# FOXTAILING OF *PINUS CARIBAEA* VAR. *HONDURENSIS* IN PENINSULAR MALAYSIA: FREQUENCY, GROWTH RATE AND SPECIFIC GRAVITY

by

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# ABSTRACT

Foxtailing is a common feature in the plantations of *Pinus caribaea* var. *hondurensis* Barrett and Golfari in Peninsular Malaysia. Frequency of foxtailing in Kemasul and Ulu Sedeli pine plantations, aged between 1 to 8 years, was found to vary between 4.3 to 36.0 percent. Ulu Sedeli plantation has 5.3 percent more foxtail than in Kemasul plantation. This study indicates that the occurrence of foxtailing varies with site and age. The most common form of foxtailing is the sub-terminal foxtail which constitutes about 60.0 percent of the foxtail population. The increasing proportion of sub-terminal to terminal foxtail with age of the trees suggests that foxtailing is a plastic trait.

Average total height of foxtailed trees was greater than normal trees at all ages, however, larger diameters were evident only during the juvenile stage. The specific gravity of foxtailed trees was found to be slightly less dense than that of normal trees though the difference was not significant.

Although breeding of true terminal foxtail trees may hold some promise of economic gains, the inherent limitations and foreseen problems render such proposition to be not feasible. Selection against foxtailing will continue to be a more practicable approach.

Some future research studies on foxtailing are proposed: juvenile-mature correlation studies, long term growth and wood quality studies.

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# CHAPTER I

# INTRODUCTION

Foxtailing, an extreme expression of apical dominance, is a common feature in plantations of *Pinus caribaea* var *hondurensis* Barrett and Golfari in Peninsular Malaysia and other tropical countries. This peculiar growth phenomenon is considered an undesirable trait. It is associated with wind breakage, development of compression wood, absence of late-wood formation and restriction of seed production (Kozlowski and Greathouse 1970; Wright 1976).

However, foxtail trees often produce straight and knot-free timber. The narrow and conical-shaped crown of foxtail trees suggests that on a given planting area a higher volume production is expected from a pure "foxtail-tree" plantation than a pure "normal-tree" plantation. The narrow crown of foxtail trees permits higher stocking density without causing any serious crown competition and early canopy closure. These characteristics give the impression that foxtailing may not be a totally undesirable trait. Kozlowski and Greathouse (1970) and Whyte *et al*. (1981) advocated breeding of foxtail trees for clean-boled trees. However, other traits of foxtail trees, such as growth rate and wood quality, need to be evaluated and compared with normal trees in order to make a valid appraisal of the value of foxtailing. A large portion of this study is directed at the investigation of frequency and growth rate of foxtail trees in Peninsular Malaysia. In addition a limited study on wood specific gravity in foxtail trees was carried out.

## SECTION I - Objectives

The objectives of this study are:

1. to determine the frequency of foxtail trees in plantations of *Pinus caribaea* var. *hondurensis* in Peninsular Malaysia,
2. to assess and compare the growth rate, in terms of diameter over-bark and height growth, of normal and foxtail trees,
3. to compare wood quality, in terms of specific gravity, of normal and foxtail trees, and
4. to evaluate the prospects and problems of breeding foxtail trees.

## SECTION II - Definition

Foxtailing is an abnormal growth behaviour where a tree has a single, dominant and elongated shoot with no branches. In this study a stem which is longer than 0.8 metre with no branches is considered as foxtailed.

There are two main classes of foxtail (Whyte *et al.*, 1981), namely:

Class I - Terminal foxtail, in which the stem continues to foxtail from a certain point in the stem up to the tip of the tree. However, in this study this class has been further sub-divided into two sub-classes;

Class IA - True terminal foxtail, where continuous growth of the terminal leader results in a single stem with no side branches (Figure 1.1).

Figure 1.1. Class IA - True terminal foxtail. A 4 year old true terminal foxtail with single dominant stem. Arrows show the formation of branches indicating that this true terminal foxtail is changing into a sub-terminal foxtail.

Class IB - Normal terminal foxtail, where a normal pattern of shoot growth occurs during the earlier period and the foxtail develops during later period (Figure 1.2).

Class II - Sub-terminal foxtail, in which the top portion of the stem resumes a normal branched pattern after a period of foxtailing growth (Figure 1.3).

Figure 1.2. Class IB - Normal terminal foxtail. This 4 year old terminal foxtail developed after a normal shoot growth pattern.

Figure 1.3. Class II - Sub-terminal foxtail.
A 7 year old sub-terminal foxtail.
Earlier foxtailing was followed by
normal branch development.

# CHAPTER 2

## LITERATURE REVIEW

Information available on foxtailing is very limited. Lloyd (1914) was the first to describe the morphology of foxtailing in pine. Real interest in foxtailing began as recently as the early 1970's when *Pinus caribaea* Morelet gained recognition as one of the promising species for plantation forestry in many tropical countries. Foxtailing is a relatively new subject of research.

To facilitate discussion of the available information this is considered under two sections: foxtailing and specific gravity.

### SECTION I - Foxtailing

There is no difference in the pattern of normal shoot growth in the tropics and temperate zones (Kozlowski and Greathouse 1970). It involves the elongation of the axis by extension of a succession of buds formed on the terminal leader of the main stem. The period of elongation is interrupted for a while with the formation of new terminal bud clusters. These newly formed buds then expand to lengthen further the terminal leader and to produce a whorl of lateral branches. There may be two to four of such growth sequences annually.

However, some abnormal growth of the tree may occur. In some pines, trees develop abnormally as a result of failure to set bud clusters which would differentiate into lateral branches. Such growth is known as "foxtailing" because the upper part of the abnormally elongated shoot has a conical or "fox-tail" appearance (Lloyd 1914).

There is no concrete evidence to explain what causes foxtailing. Based on the knowledge of bud dormancy and the balance of growth promoter-inhibitor in controlling shoot growth, Kozlowski and Greathouse (1970) speculated that in foxtailing growth there may be a continuous hormonal balance that favours one or more growth promoters which promote continuous shoot growth.

Kozlowski and Greathouse (1970) also reported that foxtailing occurs in Pinus canariensis Smith, Pinus caribaea Morelet, Pinus cembroides Link, Pinus echinata Link, Pinus elliottii Engelm., Pinus kesiya Royle ex Gordon, Pinus merkusii De Vriese, Pinus oocarpa Schiede, Pinus palustris Mill., Pinus radiata D. Don, Pinus taeda L. and Pinus tropicalis Morelet.

A. Growth Characterisitics of Foxtail Trees

In the shoot of a foxtail trees the needles usually decrease in length towards the terminal end. Near the tip, the unexpanded needles are tightly packed and enclosed in an unbroken sheath. Below these the needles penetrate their sheath and increase in length, giving the upper part of the continuous expanding shoot a conical appearance. Needle retention appears to be increased during the periods of foxtailing. This results in a distinctive dimpled bark pattern.

The reproductive pattern of foxtail trees differs from that of normal trees (Kozlowski and Greathouse 1970). In a normal tree of Pinus caribaea, megasporangiate strobili are produced in the top fourth of the live crown while microsporangiate strobili are localised in the lower branches and on the third and fourth order side branches. During the periods of apical foxtail growth no strobili were reported on trees up to 15 years old. However, the terminal shoots of foxtail trees are said occasionally to produce a large number of microsporangiate strobili.

## B. Occurrence of Foxtail Trees

Among the tropical pines, such as Pinus caribaea, Pinus oocarpa and Pinus merkusii, which have been planted in Peninsular Malaysia, foxtailing is more frequently observed in Pinus caribaea. Tho (1979) reported that among the three species mentioned above, there was 31.7 percent foxtailing in Pinus caribaea, 19.5 percent in Pinus merkusii and 0 percent in Pinus oocarpa. Within the three varieties of Pinus caribaea namely var. hondurensis Barrett and Golfari, var. bahamensis Barrett and Golfari and var. caribaea Barrett and Golfari, foxtailing is common in var. hondurensis (31.7 percent) as compared to 8.0 percent in var. bahamensis and 0 percent in var. caribaea (Musalem et al., 1973; Wiersum 1973).

