REALISED GENETIC GAIN IN *PINUS RADIATA* FROM "850" SEED-ORCHARD SEEDLOTS GROWN COMMERCIALLY IN THE CENTRAL NORTH ISLAND, NEW ZEALAND.

PART 1: GROWTH

J. A. TURNER

New Zealand Forest Research Institute Limited,
Private Bag 3020, Rotorua, New Zealand

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ABSTRACT

Analysis of covariance models of diameter and height of 13-year-old *Pinus radiata* D. Don grown in commercial forests in the central North Island formed the basis for comparing average stand tree diameter ($\bar{d}$) and mean top height (MTH) of non-seed-orchard and "850" seed-orchard seedlots. Both the $\bar{d}$ and MTH models used several groupings of seedlots to determine the impact of these first tree selections on $\bar{d}$ and MTH. The models included several variables to remove other growth-affecting factors. For the modelling of $\bar{d}$, altitude and crop stocking were used, and the MTH model used site index. The analyses of covariance for both $\bar{d}$ and MTH, show no significant improvement overall of "850" seed-orchard seedlots over Kaingaroa climbing select or Kaingaroa (bulk) seedlots at age 13. The Gwavas "850" seed-orchard 25-clone seedlots did show a significant improvement in $\bar{d}$ over Kaingaroa bulk, but not over Kaingaroa climbing select. The results of this study differed from those of large-plot genetic gain and progeny trials. This may be for several reasons. The first 8 to 10 years of seed production from the "850" seed orchards contained seed of poorer quality than later seed production. The assessment of *P. radiata* at age 13 may be too early for the detection of divergence of "850" seed-orchard material from non-seed-orchard material to be noticeable in commercial stands. Superior "850" seed-orchard seedlots may have been better than those planted in commercial stands.

Keywords: "850" seed orchard; genetic gain; Kaingaroa bulk seed; tree diameter; mean top height; *Pinus radiata*.

INTRODUCTION

History of New Zealand *Pinus radiata* Improvement

The original plantings of *Pinus radiata* in New Zealand were made using bulked seed collected predominantly from Año Nuevo, California (Burdon 1992). Collection of this seed took no account of the phenotype* of the parents. These collections thus comprise an

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*Phenotype refers to the physical characteristics expressed by a tree due to the interaction between the environment and the particular set of genes it has, i.e., its genotype (Falconer 1989).

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unimproved bulk seedlot (a seedlot is a specific collection of seed from either a seed orchard or a commercial forest), with an approximate rating for growth and form (GF) of 1 to 3 (Vincent 1987; Vincent & Dunstan 1989). Bulk unimproved material was planted in Kaingaroa Forest until the mid-1970s, and elsewhere up to the mid-1980s. During the late 1950s initial attempts at providing improved seed material were made by collection of open-pollinated seed from phenotypically superior trees either by felling trees in stands approx. 40 years old ("felling select" seed) or by climbing trees in young stands 14 to 20 years old ("climbing select" seed). Stands were then planted from the bulked seed (Shelbourne *et al.* 1986; Burdon 1992). Trees grown from felling-select seed have an estimated average GF rating of 3 (Vincent & Dunstan 1989). Trees grown from climbing-select material have an estimated GF rating of 7 (Vincent & Dunstan 1989). Both these methods of selection were used in the 1950s and early 1960s and were based on a selection intensity of the best 10 to 25 trees/ha.

Selection of superior "plus" trees for planting in "850"* seed orchards began in 1950 and continued until 1966. Plus trees were intensively selected (approximately 1 tree/100 ha) for the central North Island, Nelson, Canterbury, and Otago/Southland from "old crop" stands planted between 1925 and 1935 (Shelbourne *et al.* 1986; Burdon 1992). Plus trees were chosen for a combination of the following desired characteristics (Shelbourne *et al.* 1986):

- freedom from forking and ramicorn branches;
- straightness of stem;
- absence of stem cones low on the stem;
- vigour equal to or better than neighbouring dominants;
- regularly spaced, light, flat-angled branching.

These features were chosen because of their importance for the successful utilisation of *P. radiata* (Thulin 1957). Since this original plus-tree selection there has been continuing emphasis in tree breeding on straighter stems and on finer branching characteristics (Wilcox 1983).

The first seed orchard was established in Kaingaroa Forest in 1957 using clones of the 14 phenotypically best trees from the "850" series collection (Shelbourne *et al.* 1986). It was anticipated that trees grown from this genetically improved material would have a considerable improvement in growth and form over unimproved felling- and climbing-select material, with an estimated GF rating of approximately 13 (Vincent & Dunstan 1989). Another seed orchard was established in the central North Island at Gwavas in 1958. Later establishment of "850" seed orchards at Gwavas and Kaingaroa used the 25 and 36 phenotypically best clones (Shelbourne *et al.* 1986). Seed from 25- and 36-clone seed orchards has a GF rating of approximately 14 (Vincent & Dunstan 1989). These early seed orchards were open pollinated, so good isolation from external, genetically inferior pollen was considered necessary to maximise gain (Shelbourne *et al.* 1986; Carson *et al.* 1990).

