Living Snow Fence Analysis Year 5: Measurement years 2003-2007

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Introduction

In the spring of 2003 a living snow fence was established near Davenport, WA to investigate the utility of using living trees to prevent or reduce the accumulation of windblown snow on roads. The living snow fence was established along 900 feet of a north-south segment of Highway 25 approximately 14 miles north of Davenport. The living snow fence consists of four rows of Rocky Mountain juniper trees (*juniperus scopulorum*) planted as two pairs of two identical rows. The two row pairs were spaced 42 feet apart, 100 feet west of Highway 25, and were planted parallel to the highway. The two rows within each pair of rows were spaced 8 feet apart, and each row contained 133 trees spaced approximately 6.75 feet apart along north-south line parallel to the highway, giving a total of 532 planted trees.

Locations of the pairs of twin rows were designated as west (W) and east (E), with the east pair of rows being closer to the highway. The individual rows located within each pair of rows were identified as row one (1) and row two (2), with row two being closer to the highway, or east of row one. Row E2, then, designates the row that is closest to Highway 25 and row W1 designates the row that is furthest from Highway 25. Each row was further subdivided into three equal segments, North, Middle, and South that were used to assess potential variation in tree development by north-south position within each row. The nesting levels for the living snow fence installation along Highway 25 are shown in Table 1.

Tree measurements were taken annually in the fall from 2003 to 2007. The measurements were taken in early October for 2003, 2004, 2006, and 2007 and in early September for 2005. Every fifth tree in each row was measured beginning with the northern most tree and proceeding southward along the rows. A total of 27 trees were, therefore, sampled in each row, giving an overall total of 108 possible tree measurements for each year: 54 trees for each location, 27 trees for each row within a location, and 9 trees for each position within a row. Survivorship of the initially measured trees has been 100% in all measurement years to date. Total tree height and crown width in inches were measured for each sampled tree.

The living snow fence was installed in an active agricultural field adjacent to the highway. The prevailing wind direction at this installation was from the west, making the west location windward and the east location leeward, with row one being the windward row and row two being the leeward row within each location. In addition to the prevailing wind direction, there was also a slight mound centered along the north-south line within the rows of planted trees.

Given the preferential wind direction and central mound within the rows, identifying differences in average tree size between the locations of the paired rows, between the rows within a location, and among the positions within a row for each location and measurement year were of primary interest. Also of interest was whether the initial relationships and differences in average tree size that were observed within each nesting level would persist as longer term trends over time. Finally, with five years of measurements it was feasible to investigate annual differences in mean growth rates for tree height and crown width over the four growing seasons, within each nesting level.

Methods

To identify potential differences in mean tree size by year and nesting level a nested or hierarchical analysis of variance (ANOVA) was performed. A fixed effects model was assumed for the analysis and the nested layout described in Table 1 was used for each measurement year, making measurement year an additional nesting level above location. Total tree height and tree crown width were the two tree size attributes used for separate analyses. Significant differences by year were anticipated for each measured characteristic, the trees grew and became larger in each year, but year was included in the ANOVA so that all of the relevant comparisons beneath measurement year could be performed within a single ANOVA procedure for each characteristic, rather than performing separate ANOVA procedures for each year and characteristic. An α-level of 0.05 and the corresponding critical values from the F distribution were used to determine statistical significance for each of the ANOVA procedures.

Table 1 Nested design for the living snow fence installation.

Location	Row	Position
West	One	North Middle South
	Two	North Middle South
East	One	North Middle South
	Two	North Middle South

To identify potential differences in annual mean tree growth rates by year and nesting level a second pair of nested (ANOVA) procedures were performed. A fixed effects model was also assumed for the growth rate analysis and the same nested layout was used for mean growth rates computed from consecutive measurement years. In each pair of measurement years, the growing season was associated with the spring of the second measurement year, so as before growing season was an additional nesting level above location. Growth rates were computed for total tree height and tree crown width by taking the differences between the measurements for each tree on consecutive measurement years. Significant differences by year were, again, anticipated for the mean growth rates of each measured characteristic, but no specific patterns were anticipated. Again, an α-level of 0.05 and the corresponding critical values from the F distribution were used to determine statistical significance for each of the ANOVA procedures.

Tree measurements were collected one month sooner in 2005, in September rather than October. Tree growth occurs at different rates throughout the year, making any corrections to the 2005 and 2006 growth rates difficult. This one month difference should, however, have a minimal impact on the annual mean growth rates for the 2005 and 2006 growing seasons, since tree growth would have slowed dramatically by autumn, with the bulk of the tree growth occurring in the spring. In addition, climatic variability during these growing seasons would be expected to have a much greater impact on tree growth rates than the one month difference in the growing years for 2005 and 2006. For these reasons, the tree measurement data were used *as is* to compute approximate annual mean growth rates.

Significant results identified by an ANOVA procedure for each size and growth rate characteristic were examined further by using approximate 95% confidence intervals (CIs) for the means within each nesting level to perform a multiple comparisons analysis. The 95% CIs were computed using critical values from the Student's *t*-distribution using an α-level of 0.05 with the appropriate degrees of freedom for each nesting level. The multiple comparisons analyses were used to identify potential differences in mean tree size or mean growth rate between the locations, between rows within a location, and among positions within a row for each year.

When performing the multiple comparisons tests within each nesting level, approximate 95% CIs were obtained using the mean and standard error values computed from the tree measurements or growth increments within the individual cells of each nesting level. Comparisons between any two cells within a nesting level may then produce one of three possible outcomes:

1) the 95% CIs for both of the cells being compared contain the mean for the other cell;
2) the 95% CI for one of the two cells does not contain the mean of the other cell;
3) the 95% CIs for both of the cells being compared do not contain the mean value for the other cell.

These outcomes were assumed to indicate 1) no detectable potential differences in mean values, 2) weak potential differences in mean values, and 3) strong potential differences in mean values. The combined effects of any observed strong or weak potential differences in mean values were assumed to be the cause of any significant results obtained for a particular nesting level within the ANOVA procedures that were performed.

Results

Results are presented in two stages. The ANOVA results for total tree height and crown width and their respective annual growth rates are presented first in the next section. Results of the multiple comparisons analysis of mean values for total tree height and crown width and their respective annual mean growth rates within the different nesting levels follow. The multiple comparisons analysis highlights potential differences within the nesting levels identified by the respective ANOVA procedures.

ANOVA Results

The ANOVA results for total height and crown width are presented in Table 2 and Table 3, respectively. As anticipated average tree size differed among measurement years for both total height and crown width. Significant differences were also found by position within a row for total tree height, with a *p*-value of $p = 0.0012$ and between locations for mean crown width, with a *p*-value of $p = 0.0025$.

Table 2 ANOVA results for mean height. Significant effects at α=0.05 are indicated by an asterisk*.

Factor nesting	*DF*	*SS*	*MS*	*F*	*Pr(>F)*
Year	4	223265	55806	878.757	0*
Year/location	5	130	26	0.408	0.8430
Year/location/row	10	468	47	0.738	0.6892
Year/location/row/position	40	4570	114	1.799	0.0025*
Residual	480	30488	64		

Table 3 ANOVA results for mean crown width. Significant effects at α=0.05 are indicated by an asterisk*.

Factor nesting	*DF*	*SS*	*MS*	*F*	*Pr(>F)*
Year	4	122473	30618	751.907	0*
Year/location	5	763	153	3.746	0.0025*
Year/location/row	10	56	6	0.138	0.9992
Year/location/row/position	40	1834	46	1.126	0.2796
Residual	480	19546	41		

The ANOVA results for annual mean height and crown width growth rates are presented in Table 3 and Table 4, respectively. As anticipated annual mean growth rates differed among growing years for both total height and crown width. No other significant differences were found for mean height growth rate, but there was a significant result observed for the annual mean crown width growth rates between locations, with a *p*-value of $p = 0.0014$. A nearly significant result was obtained for mean crown width growth rates by position within rows, with a *p*-value of $p = 0.0601$.

Table 4 ANOVA results for mean height growth rate. Significant effects at α=0.05 are indicated by an asterisk*.

Factor nesting	*DF*	*SS*	*MS*	*F*	*Pr(>F)*
Year	3	3385.9	1128.6	66.291	0*
Year/location	4	109.5	27.4	1.608	0.1714
Year/location/row	8	60.7	7.6	0.446	0.8930
Year/location/row/position	32	505.2	15.8	0.927	0.5841
Residual	384	6537.7	17.0		

Table 5 ANOVA results for mean crown width growth rate. Significant effects at α=0.05 are indicated by an asterisk*.

Factor nesting	*DF*	*SS*	*MS*	*F*	*Pr(>F)*
Year	3	31346	10448.7	589.390	0*
Year/location	4	321.2	80.3	4.530	0.0014*
Year/location/row	8	65.8	8.2	0.464	0.8812
Year/location/row/position	32	818.5	25.6	1.443	0.0601
Residual	384	6807.6	17.7		

Height results

Mean tree height increased for each measurement year after the initial measurement for all positions within a row, rows within a location, and locations. Mean values for total tree height, in inches, with standard errors and sample sizes for all nesting levels are presented in Table 6. The differences in mean height among the measurement years were highly statistically significant with a *p*-value approximately equal to zero. Mean height values ± one standard error were 22.4±0.42 inches, 40.1±0.58 inches, 54.1±0.71 inches, 69.4±0.88 inches, and 79.4±1.14 inches, respectively, for measurement years 2003 through 2007. As mean tree size increased so did the variability in individual tree size, as indicated by increasing values for the standard errors over time.

