year]** | 0.59 | 2.27 | **CCB** | 1.02 | 17.26 | <.01 |
| | | | **CCR** | 0.89 | | |
| | | | **N** | 0.12 | | |
| | | | **WCB** | 0.32 | | |
| | | | **WCR** | 0.29 | | |
| **Planned Contrasts volume increment (2004)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 15.42 | 0.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0.6 | 0.44 |
| Woody Control vs. Complete Control | | | | | 42.31 | <.01 |
| Interaction | | | | | 0.27 | 0.60 |
| **Volume Increment 2005 [$cm^3$/year]** | 0.72 | 3.54 | **CCB** | 0.56 | 3.16 | 0.01 |
| | | | **CCR2** | 0.67 | | |
| | | | **CCR3** | 0.99 | | |
| | | | **N** | 0.05 | | |
| | | | **WCB** | 0.22 | | |
| | | | **WCR** | 0.24 | | |
| **Planned Contrasts volume increment (2005)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 3.12 | 0.07 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 1.01 | 0.31 |
| Woody Control vs. Complete Control | | | | | 4.92 | 0.02 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 1.33 | 0.24 |
| Interaction | | | | | 1.09 | 0.29 |

Table 4.8. Statistical results for analysis of volume increment (cumulative for both 2004 and 2005).

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **Volume Increment [$cm^3$/2 years]** | 4.06 | 3.893814 | **CCB** | 6.31 | 12.90 | <.01 |
| | | | **CCR2** | 5.32 | | |
| | | | **CCR3** | 6.34 | | |
| | | | **N** | 0.40 | | |
| | | | **WCB** | 2.47 | | |
| | | | **WCR** | 1.54 | | |
| **Planned Contrasts volume increment** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 19.1 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0 | 0.99 |
| Woody Control vs. Complete Control | | | | | 26.45 | <.01 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 1.06 | 0.30 |
| Interaction | | | | | 1.1 | 0.29 |

Table 4.9. Statistical results for analysis of height to diameter ratio (HDR) in 2004 and 2005.

CCB – Broadcast Complete Control; CCR – Radial Complete Control; CCR2 – Complete Control Radial 2 years; CCR3 – Complete Control Radial 3 years; N – No Treatment; WCB – Broadcast Woody Control; WCR – Radial Woody Control.

| Variable | Total mean | RMSE | Treat | LS Mean | F | *p* |
|---|---|---|---|---|---|---|
| **HDR 2004** | 38.63 | 6.88 | **CCB** | 34.53 | 26.79 | <.01 |
| | | | **CCR** | 35.81 | | |
| | | | **N** | 51.92 | | |
| | | | **WCB** | 39.14 | | |
| | | | **WCR** | 38.67 | | |
| **HDR 2005** | 42.86 | 9.64 | **CCB** | 33.3 | 26.49 | <.01 |
| | | | **CCR2** | 37.7 | | |
| | | | **CCR3** | 36.2 | | |
| | | | **N** | 60.6 | | |
| | | | **WCB** | 47.4 | | |
| | | | **WCR** | 45.5 | | |
| **Planned Contrasts HDR (2004)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 91.71 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0.12 | 0.72 |
| Woody Control vs. Complete Control | | | | | 9.97 | 0.01 |
| Interaction | | | | | 0.55 | 0.46 |
| **Planned Contrasts HDR (2005)** | | | | | | |
| Treated vs. Untreated (No treatment vs. all treatments) | | | | | 88.18 | <.01 |
| Mixedwood vs. Pure (Radial vs. Broadcast) | | | | | 0.08 | 0.77 |
| Woody Control vs. Complete Control | | | | | 35.41 | <.01 |
| 2 vs. 3 years (CCR2 vs. CCR3) | | | | | 0.43 | 0.51 |
| Interaction | | | | | 0.32 | 0.56 |

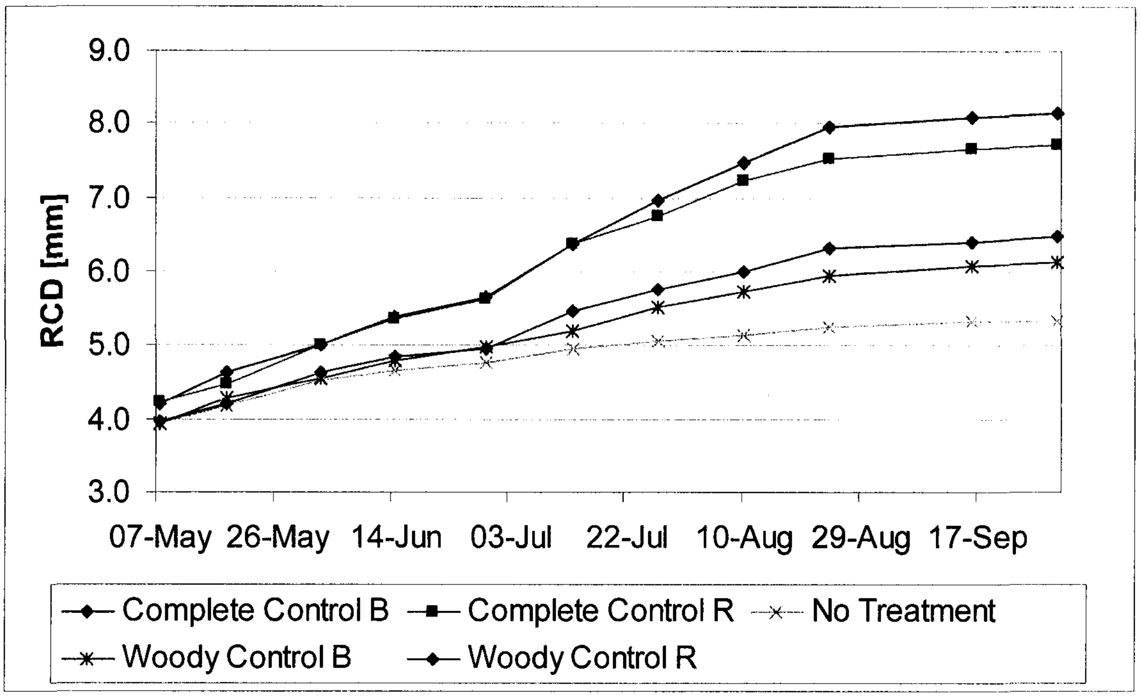



Figure 4.1. Root collar diameter (RCD) seasonal trends from May 08 to September 29, 2004. B – Broadcast; R – Radial.

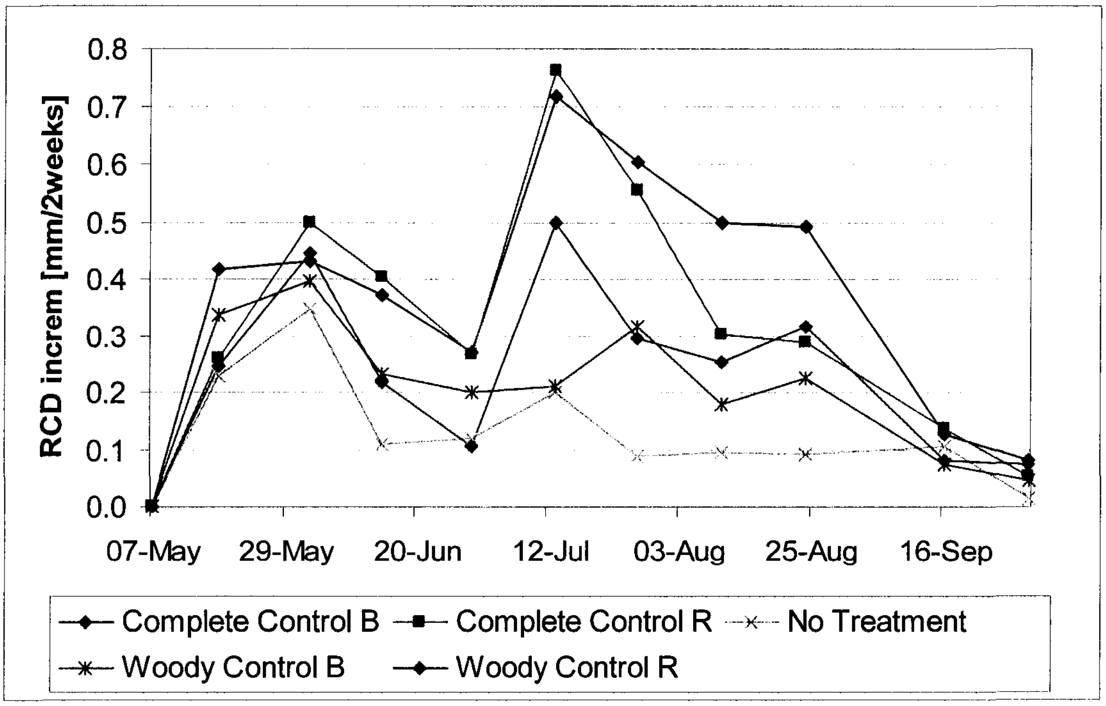



Figure 4.2. Root collar diameter (RCD) increment seasonal trends from May 08 to September 29, 2004. B – Broadcast; R – Radial.

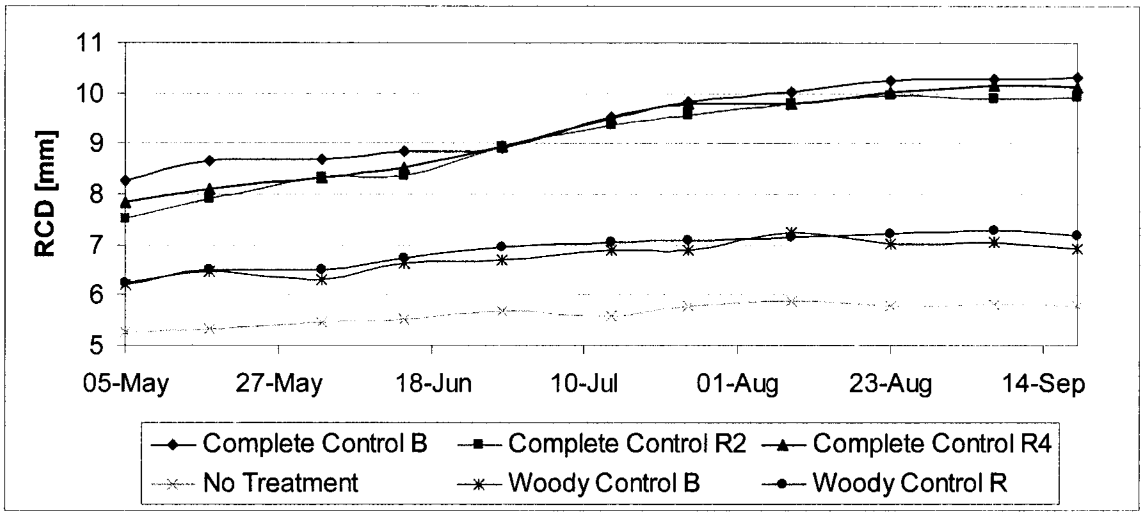



Figure 4.3. Root collar diameter (RCD) seasonal trends from May 03 to September 19, 2005. B – Broadcast; R – Radial; R2 – Radial 2 years; R4 – Radial 3 years.

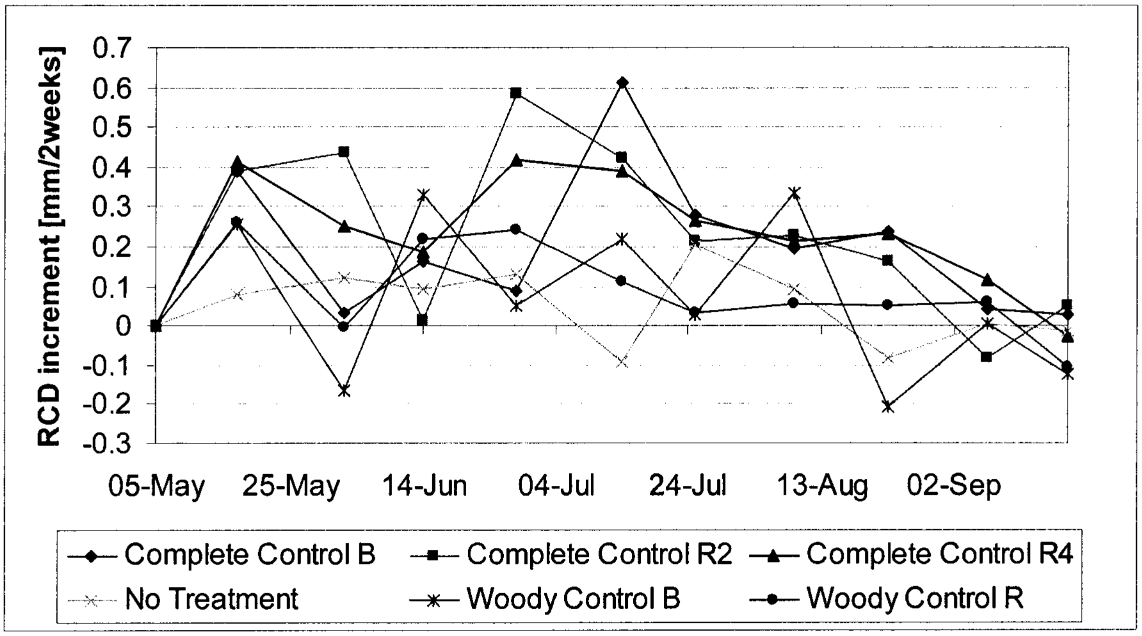



Figure 4.4. Root collar diameter (RCD) uncrement seasonal trends from May 03 to September 19, 2005. B – Broadcast; R – Radial; R2 – Radial 2 years; R4 – Radial 3 years.

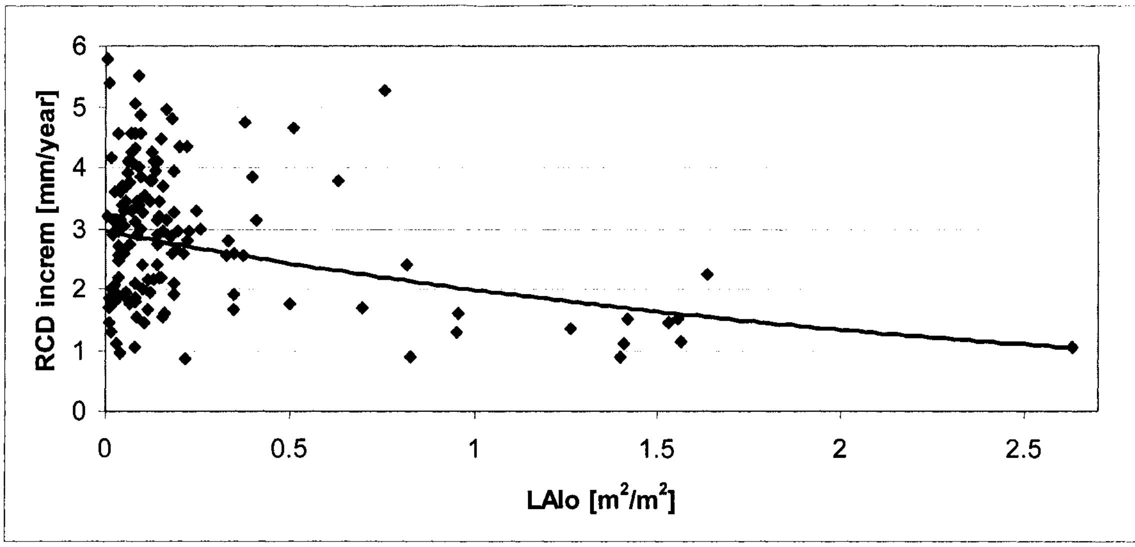



Figure 4.5a. Relationship between overstory Leaf Area Index (LAIo) and root collar diameter increment (RCDinc) in 2004. The line shows the relationship described by the equation: $RCDinc = 0.641947 \cdot InitH^{0.58647} \cdot e^{-0.39738 \cdot LAIo - 0.25477 \cdot LAIh}$, InitH – Initial Height, LAIo – Overstory LAI, LAIh – Herbaceous Vegetation LAI. $\mathbf{R^2 = 0.4972}$, $R^2_{adj} = 0.4863$, RMSE = 0.3127, $n = 143$. For the line shown, LAIh = 0.83 $m^2/m^2$ and InitH = 19.3 cm (average values).