Some difficulties were experienced initially in producing improved seed from the "850" seed orchards. The selection of plus trees based only on phenotype meant there was a lack of full evidence for good genotype as confirmed by the ability to transmit characteristics to

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* The prefix "850" denotes a particular series of clones. The first digit in the clonal series number refers to the regional origin of the clone (8 signifies collections carried out by FRI, not necessarily within one region). The other two digits refer to the year of selection, here 1950 (Vincent & Dunstan 1989).

offspring (Thulin 1957). This situation arose for the "850" series as a result of delayed progeny testing and a lack of intensive re-selection, or roguing, in orchards, based on the performance of progeny (Carson *et al.* 1990). Roguing that was carried out met with limited success because the "850" seed orchards were based initially on relatively few clones and there were additional losses due to the incompatibility of grafts used to produce some clones for the seed orchard (Carson *et al.* 1990). The seed orchards also suffered pollen contamination from "wild pollens" from outside the orchard and a disproportionate contribution of pollen from poorer performing clones within the seed orchard (Carson *et al.* 1990).

Studies of Growth Performance of "850" Seed-orchard Material

The ultimate success of a seed orchard depends on the performance of seed produced, in terms of the features subjected to selection. Large-plot genetic gain trials (Shelbourne *et al.* 1986; Sorensson & Shelbourne in prep.) are used to quantify realised gains in genetically improved material over non-seed-orchard or unimproved seed (with the difference expressed as a percentage of the unimproved seedlot mean), and progeny trials rank material at different levels of improvement (Shelbourne 1970). As expected, these trials indicate that growth performance of "850" seed orchard material is better than that of unimproved and non-seed-orchard *P. radiata* (Shelbourne 1970; Wilcox 1983; Shelbourne *et al.* 1986). The first open-pollinated (OP) seed orchards, however, were limited to predicted genetic gains in volume of approximately 15% compared to unimproved seedlots (Shelbourne, Firth & Low, unpubl. data; King *et al.* 1988; Carson *et al.* 1990). This was because:

- Pollen from unimproved stands entered the seed orchards, leading to less crossing between selected clones;
- Pollen contribution from different clones in the orchards was unequal, with a greater contribution from poorer quality clones;
- Clones were lost due to graft incompatibility;
- OP seed orchards were established conservatively with large numbers of clones as a safety measure to ensure cross-pollination, yet they offered limited scope for roguing from the results of progeny testing.

Results from 1955 and 1968 OP progeny tests comparing commercial "850" seedlots with a bulk unimproved seedlot found a 4% gain in mean diameter at breast height 1.4 m over bark (dbh) (Shelbourne *et al.* 1986). In 1978 a series of large-plot genetic gain trials was established on a sawlog regime to compare an OP commercial "850" seedlot from 21 clones selected in the central North Island (at Gwavas in 1976) with a Kaingaroa bulk unimproved seedlot. An age 5 assessment of this trial showed a 4% gain in mean dbh (Shelbourne *et al.* 1986) and at age 12 it was 8.7% (Sorensson & Shelbourne in prep.).

Current Study

Early stands planted with genetically improved seed from the "850" seed orchards in the 1960s will be approaching a harvestable age in the next 5 years. A large series of genetic gain trials and silvicultural trials has been established since 1978 in order to predict genetic gain that could be realised in commercial plantings (Shelbourne *et al.* 1986; Sorensson & Shelbourne in prep.). This study endeavoured to complement these genetic gain and silvicultural trials by identifying realised genetic gain in the commercial planting of "850" seed-orchard seedlots in the central North Island.

The aim of this study was to determine the extent to which the increased stand average diameter ($\bar{d}$) and mean top height* (MTH) of "850" seed-orchard material in commercial stands is the result of phenotypic selection in the breeding programme. Analysis of covariance models for $\bar{d}$ and MTH, derived from inventory data for stands planted from 1970 to 1979, which included genetic, environmental, and, for $\bar{d}$, silvicultural effects, formed the basis for quantifying the differences in $\bar{d}$ and MTH among aggregations of *P. radiata* seedlots grown commercially in the central North Island. Part 2 of this study (Turner 1997) aimed to quantify realised genetic gain in multinodality, stem straightness, the occurrence of leader malformation, and stem cone cluster incidence.

METHOD

Data Collection

Data for $\bar{d}$ and MTH models were obtained from Forestry Corporation of New Zealand Ltd (now Fletcher Challenge Forests Ltd) age 13 pre-thinning inventory data for stands planted between 1970 and 1979. The inventory data for each stand contained information on:

- Year and month planted;
- Year and month measured;
- Live tree basal area (m^2/ha);
- Mean top height (MTH);
- Stocking (stems/ha);
- Number of pruned stems per hectare.