Annual mean height growth rates varied over the four growing years, with 2004 and 2006 producing the largest values and 2005 and 2007 producing the smallest values. Mean height growth rates, in inches, with standard errors and sample sizes for all nesting levels are presented in Table 7. The differences in annual mean height growth rates among the measurement years were highly statistically significant with a *p*-value approximately equal to zero. The observed annual mean height growth rates ± one standard error were 17.7±0.31 inches, 14.0±0.37 inches, 15.3±0.40 inches, and 10.0±0.48 inches, respectively, for growing years 2004 through 2007.

Height and height growth rate among positions within a row

Mean height values by year and position within a row are presented graphically in Figure 1 with 95% confidence intervals indicated and in Table 6, along with standard errors and sample sizes. Individual tree heights within each position were somewhat variable, with mean height values increasing over time for all positions within each row. The patterns of height development, however, varied by row.

In row W1, the south position had the smallest mean height values for all measurement years, with its north and middle positions having mean heights that were essentially equal for all measurement years. Within this row, strong potential differences in mean height were identified between the north and middle positions and its south position for measurement years 2003 - 2005, and between only the north and south positions in 2006 and 2007. Weak potential differences in mean height occurred for this row in 2006 and 2007 between the middle and south positions.

In row W2, the north position had the smallest mean height values for all measurement years, with the middle and south positions being essentially equal for 2003 and 2004. Mean heights for the middle position became larger than those for the south position beginning in 2005 and continuing to 2007. In addition, the differences in mean height between the middle and south positions within this row may be increasing, as indicated by the widening vertical gaps between the trajectories in Figure 1. Within this row, strong potential differences in mean height occurred between the north and south positions and the middle position in 2005 and 2007, and between the north and middle positions in 2006. Weak potential differences in mean height for this row occurred between the north and south positions and the middle for 2005 and between the middle and south positions in 2006.

In rows E1 and E2, the south position had the largest mean height values for all years, with the north and middle positions being essentially equal. Within Row E1, strong potential differences in mean height occurred between the middle and south positions in 2004 and 2006. Weak potential differences in mean height for this row occurred between the north and south positions in 2003 and 2004, between the middle and south positions in 2005, and between the south and north positions in 2007. Within row E2, strong potential differences in mean height occurred between the middle and south positions only in 2003. Weak potential differences in mean height occurred for this row between the south position and the north and middle positions in 2005, and between the south position and the north position in 2006 and 2007.

Annual mean height growth rates by year and position within a row are presented graphically in Figure 2 with 95% confidence intervals indicated and in Table 7, along with standard errors and sample sizes. Annual height growth rates for individual trees within each position were quite variable. The mean height growth rates in 2005 and 2007 were typically smaller than those for the other two growing years for all positions, but the patterns of mean height growth rate varied by row.

In row W1, the mean height growth rate for the north position was greatest, followed by the middle and south positions, respectively, in 2004. In 2005, all three positions had essentially equal growth rates, all of which were smaller than their respective 2004 growth rates. In 2006, the height growth rate for the north position in the row was again the largest, while the growth rates for the middle and south positions were essentially equal, and only the growth rate for the north position had increased relative to its value in 2005. Mean height growth rates in 2007 were the smallest values over all growing years and were more variable than in previous years, with the north position producing the smallest value and the middle position producing the largest value.

In row W2, the mean height growth rate for the middle position was larger than those for the other two positions in 2004, 2005 and 2007, but was nearly equal to the growth rate for the south position in 2006. Mean height growth rates for all three positions declined from 2004 to 2005, with the growth rate for the south position being slightly smaller than that for the north position. The mean height growth rate for the south position increased from 2005 to 2006, while the growth rates for the north and middle positions decreased or remained essentially unchanged from their 2005 values, respectively. Mean height growth rates declined for all three positions from 2006 to 2007, with the decline for the south position being greatest.

In row E1, the south position had the largest mean height growth rate in 2004, 2006, and 2007, with the north position having the largest growth rate in 2005. The north position had the second largest mean height growth rates in 2004 and 2007, but the middle position had the second largest growth rate in 2006. The mean height growth rates for all three positions in this row decreased from 2004 to 2005, with the growth rates for the middle and south positions increasing and the growth rate for the north position continuing to decline for 2006. Mean height growth rates for all three positions declined again from 2006 to 2007.

In row E2, all three positions had essentially equal mean height growth rates in 2004. The mean height growth rate for the south position was greater then the growth rates for the north and middle positions which were nearly equal in 2005. The mean height growth rate for the middle position was greatest in 2006, with the north and south positions having similar growth rate values. All three growth rates were nearly equal in 2007. The mean height growth rates for all three positions decreased from 2004 to 2005, with the south position declining the least. Mean growth rates increased for the north and middle positions but decreased slightly for the south position from 2005 to 2006, and the growth rates for all three positions declined from 2006 to 2007.

There was only one strong potential difference in mean height growth rates, and it occurred between the north and middle positions of row W2 in 2004. Weak potential differences were observed for row W2 between the middle and south positions in 2004, between the north position and the middle and south positions in 2006 and 2007, and between the north and south positions in row E1 in 2006 and 2007.

Height and height growth rate between rows within a location
Mean height values by year and row within a location are presented graphically in Figure 3 with 95% confidence intervals indicated and in Table 6, with standard errors and sample sizes. The mean height values for all rows within each location increased over time. Within each location, the windward rows, rows W1 and E1, had smaller mean height values than the leeward rows, rows W2 and E2, respectively, for all measurement years. A strong potential mean height differences between rows within a location was found only in 2004 for rows E1 and E2 of the east location. A weak potential mean height difference was also found in 2003 for the east location, the mean for row E2 was outside the 95% CI computed for row E1.

Annual mean height growth rates by year and row within a location are presented graphically in Figure 4 with 95% confidence intervals indicated and in Table 7 with standard errors and sample sizes. The mean height growth rates for the pairs of rows within each location showed no consistent patterns over time. For the 2004 growing year, the mean height growth rates for the leeward rows, rows W2 and E2, were greater than those for their respective windward rows, rows W1 and E1. In the 2005 growing year, the relationship for the mean height growth rates was reversed for the west rows, while the east rows had equal growth rates. The mean height growth rates for the windward rows, rows W1 and E1, were greater than their respective growth rates for the leeward rows, rows W2 and E2, in the 2006 growing season reversing the original relationships. In 2007 the relationships reversed again, with the leeward rows W2 and E2 producing slightly greater mean growth rates than the windward rows W1 and E1.

Only two weak potential differences were found for mean height growth rates between rows within the locations. They both occurred in the 2004 growing year, where the mean growth rate for row W2 was outside the 95% CI for the row W1 and the mean growth rate for row E1 was outside the 95% CI for row E2. The means for rows W2 and E1 were outside the 95% CIs for their respective comparisons, by only 0.01 and 0.30 inches, respectively, indicating that the potential differences detected may not be relevant, and could be attributable to random variation.

Height and height growth rate between locations
Mean height values by year and location are presented graphically in Figure 5 with 95% confidence intervals indicated and in Table 6 with standard errors and sample sizes. The mean height values for all locations increased over time. The mean height values for the west (windward) location were smaller than the mean height values for the east (leeward) location for the measurement years 2003 and 2004, 22.0±0.68 inches and 39.6±0.91 inches for the west location and 22.8±0.48 inches and 40.6±0.71 inches for the east location, respectively. This relationship was reversed for measurement years 2005 to 2007, where the mean heights for the west location 54.6±0.97 inches, 69.8±1.15 inches, and 79.9±1.40 inches, respectively, became greater than the mean heights of the east location for those years, 53.5±1.03 inches, 68.9±1.34 inches, and 78.8±1.82, respectively. No strong or weak potential differences in mean height were identified between the east and west locations for any year.

Annual mean height growth rates by growing year and location are presented graphically in Figure 6 with 95% confidence intervals indicated and in Table 7 with standard errors and sample sizes. The mean height growth rates for the east and west locations were nearly identical for the 2004, 2006, and 2007 growing years, 17.7±0.43 inches and 17.7±0.44 inches for the west and east locations, respectively, in 2004, 15.2±0.48 inches and 15.4±0.64 inches in 2006, and 10.1±0.72 inches and 9.9±0.65 inches in 2006. Both mean height growth rates decreased to 15.0±0.46 inches and 13.0±0.55 for the west and east locations, respectively, from the 2004 growing year to the 2005 growing year. The mean height growth rates then increased from the 2005 growing year to the 2006 growing year, and then declined again from 2006 to 2007. The decline of 4.7 inches in the mean growth rate for the east location from 2004 to 2005 was almost twice the 2.7 inch decline of the west location, and the declines in mean growth rates for both locations from 2006 to 2007 were nearly equal. A strong potential difference in mean height growth rates between locations was identified only for the 2005 growing year.

Table 6 Mean height values and standard errors for each nesting level in the living snow fence layout (with sample sizes in parentheses). Mean values within a level that were outside the 95% confidence interval for other values within that level are indicated by an asterisk* or the letter n, m, or s to indicate that the mean was outside confidence interval for the north, middle, or south position.