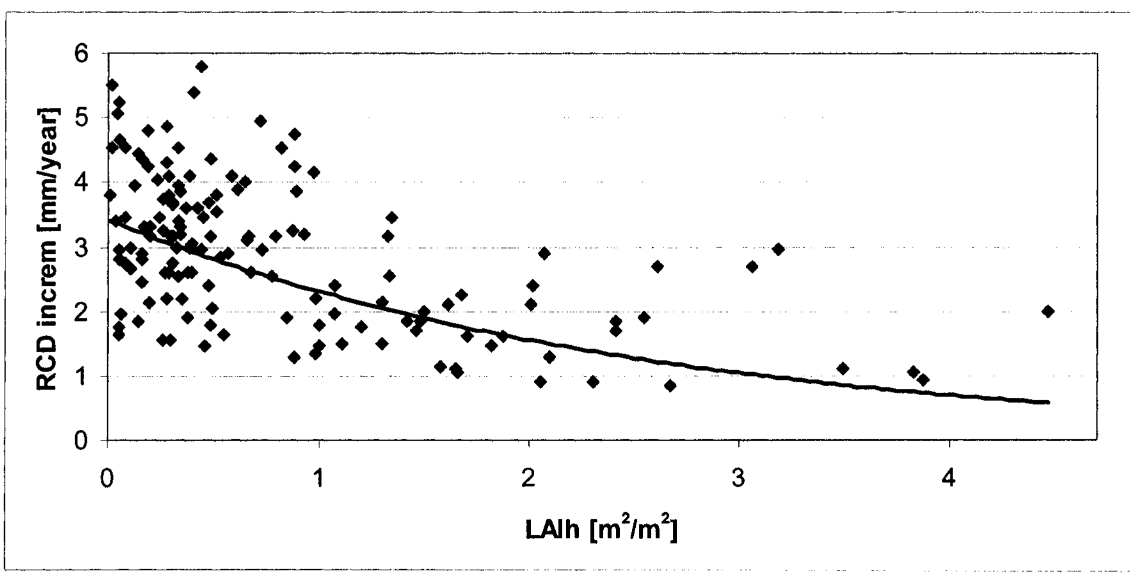



Figure 4.5b. Relationship between herbaceous vegetation Leaf Area Index (LAIh) and root collar diameter increment (RCDinc) in 2004. The line shows the relationship described by the equation: $RCDinc = 0.641947 \cdot InitH^{0.58647} \cdot e^{-0.39738 \cdot LAIo - 0.25477 \cdot LAIh}$, InitH – Initial Height, LAIo – Overstory LAI, LAIh – Herbaceous Vegetation LAI. $\mathbf{R^2 = 0.4972}$, $R^2_{adj} = 0.4863$, RMSE = 0.3127, $n = 143$. For the line shown, LAIo = 0.25 $m^2/m^2$ and InitH = 19.3 cm (average values).

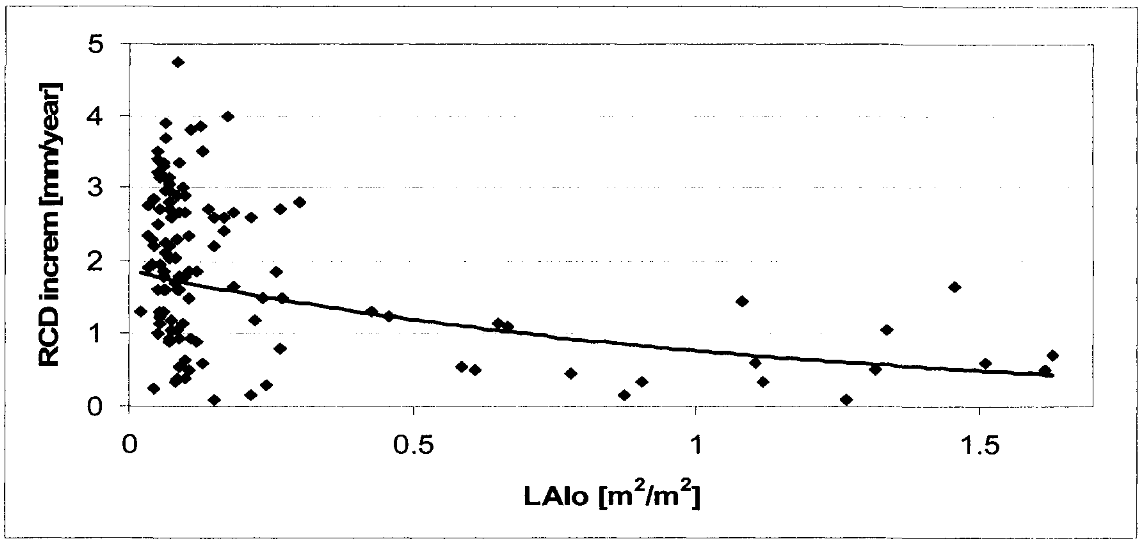



Figure 4.6a Relationship between overstory Leaf Area Index (LAIo) and root collar diameter increment (RCDinc) in 2005. The line shows the relationship described by the equation: $RCDinc = 0.06135 \cdot InitH^{1.14154} \cdot e^{-0.88777 \cdot LAIo - 0.30797 \cdot LAIh}$, InitH – Initial Height, LAIo – Overstory LAI, LAIh – Herbaceous Vegetation LAI. $\mathbf{R^2 = 0.4591}$, $R^2_{adj} = 0.4451$, RMSE = 0.60725, $n = 120$. For the line shown, LAIh = 1.21 $m^2/m^2$ and InitH = 25.79 cm (average values).

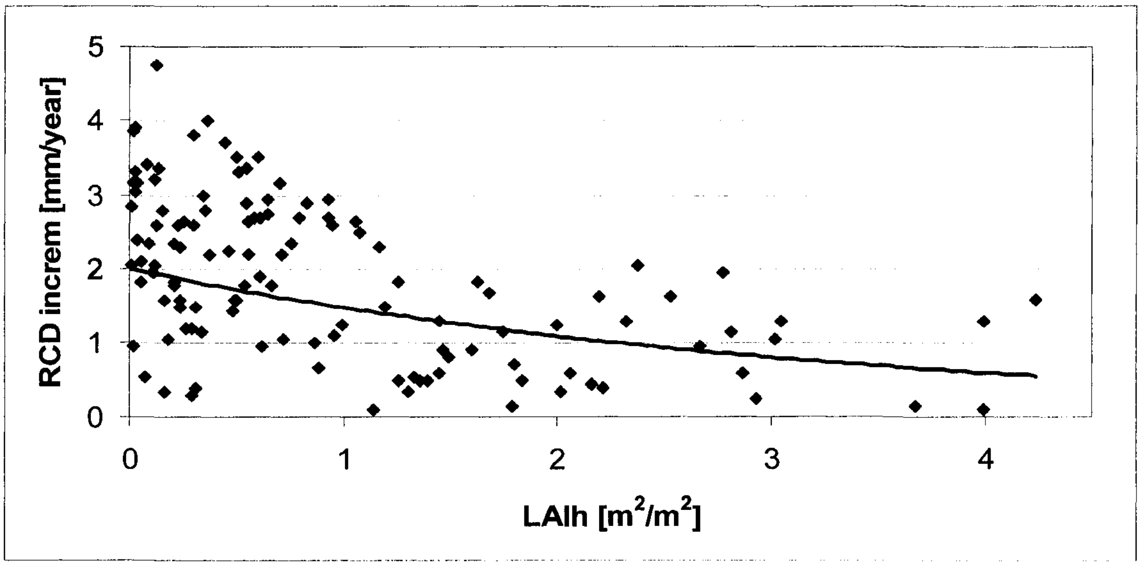



Figure 4.6b Relationship between herbaceous vegetation Leaf Area Index (LAIh) and root collar diameter increment (RCDinc) in 2005. The line shows the relationship described by the equation: $RCDinc = 0.06135 \cdot InitH^{1.14154} \cdot e^{-0.88777 \cdot LAIo - 0.30797 \cdot LAIh}$, InitH – Initial Height, LAIo – Overstory LAI, LAIh – Herbaceous Vegetation LAI. $\mathbf{R^2 = 0.4591}$, $R^2_{adj} = 0.4451$, RMSE = 0.60725, $n = 120$. For the line shown, LAIo = 0.26 $m^2/m^2$ and InitH = 25.79 cm (average values).

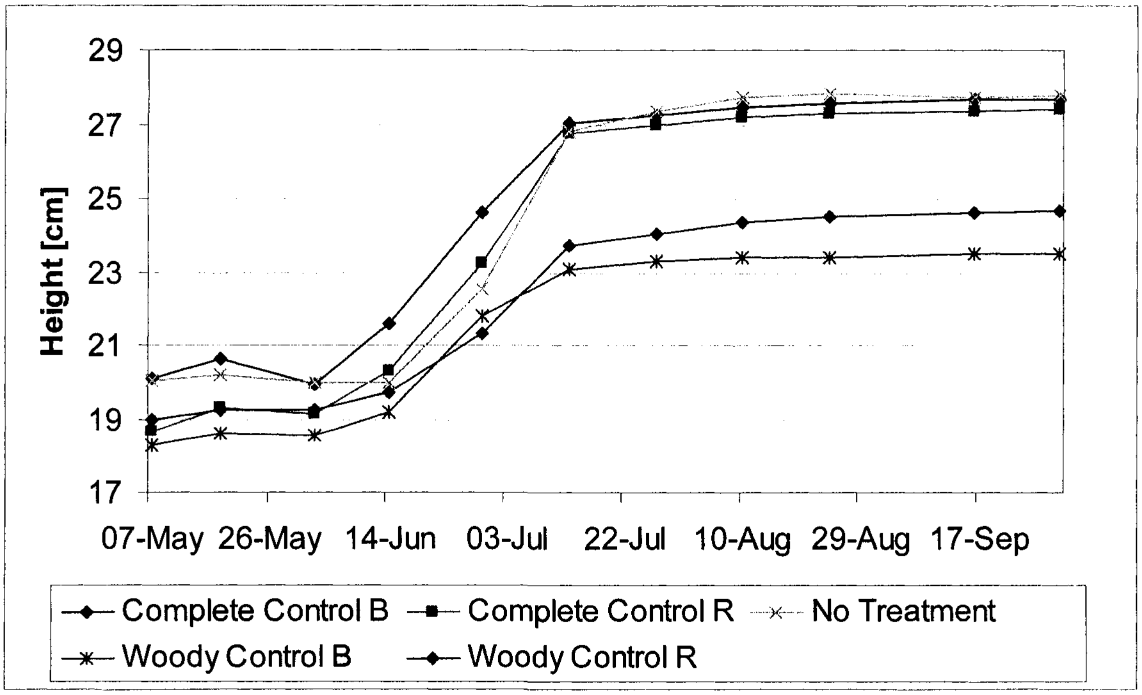



Figure 4.7. Height seasonal trends from May 08 to September 29, 2004. B – Broadcast; R – Radial.

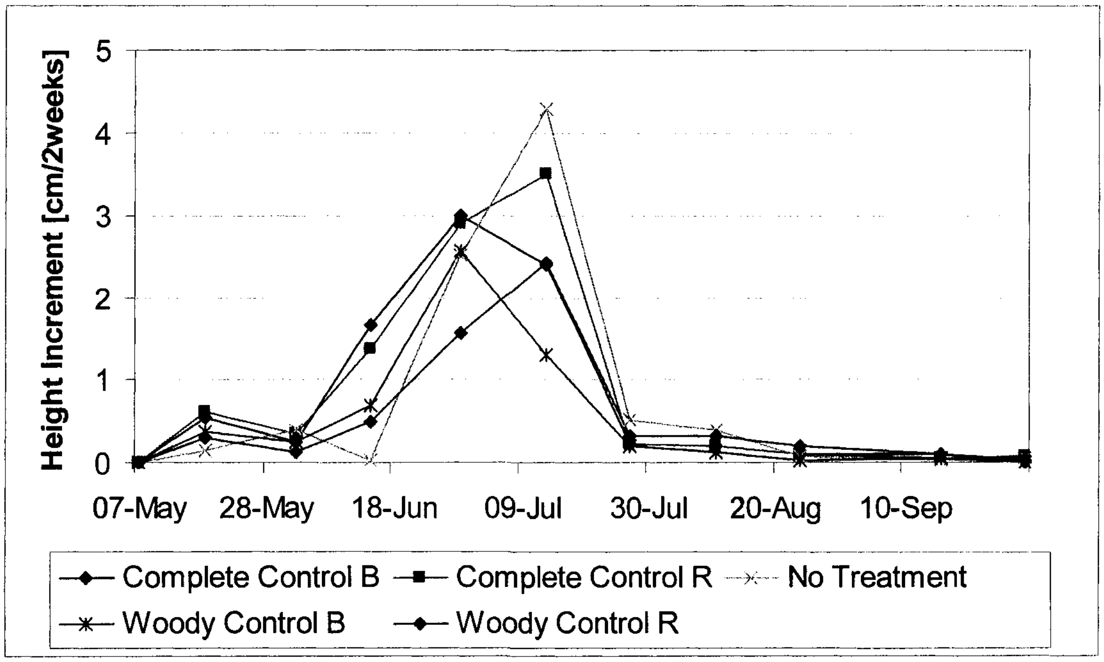



Figure 4.8. Height increment seasonal trends from May 08 to September 29, 2004. B – Broadcast; R – Radial.

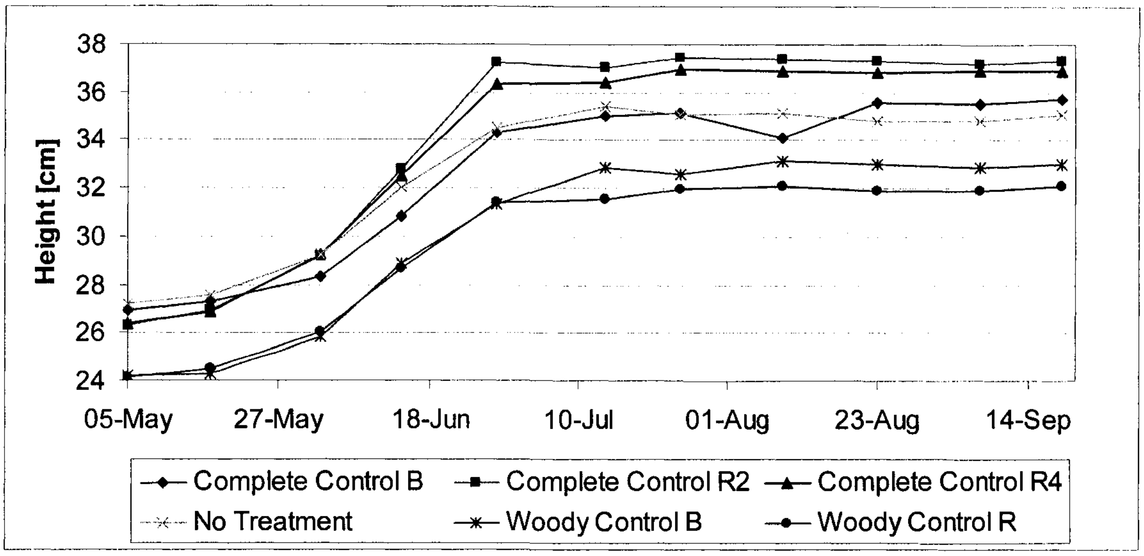



Figure 4.9. Height seasonal trends from May 03 to September 19, 2005. B – Broadcast; R – Radial; R2 – Radial 2 years; R4 – Radial 3 years.

