

**CAUSES AND POTENTIAL APPROACHES TO  
OVERCOME INFERIOR STEM FORM AND  
BRANCHING HABIT IN RADIATA PINE  
GROWN ON FARM SITES  
— A LITERATURE REVIEW**

**J.A. TURNER**

**Report No. 33**

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# **FOREST AND FARM PLANTATION MANAGEMENT COOPERATIVE**

## **EXECUTIVE SUMMARY**

### **CAUSES AND POTENTIAL APPROACHES TO OVERCOME INFERIOR STEM FORM AND BRANCHING HABIT IN RADIATA PINE GROWN ON FARM SITES - A LITERATURE REVIEW**

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85% of new land plantings of radiata pine in New Zealand are now occurring on fertile farm sites. The unique characteristics of these planting sites, particularly relating to nutrient status have resulted in higher levels of stem and branch malformation compared with traditional forestry sites. In a review of the literature relating to the effects of site, silviculture and genetics on stem quality characteristics, site nutrient characteristics of high fertility locations have a dominant role in determining stem quality. Silvicultural control of stem form of radiata pine appears to be limited to appropriate selection of stems at thinning, an operation which is in itself limited in its effectiveness because of the inability to clearly identify economically significant stem quality defects at first pruning when selection of final crop trees often occurs. Selection of appropriate radiata pine breeds (a "farm breed"), therefore, offers the best opportunity for improvement in the stem quality of radiata pine grown on fertile farm sites, in particular the use of radiata pine from the Guadalupe provenance, and three year old physiologically aged cuttings. Radiata pine from these sources has shown improved stem form on fertile sites over traditional plantings of radiata pine seedlings. In developing a "farm breed", analysis of other stem and wood quality traits which could be considered for inclusion, eg., wood density, branch size, will be needed. This will form part of a programme of research which focuses on the ranking of traits, eg., stem sinuosity, branch cluster frequency, density, etc., in terms of their importance to being able to produce different end products on a variety of sites. This will enable the identification of the particular end products that may be produced from certain sites for the range of silvicultural treatments, and genetic material available.

## INTRODUCTION

Stem quality is first and foremost influenced by the intended end use as dictated by future markets, whether they be a pulp mill, LVL plant, sawmill or firewood merchant. Each of these end users has different requirements regarding desirable quality characteristics of the wood they utilise. The ability of the forest/ woodlot owner to meet the quality demands of different markets for wood products is then influenced by three factors; site, silviculture, and genetics. The relative importance of each of these factors in influencing stem quality defines the sorts of markets a particular forest/ woodlot owner may produce wood for and the management approaches taken to meet specific market demands.

The predominance of new-land plantings on fertile farm sites (Ministry of Forestry sources estimate 85% of new land plantings occur on these sites) makes it apparent that attention needs to be given to the interplay of genetics, silviculture, and site as they affect quality traits on farm plantings of radiata pine which are on sites with characteristics, particularly relating to nutrient levels, that are radically different from those on traditional forest sites. Changes in silvicultural practice and the selection of particular traits from the breeding programme may be needed in order to develop high value plantation resources on farm sites as opposed to conventional sites.

This report, aims to review the literature on site, silviculture, and genetic influences on the branching frequency, stem sinuosity, and malformation of radiata pine. The findings of the literature review are then discussed in the summary of each section in terms of what they mean for the management of forests planted on to ex-pasture sites.

### **Note on Genetic Parameters**

In interpreting the influence of genotype on various quality characteristics of radiata pine a brief mention needs to be made of the terminology used by quantitative geneticists to describe, and quantify the genetic component of the variation in a quality characteristic (*trait*) of a population. The terms which follow, therefore, tend to be different ways of expressing that amount of variation in a quality trait that is explained by a family's genotype, the remaining variation being due to environmental factors.

*Breeding values* express the value of a certain trait of an individual as the mean value of its progeny (Falconer 1989). Breeding values fit the value of a trait for a family in a particular population to a normal distribution allowing the identification of families with extreme quality traits.

*Narrow sense heritabilities* express the reliability of the phenotypic<sup>1</sup> value as a guide to the breeding value, and can be calculated on an individual or family basis (Cotterill & Zed 1980), ie. the degree of resemblance between relatives in a particular breeding population, at a particular site (Falconer 1989). Narrow sense heritabilities may be calculated at an individual or family level. *Individual heritabilities* are used to determine expected responses from individual selection, eg., the selection of plus trees for inclusion into a breeding programme (Cotterill & Zed 1980). *Family heritabilities* are used to determine expected responses from progeny test selection (Cotterill & Zed 1980).

*Broad sense heritabilities* on the other hand express the extent to which individuals' phenotypes are determined by genotype (Falconer 1989), ie. how much of how a tree looks is determined by its genes as opposed to the environment. Broad sense heritabilities, therefore, are important in identifying quality traits which may be easily selected in the field as providing a genetic improvement in the characteristic. The narrow sense heritabilities are of more use in identifying genetic effects on quality characteristics as they indicate the extent to which progeny from the same parents can be expected to be similar. When heritabilities are calculated by geneticists they are indicative only of the population and site from which the data was collected, therefore, they will tend to reflect any biases in traits of the selected site and population (Bannister 1980).

*Genetic gain* is another measure used to express the level of improvement in a particular trait achieved through breeding. Genetic gain is expressed as the difference between the average of the improved progenies and the unimproved seedlot characteristic, expressed as a % of the unimproved seedlot mean.

A final important term is the definition of *genetic correlation*. This refers to the extent to which two traits are influenced by the same genes (Falconer 1989). This is important in predicting the magnitude and direction of response in one trait to selection for another trait (Falconer 1989).

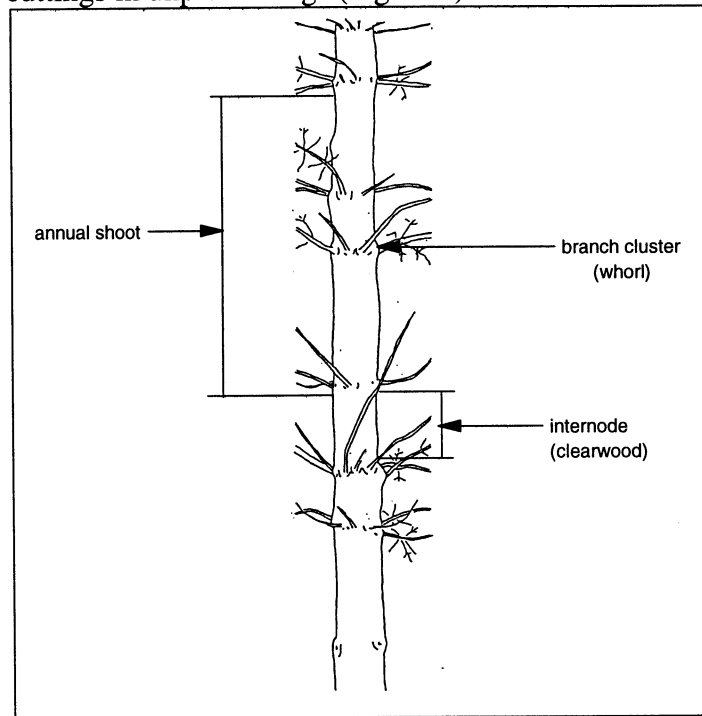
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<sup>1</sup>Phenotype is the physical characteristics expressed by a tree due to the interaction between the environment and the particular set of genes, ie., its genotype it has.

