Growth of Aspen and White Spruce in Planted Mixtures

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Introduction

Mixedwood stands dominated by aspen and white spruce are the most common tree mixture in Canadian boreal forests, particularly in the west (Rowe 1972). The review by Man and Lieffers (1999) indicated that aspen and white spruce interactions in mixture could lead to a greater yield than in pure species stands, through competitive reduction and facilitation (Vandermeer 1989, Kelty 1992). The 'mixedwood productivity gain' likely depends on species interactions that not only differ with species involved, but also vary with composition and vertical and horizontal structure. While the ecological benefits of mixedwoods are well recognized (MacDonald 1995), little is known about the magnitude of productivity gain relative to stand structural attributes.

The objective of this study is to examine the early growth of aspen and white spruce in planted mixtures varying in species composition and to relative compare productivity (plot volume production). Results will help practitioners manage species composition and structure when creating and maintaining mixedwood stands.

Methods

Experimental design and treatments

The study site is located on the Alberta Research Council's research station at Vegreville, Alberta. The soil is Dark Gray Chernozem with good soil drainage (Soil Classification Working Group 1998).

A randomized block design was replicated three times. Twenty treatments resulted from combinations of 5 species compositions described based on proportions: from pure aspen (Aw100), mixed aspen and spruce (Aw83Sw17, Sw50Aw50, Aw17Sw83), and pure spruce (Sw100), two moisture regimes (irrigation and control), and two nutrient conditions (fertilization and control). Moisture was added through irrigation based on 30-year average growing season rainfall in the study area, while the control served as the scenario of reduced soil moisture resulting from climatic drought during the course of experiment. Each treatment plot is 5 x 4 m surrounded by metal sheets inserted vertically 60 cm deep. The soil was ripped to a depth of approximately 30 cm before planting and Propex 3919 landscape fabric was used to hinder development of competitive vegetation.

White spruce and aspen seedlings (provided by Smoky Lake Forest Nursery, AlPac seedlot and K & C Silviculture, Weyerhaeuser Drayton Valley seedlot) were planted in early June 1999. The one-year old aspen seedlings had been trimmed to approximately 15 cm and cold stored until planting. The white spruce seedlings were started from seed, field grown for 1.5 years and cold stored until the time of outplanting. Seedlings were planted on a 50 cm grid so that a total of 63 seedlings were planted in each plot. Aspen and spruce were interspersed in the mixed-species plots. The 25 seedlings in plot centre were used for growth measurements. A handful of forest soil from a natural mixedwood stand and Plant Starter Fertilizer 10-52-10 (Plant-Prod® Water Soluble Fertilizer) were applied to each seedling at the time of transplanting. Regular watering was carried out in the first year to improve the establishment of all seedlings.

Both moisture and nutrient conditions were differentiated among treatments from the second year. The fertilized plots received a split application each year in the second and third year after planting. The first application was shortly after the snow melted (mid-April) and the second was in early July. Fertilization rates in each application were ammonium nitrate (34-0-0) at 150 kg N (nitrogen)/ha and phosphorus pentoxide 0-45-0 at 50 kg P (phosphorus)/ha. The granular fertilizers were mixed and applied around the base of each tree and between rows, followed by immediate irrigation to all plots at approximately 100 litres per plot (5 mm depth).

The intensity and frequency of irrigation varied depending on weather. Rainfall was close to normal in the second year and spread evenly throughout the summer. Irrigation was not carried out until August when soil moisture was low based on Time Domain Reflectometry (TDR) readings. Plots were watered every two weeks, with approximately 5 mm of water delivered each time.

Manual irrigation was continued for the entire growing season in the third year, following the same intensity and frequency. In the fourth year, manual irrigation was replaced with a drip semi-automatic system installed at individual tree bases. Due to the extremely dry weather in 2002, a total of 180 mm water was added to the irrigated plots. Approximately 50 mm water was manually added to the non-irrigated control plots to reduce the risk of massive mortality.

Weeds and aspen suckers inside the plots were hand-cleared. Aspen roots that grew over the metal insulator were severed. Planted seedlings that died in the first summer and winter were replaced in spring of second year to maintain plot density and species composition, with spare seedlings of the same stock reserved in a nearby planting. Each year, snow fence was set up on the north side of the plots in late October and removed in late April to reduce the risk of winter desiccation. The entire study area was fenced to prevent deer browsing and rabbit damage.