These data were gathered to support future growth and yield estimates, and for estimating subsequent production thinning yields. Sampling for the age 13 inventory was carried out in systematically located plots in a combination of unbounded point samples and bounded circular plots in which dbh of each tree and a sample of tree heights were measured (Burn-Murdoch unpubl. data). The sampling intensity was designed to estimate total stand volume within ±10% at the 95% confidence interval.

Seedlot data for each stand were extracted from the Forestry Corporation of New Zealand Ltd stand record system (SRS), and checked for reliability using the "FRI Register of Commercial Seedlots" (Vincent & Dunstan 1989). Stands with no recorded seedlot, wrongly recorded seedlots (i.e., a corresponding seedlot code could not be found in the "Register of Commercial Seedlots"), or combinations of seedlots planted in them, were discarded.

For the 252 stands containing reliable seedlot origin information, details relating to factors influencing tree diameter and height were added. From the SRS the following data were collected:

- Planted stocking (stems/ha);
- Rotation number (first, second, etc.);
- Occurrence of regeneration thinning (1 = yes, 0 = no);
- Thinning regime (age of tree at thinning and residual stems/ha for each thinning);
- Pruning regime (age at pruning, pruned height, and number of pruned stems/ha for each pruning lift).

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* The height predicted by the Petterson height/dbh curve for a dbh corresponding to the quadratic mean dbh of the 100 largest-diameter trees/ha in a stand (Goulding 1995).

From compartment maps, information was gathered on releasing treatments, burning, windrowing, fertiliser treatment, blanking, crushing, spraying for *Dothistroma pini* Hulbary, mechanical land preparation. For each of these, the area undergoing the treatment was given as a proportion of total stand area. Soil-type information was obtained from the New Zealand Land Resource Inventory maps (Page *et al.* 1978, 1: 63 360). Altitude and aspect information was derived from Department of Survey and Land Information topographic maps.

Analysis

Statistical analyses were performed using the SAS system (SAS Institute Inc. 1986) procedures CORR and GLM. The development of analysis of covariance (ANCOVA) models to determine the level of realised genetic gain in $\bar{d}$ and MTH from "850" seed-orchard seedlots required, firstly, the identification of variables which significantly influence $\bar{d}$ and MTH. Correlation analysis of $\bar{d}$ and MTH against the independent variables was performed to find significant "growth-affecting" variables and confounding factors. Variables significantly correlated with $\bar{d}$ and MTH were plotted to establish the nature of the relationship between them. $\bar{d}$ and MTH ANCOVA models were developed by adding variables one at a time, checking the correlation of residuals against the remaining growth affecting variables to establish major influences on unaccounted variation. ANCOVA statistical assumptions were then checked using residual plots. Least square means were calculated from ANCOVA models to determine adjusted $\bar{d}$ and MTH for each seedlot aggregation. Finally, the degree of statistical difference among adjusted means of seedlot aggregations was tested using the LSD multiple comparison procedure.

RESULTS

Stand Average Tree Diameter

Aggregation of seedlots enabled differentiation of genetic gain in basal area per hectare among the broad groups of seedlots (Table 1). Details of the individual seedlots in each seedlot grouping are given in Appendix 1. Each of the seedlot group names includes the region in which the seed was collected, the type of collection (i.e., "850" seed orchard, climbing-select, or bulk), and, for seed orchards, the number of phenotypically "best" clones represented in that seed orchard (Vincent & Dunstan 1989). Ranking of these seedlot groups

TABLE 1–Seedlot groupings, their approximate estimated GF rating, number of stands in each group, and unadjusted mean basal area (m^2/ha) and standard error of the mean. Seedlot groups are ranked by mean basal area.

Seedlot group	GF rating	Number of stands	Mean BA (m^2/ha)	Standard error
Gwavas "850" 25-clone	14	60	28.3	0.59
Kaingaroa climbing-select	7	14	28.1	1.22
Kaingaroa "850" 25-clone	14	9	27.3	1.53
Kaingaroa bulk	1–3	35	26.6	0.77
Waimihia "850" 36-clone	14	16	26.6	1.14
Kaingaroa "Uninodal"	–	31	26.3	0.82
Kaingaroa select	3–7	25	25.1	0.92
Gwavas "850" 14-clone	13	11	24.9	1.38
Kaingaroa "850" 14-clone	13	7	24.4	1.73

by basal area per hectare unadjusted for site and silvicultural effects (Table 1) shows the relative performance of the seedlot groups used.

Subsequent analyses used $\bar{d}$ as the dependent variable rather than basal area, as the use of $\bar{d}$ reduces the confounding effect of stocking among seedlot groups. Other than genotype, two factors influencing $\bar{d}$ identified by the correlation analysis were altitude, representing site growth potential, and stocking at age 13, representing silvicultural regime. The linear relationship between altitude and $\bar{d}$ has a coefficient of determination (r^2) of 0.27 and a root mean square error (RMSE) of 2.47 (Fig. 1). The linear relationship between stocking at age 13 and $\bar{d}$ has r^2 0.43 and RMSE 2.18 (Fig. 2). No other factors identified as possibly influencing diameter were significantly correlated (p>0.05) with $\bar{d}$.

