I.Warren George Gordon..hereby give permission for the Australian National University to allow any bona fide research worker access to my honours thesis on condition that where any of the material contained therein is quoted subsequently full acknowledgment of the author be given in the normal manner.

.....W. G. Gordon.....

.....2nd.....March.....1980.

EFFECT OF INITIAL ESPACEMENT ON CROWN AND STEM DEVELOPMENT IN HONDURAS CARIBBEAN PINE.

by

W.G. GORDON

Thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Science (Forestry) with Honours at the Australian National University.

November, 1980

ACKNOWLEDGEMENTS

I wish to thank the following people and organizations who, during the course of this project, gave me valuable assistance and/or advice.

* Dr Geoff Wood for organizing the project and for his help, guidance and patience throughout.

* Dr Ken Shepherd for his constructive comments on project proposals and his criticism of sections of the manuscript.

* The Queensland Department of Forestry for allowing me access to their experiments, files and records, for providing substantial technical assistance with the measurement program and for arranging accommodation and transport at Kennedy and Byfield.

* The North Australia Research Unit, A.N.U., for financial support which made the project possible.

* Staff of the Department of Forestry, A.N.U., in particular Joe Miles and Frank Howe, for their help and technical advice.

* My parents for their encouragement and financial assistance throughout my undergraduate course.

* Mrs Duncanson for her excellent typing.

TABLE OF CONTENTS

	Page
List of Tables	iv
List of Figures	viii
List of Abbreviations	ix
Glossary	xi
Abstract	xii
1. Introduction	1
2. Literature Review	5
2.1 Introduction	5
2.2 Effects of Initial Espacement on Tree Growth	7
2.3 The Tree Crown	9
2.4 Branching Characteristics and Wood Quality	11
3. Materials and Methods	17
3.1 Experimental Materials	17
3.1.1 Source and Location	17
3.1.2 Site	17
3.1.3 Layout of Experiments	18
3.1.4 History of Experiments	20
3.1.5 Present Status	20
3.2 Experimental Method	20
3.2.1 Stem Diameter and Bark Thickness	22
3.2.2 Point Density	22
3.2.3 Branch Parameters	23
3.3 Data Analysis	25
3.3.1 Choice of Statistical Package	25
3.3.2 Tests Used	26

Table of Contents Cont'd

	Page
4. Results	28
4.1 Tree Parameters	28
4.2 Branch Characteristics	48
4.2.1 Branch Relationships	53
4.3 Crown Relationships	53
4.4 Influence of Orientation on Branch Growth	57
4.5 Point Density	60
5. Discussion	63
5.1 Introduction	63
5.2 Diameter Growth	64
5.3 Height Growth	65
5.4 Volume Production	65
5.5 Stem Taper	67
5.6 Absolute Form Quotient	68
5.7 Branch Growth	70
5.8 Wood Quality	72
5.9 Management Implications	75
5.10 Conclusions	76
Appendix 1	78
Appendix 2	79
Appendix 3	82
Appendix 4	93
Appendix 5	99
Bibliography	102

LIST OF TABLES

Table	Caption	Page
1.1	Plantings of Honduras pine in North Queensland by forest administrative districts.	2
2.1	General effects of increasing initial espacement on a number of tree and crown parameters.	8
3.1	Plots represented in this study.	19
3.2	Regrouping of plots - Expt. 106 Bowenia.	27
4.1	Effect of initial espacement on dbhob (cm).	29
4.2	Effect of initial espacement on diameter over bark (cm) at points along the tree bole - Expt. 438 Atherton.	30
4.3	Effect of initial espacement on diameter under bark (cm) at points along the tree bole - Expt. 438 Atherton.	31
4.4	Effect of initial espacement on diameter over bark (cm) at points along the tree bole - Expt. 106 Bowenia.	32
4.5	Effect of initial espacement on diameter under bark (cm) at points along the tree bole - Expt. 106 Bowenia.	33
4.6	Effect of initial espacement on average bark thickness (2BT) (cm) at points along the tree bole - Expt. 438 Atherton.	35
4.7	Effect of initial espacement on average bark thickness (2BT) (cm) at points along the tree bole - Expt. 106 Bowenia.	36
4.8	Effect of initial espacement on stand basal area (m^2 ha^{-1}).	37
4.9	Effect of initial espacement on stem taper (cm m^{-1}).	38
4.10	Effect of initial espacement on absolute form quotient.	40

List of Tables Cont'd

Table	Caption	Page
4.11	Effect of initial espacement on the volume (m^3) of the 9.5 m log over and under bark, and bark volume (m^3).	42
4.12	Effect of initial espacement on total height (m).	43
4.13	Effect of initial espacement on height to crown base (m) - Expt. 106 Bowenia.	44
4.14	Effect of initial espacement on crown depth (m) - Expt. 106 Bowenia.	46
4.15	Effect of initial espacement on green crown percent (%) - Expt. 106 Bowenia.	47
4.16	Distribution of differences in branch age (age ex height - age curve minus age ex stem core) - Expt. 106 Bowenia.	49
4.17	The differences between using height-age curves to estimate branch age (years) and stem cores on an individual plot basis - Expt. 106 Bowenia.	49
4.18	Effect of initial espacement on branch growth - Expt. 106 Bowenia.	50
4.19	Effect of initial espacement on potential knot sectional area (cm^2) - Expt. 106 Bowenia.	52
4.20	Effect of initial espacement on branch terminal bud condition - Expt. 106 Bowenia.	52
4.21	Effect of initial espacement on crown overlap (%) - Expt. 106 Bowenia.	54
4.22	Relationships between branch angle (degrees) and branch diameter (cm) - Expt. 106 Bowenia.	56
4.23	Relationships between dbhob, crown depth and initial espacement - Expt. 106 Bowenia.	59
4.24	Effect of orientation on branch growth - Expt. 106 Bowenia.	61
4.25	Mean point density ($m^2 ha^{-1}$) for each initial espacement.	62

List of Tables Cont'd

Table	Caption	Page
5.1	Effect of initial espacement on the number and percentage of trees per hectare greater than a specified dbhob (cm).	66
5.2	Effect of initial espacement on tree height/girth ratio (m cm^{-1}).	70
5.3	Effect of initial espacement on branch diameter (cm).	71
5.4	Effect of initial espacement on the percentage of knots which are less than the maximum allowable knot size for each timber piece dimension in each timber grade for timber used for structural purposes - Expt. 106 Bowenia.	74
A1.1	Plot dimensions and areas.	78
A3.1	Analysis of interaction effects. Expt. 438 Atherton. Dbhob (cm) of all trees, select stems and other than select stems.	82
A3.2	Analysis of interaction effects. Expt. 106 Bowenia. Dbhob (cm) of all trees and other than select stems.	83
A3.3	Analysis of interaction effects. Expt. 106 Bowenia. Stem taper (cm/m) over and under bark.	84
A3.4	Analysis of interaction effect. Expt. 438 Atherton. Height (m) of sample trees.	85
A3.5	Analysis of interaction effects. Expt. 106 Bowenia. Height (m) of all trees, select stems and other than select stems.	86
A3.6	Analysis of interaction effects. Expt. 106 Bowenia. Height to LGB (m) of all trees, select stems and other than select stems.	87
A3.7	Analysis of interaction effects. Expt. 106 Bowenia. Height to LGW (m) of all trees, select stems and other than select stems.	88

List of Tables Cont'd

Table	Caption	Page
A3.8	Analysis of interaction effects. Expt. 106 Bowenia. Crown depth based on LGB (m) of all trees and other than select stems.	89
A3.9	Analysis of interaction effects. Expt. 106 Bowenia. Green crown per cent (%) based on LGB of all trees, select stems and other than select stems.	90
A3.10	Analysis of interaction effects. Expt. 106 Bowenia. Green crown per cent (%) based on LGW of all trees and other than select stems.	91
A3.11	Analysis of interaction effects. Expt. 106 Bowenia. Branch angle (degrees) for sample trees.	92
A4.1	Effect of orientation on branch diameter (cm) - Expt. 106 Bowenia.	93
A4.2	Effect of orientation on branch angle (degrees) - Expt. 106 Bowenia.	94
A4.3	Effect of orientation on potential knot sectional area (cm^2) - Expt. 106 Bowenia.	95
A4.4	Effect of orientation on number of branches in each octant - Expt. 106 Bowenia.	96
A4.5	Effect of orientation on number of live branches in each octant - Expt. 106 Bowenia.	97
A4.6	Effect of orientation on number of dead branches in each octant - Expt. 106 Bowenia.	98

LIST OF FIGURES

Figure	Caption	Page
3.1	Layout plans for Expts. 438 Atherton and 106 Bowenia.	21
4.1	Plot of branch length (m) against branch diameter (cm) - Expt. 106 Bowenia.	55
4.2	Plot of the linear regression lines representing the regression models for branch angle (degrees) and branch diameter (cm) outlined in Table 4.22 - Expt. 106 Bowenia.	57
4.3	Plot of mean branch diameter in LGW (cm) against dbhob (cm) showing the derived regression line and model - Expt. 106 Bowenia.	58
5.1	Effects of initial espacement (m) on tree height (m), height to crown base (m) and crown depth (m) - Expt. 106 Bowenia.	69

LIST OF ABBREVIATIONS

approx.	-	approximately
a.s.l.	-	above sea level
cf.	-	confer
cm	-	centimetre
cm^2	-	square centimetre
dbhob	-	diameter at breast height over bark
dob	-	diameter over bark
dub	-	diameter under bark
E	-	east
e.g.	-	*(exempli gratia)* for example
et al.	-	*(et alii)* and others
Expt.	-	Experiment
FqOB	-	absolute form quotient over bark
FqUB	-	absolute form quotient under bark
ft	-	feet
GLIM	-	General Linear and Inter-active Modelling
ha	-	hectare
i.e.	-	*(id est)* that is
kg	-	kilogram
lat.	-	latitude
LGB	-	lowest green branch
LGW	-	lowest green whorl
long.	-	longitude
M	-	million
m	-	metre
m^2	-	square metre
m^3	-	cubic metre
mm	-	millimetre

List of Abbreviations Cont'd

N	-	north
N.B.	-	*(nota bene)* note well
p	-	probability
pers. comm.	-	personal communication
r^2	-	coefficient of determination
S	-	south
s	-	stems
S.E.	-	standard error
var.	-	variety
viz.	-	*(videlicet)* namely
W	-	west
$\bar{X}$	-	mean
~	-	about
>	-	greater than
<	-	less than
%	-	per cent
2BT	-	two times bark thickness

GLOSSARY

All trees - all trees in the stand i.e. other than select stems plus select stems.

High pruned stems - see Select stems.

Knotty core size - the maximum diameter over branch stubs of the pruned section of the stem.

Other than select stems - trees in the stand which will be thinned out progressively before the end of the rotation.

Sample trees - trees which were randomly selected from the select stems' population for the purposes of this study (Section 3.2).

Select stems - trees in the stand which have been selected as a final crop trees and as a consequence have been pruned to 5.2 m.

Southern pines - *Pinus elliottii* Engelm. var. *elliottii* L. and D. (slash pine) and *P. taeda* L. (loblolly pine).

Total height - tree height from ground to the tip of the tree.

ABSTRACT

This study examines effects of initial espacement on crown and stem development in *Pinus caribaea* Mor. var. *hondurensis* Barr. and Golf. in North Queensland. Measurements of many tree and branch characteristics were taken in plantation stands aged 11-12 years which were established at five square espacements (2.13^2, 2.44^2, 2.74^2, 3.05^2 and 3.66^2 m) in a 5 × 4 randomised block design. The design was replicated at Bowenia (Lat. 23° 52' S, Long. 150° 37' S) and Kennedy (Lat. 18° 12' S, Long. 145° 57' S).

In some cases, effects of initial spacing on select stems (high pruned (5.2 m) final crop trees - 250 s ha^{-1}) were similar at the two locations e.g. stem dbhob and volume of the lower bole (9.5 m section) both increased significantly ($p < 0.01$) with increase in spacing whereas absolute form quotient and bark thickness at breast height were not affected. In other cases, effects were different. Total height growth increased significantly ($p < 0.01$) with increase in spacing at Bowenia but was not affected at Kennedy, and taper of the lower bole increased significantly ($p < 0.01$) at Kennedy but was unaffected at Bowenia. Of the other characteristics measured on select stems at Bowenia (but not at Kennedy due to the effects of a fire), crown depth, green crown percent, branch size and potential knot size increased with spacing ($p < 0.01$), whereas height to the lower green crown, age of branches and their arrangement around the bole were not affected. Average branch size was greater on the northernside of a tree than on the southern side at all spacings.

1. INTRODUCTION

Pinus caribaea Mor. var. *hondurensis* Barr. and Golf. (Honduras Caribbean pine or Honduras pine), an indigenous species of Central America (Barret and Golfani, 1962 (cited in Lamb, 1973)) is becoming a major commercial timber tree especially in the tropical and sub-tropical regions of the world. In mid-1977 the world plantation area of Honduras pine was over 280 000 ha. The annual planting rate was more than 50 000 ha with an expected increase to 90 000 ha a year by the mid-1980's (Nikles, 1979).

Honduras pine was first planted in Queensland in 1948 as part of the exotic pine plantation program of the Queensland Department of Forestry (Hawkins and Muir, 1968). Since then the planting of this species has become increasingly important, especially in North Queensland (Slee and Nikles, 1968) and more recently in southern Queensland. Honduras pine is attractive as a plantation tree not only because of its fast growth rate, but also because it can now be planted using open-root planting techniques and significant improvement in tree quality resulting from tree breeding has been made (Bryan, 1978). North Queensland is likely to remain the major region for plantations of Honduras pine in Queensland. The extent of current and potential plantings is as shown in Table 1.1.

The Queensland Department of Forestry envisages that the North Queensland plantations will provide sawn material and, later perhaps, plywood. The timber is suitable for a full range of general purpose sawnwood and pulp and

TABLE 1.1

Plantings of Honduras pine in North Queensland by forest administrative districts.

Forest Sub-District	Area Planted (ha)	Potential Planted Area (ha)
Atherton	500	> 30 000
Ingham	2 000	-
Mackay	500	3 500
Rockhampton	3 700	~ 11 200
Total	6 700	~ 44 700

paper applications (Hawkins, Nikles and Smith, 1978). The demand for this sawn timber will to some extent be inversely related to the supply of timber from rainforest sources. However, supplies of rainforest species are likely to decline because of factors of slow growth, adverse economics of logging and pressures for conservation of remaining rainforest.

Also, with the proposal to establish a $200 M wood pulp plant at Beerburrum, in south-east Queensland by 1984 (Dempster, 1980) there is a possibility that some of the production of the plantations at Byfield in the Rockhampton Sub-District could be used as a source of pulpwood for this mill. For North Queensland as a whole the Department of Forestry is not planning for a major pulp or chip market mainly because of the comparatively small area planted to date and the fairly slow rate of increase of the resource (~ 1 000 ha per year). However, this situation could change later. There are a number of unknown factors here, e.g.

chips could be exported or perhaps used locally in conjunction with sugar cane residue. Nevertheless, one of the major production aims of the planting program is sawn timber.

To grow the desired end product to the required quality, knowledge is needed of the performance of the species, of particular genetic constitution on various sites and under various silvicultural regimes. At present, the Queensland Department of Forestry is basing its management of plantations of Honduras pine largely on knowledge accumulated over the past 50 years with the southern pines. Obviously, knowledge specific to this species is needed to manage these plantations most efficiently.

One of the first things which must be known is a desirable initial spacing for a plantation site and/or locality. In Queensland, a spacing of 3 m × 3 m has been adopted for all plantings of Honduras pine using stock raised from improved seed. This initial espacement was determined from experiments concerned with growth, silvicultural considerations and harvesting requirements (R. Grimes, 1980, pers. comm.). Such a rigid adherence to a particular initial spacing is claimed by Wilde *et al.* (1968) to be one of the gravest errors a forester can commit considering both ecological and economic aspects. But establishing the most suitable spacing for a locality is difficult.