Year	Location	Row	Position	
2003* 22.4±0.42 (108)	West 22.0±0.68 (54)	One 21.5±0.85 (27)	North^{s}	22.8±1.59 (9)
			Middle^{s}	23.6±0.92 (9)
			South^{n,m}	18.2±1.29 (9)
		Two 22.4±1.06 (27)	North	20.6±2.26 (9)
			Middle	23.4±1.56 (9)
			South	23.2±1.67 (9)
	East 22.8±0.48 (54)	One 22.1±0.56 (27)	North	21.2±0.93 (9)
			Middle	21.6±1.03 (9)
			South^{n}	23.4±0.97 (9)
		Two* 23.6±0.75 (27)	North	23.4±1.37 (9)
			Middle^{s}	22.0±1.19 (9)
			South^{m}	25.2±1.25 (9)
2004* 40.1±0.58 (108)	West 39.6±0.91 (54)	One 38.7±1.12 (27)	North^{s}	40.9±1.71 (9)
			Middle^{s}	40.9±1.50 (9)
			South^{n,m}	34.2±1.82 (9)
		Two 40.6±1.42 (27)	North^{m}	37.6±2.75 (9)
			Middle	43.8±1.30 (9)
			South^{m}	40.6±2.84 (9)
	East 40.6±0.71 (54)	One* 39.2±0.97 (27)	North^{s}	38.2±1.92 (9)
			Middle^{s}	37.7±1.38 (9)
			South^{m}	41.8±1.53 (9)
		Two* 41.9±1.00 (27)	North	41.8±1.47 (9)
			Middle	40.2±1.59 (9)
			South	43.7±2.06 (9)
2005* 54.1±0.71 (108)	West 54.6±0.97 (54)	One 54.1±1.31 (27)	North^{s}	56.3±1.83 (9)
			Middle^{s}	56.2±2.31 (9)
			South^{n,m}	49.9±2.18 (9)
		Two 55.1±1.46 (27)	North^{m}	51.7±2.97 (9)
			Middle^{n,s}	59.6±1.94 (9)
			South^{m}	54.1±2.00 (9)
	East 53.5±1.03 (54)	One 52.2±1.59 (27)	North	52.0±3.66 (9)
			Middle	49.7±1.97 (9)
			South^{m}	55.0±2.34 (9)
		Two 54.9±1.29 (27)	North	53.7±1.28 (9)
			Middle	52.7±2.26 (9)
			South^{n,m}	58.1±2.74 (9)

2006* 69.4±0.88 (108)	West 69.8±1.15 (54)	One 69.4±1.50 (27)	North^{s}	72.4±2.07 (9)
			Middle^{s}	70.9±3.06 (9)
			South^{n}	64.9±2.09 (9)
		Two 70.3±1.77 (27)	North^{m}	64.7±3.20 (9)
			Middle^{n}	75.9±2.43 (9)
			South^{m}	70.3±2.73 (9)
	East 68.9±1.34 (54)	One 67.9±2.19 (27)	North	65.9±5.23 (9)
			Middle^{s}	65.6±2.79 (9)
			South^{m}	72.3±2.87 (9)
		Two 69.9±1.57 (27)	North	67.9±1.27 (9)
			Middle	69.2±3.15(9)
			South^{n}	72.7±3.31(9)
2007* 79.4±1.14 (108)	West 79.9±1.40 (54)	One 79.3±1.83 (27)	North^{s}	80.9±2.53 (9)
			Middle^{s}	82.2±4.13 (9)
			South^{n}	74.8±2.30 (9)
		Two 80.49±2.14 (27)	North^{m}	75.2±3.39 (9)
			Middle^{n,s}	88.6±2.71 (9)
			South^{m}	77.7±3.64 (9)
	East 88.8±1.82 (54)	One 77.5±2.91 (27)	North	75.5±6.71 (9)
			Middle	74.4±4.35(9)
			South^{n}	82.7±3.64(9)
		Two 80.1±2.22 (27)	North	78.1±1.61 (9)
			Middle	79.2±5.00 (9)
			South^{n}	83.1±4.31 (9)

Table 7 Mean annual height growth rate values and standard errors for each nesting level in the living snow fence layout (with sample sizes in parentheses). Mean values within a level that were outside the 95% confidence interval for other values within that level are indicated by an asterisk* or the letter n, m, or s to indicate that the mean was outside confidence interval for the north, middle, or south position.

Year	Location	Row	Position	
2004* 17.7±0.31 (108)	West 17.7±0.43 (54)	One 17.1±0.52 (27)	North^{s}	18.1±0.91 (9)
			Middle	17.3±1.03 (9)
			South	16.0±0.73 (9)
		Two* 18.2±0.68 (27)	North^{m}	17.0±0.73 (9)
			Middle^{n}	20.3±1.01 (9)
			South^{m}	17.3±1.47 (9)
	East 17.7±0.44 (54)	One* 17.1±0.76 (27)	North	17.0±1.68 (9)
			Middle	16.1±1.02 (9)
			South	18.3±1.19 (9)
		Two 18.3±0.44 (27)	North	18.3±0.47 (9)
			Middle	18.2±0.76 (9)
			South	18.4±1.06 (9)
2005* 14.0±0.37 (108)	West* 15.0±0.46 (54)	One 15.5±0.54 (27)	North	15.4±0.77 (9)
			Middle	15.3±1.26 (9)
			South	15.7±0.82 (9)
		Two 14.5±0.75 (27)	North	14.1±0.79 (9)
			Middle	15.8±1.21 (9)
			South	13.6±1.73 (9)
	East* 13.0±0.55 (54)	One 13.0±0.83 (27)	North	13.8±1.86 (9)
			Middle	12.0±1.14 (9)
			South	13.2±1.31 (9)
		Two 13.0±0.75 (27)	North	12.0±1.13 (9)
			Middle	12.4±1.38 (9)
			South	14.4±1.37 (9)
2006* 15.3±0.40 (108)	West 15.2±0.48 (54)	One 15.3±0.62 (27)	North	16.1±1.52 (9)
			Middle	14.7±0.97 (9)
			South	15.0±0.58 (9)
		Two 15.2±0.76 (27)	North^{m}	13.0±1.50 (9)
			Middle^{s}	16.3±0.81 (9)
			South^{n,m}	16.2±1.35 (9)
	East 15.4±0.64 (54)	One 15.7±0.85 (27)	North	13.9±1.88 (9)
			Middle	15.9±1.43 (9)
			South	17.3±0.82 (9)
		Two 15.1±0.97 (27)	North	14.1±1.16 (9)
			Middle	16.5±1.14 (9)
			South	14.6±2.46 (9)

2007* 10.0±0.48 (108)	West 10.1±0.72 (54)	One 9.9±1.12 (27)	North	8.5±2.93 (9)
			Middle	11.3±1.32 (9)
			South	9.9±1.23 (9)
		Two 10.2±0.91 (27)	North[m,s]	10.6±1.35 (9)
			Middle	12.7±0.78 (9)
			South	7.4±1.96 (9)
	East 9.9±0.65 (54)	One 9.6±1.02 (27)	North[s]	9.6±1.63 (9)
			Middle	8.8±2.10 (9)
			South	10.4±1.69 (9)
		Two 10.2±0.83 (27)	North	10.2±0.58 (9)
			Middle	10.0±2.02 (9)
			South	10.4±1.53 (9)

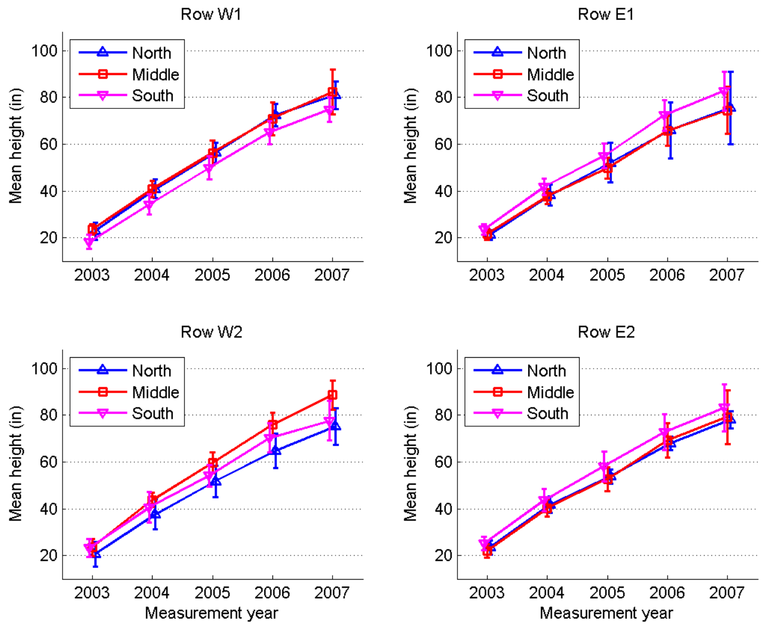

Figure 1 Mean height results for each measurement year by position within a row and 95% confidence intervals. Points have been jittered to increase the visibility for each position within a row.