## BRANCH CLUSTER FREQUENCY IN THE ANNUAL SHOOT

### Introduction

The discussion of branching in radiata pine which follows focuses in particular on site, genetic and silvicultural influences on branch cluster frequency within the annual shoot, and how this quality characteristic in association with tree height and branch cluster depth relates to production of clear cuttings in unpruned logs (Figure 1).



**Figure 1: Identification and definition of branching characteristics.**

Silvicultural practices involving radiata pine in New Zealand have placed an emphasis on the production of clearwood (knot-free wood) by pruning of the butt log and carrying out heavy, early thinnings to increase diameter growth on pruned trees (Sutton 1984). These practices have been warranted because of the relatively large size and persistence of branches in radiata pine, and the financial premiums that are placed on clear cuttings. It is these premiums for clear cuttings, combined with improvements in timber utilisation technology which have allowed the present processing of clear lengths as short as 0.3 m (Carson & Inglis 1988). With this technological ability it has become apparent that the unpruned second log and even third log may yield substantial volumes of clear cuttings from internodes, therefore, there has been an increasing interest in means of manipulating branch cluster frequency and hence, clear cuttings from internode lengths in radiata pine.

Before endeavouring to identify factors which influence branch cluster frequency in radiata pine it must be pointed out that the identification of important factors is clouded by the different measures used by researchers to express branch cluster frequency, and associated

with this, clearwood length. Measures include: number of branch clusters per annual shoot, total number of branch clusters in a log length, mean internode length<sup>2</sup> (MIL), and mean internode index<sup>3</sup> (MIX). The number of clusters in the annual shoot will enable the clear identification of factors influencing branch cluster frequency alone, while total number of branch clusters in a log will be confounded by factors which also influence tree growth. MIL and MIX measures of branch cluster frequency as well as being influenced by factors which determine branch cluster frequency and tree growth, are both also influenced by factors which affect branch size and angle. This issue must be kept in mind when comparing the results of studies in which different measures of branching frequency have been used.

The number of branch clusters in an annual shoot has been found to be influenced, to varying degrees, by the following factors:

- tree age, corresponding to changes in annual height growth;
- tree size;
- site characteristics;
  - i) site fertility;
  - ii) latitude;
  - iii) altitude;
  - iv) mean annual rainfall (MAR);
- silviculture, in particular, thinning history;
- genotype.

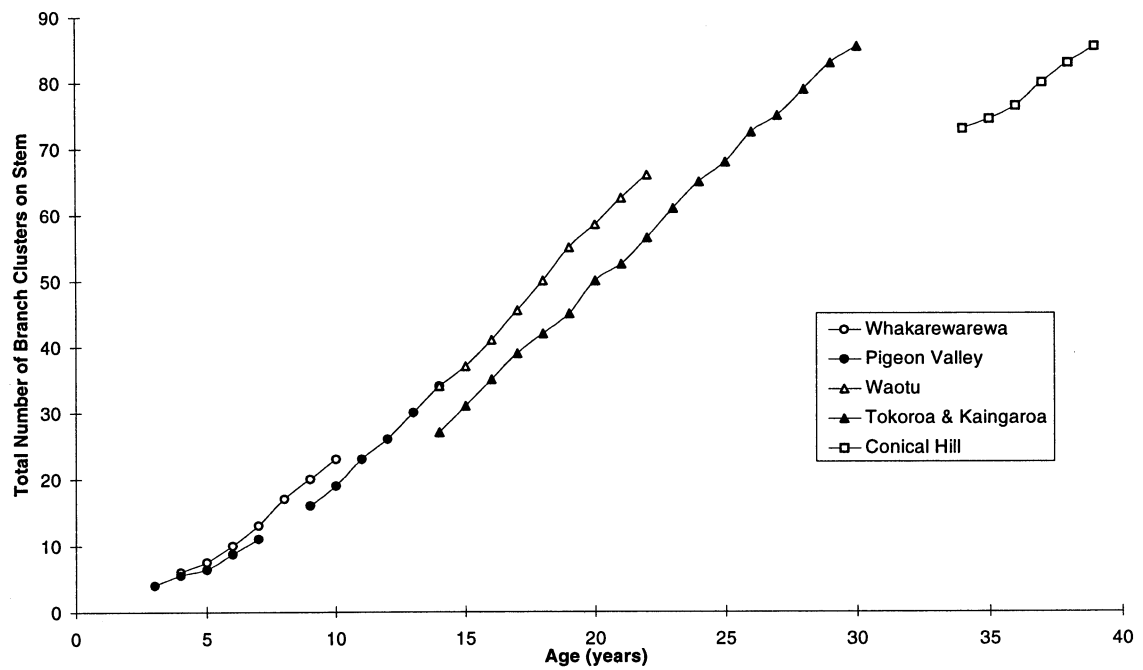
### **Tree Age**

The number of branch clusters produced in the annual shoot has been found to increase with tree age (Figure 2) up to age 20 (Bannister 1962). This increase in cluster number with age corresponds to increases in annual height growth with age (Figure 2 and Figure 3), resulting in a similar number of clusters for different sections of the stem (Carson & Inglis 1988). Beyond about age 14 the number of branch clusters in the annual shoot is negatively correlated with annual height growth (Bannister 1962; Burdon 1971), resulting in fewer branch clusters during periods of rapid height growth.

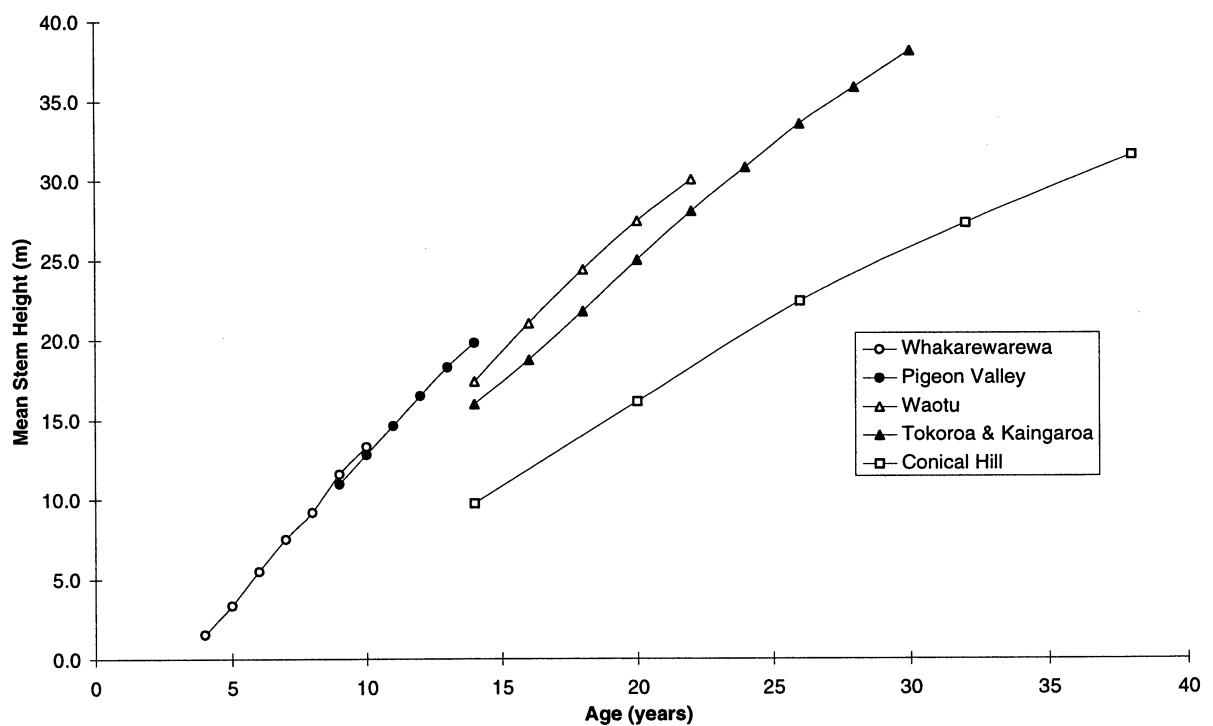
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<sup>2</sup>mean internode length (MIL) is  $\Sigma$  length (m) of internodes in log/ number of internodes in log.