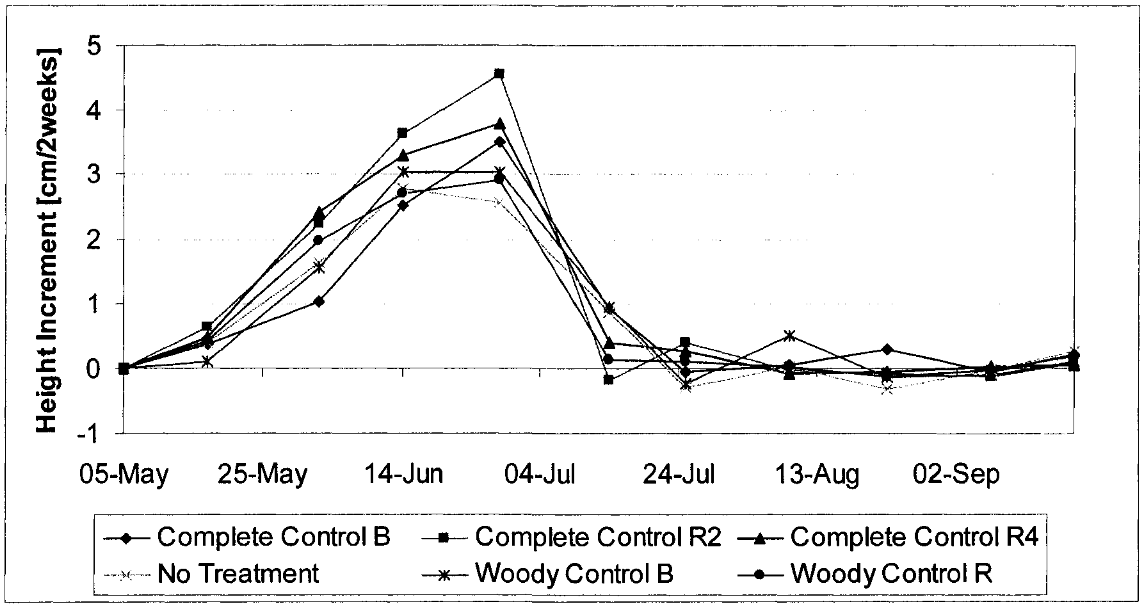



Figure 4.10. Height seasonal increment trends from May 03 to September 19, 2005. B – Broadcast; R – Radial; R2 – Radial 2 years; R4 – Radial 3 years.

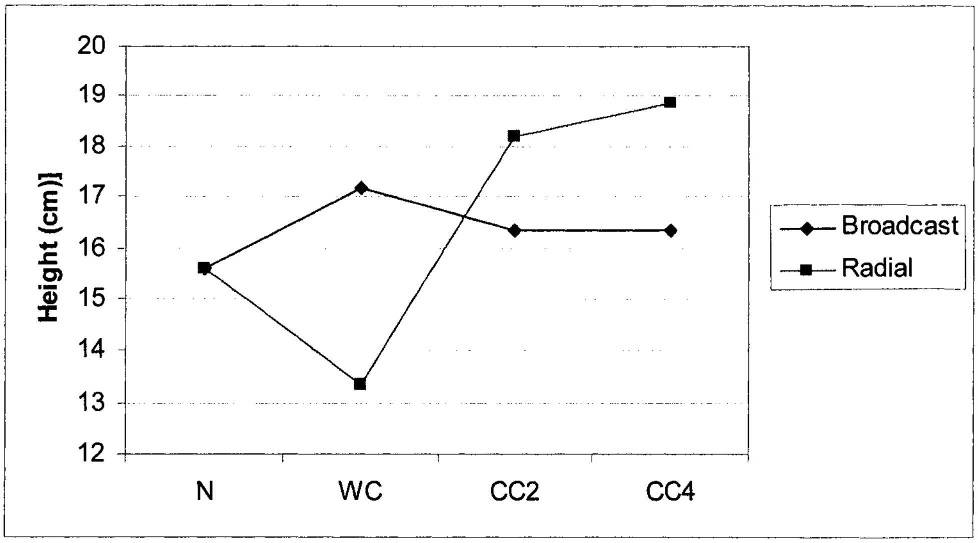



Figure 4.11. Cumulative height (2004 and 2005) interaction. N – No treatment; WC – Woody Control; CC2 – Complete control 2 years; CC4 – Complete Control 3 years.

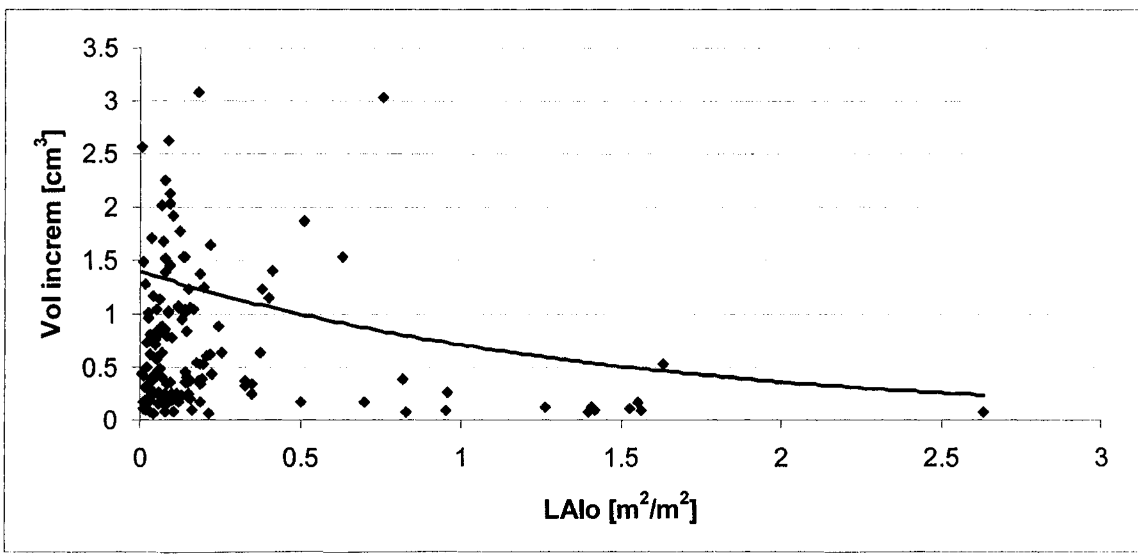



Figure 4.12a. Relationship between overstory Leaf Area Index (LAIo) and volume increment (VolInc) in 2004. The line shows the relationship described by the equation: $VOLInc = 0.040492 \cdot InitH^{1.05414} \cdot e^{-0.67492 \cdot LAIo - 0.56479 \cdot LAIh}$, InitH – Initial Height, LAIo – Overstory LAI, LAIh – Herbaceous Vegetation LAI. $\mathbf{R^2 = 0.4036}$, $R^2_{adj} = 0.3907$, RMSE = 0.76591, $n = 143$. For the line shown, LAIh = 0.83 m$^2$/m$^2$ and InitH = 19.3 cm (average values).

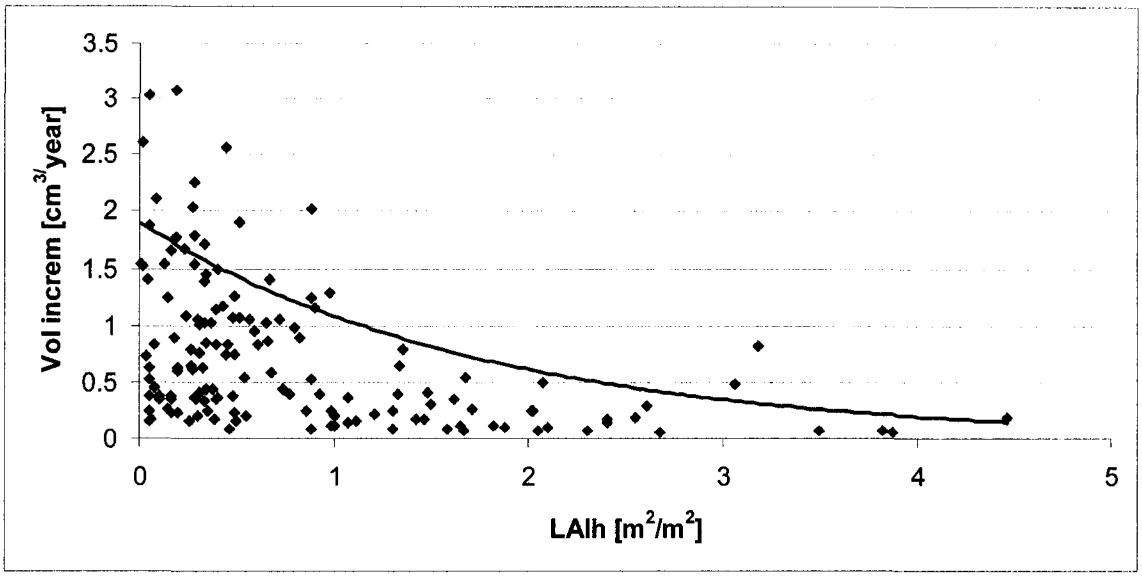



Figure 4.12b. Relationship between herbaceous vegetation Leaf Area Index (LAIh) and volume increment (VolInc) in 2004. The line shows the relationship described by the equation: $VOLInc = 0.040492 \cdot InitH^{1.05414} \cdot e^{-0.67492 \cdot LAIo - 0.56479 \cdot LAIh}$, InitH – Initial Height, LAIo – Overstory LAI, LAIh – Herbaceous Vegetation LAI. $\mathbf{R^2 = 0.4036}$, $R^2_{adj} = 0.3907$, RMSE = 0.76591, $n = 143$. For the line shown, LAIo = 0.25 $m^2/m^2$ and InitH = 19.3 cm (average values).

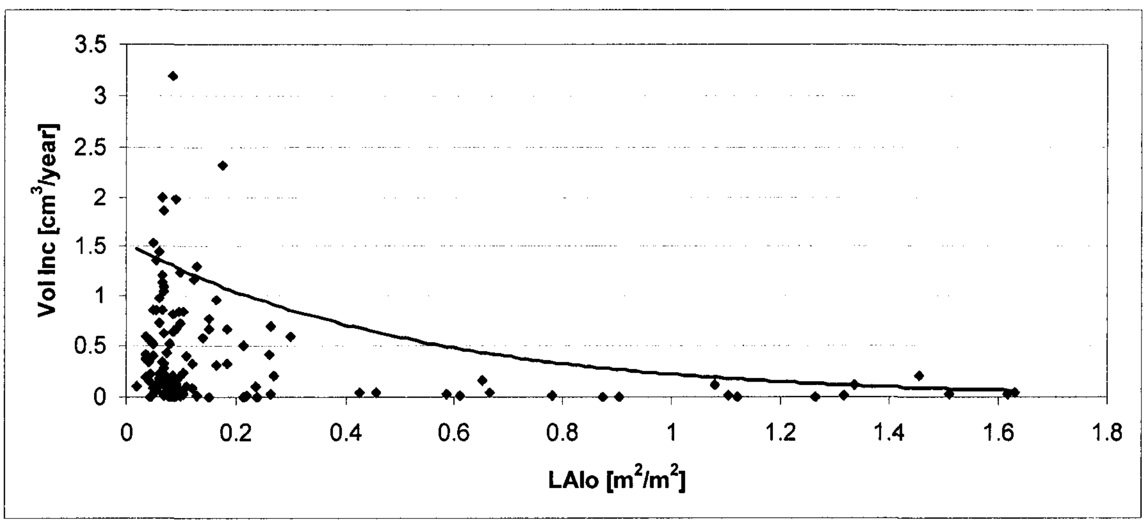



Figure 4.13a. Relationship between overstory Leaf Area Index (LAIo) and volume increment (VolInc) in 2005. The line shows the relationship described by the equation: $VOLInc = 0.000194 \cdot InitH^{3.78275} \cdot e^{-1.95884 \cdot LAIo - 0.55593 \cdot LAIh}$, InitH – Initial Height, LAIo – Overstory LAI, LAIh – Herbaceous Vegetation LAI. $\mathbf{R^2 = 0.4130}$, $R^2_{adj} = 0.3979$, RMSE = 1.52808, $n = 120$. For the line shown, LAIh = 0.97 $m^2/m^2$ and InitH = 25.84 cm (average values).

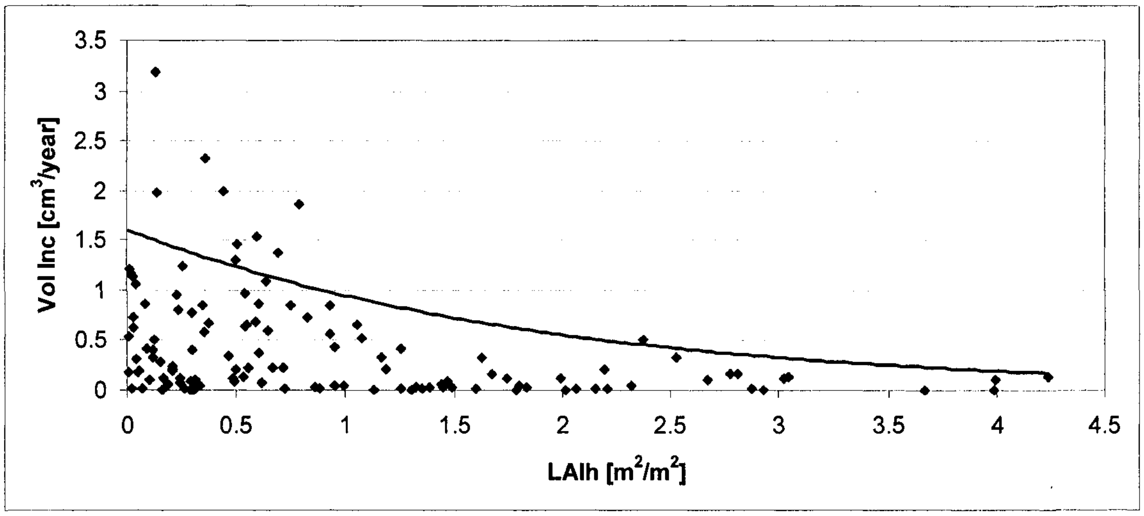



Figure 4.13b. Relationship between herbaceous vegetation Leaf Area Index (LAIh) and volume increment (VolInc) in 2005. The line shows the relationship described by the equation: $VOLInc = 0.000194 \cdot InitH^{3.78275} \cdot e^{-1.95884 \cdot LAIo - 0.55593 \cdot LAIh}$, InitH – Initial Height, LAIo – Overstory LAI, LAIh – Herbaceous Vegetation LAI. $\mathbf{R^2 = 0.4130}$, $R^2_{adj} = 0.3979$, RMSE = 1.52808, $n$ = 120. For the line shown, LAIo = 0.25 $m^2/m^2$ and InitH = 25.84 cm (average values).