Data collection and analysis

Data collection included individual tree growth of 25 trees in plot center, foliar chlorophyll fluorescence, leaf area index, foliar and soil nutrient levels, and soil moisture.

Annual growth measurements were conducted in late September and early October. Measurements included total height, RCD (root collar diameter), and crown width averaged from two directions, south-north and east-west.

Chlorophyll fluorescence of white spruce in *situ* was measured annually with a portable chlorophyll fluorescence meter (PAM 2000, Heinz - Walz GmbH, Germany) to examine the effects of different treatments on the integrity of the photosynthetic system. Readings were taken twice a year, in mid-summer between late July and early August and in the fall between late September and mid-October. Five seedlings were randomly selected from the growth measurement trees within each plot and individual tree readings were averaged by plot. The 'Yield" parameter, defined as the ratio of (Fm'-Ft)/Fm' and commonly determined under steady-state illumination, was chosen to reflect chlorophyll fluorescence yield. Dark cloudy days were preferred for fluorescence measurement, but late afternoon/early evening (when sampled foliage did not receive direct sunlight) measurements were also used.

Leaf area index (LAI) was determined annually starting in the second year. All treatment plots were assessed in mid-August using LAI 2000 Plant Canopy Analyzer. Readings were taken at five locations within each plot, four in the corners and one at the plot centre, and the values were averaged by plot.

Soil and foliar samples were collected in 2000, the second year after planting, to assess the nutrient status in soil and foliage. In mid-September, four soil cores were taken to a depth of 25 cm from each plot and bulked together. Soil samples were air-dried and analyzed for N, P, and K (potassium). Foliar samples from growth measurement trees were collected in mid-August for aspen and in mid-September for spruce. Collected foliar samples were freeze-dried and analyzed for N, P, K, magnesium, calcium, and sodium.

Soil moisture was monitored in all treatment plots with single diode TDR probes inserted vertically at plot center at three depths, top (0-20 cm), middle (20-40 cm) and bottom (40-60 cm) layers. Rod length was 16.5 cm. Volumetric soil moisture content readings were taken bi-weekly between early May and early October except for a two-month delay the first year. Two readings were taken each time and averaged for each probe using the TDR unit (Moisture Point TK-917, Environmental Sensors Inc., Victoria, BC).

Data were analyzed with Pro Mixed procedure available with SAS 8.02. The effects of treatments on height, RCD, crown width, and chlorophyll fluorescence were assessed by tree species and measurement time. All individual-tree measurements were averaged to generate plot-level means prior to statistical analysis. Trees replaced in the first year, from mortality not likely caused by experimental treatments (watering, fertilization, or species composition), were excluded from the plot average calculation for tree height, RCD, and crown width. A similar analytical approach was applied to determine treatment effects on soil moisture at three depths, soil and foliar nutrient content, and LAI.

Total volume by species at plot level was the sum of individual-tree stem volume calculated from height and RCD using a cone model and plot density and composition. Since volumes of mixes are not directly comparable due to different growth rates of aspen and spruce, a relative volume production by plot was used to facilitate comparisons. The relative volume production of spruce or aspen was defined as the total volume in mixture divided by the total volume in pure species plots (Kelty 1992). The relative volume total is the sum of relative volume production of both aspen and spruce in the mixed-species plots.

Results

Soil moisture and nutrient levels

A period of severe drought occurred during the experiment. Based on data from a nearby weather station in Vegreville, total precipitation was 305 mm in 1999, 386 mm in 2000, 238 mm in 2001, and 201 mm in 2002, compared to 374 mm, the 30-year normal from 1971-2000 (Environment Canada weather station data). Soil moisture was similar at different depths, ranging from 13-40% for the top layer, 11-38% for middle layer, and 11-42% for bottom layer. Mean soil moisture generally decreased with depth and over time (from year 1 to 4) as well as within years from beginning to end of growing season (Fig. 1).

Soil moisture tended to decrease with increased proportion of aspen in the plots, particularly in the first two years when moisture levels were relatively high (Fig. 1). Mean soil moisture averaged over the four years and three soil depths are 18% for mostly aspen plots (Aw83Sw17 and Aw100), and 20% for mostly spruce plots (Sw83Aw17and Sw100). Differences in soil moisture content among the five composition treatments decreased with increased soil depth and reduced soil moisture (Fig. 1).