The Queensland Department of Forestry, recognizing the need to determine desirable initial spacings for Honduras pine, established the first spacing experiments for this species in 1969 at Byfield via Yeppoon and Kennedy near Cardwell. Recently further spacing experiments using

genetically improved planting stock have been established along the south-east coast of Queensland on both ridge and swamp sites (Bacon, 1979). The aim of these experiments is to provide basic data on the growth and yield of improved stock of the species planted at various spacings (Hawkins, 1969). This present study, based on the experiments established in 1969 at Byfield and Kennedy, examines the effect of initial espacement on crown and stem development at age 11-12 years. More specifically, questions to be answered are:

(i) to what extent does initial spacing affect tree diameter and height growth, recession of the green crown, branch longevity and branch size, angle and orientation?

(ii) does initial spacing affect bark thickness and solid shape and taper of the lower bole?

Answers to these questions are needed to formulate sound decisions on initial espacement and subsequent management of plantations of Honduras pine. Even if the lower bole of the best or final crop trees in the plantation are pruned (economics could limit this height of pruning to about 5.2 m), there will be a large volume of unpruned log material available for sale. The size of knots and whether these are from dead or living branches will influence the strength of the sawn produce. The influence of these knots on wood quality will be of more importance economically in sawn timber than in structural material.

2. LITERATURE REVIEW

2.1 INTRODUCTION

A tree, like any other living organism requires space to grow and develop, the amount varying with species, age and site. According to Gevorkiantz and Hosley (1929), growing space is one of the most important factors governing the production of trees of specified form, size and quality and the improvement of existing stands. This is because the growing space available to a tree affects its micro-environment viz., incident solar radiation, moisture, nutrients, frost and wind-factors, all of which influence the rate of tree growth and development of the crown and trunk (Evert, 1971).

In plantation stands, the forester controls the growing space available to trees in two ways:-

(i) Initial espacement - this refers to the planting distance between rows of trees and between trees within a row. The espacement is normally square or rectangular. A nominal espacement may be altered due to the death of seedlings at establishment or mortality before thinning occurs.

(ii) Thinning - this involves the planned removal of some trees at various stages during the life of the stand to promote the growth of other trees selected for retention.

Effects of initial espacement on tree growth are most marked up to the stage of canopy closure (Whyte, 1970). Effects on growth after this are mostly due to thinning operations. While tree mortality can occur at any time in the life of a forest stand it is more common prior to first thinning. Subsequent to this, thinning tends to remove unthrifty trees which might otherwise die. Today, the effects of mortality are relatively minor because of the intensity of site preparation, the high quality of planting stock and other protective measures such as the reduction of rabbit populations through the use of 1080 baiting. Therefore initial espacement is the major factor affecting the growing space available to a tree prior to first thinning. It also has an important bearing on the cost of establishing the stand and on the return obtained from the sale of timber once the stand comes into production (Wardle, 1967). Wide spacings result in lower costs of establishment, avoidance of early unmerchantable thinning and increased growth of individual trees (Stevenson and Bartoo, 1939). According to Smith (1962) selection of the appropriate spacing for a particular planting should be made having considered such factors as site, growth habit of the species, expected survival, management objectives, future silvicultural treatment, and the kind of logging equipment likely to be used in future cuttings. However, most emphasis should be placed on management objectives (production of the desired products). Attainment of these objectives is to some extent dependent on growth in the early phase of forest plantation establishment i.e. on initial spacing, as wood

volumes and values are concentrated in the lower tree bole. Thus, control of characteristics in the butt and second logs is more important than in higher logs (Fenton and Sutton, 1968).

2.2 EFFECTS OF INITIAL ESPACEMENT ON TREE GROWTH

Bramble, Cope and Chisman (1949) concluded that the general nature of the effects of spacing on tree growth is fairly well understood although the magnitude of these effects on individual species is still uncertain. Twenty-two years later, Evert (1971) in a major review of spacing effects on tree growth, came to the same conclusion. Such is certainly the situation for Honduras pine which is the subject of this study.

The generally accepted effects of initial espacement on tree parameters which are of particular interest in this study are summarized in Table 2.1. These effects relate to the range of spacings commonly used in forestry practice.

As would be expected, exceptions to the general trends occur. For example, Bella and de Franceschi (1974) found that spacing significantly affected the diameter growth of 11-year-old jack pine (*P. banksiana*, Lamb) planted at spacings of 1.3 m × 1.3 m, 2.0 m × 2.0 m, 2.6 m × 2.6 m and 3.3 m × 3.3 m. However, average diameter was 15 per cent greater at the two intermediate spacings than at the two extremes. Similar results have been reported for some species in northern Europe (Sjolte - Jørgensen, 1967). However, this difference from the expected finding only occurs at a relatively young age and is attributed to the trees at the wider spacings taking a somewhat longer time

TABLE 2.1

General effects of increasing initial espacement on a number of tree and crown parameters.

Parameter	Effect
Dbhob	increases
Volume	increases
Total height	variously affected
Crown depth	increases
Crown per cent	increases
Height to base of crown	decreases
Bole taper	increases
Bole shape	less cylindrical
Bark thickness	increases
Branch diameter	increases
Branch length	increases
Branch longevity	increases
Branch angle	more acute

to establish themselves and utilize the extra growing space available to them (Sjolte - Jørgensen, 1967). The reason for this delayed response is not known.

There is conflicting evidence on the effect of spacing on height growth (Hamilton and Christie, 1974). The evidence suggests that as initial espacement increases height growth may be affected in one of five ways:-

(i) unaffected.

(ii) unaffected until the trees are a certain age and then increases.

(iii) increases.

(iv) decreases.

(v) greatest at intermediate spacings.

Evert (1971) advocates caution in making broad generalizations on the effect of initial spacing on height growth of plantation trees. He concludes, however, that in relatively young, dense plantations on poor to medium sites, height growth is likely to increase with increased spacing, while at lower stocking densities on good sites, it is little affected. Hamilton and Christie (1974) suggest as an explanation for the increase in tree height with increased spacing, that "with the development of densely stocked stands, a higher proportion of trees occupy the lower canopy than in less dense stands. The consequent restriction of height growth of these individuals effectively depresses the mean height of the stand".

2.3 THE TREE CROWN

Growth of the stem is controlled directly by the crown and therefore indirectly by spacing (Stiell, 1966) as environmental factors eventually influence cambial growth both by affecting formation and expansion of leaf primordia as well as by influencing physiological activity of fully expanded leaves (Kozlowski, 1971). Therefore, according to Stiell (1966) a knowledge of crown - spacing relationships is important for conscious regulation of the amount, quality and distribution along the tree bole of wood produced.

Closer spacings contain greater standing volumes at all ages than do wider spacings, although the relative difference decreases with age. However, merchantable volume as a proportion of total volume increases with age, and is greater at wider than closer spacings (Evert, 1971). These

effects can be explained in terms of the number of trees per unit area, the higher proportion of larger sized trees at wider spacings and the crown - spacing effects. At closer spacings trees have smaller crowns, the volume of individual trees is less but, overall, there are many more trees.

The distribution of the volume of wood along the tree bole can be just as important as the volume itself, particularly where the wood is being grown for end products such as sawntimber and veneer. With pulpwood production, volume *per se* is more important. The bole of a tree at any particular time appears as a solid body regenerated by the revolution of a tapering radial profile about a vertical axis (Carron, 1968).

The role and influence of the tree crown on stem taper is explained by Kozlowski (1971). He argues that because the annual accretion of xylem at upper or lower levels of the stem is a function of the capacity of the foliage to synthesize carbohydrates and growth hormones, the size of the crown strongly determines the degree of stem taper. Stems of open-grown trees with long crowns tend to be more tapered than stems of trees with small crowns in closed stands. These differences are related to variations in both the rate of xylem increment along the entire bole and its vertical distribution along the stem. As height growth is little affected by stand density (*sic*) and the rate of radial growth of the bole is greater in large-crowned than small-crowned trees, one must expect increased taper in the former. In addition, open-grown trees with large crowns tend to distribute significant amounts of metabolites to the lower

stem, resulting in appreciable xylem increment there, further increasing stem taper. As crown length is decreased in closed stands and competition among trees is intensified, xylem increment along the entire stem is decreased and is concentrated in the upper part of the tree resulting in a stem which approaches cylindricity.

Such cylindricity is certainly a desirable log characteristic because with sawlogs using the usual sawing patterns, and with ply logs, taper reduces recovery and causes sloping grain in the products (Brown, 1970). However, the trees which produce such cylindrical logs occur only in small log sizes. Normally therefore large log size is a more desirable characteristic than cylindricity.

Therefore the forester, by using such means as initial stocking, pruning, thinning and fertilizing to manipulate tree crown size, can influence stem taper and shape and more particularly, stem volume.

2.4 BRANCHING CHARACTERISTICS AND WOOD QUALITY

Obviously the branching characteristics of a tree as influenced by various genetic, environmental and cultural factors determine many of the properties of its crown. Branch length, angle, diameter and longevity all influence crown width while branch longevity has an effect on crown depth (and height of the crown base). It is this resultant crown, and to some extent individual whorls of branches and individual branches that have important effects on wood quality and therefore influence its end use. External factors of the environment as well as silvicultural practices tend to modify crown development which, in turn,

causes variations in the basic pattern of stem growth inherent in all trees, and hence in wood quality (Larson, 1962).

One of the important effects of branching characteristics on wood quality is via the size, number, distribution and type of knots plus several other associated factors such as grain distortion around the knots, adjacent compression wood, and the diameter of the knotty core. Knots are the most common defect in timber and more than any other wood characteristic affect the commercial acceptance of wood and its suitability for use (Brazier, 1977). Knots are by far the most important property influencing timber stiffness and strength (Whiteside, Wilcox and Tustin, 1977), in addition to affecting warping during seasoning and machining, and causing checking and painting problems with exterior woodwork (Meney, 1976).

The size of knots is determined by the size and entrance angle of the branches (Fisher, 1978). Large, highly angled branches result in bad knots and such branches sometimes compete strongly with the main leader (Meney, 1976). Therefore it is desirable for branches to be as small and as horizontal as possible (Shelbourne, 1970).

Branch diameter is influenced by initial spacing, establishment methods and by the thinning regime adopted. Thus, at least in the two lower log lengths, branch diameter can be influenced by the forester to a large degree (Whiteside, Wilcox and Tustin, 1977). However, the effect of growing space on branch size is said to be indirect as branch diameter is closely correlated with tree size. Growth conditions

which promote diameter growth of the stem also promote branch growth. The extent to which diameter growth of the branch is promoted by site conditions and silvicultural treatment is the same as for diameter growth of the stem (Cromer and Pawsey, 1957; Wardle, 1967; Wright, 1970). Some researchers do not accept the relationship between branch diameter and tree size and claim, as Stiell (1964, 1966) does, that branches at wider spacings are larger simply because they live longer. However, Brown (1962), Whiteside (1962) and Powell (1979) all have found for the usual range of initial spacing that each branch at first increases in diameter rapidly, but after a few years, growth declines sharply. Thereafter, although the branch may continue to live for a number of years, diameter growth is usually very slight and is frequently too small to measure. Branch longevity, however, does affect the type of knot produced as will be discussed later.

However, following thinning every part of the tree is essentially re-juvenated and starts on a period of accelerated growth, not unlike that of youth, which comes to an end for the same reason as in young trees : all available growing space is being utilized (Baker, 1950). Most branches that are alive at the time of thinning respond (James, 1970), with those branches in the mid-crown responding most, because before thinning they were growing under conditions of shading (absence of light is apparently primarily responsible for branch death) but now have good exposure (Forward and Nolan, 1961).

Branch diameter and branch angle are negatively correlated (Jacobs, 1938; Fielding, 1960). However, branch

angle is controlled primarily by genetic influences (Shelbourne, 1970; Wright, 1970) so, unlike branch diameter is only slightly influenced by site conditions and silvicultural treatment.

Besides influencing knot size, branch angle determines the occurrence of bark inclusions in the wood. In *P. radiata* D. Don almost all branches forming angles more acute than 30 degrees with the main stem have extensive resin or bark pockets along their upper edge (Fenton and Familton, 1961). These pockets lead to serious defects in both board and framing timber (Jacobs, 1938; Meney, 1976). Acute angled branches are more difficult and costly to prune (Jacobs, 1938; Fielding, 1960).

The number and distribution of knots are also under genetic control. Both are unaffected by silvicultural treatment (Nylinder, 1959 (cited by Sjolte-Jørgensen, 1967); Sutton, 1968).

Knots represent the basal sections of branches encased in the stem. A branch is a fixed entity arising from the central meristem of the stem. While the branch is alive its cambium is continuous with that of the stem. As the stem increases in diameter it grows over the branches whose bark sloughs off. Consequently the stem wood becomes intergrown with that of the branch and gives rise to intergrown knots. When the branch dies its cambium dries out and the bark no longer sloughs off. The stem subsequently encompasses the branch and its dead bark forming bark-encased knots (Jacobs, 1938; Brown, 1962). Intergrown knots are preferable to bark-encased knots (Brown, 1970) because being intergrown

with the stem wood they are firm while the bark-encased knots tend to be loose. In sawn timber and ply veneers, bark-encased knots often fall out altogether and from a decorative point of view, they are unsightly.

The moribund phase of the life of a branch seems to begin when the terminal shoot fails to produce buds, or forms buds that will not open (Stiell, 1962). Hence no new foliage is formed. The existing needles live out their life span and the branch then dies (Stiell, 1966). The branch remains attached to the stem until it rots or breaks off.

Loblolly pine (*P. taeda* Linn.) in the United States takes about 8 years to self-prune after the branches die (Whitesell, 1970). For many of the pine species grown in Australia the self-pruning period is substantially longer. Conditions that favour the retention of moisture in dead branches appear to hasten the rotting and shedding of branches. The hot,dry climate in Australia does not favour the process. Throughout the self-pruning period bark-encased knots are being formed.

The artificial removal of branches hastens the production of knot-free or clear wood (Helmers, 1946). Where pruning is carried out as a means of controlling wood quality, the branches are usually removed from the base of the crown when they are still alive but largely unproductive, and when tree diameter is such that the knotty core diameter is kept to a minimum. As well as being affected by stem diameter, knotty core size is affected by the diameter of the pruned branches. Larger branches result in greater stem

swelling at the nodes, greater stub length after pruning and protracted rates of occlusion following pruning (Whiteside, 1962). Pruning also affects log quality as it improves stem form by reducing taper in the pruned section, but whether it does so appreciably depends on its severity and timing as well as on crown characteristics of the tree prior to pruning (Brown, 1962; Kozlowski, 1971).

As mentioned previously initial spacing has most effect on the wood quality of the lower stem. Sjolte-Jørgensen (1967) reviewed the influence of initial spacing on wood quality and concluded that in general, the quality of the wood produced in coniferous plantations decreases with increasing spacing. He added, however, that the influence these differences have on economic value depends on the standards of wood quality adopted in each country, in each locality, and for each species. For timber of Honduras pine in Australia, wood quality standards are based primarily on knot type and size in relation to piece size (Standards Association of Australia, 1977). Therefore wood quality and economic value of Honduras pine are dependent on the effects of initial spacing.

3. MATERIALS AND METHODS

3.1 EXPERIMENTAL MATERIALS

3.1.1 Source and Location

The source of the experimental material was two plant espacement experiments, Expts. 106 Bowenia and 438 Atherton, of identical design established in March, 1969 by the Queensland Department of Forestry. Expt. 106 Bowenia is located in Compartment 12, Upper Stoney Logging Area in State Forest Reserve 865 at Byfield via Yeppoon, Queensland (Lat. 23° 52'S, Long. 150° 37'S) and Expt. 438 Atherton is located in Compartment 7, Carruchan Logging Area in State Forest Reserve 461 at Kennedy, Queensland (Lat. 18° 12'S, Long. 145° 57'S).

3.1.2 Site

Each experimental site is relatively uniform and was chosen to be representative of the average site conditions existing for future plantings of Honduras pine in the particular district.