Foxtailing of Pinus caribaea var, hondurensis appears to be an inherited growth phenomenon with its expression modified considerably by site and climatic factors. In an experiment of family variation within provenances for foxtailing growth form in Pinus caribaea var. hondurensis, Ledig and Whitmore (1980) reported 0.17 heritability of foxtailing. Although this value is low, selection against foxtailing could still be effective. Earlier in 1968, Slee and Nikles indicated that an unselected stand of Pinus caribaea var. hondurensis in Queensland, Australia, had a much higher frequency of foxtail than did unselected var. bahamensis and var. caribaea. However, after selection the progenies of selected var. hondurensis parents had a lower incidence of foxtailing.

The climatic control of foxtailing also appears to be pronounced. Lucknoff in 1964 (quoted by Kozlowski and Greathouse 1970) observed that foxtailing of *Pinus caribaea* was reduced at higher elevation and cooler temperature. In coastal areas of Zululand (altitude approximately 45 to 60 metres) foxtail frequency was 43 percent; at Ntsubane (altitude approximately 400 metres) 26 percent; and at Dargal in the Natal Midlands (altitude approximately 1200 metres) 13 percent.

Occurrence of foxtailing also varies with site quality. Using a single provenance of *Pinus caribaea* var. *hondurensis* seeds, Ibrahim and Greathouse (1972) observed different frequencies of foxtail when the seeds were planted at two different locations in Peninsular Malaysia. On the fertile site the foxtail frequency was 39 percent while on the poorer site the frequency was 49 percent.

## C. Growth Rate of Foxtail Trees

Except for the peculiar crown of foxtail trees, their growth performance, in terms of diameter and height, is comparable and at times superior to normal trees.

Most reports (Ibrahim and Greathouse 1972; Wood *et al.*, 1979 and Whyte *et al.*, 1981) indicate that foxtail trees have superior height growth compared to normal trees. However, the diameter growth of foxtail trees varies with age as compared to normal trees. In a 6 year old plantation foxtail trees have smaller diameter than normal trees (Ibrahim and Greathouse 1972). Similarly, Wood *et al.* (1979) also indicated that in a 6 year old plantation the average diameter of foxtail trees was significantly less than normal trees. In a frequency and growth rate study of foxtail trees in plantations aged 3 to 9 years, Whyte et al. (1981) concluded that foxtail trees were larger in diameter up to age 5 years but smaller thereafter when compared to normal trees.

## SECTION II - Specific Gravity

Specific gravity is defined as the ratio of the density of a given substance to the density of water at standard temperature and pressure. The specific gravity of wood may be based on volume when oven dry (dried at 105°C to constant bone-dry weight); or when green (at fully swollen condition, at some moisture content above the fibre saturation point); or at some moisture content intermediate between these two extreme conditions. Due to the probability of unequal shrinkage in different wood samples when drying from green to oven dry weight, specific gravity based on oven dry weight and green volume is the preferred measure in all cases when comparisons are made (Smith 1954).

Due to the ease of measurement and straightforward interpretation, specific gravity is an excellent index of the amount of wood substance contained in a given volume of wood. Therefore it is a good indicator of strength properties (U.S.D.A. 1955). There is a strong correlation between wood specific gravity and compression, bending strength and hardness (Panshin and De Zeeuw 1980).

Specific gravity and wood density are usually used synonymously when the former is based on oven dry weight and green volume and the latter is measured in grams per cubic centimetre green volume.

## A. Variation in Specific Gravity

A piece of dry timber is composed of solid material (cell walls) and cell cavities. The difference in the ratio of cell walls to cell cavities gives rise to the difference in wood specific gravity within and between trees (Desch 1981). Variations in the amount of cell wall substance in wood are due to the changes of the anatomical characteristics of the cell wall and proportion of different cell types occurring in different parts of the trees.

There are basically two general trends of variability in specific gravity within the tree, namely variation of specific gravity along the stem length and variability of specific gravity in the stem cross section (Elliott 1970; Panshin and De Zeeuw 1980). In many coniferous species the heaviest wood is found at the base of the trunk and decreases in successively higher levels in the trunk, and at any given height of the tree trunk specific gravity increases from the pith outwards. The former variation is due to the increase percentage of young material in the successive increment from the base to the top of the trunk and the latter is due to the increased proportion of dense late-wood in the successive increment from the pith outwards. Harris (1973) observed a steep density gradient from the pith outwards in *Pinus caribaea* grown in Peninsular Malaysia. It appeared that the increase in wood density from the pith outwards terminated between the 8th and 12th growth layer. Multiple bands of very dense late-wood in each annual growth layer were also observed.

The variation in specific gravity among trees of the same species is influenced by inherent characteristics of the tree, geographical and environmental factors (Harris 1978; Panshin and De Zeeuw 1980; Cown 1981). Silvicultural practices, such as fertilizer application and manipulation of crown size and growing space to promote growth rate, have significant influence on specific gravity (Elliott 1970 and Panshin and De Zeeuw 1980).

## B. Specific Gravity of Foxtail Trees

It appears that the specific gravity of foxtail trees is lower than that of normal trees. Plumptre (1978) and Whyte *et al*. (1981) made comparative studies of specific gravity between normal and foxtail trees of *Pinus caribaea* using samples from an 8 year old plantation. Both reports indicated that timber from foxtail trees was less dense than that of normal trees by 8 percent (Plumptre 1978) and by 0.8 percent (Whyte *et al*., 1981).

# CHAPTER 3

## MATERIALS AND METHODS

This chapter is divided into four main sections: description of study area; methods of sampling; frequency count, growth rate measurement and specific gravity determination; and methods of statistical analysis.

### Section I - Description of Study area

This study was carried out in two *Pinus caribaea* var. *hondurensis* plantations in Peninsular Malaysia, namely Kemasul Pine Plantation and Ulu Sedeli Pine Plantation (Figure 3.1).

The Kemasul plantation is located about 145 kilometres east of Kuala Lumpur, covering an area of 25,000 hectares of which 22,000 hectares are suitable for reforestation (Anon. 1983). The Ulu Sedeli plantation is situated about 400 kilometres southeast of Kuala Lumpur, covering an area of 34,885 hectares of which 29,434 hectares are suitable for planting (Anon. 1982).

Both plantations are in the undulating lowland areas with an average altitude of 60 metres above sea level. Table 3.1 summarized the climatic data of both plantations for five year period, 1977-1981.

In this period, it seems that both plantations appeared to have similar climatic conditions though Ulu Sedeli plantation is slightly wetter than Kemasul plantation.