Soil moisture was generally similar between the irrigated and control plots at all three depths, with an exception in the third year (2001) when higher moisture content from irrigation was measured in most middle layer and a few bottom layer observations during mid and late season. The average difference was 2% in the middle layer, but decreased to about 1.5% in the bottom layer.

Total soil N, P, and K in the second year were 3000, 700, and 140 µg/g and not affected by any treatments. The mean available ammonium was 2.67 µg/g in the irrigated plots and 2.45 µg/g in the control plots (P=0.0547). Irrigation treated plots also had higher available soil nitrate (49.02 vs 17.74 µg/g for irrigated and control plots, P<0.0001) and P (5.05 vs 4.04 µg/g for irrigated and control plots, P=0.0133). Among the five species mixtures, available P increased as the proportion of aspen decreased from 4.00 µg/g in Aw100 to 5.03 µg/g in Sw100 (P=0.0029).

Seedling growth

Average aspen trees were 11.2 mm in RCD, 75 cm in total height and 39 cm in crown width by the end of first year. The largest increment occurred in the second year, with an average increase of 13.0 mm in RCD, 113 cm in height and 57 cm in crown width. Aspen growth slowed down in the third year, particularly crown width, which remained unchanged in the fourth year (Fig. 2).

RCD in white spruce followed the same pattern as that in aspen, with the largest average increment (6.1 mm) in the second year, and the smallest (1.8 mm) in the fourth year. Mean total height of spruce trees was 40 cm by the end of first year, followed by increments of 14 cm, 21 cm, and 17 cm from second to fourth year. Mean crown width was 20 cm in the first year and increased 15 cm the second year, 14 cm the third year, and 12 cm the fourth year.

Both aspen and white spruce showed a general trend of reduced growth as the proportion of aspen increased in the plots. The only exception was crown width of white spruce with the best growth in the mixed-species of Aw50Sw50 or Aw17Sw83 (Fig. 2). The effect of composition became apparent in the second year and increased over time with tree size. By year 4 mean aspen trees were 46% bigger in RCD, 11% taller in total height, and 53% larger in crown width as aspen proportion decreased from 100% to 17%, while the corresponding changes in white spruce were 41%, 18%, and 3% with aspen proportion decreasing from 83% to 0%.

Irrigation did not affect seedling growth of either species until the fourth year. At the end of fourth year, irrigated aspen averaged 38.7 mm in RCD, 296 cm in height, and 107 cm in crown width, compared to 35.5 mm, 256 cm, and 98 cm for the non-irrigated control trees (P=0.005, 0.0001, and 0.0008 for the three growth parameters). By year 4, irrigated spruce trees averaged 21.3 mm in RCD, 95 cm in height, and 62 cm in crown width, while non-irrigated spruce averaged 20.5 mm, 88 cm, and 60 cm, respectively (P=0.0172, 0.0001, and 0.0103). Irrigation increased aspen growth by 9%, 16%, and 9%, and spruce growth by 4%, 8%, and 3%, respectively. The relation between growth and species composition was also significantly different between irrigated and controlled plots for spruce at year 4 (P=0.0004 for RCD, 0.0004 for height and 0.0005 for crown width for the irrigation and composition interaction).