Expt. 106 Bowenia is situated on an alluvial flat adjacent to Upper Stoney Creek. Soils are deep (> 90 cm) yellow brown to red brown sands and sandy loams with gravel or concretions occurring below 30 cm. The original vegetation was mixed sclerophyll forest > 20 m in height containing *Eucalyptus trachyphloia* F. Muell., *E. acmenioides* Schau., *E. micrantha* D.C. and *Tristania suaveolens* (Soland. ex Goertn) Sm. The understorey consisted

of *Casuarina torulosa* Ait. together with species of *Alphitonia, Acacia* and *Glochidion*. Topography is level or very gently sloping to the N and NE.

The soil in Expt. 438 Atherton is a grey brown loam to clay loam over a red yellow silty clay loam to silty clay. Granitic grit and coarse sand occur throughout the profile. The original vegetation was mixed sclerophyll forest 15 to 18 m tall containing *E. trachyphloia* and *E. acmenioides* and occasional *E. crebra* F. Muell. and scattered *Acacia*. The understorey was mainly *Planchonia careya*, *Coelospermum reticulatum* Benth., and *Xylomelum scottianum* F.v.M. Topography is generally rolling. Aspect is N to NE and slope 4-6°. Elevation is 15 m a.s.l.

3.1.3 Layout of Experiments

At each centre, five treatments were established, namely:-

Treatment	Initial Espacement		Stems ha^{-1}
	m	(ft)	
A	2.13 × 2.13	(7 × 7)	2200
B	2.44 × 2.44	(8 × 8)	1680
C	2.74 × 2.74	(9 × 9)	1330
D	3.05 × 3.05	(10 × 10)	1075
E	3.66 × 3.66	(12 × 12)	750

Each experiment was laid out as a randomised complete block with four replications of each treatment and thus comprises 20 plots. However, only 10 plots of Expt. 106 Bowenia are included in this study as stocking in the other 10 plots was adversely affected by wildfire in 1971 (Table 3.1). Each plot is square in shape with a nett plot area of about 0.08 ha, and surrounded by an isolation strip of width at

TABLE 3.1

Plots represented in this study.

BLOCK	INITIAL ESPACEMENT (m)				
	2.13^2	2.44^2	2.74^2	3.05^2	3.66^2
	EXPERIMENT 438 ATHERTON				
1	5	2	3	1	4
2	9	6	10	8	7
3	12	13	14	15	11
4	18	19	16	17	20
	EXPERIMENT 106 ATHERTON				
1	5	18*	11*	20	1
2	12*	6	3	2	4
3	13	15*	16*	17*	14*
4	10*	8	7	19*	9*

*Deleted from study because of fire damage.

least 8 m (Appendix 1). The layout plans for the experiments are presented in Figure 3.1.

3.1.4 History of Experiments

The history of each experiment is summarised in Appendix 2.

3.1.5 Present Status

Both experiments have been measured annually since their establishment. Examination of this growth information indicates that Plot 13 in Expt. 106 Bowenia is inferior to the other plots. The plot has a depression on one side and was truncated on the other side by fire arising from lightning strike in 1971. Plots 1 and 4 appear to be slightly superior to all other plots. In Expt. 438 Atherton, Plot 20 appears to be on a slightly poorer site than the rest of the plots.

3.2 EXPERIMENTAL METHOD

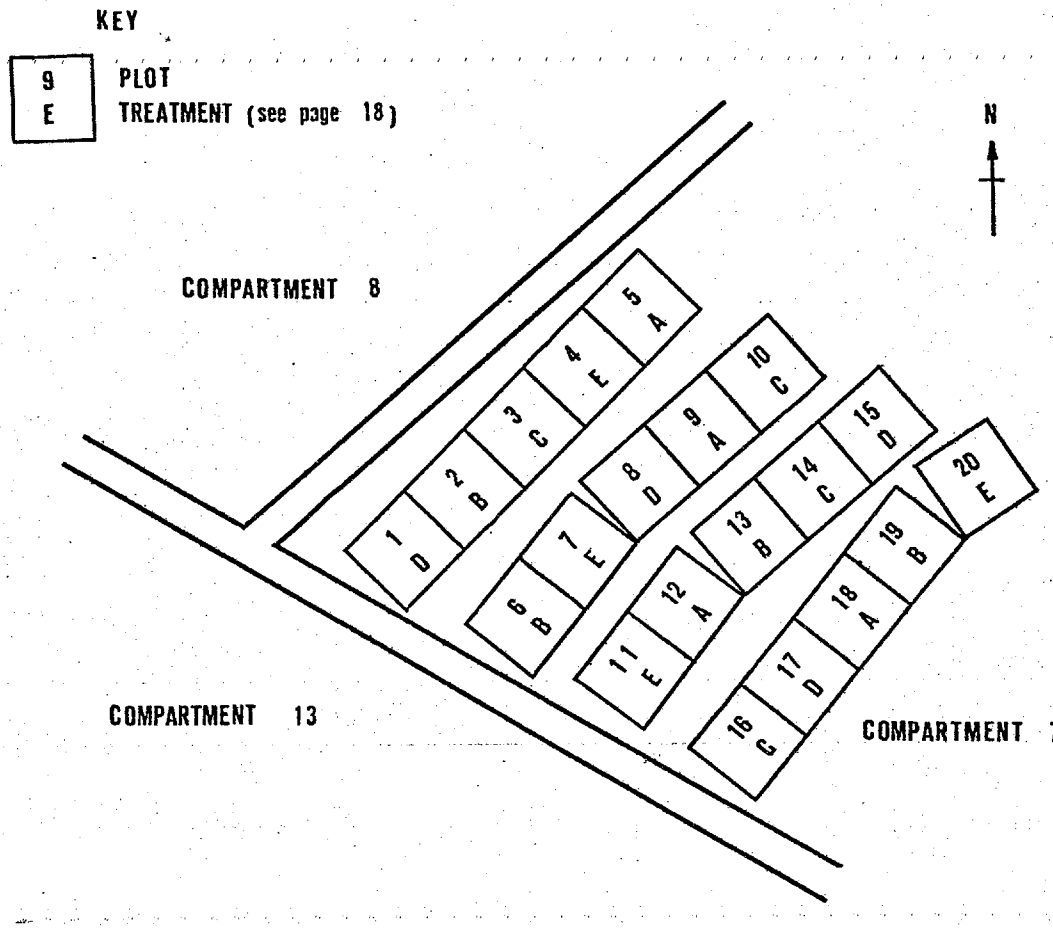
Initially it was intended that each experiment be measured in an identical way. However, the crowns of trees in Expt. 438 Atherton were scorched during controlled burning operations in April, 1979 which precluded measurement of crown and branch parameters.

During May-June, 1980, diameter at breast height over bark (dbhob) was measured on all stems in all plots of both experiments. Total height and heights to the lowest green branch (LGB) and lowest green whorl (LGW) of all stems were measured at Bowenia, but manpower difficulties at Kennedy restricted measurement of total height to five randomly selected sample trees per plot.

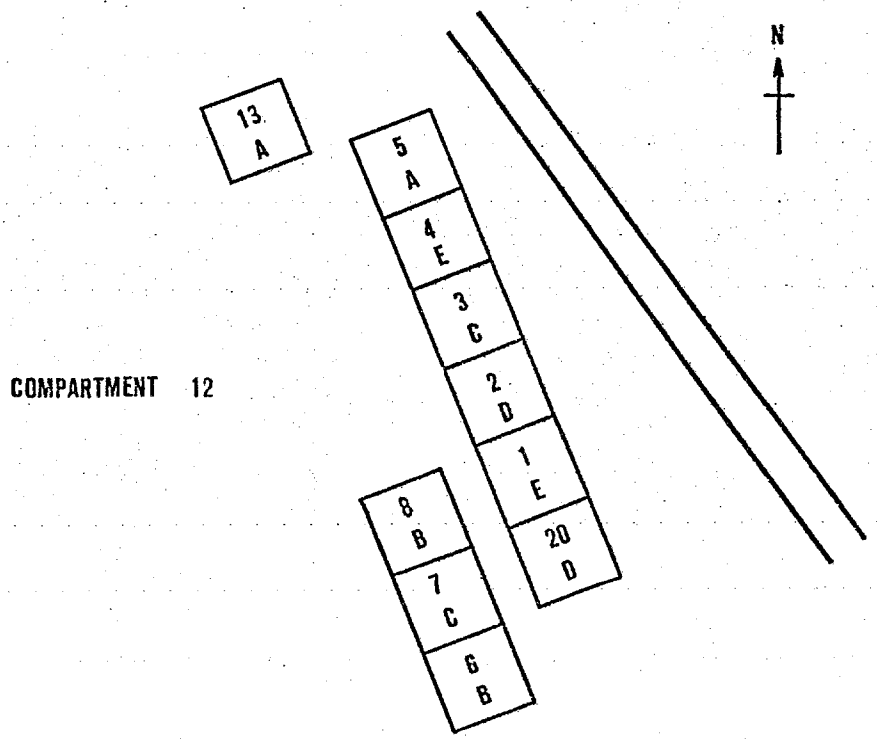
Measurement of other crown and stem variables

FIGURE 3.1

Layout plans of Expts. 438 Atherton and 106 Bowenia.



Layout of Expt. 438 Atherton, Carruchan Logging Area.



Layout of Expt. 106 Bowenia, Upper Stoney Logging Area.

was based on a sample of 100 high pruned stems selected at random from each experiment. Using proportional allocation, five trees per plot were selected at Kennedy and ten at Bowenia. This constituted a 25% and 50% sample respectively of high pruned stems. Selection within a plot was weighted based on the distribution of high pruned trees within diameter classes at the 1979 annual measure. Stems selected which were found to have a defect or malformation considered likely to have adversely affected their pattern of growth (e.g. top broken out, multiple leader) were replaced by another random selection. A total of seven trees at Kennedy and six at Bowenia were replaced on this basis.

Measurements made on each of these sample trees are described below:-

3.2.1 Stem Diameter and Bark Thickness

Measured at both experimental sites.

Diameter over bark and bark thickness were measured by diameter tape and Swedish bark gauge at 0.5, 1.3, 2, 4, 6, 8 and 10 metres above ground. When the point of measurement fell on an unrepresentative point such as a whorl, measurements equidistant above and below the point were taken and averaged. Bark thickness at each height was measured on the N, E, S and W faces.

3.2.2 Point Density

Measured at both experimental sites.

Even in stands planted at nominally regular spacing, as is the case with these experiments, variations in stocking around each tree inevitably occur due to planting errors, mortality, thinning or accident. Consequently, point

density about each sample tree was determined using the angle summation method of Spurr (1962). This involved making a sweep about each sample tree, using mostly Band 4 of a Spiegel Relaskop, and recording the dbhob and distance of each tree from the subject sample tree included in the sweep. From seven to fourteen trees, including the sample tree, constituted the point density sample.

These point density estimates give an indication of the current spacing or stocking under which each tree is growing. In many cases the initial espacement is not representative of the current spacing i.e. in particular in the thinned plots of Expt. 106 Bowenia. These estimates may be able to help explain the findings for the other parameters measured.

3.2.3 Branch Parameters

Measured in the LGW of each sample tree at Bowenia only.

(i) Diameter over bark 5 cm from the junction with the stem was measured by diameter tape on all living branches.

(ii) Branch angle, defined as the included angle between the stem and the upper side of the branch, was recorded for all branches, living and dead, using a branch protractor (Brown, 1967).

Data from (i) and (ii) gives an indication of potential knot size in the main bole of the trees sampled.

(iii) Orientation of the basal 0.5 m length of both

living and dead branches was recorded by compass using an octant system referenced to row direction (approx. 60°), namely:

Octant	Branch orientation (degrees)
1	37-81
2	82-126
3	127-171
4	172-216
5	217-261
6	262-306
7	307-351
8	352-36

Branch orientation was recorded because some of the variation in branch size around a stem might be explained by variation in the micro-environment with a given spacing viz., abrasion, light penetration, direction of the prevailing wind.

(iv) Branch length was measured on one branch selected at random from the living branches in the LGW and severed at its junction with the stem.

(v) Terminal bud condition and branch vigour. The condition of the terminal bud of the branch severed in (iv) was recorded using the following classification:

Condition Class	Description
1	Terminal bud alive and healthy
2	Terminal bud alive but unhealthy
3	Terminal bud dead

In addition, a count of the number of needle flushes on the primary branch was made as an indication of branch vigour at the base of the crown.

(vi) Branch age. A surface to pith stem core was taken by "Pressler" corer just below the level of the LGW. The core was wrapped in newspaper and labelled with a unique code based on experiment, plot, row and tree number e.g. 106/13/7-1 i.e. Expt. 106 Bowenia, Plot 7, Row 7, Tree 1. Subsequently, each core was mounted firmly in a block of wood and sanded using progressively finer grades of wet and dry paper (120, 600 and 1200 grades). It was then aged by counting the number of annual growth rings (10 × magnification) and branch age subsequently determined.

As a check on this aging procedure, the height-age curve for each sample tree was drawn using data obtained from the Queensland Department of Forestry. Then, knowing the height to the LGW for each sample tree, the age at which the branches in the LGW were initiated was read off. Current age of tree minus age of tree when LGW branches were initiated equals branch age.

3.3 DATA ANALYSIS

3.3.1 Choice of Statistical Package

Statistical analysis of the data was done using GLIM (General Linear and Inter-active Modelling). Vanclay (1977) found this package superior to other statistical

packages available at the Australian National University.

In association with the use of GLIM, several Fortran V programmes were written by the author to:-

(i) calculate the Chi-square statistic needed for Bartlett's test.

(ii) calculate stand basal area, tree volume, crown depth, green crown percent and potential knot sectional area.

(iii) rearrange the data into various forms prior to statistical analysis.

(iv) calculate means and standard errors.

3.3.2 Tests Used

Analysis of the data involved analysis of variance, linear regression, and tests of least significant differences. Prior to these analyses, Bartlett's test (test for the equality or homogeneity of several variances) was carried out on the data. A residual analysis test in GLIM was used to test normality. (The data passed these provisional tests).

Because of the 1971 wildfire in Expt. 106 Bowenia, the ten unburnt plots were re-grouped to allow analysis of variance to be used. Regrouping was based on whether the plots were unthinned or thinned (Table 3.2).

Statistical analysis was used only to determine the significance of differences detected between treatments at each location for the parameters studied. The effect of location itself was not determined due to the difficulty of arranging the treatments and "blocks" at each experiment in such a way that they would be directly comparable using analysis of variance.

TABLE 3.2

Regrouping of plots - Expt. 106 Bowenia.

INITIAL ESPACEMENT TREATMENT (m)	GROUP	
	I	II
2.13^2	PLOT 5 BLOCK I UNTHINNED	PLOT 13 BLOCK III THINNED
2.44^2	PLOT 8 BLOCK IV UNTHINNED	PLOT 6 BLOCK II THINNED
2.74^2	PLOT 3 BLOCK II UNTHINNED	PLOT 7 BLOCK IV THINNED
3.05^2	PLOT 20 BLOCK I UNTHINNED	PLOT 2 BLOCK II THINNED
3.66^2	PLOT 1 BLOCK I UNTHINNED	PLOT 4 BLOCK II THINNED

All statistical analyses were run on a Univac 1100 series computer (time-sharing system).

4. RESULTS

Results of the study are summarised in Tables 4.1 to 4.25, Figures 4.1 to 4.3 and Appendixes 3 and 4.

4.1 TREE PARAMETERS

Diameter growth

At both locations, dbhob of all trees, select stems and other than select stems increases significantly with increase in initial espacement (Table 4.1). In some cases, the interaction between treatment and block is significant ($p < 0.01$). Analyses of these effects are presented in Table A3.1 and A3.2 (Appendix 3). Ranking dbhob for each tree type for each plot confirms the increase in dbhob observed with increase in initial spacing.

At both locations, diameter growth over and under bark at the seven points along the main bole also increases with increase in initial espacement (Tables 4.2 to 4.5). However, the effect is much more marked at Bowenia (Expt. 106 Bowenia), particularly at points along the bole above 4 m. Interactions are significant at Kennedy (Expt. 438 Atherton) for dob and dub at both 8 and 10 m above the ground (8 m, $p < 0.05$; 10 m, $p < 0.01$). The effects, however, were not analysed as trends were well established.