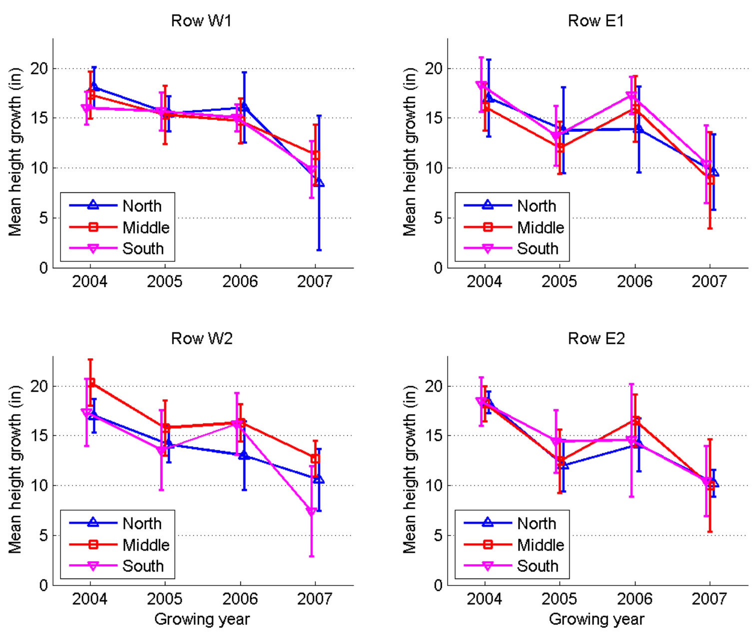

Figure 2 Annual mean height growth results for each growing year by position within a row and 95% confidence intervals. Points have been jittered to increase the visibility for each position within a row.

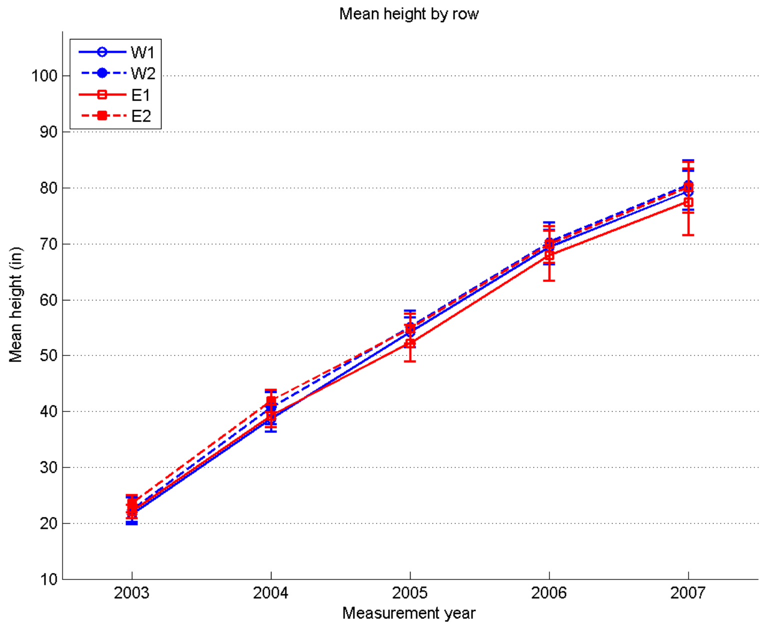

Figure 3 Mean height results for each measurement year by row with 95% confidence intervals.

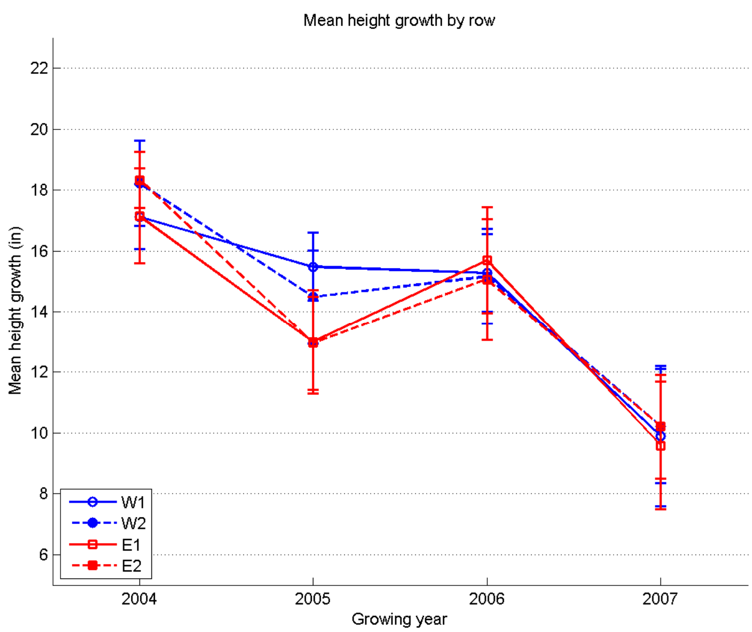

Figure 4 Mean height growth results for each growing year by row with 95% confidence intervals.

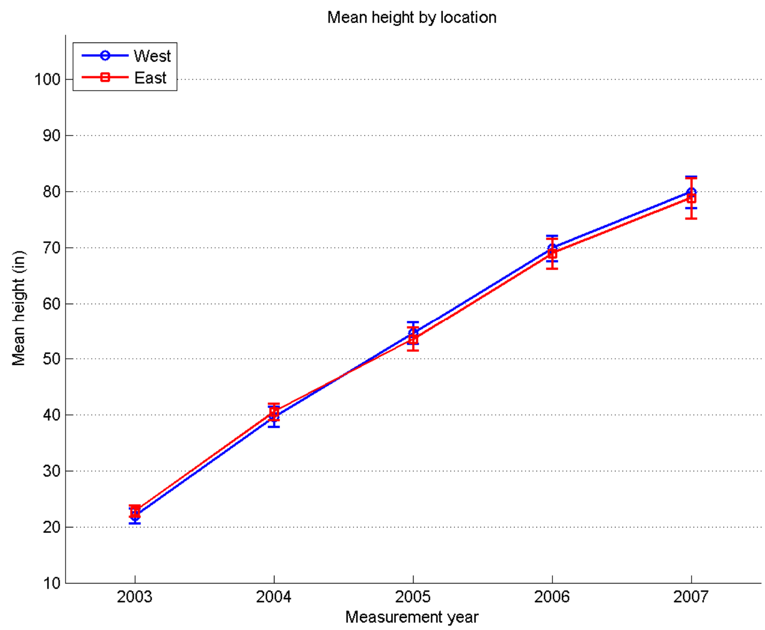

Figure 5 Mean height results for each measurement year by location.

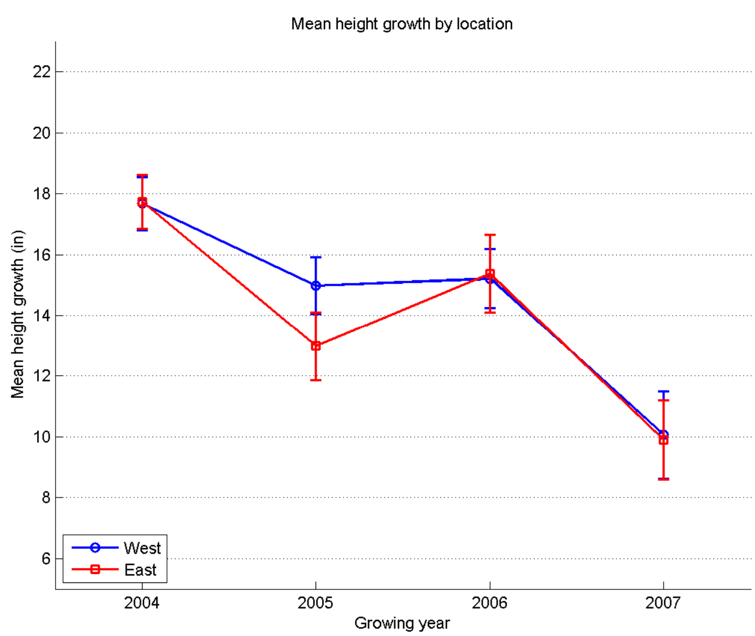

Figure 6 Mean height growth results for each measurement year by location.

Crown width results

Mean crown width increased for each measurement year, except for 2007 when they decreased, for all positions within a row, rows within a location, and locations. Mean crown width values, in inches, with standard errors and sample sizes for all nesting levels are presented in Table 8. Differences in mean crown width among the measurement years were highly statistically significant with a *p*-value approximately equal to zero. Mean crown width values ± one standard error were 12.0±0.27 inches, 24.3±0.42 inches, 32.1±0.49 inches, 52.2±0.88 inches, and 48.8±0.81 inches, respectively, for measurement years 2003 through 2007.

Annual mean crown width growth rates varied over the four growing years, with 2004 producing an intermediate value 2005 and 2007 producing the smallest values, and 2006 producing the largest value. Mean crown width growth rates, in inches, with standard errors and sample sizes for all nesting levels are presented in Table 9. The differences in annual mean crown width growth rates among the measurement years were highly statistically significant with a *p*-value approximately equal to zero. The observed annual mean crown width growth rates ± one standard error were 12.3±0.27 inches, 7.8±0.28 inches, 20.1±0.54 inches and -3.4±0.50 inches, respectively, for growing years 2004 through 2007.