<sup>3</sup>mean internode index (MIX) is  $\frac{\Sigma (\text{internode lengths} > 0.6\text{m})}{5.5\text{m}}$ .



**Figure 2: Number of branch clusters in the annual shoot, against age, for forest sites. After (Bannister 1962).**



**Figure 3: Height growth curves for radiata pine grown on forest sites. After Bannister (1962).**

### **Tree Size**

Trees which are greater in diameter and/ or height tend to have a greater number of branch clusters in the annual shoot (Fielding 1960; Madgwick 1983a,b; Carson & Inglis 1988). This is the multinodal tree that was selected for by tree breeders in New Zealand during the first series of plus tree selections because of the genetic correlation between diameter and high branch cluster production (Shelbourne *et al.* 1986). These interactions between height growth and branch cluster production, and tree size and cluster production make the identification of factors influencing annual branch cluster production more complex, as factors influencing height growth, and tree diameter must be separated from those influencing branch cluster production. Unless the measure of branching used by authors is branch cluster frequency in the annual shoot, it is not possible to clearly separate influences on height and diameter growth from those affecting branching frequency.

### **Site Factors**

Site factors which appear to influence branch cluster frequency include, nutrient status, latitude, altitude, and rainfall. Any effect of site nutrient status, in particular levels of nitrogen and phosphorus, on branch cluster production appear to be small, to negligible (Will & Hodgkiss 1977; Beets & Madgwick 1988). Will (1971), Will and Hodgkiss (1977) and Knight (1973), found a slightly positive linear relationship between branch cluster production and nitrogen levels (Table 1). In a study of genetic and site influences on MIL, Carson and Inglis (1988) found site MIL to be lower on low fertility sites and at lower latitudes, with Woodhill forest, having the lowest MIL of the sites measured. The influence of latitude on MIL may relate to changes in the length of the growing season with a shift from southern latitudes to northern latitudes. It is not possible to clearly determine if site fertility and latitude influence branch cluster production alone as these findings (Carson & Inglis 1988) are partially confounded by the use of MIL as the measure of branching habit. Branch cluster production on the stem has been found to decrease with increasing altitude and increasing rainfall (Grace & Carson 1992). Again, these results are partially confounded in terms of being able to identify factors influencing branch cluster production in the annual shoot, and as such, changes in altitude and rainfall as they impact on height and diameter growth may also be implicated in influencing these results (Grace & Carson 1988).

**Table 1: Mean number of branch clusters per seedling for different levels of nitrogen application. Source: Knight (1973).**

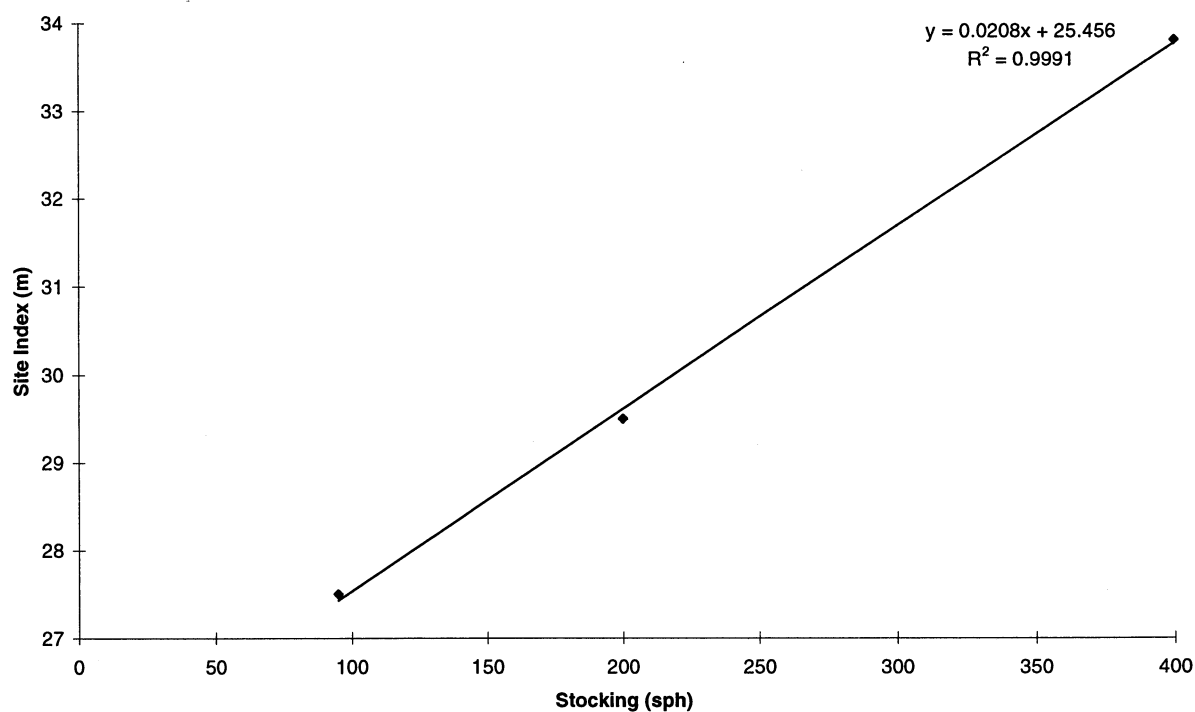
<b>NITROGEN SUPPLY (ppm)</b>	<b>NO. OF BRANCH CLUSTERS PER SEEDLING</b>
0	0.9
25	2.5
50	2.6
75	2.9
100	3.7