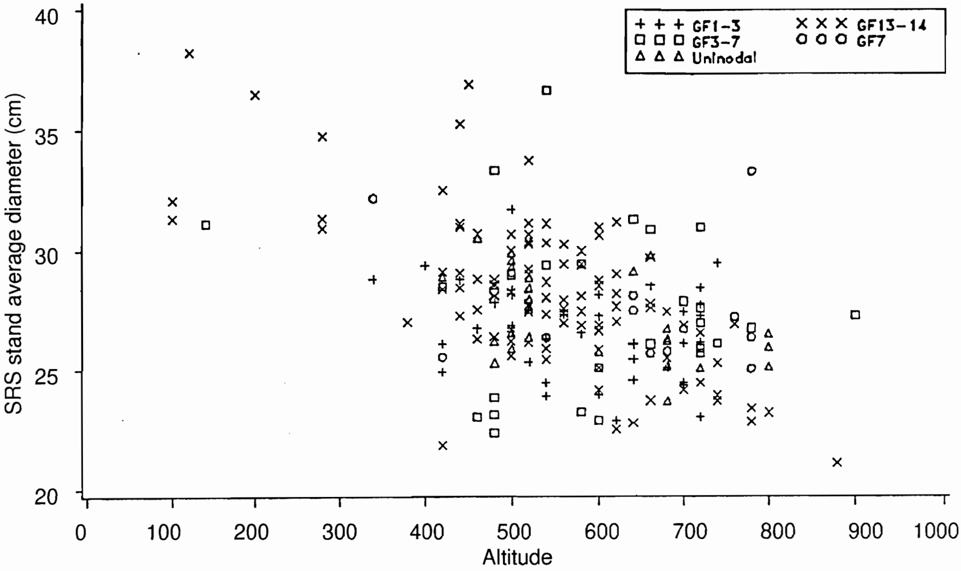

FIG. 1–Altitude against SRS stand average diameter at age 13.

The ANCOVA model fitted to the data:

$$\text{SRS } \bar{d} = \text{Altitude} + \text{Stocking age 13} + \text{Seedlot group}$$

has r^2 0.64 and RMSE 1.69, with residual plots showing no violation of statistical assumptions. The ANCOVA indicates that the effect of altitude (p=0.01) and age 13 stocking (p=0.01) on $\bar{d}$ are significant. Overall there is no significant difference (p>0.05) in SRS $\bar{d}$ between the seedlot groups. Individual comparisons (Table 2), however, indicate that Kaingaroa climbing-select and Gwavas 25-clone seedlot groups have significantly higher (p=0.01) mean $\bar{d}$ than the Kaingaroa bulk seedlot group. All other comparisons among seedlot groups were non-significant (p>0.05).

Alternative Stand Average Tree Diameter Models

Exploration of the pruning and thinning regimes applied to the different seedlot groups in the study identified significant levels of bias among the seedlot groups in their silvicultural

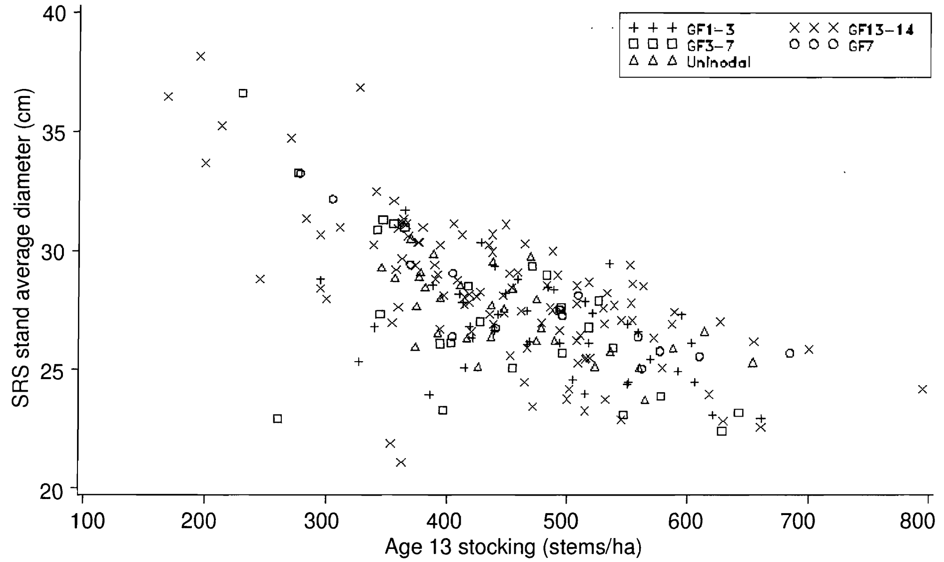

FIG. 2–Age 13 stocking (stems/ha) against SRS stand average diameter at age 13.