The soil varies between and within sites. The most common soil in Kemasul is derived from sandstone and shale (Teoh 1981), while in

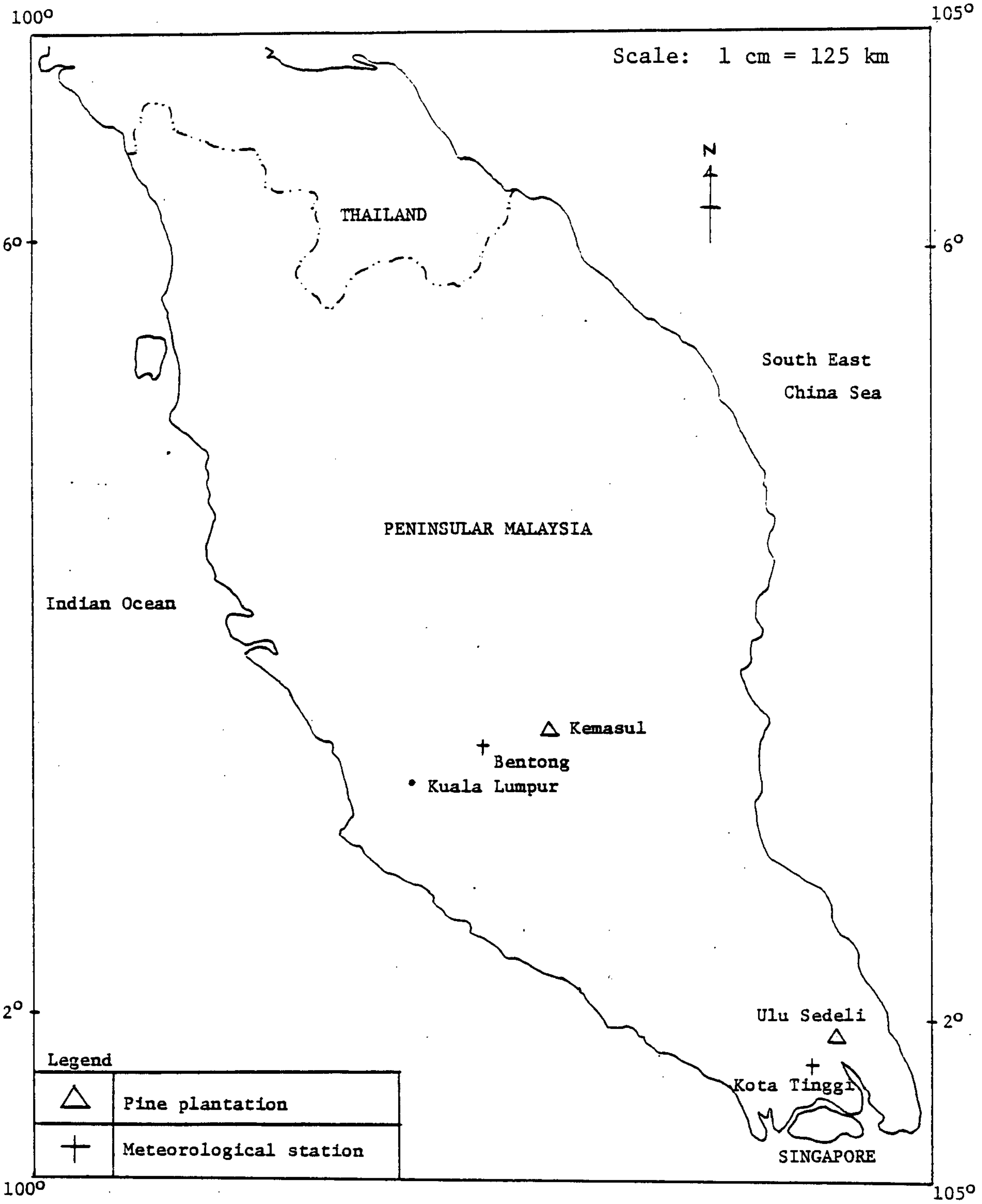


Figure 3.1 Location of Kemasul and Ulu Sedeli pine plantations in Peninsular Malaysia.

TABLE 3.1 Summary of climatic data of Kemasul and Ulu Sedeli plantations

| Meteorological Station | Year | Max. Daily Temperature (°C) | Min. Daily Temperature (°C) | Total Annual Rainfall (mm) |
|---|---|---|---|---|
| | 1977 | 32.2 | 22.4 | 2280.4 |
| | 1978 | 33.4 | 21.4 | 1747.9 |
| Bentong* | 1979 | 34.1 | 21.2 | 2560.0 |
| | 1980 | 33.1 | 22.1 | na |
| | 1981 | 32.9 | 22.1 | 2098.4 |
| Average | | 33.3 | 21.9 | 2171.7 |
| | 1977 | 31.9 | 22.0 | 2118.8 |
| | 1978 | 32.2 | 21.8 | 2501.3 |
| Kota Tinggi** | 1979 | 32.3 | 21.8 | 2505.0 |
| | 1980 | 32.2 | 22.7 | 2359.7 |
| | 1981 | 31.6 | 22.8 | 1999.0 |
| Average | | 32.0 | 22.2 | 2296.0 |

* and ** - Meteorological stations nearest to Kemasul and Ulu Sedeli plantations, respectively (Figure 3.1).

na - Not available.

Ulu Sedeli the soils are mostly derived from granodiorite (Amir 1983, personal communication).

Planting in both sites started in early 1975. To date about 2700 hectares have been planted in Kemasul and about 1750 hectares in Ulu Sedeli. No planting was carried out in 1980 in Kemasul and in 1982 in Ulu Sedeli. The planting distance used in both plantations is 9 feet by 7 feet (2.7 metres by 2.1 metres), along the east-west direction, with a stocking density of 691 trees per acre (1780 trees per hectare). Seedlings were raised from seeds purchased overseas. From 1974 to 1976 seeds were obtained from Central America. After the seed supply from Central America was discontinued, Australia became the seed supplier in 1977. Due to the high cost and limited seed supply for Australia, the Fiji Pine Commission became the current seed supplier since 1979 till today.

## SECTION II - Methods of Sampling

### A. Frequency and Growth Rate Studies

In both plantations the annual planting areas are normally divided into several blocks which range from 10 to 100 hectares. In view of this fact a stratified random sampling without replacement was used in this study. In each plantation the population was stratified into 7 age classes. From each age class a planting block was randomly selected. In the selected block a linear sampling of 2 percent intensity was carried out to determine the frequency and growth rate (diameter over-bark and total height) of normal and foxtail trees. Table 3.2 indicates the extent of sampling carried out.

A sampling line consists of 4 rows of trees which run across the block along the east-west direction. In determining the initial sampling line, a point was selected randomly from a set of distances measured from the left-hand corner of the block: 5, 10, 15, 20 and 25 metres. In this case a distance of 10 metres was selected and used to set the initial sampling line throughout sampling of the entire population of the plantation.

TABLE 3.2 Extent of 2 percent sampling in Kemasul and Ulu Sedeli plantations

| Plantation | Age (year) | Selected block | Area of selected block (ha) | Area sampled (ha) | No of trees sampled |
|---|---|---|---|---|---|
| | 1 | 2C3 | 62.8 | 1.25 | 1196 |
| | 2 | 2A5 | 56.7 | 1.13 | 1127 |
| | 4 | 1D5 | 57.0 | 1.14 | 448 |
| Kemasul | 5 | 1D6 | 68.9 | 1.37 | 756 |
| | 6 | 1C7 | 32.0 | 0.64 | 640 |
| | 7 | 1B4 | 44.5 | 0.89 | 416 |
| | 8 | 1A3 | 30.4 | 0.60 | 854 |
| Total | | | 352.3 | 7.02 | 5437 |
| | 2 | 5.7 | 22.3 | 0.44 | 304 |
| | 3 | 4.11 | 40.4 | 0.80 | 511 |
| | 4 | 4.6 | 30.7 | 0.61 | 339 |
| Ulu Sedeli | 5 | 4.1 | 47.3 | 0.94 | 670 |
| | 6 | 3.4C | 18.0 | 0.36 | 302 |
| | 7 | 2.2C | 38.4 | 0.76 | 559 |
| | 8 | 1.2 | 37.3 | 0.74 | 816 |
| Total | | | 234.4 | 4.65 | 3501 |

Depending on the size and shape of the block one or more sampling lines were required to cover the 2 percent sampling intensity. In blocks where more than one sampling line was needed the subsequent lines were set at 10 metre intervals from the previous line.

B. Specific Gravity

A complete randomised design with hierarchal arrangement was used in this study. In each plantation five normal trees and five foxtail trees were selected at random from the 8 year-old stand. Table 3.3 indicates the size of the selected trees.