Crown width and crown width growth rate among positions within a row

Mean crown width values by year and position within a row are presented graphically in Figure 7 with 95% confidence intervals and in Table 8 with standard errors and sample sizes. The mean crown width values for all positions within each row increased over time from 2003 through 2006 and declined in 2007 for each position. The patterns of crown width development over time were similar for all positions within each row, but with some variability by position.

In row W1, the south position had the smallest mean crown width values for measurement years 2003 to 2005 and 2007, with the north and middle positions having mean crown widths that were essentially equal for these years. For the 2006 measurement year, all three positions had nearly equal mean crown widths. Crown width development slowed for all positions in this row between 2004 and 2005, indicated by a flattening of the line segment connecting these years, relative to the slopes of the adjacent line segments connecting the values for 2003 and 2004 and 2005 and 2006. The slowdown was nearly the same for all three positions within this row. Mean crown width declined between 2006 and 2007 for all positions within the row. Strong potential differences in crown width were identified between the north and middle positions of row W1 and its south position for measurement years 2003 through 2005, but there were no potential differences in the 2006 and 2007 measurement years.

In row W2, the north position had the smallest mean crown width values for all years, with the middle and south positions being essentially equal for the first two years and the middle position being the largest for measurement years 2005 through 2007. Mean crown width values were essentially equal for the north and south positions in 2007. As for row W1, crown width development slowed between 2004 and 2005 for all positions, relative to 2003 and 2004 and 2005 and 2006, and mean crown widths declined between 2006 and 2007. The slower development between 2004 and 2005 was greatest for the south position, and was negligible for the north position in this row. The decline in crown width was also greatest for the south position, with smaller declines for the middle and north positions. Strong potential differences for this row were identified between the north and south positions in 2003, between the middle and south positions and the north position in 2004, and between the middle and north positions in 2005 and 2006. Weak potential differences within this row were detected between the middle and south positions in 2004, between the north and middle positions and the south position in 2005, between the middle and south positions in 2006, and between the middle and the north and south positions in 2007.

In row E1, all three positions had essentially equal mean crown width values for all measurement years. A small amount of differentiation among the positions is identifiable in the 2006 and 2007 measurement years, with the south position having a slightly greater value than the north and middle positions. Consistent with the positions in the west rows, this row showed slower crown width development between 2004 and 2005 and a decline in mean crown width for all positions between 2006 and 2007. No strong potential differences were identified for this row, but a weak potential difference was detected between the north position and the middle and south positions in 2003.

In row E2, mean crown width values were essentially equal for all three positions in 2003, 2005, and 2007. In 2004 and 2006, the mean crown width for the south position was greater then those of the north and middle positions, which were nearly equal in 2004, while in 2006 the mean crown width for the north was slightly greater than that for the south. As for all other rows, a slowing in crown width development occurred between 2004 and 2005 and a decline in mean crown width occurred between 2006 and 2007. No strong or weak potential differences were identified among the positions in this row.

Annual mean crown width growth rates by year and position within a row are presented graphically in Figure 8 with 95% confidence intervals indicated and in Table 9, along with standard errors and sample sizes. Annual crown width growth rates for individual trees within each position were somewhat variable. The mean crown width growth rates for the 2005 and 2007 growing years were typically smaller than those for the other two growing years for all positions, with the values for 2007 being the smallest, and this pattern was consistent for all rows.

In row W1, the mean crown width growth rate for the south position was smallest in the 2004 growing year, with values for the north and middle positions being nearly equal. For the 2005 and 2006 growing years, the mean crown width growth rate for the south position was greatest, followed by the value for the middle position, which was greater than that of the north position. For the 2007 growing year, the south position had the smallest mean growth rate and the north position had the largest mean growth rate. All three positions within this row showed a dramatic decline in mean crown width growth rate for the 2005 and 2007 growing years. No strong potential differences were observed among positions within this row, but weak potential differences in mean growth rate were identified for this row between the north and south positions in the 2004 growing year, middle and south positions in the 2005 growing year.

In row W2, the mean crown width growth rate trends were quite variable. The mean crown width growth rate for the north position was greatest for the first three growing years and smallest for the 2007 growing year. The values for the south position were between the values for the north and middle positions in the 2004 and 2006 growing years, with the north position being the smaller of the two, and values for the south position were smallest in the 2005 and 2007 growing years, with the north and middle positions being nearly equal in 2005 and the north being greater in 2007. As for row W1, all three positions had dramatic declines in mean crown width growth rate for the 2005 and 2007 growing years. Strong potential differences were identified within this row between the north position and the middle and south positions for the 2004 growing year, between the south and middle positions in the 2005 growing year, and between the north and middle positions in the 2006 growing year. A weak potential difference was also identified between the north and south positions for the 2005 growing year.

In row E1, the relationships among the three positions were consistent for all three growing years. The mean crown width growth rates for all three positions were nearly equal for the 2004 and 2005 growing years, becoming more variable in the 2006 and 2007 growing years. In the 2006 growing year, the largest mean crown width growth rate occurred for the south position and the smallest value occurred for the north position. This relationship was reversed in the 2007 growing year. The differences among the mean crown width values were small for the 2004 and 2005 growing years, but became larger for the 2006 and 2007growing years, possibly indicating the development of differences in the rate of crown development among the positions within this row. As for the west rows, a sharp decline in mean growth rate for the 2005 and 2007 growing years was observed. No strong potential differences were found among the positions within this row, but one weak potential difference was found between the north and south positions for the 2006 growing year.

In row E2, the relative rankings of the mean crown width growth rates varied by growing year. In the 2004 growing year, the south position had the largest mean crown width growth rate, with the north and middle positions having nearly equal values. In the 2005 growing year, the middle position produced the largest mean growth rate, followed, respectively, by the values for the north and the south positions. In the 2006 growing year, the south position, again, produced the largest mean crown width growth rate, followed by the value for the north position and then that of the south position. In the 2007 growing year, the middle position produced the largest mean crown width growth rate, with the north and south positions producing nearly equal growth rates. Once again, there was a decline in growth rates for the 2005 and 2007 growing years. A single strong potential difference was observed only for between the middle position and both the north and south positions for this row in the 2007 growing year. No weak potential differences were found among the growth rates for this row.

Crown width and crown width growth rate between rows within a location
Mean crown width values by year and row within a location are presented graphically in Figure 8 with 95% confidence intervals and in Table 7 with standard errors and sample sizes. The mean crown width values for both rows within each location increased over time from 2003 to 2006, but declined in 2007, with the decline being largest for the two west rows.

The mean crown width values for both rows within each location were nearly equal for all measurement years, and all rows exhibited a flattening of the slope of the line segment between the 2004 and 2005 measurement years, relative to the two adjacent measurement intervals, indicating slower development of crown width during this interval and a decline in mean crown width from 2006 to 2007. No strong potential differences were found between the rows within each location, and a weak potential difference in mean crown width was found only in 2003 for the east location, where the mean value for row E1 was outside the 95% CI computed for row E2.

Annual mean crown width growth rates by year and row within a location are presented graphically in Figure 10 with 95% confidence intervals indicated and in Table 9 with standard errors and sample sizes. The mean crown width growth rates for the pairs of rows within each location demonstrated a consistent pattern over time, having nearly equal values for all measurements, with the mean crown width growth rates for all rows declining for the 2005 and 2007 growing years and increasing for the 2006 growing year. No other consistent patterns emerged at this nesting level. No strong potential differences were found between the rows within each location, and a weak potential difference was found only in the 2004 growing year where the value for row E2 was outside the 95% CI for row E1.

Crown width and crown width growth rate between locations
Mean crown width values by year and location are presented graphically in Figure 11 with 95% confidence intervals and in Table 8 with standard errors and sample sizes. The mean crown width values for both locations increased over time from 2003 to 2006 and declined in 2007, with the decline being greater for the west location. The mean crown width values for the west (windward) location were smaller than the mean crown width values for the east (leeward) location for all measurement years, having values of 11.1±0.36 inches, 23.5±0.62 inches, 31.8±0.67 inches, 51.6±1.21 inches, and 46.5±1.03 inches for the west location and 12.9±0.37 inches, 25.1±0.54 inches, 32.4±0.72, 52.9±1.29 inches, and 51.1±1.17 inches for the east location, respectively, for measurement years 2003 through 2007. In addition, the flattening of the crown width development between 2004 and 2005 and the decline between 2006 and 2007 are readily apparent. Strong potential differences in mean crown width were observed between locations for measurement years 2003, 2004, and 2007.

Annual mean crown width growth rates by growing year and location are presented graphically in Figure 12 with 95% confidence intervals indicated and in Table 9 with standard errors and sample sizes. The mean crown width growth rates for the east and west locations were nearly identical for the 2004 growing year, 12.4±0..37 inches and 12.2±0.39 inches for the west and east locations, respectively. Both mean crown width growth rates decreased for the 2005 growing year to 8.2±0.41 inches and 7.3±0.39 inches for the west and east locations, respectively. The mean height growth rates then increased from the 2005 growing year to the 2006 growing year, obtaining values of 19.8±0.74 inches and 20.5±0.79 inches for the west and east locations, respectively. For the 2007 growing year, the mean crown width growth rates declined again, becoming negative, with values of -5.0±0.62 inches and -1.8±0.72 inches for the west and east locations, respectively. The decline of 4.2 inches in the mean growth rate for the west location from 2004 to 2005 was somewhat smaller than the 4.9 inch decline of the east location, but the relationship was reversed for 2005 to 2006, with the east location having the greater increase in growth rate for that time period. For 2006 to 2007 there was a decline in the mean crown width growth rate, with the growth rates for each location becoming negative. The relationship between the locations for this growing year was consistent with the previous growing year, with the east location having the smaller decline in mean crown width growth rate. Strong potential difference in mean crown width growth rates between locations were identified for the 2005 and 2007 growing years.