### **Silviculture**

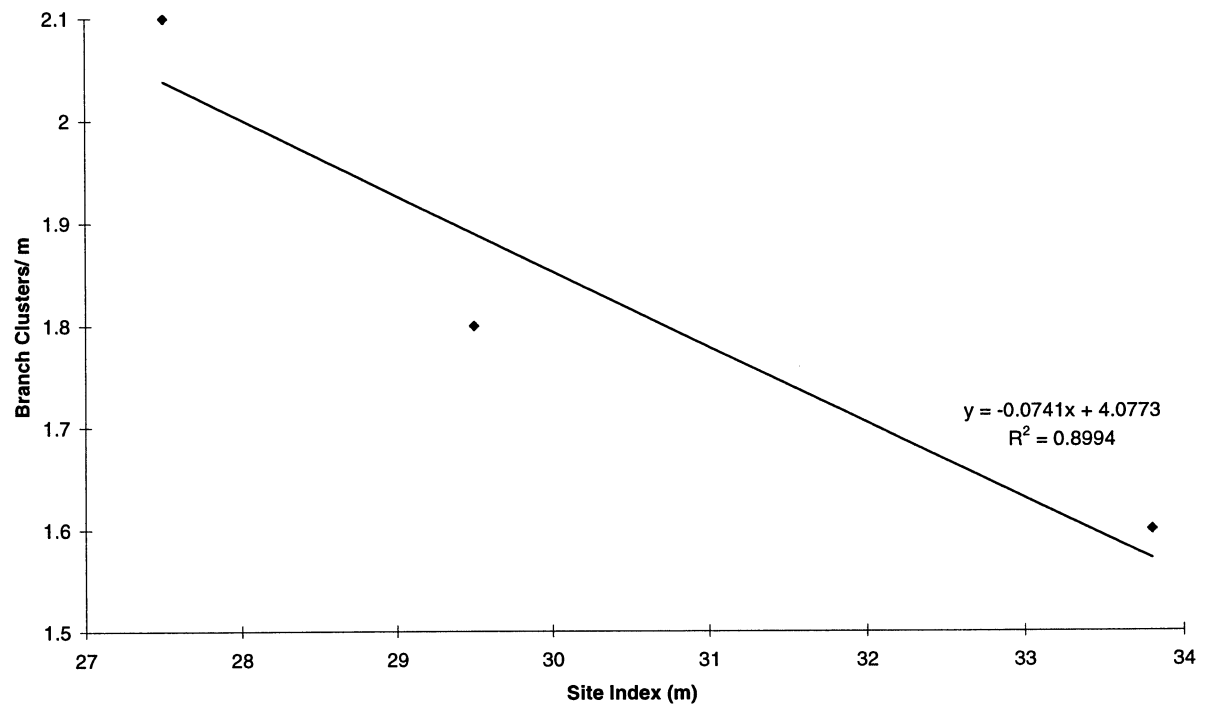
Silvicultural practice, in particular stocking, has not been identified as having an effect on branch cluster frequency (Table 2) (Siemon *et al.* 1976; Beets & Madgwick 1988; Tombleson, Grace & Carson 1990; Grace & Carson 1992; Knowles & Kimberley 1992). Knowles and Kimberley (1992) using an alternative measure of clear cutting potential to those used traditionally which expresses the proportion of log length which is knotty (clear cutting index), and found this index to decrease with increasing stocking on both forest and farm sites, ie., the amount of clear cuttings increased with increasing stocking. The clear cutting index does not, however, separate the effect of stocking on branch size, and hence branch cluster depth, from the stocking effect on branch cluster frequency in the annual shoot. These results may also be influenced by the interaction between height growth and final crop stocking under a constant selection ratio (Maclaren *et al.* 1995). The increase in clear cuttings with increasing stocking measured using the clear cutting index may, therefore, be due to the increasing stocking resulting in taller trees compared with lower stockings (Maclaren *et al.* 1995) (Figure 4 and Figure 5).

**Table 2: Mean internode length for three final crop stocking trials in Kaingaroa. Source: Tombleson, Grace & Carson (1990).**

SITE	SITE INDEX (m)	NOMINAL FINAL STOCKING (stems/ ha)	MIL (m)
Matea	24	150	0.34
		250	0.38
		350	0.34
Goudies	29	117	0.42
		250	0.37
		390	0.38
Northern Boundary	33	150	0.45
		250	0.46
		350	0.46



**Figure 4: Change in site index (mean top height at age 20) for increasing stockings at Tikitere. Source: Knowles & Kimberley 1992.**



**Figure 5: Change in branch cluster frequency (branch clusters per metre) by site index at Tikitere.**  
Source: Knowles & Kimberley 1992.

### Genetic Control

The extent to which genetics influences branch cluster frequency is reflected in the narrow sense heritability of this trait. The heritabilities measured by various authors (Table 3) indicate that branch cluster production is highly heritable, and therefore, is under strong genetic control.

**Table 3: The individual narrow sense heritability for branch cluster production calculated by different authors.**

AUTHOR	HERITABILITY
Fielding (1960)	0.40 to 0.70
Bannister (1962)	0.45
Bannister (1980)	0.40 to 0.50
Shelbourne & Low (1980)	0.45
Carson & Inglis (1988)	0.50
Cotterill & Zed (1988)	0.47 to 0.53

Bannister (1980) in reference to unpublished data (Shelbourne *et al.*) found that individual narrow sense heritability for branch cluster frequency increased with age, suggesting the

genetic control of branching in radiata pine increases with tree age. This increase in genetic control may be due to phenotypic variance of young trees being largely environmental, so that if juvenile height increments are excluded the heritability calculated will be higher (Bannister 1980). Also under strong genetic control is the relationship between tree height and total number of branch clusters on the stem (Forrest & Ovington), resulting in different clones having different relationships between tree height and number of branch clusters. While branch cluster production appears to be under strong genetic control beyond the juvenile growth phase, there is still a large level of variability in branch habit between progeny of a particular family (Forrest & Ovington 1971; Madgwick 1983).

Selection for both uninodal branching and increased branch cluster frequency in the Genetics and Tree Improvement (GTI) breeding programme has lead to large realised genetic gains in this characteristic over unimproved radiata pine (Table 4 and Figure 6) (Shelbourne & Briscoe 1983; Cleland 1986; Shelbourne *et al.* 1986; Sorrenson & Low 1995), further indicating the strong genetic control of branching frequency which exists in radiata pine.

**Table 4: Average percentage genetic gain in characteristics selected for improvement in "850"<sup>4</sup> series seed orchard material (approximate GF of 13 to 14) compared with Kaingaroa Felling Select material (approximate GF of 3) at age 12. Gains are given for the genetic gains trial at Kaingaroa Cpt 1210, for the large plot trials, the row plot trials and a national average. Data from the 1978 large-plot genetic gain trial series on a sawlog regime. Source: Sorensen and Low (1995).**

<b>Average Genetic Gain for:</b>	<b>DBH</b>	<b>Bole straightness score<sup>5</sup></b>	<b>Branch frequency score<sup>6</sup></b>	<b>Malformation score<sup>7</sup></b>
<b>Kaingaroa Cpt 1210</b>	12.5	17.9	19.6	9.4
<b>Large Plot</b>	8.4	19.4	27.9	8.6
<b>Row Plot</b>	10.1	28.2	34.2	8.5
<b>National Average</b>	9.4	24.4	31.5	8.6

<sup>4</sup> The number "850" is a prefix number denoting a particular series of clone selection. The first digit in the clonal series number refers to the regional origin of the clone. The second two digits refer to the year of selection, in this, case 1950 (Vincent & Dunstan, 1989).