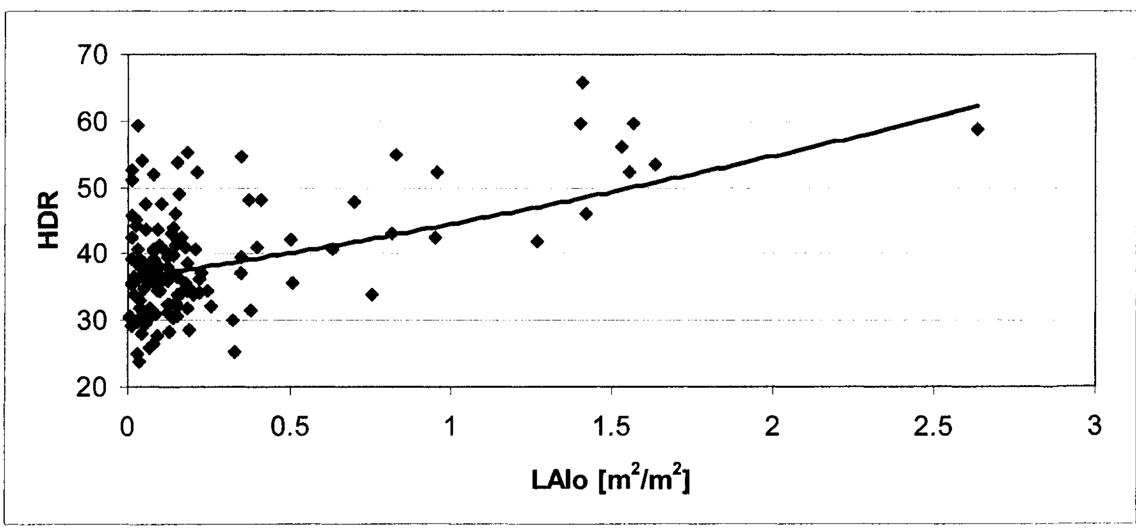



Figure 4.14a. Relationship between height to diameter ratio (HDR) and overstory leaf area index (LAIo) in 2004. The line shows the relationship described by the equation: $HDR = 18.99945 \cdot InitH^{0.19036} \cdot e^{(0.20534 \cdot LAIo + 0.09899 \cdot LAIh)}$ .InitH – Initial height at beginning of 2004 growing season. $\mathbf{R^2 = 0.4650}$, $R^2_{adj} = 0.4535$, RMSE = 0.15008, $n$ = 143. For the line shown, LAIh = 0.83 $m^2/m^2$, InitH = 19.32 cm (average values).

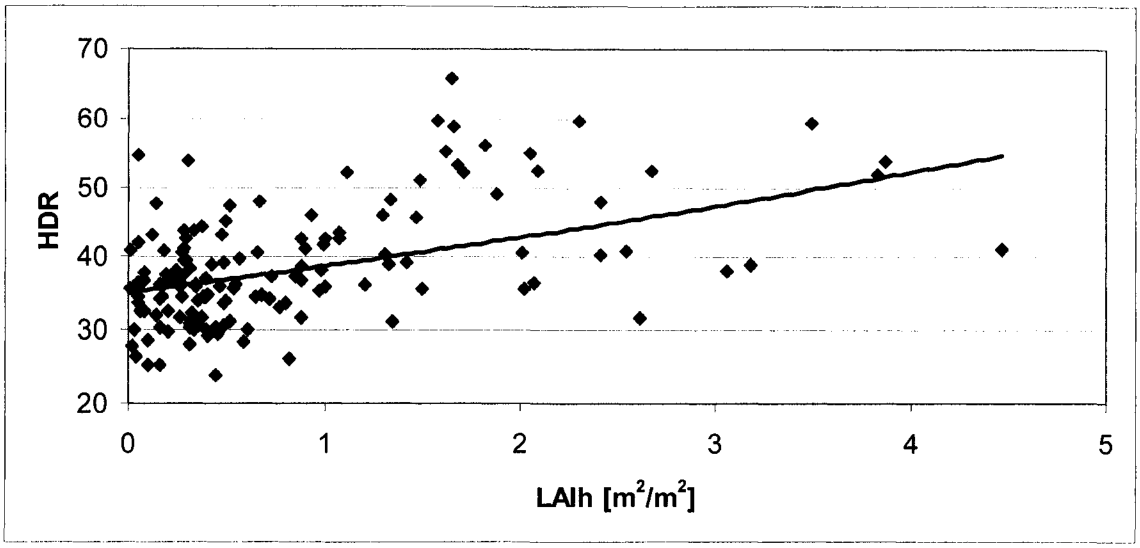



Figure 4.14b. Relationship between height to diameter ratio (HDR) and understory leaf area index (LAIh) in 2004. The line shows the relationship described by the equation: $HDR = 18.99945 \cdot InitH^{0.19036} \cdot e^{(0.20534 \cdot LAIo + 0.09899 \cdot LAIh)}$ .InitH – Initial height at beginning of 2004 growing season. $\mathbf{R^2 = 0.4650}$, $R^2_{adj} = 0.4535$, RMSE = 0.15008, $n = 143$. For the line shown, LAIo = 0.25 $m^2/m^2$, InitH = 19.32 cm (average values).

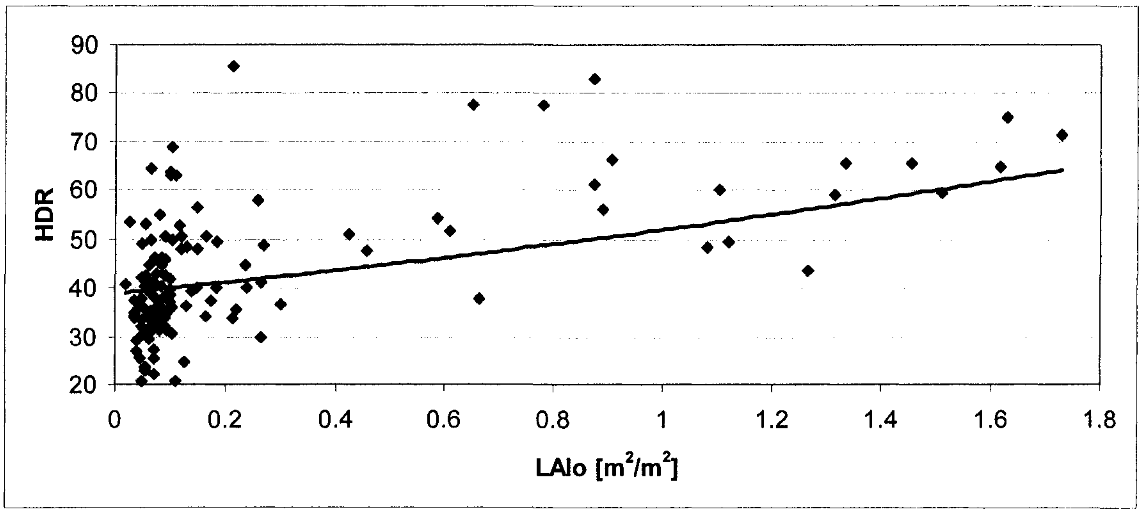



Figure 4.15a. Relationship between height to diameter ratio (HDR) and overstory leaf area index (LAIo) in 2005. The line shows the relationship described by the equation: $HDR = 5.717948 \cdot InitH^{0.54303} \cdot e^{(0.28928 \cdot LAIo + 0.1411 \cdot LAIh)}$ .InitH – Initial height at beginning of 2005 growing season. $\mathbf{R^2 = 0.6580}$, $R^2_{adj} = 0.6499$, RMSE = 0.17384, $n = 131$. For the line shown, LAIh = 1.08 $m^2/m^2$, InitH = 25.78 cm (average values).

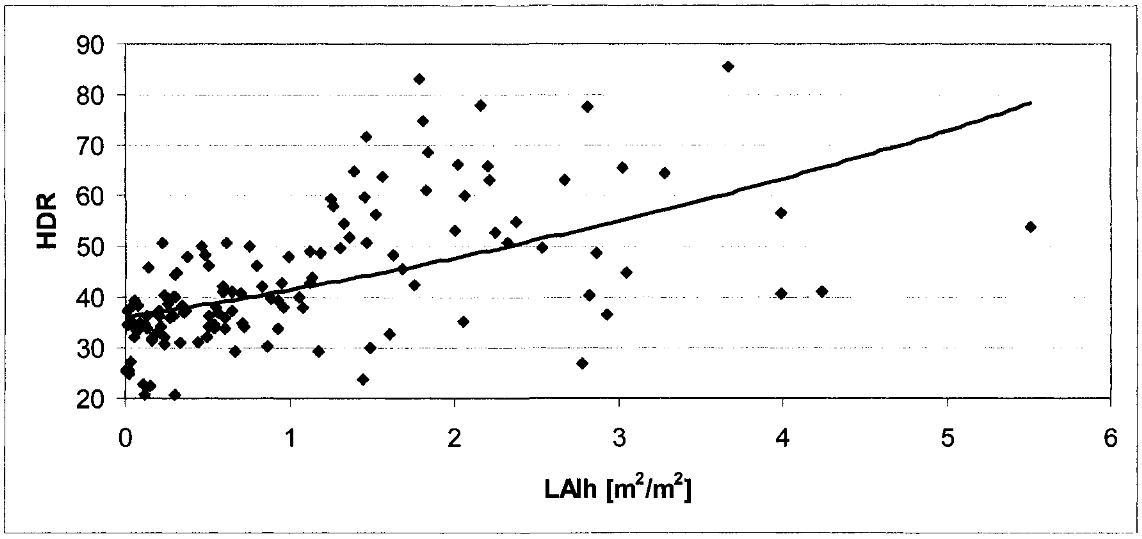



Figure 4.15b. Relationship between height to diameter ratio (HDR) and understory leaf area index (LAIh) in 2005. The line shows the relationship described by the equation: $HDR = 5.717948 \cdot InitH^{0.54303} \cdot e^{(0.28928 \cdot LAIo + 0.1411 \cdot LAIh)}$ .InitH – Initial height at beginning of 2005 growing season. $\mathbf{R^2 = 0.6580}$, $R^2_{adj} = 0.6499$, RMSE = 0.17384, $n$ = 131. For the line shown, LAIh = 1.08 m$^2$/m$^2$, InitH = 25.78 cm (average values).

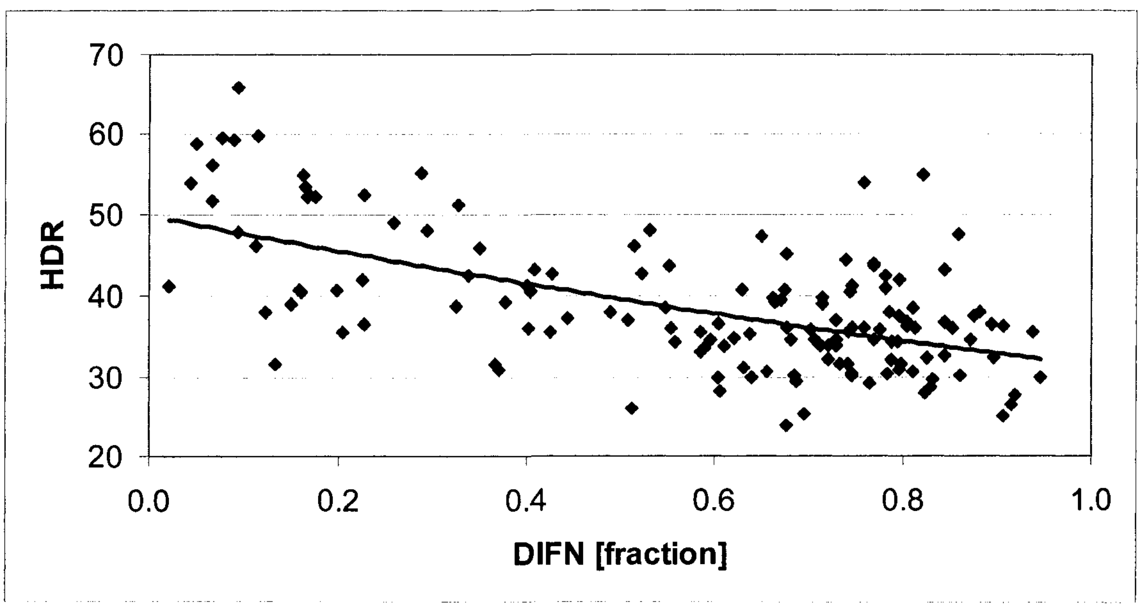



Figure 4.16. Relationship between height to diameter ratio (HDR) and light (DIFN) in 2004. The line shows the relationship described by the equation: $HDR = 24.50752 \cdot InitH^{0.23965} \cdot e^{-0.46089 \cdot DIFN}$. InitH – Initial height at beginning of 2004 growing season. $\mathbf{R^2 = 0.4014}$, $R^2_{adj} = 0.3928$, RMSE = 0.15819, $n$ = 143. For the line shown InitH = 19.32 cm (average value).

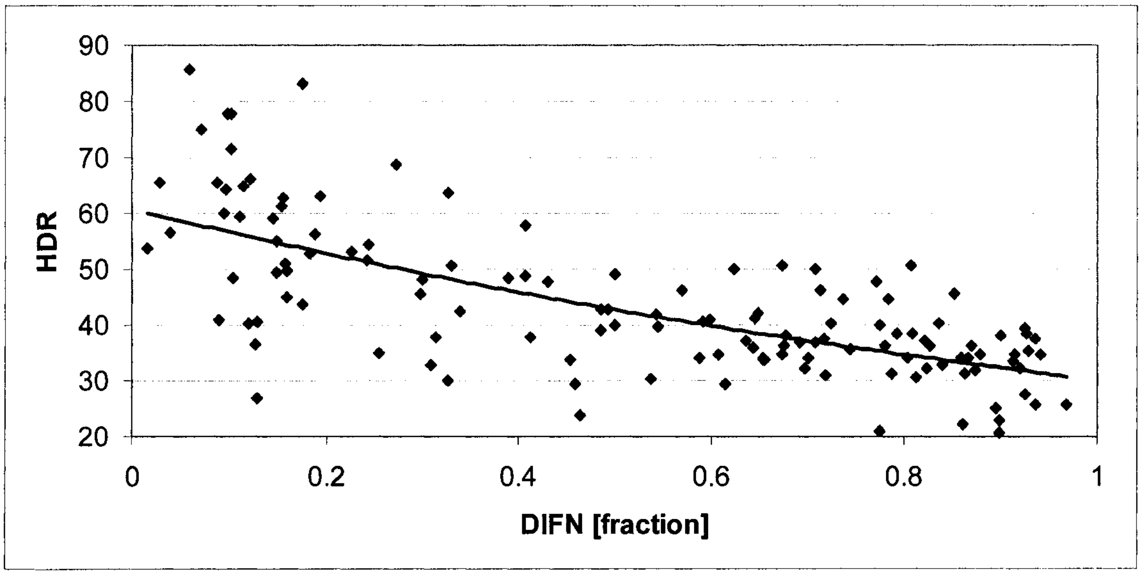



Figure 4.17. Relationship between height to diameter ratio (HDR) and light (DIFN) in 2005. The line shows the relationship described by the equation: $HDR = 8.198326 \cdot InitH^{0.61644} \cdot e^{-0.7036 \cdot DIFN}$. InitH – Initial height at beginning of 2005 growing season. $\mathbf{R^2 = 0.6725}$, $R^2_{adj} = 0.6674$, RMSE = 0.16943, $n = 131$. For the line shown InitH = 25.78 cm (average value).