Table 8 Mean crown width values and standard errors for each nesting level in the living snow fence layout (with sample sizes in parentheses). Mean values within a level that were outside the 95% confidence interval for other values within that level are indicated by an asterisk* or the letter n, m, or s to indicate that the mean was outside confidence interval for the north, middle, or south position.

Year	Location	Row	Position	
2003* 12.0±0.27 (108)	West* 11.1±0.36 (54)	One 10.9±0.51 (27)	North^{s}	12.8±0.98 (9)
			Middle^{s}	11.2±0.60 (9)
			South^{n,m}	8.8±0.43 (9)
		Two 11.3±0.52 (27)	North^{s}	9.9±1.05 (9)
			Middle	11.7±0.82 (9)
			South^{n}	12.4±0.67 (9)
	East* 12.9±0.37 (54)	One* 13.4±0.58 (27)	North^{m,s}	14.6±1.48 (9)
			Middle	12.7±0.71 (9)
			South	12.9±0.54 (9)
		Two 12.7±0.46 (27)	North	12.4±0.84 (9)
			Middle	12.0±0.69 (9)
			South	12.7±0.91 (9)
2004* 24.3±0.42 (108)	West* 23.5±0.62 (54)	One 23.5±0.86 (27)	North^{s}	26.0±1.68 (9)
			Middle^{s}	24.3±1.29 (9)
			South^{n,m}	20.2±0.74 (9)
		Two 23.6±0.91 (27)	North^{m,s}	20.2±1.31 (9)
			Middle^{n}	25.2±1.75 (9)
			South^{n}	25.2±1.09 (9)
	East* 25.1±0.54 (54)	One 24.8±0.70 (27)	North	25.7±1.61 (9)
			Middle	24.1±1.17 (9)
			South	24.7±0.83 (9)
		Two 25.3±0.84 (27)	North	25.0±1.52 (9)
			Middle	24.4±1.18 (9)
			South	26.6±1.68 (9)
2005* 32.1±0.49 (108)	West 31.8±0.67 (54)	One 32.2±0.89 (27)	North^{s}	33.6±1.48 (9)
			Middle^{s}	33.4±1.57 (9)
			South^{n,m}	29.6±1.32 (9)
		Two 31.4±1.02 (27)	North^{m,s}	28.9±1.84 (9)
			Middle^{n,s}	34.7±2.06 (9)
			South	30.6±0.65 (9)
	East 32.4±0.72 (54)	One 32.4±1.10 (27)	North	32.8±2.49 (9)
			Middle	31.8±1.93 (9)
			South	32.6±1.35 (9)
		Two 32.4±0.95 (27)	North	32.1±1.75 (9)
			Middle	32.6±1.61 (9)
			South	32.6±1.78 (9)

2006* 52.2±0.88 (108)	West 51.6±1.21 (54)	One 52.2±1.60 (27)	North	51.9±3.00 (9)
			Middle	53.0±3.05 (9)
			South	51.8±2.58 (9)
		Two 50.9±1.85 (27)	North[m]	46.1±3.35 (9)
			Middle[n,s]	56.4±3.25 (9)
			South	50.2±2.15 (9)
	East 52.9±1.29 (54)	One 53.1±1.66 (27)	North	52.2±4.27 (9)
			Middle	52.4±2.56 (9)
			South	54.6±1.27 (9)
		Two 52.7±2.00 (27)	North	53.2±2.67 (9)
			Middle	50.2±3.93 (9)
			South	54.7±3.90 (9)
2007* 48.8±0.81 (108)	West* 46.5±1.03 (54)	One 46.8±1.36 (27)	North	47.3±2.89 (9)
			Middle	47.9±2.36 (9)
			South	45.1±1.93 (9)
		Two 46.33±1.58 (27)	North	43.1±1.95 (9)
			Middle[n,s]	51.4±3.69 (9)
			South	44.4±1.39 (9)
	East* 51.1±1.17 (54)	One 51.0±1.66 (27)	North	50.4±3.43 (9)
			Middle	50.0±2.43 (9)
			South	52.6±2.97 (9)
		Two 51.2±1.68 (27)	North	49.6±2.79 (9)
			Middle	53.1±2.80 (9)
			South	51.0±3.33 (9)

Table 9 Mean annual crown width growth rate values and standard errors for each nesting level in the living snow fence layout (with sample sizes in parentheses). Mean values within a level that were outside the 95% confidence interval for other values within that level are indicated by an asterisk* or the letter n, m, or s to indicate that the mean was outside confidence interval for the north, middle, or south position.

Year	Location	Row	Position	
2004* 12.3±0.27 (108)	West 12.4±0.37 (54)	One 12.6±0.52 (27)	North^{s}	13.2±1.00 (9)
			Middle	13.1±0.87 (9)
			South	11.4±0.77 (9)
		Two 12.2±0.54 (27)	North^{m,s}	10.3±0.60 (9)
			Middle^{n}	13.6±1.23 (9)
			South^{n}	12.8±0.52 (9)
	East 12.2±0.39 (54)	One 11.4±0.52 (27)	North	11.1±0.90 (9)
			Middle	11.4±0.71 (9)
			South	11.8±1.15 (9)
		Two* 13.0±0.54 (27)	North	12.6±1.09 (9)
			Middle	12.4±0.80 (9)
			South	13.9±0.90 (9)
2005* 7.8±0.28 (108)	West* 8.2±0.41 (54)	One 8.7±0.47 (27)	North	7.6±0.65 (9)
			Middle^{n}	9.1±0.81 (9)
			South^{n}	9.3±0.94 (9)
		Two 7.8±0.67 (27)	North^{s}	8.7±1.23 (9)
			Middle^{s}	9.4±0.96 (9)
			South^{m}	5.3±0.83 (9)
	East* 7.3±0.39 (54)	One 7.6±0.56 (27)	North	7.1±1.02 (9)
			Middle	7.7±0.90 (9)
			South	7.9±0.86 (9)
		Two 7.1±0.54 (27)	North	7.1±0.48 (9)
			Middle	8.1±1.11 (9)
			South	6.0±1.05 (9)
2006* 20.1±0.54 (108)	West 19.8±0.74 (54)	One 20.0±1.08 (27)	North	18.3±1.89 (9)
			Middle	19.6±1.86 (9)
			South	22.2±1.80 (9)
		Two 19.6±1.03 (27)	North^{m}	17.2±1.61 (9)
			Middle^{n}	21.8±1.71 (9)
			South	19.7±1.85 (9)
	East 20.5±0.79 (54)	One 20.7±0.84 (27)	North^{s}	19.4±2.12 (9)
			Middle	20.7±1.18 (9)
			South	22.0±0.80 (9)
		Two 20.3±1.36 (27)	North	21.1±1.72 (9)
			Middle	17.7±2.81 (9)
			South	22.1±2.43 (9)

2007* -3.4±0.50 (108)	West* -5.0±0.62 (54)	One -5.4±0.73 (27)	North	-4.6±1.09 (9)
			Middle	-5.1±1.45 (9)
			South	-6.7±1.29 (9)
		Two -4.6±1.01 (27)	North	-3.0±1.72 (9)
			Middle	-5.0±1.94 (9)
			South	-5.8±1.66 (9)
	East* -1.8±0.72 (54)	One -2.1±0.98 (27)	North	-1.8±1.71 (9)
			Middle	-2.4±0.88 (9)
			South	-2.0±2.38 (9)
		Two -1.5±1.08 (27)	North[m]	-3.7±1.97 (9)
			Middle[n,s]	2.9±1.57 (9)
			South[m]	-3.7±1.20 (9)

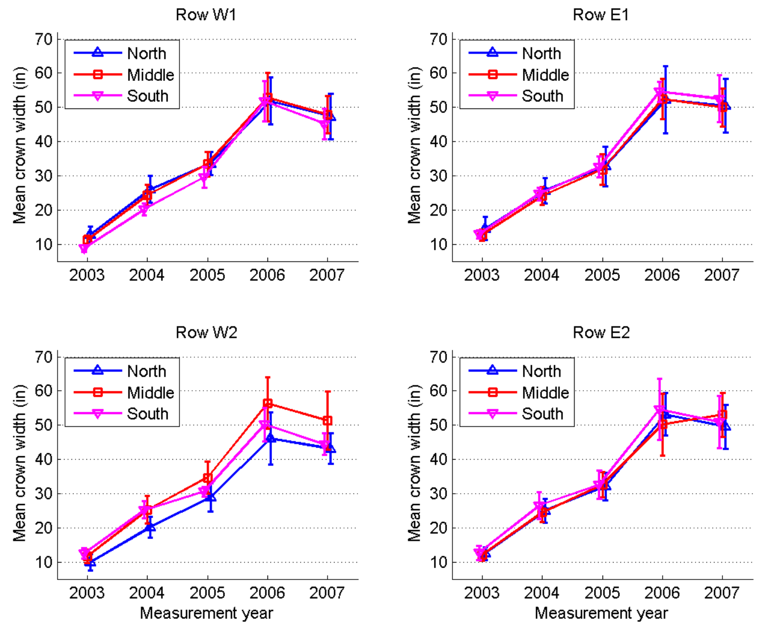

Figure 7 Mean crown width results for each measurement year by position within a row and 95% confidence intervals. Points have been jittered to increase the visibility for each position within a row.