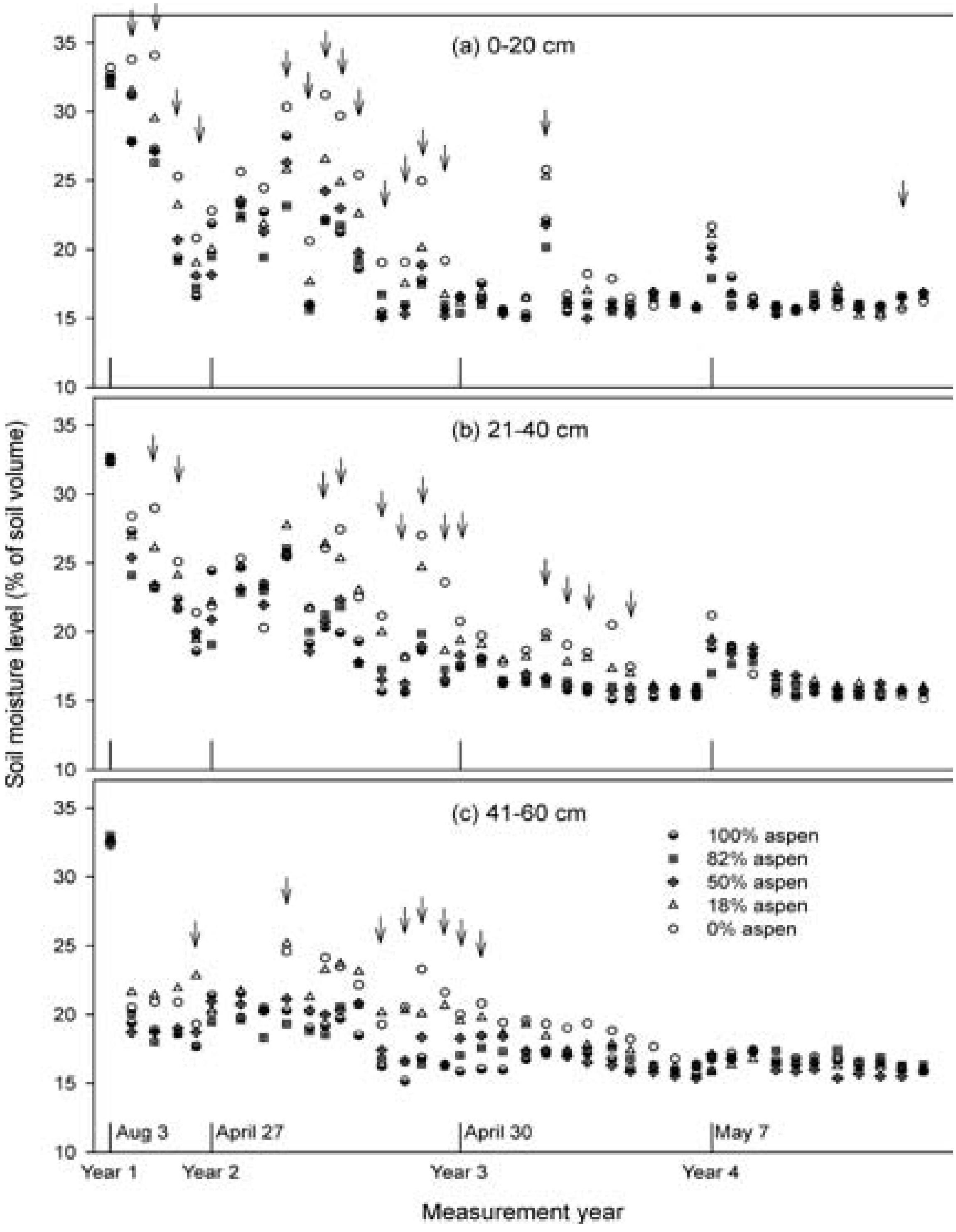

__Figure 1.__ Mean soil moisture by tree species composition at three depths in aspen - white spruce mixture study in Alberta (arrows indicate significance).