<sup>5</sup>bole straightness score - a 1-9 subjective score where 1 = crooked, 9 = very straight (Carson 1991).

<sup>6</sup>branch frequency score - measured using a 1-9 subjective score where 1 = extremely uninodal, 9 = extremely multinodal (Carson 1991).

<sup>7</sup>malformation score - measured using a 1-9 subjective score where

9 = no malformation,

8 = 1 ramicorn,

7 = 2 ramicorns or 1 ramicorn intermediate in diameter between normal ramicorn and a fork,

6 = 3 or more ramicorns or 1 severe plus one average ramicorn,

5 = basket whorl with stem not deflected,

4 = basket whorl with stem deflection up to half diameter,

3 = basket whorl with stem deflection greater than diameter,

2 = fork,

1 = more than 1 fork.



**Figure 6: Long internode radiata pine (left) and multinodal radiata pine(right). Source: FRI Photo Library.**

Genetic control of branching characteristics in radiata pine has also been achieved through the use of physiologically aged cuttings. While cuttings have been shown to have similar numbers of branch clusters in the lower stem as seedlings (Klomp & Hong 1985; Menzies & Klomp 1988), cuttings from trees greater than two years old also tend to have fewer branches per branch cluster, smaller branches and an average angle of branching which is more horizontal (Burdon & Bannister 1985; Menzies & Klomp 1988). This lighter branching habit in radiata pine aged cuttings leads to potentially greater clearwood and reduced pruning times compared with seedlings.

### **Summary**

The strong genetic influence on branch cluster number, and the relationship between branch cluster number and height, along with no clear evidence of a silvicultural influence on branch cluster production, places the emphasis on the breeding programme to produce trees which meet certain branch cluster frequency specifications. The ability to breed for a particular branching habit in radiata pine is to a certain extent limited, however, by several factors. Firstly, the fact that there is large variability in branching habit between progeny within a family. Clear cuttings production at the stand level may, therefore be controlled, but it may not

be easily controlled at the tree level. Control of branching habit at the individual tree level may, however, be achieved more precisely through clonal forestry. A further limit to breeding for a certain level of branch cluster production results from the interaction between height growth and branch cluster production. The ability to produce a particular branching habit on a certain site is, therefore, limited by the impact of site characteristics on height growth. On sites with limited height growth where annual shoots are short, internode lengths will be constrained to, at best, the length of the annual shoot. The range of possibilities for levels of clear cuttings production are, therefore, less on sites with poor height growth, than for sites with greater rates of height growth (Turner *et al.* 1997). Another constraint to being able to breed for internodes is the genetic correlation between tree diameter, branch angle, branch size, stem form, and branching frequency. In radiata pine, families with long internodes also have associated with this low branching frequency, a slower diameter growth, steeper branching angles, poorer stem form, larger branches and a greater likelihood of damaged leaders due to wind storms (Carson 1988). Breeding for longer internodes, therefore involves trade offs between clear cuttings in the upper logs and clearwood in the pruned butt log (Carson 1988). The actual nature of these trade offs depends on the discount rate and price relativities between clear cuttings, and high quality framing timber (Table 5). The use of physiologically aged cuttings and the lighter branching associated with these may improve the trade offs that have to be made in selecting for longer internodes.

**Table 5: Predicted profitability of four radiata pine breeds grown in a Central North Island forest under a direct sawlog regime as modelled in Standpak on a rotation length of 30 years. Present net worth (PNW) was calculated using a 7% discount rate. Source: Carson 1988.**

Breed	PNW (\$/ ha)		
	Price list 'base'	Price list '6' <sup>8</sup>	Price list '7' <sup>9</sup>
<b>Climbing select</b>	2103	2433	1935
<b>Growth and Form</b>			
(i) First orchard	3130	3220	3254
(ii) Second orchard	4502	4080	5081
<b>Long-internode</b>	3302	4361	2607

<sup>8</sup> Price list '6' is for 'Export 2000 High Clears, Low Framing'

<sup>9</sup> Price list '7' is for 'Export 2000 Low Clears, High Framing'

## STEM SINUOSITY

### Introduction

Sweep in the pruned butt log has an important impact on the value of pruned logs (Cown *et al.* 1984; West & Kimberley 1991). The level of stem sinuosity in the pruned butt log, in conjunction with log size, affects the level of conversion of a log to sawn timber which in turn results in lower log values for highly swept pruned butt logs due to the reduced conversions that can be achieved (Cown *et al.* 1984) (Figure 7).

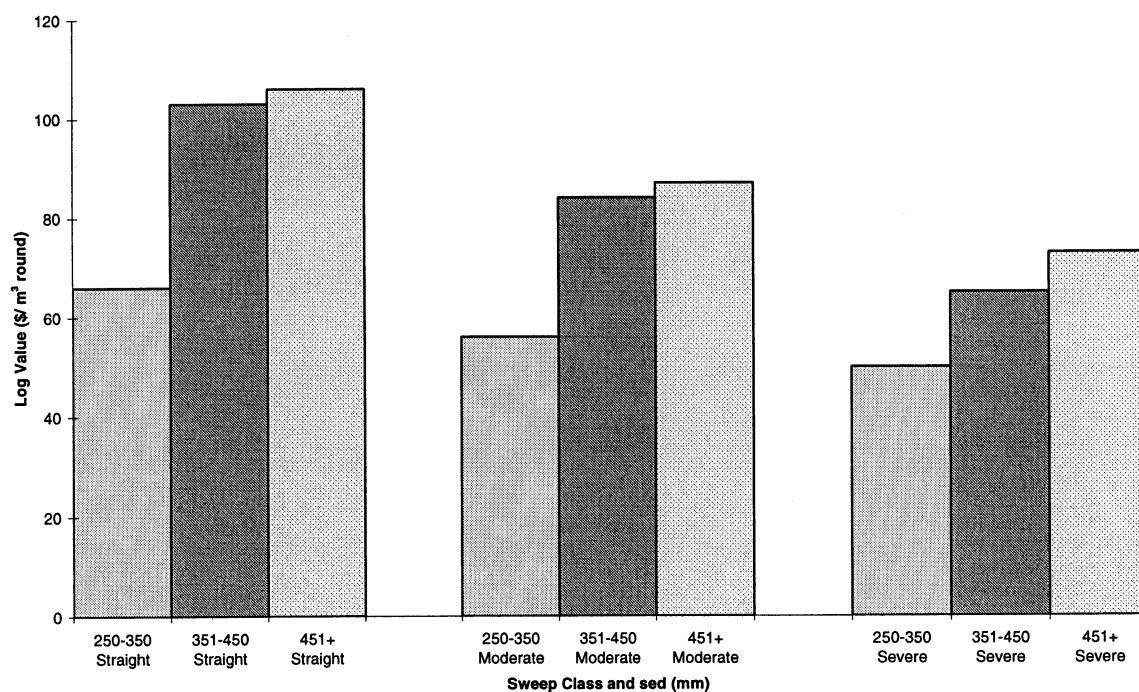


Figure 7: Effect of log size and sweep on pruned log value including a credit of \$12.5/ m<sup>3</sup> for sawmill residues. The sweep classes are straight < 10 mm/ m, moderate 11-20 mm/ m, and severe > 20 mm/ m. Source: Cown *et al.* 1984.

