Family variation of biomass and root/shoot ratio in Sitka spruce (*Picea sitchensis* (Bong.) Carr.)

K. Byers[1], G.J. Mayhead[1] and S.J. Lee[2]

Summary
Twelve families of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) were grown at 1 m x 1 m spacing on a sheltered fertile site in weed-free conditions. After 3 growing seasons, the trees were lifted and growth parameters recorded. There was a wide range of growth rates between families and blocks and significant differences were demonstrated between dry root and dry shoot biomass, root spread and rooting depth. There were no significant differences between root/shoot ratios. Despite breeding for improved above-ground characteristics, there was no evidence of this compromising factors relating to tree stability.

Introduction
It is known that different seed sources and origins of timber species have different growth characteristics. Variation in form and growth rate has been frequently demonstrated in Sitka spruce (*Picea sitchensis* (Bong.) Carr.). A tree can be taller or produce greater main stem volume than its neighbours by reallocating materials from its root system or crown or by actually photosynthesising more quickly and producing more total biomass. A consequence of the first alternative might be a smaller or different root system which might be less successful at anchoring the tree into the soil. Tree stability is already a major problem in Sitka spruce crops in Britain, and the possibility of mechanically less effective root systems arising from tree breeding programmes is of major concern on windy sites. Little is known, however, about the variation in root/shoot ratio (R/S) within this context. Various authors (Cannell, 1974; Cahalan, 1981; Clair, 1993) have demonstrated differences between Sitka spruce families in the partitioning of assimilates between crown and stem. Fraser and Gardiner (1967) demonstrated how the fresh R/S of 10-15 m tall Sitka spruce increased with decreasing soil fertility. In the study, R/S values for brown earth, peaty gley and deep peat were 0.38, 0.54 and 0.61 respectively.

Cannell and Willett (1976) examined R/S in 1 and 2 year old Sitka spruce in nurseries and reported seasonal variation. Coutts and Nicoll (1990) reported clonal differences in Sitka spruce for total root and shoot growth. Nicoll *et al.* (1995) found no evidence of stem biomass improvements taking place at the expense of root growth in 11 year old Sitka spruce. In that study, R/S was a poor indicator of stability when the whole stump was included in the root mass. Nielsen (1992) adopted the idea of "thin" and "thick" R/S to take account of variations in stump size and found "thin" R/S to be more meaningful. Henderson *et al.* (1983) and Deans *et al.* (1992) recorded differences in size and complexity of young root systems of Sitka spruce. Overall, a study of R/S is thus complicated greatly by changing root growth rates and architecture with increasing age, in addition to differing site characteristics.

[1] School of Agricultural and Forest Sciences, University of Wales, Bangor, LL57 2UW, Wales.
[2] Tree Improvement Branch, Forest Research, Roslin, EH25 9SY, Scotland.

The objective of this study was to investigate differences in R/S and other growth parameters between different phenotypically improved families of Sitka spruce grown to 1.5 m height under similar site conditions.

Method

Twelve seed sources of Sitka spruce were used in the experiment, 11 from families of genetically improved Queen Charlotte Islands origin (phenotypically selected for height, diameter and stem form), and a control of an unimproved import from Washington (Table 1). Seed was provided from the UK Forestry Commission's Forest Research tree improvement programme. The experiment was laid out at Nant Porth Nursery near Bangor, Wales, on a well-cultivated, well-drained and fertile clay loam above limestone. Rooting depth remained unrestricted throughout the duration of the trial. The site, sheltered and fairly frost-free, experiences a rainfall of approximately 1,000 mm/yr. The 1+1 transplants were pit-planted at 1 m x 1 m spacing in late March 1993.