# Chapter 5. Conclusions

## 5.1. Conclusions

The main objectives of this study were to examine the effects of selected treatments on: 1) vegetation development, particularly LAI and root surface area; 2) major factors and resources influencing spruce growth (light, soil moisture, soil nitrogen availability, air temperature and soil temperature); and, 3) growth of planted white spruce. The following null hypotheses were tested in a young mixedwood stand in central Alberta, during 2004 and 2005 growing seasons:

- Competitive effects of woody and herbaceous layers do not have different influences on resource (light, soil moisture and soil nitrogen) availability and consequently on spruce growth

- Vegetation management treatments do not influence resource availability and subsequent spruce growth is not being affected by these changes

The above null hypotheses generated the following questions that were explored during this study period:

- Do woody and herbaceous layers have similar effects on resource (light, soil moisture and soil nitrogen) availability during the first 3 years after regeneration?

- Is spruce growth related to changes in resource availability resulting from vegetation management treatments?

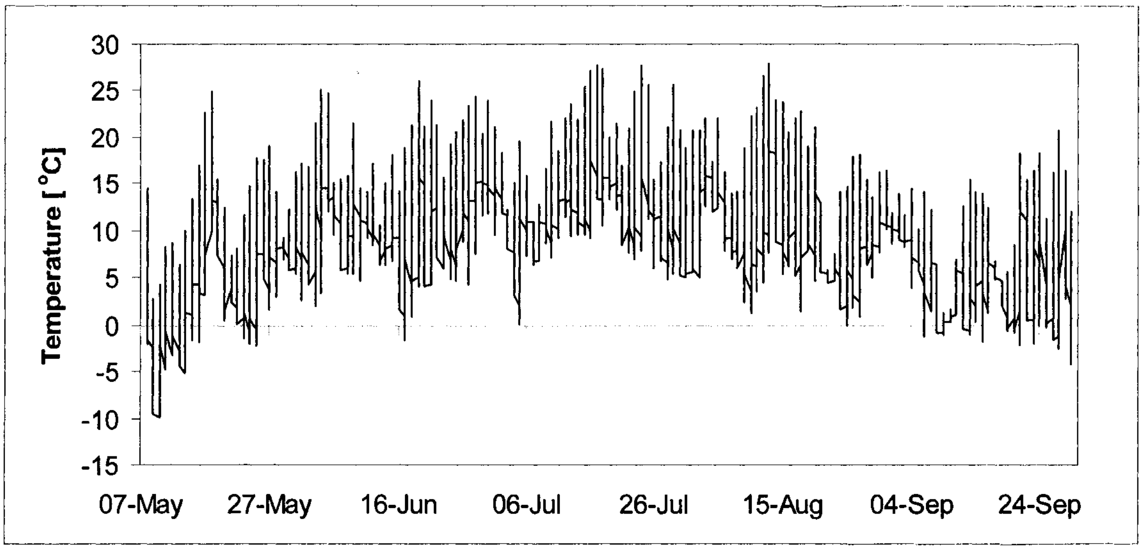
Based on the results and analysis of data collected, competition for water did not appear to be a limiting factor on this site during the 2004 and 2005 growing seasons, likely due to relatively high precipitation levels during this period. However, removal of vegetation through treatment application had a major affect on vegetation levels (leaf area index), which subsequently influenced the availability of other resources (light, soil nitrogen availability, and air and soil temperature). Of these, competition for light appears to be of high importance, explaining approximately half of the variation in spruce growth observed, while soil nitrogen availability was strongly correlated with leaf area index of surrounding vegetation, and appeared to be only marginally related to spruce growth. The few air and soil temperature effects found, did not have major affects on vegetation during the growing season, but did cause spruce injury during the winter of 2004/2005. Moreover, this study demonstrated that removal of the woody component alone can result in substantial increases in grass cover, with an increase in grass competition compensating for the reduction in competition from aspen and other woody vegetation. The consequence might be that spruce growth does not increase as much as in cases where all vegetation is removed. However, this study indicates that overstory had a stronger negative effect than understory (herbaceous) on spruce growth in the 3$^{rd}$ growing season. A 2-m radius of complete vegetation control around spruce seedlings seemed to provide a favorable environment for growth of white spruce, with adequate light levels and reduced competitive effects of surrounding vegetation, at least for first 3 years after establishment. Differences between 2 and 3 years of vegetation control weren't detected so far. Ongoing research is needed to see if this beneficial effect will last in the future years.

### 5.2. Practical applicability and future research

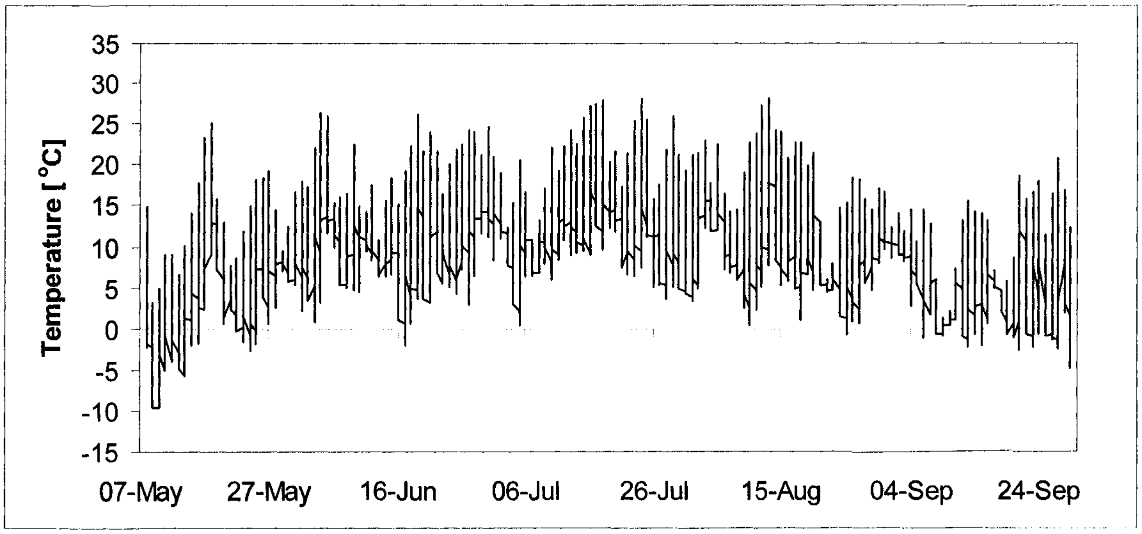
Results obtained to date from this study suggest that controlling vegetation can have a significant effect on growth of crop species, by reducing the competitive effects of surrounding vegetation. Competition during 2004 and 2005 on this site appears to have been primarily for light and secondly for soil nitrogen. In addition, overtopping woody (aspen) vegetation cover appears to have had a beneficial effect through its reduction of winter injury. At young stages, in a mixedwood stand, controlling only woody vegetation is unlikely to provide conditions for the best growth of planted spruce, and may not result in growth increases over those found without treatment, since woody removal results in expansion of grass, which exerts competitive effects that are at least equal to those of the woody vegetation. The radial complete control treatment is a promising alternative to classical broadcast treatments for establishing spruce in a mixedwood stand. A radial treatment reduces competitive effects, provides a protective environment against extreme weather, and retains sufficient aspen to allow development of a nearly intimate mixture of aspen and spruce. The application of spot radial treatments are likely to provide the best yields of spruce if they are followed by juvenile tending of aspen at an appropriate age, but this requires further study.

Results from this study can be used by foresters in the management of young mixedwood stands. However, continuing measurement at Judy Creek is needed to evaluate effects of surrounding aspen and herbaceous vegetation on spruce growth. A limitation of this present study is the apparent lack of treatment effects on soil moisture. Other studies have suggested that during some years, at least, competition for soil moisture may be a problem in young mixedwood stands. The fact that 2004 and 2005 were relative wet growing seasons resulted in our inability to detect competition for moisture. However, this may still occur during dry summers, or during dry periods in the summer, and merits ongoing monitoring at the Judy Creek site. Additional studies designed to examine these questions are also needed on other sites in order to provide information that can be used to test the general application of these results.

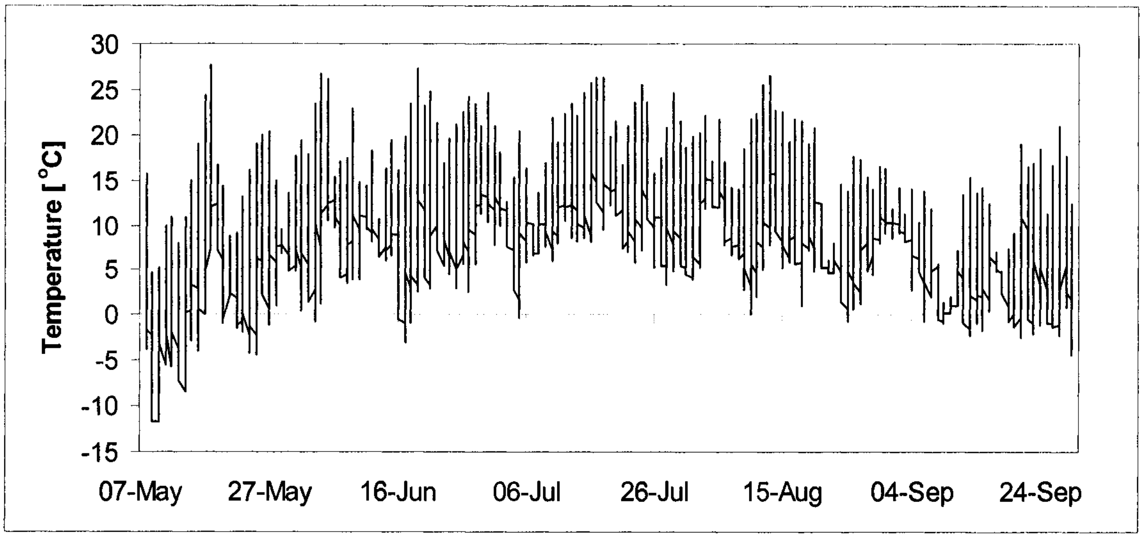
# APPENDIX 1



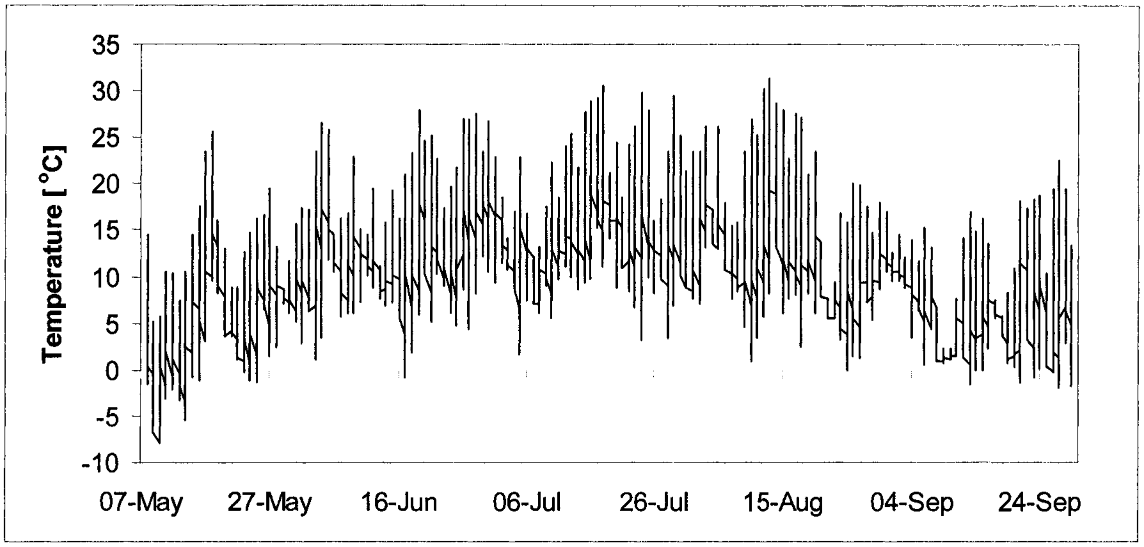

Trends for air temperature at 30 cm height in the growing season of 2004 (May 08 – September 29) for **broadcast complete control** treatment. Note: hourly average values were used to show the trends.



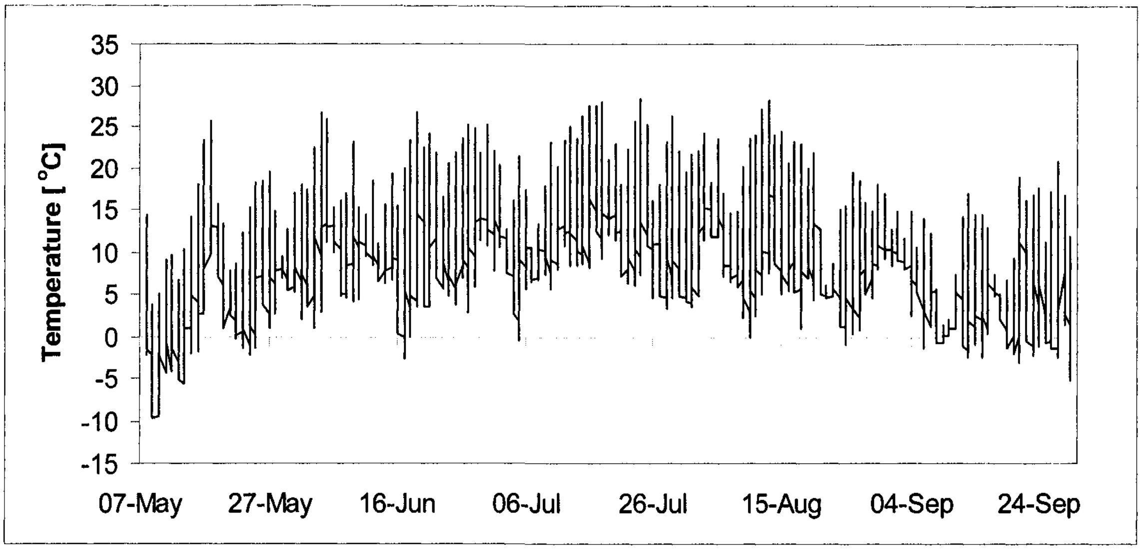

Trends for air temperature at 30 cm height in the growing season of 2004 (May 08 – September 29) for **radial complete control** treatment. Note: hourly average values were used to show the trends.



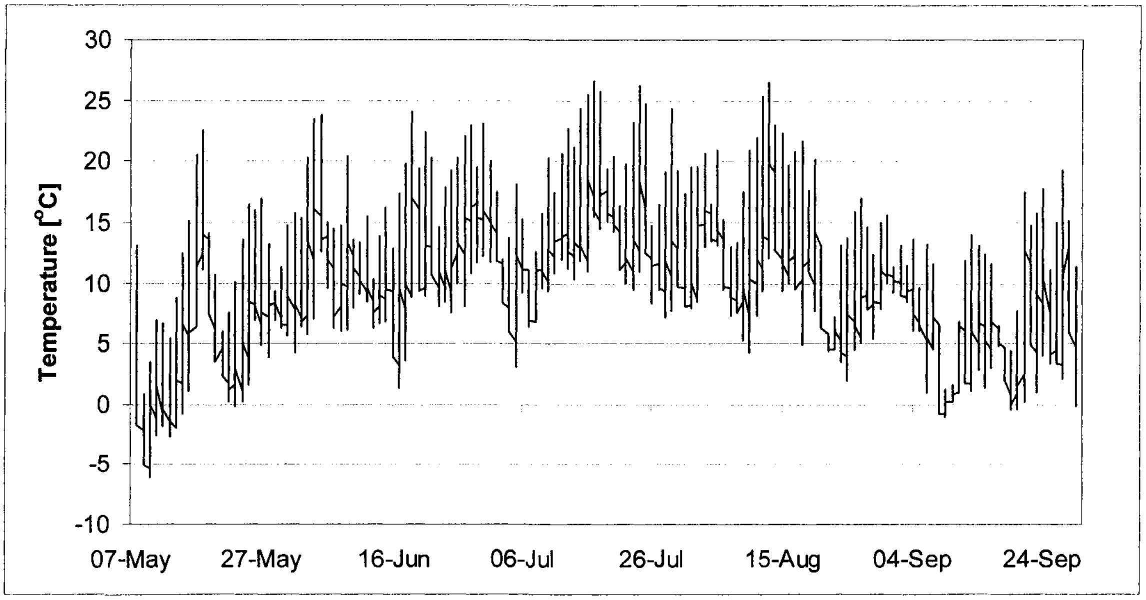

Trends for air temperature at 30 cm height in the growing season of 2004 (May 08 – September 29) for **no treatment**. Note: hourly average values were used to show the trends.