As well as reduced log value due to sweep, sawn timber defects which arise from stem sinuosity, such as sloping grain, compression wood, and pith defects, also reduce pruned log value (Fielding 1940; Nicholls 1982).

Stem sinuosity is influenced by the following factors:

- tree diameter growth;
- toppling of juvenile seedlings;
- site characteristics;
  - i) nitrification levels;
  - ii) site fertility;
  - iii) nutrient imbalances;
- genotype.

### **Tree Diameter Growth**

Tree diameter growth influences external sweep, but does not strongly influence the sinuosity of the pith. A tree which has toppled at age two or three is restored to the vertical by geotropic curvature in the lower part of the stem (Burdett *et al.* 1986), resulting in juvenile sweep. As the tree grows the juvenile sweep arising from the correction of topple is obscured by radial growth, resulting in less external sweep on mature trees compared with juvenile trees (Burdett *et al.* 1986; Bail & Pederick 1989; Maclaren 1993). The obscuring of the juvenile sweep of a stem while resulting in an apparent decline in stem sinuosity will still have characteristics associated with it which degrade the timber close to the pith, such as compression wood, and sloping grain (Cown *et al.* 1984). The effect of tree diameter growth on stem sinuosity therefore, serves to hide and dilute the effects of juvenile sweep, rather than reducing it directly. The dilution of stem sweep with diameter growth means that stem sinuosity appears most severe at ages three to six years (Bail & Pederick 1989).

### **Toppling of Juvenile Seedlings**

Tree lean due to toppling of juvenile seedlings (Figure 8) results in sweep as the tree grows to correct the lean resulting from toppling (Figure 9) (Chavassee 1978; Mason 1985; Burdett *et al.* 1986; Wilcox 1990; Maclaren 1993). The incidence of toppling in juvenile seedlings is influenced by several factors which are themselves influenced to varying degrees by site, establishment practices, and genetics. The discussion of these factors, and their relative importance in influencing sweep incidence is, however, beyond the scope of this report, so they will only be briefly touched on in this report in terms of important factors implicated as affecting the incidence of toppling. Some of the factors which have been identified as important in the incidence of toppling are:

- tree size (Mason 1985);
- planting stock, ie., seedlings versus physiologically aged cuttings from two or three year old trees (Menziess & Klomp 1988; NZ Forest Research Institute 1991; Holden *et al.* 1996)
- poor root systems (Chavassee 1978);
- poor planting practice (Chavassee 1978);
- planting on very fertile, wet, silt or clay soils (Chavassee 1978);
- wind characteristics of site (Fielding 1940; Nicholls 1982);
- cultivation treatment (Mason 1985).



**Figure 8: The Tikitere Agroforestry Research Trial toppled at age two years by Cyclone Alison. Source: FRI Photo Library.**



**Figure 9: Stem sinuosity arising from toppling. Source: FRI Photo Library.**

### **Site Characteristics**

Site characteristics which have been identified as playing an important role in the incidence of sweep are site fertility, levels of nitrification, and nutrient imbalances. In comparisons of the incidence of sweep on sites in New South Wales, Australia, with different previous land uses Birk *et al.* (1993), found greater incidences of stem sinuosity on ex-cultivated pasture, than ex-native or ex-pasture land. These differences are believed to be related to the higher fertility, in particular higher N levels of the ex-cultivated pasture site, resulting in what is commonly termed "speed wobbles" (Birk *et al.* 1993). These findings are supported by those made by Will & Hodgkiss (1977), who studied the effect of different levels of nitrogen and phosphorus on radiata pine form. The nitrification potential of a site, which is related to the C:N ratio, has been implicated in determining the incidence of sweep at a site with the lower C:N ratios of ex-cultivated pasture and ex-pasture sites resulting in higher levels of nitrification, and hence greater levels of stem sinuosity (Birk 1990). This effect is anticipated to decline as the C:N ratio increases during the growth of a woodlot (Cossens & Crossan 1995) and into the second rotation, due to the resulting decline in nitrification (Bail & Pederick 1989).

Although it is clear that nitrogen availability is associated with poor stem form (Knight 1973; Will & Hodgkiss 1977), it is not clear whether or not nitrogen is directly involved, or that it is implicated through an interaction with other nutrients such as boron and sulphur (Birk 1990). Nutrient imbalances, in particular boron and sulphur deficiencies have been implicated in a greater incidence of stem sinuosity, and malformation in general (Birk 1990, 1991) due to the death of the terminal bud. Deficiencies in boron and sulphur on ex-pasture sites may result in part from the particular soil formation, excess nitrogen, weed competition, and grazing (Birk 1990).

### **Silviculture**

There does not appear to be a direct silvicultural effect on the incidence of stem sinuosity. In a study of levels of stem sinuosity in the four stockings at the Tikitere agroforestry trial McInnes & Beamish-White (1993) found no significant difference in the incidence of sweep between the different stockings at this trial (Table 6). The results of this study, however, will be slightly confounded by the greater diameter growth in the lower stockings masking stem sinuosity at these stockings.

**Table 6: Mean sweep in each of the four stockings at Tikitere. source: McInnes & Beamish-White (1993).**

Stocking (stems/ ha)	Mean Sweep (mm/ m)
50	8.1
100	7.8
200	8.0
400	6.9
Average	7.7

Indirect silvicultural influences on stem sinuosity incidence do, however, exist in terms of planting stockings, and thinning stockings determining the selection ratio, and therefore, influencing the opportunity to remove swept trees during thinning selection.

### **Genetic Control**

The extent to which genetics influences stem straightness is reflected in the narrow sense heritability of this trait. The heritabilities measured by various authors (Table 7) indicate that stem straightness is moderately heritable, and therefore, is under a certain degree of genetic control.

**Table 7: The individual narrow sense heritability for stem sinuosity calculated by different authors.**  
\* family sense heritability.

AUTHOR	HERITABILITY
Shelbourne <i>et al</i> in Bannister (1980)	low
Cotterill & Zed (1980)	0.78*
Bail & Pederick (1989)	0.44
Pederick (1990)	0.33
Cotterill & Dean (1990)	0.20

Further evidence of the level of genetic control of stem sinuosity are the results of progeny tests and genetic gains trials, all of which show improvements of stem straightness resulting from the GTI breeding programme. Results from 1955 and 1968 open pollinated (OP) progeny tests comparing commercial "850" seedlots with a bulk unselected seedlot found an 18% gain in bole straightness score (Shelbourne *et al.* 1986). An age 5 assessment of the 1978

large plot genetic gain trial in which an OP commercial "850" seedlot was compared with a felling select seedlot indicated a 19% gain in stem straightness (Shelbourne *et al.* 1986). The same trial provided similar results at age 12 (Sorensson & Low 1995) as shown in Table 4.