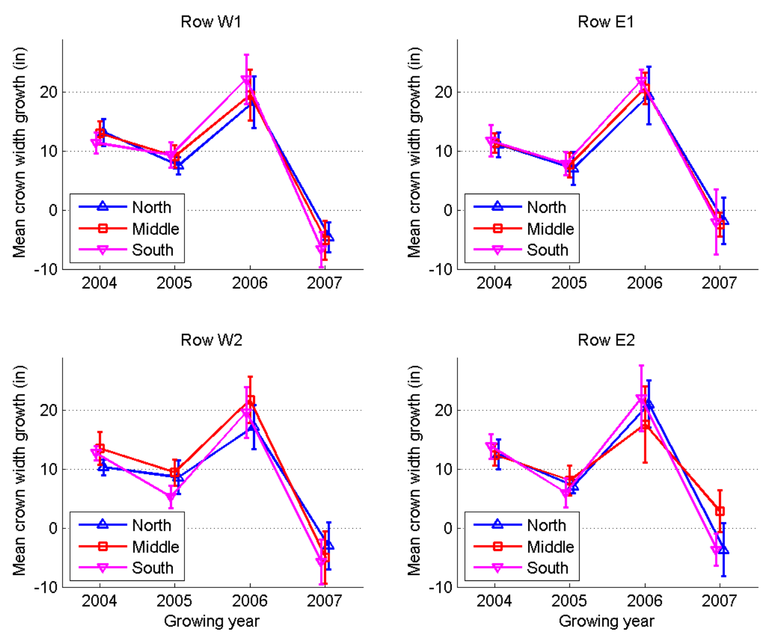

Figure 8 Mean crown width growth results for each measurement year by position within a row and 95% confidence intervals. Points have been jittered to increase the visibility for each position within a row.

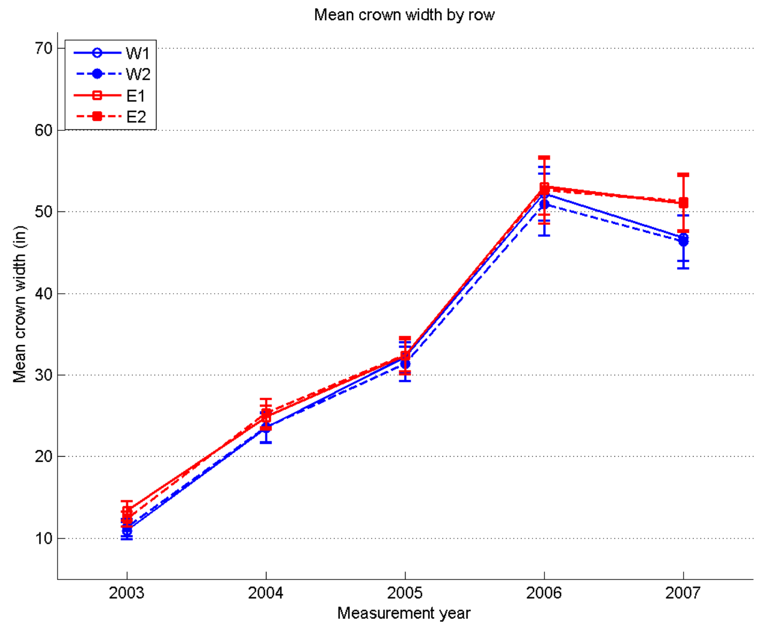

Figure 9 Mean crown width results for each measurement year by row with 95% confidence intervals.

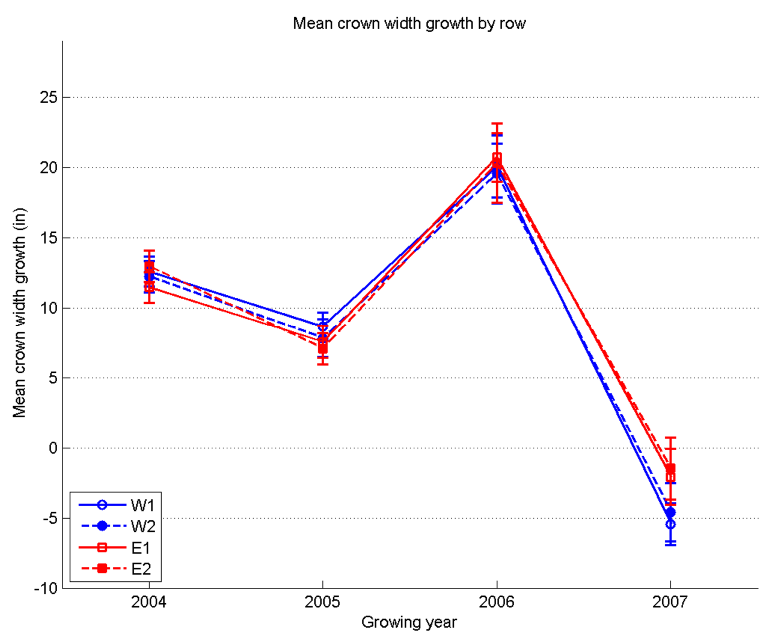

Figure 10 Mean crown width growth results for each measurement year by row with 95% confidence intervals.

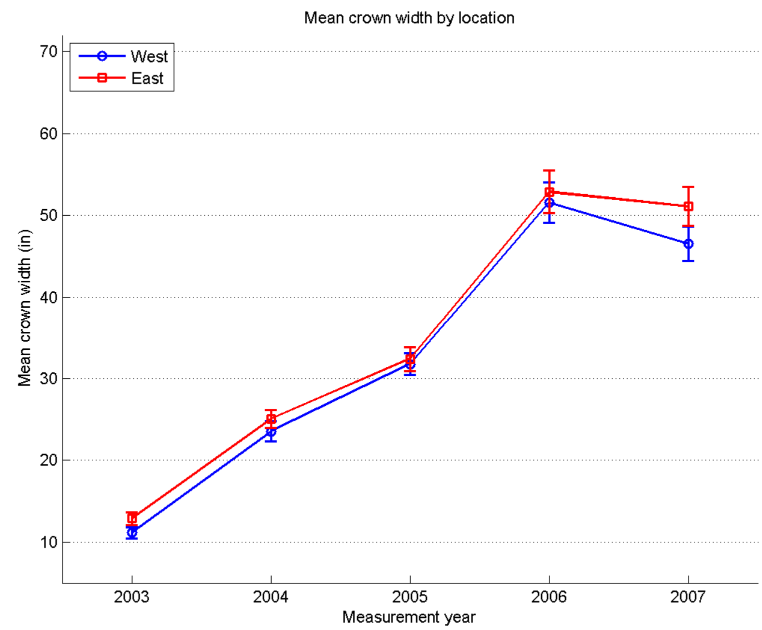

Figure 11 Mean crown width results for each measurement year by location.

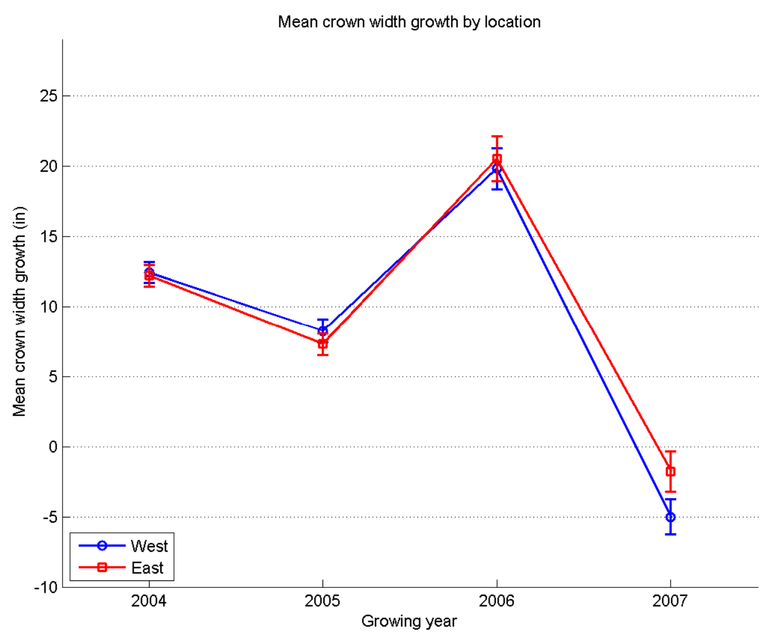

Figure 12 Mean crown width growth results for each measurement year by location.