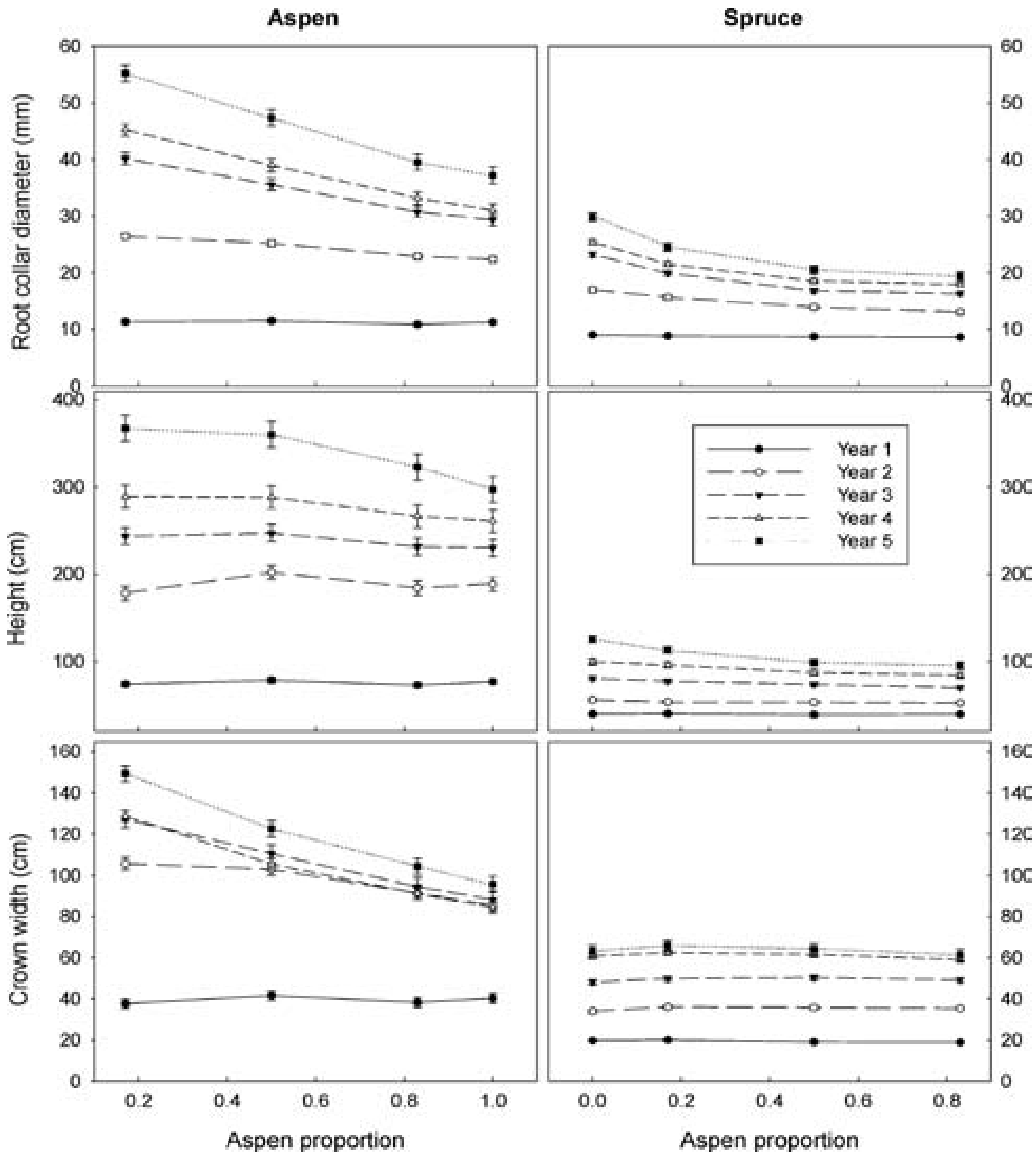

Figure 2. *Relationships between seedling growth and proportion of aspen in mixed plantings in the first four years after establishment in Alberta.*

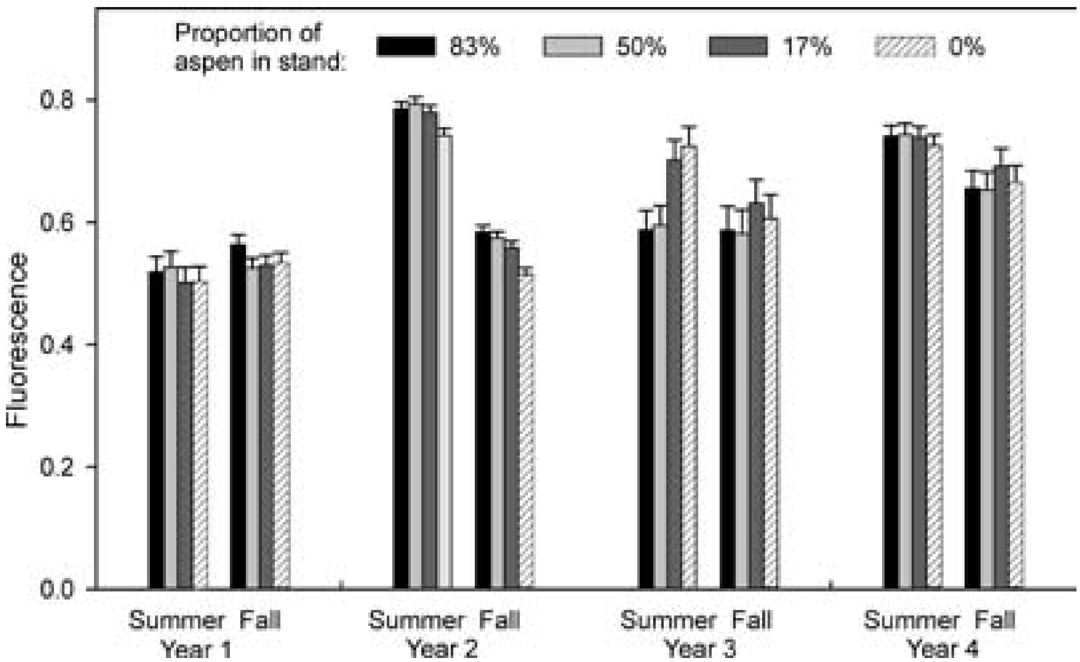

Figure 3. *Chlorophyll fluorescence of white spruce in mixtures by proportion of aspen, season, and years after planting.*