Bail & Pederick (1989) found evidence for a site x genotype interaction suggesting that sweep and stem deformity on high fertility sites may be under the control of separate genes to those which influence deformity on less fertile sites. This may relate to the genetic control of nutrient use so that limiting levels of key elements influencing stem form, such as boron and sulphur may be different for different genotypes, or there may be differences in the ability of various clones to translocate key elements to the leading shoot. The Guadalupe provenance is a seed source which may provide trees with good form on high fertility sites (Burdon & Bannister 1973; Burdon & Bannister 1985; Bail & Pederick 1989). In plantings of Guadalupe provenance radiata pine on a farm site in Australia, it was found that there was a significantly lower incidence of sweep in trees from the Guadalupe provenance than compared with local Australian provenances (Bail & Pederick 1989). Studies of Guadalupe provenance radiata pine grown in New Zealand have show this provenance to have a longer and more extensive rooting system, thus providing greater wind stability and associated with this, reduced stem sinuosity (Burdon 1969). Guadalupe x New Zealand landrace hybrids also appear to provide an opportunity for achieving improved form in radiata pine, while still maintaining good vigour (Smith *et al.* 1996). Guadalupe provenance radiata pine also confers additional benefits which may be of use for particular end uses in terms of the provenances higher density (Simmons 1983; Low & Stovold 1990; Smith *et al.* 1996) and reduced susceptibility to *Dothistroma pini* (Libby *et al.* 1968).

A further option for genetic control of stem sinuosity and stem form in general is the use of physiologically aged cuttings (Klomp & Hong 1985; Menzies & Klomp 1988; Holden *et al.* 1996). In a study comparing physiologically aged cuttings of various ages with seedlings Menzies and Klomp (1988) found that cuttings from 3-year-old trees had similar growth rates to seedlings but with improved form. While cuttings from 4 and 5-year-old trees provide even greater improvements in tree form over seedlings this is at an increasing cost in rates of tree growth (Menzies & Klomp 1988; Holden *et al.* 1996).

### **Summary**

Stem sinuosity, in conjunction with log size influences pruned butt log value in terms of conversion at milling, and the existence of sweep related defects such as compression wood, sloping grain and pith defects. The extent to which stem straightness may be controlled therefore, is potentially of great interest to forest growers. Toppling of juvenile seedlings due to a mix of various causes may be implicated as an important cause of stem sinuosity, along

with nutrient imbalances. These influences on stem sinuosity are both common to farm sites and therefore, may be an important influence on the quality of logs being grown in New Zealand in the next few decades due to the large amount of new plantings now occurring on farm sites. Toppling can be controlled to a large extent through proper planting practices, silvicultural treatments to reduce crown area, use of aged cuttings for planting, and identification of clones with ideal root systems (Chavassee 1978; Mason 1985; Mason 1989; Trewin 1991). The impact of nutrient imbalances and the high nitrification levels of pasture soils on stem straightness may be anticipated to become less of a problem if/ when farm plantings move into a second rotation, due to the increasing C:N ratios associated with aging plantation forest soils.

The breeding programme as with branch cluster frequency has an important role to play in enabling the reduction of the incidence of sweep on fertile farm sites, in particular relating to the possibility of differing genetic control of stem straightness on these sites as opposed to less fertile sites. A Guadalupe, Kaingaroa provenance hybrid may provide useful material on which to base a breeding programme focusing on reducing stem sinuosity on fertile farm sites. The use of aged cuttings on fertile farm site plantings rather than seedlings also offers an opportunity to achieve improved stem form through both the reduction in the incidence of toppling and the improvement in general straightness associated with cuttings from 3-year-old trees.

## **LEADER MALFORMATION**

### **Introduction**

Poor tree form relating to leader malformations, such as ramicorns, double and multiple leaders, has an important effect on the volume returns of radiata pine at harvesting (Birk *et al.* 1993) due to the lack of a market for leaders in malformed trees (Table 7). Leader malformations mean that volume is put into essentially unmarketable logs.

The identification of clear genetic, site and silvicultural influences on the incidence of leader malformation is constrained by the many potential sources of leader malformation due to damage to the terminal bud or leader by (Bannister 1980):

- storm damage;
- the fungus *Diplodia pinea*;
- drought;
- hail;
- frost;
- nutrient disorders.

These many potential sources of malformation make the task of identifying causes of malformation difficult.

### Site Factors

There has been a clear identification of soil nutrient levels as having an influence on leader malformation. The nutrient factors which influence the incidence of malformation are similar to those which also influence the incidence of stem straightness. Site fertility, particularly nitrogen levels relating to previous land use, has been shown to influence apical dominance in radiata pine (Will 1971; Knight 1973; Will & Hodgkiss 1977; Beets & Madgwick 1988), with high levels of nitrogen resulting in a condition known as "retarded leader" and subsequent malformation. Under circumstances of high nitrogen levels the lateral buds surrounding the terminal bud may extend in autumn to lengths of 30 cm while the terminal bud remains dormant (Will 1971). Where branches have sufficient vigour they may compete and suppress the main shoot resulting in the formation of a leader malformation such as forking or multi-leader trees (Will 1971). Nutrient imbalances, in particular boron or sulphur deficiencies have also been shown to result in a greater incidence of leader malformation due to death of the terminal bud (Stone & Will 1965; Birk 1990, 1991). These deficiencies in boron and sulphur are common on ex-pasture sites and result from excess nitrogen, weed competition and grazing (Birk 1990) (Table 8). New Zealand forest sites which are known to have boron deficiencies are those in the Nelson region which occur in the Kaiteriteri area, or on Moutere gravels (Stone & Will 1965). Boron deficiency, however, appears to be uncommon in other plantation forests in New Zealand.

**Table 8: Yields in relation to previous land use: Source: Birk *et al.* (1993).**

Component	Volume (m <sup>3</sup> / ha) by Previous Land Use		
	Native Forest	Pasture	Cultivated Pasture
Saw logs	54	69	75
Pulp logs	89	141	116
Total recovery	143	210	191
Total stem volume	154	232	262
Recovery (%)	93	97	73

Another site factor which may influence the incidence of leader malformation is the climatic characteristics of the site. Sites which are particularly prone to frost, storm damage, droughts

or hail are likely to have higher incidences of loss of the terminal bud due to damage resulting from these factors.

### **Tree Age**

The age of the tree can affect malformation severity, with leader malformations, such as ramicorns, appearing to become less severe as the tree matures (Maclaren 1993; Maclaren 1995), ie., trees appear to grow out of this malformation.

