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An Indication of the Likely Volume Gains from Improved Sitka Spruce Planting Stock

INFORMATION NOTE

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SUMMARY

Volume gains from an old Sitka spruce tree breeding experiment were evaluated, allowing predictions to be made of the likely volume increases which could be expected from modern tested seed orchards and family mixtures. Estimation of stem volume was carried out in a 38-year-old open-pollinated Sitka spruce progeny trial growing in Clocaenog Forest, north Wales, which had previously been measured for 10-year height. The mean volume production of all the families grown from selected plus-trees was estimated to be 21% greater than the Queen Charlotte Island (QCI) control; the mean of the best three families in the experiment was 32% greater than the QCI control and the estimated volume of the very best family was 42% greater than the QCI control. If the results of this study were to be extrapolated to seed stock currently available from tested clonal seed orchards, final rotation volume gains could be expected to exceed unimproved QCI seed stock by between 21% and 29%.

INTRODUCTION

It is a requirement of tree breeders to provide estimates of gains from their improved planting stock. Rather than waiting until the final rotation, breeders present part-rotation gains based on actual data they have collected, e.g. 10-year height (Lee, 1991) and latterly 15-year diameter, stem form and wood density (Lee, 2001). There are two potential problems with this approach. Firstly, breeders are not able to state actual final rotation volume gain which is important to forest managers and, secondly, there is the possibility that breeders may not be maximising final volume gains if selections have been based on the performance of correlated traits at an early age such as 10-year height.

In the early 1990s an opportunity arose to address these problems by measuring stem volume in one of the first Sitka spruce progeny tests ever planted, which was then close to final rotation age. This permitted the performance of different families to be assessed in terms of a variable very closely related to final yield and also permitted comparison with an earlier assessment of performance based on height.

The impact of growth rate on characteristics affecting timber quality, while recognised as an important part of the tree improvement work carried out by Forest Research, was not addressed here.

METHODS AND MATERIALS

In 1953 the first Sitka spruce open-pollinated progeny trial was planted over three sites in Britain. Seed had been collected from 11 ‘plus-trees’ (highly selected phenotypes with well above average growth rates and stem quality) growing in different forests in Britain. The experiment was designed to give information about the genetic value or breeding value (BV) of the mother plus-tree by measuring the performance of all the progeny (collectively known as a *family*) derived from that tree.

Experimental design consisted of 10 x 10 tree block-plots at 1.5 m square spacing and five complete replications at each site. By 1990, the only remaining site from this series was located at Clocaenog Forest in north Wales. The trial had been largely neglected following an assessment of 10-year height in 1962. No thinning had ever taken place, leading to a large number of tall, dead trees that in many cases were still standing, scattered among the live trees to be assessed.

In 1990 the Clocaenog site was revisited and the 38-year-old experiment was assessed for diameter and volume. Diameter at breast height (DBH) was recorded for all live trees greater than 10 cm within the inner 8 x 8 trees in each plot, which covered an area of 0.0144 ha. Sample trees, selected systematically throughout the observed DBH distribution for each treatment, were assessed for height and stem volumes according to standard Forest

Research mensuration sample plot protocols, as described in Hummel *et al.* (1959). Top height was estimated as the mean of the total heights of dominant trees in each treatment which, combined with the stand age, gave an estimate of General Yield Class (GYC; Edwards and Christie, 1981). The Local Yield Class (LYC) of each treatment was estimated by comparing the average volume per hectare with predictions estimated from an early version of an interactive computer-based yield model for Sitka spruce stands then under development (Matthews and Sencee, 1993).

Family performance in terms of yield was assessed by comparing 38-year diameter, top height and volume as well as 10-year height for the 11 families against the standard QCI control. Breeders can use these results to estimate the BV of the original plus-trees relative to the QCI control. It is the original plus-trees which are subsequently involved in any further cross-pollination to produce improved planting stock. BV is a measure of the heritable genetic value net of any environmental effects which can be expected from using a given plus-tree in a crossing programme. Predicted gain from a tested seed orchard or family mixture is the mean of the breeding values estimated for the constituent trees.