TABLE 2–The least square means and associated standard errors for each seedlot group calculated from the stocking and altitude average tree diameter model. The final column of the table indicates those seedlots that have a significantly different $\bar{d}$ (cm) based on the LSD test. Seedlots followed by the same letter do not differ significantly ($p>0.05$).

Seedlot group	Adjusted mean ($\bar{d}$)	Standard error ($\bar{d}$)	
Kaingaroa climbing-select	28.2	0.38	a
Gwavas "850" 25-clone	28.0	0.21	a
Waimihia "850" 36-clone	28.0	0.41	ab
Gwavas "850" 14-clone	27.6	0.41	ab
Kaingaroa "850" 14-clone	27.6	0.65	ab
Kaingaroa "Uninodal"	27.5	0.30	ab
Kaingaroa select	27.4	0.34	ab
Kaingaroa "850" 25-clone	27.3	0.55	ab
Kaingaroa bulk	27.2	0.24	b

treatments. Stocking was biased by seedlot group, indicating a general trend for "850" seed-orchard seedlots to be planted at slightly lower stockings than non-seed-orchard material. The effect of the interaction of the many treatment variables which make up a single silvicultural regime, on final levels of $\bar{d}$, precluded the inclusion of a single treatment variable; therefore, an aggregate variable was derived. The FRI stand modelling system STANDPAK (West *et al.* 1982; Whiteside *et al.* 1989) provided a useful tool for modelling the effect of different silvicultural regimes on stand basal area growth for each of the stands used in this study.

Each stand was modelled in STANDPAK at GF 7 (*see* Appendix 2), and a site index (SI_{20} = MTH at age 20) of 29, deriving a regime covariate (STANDPAK-predicted basal area per hectare) representing the stand $\bar{d}$ growth potential of the particular regime applied. While altitude had a reasonable relationship with SRS $\bar{d}$ for the stands used to calculate the STANDPAK basal area (r^2 0.24, RMSE 2.46), the inclusion of SI_{20} in the revised model is likely to provide a more useful explanation of the variation in $\bar{d}$ across sites. SI_{20} for each stand was obtained from estimates made by Höck *et al.* (1993) who used geostatistical techniques to interpolate compartment MTH at age 20. The MTH at age 20 used to estimate compartment SI_{20} was derived from MTH measured in inventory plots at various stand ages (Höck *et al.* 1993). SI_{20} showed a slightly improved linear relationship with SRS $\bar{d}$ (r^2 0.31, RMSE 2.36). The possibility of the effect of regime on $\bar{d}$ differing with SI_{20} was tested by including an interaction term in the ANCOVA model. This interaction term was non-significant ($p>0.05$), suggesting the effect of regime on $\bar{d}$ was the same across the SI_{20} in the study area.

Despite the non-significant interaction between SI_{20} and the regime covariate there was an indication that regime and SI_{20} were confounded among seedlot groups. The Kaingaroa "850" 25-clone seedlots tended to be at low SI_{20} on a high basal area regime, while Gwavas "850" 14-clone and Kaingaroa "850" 14-clone seedlots were at high SI_{20} sites on low basal area regimes. The confounding due to bias in regime and SI_{20} among seedlot groups led to the calculation of STANDPAK $\bar{d}$ with SI_{20} for the compartment included (Appendix 2 contains details of the STANDPAK runs), and calculating the dependent variable as the residual diameter (SRS $\bar{d}$ – STANDPAK $\bar{d}$). The difference between the SRS $\bar{d}$ and the STANDPAK-derived $\bar{d}$ with SI_{20} included, represents genetic effects on $\bar{d}$, with silvicultural and site effects removed.

These two revised models had poorer fits to the data than the stocking and altitude model (Table 3), and this resulted in changes in the ranking of the seedlot groups, widening of the range of adjusted means, an increase in the adjusted mean standard errors, and a change in the significant differences between seedlot groups. The conclusions derived from the stocking and altitude model regarding the level of improvement in "850" seed-orchard material over climbing-select material remained the same, however. Further analyses comparing the adjusted mean $\bar{d}$ among different seedlot groupings were therefore made using the stocking and altitude model.

TABLE 3—Root mean square error for the three models fitted to $\bar{d}$ data

Model	RMSE
Stocking, altitude	1.69
Regime covariate, SI_{20}	1.88
STANDPAK residual $\bar{d}$	2.09

Seedlot Groupings

Contrasting GF

The GF ratings for the seedlot groupings used in this comparison are provided in Table 1. The ANOVA model had r^2 0.54 and RMSE 1.93. The effect of GF was not significant ($p>0.05$). This suggests that overall there was no significant difference in $\bar{d}$ between the levels of GF. The results of the LSD comparison (Table 4) between individual levels of GF also indicated that there was no difference ($p>0.05$) in $\bar{d}$ between the seedlot groupings.

TABLE 4–Least squares means, associated standard errors, realised genetic gain (%) of seedlot groups at age 13 over Kaingaroa bulk seedlots, and 95% confidence intervals for genetic gain estimates by seedlot group.