TABLE 3.3 Diameter over-bark and total height measurements of selected trees

| Plantation | Normal Diameter (cm) | Normal Total Height (m) | Foxtail* Diameter (cm) | Foxtail* Total Height (m) |
|---|---|---|---|---|
| | 10.5 | 10.3 | 12.7 | 12.1 |
| | 10.5 | 10.3 | 11.7 | 12.1 |
| Kemasul | 9.8 | 10.3 | 11.7 | 10.9 |
| | 11.6 | 10.6 | 8.2 | 10.3 |
| | 11.4 | 9.1 | 10.5 | 10.3 |
| | 13.2 | 13.7 | 12.5 | 18.2 |
| | 13.2 | 12.8 | 11.3 | 18.2 |
| Ulu Sedeli | 13.5 | 12.1 | 11.3 | 15.3 |
| | 12.7 | 12.1 | 11.0 | 14.3 |
| | 11.8 | 12.1 | 11.6 | 15.2 |

*Foxtail of Class I where foxtail occurs from 10 percent of total height upwards.

A disc of 2 centimetres in thickness was taken from each tree at five different percentage-height levels of the tree: 10; 30; 50; 70; 90 percent. Each disc was divided into four quarters as replications. The samples were then debarked and prepared for testing.

Percentage-height sampling is chosen over sampling at fixed position along the stem because it allows for between tree comparison and at the same time accounts for the systematic variation of specific gravity within the stem (Elliott 1970).

## SECTION III - Frequency Count, Growth Rate Measurement and Specific Gravity Determination

### A. Frequency Count

In the sampling line the occurrence of normal and foxtail trees was recorded and tallied. For foxtail trees, the trees were further categorised according to their classes.

### B. Growth Rate Measurement

Except in the 1 and 2 year old age classes diameter over-bark at breast height (1.4 metres) of normal and foxtail trees was measured using a diameter tape (measured to the nearest 0.1 centimetre). Height sticks were used to measure the total height of normal and foxtail trees in all age classes (measured to the nearest 0.1 metre). In addition, measurement of the longest internode length (length between 2 whorls of branches) of normal and foxtail trees in the 4, 7 and 8 year old stand at Kemasul were also taken. These measurements were used to define foxtail characteristics quantitatively as mentioned in Chapter I.

### C. Specific Gravity Determination

Specific gravity is expressed as the ratio of the density of a given substance to that of water. Specific gravity is therefore a unit-less value but numerically equal to the density of the substance. In this study specific gravity or density was determined gravimetrically based on the oven dry weight and green volume of sample. The formula used for wood density is:

$$\text{Wood density} = \frac{\text{Oven dry weight of sample}}{\text{Green volume of sample}}$$

The green volume of the sample was determined as follows:

A beaker of water was placed on a balance pre-set to the weight of the beaker and water. The test sample suspended by a needle was lowered in the beaker and completely immersed in water. Care was taken so that the immersed sample was not in contact with either the sides or bottom of the beaker. The reading on the balance was then recorded. The weight of the displaced volume of water represents the green volume of the sample.

The procedure to determine the oven dry weight of the sample was as follows:

The labelled samples were placed in a controlled temperature oven at 105°C for 48 hours. At the end of the period 15 samples were chosen at random and placed in a desiccator containing granulated anhydrous calcium chloride ($CaCl_2.2H_2O$). After a period of conditioning at laboratory temperature the samples were weighed on a balance (weighed to 3 decimal places). After the first oven dry weight was determined, samples were replaced in the oven for another 24 hours under the same temperature condition. This cycle was repeated until a constant oven dry weight was recorded.

SECTION IV - Methods of Statistical Analysis

Two standard statistical texts were used as reference sources for the analyses computed in this study: Spiegel (1972) and Snedecor and Cochran (1980).

A. Frequency Study

This study deals with two classes of individuals in a population: normal and foxtail trees. Since a tree can either be normal or foxtail in form, the outcomes of this study can be expressed as percentage, proportion or number of individuals in one of the two classes. These conditions fit the binomial distribution model.

Chi-square test for goodness of fit in a RxC contingency table is used to compare the proportions of normal to foxtail trees and sub-terminal and terminal foxtails. The hypotheses tested are: the proportion of normal to foxtail trees is constant over age; and proportion of sub-terminal to terminal foxtail is constant over age. Before carrying out the test the proportions are transformed by angular transformation (arc-sine). The test is computed in the following manner (Table 3.4):

TABLE 3.4 Chi-square test of binomial proportions

| Component | Element I | Element II |
|---|---|---|
| Observed, f | r | n-r |
| Expected, F | np | nq = n-np |
| Observed-Expected, f-F | r-np | -(r-np) |

$$\chi^2 = \Sigma\frac{(f-F)}{F} = \frac{(r - np)^2}{np} + \frac{(r - np)^2}{np} + \ldots.$$

where: Element I = either normal tree or sub-terminal foxtail

Element II = either foxtail tree or terminal foxtail r = observed number of Element I

n = total number of sample

p = proportion of Element I

q = proportion of Element II

Degree of freedom = (R-1) (C-1)

where: R = rows

C = Columns

B. Growth Rate Study

Analysis of variance is used to compare the mean of diameter and total height between normal and foxtail trees within each age class and plantation. The analysis is based on unequal samples and carried out in the following manner (Table 3.5):

TABLE 3.5 Analysis of variance for diameter and total height of normal and foxtail trees (samples of unequal sizes)

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | a-1 | SSI | MSI | MSI/MSII |
| Within phenotypes | N-a | SSII | MSII | |
| Total | N-1 | | | |

where: a = phenotypes (normal and foxtail trees)
N = number of samples

## C. Specific Gravity Study

The mean specific gravity of normal and foxtail trees was compared by a one-way analysis of variance. The analysis was carried out for each percentage-height level separately. This study was designed in a completely randomised manner involving hierarchal arrangement. The sources of variation, degrees of freedom and expected mean squares for the analysis of variance are shown in Table 3.6.

The F-ratios were determined as follows:

(i) Between trees/phenotypes/plantations: $F = \frac{MSIII}{MSIV}$

where: MSIII = mean square for between trees/phenotypes/plantations

MSIV = mean square for residual.

(ii) If F-ratio (i) is significant then F-ratio for between phenotypes/plantations is:

$$F = \frac{MSII}{MSIII}$$

where: MSII = mean square for between phenotypes/plantations

(iii) If F-ratio (ii) is not significant then a new mean square error is derived to test the variation between plantations:

$$MSE' = \frac{SSII + SSIII}{df2 + df3}$$

where: MSE' = new mean square error

SSII = sum square between phenotypes/plantations

SSIII = sum square between trees/phenotypes/plantations

TABLE 3.6 Analysis of variance for specific gravity

| Source of variation | df | SS | MS | Expected mean square |
|---|---|---|---|---|
| Between plantations (PL) | df1 = (a-1) | SSI | MSI | $\sigma^2_e + K_1\sigma^2_{T/PH/PL} + K_2\sigma^2_{PH/PL} + K_3\sigma^2_{PL}$ |
| Between phenotypes/ plantations (PH/PL) | df2 = a(b-1) | SSII | MSII | $\sigma^2_e + K_1\sigma^2_{T/PH/PL} + K_2\sigma^2_{PH/PL}$ |
| Between trees/phenotypes/ plantations (T/PH/PL) | df3 = ab(c-1) | SSIII | MSIII | $\sigma^2_e + K_1\sigma^2_{T/PH/PL}$ |
| Residual | df4 = abc(n-1) | SSIV | MSIV | $\sigma^2_e$ |
| Total | abcn-1 | | | |

where: a = plantations

b = phenotypes

c = trees

n = number of samples

$K_1$ to $K_3$ = coefficients of the variance components.

df2 = degrees of freedom between phenotypes/ plantations

df3 = degrees of freedom between trees/phenotypes/ plantations

Then, F-ratio for between plantations: $F = \frac{MSI}{MSE}$,

where: MSI = mean square between plantations.