Table 1. *Sitka spruce seed sources used in biomass and root/shoot ratio trial.*

Type of plant	*Full code*	*Treatment No.*
Unimproved import from Washington (control)		W
Screened polycross family	SS 1572 SSPO	15
	SS 1766 SSPO	17
Screened open pollinated family	SS 692 SSOP	6
	SS 1083 SSOP	10
Non-screened polycross family	SS 1892 SSPO	18
	SS 2125 SSPO	21
	SS 280 SSPO	2
Non-screened open pollinated family	SS 765 SSO	7
	SS 814 SSOP	8
	SS 1182 SSOP	11
	SS 1344 SSOP	13

The experiment design was a complete randomised block with four trees in a linear plot and five blocks (total 240 trees). There were three linear plots per row. The experiment was surrounded by a one-row buffer of unimproved Sitka spruce, planted at 1 m spacing. No irrigation or fertilisers were used. Complete weed control was maintained through the application of non-residual herbicides and hand picking. Trees were sprayed with permethrin according to need, in order to reduce aphid infestation. Individual mortalities were replaced with trees of the corresponding family at the end of the first growing season. Height (cm), survival and stem diameter (mm) (measured 10 cm above ground level) were recorded. Tree form was assessed subjectively out of a total score of 25, based on five parameters (*viz.* apical dominance, stem straightness, forking, lean and branchiness) individually scored on a scale of 1 to 5 (bad to good). Foliage colour was assessed subjectively on a scale of 1 to 5 (yellow to blue). Trees were hand lifted at the end of the third growing season

(1995) prior to the onset of serious between-plant competition at root or shoot level. Root depth (cm) and root spread (cm) (mean of two orthogonal directions recorded to a minimum of 2 mm root diameter) were measured. Root systems were severed from the shoots and both dried separately in paper bags in a kiln at 105°C to constant weight. R/S was then calculated. All data were found to be normally distributed, except for survival which became so following angular transformation. All data were subjected to two-way analysis of variance. Tukey's tests were carried out and 5% LSD values calculated.

Results

All trees established poorly, with extensive defoliation and poor growth experienced during the first year (1993). Only 15 of the 240 plants, however, required replacement, with no significant treatment or block differences. The results after the third year are summarised in Table 2.

Table 2. *Mean tree values after 3 growing seasons (August 1995).*

Treatment	*Height cm*	*Stem diameter mm*	*Tree form score/25*	*Foliage colour score/5*	*Dry root weight g*	*Dry shoot weight g*	*Dry R/S*	*Root depth cm*	*Root spread cm*
W	125.3	25.9	23.9	3.2	187	464	0.42	19.8	100
15	119.8	25.9	23.0	4.4	170	409	0.44	20.3	100
17	148.0	29.2	23.7	4.0	221	576	0.40	23.5	115
18	128.5	25.1	23.5	3.8	154	362	0.44	23.1	123
21	139.5	31.6	23.8	3.7	241	638	0.38	23.3	110
2	143.0	28.5	23.9	3.7	257	569	0.46	22.1	115
6	143.4	30.7	24.5	3.4	257	639	0.41	24.0	110
10	135.8	28.6	24.1	3.8	235	546	0.44	21.8	113
7	143.0	29.1	24.5	4.0	224	567	0.40	27.9	110
8	142.7	30.4	24.3	4.3	246	662	0.38	30.0	97
11	141.1	29.2	24.2	3.5	242	620	0.42	23.5	94
13	122.3	25.8	22.8	3.7	188	429	0.47	24.7	95
Mean	136.0	28.3	23.8	3.8	219	540	0.42	23.7	107
5% LSD	28.3	4.9	1.5	0.8	73	205	NS	9.7	21
Block									
1	157.5	31.7	24.0	3.3	287	729	0.39	25.5	116
2	141.3	29.3	24.3	4.0	227	565	0.41	26.3	115
3	134.2	28.2	23.9	3.7	204	501	0.42	26.4	109
4	115.8	25.4	23.3	3.6	183	434	0.44	22.2	99
5	131.3	26.8	23.7	4.3	193	472	0.41	17.9	95
5% LSD	15.3	2.6	NS	0.4	39	110	NS	3.6	11

There was a wide range of individual tree heights after 3 years of growth (63.0-257.0 cm). The mean treatment tree height values varied from 119.8 cm (family 15) to 148.0 cm (family 17), with only these two treatments just being significantly different from each other. Tree height in the control was well below the overall mean. There were significant block differences, with block 4 being of much lower mean height. Stem diameter showed significant treatment differences. Again, block 4 was much smaller in this regard. The foliage was not as blue as might have been expected from other trees on the site, even though the trees grew vigorously, with mean treatment height increments in year 3 in the range of 57.0-73.0 cm. Although there were significant differences, trees were generally of excellent form, with small variation.