Bark thickness

At both locations, average bark thickness[1]

[1] Average bark thickness = (Bark thickness on north side + Bark thickness on south side + Bark thickness on east side + Bark thickness on west side) / 2

TABLE 4.1

Effect of initial espacement on dbhob (cm).

TREE TYPE		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
EXPERIMENT 438 ATHERTON							
ALL TREES	$\bar{X}$	17.3	18.5	19.6	21.3	22.5	**
	S.E.	3.6	3.8	3.8	3.7	3.4	
SELECT STEMS	$\bar{X}$	21.6	22.4	23.2	24.5	24.5	**
	S.E.	2.3	2.4	2.3	2.8	2.4	
OTHER THAN SELECT STEMS	$\bar{X}$	16.6	17.7	18.6	20.2	21.4	**
	S.E.	3.3	3.5	3.5	3.4	3.4	
EXPERIMENT 106 BOWENIA							
ALL TREES	$\bar{X}$	17.6	20.5	21.4	22.8	25.2	**
	S.E.	3.9	3.5	3.3	2.6	2.7	
SELECT STEMS	$\bar{X}$	21.9	24.1	24.4	25.1	26.5	**
	S.E.	2.1	2.1	2.1	1.9	2.4	
OTHER THAN SELECT STEMS	$\bar{X}$	16.8	19.6	20.5	22.0	24.4	**
	S.E.	3.5	3.1	3.4	2.5	2.8	

significant levels: **, 0.01

N.B. Values not underscored by the same line are significantly different at 0.05.

TABLE 4.2

Effect of initial espacement on diameter over bark (cm) at points along the tree bole - Expt. 438 Atherton.

HEIGHT ABOVE GROUND (m)		INITIAL ESPACEMENT (m)					SIG#
		2.13[2]	2.44[2]	2.74[2]	3.05[2]	3.66[2]	
0.5	$\bar{X}$	24.1	24.9	25.5	27.2	27.4	**
	S.E.	2.3	2.7	2.8	3.3	2.5	
1.3	$\bar{X}$	22.2	22.6	23.0	25.0	24.8	**
	S.E.	2.0	2.2	2.2	2.9	2.5	
2.0	$\bar{X}$	21.2	21.5	21.9	23.5	23.6	**
	S.E.	2.0	2.0	2.0	2.7	2.4	
4.0	$\bar{X}$	19.7	19.8	20.3	21.7	21.6	**
	S.E.	2.1	2.1	1.9	2.8	2.5	
6.0	$\bar{X}$	18.1	18.0	18.6	19.7	19.7	**
	S.E.	1.9	2.1	1.9	2.6	2.5	
8.0	$\bar{X}$	16.4	16.2	16.8	17.8	17.8	*
	S.E.	1.8	2.0	1.7	2.7	2.6	
10.0	$\bar{X}$	14.7	14.3	15.0	15.7	15.9	**
	S.E.	1.7	1.9	1.6	2.6	2.6	

#significant levels: *, 0.05; **, 0.01.

TABLE 4.3

Effect of initial espacement on diameter under bark (cm) at points along the tree bole - Expt. 438 Atherton.

HEIGHT ABOVE GROUND (m)		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
0.5	$\bar{X}$	19.2	19.3	20.2	21.3	21.2	**
	S.E.	2.2	2.4	1.9	3.0	2.6	
1.3	$\bar{X}$	17.9	18.1	18.7	20.4	20.0	**
	S.E.	2.0	2.2	1.7	2.5	2.5	
2.0	$\bar{X}$	17.6	17.7	18.4	19.5	19.5	**
	S.E.	2.0	2.0	1.7	2.4	2.3	
4.0	$\bar{X}$	17.0	16.9	17.7	18.7	18.3	**
	S.E.	2.0	2.0	1.7	2.4	2.4	
6.0	$\bar{X}$	15.9	15.7	16.4	17.4	17.0	*
	S.E.	1.7	1.9	1.6	2.5	2.3	
8.0	$\bar{X}$	14.6	14.2	14.9	15.8	15.4	N.S.
	S.E.	1.6	1.9	1.4	2.5	2.4	
10.0	$\bar{X}$	13.0	12.5	13.3	13.8	13.8	N.S.
	S.E.	1.6	1.7	1.3	2.4	2.4	

#significant levels: *, 0.05; **, 0.01; N.S.,not significant.

TABLE 4.4

Effect of initial espacement on diameter over bark (cm) at points along the tree bole - Expt. 106 Bowenia.

HEIGHT ABOVE GROUND (m)		INITIAL ESPACEMENT (m)					SIG#
		2.13[2]	2.44[2]	2.74[2]	3.05[2]	3.66[2]	
0.5	$\bar{X}$	24.4	26.6	27.2	28.0	29.3	**
	S.E.	2.5	2.6	2.7	3.2	2.4	
1.3	$\bar{X}$	21.8	24.0	24.5	25.0	26.5	**
	S.E.	2.2	2.2	2.3	1.8	2.6	
2.0	$\bar{X}$	20.6	22.5	23.3	23.6	24.9	**
	S.E.	1.9	2.0	2.0	2.3	2.3	
4.0	$\bar{X}$	18.2	20.2	20.8	21.3	22.4	**
	S.E.	2.2	2.0	1.8	2.8	2.5	
6.0	$\bar{X}$	16.3	18.3	18.7	19.1	20.4	**
	S.E.	1.7	2.0	2.1	2.4	2.3	
8.0	$\bar{X}$	14.3	16.2	16.8	17.1	18.3	**
	S.E.	1.7	2.1	1.8	1.9	2.4	
10.0	$\bar{X}$	12.3	14.3	14.9	15.2	16.1	**
	S.E.	1.6	1.6	1.9	1.6	2.1	

#sigificant levels: **, 0.01.

TABLE 4.5

Effect of initial espacement on diameter under bark (cm) at points along the tree bole - Expt. 106 Bowenia.

HEIGHT ABOVE GROUND (m)		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
0.5	$\bar{X}$	18.7	20.6	21.1	21.3	22.9	**
	S.E.	1.9	2.2	1.6	1.7	2.7	
1.3	$\bar{X}$	17.3	18.9	19.7	20.2	21.4	**
	S.E.	2.0	1.9	1.7	1.4	2.4	
2.0	$\bar{X}$	16.7	18.2	19.3	19.3	20.7	**
	S.E.	1.8	1.8	1.5	1.3	2.5	
4.0	$\bar{X}$	15.3	16.9	17.8	18.2	19.2	**
	S.E.	1.8	1.7	1.5	1.0	2.1	
6.0	$\bar{X}$	13.8	15.6	16.2	16.6	17.7	**
	S.E.	1.7	1.5	1.4	1.0	1.9	
8.0	$\bar{X}$	12.2	13.9	14.6	14.9	16.0	**
	S.E.	1.6	1.4	1.6	1.0	1.9	
10.0	$\bar{X}$	10.4	12.3	13.0	13.2	14.0	**
	S.E.	1.5	1.3	1.5	1.2	1.7	

#significant level: **, 0.01.

along the tree bole tends to increase with increase in initial espacement (Tables 4.6, 4.7). At Bowenia, however, the effect is not significant. Interaction effects are significant ($p < 0.05$) at 10 m above the ground at Kennedy and from 0.5 to 2.0 m above the ground at Bowenia but they were not analysed because the trends are well established.

Basal area

At both locations, basal area of all trees i.e. stand basal area, and other than select stems decreases with increase in initial espacement whereas the basal area of select stems increases (Table 4.8). The latter is a direct consequence of the effect of spacing on dbhob (Table 4.1) and the fixed stocking of select stems per hectare (250 stems ha^{-1}) in all treatmemts.

Stem taper

Stem taper[2] over and under bark at Kennedy tends to increase significantly with increase in initial espacement (Table 4.9). At Bowenia, the effect is not significant (Table 4.9) although interaction effects are significant (overbark, $p < 0.01$; underbark, $p < 0.05$). Analysis of these effects confirms that spacing does not affect taper (Appendix 3, Table A3.3).

Taper at both location is much greater over bark than under bark, and is a consequence of the thick bark

[2] Stem taper = Diameter at 1.3 m above ground − Diameter at 10 m above the ground

TABLE 4.6

Effect of initial espacement on average bark thickness (2BT)(cm) at points along the tree bole - Expt. 438 Atherton.

HEIGHT ABOVE GROUND (m)		INITIAL ESPACEMENT (m)					SIG#
		2.13[2]	2.44[2]	2.74[2]	3.05[2]	3.66[2]	
0.5	$\bar{X}$	4.9	5.6	5.3	5.9	6.2	**
	S.E.	1.0	1.3	1.0	0.98	0.95	
1.3	$\bar{X}$	4.2	4.6	4.4	4.6	4.8	N.S.
	S.E.	0.70	0.92	0.81	0.91	0.79	
2.0	$\bar{X}$	3.6	3.9	3.6	4.0	4.1	*
	S.E.	0.55	0.88	0.52	0.71	0.69	
4.0	$\bar{X}$	2.7	2.9	2.6	3.0	3.3	**
	S.E.	0.53	0.73	0.36	0.57	0.65	
6.0	$\bar{X}$	2.1	2.2	2.2	2.3	2.7	**
	S.E.	0.44	0.47	0.36	0.41	0.52	
8.0	$\bar{X}$	1.9	2.0	1.9	2.0	2.4	**
	S.E.	0.39	0.30	0.33	0.43	0.45	
10.0	$\bar{X}$	1.7	1.8	1.7	1.8	2.1	**
	S.E.	0.25	0.33	0.30	0.40	0.34	

#significant levels: *, 0.05; **, 0.01; N.S., not significant.

TABLE 4.7

Effect of initial espacement on average bark thickness (2BT)(cm) at points along the tree bole - Expt. 106 Bowenia.

HEIGHT ABOVE GROUND (m)		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
0.5	$\bar{X}$	5.6	6.0	6.0	6.6	6.4	N.S.
	S.E.	0.97	1.0	1.1	1.3	1.3	
1.3	$\bar{X}$	4.4	4.9	4.8	4.8	5.0	N.S.
	S.E.	1.0	0.97	0.84	0.84	1.0	
2.0	$\bar{X}$	3.9	4.3	4.0	4.2	4.2	N.S.
	S.E.	0.87	0.67	0.76	0.77	1.0	
4.0	$\bar{X}$	2.9	3.2	3.0	3.1	3.3	N.S
	S.E.	0.49	0.49	0.60	0.51	0.55	
6.0	$\bar{X}$	2.5	2.6	2.5	2.5	2.7	N.S.
	S.E.	0.54	0.43	0.51	0.43	0.58	
8.0	$\bar{X}$	2.1	2.3	2.2	2.2	2.3	N.S.
	S.E.	0.42	0.40	0.42	0.32	0.49	
10.0	$\bar{X}$	1.9	2.0	1.9	2.0	2.1	N.S.
	S.E.	0.36	0.30	0.41	0.27	0.31	

#significant levels: N.S.,not significant.

TABLE 4.8

Effects of initial espacement on stand basal area (m^2 ha^{-1}).

TREE TYPE		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
EXPERIMENT 438 ATHERTON							
ALL TREES	$\bar{X}$	48.8	41.9	38.3	36.7	29.1	**
	S.E.	3.3	3.2	3.0	5.2	4.0	
SELECT STEMS	$\bar{X}$	9.7	10.5	11.2	12.4	12.5	**
	S.E.	0.4	1.0	0.7	1.1	1.2	
OTHER THAN SELECT STEMS	$\bar{X}$	39.1	31.4	27.1	24.4	16.6	**
	S.E.	3.3	2.7	2.6	2.1	3.1	
EXPERIMENT 106 BOWENIA (UNTHINNED PLOTS ONLY)							
ALL TREES		54.3	49.4	45.4	39.4	33.5	-
SELECT STEMS		10.2	11.5	11.1	12.6	13.7	-
OTHER THAN SELECT STEMS		44.6	37.9	34.4	26.7	19.8	-

#significant level: **, 0.01.

TABLE 4.9

Effect of initial espacement on stem taper (cm m^{-1}).

PARAMETER		INITIAL ESPACEMENT (m)					SIG[#]
		2.13[2]	2.44[2]	2.74[2]	3.05[2]	3.66[2]	
EXPERIMENT 438 ATHERTON							
TAPER OVER BARK	$\bar{X}$	0.86	0.96	0.93	1.07	1.02	**
(cm/m)	S.E.	0.10	0.12	0.14	0.18	0.15	
TAPER UNDER BARK	$\bar{X}$	0.57	0.64	0.62	0.75	0.71	**
(cm/m)	S.E.	0.10	0.13	0.10	0.13	0.14	
EXPERIMENT 106 BOWENIA							
TAPER OVER BARK	$\bar{X}$	1.08	1.09	1.10	1.12	1.18	N.S.
(cm/m)	S.E.	0.13	0.13	0.15	0.16	0.14	
TAPER UNDER BARK	$\bar{X}$	0.79	0.76	0.77	0.80	0.84	N.S.
(cm/m)	S.E.	0.11	0.10	0.11	0.14	0.12	

[#]significant levels: N.S., not significant; **, 0.01.

along the lower bole (Tables 4.6, 4.7).

Absolute form quotient

Absolute form quotient is defined as the ratio of diameter at half tree height above breast height to the diameter at breast height and is one index of bole shape. Form quotients of 0.35, 0.5, 0.7, and 0.8 suggest solid shapes of neiloid, conoid, second degree paraboloid and third degree paraboloid respectively.

To determine average form quotient over and under bark for each spacing at each location, average diameters along the tree bole (Tables 4.2 to 4.5) were plotted against height above ground. Diameter at half tree height (average for the spacing) above breast height was then read off and the form quotient calculated. Thus, the form quotients presented relate to the mean select stem for each spacing.

Although the data are not statistically analysable, they suggest that initial spacing does not affect form quotient over or under bark at either location and that average bole shape in the two areas is similar (Table 4.10). The difference in form quotient over and under bark (FqOB < FqUB) arises from the much more rapid reduction in bark thickness than bole diameter with height above ground.

The absolute form quotients under bark suggest a bole shape somewhat less than a second degree paraboloid.

Tree and bark volume

Volume[3] of the lower tree bole (9.5 m length)

[3] Volume was calculated using Smalian's formula.

TABLE 4.10

Effect of initial espacement on absolute form quotient.

ABSOLUTE FORM QUOTIENT	INITIAL ESPACEMENT (m)				
	2.13^2	2.44^2	2.74^2	3.05^2	3.66^2
EXPERIMENT 438 ATHERTON					
FORM QUOTIENT OVER BARK	0.63	0.60	0.61	0.60	0.60
FORM QUOTIENT UNDER BARK	0.68	0.65	0.66	0.63	0.68
EXPERIMENT 106 BOWENIA					
FORM QUOTIENT OVER BARK	0.60	0.60	0.60	0.60	0.60
FORM QUOTIENT UNDER BARK	0.65	0.65	0.65	0.64	0.63

over and under bark, and bark volume, increases significantly with increase in spacing at both locations, the increase in volume at Bowenia being 2-3 times that at Kennedy (Table 4.11). These trends are a direct consequence of the effects of spacing on dbhob (Table 4.1) and height growth (Table 4.12) at the two centres.

Height growth

Total height growth at Kennedy is not significantly affected by initial espacement (Table 4.12). However, the interaction is significant ($p < 0.01$). Analysis of the interaction confirms the lack of effect of initial spacing : ranking the mean height for each plot shows no regular ordering of the initial spacings (Appendix 3, Table A3.4). In contrast, height growth at Bowenia increases significantly with increase in initial spacing (Table 4.12). Again, the interaction is significant ($p < 0.01$) and analysis of the effects confirms that, at this location, increase in initial spacing results in increased height growth (Appendix 3, Table A3.5).

Height to crown base

Height to the base of the crown, as indicated by the LGB and LGW, of all trees and select stems at Bowenia is not affected significantly by initial spacing (Table 4.13). Results for other than select stems suggest that the crown base is lower at the wider spacings. However, interaction effects are significant ($p < 0.01$) and analysis of these indicates that the effect of spacing is negligible (Appendix 3, Tables A3.6, A3.7).