# CHAPTER 4

# RESULTS AND DISCUSSION

The presentation of this chapter is divided into four main sections: foxtail frequency; growth rate; specific gravity; and prospects and limitations of breeding foxtail trees.

## SECTION I - Foxtail Frequency

The study shows that the frequency of foxtail at Kemasul plantations aged 1 to 8 years varies between 6.1 to 36.0 percent, while at Ulu Sedeli plantations aged 2 to 8 years the frequency varies between 4.2 to 34.8 percent (Table 4.1). The overall foxtail frequencies at Kemasul and Ulu Sedeli are 18.1 $\pm$ 1.0 percent and 23.4 $\pm$ 1.4 percent respectively, a difference of 5.3 percent. More than 60 percent of foxtails in both plantations are in the form of sub-terminal foxtail: 70.8 and 64.2 percent in Kemasul and Ulu Sedeli respectively.

Table 4.1 also indicates that the proportions of foxtail to normal trees and sub-terminal and terminal foxtails tend to increase with age. The Chi-square tests (Appendix I - Tables 1 to 4) confirm that these proportions are not the same throughout the age classes.

The difference in foxtail frequency within each plantation observed in this study is suspected to be due to the differences in seed source, site and age. This observation conforms to the observations made by Ibrahim and Greathouse (1972) and Musalem *et al*. (1973). Between plantations the difference in foxtail frequency, 5.3 percent

TABLE 4.1 Frequency of foxtail trees and proportion of various classes of foxtail (%)

| Plantation | Age (year) | Foxtail | Sub-terminal foxtail | Terminal foxtail | Terminal foxtail Normal | Terminal foxtail True |
|---|---|---|---|---|---|---|
| | 1 | 6.9 | 52.4 | 47.6 | 75.6 | 24.4 |
| | 2 | 6.1 | 71.0 | 29.0 | 80.0 | 20.0 |
| | 4 | 19.2 | 51.0 | 49.0 | 87.7 | 2.3 |
| Kemasul | 5 | 19.7 | 41.7 | 58.3 | 100 | 0 |
| | 6 | 25.4 | 89.0 | 11.0 | 100 | 0 |
| | 7 | 36.0 | 96.7 | 3.3 | 100 | 0 |
| | 8 | 33.3 | 94.1 | 6.0 | 94.1 | 5.9 |
| Average foxtail frequency | | 18.1 ± 1.0 | | | | |
| | 2 | 4.2 | 46.2 | 53.8 | 100 | 0 |
| | 3 | 11.4 | 51.7 | 48.3 | 96.4 | 3.6 |
| | 4 | 8.5 | 55.2 | 44.8 | 100 | 0 |
| Ulu Sedeli | 5 | 23.7 | 57.2 | 42.8 | 100 | 0 |
| | 6 | 34.8 | 67.6 | 32.4 | 94.1 | 5.9 |
| | 7 | 31.1 | 87.4 | 12.6 | 100 | 0 |
| | 8 | 34.4 | 84.0 | 16.0 | 95.4 | 4.4 |
| Average foxtail frequency | | 23.4 ± 1.3 | | | | |

as indicated in this study, is probably due to site quality; higher frequency in poorer site (Slee and Nikles 1968; Ibrahim and Greathouse 1972). The Kemasul plantation is a better site than Ulu Sedeli plantation based on growth rate indicated in Section II of this chapter.

The design of this study does not permit the investigator to verify the speculation that proportions of foxtail to normal trees and sub-terminal to terminal foxtails increase with age. This may require the assessment and observation of the same population over a certain period of time in order to ascertain the trend of the changes. However, the work of Ibrahim and Greathouse (1972) indicates that foxtail frequency increases with age. Observing the same population of *Pinus caribaea* var. *hondurensis*, raised from seeds of a single provenance, over a period of three years the foxtail frequency increases by almost three times. The work of Whyte *et al*. (1981) indicates that the proportion of sub-terminal foxtail increases from 5 to 12 percent and the proportion of terminal foxtail decreases from 19 to 8 percent in a 3 year old plantation two years after the first assessment. This explains the higher frequency of foxtail trees and sub-terminal foxtails observed in the older stands of the study sites. The increasing proportion of sub-terminal foxtails over time suggests that foxtailing is a plastic trait, where it changes its form from terminal to sub-terminal.

All foxtail trees start in the form of terminal foxtail. In the course of its growth, a foxtail tree may either continue to show extreme apical dominance or rest to set lateral buds to produce side branches. Once the foxtail tree produces lateral branches the form changes from terminal to sub-terminal foxtail. This may mark the end of foxtailing growth or temporary conversion to normal growth pattern before foxtailing growth occurs again in later years. This means that foxtail is an unstable trait.

The foxtail frequency study also shows among the terminal foxtails the occurrence of true terminal foxtail is very low compared to normal foxtail. It is probable that the tendency for the true terminal foxtail to maintain its form is lowered with increasing age of the tree.

SECTION II - Growth Rate

Table 4.2 indicates that the overall growth of trees in Kemasul plantation is superior to that in Ulu Sedeli plantation especially in diameter growth. This may suggest that the Kemasul plantation is a better site than the Ulu Sedeli plantation. The table also indicates that the diameter growth of foxtail trees surpasses the normal trees in the early years of growth from age 4 to 5 years and 3 to 7 years in Kemasul and Ulu Sedeli plantations respectively. The analysis of variance (Appendix II - Tables 1 to 11) shows that the superiority of foxtail trees in diameter growth over normal trees is significant only in 4 year old trees at Kemasul plantation and in 3, 4 and 5 year old trees at Ulu Sedeli plantation.

In terms of height growth, foxtail trees maintain their supremacy up to 6 years old in Kemasul and 8 years old in Ulu Sedeli (Table 4.2). However, this supremacy is only significant to year three and year four at Ulu Sedeli and Kemasul plantations respectively (Appendix III - Tables 1 to 14).

Generally, the results indicate that foxtail trees are significantly superior to normal trees in diameter and height growth especially in the first 4 to 5 years of growth. These findings confirm the observations made by Ibrahim and Greathouse (1972), Wood *et al*. (1979) and Whyte *et al*. (1981).

TABLE 4.2 Mean diameters over-bark and total heights of normal and foxtail trees

| Plantation | Age (year) | Diameter over-bark (cm) | | | Total height (m) | | |
|---|---|---|---|---|---|---|---|
| | | Normal | Foxtail | F-test | Normal | Foxtail | F-test |
| Kemasul | 1 | - | - | - | 0.9 | 1.2 | ** |
| | 2 | - | - | - | 1.8 | 2.3 | *** |
| | 4 | 9.7 | 10.1 | * | 6.1 | 7.0 | *** |
| | 5 | 8.9 | 9.3 | ns | 5.6 | 6.6 | ns |
| | 6 | 12.8 | 12.7 | ns | 9.6 | 10.2 | ns |
| | 7 | 17.6 | 16.6 | *** | 11.6 | 11.5 | ns |
| | 8 | 13.7 | 13.4 | ns | 10.6 | 11.2 | ns |
| Ulu Sedeli | 2 | - | - | - | 1.8 | 3.2 | *** |
| | 3 | 2.5 | 3.9 | ** | 3.3 | 4.4 | * |
| | 4 | 2.7 | 5.7 | *** | 3.8 | 3.9 | ns |
| | 5 | 3.9 | 5.8 | *** | 6.4 | 6.9 | ns |
| | 6 | 5.4 | 6.5 | ns | 7.9 | 8.5 | ns |
| | 7 | 4.7 | 4.8 | ns | 9.3 | 9.4 | ns |
| | 8 | 7.1 | 6.1 | ns | 11.2 | 12.2 | ns |

These results also suggest that most of the foxtailing growth phenomenon in a population occurs between 1 to 4 years. This is indicated by the rapid height growth as a result of extreme apical dominance shown by foxtailing growth. After such a period most of the terminal foxtails become sub-terminal foxtails as discussed in the last section (Section I), and lose their vigour in height growth. This probably explains the non-significant height growth between normal and foxtail trees after 4 years of age.