Seedlot group	$\bar{d}$	Standard error	Genetic gain (%)	95% confidence intervals		
GF7	28.5	0.521	4.9	9.1	0.6	a
GF13–14	27.9	0.190	2.6	5.2	0.0	a
"Uninodal"	27.4	0.347	0.6	4.0	–2.8	a
GF3–7	27.4	0.389	0.6	4.2	–3.0	a
GF1–3	27.2	0.308	–	–	–	a

Contrasting non-seed-orchard and seed-orchard effects

Seed-orchard seedlots were those derived from "850" seed orchards, while non-seed-orchard seedlots were Kaingaroa bulk, Kaingaroa select, and Kaingaroa climbing-select. The ANOVA model had r^2 0.52 and RMSE 2.06. The effect of seedlot group was not significant ($p>0.05$), suggesting there was no difference in $\bar{d}$ between the seed-orchard and non-seed-orchard seedlot groups.

Seed orchard location

There was no significant difference ($p>0.05$) in $\bar{d}$ between seedlot material from the different "850" seed orchard locations—Kaingaroa, Gwavas, and Waimihia.

Mean Top Height

Aggregation of seedlots enabled differentiation of genetic gain in MTH among the broad groups of seedlots (Table 5). Ranking of the seedlot groups by MTH unadjusted for site effects (Table 5) indicated the relative performance for the seedlot groups used.

TABLE 5–Seedlot groupings, their approximate estimated GF rating, number of stands in each group, unadjusted MTH from the age 13 pre-thinning inventory, and standard error of the mean.

Seedlot group	GF rating	Number of stands	MTH (m)	Standard error
Gwavas "850" 14-clone	13	18	21.0	0.836
Gwavas "850" 25-clone	14	67	20.0	0.332
Kaingaroa "850" 14-clone	13	7	19.9	1.213
Kaingaroa bulk	1–3	50	19.5	0.333
Kaingaroa climbing-select	7	20	19.1	0.512
Kaingaroa "Uninodal"	–	32	18.8	0.402
Waimihia "850" 36-clone	14	17	18.5	0.697
Kaingaroa select	3–7	25	18.1	0.562
Kaingaroa "850" 25-clone	14	10	17.0	0.660

There was a strong linear relationship between SI_{20} (Höck *et al.* 1993) and MTH at age 13 (Fig. 3) (r^2 0.85, RMSE 1.04). No other factors identified as possibly influencing tree height were significantly correlated ($p>0.05$) with MTH.

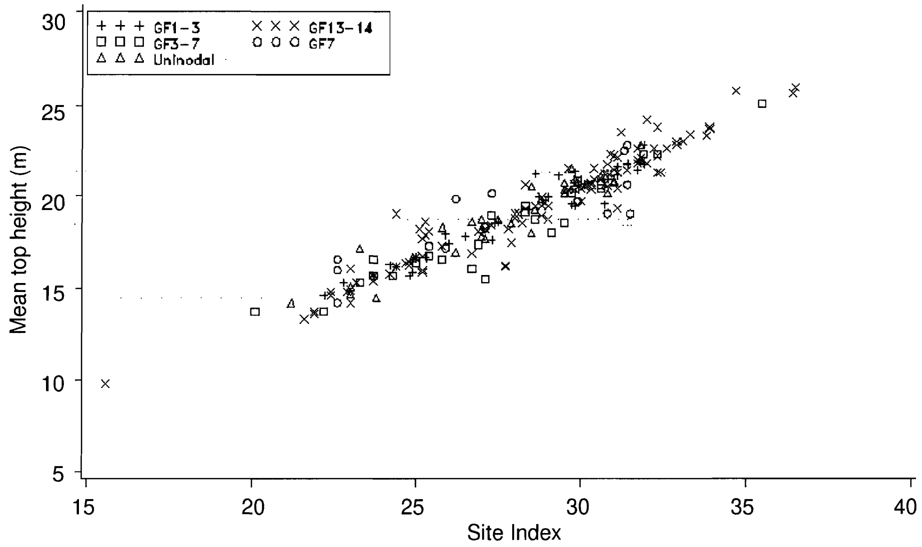

FIG. 3–Mean top height (m) at age 13 against site index.

The ANCOVA model fitted to the data:

$$MTH = SI_{20} + \text{Seedlot group}$$

had r^2 0.86 and RMSE 1.03, with residual plots showing no violation of the statistical assumptions. The ANCOVA using this model showed SI_{20} to have a strongly significant ($p=0.01$) effect on MTH. The effect of seedlot group on MTH was non-significant ($p>0.05$); therefore, overall there was no significant difference in MTH among the seedlot groups. The results of the LSD comparison (Table 6) between seedlot groups indicated that there were no individual differences ($p>0.05$) between seedlot groups.

TABLE 6–The adjusted mean top height (MTH) and standard error of the mean for each seedlot group.