Fertilization did not change the growth of aspen, but reduced height and crown development of white spruce in year 3 and 4 (P<0.0001). By the end of year 4, fertilized seedlings averaged at 86 cm in height and 59 cm in crown width, which was 12% and 8% smaller than seedlings in the non-fertilized control.

Foliar nutrient and chlorophyll florescence

The calcium level increased proportionally with the decrease of aspen proportion from 0.81% in the Aw83Sw17 plots to 0.94% in Sw100 plots (P=0.0543), while magnesium level changed from 0.16% in the Sw100 to 0.19 in Aw83Sw17 plots (P=0.0267). Significant composition effect on foliar nutrient levels of aspen trees was only observed on sodium concentration, which was 0.11% in Aw100 plots and 0.02, 0.03, and 0.01% for the three mixed-species plots.

Irrigation treatment enhanced foliar P levels in aspen from 0.24% in the irrigated plots to 0.23% in the control (P=0.0019). In white spruce, irrigation increased the foliar total N from 1.76% in the control to 1.84% in the treated plots (P=0.0016), but decreased total P (0.19% and 0.17% for control and treated plots, P<0.0001) and K (0.70% and 0.65% for control and treated plots, P=0.0011) concentrations. Fertilization did not change the foliar nutrient levels for aspen or white spruce.

A significant difference in chlorophyll fluorescence of white spruce was evident among the four species compositions in the second (P<0.0001 for the summer and P=0.0002 for the fall measurements) and third years (P<0.0001 and P=0.0415 for the two measurements). Readings in the second year were higher in the high aspen proportion plots, particularly in the fall, while the opposite was observed in the third year when chlorophyll fluorescence appeared to be higher in the low aspen proportion plots (Fig. 3).

Plot volume and leaf area index

The relative volume production of mixed-species plots by irrigation treatment is presented in Table 1. The data indicate a general increase in aspen and a decrease in spruce relative volume production over time after planting. The increase of aspen relative volume is greater than the decrease of spruce volume, particularly in the Aw50Sw50 plots. As a result, the mixed-species plots produced more volume (greater relative volume total) than pure species plots on relative basis by year 4. The relative volume production gain in mixed-species plots differs with irrigation treatment and is generally higher for irrigated plots.

The greater volume production in the Aw50Sw50 is supported by the LAI measurements starting in the second year (Table 2). The LAI in year 4 was also increased by irrigation (4.02 vs 3.03 for irrigated and control plots, P<0.0001), but decreased by fertilization (3.43 vs 3.64 for irrigated and control plots, P=0.0255).

Table 1. *Relative volume production for mixed aspen (Aw) and white spruce (Sw) plots in the first four years after establishment.*

Year	Aw83Sw17 Aw	Aw83Sw17 Sw	Aw83Sw17 Total	Aw50Sw50 Aw	Aw50Sw50 Sw	Aw50Sw50 Total	Aw17Sw83 Aw	Aw17Sw83 Sw	Aw17Sw83 Total
Irrigated plots									
1	0.80	0.18	0.98	0.62	0.51	1.13	0.28	0.81	1.09
2	0.84	0.10	0.94	0.74	0.32	1.06	0.24	0.73	0.97
3	0.90	0.07	0.97	0.85	0.24	1.09	0.37	0.62	0.99
4	0.97	0.07	1.04	0.91	0.23	1.14	0.46	0.60	1.06
Control plots									
1	0.75	0.16	0.91	0.61	0.44	0.95	0.19	0.76	0.95
2	0.84	0.10	0.94	0.63	0.32	0.94	0.23	0.63	0.85
3	0.94	0.08	1.02	0.73	0.24	0.98	0.34	0.55	0.89
4	0.96	0.08	1.04	0.82	0.24	1.06	0.37	0.54	0.91