## SECTION III - Specific Gravity

Table 4.3 represents the mean of specific gravity of normal and foxtail trees sampled at five different percentage-height levels in Kemasul and Ulu Sedeli plantations. Except for the 10 percent height

TABLE 4.3 Mean specific gravity of normal and foxtail trees

| Height level (%) | Normal | Foxtail | F-test |
|---|---|---|---|
| 10 | 0.542 | 0.569 | ns |
| 30 | 0.519 | 0.499 | ns |
| 50 | 0.490 | 0.460 | ns |
| 70 | 0.453 | 0.414 | ns |
| 90 | 0.404 | 0.362 | ns |

level, foxtail trees are slightly less dense than normal trees. The difference in mean specific gravity between normal and foxtail trees at all height levels was found to be not significant (Appendix IV - Tables 1 to 5). The finding of this study agrees with the observations made by Plumptre (1978) and Whyte et al. (1981) that the specific gravity of foxtail trees is slightly lower than normal trees. However, the difference is highly significant between trees within phenotypes and plantations. This means that variation in specific gravity is only due to variation among trees with the phenotype. The result also indicates that there is an obvious pattern in both normal and foxtail trees, that specific gravity decreases with increasing height (Figure 4.1).

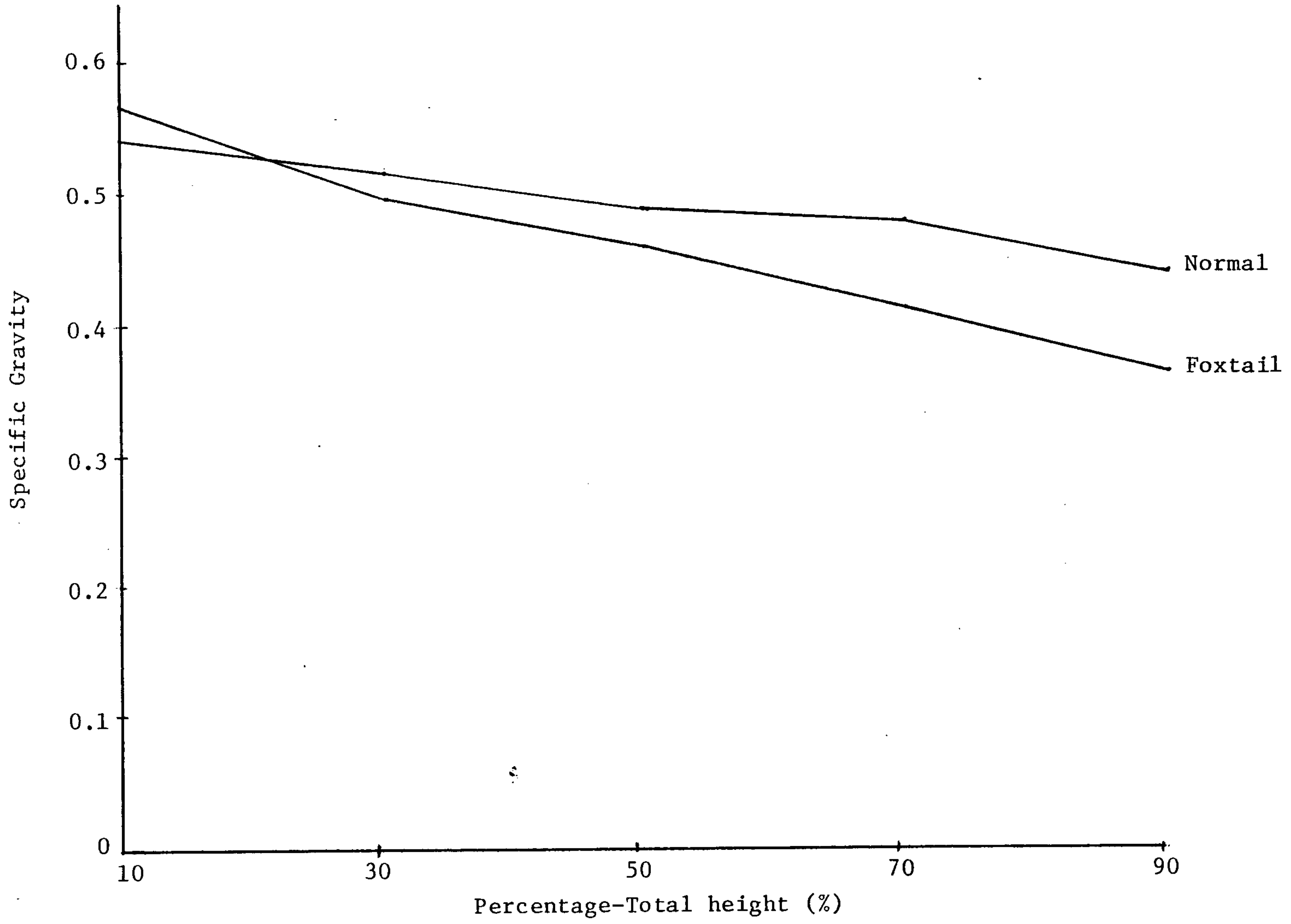


Figure 4.1 Effect of increasing height on specific gravity.

SECTION IV - Prospects and Limitations of Breeding Foxtail Trees

This study indicates that foxtail trees have fast early diameter growth, superior height growth and a specific gravity slightly less dense than normal trees. These characteristics coupled with a generally straight stem form (Whyte *et al.*, 1981) and obvious narrow crown especially with the true terminal foxtail trees suggest that breeding of true terminal foxtail trees may hold promise of some economic gains.

Plantations of true terminal foxtail tree can be envisaged as pure stands with fast early growth producing a uniform product of knot-free timber. Maximum utilization of growing space is visualized as true terminal foxtail trees can be planted at a closer spacing without experiencing serious canopy competition and early canopy closure. It is also foreseen that harvesting technique and log transportation from such plantations will be simpler and more economical than the same operations in heterogenous plantations.

However, there are some inherent limitations and foreseen problems to such breeding programme. As has been discussed earlier, true terminal foxtail is a very plastic or unstable form. Its occurrence is quite scarce and its ability to maintain such form throughout the rotation age is still questionable. This poses a major set back in initiating a breeding programme for such trait. Also its heritability is low (Ledig and Whitmore 1981), therefore a high selection intensity is required to obtain the desired genetic gain. This also means that a large breeding population is needed.

Evidence from Peninsular Malaysia indicated that locally grown *Pinus caribaea* is known to be a shy-seeder (Mitchell 1963; Freezaillah

1967). Therefore, the probability for foxtail trees to produce seeds in Peninsular Malaysia is very low if not nil. Furthermore, based on the observations of Kozlowski and Greathouse (1970) foxtail trees were not known to produce seeds. This will certainly cause major problem if the plantations of true terminal foxtail trees are to be raised from seeds. Mass propagation by stem cuttings of true terminal foxtail trees is impossible because of the absence of branches to obtain the cuttings. The other alternative is propagation by rooting needle fascicles or by means of tissue culture. Neither technique has yet been proven successful in *Pinus caribaea*.

Foxtailed trees often exhibit an above average incidence of wind breakage, compression wood formation and juvenile wood (Kozlowski and Greathouse 1970; Wright 1976). The presence of compression wood and juvenile wood will substantially reduce the quality of the timber.