TABLE 4.11

Effect of initial espacement on the volume (m^3) of the basal 9.5 m log over and under bark, and bark volume (m^3).

VOLUME		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
EXPERIMENT 438 ATHERTON							
VOLUME OVER BARK	$\bar{X}$	0.307	0.310	0.326	0.375	0.373	**
(m^3)	S.E.	0.062	0.066	0.061	0.093	0.087	
VOLUME UNDER BARK	$\bar{X}$	0.222	0.219	0.238	0.270	0.263	**
(m^3)	S.E.	0.050	0.054	0.043	0.072	0.069	
BARK VOLUME	$\bar{X}$	0.085	0.091	0.089	0.104	0.110	**
(m^3)	S.E.	0.018	0.022	0.020	0.026	0.024	
EXPERIMENT 106 BOWENIA							
VOLUME OVER BARK	$\bar{X}$	0.267	0.327	0.348	0.360	0.407	**
(m^3)	S.E.	0.055	0.060	0.066	0.046	0.088	
VOLUME UNDER BARK	$\bar{X}$	0.181	0.223	0.245	0.252	0.289	**
(m^3)	S.E.	0.041	0.044	0.042	0.031	0.064	
BARK VOLUME	$\bar{X}$	0.086	0.103	0.103	0.108	0.118	**
(m^3)	S.E.	0.021	0.021	0.027	0.021	0.032	

#significant level: **, 0.01.

TABLE 4.12

Effect of initial espacement on total height (m).

TREE TYPE		INITIAL ESPACEMENT (m)					SIG[#]
		2.13[2]	2.44[2]	2.74[2]	3.05[2]	3.66[2]	
EXPERIMENT 438 ATHERTON							
SAMPLE TREES	$\bar{X}$	20.5	20.4	20.7	20.6	20.6	N.S.
	S.E.	0.83	1.5	1.2	1.8	1.6	
EXPERIMENT 106 BOWENIA							
ALL TREES	$\bar{X}$	15.7	16.9	17.6	17.6	18.4	**
	S.E.	2.2	1.8	1.8	1.6	1.8	
SELECT STEMS	$\bar{X}$	17.2	18.7	19.0	18.7	19.4	**
	S.E.	1.6	1.0	1.1	1.1	1.0	
OTHER THAN SELECT STEMS	$\bar{X}$	15.5	16.5	17.3	17.2	17.9	**
	S.E.	2.2	1.7	1.8	1.6	1.9	

[#]significant levels: N.S., not significant; **, 0.01.

TABLE 4.13

Effects of initial espacement on height to crown base (m) - Expt. 106 Bowenia.

PARAMETER/ TREE TYPE		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
HEIGHT TO THE LGB (m)							
ALL TREES	$\bar{X}$	9.7	9.8	9.8	9.6	9.3	N.S.
	S.E.	2.0	1.5	1.6	1.4	1.5	
SELECT STEMS	$\bar{X}$	10.1	10.2	10.6	10.4	9.9	N.S.
	S.E.	1.7	1.1	1.0	1.0	1.2	
OTHER THAN SELECT STEMS	$\bar{X}$	9.6	9.7	9.6	9.3	9.0	**
	S.E.	2.1	1.6	1.7	1.4	1.6	
HEIGHT TO THE LGW (m)							
ALL TREES	$\bar{X}$	10.8	10.8	10.7	10.6	10.3	N.S.
	S.E.	1.8	1.5	1.5	1.3	1.4	
SELECT STEMS	$\bar{X}$	11.2	11.3	11.5	11.3	10.8	N.S.
	S.E.	1.6	1.2	0.83	1.1	1.1	
OTHER THAN SELECT STEMS	$\bar{X}$	10.7	10.6	10.5	10.3	10.0	**
	S.E.	1.9	1.5	1.6	1.3	1.5	

#significant levels: N.S., not significant; **, 0.01.

Crown dimensions

Crown depth[4] and green crown percent[5], based on LGB and LGW, for all trees, select stems and other than select stems increase significantly ($p < 0.01$) with increase in spacing (Tables 4.14, 4.15). Interaction effects in some cases are significant ($p < 0.01$) but analysis of these confirms the treatment effect (Appendix 3, Tables A3.8, A3.9, A3.10).

Block effects

Block effects at Kennedy are significant ($p < 0.01$) for dbhob. Analysis of these effects indicates that site quality for Block IV < Block III < Block I < Block II.

"Block" effects at Bowenia are also significant ($p < 0.01$) for most parameters measured. This could reflect effects of both differences in site and of thinning. Tree growth is better in the thinned "block" than in the unthinned "block".

---

[4] Crown depth based on LGB = Tree height − Height to LGB

Crown depth based on LGW = Tree height − Height to LGW

[5] Green crown percent based on LGB $= \dfrac{\text{Tree height} - \text{Height to LGB}}{\text{Tree height}} \times 100$

Green crown percent based on LGW $= \dfrac{\text{Tree height} - \text{Height to LGW}}{\text{Tree height}} \times 100$

TABLE 4.14

Effect of initial espacement on crown depth (m) - Expt. 106 Bowenia.

PARAMETER/ TREE TYPE		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
CROWN DEPTH (BASED ON LGB)(m)							
ALL TREES	$\bar{X}$	6.0	7.1	7.8	8.0	9.1	**
	S.E.	1.5	1.6	1.6	1.5	1.6	
SELECT STEMS	$\bar{X}$	7.1	8.5	8.4	8.4	9.4	**
	S.E.	1.4	1.3	1.4	1.4	1.2	
OTHER THAN SELECT STEMS	$\bar{X}$	5.8	6.8	7.7	7.8	9.0	**
	S.E.	1.4	1.4	1.6	1.5	1.8	
CROWN DEPTH (BASED ON LGW)(m)							
ALL TREES	$\bar{X}$	4.9	6.2	6.9	7.0	8.1	**
	S.E.	1.2	1.5	1.5	1.5	1.5	
SELECT STEMS	$\bar{X}$	6.0	7.4	7.4	7.4	8.6	**
	S.E.	1.2	1.2	1.3	1.3	1.2	
OTHER THAN SELECT STEMS	$\bar{X}$	4.8	5.9	6.8	6.9	7.9	**
	S.E.	1.2	1.4	1.5	1.6	1.6	

#significant level: **, 0.01.

TABLE 4.15

Effect of initial espacement on green crown percent (%) - Expt. 106 Bowenia.

PARAMETER/ TREE TYPE		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
GREEN CROWN PERCENT (BASED ON LGB)(%)							
ALL TREES	$\bar{X}$	38.6	42.0	44.4	45.3	49.5	**
	S.E.	9.0	7.9	7.6	7.2	7.3	
SELECT STEMS	$\bar{X}$	41.3	45.4	44.2	44.6	48.7	**
	S.E.	7.8	6.1	5.9	5.9	5.9	
OTHER THAN SELECT STEMS	$\bar{X}$	38.1	41.1	44.4	45.5	49.9	**
	S.E.	9.1	8.0	8.1	7.7	7.9	
GREEN CROWN PERCENT (BASED ON LGW)(%)							
ALL TREES	$\bar{X}$	31.5	36.3	39.2	39.7	44.0	**
	S.E.	7.0	7.5	7.1	7.3	6.7	
SELECT STEMS	$\bar{X}$	34.8	39.6	39.1	39.6	44.1	**
	S.E.	6.5	6.1	5.0	6.0	5.5	
OTHER THAN SELECT STEMS	$\bar{X}$	30.9	35.5	39.2	39.8	43.9	**
	S.E.	7.0	7.6	7.5	7.8	7.3	

#significant level: **, 0.01.

4.2 BRANCH CHARACTERISTICS

Branch age

As discussed in Chapter 3 (Methods), age of the branches in the LGW was determined using two methods viz., counting rings on surface to pith stem cores and interpolation from height-age curves. Branch age determined from the stem cores generally exceeded that derived from the height-age curves (Table 4.16), the average difference being slightly less than 1 year (Table 4.17). The discrepancy between the two estimates is due to the difficulty experienced in distinguishing between true and false growth rings on the stem cores. This difficulty was compounded by the small diameter of the cores and the fact that the cores were only surface to pith rather than surface to surface. Hence, ages derived from the height-age curves are considered to be more accurate. These data indicate that branch age does not differ significantly with spacing (Table 4.18). However, there is a significant "block" effect ($p < 0.05$), the age of branches for the unthinned plots ($\bar{x}$ = 5.0 years) being less than for the thinned plots ($\bar{x}$ = 5.2 years) (Table 4.17).

Branch growth

Branch diameter, length and potential knot

TABLE 4.16

Distribution of differences in branch age (age ex height-age curve minus age ex stem core) - Expt. 106 Bowenia.

DIFFERENCE (years)	-1	0	+1	+2	+3
NUMBER OF TREES	4	34	40	21	1

TABLE 4.17

The differences between using height-age curves to estimate branch age (years) and stem cores on an individual plot basis - Expt. 106 Bowenia.

INITIAL ESPACEMENT (m)	PLOT NO.	THINNING STATUS#	AGE FROM STEM CORES (years)	AGE FROM HEIGHT-AGE CURVES (years)	AGE DIFFERENCE (years)
2.13^2	5	U	5.7	4.8	- 0.9
	13	T	5.4	5.0	- 0.4
2.44^2	8	U	5.6	5.0	- 0.6
	6	T	5.8	5.4	- 0.4
2.74^2	3	U	6.2	4.7	- 1.5
	7	T	5.9	5.4	- 0.5
3.05^2	20	U	6.3	5.2	- 1.1
	2	T	6.2	5.1	- 1.1
3.66^2	1	U	6.2	5.2	- 1.0
	4	T	6.1	5.3	- 0.8
				$\bar{X}$	- 0.8

#U - Unthinned, T = Thinned.

TABLE 4.18

Effect of initial espacement on branch growth - Expt. 106 Bowenia.

PARAMETER		INITIAL ESPACEMENT (m)					SIG[#]
		2.13[2]	2.44[2]	2.74[2]	3.05[2]	3.66[2]	
BRANCH DIAMETER	$\bar{X}$	2.24	2.31	2.57	2.60	2.82	**
(cm)	S.E.	0.54	0.49	0.70	0.64	0.81	
BRANCH ANGLE	$\bar{X}$	67.0	65.0	69.4	69.6	64.4	*[$]
(degrees)	S.E.	12.7	12.4	14.6	11.5	12.1	
BRANCH LENGTH	$\bar{X}$	2.04	2.37	2.45	2.58	2.77	**
(m)	S.E.	0.52	0.28	0.49	0.56	0.62	
BRANCH AGE	$\bar{X}$	4.9	5.2	5.0	5.2	5.2	N.S.
(years)	S.E.	0.41	0.27	0.47	0.34	0.41	
NEEDLE FLUSHES PER BRANCH	$\bar{X}$	3.8	4.2	4.6	4.2	4.4	-
NUMBER OF BRANCHES IN LGW							
ALIVE	$\bar{X}$	3.35	3.25	3.15	3.35	3.65	-
DEAD	$\bar{X}$	0.55	0.30	0.60	0.30	0.50	-
TOTAL	$\bar{X}$	3.90	3.55	3.75	3.65	4.15	-

[#]significant levels: N.S., not significant; *, 0.05; **, 0.01.

[$]BRANCH ANGLE

3.66[2]	2.44[2]	2.13[2]	2.74[2]	3.05[2]
64.4	65.0	67.0	69.4	69.6

sectional area[6] increase significantly with increase in spacing (Tables 4.18, 4.19) while the effect on branch angle is significant ($p < 0.05$) but erratic (Table 4.18). Interaction for branch angle is significant ($p < 0.05$) and analysis confirms an inconsistent relationship between spacing and branch angle (Appendix 3, Table A3.11).

The number of needle flushes on the primary branch of the LGW shows no consistent trend with spacing and the number of live, dead and total branches in the LGW appear to be independent of spacing (Table 4.18). This suggests that the number of branches is largely under genetic control.

The condition of the terminal bud on branches in the LGW shows no consistent relationship with spacing (Table 4.20). Of the 12 branches observed to have dead terminal buds, 11 appeared to have their buds broken off. However, each of these had recently initiated a new lateral shoot a couple of centimetres back from the broken tip. In each case, this lateral shoot seem to be taking over

---

[6] Potential knot sectional area was calculated from measurements of branch diameter and angle assuming that knots in sawn timber are elliptical in shape:-

Potential knot sectional area (cm^2) = $\pi \frac{ab}{4}$

where a = the major axis of the ellipse or knot length (cm) where knot length = $\frac{\text{branch diameter}}{\text{sine(branch angle)}}$

and b = the minor axis of the ellipse or branch diameter (cm).

TABLE 4.19

Effect of initial espacement on potential knot sectional area (cm^2) - Expt. 106 Bowenia.

PARAMETERS		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
KNOT LENGTH (cm)	$\bar{X}$	2.55	2.67	2.96	2.89	3.27	**
	S.E.	0.86	0.77	1.27	0.88	1.26	
POTENTIAL KNOT SECTIONAL AREA (cm^2)	$\bar{X}$	4.82	5.10	6.60	6.32	7.92	**
	S.E.	2.8	2.4	4.9	3.6	5.3	

#significant level: **, 0.01.

TABLE 4.20

Effect of initial espacement on branch terminal bud condition - Expt. 106 Bowenia.

BRANCH TERMINAL AND CONDITION	INITIAL ESPACEMENT (m)					TOTAL BRANCHES
	2.13²	2.44²	2.74²	3.05²	3.66²	
ALIVE AND HEALTHY	14	15	19	15	18	81
ALIVE BUT UNHEALTHY	4	0	0	2	1	7
DEAD	2	5	1	3	1	12

the role of the primary branch suggesting that these branches in the lower crown are not yet moribund.

Although branch length increases significantly with increase in initial spacing, the lateral overlap of branches in the lower crowns of adjacent trees decreases significantly (Table 4.21) reflecting the lesser competition found in stands planted at wider initial spacing.

4.2.1 Branch Relationships

(i) Branch length and diameter

Branch length and diameter at the base of the branch are linearly related (Figure 4.1), the relationship derived being:

$$\underset{\text{(cm)}}{\text{Branch length}} = 0.3004 + \underset{(0.0449)}{0.8603}\ \underset{\text{(cm)}}{\text{Branch diameter}} \qquad (r^2 = 0.7927)$$

(ii) Branch angle and diameter

Relationships derived by regression for Honduras pine in this study are presented in Table 4.22 and Figure 4.2. There is a strong tendency for larger branches to be displayed at more acute angles to the main stem.

(iii) Branch diameter and tree size

The mean diameter of branches in the LGW is correlated with tree dbhob but the relationship is weak (Figure 4.3).

4.3 CROWN RELATIONSHIPS

(i) Crown depth and tree diameter

Initial espacement influences crown depth (Table 4.14) which in turn affects tree size (Whyte, 1970).

TABLE 4.21

Effect of initial espacement on crown overlap (%) - Expt. 106 Bowenia.