Discussion

At all nesting levels a dramatic decline in tree size development, both in mean height and in mean crown width and their respective mean growth rates, occurred between measurement years 2004 and 2005 and the 2005 growing year, and between measurement years 2006 and 2007 and the 2007 growing year. From 2003 through 2007 the weather in Washington State was highly variable, having some very wet years as well some very dry years. Precipitation data were obtained for Davenport, WA from the Western Regional Climate Center (WRCC, http://www.wrcc.dri.edu/index.html) for 2003 through 2007, to investigate the possibility of a potential relationship between the amount of precipitation and the development of the trees in the living snow fence.

Monthly precipitation totals and mean monthly values from the period of record were obtained and summed for October through May, the nominal water year, for 2003 through 2007. Precipitation totals, historic mean values, and overall height and crown width mean growth rates are summarized in Table 10. As can be seen from the table, precipitation amounts for the growing or water years 2004 through 2007 were 10.86 inches, 9.29 inches, and 14.17 inches, and 9.97 inches, respectively, with an historical mean of 11.91 inches. These data indicate that the 2004 growing year had a bit over an inch less precipitation than average, the 2005 growing year had over 2.5 inches less precipitation than average, the 2006 growing year had over two inches more precipitation than average, and the 2007 growing year had almost two inches less precipitation than average.

Table 10 Precipitation and mean height and crown width growth rates

Growing or water year	Precipitation (inches)	Mean height growth (inches)	Mean crown width growth (inches)
Mean	11.91	N/A	N/A
2004	10.86	17.7	12.3
2005	9.29	14.0	7.8
2006	14.17	15.3	20.1
2007	9.97	10.0	-3.4

A cursory comparison of these precipitation amounts with the mean height and crown width growth rates indicates a strong correspondence between the amount of precipitation and the magnitude of the growth rate, with the 2005 and 2007 growing years producing smaller growth rates than the other two growing years. This is particularly evident for the crown width growth rates. The 2006 growing year, which had the most precipitation, produced the second largest height growth rate and the largest crown width growth rate. This brief comparison was not intended to be definitive, but rather to suggest a possible relationship between the growth rates observed and impacts from local climate. Differences in tree size would need to be taken into account for a complete analysis, as younger or smaller trees can have larger relative and absolute growth rates than older or larger trees, and adjustments for tree size would need to be included to account for this type of effect in a more comprehensive analysis.

The decline in average crown width that occurred in 2007, indicated by the negative average growth rate, may be a consequence of the lower than average rainfall for the 2007 water year, almost two inches less than average, coupled with the larger average tree size and possibly inter-tree competition, assuming that the measurement protocol used for that year was consistent with prior years. While crown closure, an indicator of above ground competition, has not yet occurred, there may be significant below ground competition for resources, particularly water, given the proximity of the trees to one another.

The variability in the individual tree measurements increased for height over time, and the variability of tree crown width measurements increased except for the final measurement year 2007, where the variability decreased slightly or remained nearly the same as that for the previous year. Since there was 100% survivorship of the initially measured trees, this implies that as the trees are become larger, on average, the distribution of tree heights and crown widths are widening, and some form of size differentiation may be taking place, possibly caused by microsite variations, differences in the genetic potential of each tree, or competition for resources. The reduced variability in crown width for the final measurement year 2007 may be an indication of inter-tree competition.

The increasing variability over time may have had an impact on the analyses as performed, and some potential impacts of the differences in variability among the nesting levels are presented next.

ANOVA analyses

The variances of tree heights, crown widths, and their respective growth rates, by position within the rows were not all equal, an assumption necessary for an ANOVA analysis. The small sample size is the most likely the reason for the differences in variance at this nesting level, as the sample of 9 trees within each position may not be sufficient to produce a stable estimate of the variability given the degree of inherent variability in the development of the tree heights and crown widths. For this nesting level, the differences in variability among the positions may have contributed to the spurious detection of differences. At the higher nesting levels, rows within locations or locations within years, where larger samples sizes were used, the variances were more similar within the appropriate nesting levels. The homogeneous variance assumption required by the ANOVA procedures may, therefore, not have been satisfied at the level of position within row, but was satisfied for rows within locations and locations within years, where the variances were more similar. The ANOVA procedures are, however, typically robust to deviations from the homogeneous variance assumption, so this was not considered to be a significant issue.

The variability of tree heights, crown widths, and their respective growth rates, increased over time, except for crown width in 2007, leading to larger variances for later measurement and growing years within each of the ANOVA analyses. Given that significant differences were expected among measurement years and growing years this was not considered to be an issue, particularly since detecting differences within the nesting levels within each year were the results of primary interest. From a multiple comparisons perspective, the larger variances for later years simply make it more difficult to detect differences between adjacent years within a nesting level, for example by using a *t*-test.

Comparing the mean height and mean crown width ANOVA results from the 2004, 2005, and 2006 measurement year analyses with those from the current year highlights several changes in statistical significance within the nesting levels that have occurred over time. In the 2004 ANOVAs, year and position within row were the nesting levels producing significant differences for mean height with *p*-values of zero and 0.0075, respectively, while for mean crown width year, location, and position within row produced significant results with *p*-values of zero, 0.0023, and 0.0016. In the 2005 ANOVAs, year and position within row still produced significant differences for mean height with *p*-values of zero and 0.0024, respectively, while the mean crown width analysis produced significant differences for year and position within row, with *p*-values of zero and 0.0112. In 2006, year and position within row were still producing significant differences for mean height with *p*-values of zero and 0.0012, respectively, while for mean crown width only year produced significant differences with a *p*-value of zero. In the current ANOVA, year and position within row were still producing significant differences for mean height with *p*-values of zero and 0.0025, respectively, while significant differences occurred by year and location for mean crown width, with *p*-values of zero and 0.0025, respectively.

Differences between height and crown width development within nesting levels other than year, then, appear to have disappeared, or been dramatically reduced, over time. The exceptions are for mean height by position within rows, which has a strong potential difference and many weak potential differences persisting into the 2007 measurements, and mean crown width by location, which demonstrated strong potential differences in 2003, 2004, and 2007, but not in 2005 and 2006. Given the lack of significant differences found at the row within location and location within year nesting levels for mean tree height, both of which have greater sample sizes and more nearly equal within level variances, differences in the variances of tree heights among the positions within the rows may be contributing to the significant difference observed for this nesting level. The significant difference identified for mean crown width by location is dominated by the difference between the locations in the final measurement year, 2007, and may indicate an increased degree of inter-tree competition, environmental stress, or some other factor having a greater impact on the west location relative to the east location.

The ANOVAs for annual mean height growth and crown width growth performed this year support this conclusion, indicating strong potential differences between growing years for both mean height growth and mean crown width growth, both of which produce *p*-values of approximately zero, and between locations by growing year for the mean crown width growth rate, with a *p*-values of 0.0014. No other significant differences were found, but mean crown width growth rate by position within the rows was almost significant at the α=0.05 level having a *p*-value of 0.0601. Mean growth rates for tree height and crown width generally differed only by year and not nesting level within a year, indicating that, on average, trees within each nesting level developed at approximately the same rates, with the exception of crown width in the final year. Differences identified in mean height or mean crown width, for nesting levels other than year, that persist over time may, in part, be attributed to differences in initial tree size, microsite variations, or to an increase in the magnitude and variability of tree sizes over time, with the possible exception of the crown width measurements 2007.

Position within rows

Variability among the positions within a row was relatively high for tree height, with different positions within a row having variances that differed by as much as a factor of two. Crown widths among the positions within rows had more similar variances overall. There may be physical or physiological causes for the differences in the tree height variances among the positions within the rows where they occurred, e.g., differences in the soil substrate among the positions or differences in the vigor of trees that were planted within each position. It is not possible to make any inferences about potential causes of the differences among positions within the rows, but the differences in the variances among the positions are most likely not attributable to different rates of tree growth within the positions, as the differences in growth rates at this nesting level were not statistically significant.

The only consistent development pattern observed at this nesting level was the decline in growth rates for the 2005 and 2007 growing years. This was observed as a flattening of the mean height and crown width trajectories between the 2004 and 2005 and the 2006 and 2007 measurement years for most positions and declines in the respective mean growth rates for the 2005 and 2007 growing years.

Rows within locations

No overall consistent patterns in mean tree height or mean crown width development emerged at this nesting level other than the decline in growth rates for the 2005 and 2007 growing years and the fact that the trees got larger over time. The exception to this may be the decline in mean crown width observed in 2007, which may indicate an increased level of inter-tree competition within the rows.

Locations by year

No overall consistent patterns in mean tree height or mean crown width development emerged at this nesting level other than the decline in growth rates for the 2005 and 2007 growing years, which may be related to lower rainfall amounts for those two growing seasons, and the fact that the trees got larger over time. Again, the exception to this may be the decline in mean crown width observed in 2007, which may indicate an increased level of inter-tree competition within the rows.

Conclusions

After five years of measurement the results of the living snow fence analysis at the Davenport, WA location indicate several things. First, differences in tree size indicated by mean height and mean crown width for each measurement year have been significant, as were the differences in growth rates for these characteristics. Second, the impacts of initial size differences, possibly caused by differences in tree vigor or microsite variability within the rows, may be declining for height and crown width. Differences may still be present for height among the positions of some rows and for crown width between locations. Third, the mean height and crown width growth rates and size development trends show a strong correspondence to local precipitation amounts over the measurement period to date. Finally, the decline in mean crown width observed in 2007 for both the east and west locations may be an indication of inter-tree competition.