Seedlot group	Adjusted MTH	Standard error (MTH)	
Kaingaroa "850" 14-clone	20.2	0.391	a
Kaingaroa climbing-select	19.4	0.244	a
Gwavas "850" 25-clone	19.3	0.128	a
Kaingaroa "Uninodal"	19.3	0.183	a
Gwavas "850" 14-clone	19.2	0.249	a
Waimihia "850" 36-clone	19.2	0.259	a
Kaingaroa bulk	19.2	0.152	a
Kaingaroa "850" 25-clone	19.0	0.332	a
Kaingaroa select	18.8	0.208	a

Seedlot Groupings

A series of comparisons of the adjusted mean MTH among different seedlot aggregations was made using the model described above.

Contrasting GF

The ANCOVA model had r^2 0.85 and RMSE 1.080. The effect of GF was not significant ($p>0.05$). This suggests that overall there was no significant difference in mean MTH among the levels of GF. There were no significant ($p>0.05$) individual comparisons of mean MTH among levels of GF (Table 7).

TABLE 7–Adjusted mean top height (MTH), standard error of the mean, realised genetic gain of seedlot groups at age 13 over Kaingaroa bulk seedlots, and 95% confidence intervals by seedlot group.

Seedlot group	MTH	Standard error	Genetic gain (%)	95% confidence intervals		
GF7	19.3	0.228	0.8	3.6	–2.0	a
GF13–14	19.2	0.084	0.1	1.8	–1.6	a
“Uninodal”	19.2	0.153	0.4	2.5	–1.8	a
GF1–3	19.1	0.138	–	–	–	a
GF3–7	18.7	0.171	–2.0	0.3	–4.4	a

Contrasting non-seed-orchard and seed-orchard effects

Seed-orchard seedlots were those derived from “850” seed orchards, excluding the Kaingaroa “Uninodal” material, while non-seed-orchard seedlots were Kaingaroa bulk, Kaingaroa select, and Kaingaroa climbing-select. The ANCOVA model had r^2 0.85 and RMSE 1.082. The effect of seedlot group was not significant ($p>0.05$). This suggests that there was no significant difference in MTH between the seed-orchard and non-seed-orchard seedlot groups.

DISCUSSION

The results of this study did not show the genetic gain in $\bar{d}$ and MTH at age 13 anticipated from results of genetic gain trials (Sorensson & Shelbourne in prep.). No significant difference was identified between the diameter and height performance of “850” seed-orchard seedlots and non-seed-orchard seedlots at age 13 grown in the central North Island. There was, however, a significant ($p=0.01$) 4.9% gain in $\bar{d}$ for Kaingaroa climbing-select over Kaingaroa bulk at age 13. The disparity between management practices used in genetic gain trials and commercial plantations was a possible reason for the differing results. Commercial forestry practices at the time of planting “850” seed-orchard seedlots could have reduced the potential gains from planting such improved material. “850” seed-orchard material planted in the central North Island in the 1970s appears to have been planted at a lower stocking than non-seed-orchard material. By analysing the difference between $\bar{d}$ estimated using STANDPAK and SRS $\bar{d}$, however, this effect should have been eliminated.

Another possible explanation for the disparate findings is that measurement of stands in which regeneration of unimproved material had occurred would result in under-estimation of genetic gain for “850” seed-orchard material. Basal area per hectare at age 13 for “850” seed-orchard material from stands which had regeneration thinning was compared with stands in which there had been no regeneration thinning (Table 8).

Regeneration thinning did not appear to have an effect on basal area per hectare at age 13, in stands containing “850” seed-orchard material. This assumes that regeneration thinning

TABLE 8–Mean basal area per hectare and associated standard errors for stands containing "850" seed-orchard material with and without regeneration thinning.

Stand	Number of stands	Mean BA (m^2/ ha)	Standard error	
Regeneration thinning	32	27.16	0.9527	a
No regeneration thinning	182	27.16	0.3466	a

was carried out only in all those stands in which natural regeneration occurred and that the effect of planting shock on tree growth was non-existent by age 13. There was, however, a significant difference in MTH at age 13 between stands which had a regeneration thinning and those that did not (Table 9). The results are counter to those expected, with stands in which regeneration thinning had been carried out having a greater average MTH. These analyses suggest regeneration thinning of stands containing "850" seed-orchard material has not strongly confounded the ranking of seed groups measured in this study.

TABLE 9–Mean top height (MTH) and associated standard errors for stands containing "850" seed-orchard material with and without regeneration thinning.

Stand	Number of stands	MTH (m)	Standard error	
Regeneration thinning	32	20.8	0.3376	a
No regeneration thinning	182	19.1	0.2122	b

In the first 8 to 10 years of open-pollinated seed-orchard seed production there was a high incidence of pollen contamination from *P. radiata* stands outside the seed orchard (M.J.Carson pers. comm.). The first "850" series seed orchard was planted in Kaingaroa Forest in 1957 and began producing seed in 1968 (Shelbourne *et al.* 1986). The "850" seed-orchard seedlots planted into the stands in this study were from seed collections made in 1970 to 1978. These "850" seed-orchard seedlots would have contained seed fertilised by pollen from outside the seed orchard. The same situation applies to seed from the Gwavas seed orchard planted in 1958. For this reason, results of this study are likely to provide lower estimates of genetic gain than for "850" seed-orchard material planted after 1978.