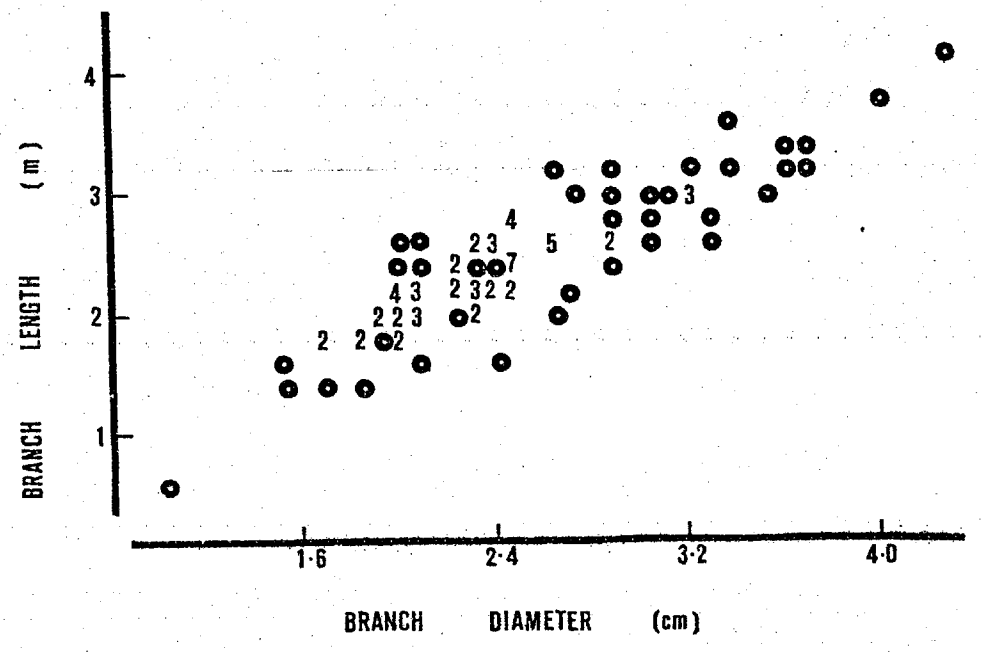
PARAMETER		INITIAL ESPACEMENT (m)					SIG#
		2.13²	2.44²	2.74²	3.05²	3.66²	
BRANCH LENGTH / INITIAL ESPACEMENT (%)	$\bar{X}$	96	97	89	85	76	**
	S.E.	24	11	18	18	17	
CROWN OVERLAP$	$\bar{X}$	91	94	75	69	51	**
	S.E.	48	23	36	36	34	

#significant level: **, 0.01.

$$\$\text{CROWN OVERLAP}(\%) = \left[2\left(\frac{\text{BRANCH LENGTH}}{\text{INITIAL ESPACEMENT}}\right)100\right] - 100$$

FIGURE 4.1

Plot of branch length (m) against branch diameter (cm) - Expt. 106 Bowenia.



(The numbers in the plot indicate the number of points that occur at that spot.)

TABLE 4.22

Relationships between branch angle (degrees) and branch diameter (cm) - Expt. 106 Bowenia.

INITIAL ESPACEMENT (m)	MODEL	r^2
ALL SPACINGS COMBINED	ANGLE = 91.72 - 9.961 DIAMETER (0.8569)	0.2893
2.13^2	ANGLE = 97.67 - 13.82 DIAMETER (2.275)	0.3622
2.44^2	ANGLE = 104.1 - 16.94 DIAMETER (2.440)	0.4336
2.74^2	ANGLE = 102.4 - 13.20 DIAMETER (1.988)	0.4195
3.05^2	ANGLE = 99.09 = 11.51 DIAMETER (1.770)	0.3979
3.66^2	ANGLE = 81.90 - 6.186 DIAMETER (1.543)	0.1845

Relationships derived by regression for Honduras pine in this study are presented in Table 4.23.

4.4 INFLUENCE OF ORIENTATION ON BRANCH GROWTH

One-way analysis of variance was used to test whether the orientation of branches in the LGW affects their growth and angle of insertion in the bole. Orientation was assessed on an octant basis as described earlier (Chapter 3). The analysis was applied firstly to the grouped data (all spacings combined) and then separately to each spacing.

FIGURE 4.2

Plot of the linear regression lines representing the regression models for branch angle (degrees) and branch diameter (cm) outlined in Table 4.22 - Expt. 106 Bowenia.

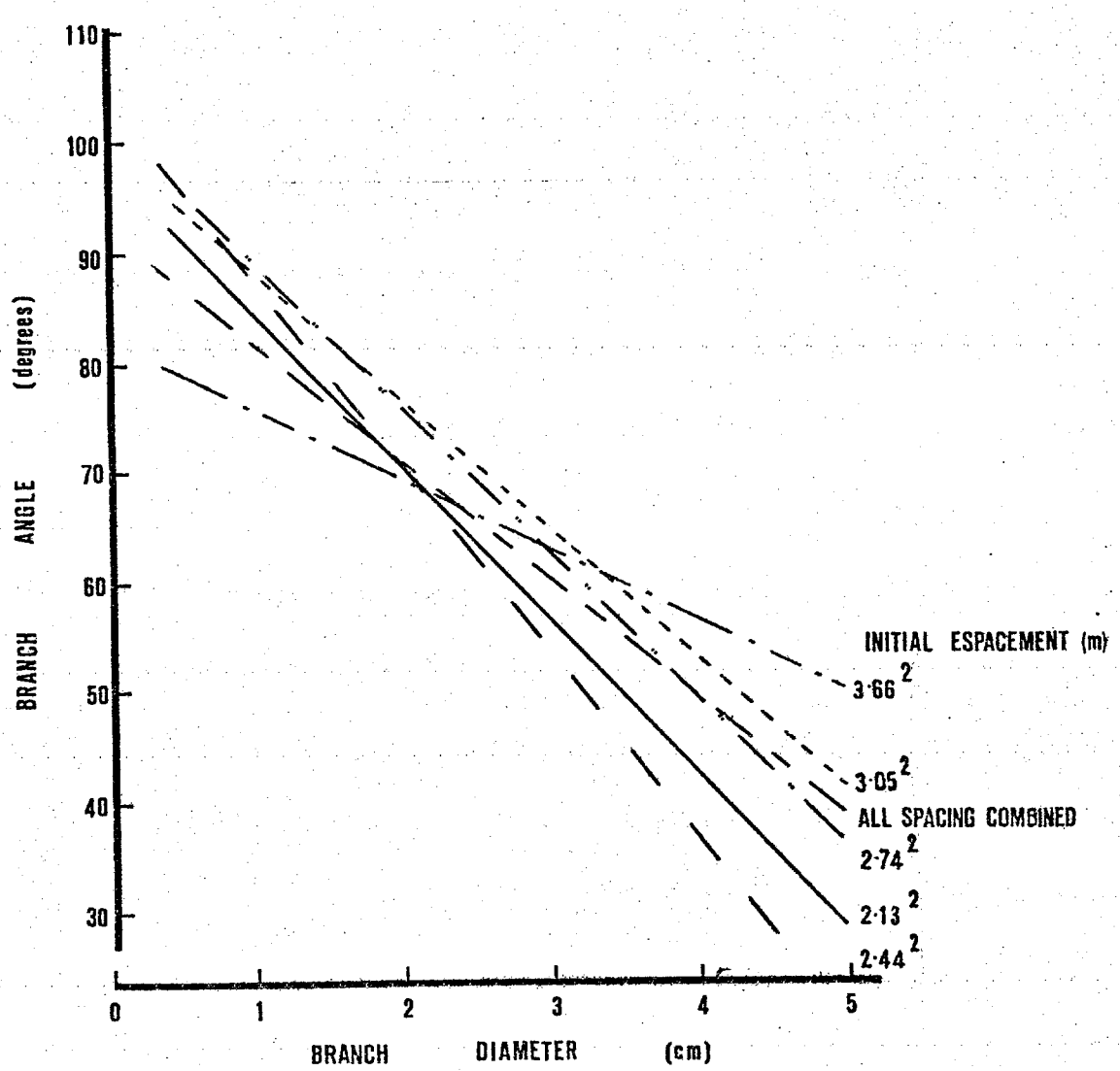
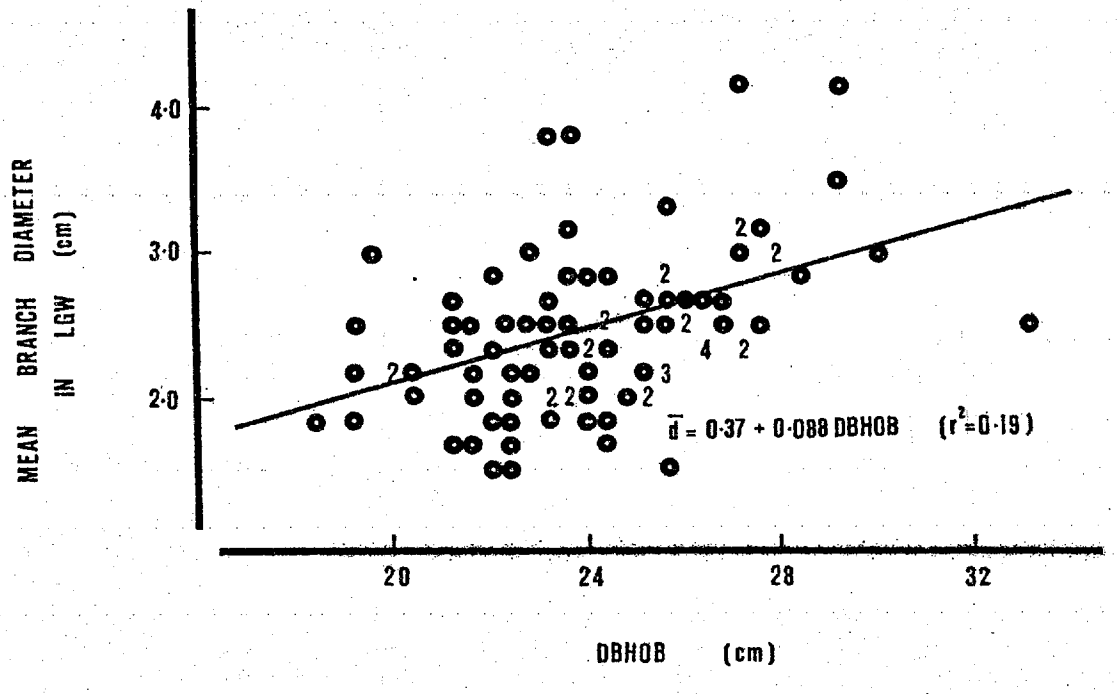


FIGURE 4.3

Plot of mean branch diameter in LGW (cm) against dbhob (cm) showing the derived linear regression line and model - Expt. 106 Bowenia.



(The numbers in the plot indicate the number of points that occurs at that spot.)

TABLE 4.23

Relationships between dbhob, crown depth
crown depth and initial espacement - Expt. 106 Bowenia.

TREE TYPE	MODEL	r^2
CROWN DEPTH BASED ON LGB		
ALL TREES	$D^* = 4.902 + 1.248\ s^{2*} + 1.627\ c^* - 0.09160\ s^2 \times c$ $(0.1515) \quad (0.1420) \quad (0.01800)$	0.5075
SELECT STEMS	$D = 13.51 + 0.9220\ s^2 + 0.9368\ c - 0.06360\ s^2 \times c$ $(0.2281) \quad (0.2730) \quad (0.03229)$	0.3682
OTHER THAN SELECT STEMS	$D = 6.549 + 1.099\ s^2 + 1.285\ c - 0.06840\ s^2 \times c$ $(0.1600) \quad (0.1551) \quad (0.01958)$	0.4888
CROWN DEPTH BASED ON LGW		
ALL TREES	$D = 5.918 + 1.137\ s^2 + 1.780\ c - 0.09620\ s^2 \times c$ $(0.1398) \quad (0.1504) \quad (0.01889)$	0.5185
SELECT STEMS	$D = 14.39 + 0.8304\ s^2 + 0.9674\ c - 0.06245\ s^2 \times c$ $(0.2628) \quad (0.2882) \quad (0.03310)$	0.3655
OTHER THAN SELECT STEMS	$D = 7.204 + 1.024\ s^2 + 1.438\ c - 0.07412\ s^2 \times c$ $(0.1499) \quad (0.1668) \quad (0.02106)$	0.5010

*where D = dbhob (cm) ; s = initial espacement (m) ; c = crown depth (m)

Branches growing on the northern side (octants 1, 6, 7 and 8) of the tree tend to be thicker (Table 4.24; Appendix 4, Table A4.1), be at a more acute angle to the stem (Table 4.24; Appendix 4, Table A4.2), produce larger knots (Table 4.24; Appendix 4, Table A4.3), and be longer (Table 4.24) than those growing on the southern side (octants 2, 3, 4 and 5). These findings apply to all initial spacings.

Also, branches growing on the northern side of the tree have more flushes of needles than branches on the southern side (Table 4.24). This supports the finding that a northerly aspect favours branch growth.

The total number of branches produced on each side of the tree is similar (Table 4.24; Appendix 4, Table A4.4) but the number of live branches on the northern side tends to exceed that on the southern side (Table 4.24; Appendix 4, Table A4.5) as there is a tendency for branch death to occur first on the southern side (Table 4.24; Appendix 4, Table A4.6).

4.5 POINT DENSITY

Mean point density in unthinned plots at both Kennedy and Bowenia decreases as spacing increases (Table 4.25) whereas in the thinned plots at Bowenia, it is relatively constant reflecting the uniform thinning prescription applied (Appendix 2). However the range of point density estimates at a given spacing (thinned or unthinned) is considerable indicating that competition within a stand is not uniform despite a fixed initial spacing.

Attempts to use point density to help explain

TABLE 4.24

Effect of orientation on branch growth - Expt. 106 Bowenia.

BRANCH PARAMETER		INITIAL ESPACEMENT (m)					ALL SPACINGS COMBINED
		2.13²	2.44²	2.74²	3.05²	3.66²	
DIAMETER (cm)							
NORTH SIDE	$\bar{X}$	2.41	2.49	2.84	2.68	2.94	2.62
SOUTH SIDE	$\bar{X}$	2.08	2.23	2.46	2.55	2.77	2.39
ANGLE (degrees)							
NORTH SIDE	$\bar{X}$	66.4	64.8	67.0	68.8	64.0	66.2
SOUTH SIDE	$\bar{X}$	67.4	64.5	71.2	70.4	64.6	67.8
POTENTIAL KNOT SECTIONAL AREA (cm^2)							
NORTH SIDE	$\bar{X}$	5.46	5.73	7.26	6.78	8.37	6.68
SOUTH SIDE	$\bar{X}$	4.23	4.78	5.76	6.00	7.79	5.66
LENGTH (m)							
NORTH SIDE	$\bar{X}$	2.20	2.47	2.65	2.64	3.07	2.62
SOUTH SIDE	$\bar{X}$	1.88	2.33	2.25	2.51	2.46	2.27
NUMBER OF NEEDLE FLUSHES							
NORTH SIDE	$\bar{X}$	4.0	4.7	5.0	4.2	4.5	4.4
SOUTH SIDE	$\bar{X}$	3.7	4.2	4.8	4.1	4.2	4.0
NUMBER OF BRANCHES							
(i) TOTAL NUMBER							
NORTH SIDE	$\bar{X}$	1.90	1.75	1.75	1.95	2.05	1.91
SOUTH SIDE	$\bar{X}$	2.00	1.80	1.70	1.70	2.10	1.89
(ii) NUMBER ALIVE							
NORTH SIDE	$\bar{X}$	1.65	1.55	1.70	1.80	1.90	1.72
SOUTH SIDE	$\bar{X}$	1.70	1.70	1.45	1.55	1.75	1.63
(iii) NUMBER DEAD							
NORTH SIDE	$\bar{X}$	0.25	0.20	0.20	0.15	0.15	0.19
SOUTH SIDE	$\bar{X}$	0.30	0.10	0.40	0.15	0.35	0.26

some of the variation in this study proved unsuccessful as the *beta* coefficients for the point density estimates in the regression equations tended not to be significantly different from zero.

TABLE 4.25

Mean point density (m^2ha^{-1}) for each initial espacement.

	INITIAL ESPACEMENT (m)				
	2.13^2	2.44^2	2.74^2	3.05^2	3.66^2
EXPERIMENT 438 ATHERTON - ALL PLOTS					
$\bar{X}$	40.3	34.6	33.1	35.7	26.9
RANGE	24.9-59.1	22.8-48.6	19.4-49.2	19.1-49.2	15.8-39.2
EXPERIMENT 106 BOWENIA - UNTHINNED PLOTS					
$\bar{X}$	47.8	40.2	39.1	32.4	31.2
RANGE	40.3-53.2	24.9-53.0	31.2-44.1	25.6-38.2	24.4-38.4
EXPERIMENT 106 BOWENIA - THINNED PLOTS					
$\bar{X}$	31.7	25.0	30.0	27.5	29.7
RANGE	17.7-39.6	17.9-34.5	22.3-40.9	18.2-31.8	24.2-34.9

5. DISCUSSION

5.1 INTRODUCTION

The findings of this study are not new in principle but they are specific to Honduras pine on the sites described. Of particular interest is (a) how initial espacement affects the growth of select stems, which are the final crop trees and the ones which will largely determine the revenue obtained from the rotation, and (b) how responses to initial spacing differ between Kennedy and Bowenia.