The amount of compression wood is influenced by the interaction of tree lean, growth rate and slope of terrain. The true terminal foxtail tree which is normally tall and branchless in form creates a very unstable structure which is susceptible to lean, sway or bend by external forces such as wind. This may cause the tree to produce compression wood in order to restore the leaning tree stem to its normal vertical orientation.

Juvenile wood is formed about the pith as a result of prolonged influence of apical meristems in the region of active crown on wood formation by the cambium (Panshin and De Zeeuw 1980). The long and vigorous crown of foxtail trees will favour the formation of juvenile wood rather than mature wood.

# CHAPTER 5

# CONCLUSIONS

Based on the study carried out during the summer of 1983, the frequency of foxtail trees, in the plantations of Pinus caribaea var hondurensis in Peninsular Malaysia, varies between and within plantations. In Kemasul pine plantation an overall foxtail frequency is 18.1 $\pm$ 1.0 percent and it ranges from 6.1 to 36.0 percent, while in Ulu Sedeli pine plantation the frequency ranges from 4.2 to 34.8 percent with an overall frequency of 23.4 $\pm$ 1.3 percent. This study indicates that the foxtail frequency increases with age, however, there is no evidence yet to determine at what age will the frequency stabilize. It is also found that the overall foxtail frequency in Ulu Sedeli plantation is higher than in Kemasul plantation by 5.3 percent. This further indicates that foxtail frequency also varies with site.

The most common form of foxtail in both plantations is the subterminal foxtail (more than 60 percent) while the occurrence of true terminal foxtail is very low. It appears that the proportion of subterminal foxtail to terminal foxtail increases with age which suggests that foxtailing is a plastic trait.

In terms of diameter growth, the superiority of foxtail trees is evident only during the early stages of growth. Generally, foxtail trees are superior in height growth than normal trees, however the superiority in height growth is significant in the first four years of growth.

In wood specific gravity, foxtail trees are slightly less dense than normal trees. However, the difference is not significant. Both normal and foxtail trees exhibit the systematic pattern of variation in which specific gravity decreases with increasing height.

Although foxtail trees, especially the true terminal foxtail, hold promise of some economic gains, the inherent limitations and foreseen problems suggest that breeding of foxtail trees may not be feasible and practicable. This is due to the plasticity of the trait, restriction of seed production and formation of juvenile and compression wood. Taking advantage of the low heritability of foxtailing trait, selection against foxtail could be very effective in environments that highly favour the incidence of foxtailing.

Much of the information of growth characteristics of foxtail trees are based on short term observations. Long term observations will provide more reliable information as to the changes of growth of foxtail trees over time. Wood quality studies of foxtail trees in relation to compression and juvenile wood formation are needed to explain and determine the extent of juvenile and compression wood formation in foxtail trees. Particularly in Peninsular Malaysia, where it has to rely upon overseas seed supply, foxtailing will still be a common feature in the local pine plantations. Selection against foxtailing could be more effective at seed source and seedling levels. Seed and juvenile-mature correlation studies of the foxtailing trait could provide useful guidelines for early selection against foxtailing.

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# APPENDIX I

Chi-square Test - Proportion of foxtail to normal trees and proportion of sub-terminal to terminal foxtails

Legend

* - significant. 5% level of probability

** - significant. 1% level of probability

*** - significant. 0.1% level of probability

ns - not significant.

TABLE 1. Chi-square test of the proportions of foxtail to normal trees at Kemasul plantation

| Age (year) | | 1 | 2 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Frequency observed, f | Normal | 74.7 | 75.7 | 64.0 | 63.6 | 59.7 | 53.1 | 54.7 | 445.5 |
| | Foxtail | 15.3 | 14.3 | 26.0 | 26.4 | 30.3 | 36.9 | 35.3 | 184.5 |
| | Total | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 630.0 |
| Frequency expected, F | Normal | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | |
| | Foxtail | 26.4 | 26.4 | 26.4 | 26.4 | 26.4 | 26.4 | 26.4 | |
| $\frac{(f-F)^2}{F}$ | Normal | 1.94 | 2.30 | 0.002 | 0.00 | 0.24 | 1.73 | 1.24 | |
| | Foxtail | 4.67 | 5.55 | 0.006 | 0.00 | 0.58 | 4.18 | 3.00 | |
| $\chi^2 = \Sigma \frac{(f-F)^2}{F}$ | | | | 25.4 *** | | | | | |

TABLE 2. Chi-square test of the proportions of foxtail to normal trees at Ulu Sedeli plantation

| Age (year) | | 1 | 2 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Frequency observed, f | Normal | 78.2 | 70.4 | 73.0 | 60.9 | 54.0 | 56.0 | 54.0 | 446.5 |
| | Foxtail | 11.8 | 19.6 | 17.0 | 29.1 | 36.0 | 34.0 | 36.0 | 183.5 |
| | Total | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 630.0 |
| Frequency expected, F | Normal | 63.8 | 63.8 | 63.8 | 63.8 | 63.8 | 63.8 | 63.8 | |
| | Foxtail | 26.2 | 26.2 | 26.2 | 26.2 | 26.2 | 26.2 | 26.2 | |
| $\frac{(f-F)^2}{F}$ | Normal | 3.25 | 0.68 | 1.33 | 0.13 | 1.50 | 0.95 | 1.50 | |
| | Foxtail | 7.91 | 1.66 | 3.23 | 0.32 | 3.67 | 2.32 | 3.67 | |
| $\chi^2 = \Sigma\frac{(f-F)^2}{F}$ | | | 32.1 *** | | | | | | |

TABLE 3. Chi-square test of the proportions of sub-terminal to terminal foxtails at Kemasul plantation

| Age (year) | | 1 | 2 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Frequency observed, f | Sub-terminal | 46.4 | 57.4 | 45.6 | 49.8 | 70.6 | 79.5 | 75.8 | 425.1 |
| | Terminal | 43.6 | 32.6 | 44.4 | 40.2 | 19.4 | 10.5 | 14.2 | 204.9 |
| | Total | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 630.0 |
| Frequency expected, F | Sub-terminal | 60.7 | 60.7 | 60.7 | 60.7 | 60.7 | 60.7 | 60.7 | |
| | Terminal | 29.3 | 29.3 | 29.2 | 29.3 | 29.3 | 29.3 | 29.3 | |
| $\frac{(f-F)^2}{F}$ | Sub-terminal | 3.36 | 0.17 | 3.76 | 1.96 | 1.61 | 5.82 | 3.76 | |
| | Terminal | 6.98 | 0.37 | 7.78 | 4.05 | 3.34 | 12.06 | 7.78 | |
| $\chi^2 = \Sigma\frac{(f-F)^2}{F}$ | | | 63.8 *** | | | | | | |

TABLE 4. Chi-square test of the proportions of sub-terminal to terminal foxtails at Ulu Sedeli plantation

| Age (year) | | 1 | 2 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Frequency observed, f | Sub-terminal | 42.8 | 46.0 | 48.0 | 49.1 | 55.3 | 69.2 | 66.4 | 376.8 |
| | Terminal | 47.2 | 44.0 | 42.0 | 40.9 | 34.7 | 20.8 | 23.6 | 253.2 |
| | Total | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 630.0 |
| Frequency expected, F | Sub-terminal | 53.8 | 53.8 | 53.8 | 53.8 | 53.8 | 53.8 | 53.8 | |
| | Terminal | 36.2 | 36.2 | 36.2 | 36.2 | 36.2 | 36.2 | 36.2 | |
| $\frac{(f-F)^2}{F}$ | Sub-terminal | 2.25 | 1.13 | 0.62 | 0.41 | 0.04 | 4.41 | 2.95 | |
| | Terminal | 3.34 | 1.68 | 0.93 | 0.61 | 0.06 | 16.55 | 4.39 | |
| $\chi^2 = \Sigma\frac{(f-F)^2}{F}$ | | | | 29.4 *** | | | | | |

# APPENDIX II

Analysis of Variance - Diameter over-bark of normal and foxtail trees

Legend

* - significant. 5% level of probability

** - significant. 1% level of probability

*** - significant. 0.1% level of probability

ns - not significant.