RESULTS

Table 1 gives results for the 11 open-pollinated families and QCI control, including 10-year mean height, 38-year quadratic mean diameter and top height, and productivity per hectare based on live volume estimates. The mean top height for the experiment was 16 m, equivalent to a GYC of 12. Estimates of LYC varied from 11 (QCI control) to 15 (family 10).

In order to account for the variability of live trees within the experiment which had arisen prior to 1990, volume estimates were adjusted to a common stocking level across families using survival observed in plots for different families as a covariate. Both unadjusted and adjusted volume estimates are shown in Table 1 although comparisons are based on the adjusted estimates. All the families have a greater estimated stem volume per hectare compared to the QCI control; this varied from +5% to +42%. The mean estimated volume of all the families relative to the QCI control was +21%.

Table 2 shows how a reselected portion of the original 11 families performed for 38-year volume relative to the QCI control, depending on the age at which the selection took

Table 1 Yield performance of the open-pollinated families representing the 11 plus-trees compared to the unimproved QCI control.

Treatment	Mean height at 10 years		Top height at 38 years		Mean DBH at 38 years		Surviving trees/plot	Live stem volume ($m^3 ha^{-1}$)	Adjusted live stem volume	
	(m)	As % of QCI	(m)	As % of QCI	(cm)	As % of QCI			($m^3 ha^{-1}$)	As % of QCI
Family 1	2.68	111	15.50	99	15.83	111	38.0	383	422	127
Family 2	2.56	106	16.50	105	14.69	103	44.8	369	363	109
Family 3	2.67	111	15.90	101	14.98	105	48.2	421	393	118
Family 4	2.87	119	16.00	102	15.12	106	45.0	405	398	120
Family 5	3.05	126	17.80	113	16.07	113	40.4	426	449	135
Family 6	2.55	106	16.20	103	15.37	108	43.6	408	410	123
Family 7	2.63	109	16.00	102	15.11	106	43.4	392	396	119
Family 8	3.14	130	17.60	112	15.02	106	48.0	424	399	120
Family 9	3.08	128	16.50	105	15.89	112	46.4	478	447	134
Family 10	3.09	128	16.20	103	16.34	115	44.0	474	473	142
Family 11	2.50	104	16.40	104	14.38	101	46.4	367	351	105
Mean	**2.77**	**115**	**16.36**	**104**	**15.25**	**107**	**44.0**	**383**	**403**	**121**
QCI control	**2.41**	**100**	**15.70**	**100**	**14.22**	**100**	**40.5**	**310**	**333**	**100**

Note: Plots were formed of 10 x 10 trees planted at 1.5 m square spacing. Assessments based on inner 8 x 8 trees giving a plot area of 0.0144 ha.

Table 2 The 38-year volume gains relative to QCI control for the best three families selected either indirectly for 10-year height or directly for 38-year volume.

	10-year height (%)	38-year diameter (%)	38-year volume (%)
Mean of all 11 families	115	107	121
Mean of top 3 of families for 10-year height	129	111	132
Mean of top 3 of families for 38-year volume		113	137

Table 3 Predicted gains from three alternative tested seed orchards.

	10-year height (%)	38-year diameter (%)	38-year volume (%)
Orchard 1: equivalent to all 11 plus-trees	121	110	129
Orchard 2: equivalent to top 3 for 10-year height	140	115	145
Orchard 3: equivalent to top 3 for 38-year volume		119	152

Note: Assumed family heritability for each trait = 0.7.

place. The top three families for 10-year height were on average 29% taller than the QCI control. These same families gave an 11% and 32% improvement when assessed for 38-year diameter and volume respectively. These figures compare well with the best three families selected directly for 38-year volume, which were 13% and 37% better than the QCI control for diameter and volume. The loss of genetic gain for 38-year volume by selecting the best families based on 10-year height was 5%.