At any location, tree growth is influenced by a large number of environmental factors, the most important ones being light, water, temperature, mineral supply, composition of the atmosphere above and below ground, soil physical and chemical properties, insects, other plants and various animals (Kozlowski, 1971). According to Larson (1963) the effects of "site" are extremely complex and not easily evaluated. Tree diameter and height growth, stem taper, bark thickness, crown dimensions, branch size and other tree characteristics have all been shown to be affected by site quality (MacDonald, 1933; Larson, 1963; Sutton, 1968).

Additional to site effects in this study is the influence of geographic location which is difficult, if not impossible, to evaluate since the factors contributing to tree growth in widely separated areas cannot be adequately compared and appraised (Larson, 1962). Kennedy is the more tropical of the two sites in this study being separated from Bowenia by 5° 40' of latitude. Perhaps differences in

photoperiod between the two locations could be one of the more important locality differences.

In addition to the environmental influences, the genetic source of seed used at each location differs. Seed batch R72P used at Bowenia is considered to be of higher genetic quality than batch R70P used at Kennedy (T. Spidy, 1980, pers. comm.).

Thus, for the two locations, the initial espacement effects are the expression of the trees' particular genetic constitutions under environmental factors which are influencing growth to different degrees.

5.2 DIAMETER GROWTH

Initial spacing has considerable influence on diameter growth and in all studies reported in the literature, mean dbhob increases with increase in initial spacing (Sjolte-Jørgensen, 1967; Evert, 1971).

Mean dbhob of select stems at the closest spacing (2.13^2 m)[1] is comparable at both locations i.e. 21.6 cm at Kennedy and 21.9 cm at Bowenia. However, at the four wider spacings, diameter growth at Bowenia is 2 to 8 per cent greater than at Kennedy (Table 4.1).

The wider the initial espacement the greater the potential growing space per tree. Thus,at these wider spacings, diameter growth is much less restricted. As a consequence of this, the proportion of larger sized logs, and hence the value of thinnings and the final crop, is increased (Miller and Maki, 1967; Sutton, 1968). The effect of initial

---

[1] 2.13^2 m refers to an initial espacement of 2.13 m × 2.13 m. Similar terminology is used for the other initial spacings.

espacement on the number and proportion of large trees at Kennedy and Bowenia is presented in Table 5.1. A notable feature of this table is that for a given spacing/stocking (trees ha^{-1}), the range of tree sizes at Bowenia is much less than that at Kennedy, particularly at the wider spacings e.g. the ranges in dbhob for the 3.66^2 m spacing are 24 cm and 15 cm at Kennedy and Bowenia respectively. This implies that a more uniform piece size may be available from silvicultural operations at Bowenia than at Kennedy.

5.3 HEIGHT GROWTH

Depending on the species and the site quality, height growth can be affected in any of five ways by initial spacing (Section 2.2) but it is most often claimed that height growth is affected at the extremes of stand density (Smith, 1962). This is certainly not the case at Bowenia where select stems at 3.66^2 m spacing are 11 per cent taller than those at 2.13^2 m spacing (Table 4.12). For other than select stems the increase in height is 13 per cent. At Kennedy, however, the effect of initial spacing on height growth is negligible (Table 4.12). As for many species, such as red pine (*Pinus resinosa* Ait.) (Stiell and Berry, 1977), there does not appear to be any consistent pattern relating height growth and initial spacing for Honduras pine in North Queensland.

5.4 VOLUME PRODUCTION

Effects of initial spacing and location on volume production are most important since the major management objective of Honduras pine plantations is wood production.

At age 11 - 12 years, mean volume under bark

TABLE 5.1

Effect of initial espacement on the number and percentage of trees per hectare greater than a specified dbhob (cm).

dbhob (cm)	INITIAL ESPACEMENT (m)									
	2.13²		2.44²		2.74²		3.05²		3.66²	
EXPERIMENT 438 ATHERTON										
	No.	%	No.	%	No.	%	No.	%	No.	%
6.5	1898	100	1440	100	1172	100	961	100	680	100
9.5	1862	98	1422	99	1165	99	954	99	677	100
12.5	1741	92	1350	94	1132	97	947	98	674	99
15.5	1459	77	1182	82	1023	87	908	94	666	98
18.5	834	44	842	58	796	68	815	85	605	89
21.5	260	14	364	25	446	38	517	54	483	71
24.5	59	3	78	5	132	11	236	24	221	32
27.5	-	-	3	0.2	10	0.8	56	6	51	8
30.5	-	-	-	-	-	-	7	0.7	3	0.4
EXPERIMENT 106 BOWENIA - UNTHINNED PLOTS ONLY										
	No.	%	No	%	No.	%	No.	%	No.	%
6.5	2029	100	-	-	-	-	-	-	-	-
9.5	2016	99	1515	100	1315	100	-	-	-	-
12.5	1977	97	1480	98	1275	97	-	-	-	-
15.5	1600	79	1375	91	1222	93	916	100	-	-
18.5	768	38	967	63	1023	78	903	99	676	100
21.5	208	10	536	35	531	40	664	72	629	93
24.5	39	2	186	12	133	10	279	30	350	52
27.5	-	-	23	2	-	-	53	6	117	17
30.5	-	-	-	-	-	-	-	-	35	5
33.5	-	-	-	-	-	-	-	-	12	2

of the basal 9.5 m section of select stems (which represents some 80 to 90 per cent of the tree's volume and value) increases from 0.222 m^3 (55.5 m^3 ha^{-1}) at 2.13[2] m to 0.263 m^3 (65.8 m^3 ha^{-1}) at 3.66[2] m at Kennedy, while at Bowenia the increase is from 0.181 m^3 (45.2 m^3 ha^{-1}) to 0.289 m^3 (72.2 m^3 ha^{-1}). This represents an increase of 15 per cent at Kennedy and 37 per cent at Bowenia i.e. an increased response at Bowenia of more than double that at Kennedy (Table 4.11).

The reason for this is not known and it warrants further investigation. Site index at Kennedy is slightly better than at Bowenia (based on top heights at the same age - Table 4.12) but growth in basal area is better at Bowenia (Table 4.8) which, presumably, more than compensates for the lower height growth at this centre. The differences in volume response, for whatever reason, suggest that adopting a common silvicultural practice for plantations in the two areas may be unsound.

5.5 STEM TAPER

The rate of taper in the lower tree bole increases with increasing initial spacing at Kennedy (cf. Hamilton and Christie (1974) for Scots pine (*Pinus silvestris*, Euc.)) but the effect at Bowenia is negligible (Table 4.9). Despite this, select stems at Kennedy taper less than those at Bowenia.

As a general rule, the larger and more vigorous the crown the faster the taper, and vice versa (Anderson, 1958; Larson, 1963). At Bowenia, crown depth increases with increasing initial spacing (Table 4.14) and stem taper

would be expected to increase accordingly. The reason it does not is possibly explained by the fact that height to the crown base at Bowenia is not significantly affected by initial spacing (Table 4.13). This again is unusual. Normally, branches at the base of the crowns of trees at wider spacings remain alive longer thus slowing down the upward recession of the crown. At Bowenia, however, the recession rate appears to be approximately uniform for all initial spacings as branch age in the LGW does not differ significantly (Table 4.18) and the differences in crown depth are due predominantly to the increase in height with increase in initial spacing (Figure 5.1).

Luckoff (1964 (cited in Slee and Nikles, 1968)) in Africa, and Slee and Nikles (1968) in southern Queensland found that the more tropical the locality the more slender the form (i.e. lower height/girth ratio) of Honduras pine. This is not supported by the results of this study; trees at the more tropical Kennedy site being less slender (Table 5.2).

Slee and Nikles (1968) suggest that one explanation for the latitudinal effect evident in their results could be that different patterns of growth in the different environments result in different early and latewood deposition. I have no evidence to suggest that differences in patterns of growth due to latitude are a plausible explanation for the results observed in this study.

5.6 ABSOLUTE FORM QUOTIENT

The finding that absolute form quotient of select stems at each location is essentially the same and that initial

FIGURE 5.1

Effects of initial espacement (m) on tree height (m), height to crown base (m) and crown depth (m) - Expt. 106 Bowenia.

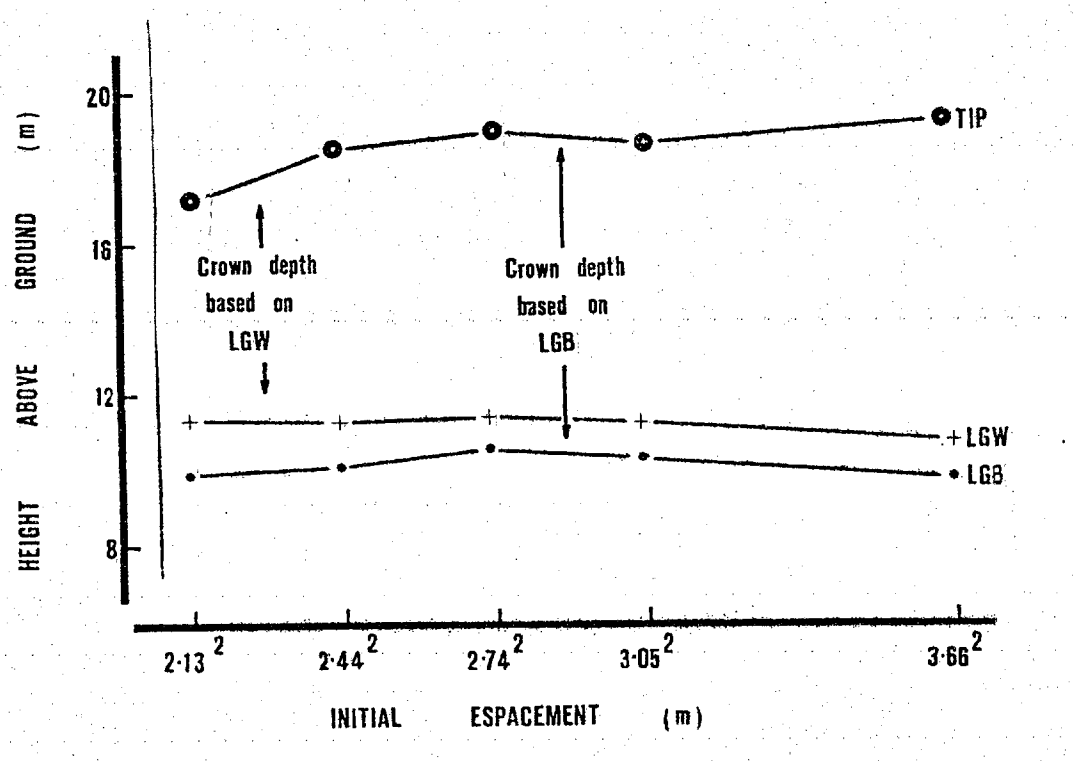


TABLE 5.2

Effect of initial espacement on tree height/girth ratio (m cm^{-1}).

	INITIAL ESPACEMENT (m)				
	2.13^2	2.44^2	2.74^2	3.05^2	3.66^2
EXPERIMENT 438 ATHERTON					
$\bar{X}$	0.293	0.288	0.287	0.263	0.265
EXPERIMENT 106 BOWENIA					
$\bar{X}$	0.250	0.249	0.249	0.242	0.233

spacing has no effect on form quotient of the bole at either centre (Table 4.10) possibly reflects the young age of the stands in question. Bramble, Cope and Chisman (1949) found for red pine at 11 years of age that initial spacing had very little effect on absolute form quotient, but the effect at 16 and 25 years of age was quite marked. This suggests that the form of the trees at Kennedy and Bowenia should be reassessed in the late 1980's.

5.7 BRANCH GROWTH

Both initial spacing and branch orientation affect branch growth at Bowenia. The wider the initial spacing, the larger the branches while for a given spacing branch growth is favoured on the northern side of a tree (Tables 4.18, 4.24).

Measurements of branch diameter at Kennedy (Expt. 438 Atherton) were recorded by R. Reilly of the Queensland Department of Forestry in July, 1979 by measuring dob of all branches in the whorl nearest to the 7 m mark

above the ground on 5 select stems per plot. He defined a whorl as having 3 or more branches. All branches measured were dead due to scorching by fire in April, 1979. Taking into account that some shrinkage would have occurred before they were measured, average branch diameter at Kennedy appears to be similar to that at Bowenia (Table 5.3).

TABLE 5.3

Effect of initial espacement on branch diameter (cm).

INITIAL ESPACEMENT (m)					SIG#
2.13²	2.44²	2.74²	3.05²	3.66²	
EXPERIMENT 438 ATHERTON$					
2.03	2.20	2.22	2.45	2.56	**
EXPERIMENT 106 BOWENIA					
2.24	2.31	2.57	2.60	2.82	**

significant level: **, 0.01

N.B. values not underlined by the same line are significantly different at 0.05 .

$ after Reilly (1979).

At Bowenia, 79 per cent of the variation in branch diameter is associated linearly with branch length (Section 4.2.1) A similar finding was made by Smith (1961) for Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco). He established that 75 per cent of the variation was explained and suggested that the best cultural control of knot size could be achieved by manipulation of crown width.

The death and/or loss of the terminal buds of

primary branches at Bowenia (Table 4.20) could have been caused by abrasion by branches of neighbouring trees. Windsway, which is a form of natural side pruning, affects branch length and has been found to limit crown spread in both red pine and radiata pine (Beckhuis, 1965; Stiell, 1966).

For a number of pine species, branch angle and diameter are negatively correlated. For radiata pine planted in the A.C.T. at 3.66² m spacing, Jacobs (1938) established the relationship[2]:

$$\text{Branch angle (degrees)} = 92.5 - 7.283 \text{ Branch diameter (cm)} \qquad (r^2 = 0.4096)$$

The relationship for Honduras pine planted at 3.66² m spacing at Bowenia has a *beta* coefficient for branch diameter which is similar to the one in Jacobs' relationship (Table 4.22). Since the regression constant at Bowenia is less than that for radiata pine, branches of similar diameter are displayed at less acute angles to the stem in Jacobs' sample of radiata pine than are those of Honduras pine at Bowenia.

5.8 WOOD QUALITY

One important consequence of the effect of initial spacing and branch orientation on branch growth is the influence on knot size. At Bowenia, a 39 per cent increase in the potential mean sectional area of knots occurs with increase in spacing from 2.13² m to 3.66² m (Table 4.19).

---

[2] This relationship is the metric conversion of the original imperical relationship: Branch angle = 18.5 - 0.37 Branch diameter, where branch angle is in units of 5 degrees and branch diameter is in tenths of inches.

Grade study results for radiata pine have shown consistently that the pattern of growth and development, particularly of branches, in the first ten years of tree life determines most of the monetary value of the final crop (Fenton, 1971). Silvicultural operations such as wide initial spacings and heavy early thinnings applied before crowns begin to recede under competition are particularly significant in affecting wood quality in the lower stem; later thinnings are important only in so far as they affect knot size in wood cut from the green crown (Brazier, 1977).

Some indication[3] of the effects of initial spacing and knot size on wood quality of select stems of Honduras pine grown at Bowenia are presented in Table 5.4 (Appendix 5 summarises the visual grading rules applicable to Honduras pine). Within each timber grade, the percentage of knots which are less than the maximum allowable size for each piece dimension, decreases as initial spacing increases but there appears to be little difference between the 2.44^2 m and 3.05^2 m spacings.

Data in Table 5.4 suggest that very little of the Honduras pine timber grown at Bowenia might make the F11 grade. In the Brisbane market, however, although F11 grade Honduras pine timber for structural purposes is available it is not generally sold as such (Forest Products Marketing, Brisbane, November, 1980. pers. comm.). Structural timber,

---

[3] This is a very conservative indication of the effect of initial spacing and knot size on Honduras pine wood quality. Firstly, branch diameter which was used to indicate knot size was measured 5 cm from the branch junction with the stem and it was measured overbark. Secondly, the branch encased in the stem is not of a uniform diameter but tapers off, rather like a sharpened pencil point, so boards cut from nearer the centre of the tree have smaller knots. Thirdly, only the effects of knots from live branches were examined and fourthly, select stems have been pruned to 5.2 m.