Analysis of variance for diameter over-bark of normal and foxtail trees

PLANTATION: KEMASUL

TABLE 1: 4 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 13.81 | 13.81 | 4.63* |
| Within phenotypes | 486 | 1451.3 | 2.98 | |
| Total | 487 | | | |

TABLE 2: 5 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 28.79 | 28.79 | 3.12 ns |
| Within phenotypes | 754 | 6953.25 | 9.22 | |
| Total | 755 | | | |

TABLE 3: 6 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 0.65 | 0.65 | 0.08 ns |
| Within phenotypes | 638 | 4831.96 | 7.57 | |
| Total | 639 | | | |

TABLE 4: 7 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 121.51 | 121.51 | 12.1*** |
| Within phenotypes | 414 | 1451.3 | 2.98 | |
| Total | 415 | | | |

TABLE 5: 8 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 20.98 | 20.98 | 1.54 ns |
| Within phenotypes | 852 | 11573.29 | 13.58 | |
| Total | 853 | | | |

PLANTATION: ULU SEDELI

TABLE 6: 3 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 93.96 | 93.96 | 10.31*** |
| Within phenotypes | 509 | 4637.13 | 9.11 | |
| Total | 510 | | | |

TABLE 7: 4 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 236.9 | 236.9 | 27.54*** |
| Within phenotypes | 337 | 2901.48 | 8.60 | |
| Total | 338 | | | |

TABLE 8: 5 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 430.87 | 430.87 | 17.09*** |
| Within phenotypes | 668 | 16836.44 | 25.2 | |
| Total | 669 | | | |

TABLE 9: 6 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 81.59 | 81.59 | 2.35 ns |
| Within phenotypes | 300 | 10400.39 | 34.66 | |
| Total | 301 | | | |

TABLE 10: 7 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 0.83 | 0.83 | 0.02 ns |
| Within phenotypes | 557 | 20560.38 | 36.9 | |
| Total | 558 | | | |

TABLE 11: 8 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 117.16 | 117.16 | 2.48 ns |
| Within phenotypes | 814 | 38368.76 | 47.13 | |
| Total | 815 | | | |

## APPENDIX III

Analysis of Variance - Total height of normal and foxtail trees

Legend

| | | |
|---|---|---|
| * | - | significant. 5% level of probability |
| ** | - | significant. 1% level of probability |
| *** | - | significant. 0.1% level of probability |
| ns | - | not significant. |

Analysis of variance for total height of normal and foxtail trees

PLANTATION: KEMASUL

TABLE 1: 1 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 6.57 | 6.57 | 4.98* |
| Within phenotypes | 1194 | 1576.08 | 1.32 | |
| Total | 1195 | | | |

TABLE 2: 2 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 16.2 | 16.2 | 25.31*** |
| Within phenotypes | 1125 | 720 | 0.64 | |
| Total | 1126 | | | |

TABLE 3: 4 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 61.48 | 61.48 | 11.11*** |
| Within phenotypes | 486 | 2687.58 | 5.53 | |
| Total | 487 | | | |

TABLE 4: 5 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 119.64 | 119.64 | 1.43 ns |
| Within phenotypes | 754 | 24399.86 | 38.30 | |
| Total | 755 | | | |

TABLE 5: 6 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 43.74 | 43.74 | 1.14 ns |
| Within phenotypes | 638 | 24441.6 | 38.30 | |
| Total | 639 | | | |

TABLE 6: 7 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 0.96 | 0.96 | 1.00 ns |
| Within phenotypes | 414 | 397.44 | 0.96 | |
| Total | 415 | | | |

TABLE 7: 8 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 68.36 | 68.36 | 0.77 ns |
| Within phenotypes | 852 | 74822.64 | 87.82 | |
| Total | 853 | | | |

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TABLE 8: 2 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 24.611 | 24.61 | 153.8*** |
| Within phenotypes | 302 | 50.19 | 0.61 | |
| Total | 303 | | | |

TABLE 9: 3 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 62.22 | 62.22 | 4.14* |
| Within phenotypes | 509 | 7635.0 | 15.0 | |
| Total | 510 | | | |

TABLE 10: 4 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 0.27 | 0.27 | 0.19 ns |
| Within phenotypes | 337 | 471.76 | 1.40 | |
| Total | 338 | | | |

TABLE 11: 5 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 30.32 | 30.32 | 0.51 ns |
| Within phenotypes | 668 | 39705.92 | 59.26 | |
| Total | 669 | | | |

TABLE 12: 6 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 24.66 | 24.66 | 0.44 ns |
| Within phenotypes | 300 | 16658.28 | 55.52 | |
| Total | 301 | | | |

TABLE 13: 7 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 1.2 | 1.2 | 1.24 ns |
| Within phenotypes | 557 | 540.29 | 0.97 | |
| Total | 558 | | | |

TABLE 14: 8 year-old

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between phenotypes | 1 | 184.24 | 184.24 | 3.58 ns |
| Within phenotypes | 814 | 41896.95 | 51.47 | |
| Total | 815 | | | |

## APPENDIX IV

Analysis of Variance - Specific gravity of normal and foxtail trees

Legend

* - significant. 5% level of probability

** - significant. 1% level of probability

*** - significant. 0.1% level of probability

ns - not significant.

Analysis of variance for specific gravity of normal and foxtail trees

TABLE 1: 10 percent height level

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between plantations | 1 | 0.0454 | 0.0454 | 9.45 ** |
| Between phenotypes/plantations | 2 | 0.0153 | 0.0076 | 1.72 ns |
| Between trees/phenotypes/plantations | 16 | 0.0710 | 0.0044 | 6.28 *** |
| Error | 60 | 0.0413 | 0.0007 | |
| Total | 79 | | | |

TABLE 2: 30 percent height level

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between plantations | 1 | 0.0163 | 0.0163 | 1.81 ns |
| Between phenotypes/plantations | 2 | 0.0087 | 0.0039 | 0.40 ns |
| Between trees/phenotypes/plantations | 16 | 0.1533 | 0.0096 | 12.0 *** |
| Error | 60 | 0.0456 | 0.0008 | |
| Total | 79 | | | |

TABLE 3: 50 percent height level

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between plantations | 1 | 0.0039 | 0.0039 | 0.32 ns |
| Between phenotypes/plantations | 2 | 0.0188 | 0.0094 | 0.75 ns |
| Between trees/phenotypes/plantations | 16 | 0.2007 | 0.0125 | 10.42 *** |
| Error | 60 | 0.0740 | 0.0012 | |
| Total | 79 | | | |

TABLE 4: 70 percent height level

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between plantations | 1 | 0.0003 | 0.0003 | 0.02 ns |
| Between phenotypes/plantations | 2 | 0.0401 | 0.0020 | 0.16 ns |
| Between trees/phenotypes/plantations | 16 | 0.1964 | 0.0123 | 13.66 *** |
| Error | 60 | 0.0573 | 0.0009 | |
| Total | 79 | | | |

TABLE 5: 90 percent height level

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Between plantations | 1 | 0.0076 | 0.0076 | 0.98 ns |
| Between phenotypes/plantations | 2 | 0.0342 | 0.0171 | 2.59 ns |
| Between trees/phenotypes/plantations | 16 | 0.1051 | 0.0066 | 8.25 *** |
| Error | 60 | 0.0509 | 0.0008 | |
| Total | 79 | | | |