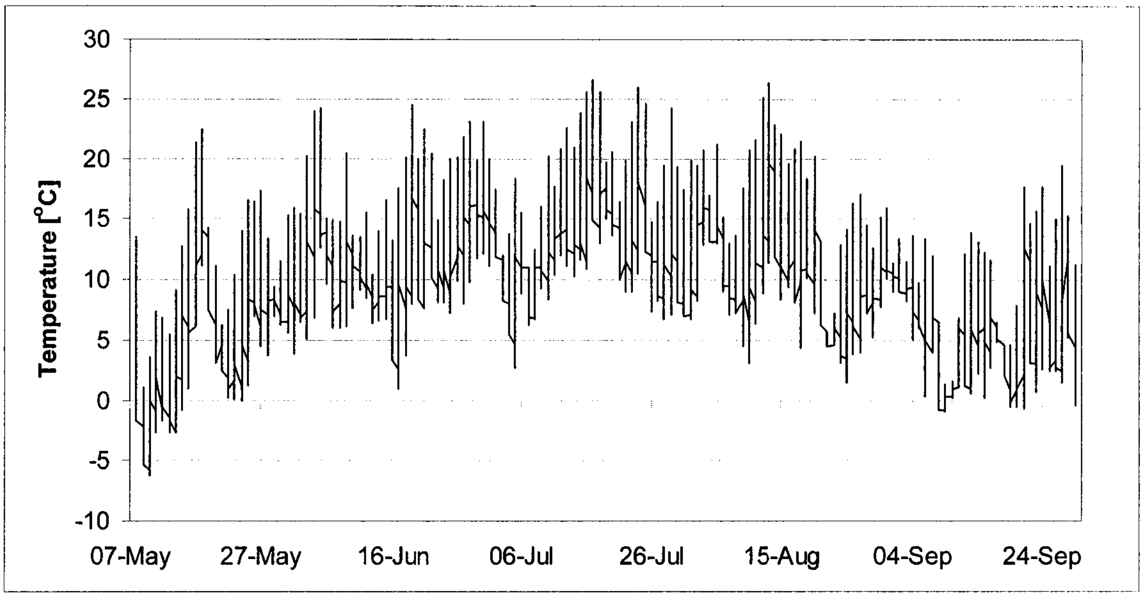

Trends for air temperature at 30 cm height in the growing season of 2004 (May 08 – September 29) for **broadcast woody control** treatment. Note: hourly average values were used to show the trends.



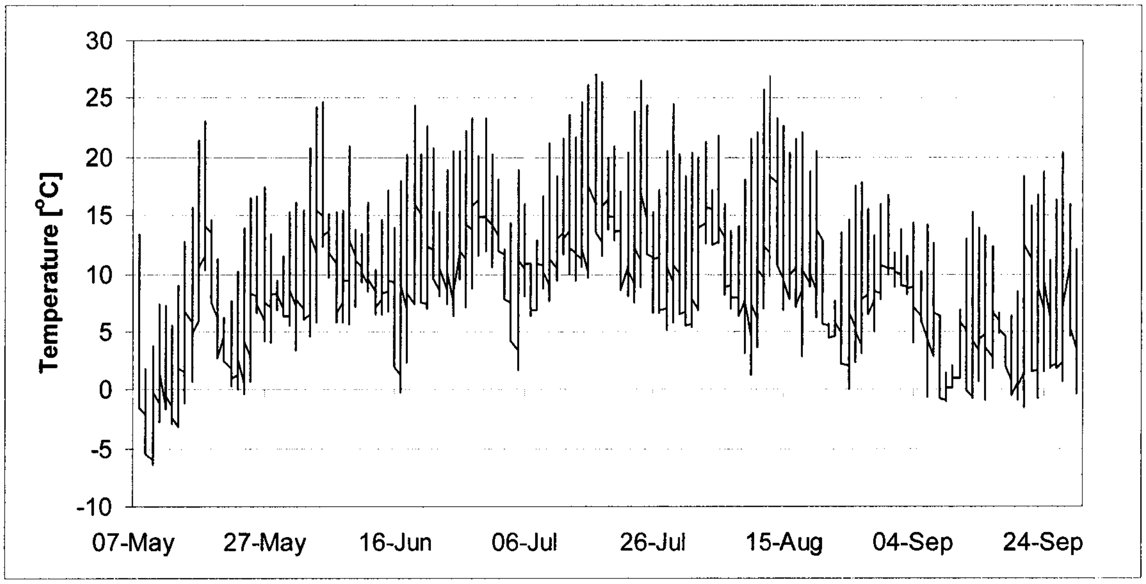

Trends for air temperature at 30 cm height in the growing season of 2004 (May 08 – September 29) for **radial woody control** treatment. Note: hourly average values were used to show the trends.



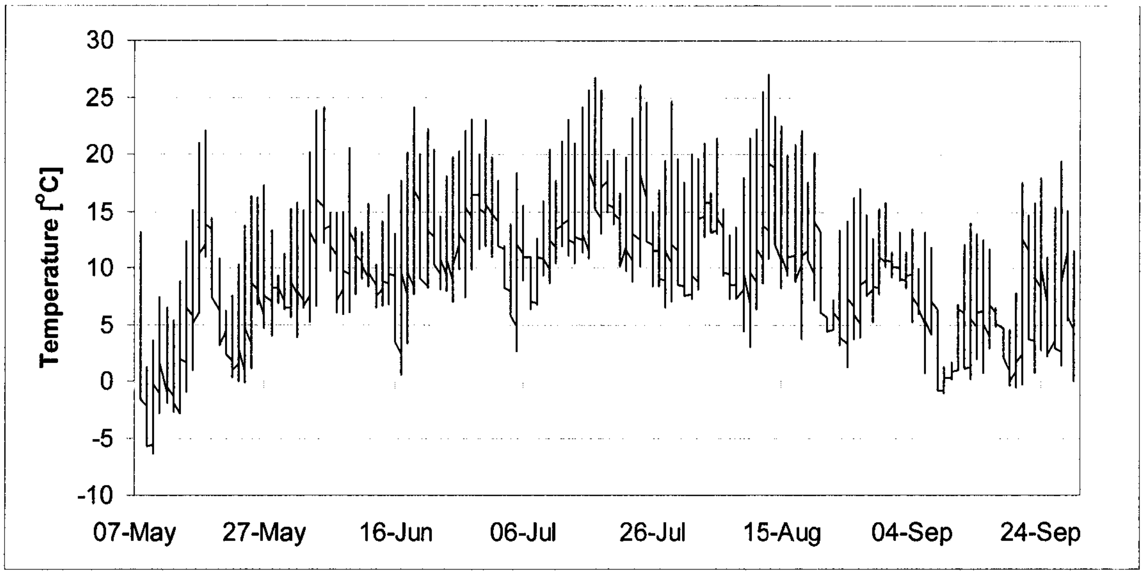

Trends for air temperature at 150 cm height in the growing season of 2004 (May 08 – September 29) for **broadcast complete control** treatment. Note: hourly average values were used to show the trends.



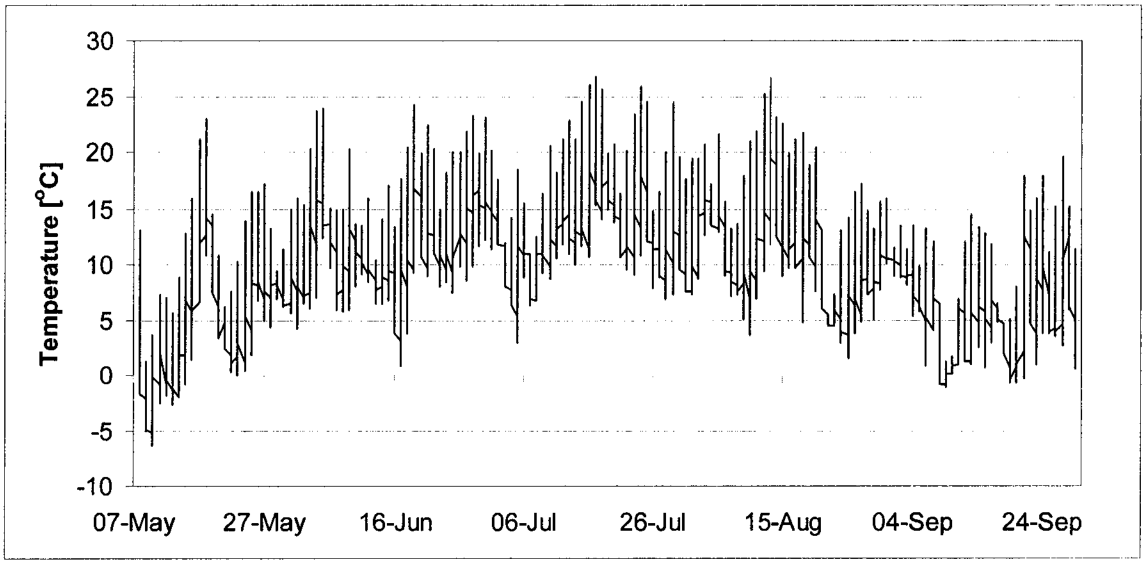

Trends for air temperature at 150 cm height in the growing season of 2004 (May 08 – September 29) for **radial complete control** treatment. Note: hourly average values were used to show the trends.



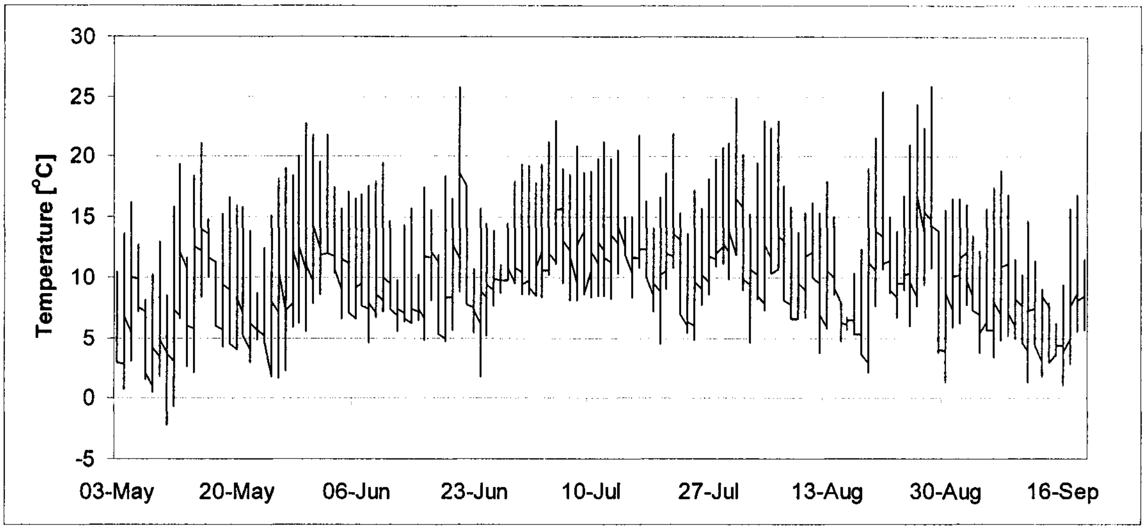

Trends for air temperature at 150 cm height in the growing season of 2004 (May 08 – September 29) for **no treatment**. Note: hourly average values were used to show the trends.



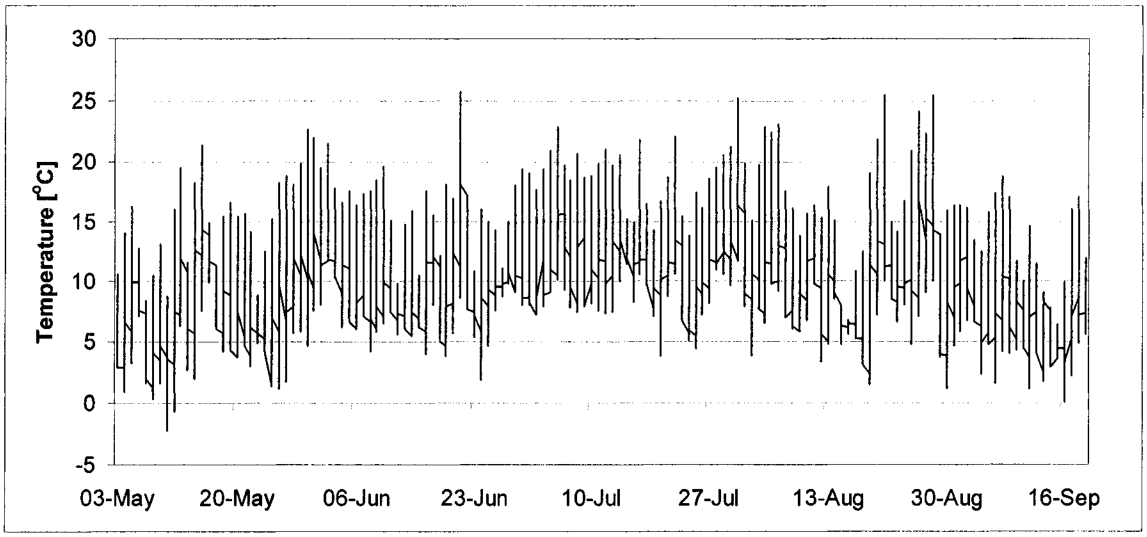

Trends for air temperature at 150 cm height in the growing season of 2004 (May 08 – September 29) for **broadcast woody control** treatment. Note: hourly average values were used to show the trends.



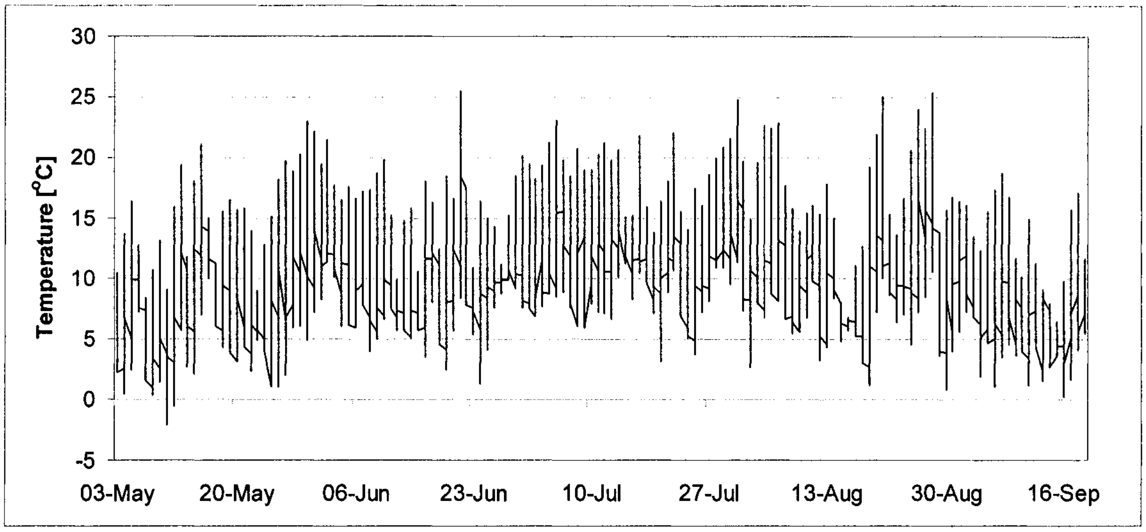

Trends for air temperature at 150 cm height in the growing season of 2004 (May 08 – September 29) for **radial woody control** treatment. Note: hourly average values were used to show the trends.