A further explanation for the disparity in results between this study and genetic gain trials is that the "850" seed-orchard seedlots used in genetic gain and progeny trials differ from those used in commercial plantings. Use of superior seed from "850" seed orchards in genetic gain trials would result in gains greater than those found in commercial plantings of "850" seed-orchard material which has been open-pollinated and has contamination from inferior and "wild" pollen.

The basal area per hectare for the stands in this study was measured at age 13 years. Another explanation for the disparity in results may be that this is too young for there to be a noticeable divergence between seed-orchard and non-seed-orchard material grown in commercial stands (M.J.Carson pers. comm.). The analysis of diameter measurements made on 20-year-old trees reported in Part 2 of this study (Turner 1997) may provide a better indication of divergence between seed-orchard and non-seed-orchard seedlots.

CONCLUSIONS

This study focused on the realised genetic gain of *P. radiata* grown in a central North Island commercial forest and should, therefore, be viewed as a survey only of the "850" seed-orchard resource, in this region. The growth performance of "850" seed-orchard material in terms of stand mean tree diameter ($\bar{d}$) and mean top height (MTH), showed no significant improvement over Kaingaroa climbing-select or Kaingaroa bulk at age 13 years. The Gwavas "850" seed orchard 25-clone seedlots did, however, show a significant improvement in $\bar{d}$ over Kaingaroa bulk, but not over Kaingaroa climbing-select.

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APPENDIX I

CODES AND NAMES OF SEEDLOTS CONTAINED IN THE DATA SET FOR ANALYSIS OF BASAL AREA PER HECTARE AND PREDOMINANT MEAN HEIGHT (from Vincent & Dunstan 1989)

Seedlot name and code	Number of stands
Waimihia "850" 36-clone	**17**
R74/A3*	7
R76/44	9
R78/A3	1
Kaingaroa bulk	**50**
R61/676	1
R72/927	49
Kaingaroa select	**25**
R73/963	12
R74/967	4
R70/900	9
Kaingaroa climbing-select	**20**
R71/902	8
R73/953	2
R73/954	1
R69/856	9
Kaingaroa "850" 14-clone	**7**
R73/A1	5
R70/A1	2
Kaingaroa "850" 25-clone	**10**
R73/A2	5
R76/42	3
R76/43	2
Kaingaroa "Uninodal"	**32**
R71/925	
Gwavas "850" 14-clone	**24**
WN73/A1	7
WN75/46	8
WN78/2	9
Gwavas "850" 25-clone	**67**
WN72/52	1
WN72/A2	1
WN74/A2	8
WN75/24	5
WN75/52	46
WN77/03	1
WN71/A2	5

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* The code attached to each seedlot describes the region in which the seed was collected, the year of collection and the collection number. For example, **WN74/A2**, is seed collected from the Forest Service, Gwavas conservancy (**WN**) in 1974 (**74**) in collection **A2** (Vincent & Dunstan 1989).

APPENDIX 2

SUMMARY INFORMATION FOR STANDPAK RUNS

Models Used in STANDPAK

Early Growth
Growth Model Type: 1 Standard growth model
Growth Model: 23 EARLY Early growth and silviculture
Basal Area Level: Medium
GF Rating: 7 (no improvement)
Height Model Type: 1 Standard height model
Height Model Number: 34 P. rad RO Interim Pumice Plateau (KGM3) 1987
Stand Volume Table: 29 KGM3 Central N.I. Pumice Plateau
Monthly Growth Table: 3 EARLY P. radiata (Jackson *et al.* 1976)

Later Growth
Growth Model: 22 PPM88 RO Pumice Plateau 1988
the other models were as for Early Growth

Initial Stand Settings

Site Index: 29 (average site index for Kaingaroa forest) and compartment SI_{20} (Höck *et al.* 1993) for second set of STANDPAK runs
Starting Date Age: 4 years
Mean Top Height (m): 4.7 m (calculated by STANDPAK)
Stocking (stems/ha): initial planted stocking from Stand Record System (SRS)
Basal Area (m^2/ha): calculated by STANDPAK from mean diameter and stocking.
Mean Diameter (cm): 5.6 cm, calculated by STANDPAK based on mean top height.

Treatments

Treatments are based on those recorded for each stand in the SRS. Important assumptions to note are:

- Thinnings are to waste from below,
- Where final thinning residual stockings prior to age 13 years differed from those measured at age 13 the thinning residual stocking was taken to be equal to the stocking measured at age 13.
- The switch from Early to the Later models was made at a mean crop height of 18 m. For all STANDPAK runs which excluded SI_{20}, this occurred several months after age 13.
- For the STANDPAK runs which included SI_{20}, the switch from Early to Later models was made at age 10.5 years, unless the last pruning was carried out later in which case the switch was made immediately after the last pruning.