Treatment mean dry root weights varied greatly from 154 g (family 18) to 257 g (families 2 and 6), with some significant differences. Blocks also varied. Values for treatment dry shoot weight varied from 362 g (family 18) to 662 g (family 8), with many significant differences. Mean dry R/S varied only a limited amount, with no significant differences between blocks or treatments.

Root growth was mainly within the top 20-25 cm of soil. Families 7 and 8, however, stand out as having penetrated deeper (28 cm and 30 cm respectively). Rooting depth of the control was the lowest (20 cm), although these trees were shorter in height. Block 5 had a significantly lower mean rooting depth of 18 cm. Root spread at a mean of 107 cm demonstrated little between-tree competition, although it varied significantly between treatments, with block 5 again having a low mean value.

Discussion

This experiment was established to investigate the concern of forest managers that tree stability in terms of root biomass may be prejudiced by an overemphasis on above-ground parameters as criteria of success in tree breeding. Since all the improved families used were derived from selected superior phenotypes in terms of height, diameter and stem form, it is not surprising that many of them were found to have much greater height and stem diameter after 3 years than the unimproved control. Similarly, it is perhaps to be expected that tree form was good and differences between improved families were not great. The differences in foliage colour were relatively large, with the unimproved control being the least healthy in terms of being yellowish (although yellowing did not relate significantly to tree growth). There were substantial block differences in foliage colour, suggesting site differences between blocks which might affect root growth and R/S.

Despite the wide variation in both dry root and dry shoot weights between families and blocks, the R/S remained remarkably constant in the range 0.38-0.47, with no significant differences. The value of 0.42 for the unimproved Washington control was very similar to the figure of 0.418 obtained by Mayhead and Jenkins (1992) on the same site for 3 year Sitka spruce of Washington origin with a mean height of 2.0 m. However, the lowest R/S in the present study did not necessarily arise from small root systems but as much from the presence of large shoots (e.g. families 8 and 21). This experiment failed to demonstrate any significant differences in R/S between the improved families and the unimproved import. Of considerable interest is the substantially greater root depth achieved by some families (e.g. families 7 and 8) and the greater root spread found in other families (e.g. families 17 and 18). Families 7 and 8 were among the tallest trees, while family 18 was among the shortest.

Forest managers seek high shoot growth and high tree stability and it is possible to identify more interesting families on the basis of this study. For example, family 2 displayed above average height, stem diameter, tree form, dry root weight, dry shoot weight and root spread. This family also displayed the second highest R/S (0.46). By comparison, family 13 had the highest R/S (0.47), but displayed a well-below average root spread, very poor height growth and low root and shoot production. Family 17 is the tallest with above average root and shoot weights, below average R/S, below average rooting depth and excellent root spread. Perhaps the most interesting point is that the unimproved Washington import was below average for all parameters except tree form. It appears that all families from the improvement programme based on QCI origin could be more stable than the reasonable fŏrest management alternative of Washington seed source.

Conclusion

The experiment demonstrated a wide range of biomass production, height and stem diameter growth between improved Sitka spruce families of QCI origin grown under sheltered, fertile and weed-free conditions. Although significant differences in root spread and rooting depth were demonstrated, there was no evidence of significant differences in root/shoot ratio or that trees selected for above-ground vigour have an inferior rooting system. This indicates that current practices within the tree breeding programme are not having a detrimental effect on tree stability, as measured by root/shoot ratio.

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