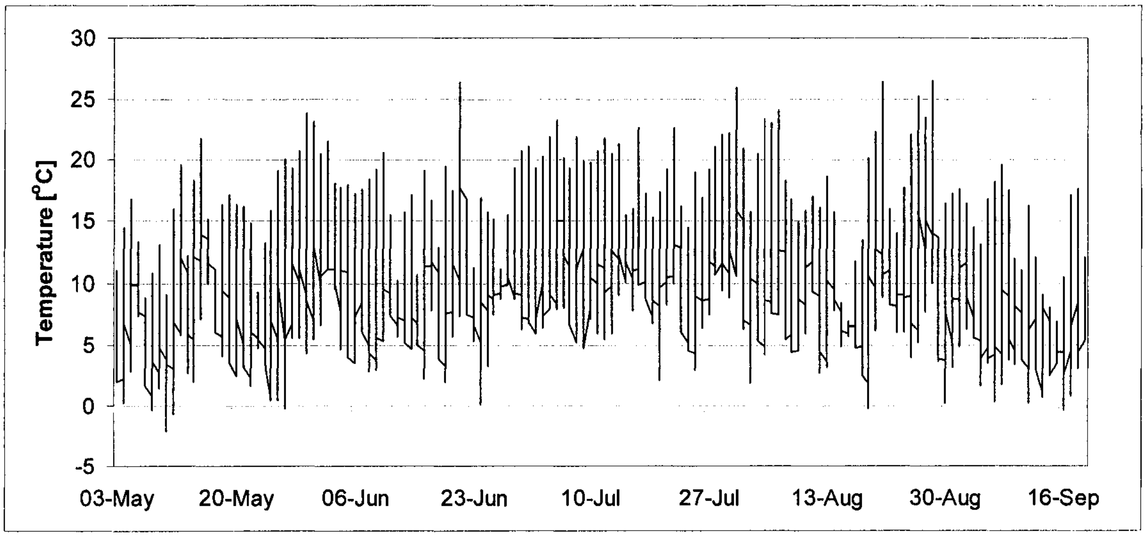

Trends for air temperature at 150 cm height in the growing season of 2005 (May 03 – September 19) for **broadcast complete control** treatment. Note: hourly average values were used to show the trends.



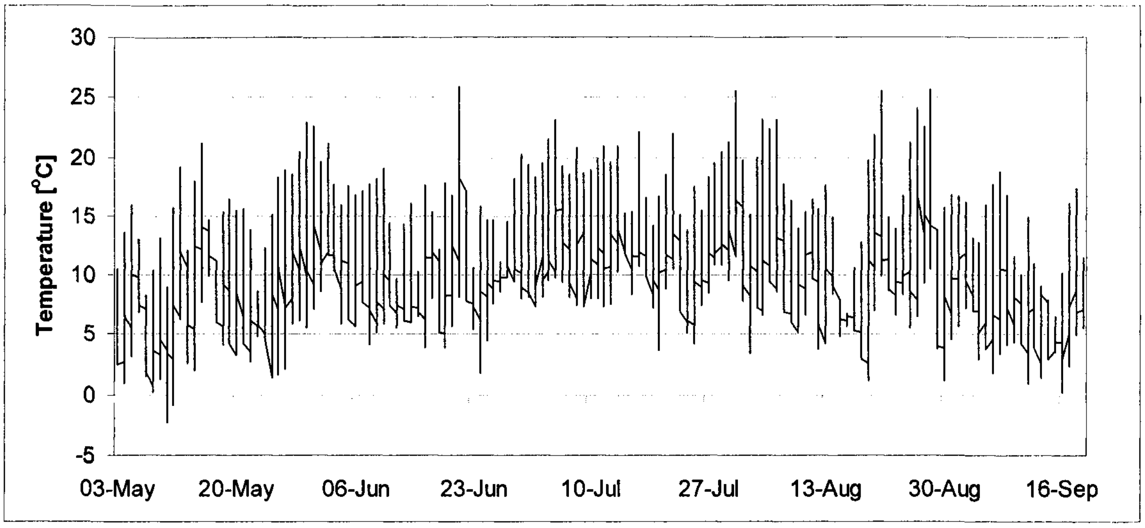

Trends for air temperature at 150 cm height in the growing season of 2005 (May 03 – September 19) for **radial complete control 2 years** treatment. Note: hourly average values were used to show the trends.



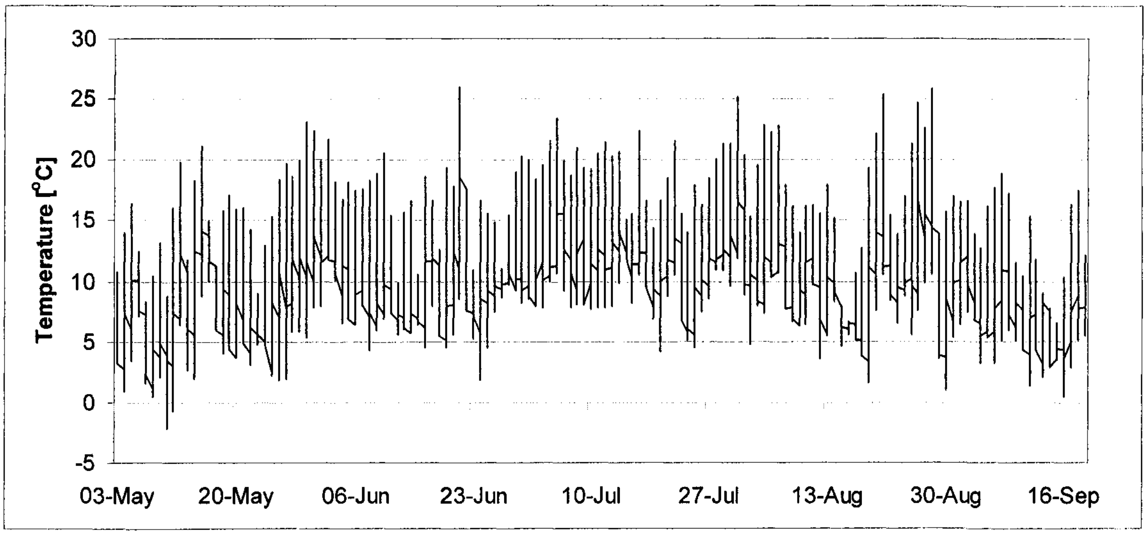

Trends for air temperature at 150 cm height in the growing season of 2005 (May 03 – September 19) for **radial complete control 3 years** treatment. Note: hourly average values were used to show the trends.



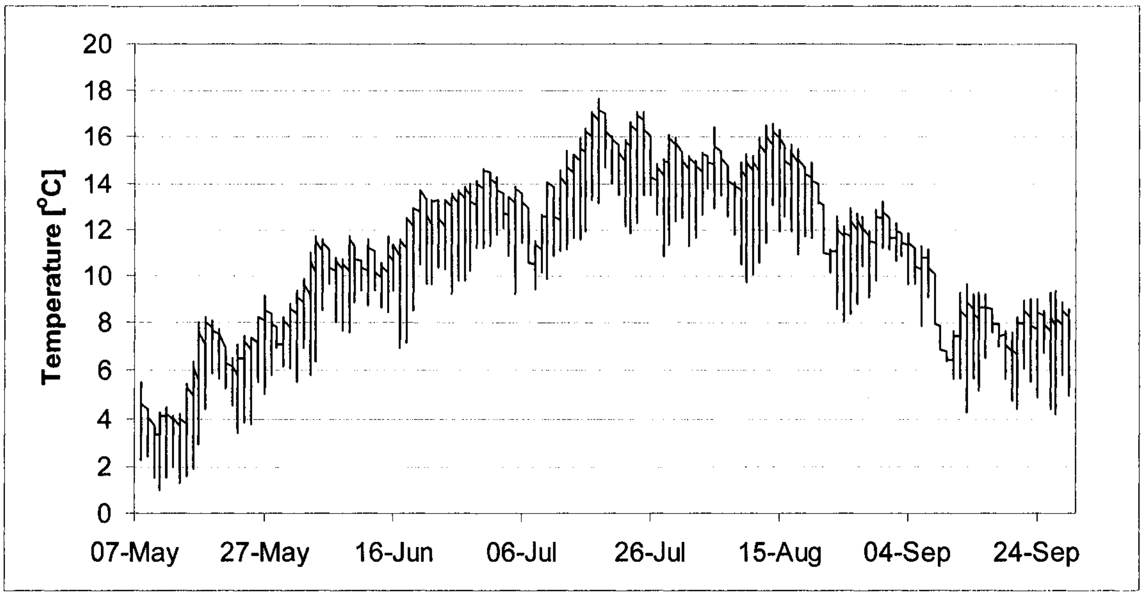

Trends for air temperature at 150 cm height in the growing season of 2005 (May 03 – September 19) for **no treatment**. Note: hourly average values were used to show the trends.



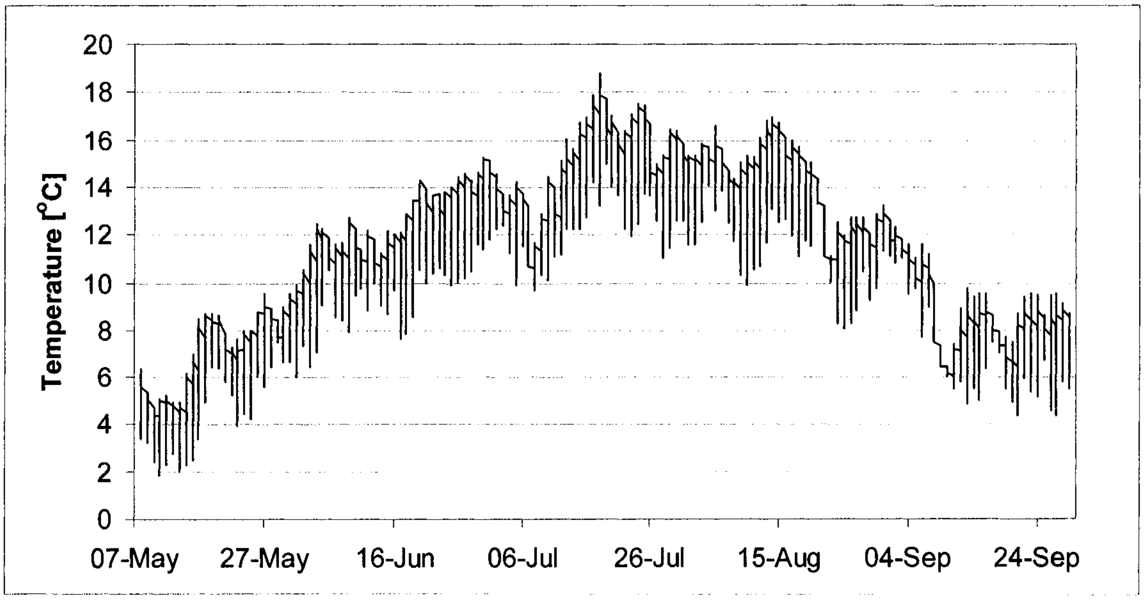

Trends for air temperature at 150 cm height in the growing season of 2005 (May 03 – September 19) for **broadcast woody control** treatment. Note: hourly average values were used to show the trends.



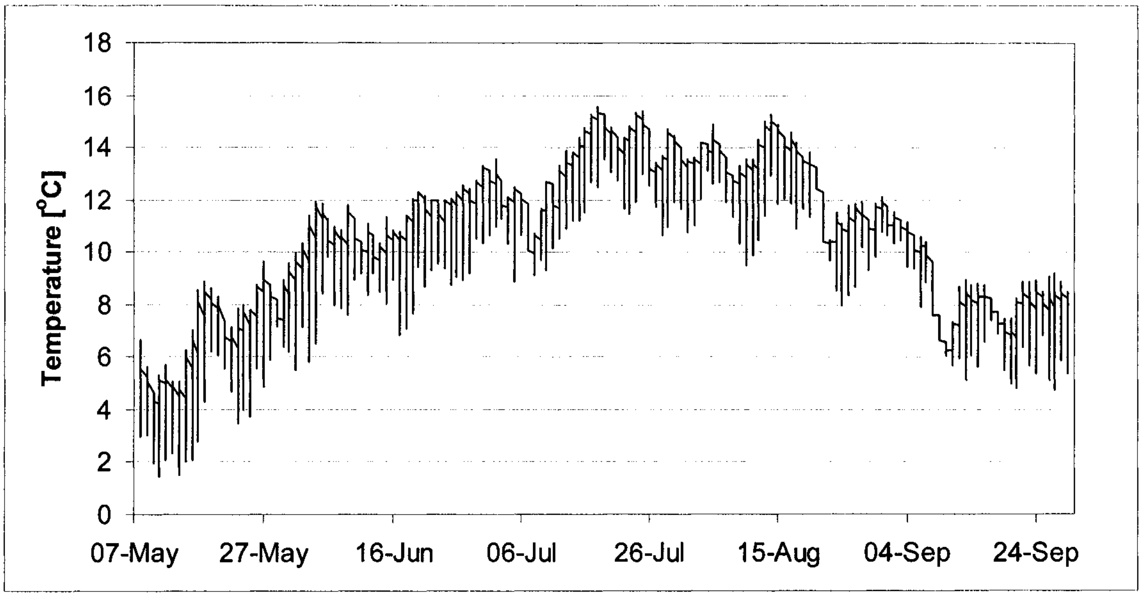

Trends for air temperature at 150 cm height in the growing season of 2005 (May 03 – September 19) for **radial woody control** treatment. Note: hourly average values were used to show the trends.



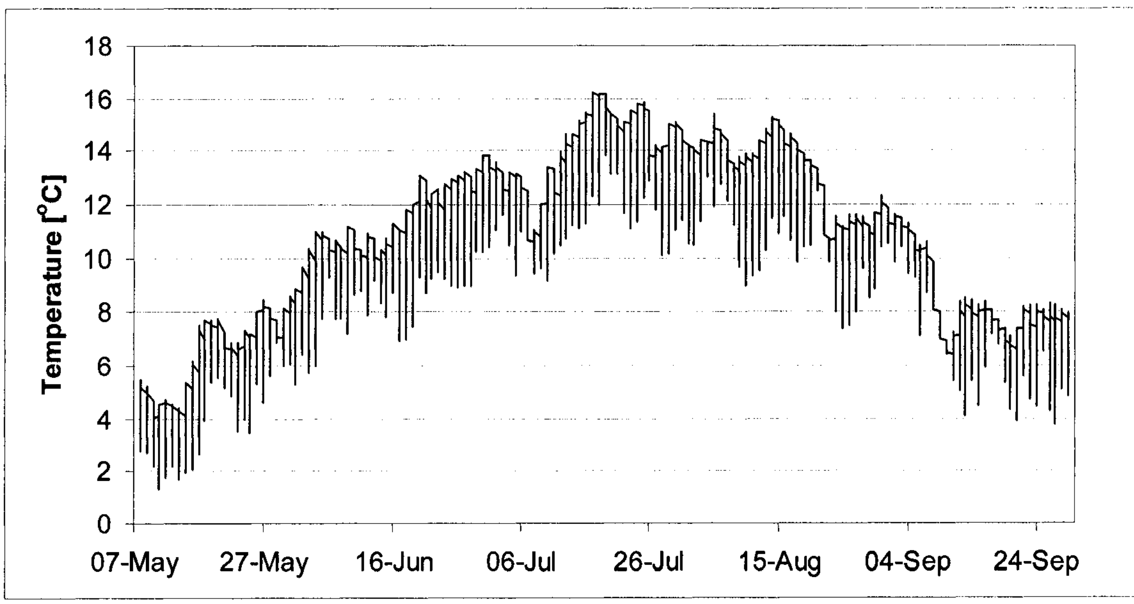

Trends for soil temperature at 20 cm depth in the growing season of 2004 (May 08 – September 29) for **broadcast complete control** treatment. Note: hourly average values were used to show the trends.