### **Silviculture**

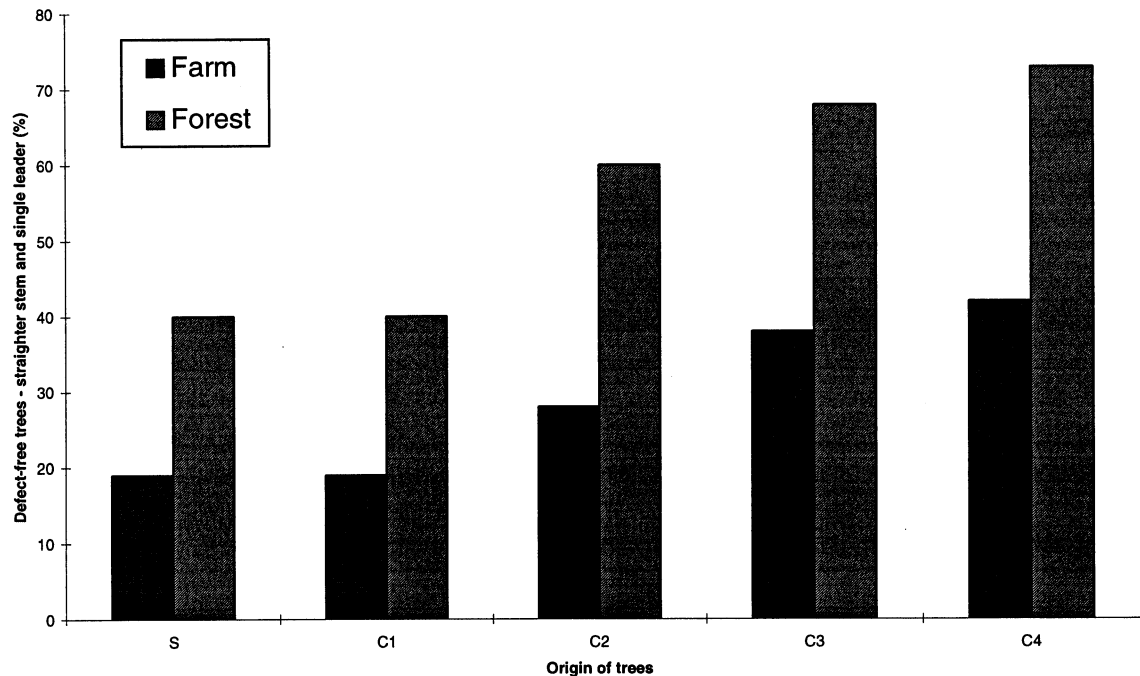
Silvicultural influences on the incidence of malformation exist in terms of planting stockings, and thinning stockings determining the selection ratio, and therefore, influencing the ability to remove malformed trees at thinning selection. Certain malformations may also be controlled through form pruning, by removing dominant branches at an early stage to allow the leader to recover dominance (Maclaren 1993).

### **Genetic Control**

The clear identification of genetic influences on malformation are difficult to determine because it is frequently impossible to accurately determine the origins of a particular malformation from the many causes of leader malformation (Bannister 1980). There is, however, evidence that certain clones of radiata pine may have a genetic disposition to leader malformation resulting from certain factors (Bannister 1980). The planting of these particular clones onto sites which are prone to leader malformation from a particular cause such as *D. pinea* may result in a lower incidence of leader malformation if those clones selected have a genetic disposition towards reduced damage from *D. pinea*.

Studies of genetic gains in malformation, ie., reductions in the level of malformation indicate that the GTI breeding programme has been successful in reducing the incidence of malformation in radiata pine, and therefore, leader malformation is under a certain level of genetic control. Shelbourne *et al.* (1986) found a 6% increase in malformation score for "850" seed orchard material over unimproved material. An age 12 assessment of the 1978 large plot genetic gain trial (Sorensson & Low 1995) indicated an 8.5% gain in malformation score (Table 4).

The similarity in site factors influencing stem straightness and malformation mean that the use of physiologically aged cuttings from 2 or 3-year old trees (Klomp & Hong 1985; Menzies & Klomp 1988; Holden *et al.* 1996) and radiata pine from Guadalupe hybrids (Burdon & Bannister 1973; Burdon & Bannister 1985) may provide improvements in the level of malformation of radiata pine grown on farm sites (Figure 10).



**Figure 10: Percentage of defect-free trees at low pruning for trees grown from cuttings versus trees grown from seedlings on a range of North Island forest and farm sites. S=seedling, C1=cutting from 1-year old tree, C2=cutting from 2-year old donor tree, C3=cutting from 3-year old tree, C4=cutting from 4-year old donor tree. Source: New Zealand Forest Research Institute 1991.**

### Summary

Leader malformation is an important influence on the volume of merchantable timber from radiata pine, therefore, the identification of means of controlling malformation has been an important part of research into stem quality characteristics in *P. radiata*. Malformation is influenced by a large number of factors, many of which are beyond the control of forest managers. There is, however, opportunity for the control of malformation in juvenile trees through form pruning, although this practice needs to be weighed against the fact that for certain malformation types, trees will 'grow out' of the malformation. Levels of leader malformation have already been controlled to a large degree through the efforts of the GTI breeding programme, and associated with this there are expected to be large gains in merchantable volumes. The fertility/ nutrient characteristics of farm sites make them particularly prone to leader malformation. This fact in combination with the high level of new land plantings occurring on farm sites, means that improvements that can be made in the incidence of leader malformation on farm sites will greatly increase the merchantable volume of radiata pine produced in New Zealand in the future. The use of physiologically aged cuttings from two or three year old trees and radiata pine from the Guadalupe hybrid provide an opportunity to potentially improve the stem form of radiata pine grown on fertile farm sites.

## CONCLUSION

The findings of the various studies mentioned in this report may be summarised in a 3 x 3 table indicating the relative importance of site, genetics and silviculture on branch cluster frequency, stem straightness and malformation (Table 9) in terms of high, medium, or low influence.

**Table 9: The relative importance of site, genetics and silviculture on branch cluster frequency, stem straightness and malformation in terms of high, medium, or low influence.**

	Site	Genetics	Silviculture
<b>Branch Cluster Frequency</b>	high	high	low
<b>Stem Straightness</b>	high	medium	medium
<b>Leader Malformation</b>	high	medium	medium

Site is an important influence on log quality, and this is particularly so on high fertility farm sites. The ability of forest/ woodlot owners to influence site impacts is very limited, therefore, genetics and silviculture become important means of manipulating, and improving stem quality. The silvicultural influence on the quality characteristics discussed in this report is largely limited to selecting for better form trees at thinning. The success of thinning selection is limited at early ages until age 14 when malformations which are likely to be carried through to harvest are identified. By this time important decisions have already been made regarding the selection of final crop trees. Genetic selection is likely to offer the greatest improvements in the stem quality characteristics mentioned in this report through a breeding programme focused on a radiata pine breed suited to the unique characteristics of fertile farm sites, ie. a "farm breed". The breeding programme has already achieved large improvements in the stem quality of radiata pine grown on forest sites, the unique fertility characteristics of farm sites, however, mean that there are specific breeding requirements for radiata pine which is to be grown on farm sites. Two potentially useful avenues for identifying a "farm breed" are the use of the Guadalupe hybrid which has demonstrated high density, and good form on extreme sites, and the use of physiologically aged cuttings from trees greater than 2 years old which have also shown excellent stem form compared with seedlings, as well as reduced likelihood of toppling, another common problem on farm sites which limits financial returns from woodlots.

The findings of this report suggest that there is a need for work to be carried out to achieve a detailed assessment of the comparative growth, form, and wood quality of improved seedlings, Guadalupe hybrid seedlings, and physiologically aged cuttings from two or three year old trees, grown on fertile farm sites. This work will need to be part of an overall programme of research which focuses on the identification of "target trees" for producing different end products on various sites. This research requires the ranking of various traits, eg., stem sinuosity, branch cluster frequency, wood density, branch size, in terms of their influence on being able to produce different end products on a variety sites. An understanding of the links between stem quality traits, site qualities, and end products will enable the identification of the particular end products that may be produced from certain sites for the range of silvicultural treatments, and genetic material available.

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