In reality, it is not the progeny but the parental plus-trees which are ultimately planted in tested seed orchards. Gains from seed orchards are not directly equivalent to those observed in Table 2 for two reasons. Firstly, the progeny give an imprecise estimate of the parental BV; family performance has to be weighted by either assumed or directly estimated heritability (the degree to which the trait is under genetic control varies from 0 to 1). Secondly, in a tested seed orchard all the parents are selected whereas in an open-pollinated trial only the mother tree has been selected – the pollen input is considered to be random and assumed to be equivalent to the population average. Therefore, estimates are needed of the potential genetic gain from three alternative tested seed orchards based on data collected in the Clocaenog trial, as shown in Table 3. The first of these is based on the assumption that a seed orchard is planted with parents equivalent to the mean for all the plus-trees represented in the Clocaenog progeny test. The second and third orchards are assumed to be planted with plus-trees equivalent to the selected proportions in Table 2. Orchard 2 is made up of parents equivalent to the best three at Clocaenog when selection is made early based on 10-year height, and orchard 3 is made up of parents equivalent to the best three when selection is delayed until 38-year volume is available.

Orchard 1 has a predicted genetic gain of +21% for 10-year height and +29% for 38-year volume. The gain for 38-year volume increases to +45% for orchard 2 and +52% for orchard 3. The gain foregone in 38-year volume by establishing an orchard based on the best families for 10-year height rather than directly for 38-years volume is estimated as just 7% (52%–45%).

DISCUSSION

There are problems associated with this study when trying to extrapolate countrywide. These include:

- the small number of progeny included in the experiment;
- competition effects in the experiment which do not relate well to forest stand conditions;
- the lack of replication across different forests or site types.

It is possible that the results could be peculiar to this site and are not applicable elsewhere. However, it does appear that the best families for 10-year height tend to retain their superiority much later into the rotation, resulting in only minor differences relative to the maximum genetic gain when evaluated based on direct selection for 38-year volume. Two out of the best three families for 10-year height were in the top three for 38-year volume. This study supports others (Gill, 1987; Lee, 2001), in asserting that it is not necessary to wait until close to final rotation age before selecting superior parental trees for seed orchards. More generally, results from Tables 2 and 3 suggest it is likely that the *percentage* increase in final rotation volume will be greater than the predicted percentage gain for 10-year height.

Relating the performance of these trees to that of planting stock from modern seed orchards is also problematic. Lee (1991) predicted the genetic gain from tested clonal seed orchards composed of the best parents to be around +15% for 10-year height. This is the same as the family mean performance for 10-year height measured in this study, suggesting that 38-year volume gains of +21% could be expected (Table 2). However, Lee (2001) also stated that seed orchard gains for 10-year height had perhaps been underestimated. If the true seed orchard gains for 10-year height are closer to the 21% predicted here (Table 3), then 38-year seed orchard volume gains ought to be around 29%.

Reselection among the 11 plus-trees clearly increases the predictions of genetic gains for volume but these are perhaps somewhat artificial figures since they are based on the improvements observed for a limited number of progeny from only one site. A seed orchard contains around 40 tested parent trees which have been reselected based on the performance of their progeny across at least three contrasting sites.

While high levels of volume gain may be possible if selection was based exclusively on growth rate, in practice reselection is also based on other, sometimes conflicting traits such as stem straightness and wood density (Lee, 1999). These other important traits can cause final selections to be something of a compromise in terms of individual trait gains, but are thought to maximise final crop economic value. Stem straightness and wood density were not assessed here and so it is not possible to say how the top three families performed for these traits relative to the QCI control.

CONCLUSIONS

These are preliminary results and need to be treated with caution, but it seems safe to assume that selection based on 10-year height would cause only minimal loss of 38-year volume relative to selection based directly on 38-year volume. If the results from this study were extrapolated to modern, tested seed orchards the 38-year volume gain could be expect to be at least 21% and up to 29% more than unimproved QCI material. Modern improved seed orchards and family mixtures differ from the families measured here in that the component parent trees have been reselected for improved quality as well as growth rate which should further improve their final economic value.

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