Table 2. *Leaf area index (means ± standard errors) of aspen (Aw) and white spruce (Sw) mixtures in the first few years after planting.*

Year after planting	Aw100	Aw83Sw17	Aw50Sw50	Aw17Sw83	Sw100
Year 2	2.45 ± 0.18	2.45 ± 0.18	2.36 ± 0.18	1.74 ± 0.18	1.07 ± 0.18
Year 3	3.66 ± 0.40	3.48 ± 0.40	3.63 ± 0.40	3.37 ± 0.40	2.15 ± 0.40
Year 4	3.38 ± 0.17	3.59 ± 0.17	3.91 ± 0.17	3.59 ± 0.17	3.22 ± 0.17

Discussion

Aspen leaves have less control of water loss than spruce (Jarvis and Jarvis 1963), which may explain why aspen were more sensitive to drought during the experiment. Mean growth increases of aspen in response to irrigation treatments were almost twice those of white spruce: 9%, 16%, and 9% versus 4%, 8%, and 3% for RCD, total height, and crown width, respectively. The greater response of height growth suggests that tree height is more sensitive to drought than RCD or crown width. The improvement of tree growth by irrigation may be the result of higher soil moisture and greater soil nutrient availability. For example, irrigation may have enhanced foliar concentration of total P in aspen and total N in spruce.

High water consumption by aspen on per unit leaf area basis (Peterson and Peterson 1992) may have resulted in lower soil moisture on the higher proportion aspen plots and reduced individual tree growth for both species. Again, aspen seems more sensitive to the change of aspen density, especially in crown width. Besides soil moisture, competition for light is also responsible for the strong response of RCD to the variation of aspen density in both species. In aspen, there was a close relationship between crown width and aspen density, while white spruce show little difference in crown width with aspen density. Species composition also affects soil P availability and foliar concentrations of total Ca and total Mg in spruce and total Na in aspen, likely due to the different demand for nutrients between aspen and white spruce (Peterson and Peterson 1992).

The lack of response to fertilization treatment in both aspen and spruce is likely attributed to the adequate soil nutrient supplies, as indicated by soil and foliar analysis and absence of visual symptoms for nutrient deficiency (Ballard and Carter 1983; van den Driessche 1989). Nutrient availability may have been reduced by low soil moisture from the drought. van den Driessche and Ponsford (1995) found that the increase of nitrogen availability through fertilization created requirements for other nutrients, which could induce nutrient deficiency. This may be the main reason for negative growth response of spruce to fertilization in this study.

The results of this study support current mixedwood practices that create mixedwood stands with equal proportions of hardwood and conifers. High initial density may result in the interaction between aspen and white spruce in the planted mixtures by year 4 being similar to that of 20- to 30-year-old stands established at 2- to 3-m spacing, based on LAI (Lieffers et al. 2002) and crown development. As species interaction in mixtures may intensify with the growth of crown width, the mixedwood productivity gain might shift to mixtures with a smaller proportion of hardwood and reach to a higher level with the reduction of stand density as trees age, as indicated by Man and Lieffers (1999) in examining unmanaged natural mixedwood stands in Alberta.

Both LAI and relative volume production show a similar trend among treatments and over time. LAI in pure aspen plots peaked at year 3 and started to decline by year 4, while LAI of pure spruce and mixed-species plots continue to increase (Table 2). At the end of year 4, mixed-species plots carried a greater LAI than pure species plots and the highest LAI was in the Aw50Sw50 plots.

Because of competitive advantage of aspen over spruce, relative volume production of aspen increased and that of spruce decreased from year 1 to 4 after planting (Table 1). However, the change in volume production is smaller in spruce, likely due to shade tolerance. White spruce may also photosynthesize during spring and fall when aspen is lacking leaves (Man and Lieffers 1997).

This study shows that species mixtures of aspen and white spruce can produce more volume. A similar volume production gain is expected for natural mixedwood stands under similar weather conditions. It is unclear from this study if non-irrigated control plots can achieve similar volume gains within a longer period of time.

In this study aspen and white spruce were grown in mixtures in the aspen parkland zone of Alberta. The weather in this zone is dry and restricts tree growth, compared to boreal forest zone (Hogg and Hurdle 1995). With a greater availability of rainfall and therefore soil moisture in the boreal mixedwood zone and eastern boreal forest, mixedwoods may provide a greater volume gain possibly at earlier stages of stand development.

Acknowledgements

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