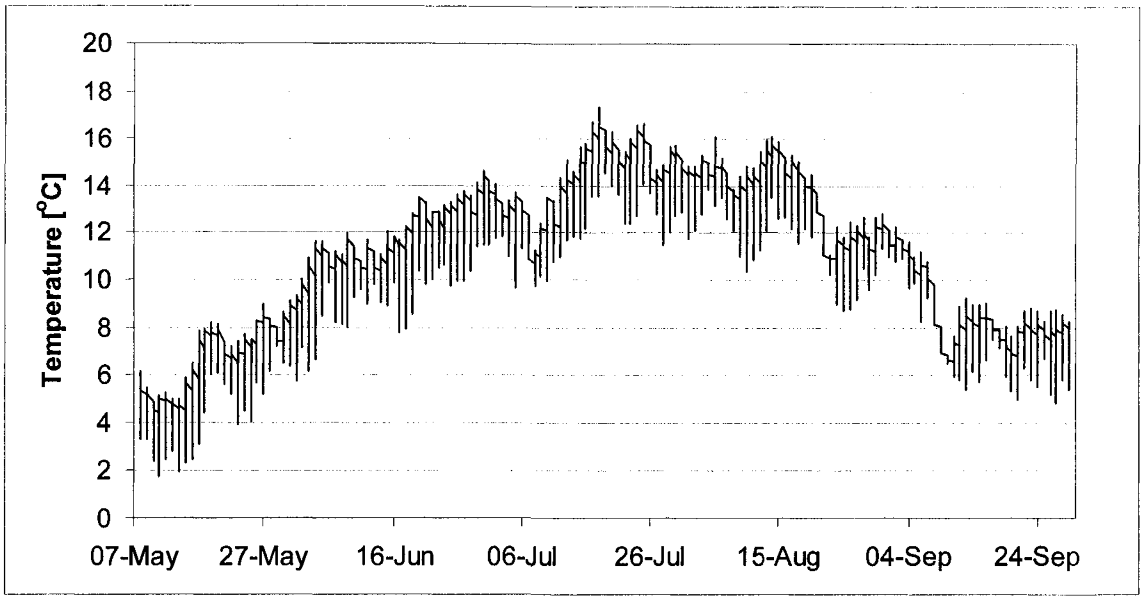

Trends for soil temperature at 20 cm depth in the growing season of 2004 (May 08 – September 29) for **radial complete control** treatment. Note: hourly average values were used to show the trends.



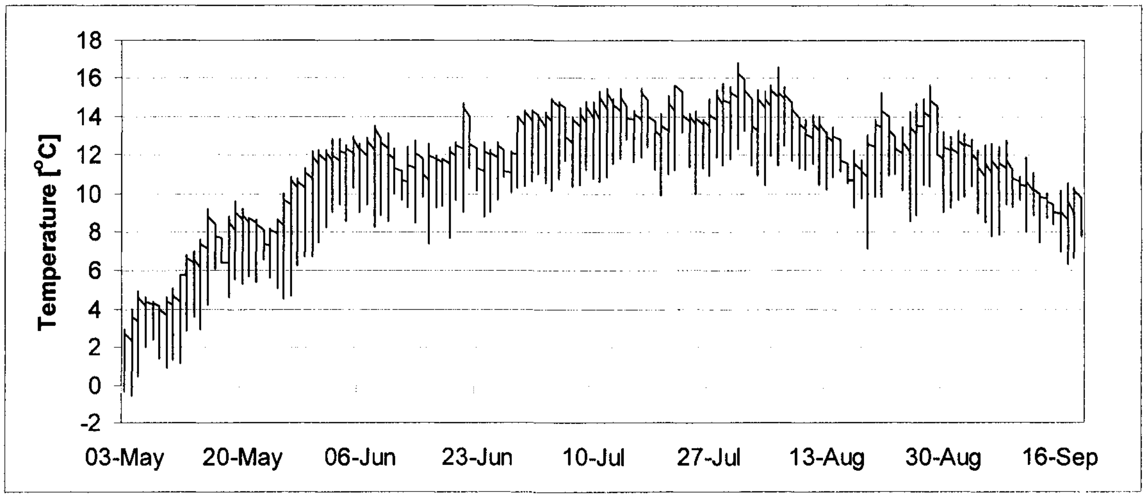

Trends for soil temperature at 20 cm depth in the growing season of 2004 (May 08 – September 29) for **no treatment**. Note: hourly average values were used to show the trends.



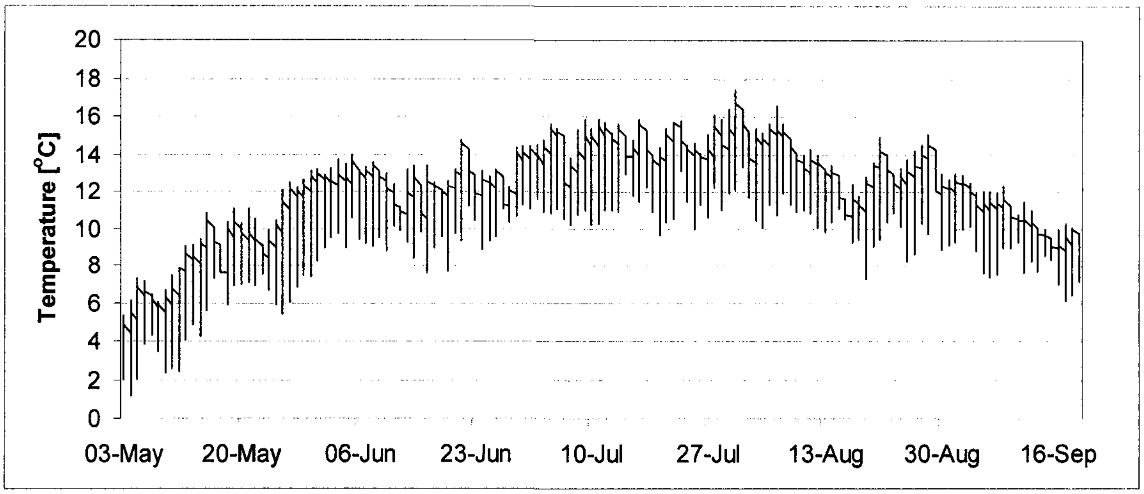

Trends for soil temperature at 20 cm depth in the growing season of 2004 (May 08 – September 29) for **broadcast woody control** treatment. Note: hourly average values were used to show the trends.



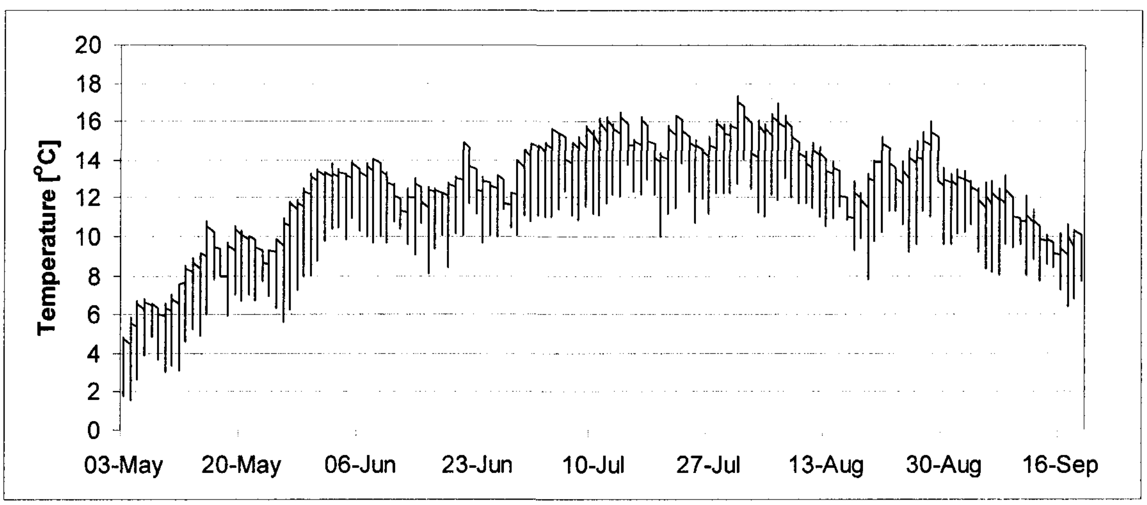

Trends for soil temperature at 20 cm depth in the growing season of 2004 (May 08 – September 29) for **radial woody control** treatment. Note: hourly average values were used to show the trends.



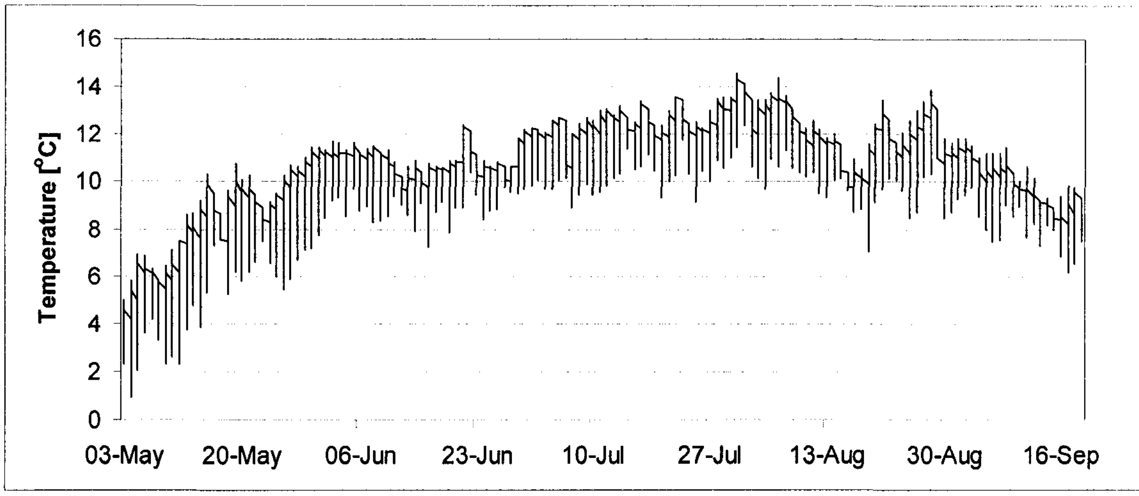

Trends for soil temperature at 20 cm depth in the growing season of 2005 (May 03 – September 19) for **broadcast complete control** treatment. Note: hourly average values were used to show the trends.



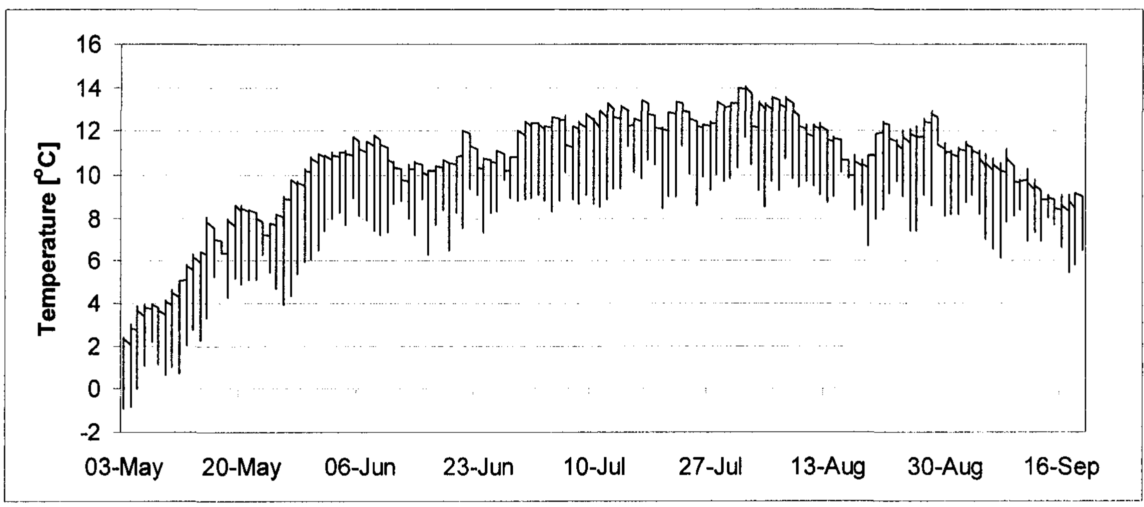

Trends for soil temperature at 20 cm depth in the growing season of 2005 (May 03 – September 19) for **radial complete control 2 years** treatment. Note: hourly average values were used to show the trends.



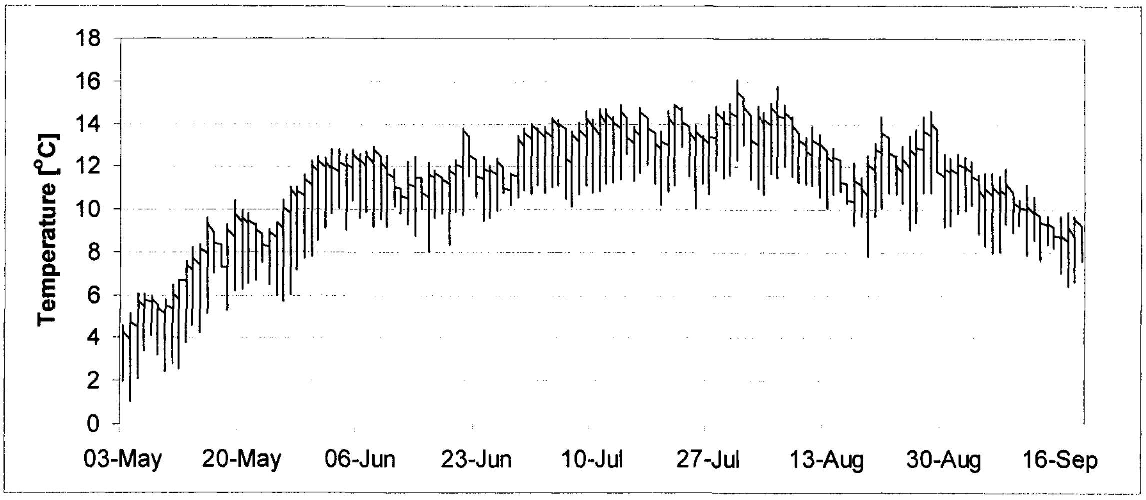

Trends for soil temperature at 20 cm depth in the growing season of 2005 (May 03 – September 19) for **radial complete control 3 years** treatment. Note: hourly average values were used to show the trends.




Trends for soil temperature at 20 cm depth in the growing season of 2005 (May 03 – September 19) for **no treatment**. Note: hourly average values were used to show the trends.




Trends for soil temperature at 20 cm depth in the growing season of 2005 (May 03 – September 19) for **broadcast woody control** treatment. Note: hourly average values were used to show the trends.




Trends for soil temperature at 20 cm depth in the growing season of 2005 (May 03 – September 19) for **radial woody control** treatment. Note: hourly average values were used to show the trends.