TABLE 5.4

Effect of initial espacement on the percentage of knots which are less than the maximum allowable knot size for each timber piece dimension in each timber grade for timber used for structural purposes - Expt. 106 Bowenia.

MINIMUM SEASONED TIMBER DIMENSIONS (mm)	APPLICABLE FACE OR EDGE#	STRUCTURAL GRADE NO. 1 (F11)						STRUCTURAL GRADE NO. 2 (F8)					
		MAXIMUM ALLOWABLE KNOT SIZE (mm)	INITIAL ESPACEMENT (m)					MAXIMUM ALLOWABLE KNOT SIZE (mm)	INITIAL ESPACEMENT (m)				
			2.13	2.44	2.74	3.05	3.66		2.13	2.44	2.74	3.05	3.66
19	W	5	-	-	-	-	-	6	-	-	-	-	-
19	T	5	-	-	-	-	-	8	-	-	-	-	-
35	W	9	-	-	-	-	-	12	1	6	2	-	3
35	T	9	-	-	-	-	-	14	6	6	3	-	6
45	W	11	1	3	2	-	3	15	10	6	6	2	7
45	T	11	1	3	2	-	3	18	22	14	10	8	8
70	W	18	22	14	10	8	8	23	63	49	39	42	26
70	T	18	22	14	10	8	8	28	89	89	71	65	53
90	W	23	63	49	39	42	26	30	91	97	78	78	68
90	T	23	63	49	39	42	26	36	100	100	90	92	85

MINIMUM SEASONED TIMBER DIMENSIONS (mm)	APPLICABLE FACE OR EDGE#	STRUCTURAL GRADE NO. 3 (F7)						STRUCTURAL GRADE NO. 4 (F5)					
		MAXIMUM ALLOWABLE KNOT SIZE (mm)	INITIAL ESPACEMENT (m)					MAXIMUM ALLOWABLE KNOT SIZE (mm)	INITIAL ESPACEMENT (m)				
			2.13	2.44	2.74	3.05	3.66		2.13	2.44	2.74	3.05	3.66
19	W	8	-	-	-	-	-	10	1	2	-	-	3
19	T	10	1	2	-	-	3	11	1	3	2	-	3
35	W	14	6	6	3	-	6	18	22	14	10	8	8
35	T	18	22	14	10	8	8	21	42	32	26	29	19
45	W	18	22	14	10	8	8	23	63	49	39	42	26
45	T	23	63	49	39	42	26	27	86	82	71	63	48
70	W	28	89	89	71	65	53	35	100	100	88	89	84
70	T	35	100	100	88	89	84	42	100	100	98	100	94
90	W	36	100	100	90	92	85	45	100	100	98	100	97
90	T	45	100	100	98	100	97	54	100	100	100	100	100

#W - width of the piece of timber

T - thickness of the piece of timber.

90 mm × 45 mm in dimensions, cut from trees grown at 2.74² m spacing might contain knots of which only 10 per cent are less than the maximum allowable knot size for F8 timber 45 mm in thickness compared to 71 per cent for F5 timber. Similar differences occur at the other spacings. When the monetary value of the various grades are considered such differences are very important. The Brisbane market price for 90 mm × 45 mm dressed and seasoned Honduras pine F8 timber, when sold in cottage lots, is $157.95 per 100 m for lengths up to 4.8 m compared to $137.35 for F5 timber, i.e. a 13 per cent price difference (Forest Products Marketing, Brisbane, November, 1980, pers. comm.).

5.9 MANAGEMENT IMPLICATIONS

The time taken to prune an area has several components viz.,

that to (a) cut the branches

(b) manipulate the pruning tool between branches

and (c) to move from tree to tree (Jacobs, 1938).

The time required to cut branches of select stems of Honduras pine at 3.66² m spacing using modern equipment (chain saws) is not likely to be any different than at the closest spacing (2.13² m) despite an average difference in sectional area of some 39 per cent. The time required to manipulate the pruning tool would be roughly the same for all spacings as branch angle and the spacial arrangement of branches around the stem are not greatly affected by spacing (Tables 4.18, A4.4); and since 250 select stems per ha are required no matter what the initial spacing, the time taken to move from tree to tree should also be similar at all spacings. However, the amount of undergrowth

is affected by spacing being more prevalent and vigorous at wider spacings and this may hinder movement from tree to tree. But, at closer spacings, movement could be restricted just as much by the profusion of branches from closely spaced trees. Thus, the costs of pruning areas of very different initial spacing are not likely to differ much.

The finding that branch growth is favoured on the northern side of a tree suggests it may be advantageous to prune branches on this side a year or two earlier than those on the southern side. Such a prescription is totally impractical in plantation forestry but could be practical in a small scale operation such as a farmer's woodlot or agro-forest. Pruning schedules similar to this have been introduced in some radiata pine agro-forests (F. Clarke, 1980, pers. comm.). At present, agro-forestry trials for Honduras pine in North Queensland are in their infancy (J. Morley, 1980, pers. comm.), but it may be beneficial to bear such a pruning prescription in mind.

Results relating branch size to orientation of branch also have implications for management should row thinning of Honduras pine plantations be practiced. In this case, it would be desirable to align rows in a north-south direction at planting. This would limit the response of branches on the northern side of trees adjacent to outrows and, hopefully, reduce the overall maximum size of branches.

5.10 CONCLUSIONS

The aims of this study have been met. The effects of initial espacement on crown and stem development of Honduras pine at age 11-12 years have been established for two locations in North Queensland viz., Kennedy and Bowenia.

The results should enable sounder decisions to be made with respect to establishing plantations of the species at these two centres and in neighbouring areas.

A notable feature of the study has been the differential response to initial spacing between locations of some tree and crown characteristics. Whether the cause is a site effect, a latitudinal effect or some combination of these and other factors is not known and further investigation is warranted. However, the differences imply that similar silvicultural treatment of Honduras pine plantations at the two locations may be inappropriate.

APPENDIX 1

TABLE A1.1

Plot dimensions and areas.

INITIAL ESPACEMENT (m)	NETT PLOTS(1)		ISOLATIONS		GROSS PLOTS(2)	
	DIMENSIONS(m)	ROWS × TREES	WIDTHS(m)	NUMBER OF ROWS	DIMENSIONS(m)	ROWS × TREES
2.13^2	27.74 × 27.74	13 × 13	8.99	4	45.72 × 45.72	21 × 21
2.44^2	29.26 × 29.26	12 × 12	8.23	3	45.72 × 45.72	18 × 18
2.74^2	27.43 × 27.43	10 × 10	9.14	3	45.72 × 45.72	16 × 16
3.05^2	27.43 × 27.43	9 × 9	9.14	3	45.72 × 45.72	15 × 15
3.66^2	29.26 × 29.26	8 × 8	8.23	2	45.72 × 45.72	12 × 12

(1) Average nett plot area: 0.08 ha.

(2) Average gross plot area: 0.21 ha.

APPENDIX 2

HISTORY OF EXPERIMENTAL MATERIAL *

Experiment 106 Bowenia	Experiment 438 Atherton
Site Preparation	
Machine cleared and windrowed Autumn, 1968. Burnt August, 1969. Sprayed twice (November, 1968 and January, 1969) with 1% 2,4,5-T ester in water using tractor mounted high volume spray.	Machine cleared and windrowed October, 1968. Sprayed once (January, 1969) with 1% 2,4,5-T ester in water.
Experimental Layout	
To avoid ashbed effects the experimental blocks were laid out between the burnt windrows.	
Seed Source	
Batch R72P from Experiment 88B Bowenia	Batch R70P from Experiment 58B Bowenia
The object was to use stock of comparable quality to that expected from future seed orchards. Batch R72P is considered to be of higher quality than Batch R70P.	
Planting Stock	
All planting material was selected from tubed stock in the nursery using the following criteria: (i) Hard topped stock with dormant bud, well developed secondary needles, good form and more than 10 cm in height, and (ii) Stock about to form a dormant tip, with some secondary needles, good form and more than 10 cm in height. The ratio of category (i) to category (ii) plants selected was 4 : 1.	
Planting	
Planted between March 3 and March 19, 1969. Initial survival over all plots was 99.6%. Refilling early July, 1969.	Planted between March 3 and March 7, 1969. Survival was uniformly high (~ 99%) and refilling was not deemed necessary.

Appendix 2 cont'd

History of Experimental Material (cont'd)

Experiment 106 Bowenia	Experiment 438 Atherton
Brushing	
No brushing.	Brushed in late 1971 and the regrowth was sprayed with 2, 4,5-T butytester.
Pruning	
A two stage pruning schedule was applied to all plots viz.,	
August, 1975. Ground pruned to 2.44 m - 500 s ha^{-1} irrespective of spacing.	April, 1974. Ground pruned to 2.44 m.
October, 1976. Pruning lifted to 5.2 m - 300 s ha^{-1}.	Winter, 1978. Pruning lifted to 5.2 m - 250 s ha^{-1}.
Selected Trees	
August, 1977. 250 of the 300 high pruned stems per hectare were selected as final crop trees. Selection was based on vigour, form and spacing.	Carried out in conjunction with second pruning lift.
Thinning	
First thinning to 30 m^2 ha^{-1} basal area was applied in July, 1978 to one plot from each spacing (Plots 2,4,6,7 and 13). The remaining plots were left unthinned. The prescription applied was: Thin other than select stems less than 12 cm dbhob. (pulpwood limit) initially from above removing serious competitors to selects and then from below to the residual basal area (30 m^2 ha^{-1}).	No thinning.

Appendix 2 cont'd

History of Experimental Material (cont'd)

Experiment 106 Bowenia	Experiment 438 Atherton
Fire History	
A lightning fire during November, 1971 when the trees were 2 years 8 months old caused sufficient damage to Plots 9-12 and 14-19 to exclude them from this study. A control burn in May, 1978 achieved excellent results with a minimum of scorch well within accepted limits.	A control burn in April, 1979 resulted in crown scorching of trees throughout the experiment.
Fertilization	
June, 1979. Fertilizer was applied to all plots at the following rates: Phosphous 80 kg ha^{-1} Zinc 15 kg ha^{-1}	No fertilization.
Cyclone Damage	
No major cyclone damage.	Cyclones, 15 January and 10 February, 1974 caused sufficient damage to warrant removal of up to 7 per cent of the trees in individual plots in August, 1975.

* From: Files S107/33: Spacing in Plantations, Expt. 106 Bowenia and S107/33: Spacing in Plantations, Expt. 438 Atherton. Qld. Dept. of For.

APPENDIX 3

TABLE A3.1

Analysis of interaction effects. Expt. 438 Atherton. Dbhob (cm) of all trees, select stems and other than select stems.

ALL TREES				SELECT STEMS				OTHER THAN SELECT STEMS			
SPACING (m)	BLOCK	$\bar{X}$	S.E.	SPACING (m)	BLOCK	$\bar{X}$	S.E.	SPACING (m)	BLOCK	$\bar{X}$	S.E.
2.13	1V	17.4	3.4	2.44	1V	21.1	1.7	2.13	1V	16.8	3.2
2.44	1V	17.7	3.1	2.13	1V	21.4	1.9	2.13	1	17.0	3.3
2.13	1	17.8	3.7	2.13	111	21.9	2.9	2.44	1V	17.0	2.9
2.13	111	17.8	3.6	2.13	11	22.2	2.0	2.13	111	17.2	3.4
2.13	11	18.0	3.9	2.44	111	22.7	1.8	2.13	11	17.3	3.7
2.44	111	19.1	3.4	2.13	1	22.8	2.2	2.44	1	18.3	3.7
2.44	1	19.3	4.0	2.74	1	23.2	2.4	2.44	111	18.3	3.2
2.74	1	19.4	3.8	2.74	111	23.2	2.1	2.74	1	18.3	3.4
2.44	11	19.8	4.3	2.44	1	23.4	2.2	2.44	11	18.8	4.0
2.74	111	19.8	3.4	3.05	111	23.5	3.2	2.74	111	18.9	3.1
2.74	11	20.4	3.8	2.74	1V	23.7	2.0	2.74	11	19.4	3.4
2.74	1V	20.4	4.0	3.66	1	23.9	1.8	2.74	1V	19.5	4.0
3.05	111	20.7	3.5	2.44	11	24.1	2.2	3.05	111	19.8	3.1
3.05	11	21.8	3.8	2.74	11	24.1	2.6	3.66	1V	20.6	2.8
3.05	1V	21.9	3.1	3.66	1V	24.3	2.0	3.05	11	20.7	3.5
3.66	1V	22.0	3.1	3.05	1V	24.7	2.3	3.05	1V	20.8	2.6
3.66	1	22.3	3.2	3.05	11	24.9	2.7	3.05	1	21.4	3.9
3.05	1	22.7	4.2	3.66	11	25.4	2.8	3.66	1	21.4	3.4
3.66	11	23.4	3.4	3.66	111	26.2	2.4	3.66	11	22.2	3.2
3.66	111	24.1	3.6	3.05	1	26.5	1.9	3.66	111	23.0	3.7

N.B. Values not connected by the same line are significantly different at 0.05.

Appendix 3 Cont'd

TABLE A3.2

Analysis of interaction effects: Expt. 106 Bowenia
Dbhob (cm) of all trees and other than select stems.

ALL TREES				OTHER THAN SELECT STEMS			
SPACING (m)	BLOCK/ THINNING#	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
2.13	111/T	17.4	3.9	2.13	111/T	16.5	3.5
2.13	1/U	17.8	3.2	2.13	1/U	17.2	2.9
2.44	1V/U	20.1	3.5	2.44	IV/U	19.2	3.1
2.74	11/U	20.7	3.5	2.44	11/T	20.0	1.7
2.44	11/T	20.9	2.4	2.74	11/U	20.0	3.4
2.74	1V/T	22.1	3.3	2.74	1V/T	21.1	3.0
3.05	11/T	22.5	2.6	3.05	11/T	21.5	2.3
3.05	1/U	23.2	2.7	3.05	1/U	22.5	2.5
3.66	1/U	24.9	2.9	3.66	1/U	24.0	2.4
3.66	11/T	25.4	2.6	3.66	11/T	24.8	2.8

U - Unthinned

T - Thinned

Appendix 3 Cont'd

TABLE A3.3

Analysis of interaction effects. Expt. 106 Bowenia. Stem taper (cm/m) over and under bark.

TAPER OVER BARK (cm/m)				TAPER UNDER BARK (cm/m)			
SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
2.13	1/U	1.00	0.08	2.74	11/U	0.70	0.09
2.74	11/U	1.02	0.11	2.44	11/T	0.74	0.11
2.44	11/T	1.05	0.14	3.05	11/T	0.76	0.13
3.05	11/T	1.06	0.12	2.13	1/U	0.77	0.07
2.44	1V/U	1.14	0.11	2.44	1V/U	0.79	0.08
2.13	111/T	1.15	0.13	3.66	1/U	0.80	0.12
3.66	11/T	1.16	0.11	2.13	111/T	0.81	0.14
3.05	1/U	1.18	0.18	2.74	1V/T	0.84	0.09
2.74	1V/T	1.19	0.14	3.05	1/U	0.85	0.15
3.66	1/U	1.19	0.16	3.66	11/T	0.87	0.11

Appendix 3 Cont'd

TABLE A3.4

Analysis of interaction effect. Expt. 438 Atherton. Height (m) of sample trees.

SAMPLE TREES			
SPACING (m)	BLOCK	$\bar{X}$	S.E.
2.44	1V	18.8	0.55
3.05	111	19.6	2.3
3.66	11	19.8	0.79
3.66	1V	19.8	1.4
2.13	1V	20.1	0.61
2.44	1	20.2	0.84
2.13	1	20.2	0.78
2.74	111	20.2	1.2
3.66	1	20.3	1.0
2.13	11	20.4	0.97
3.05	111	20.4	1.8
2.74	1	20.5	1.1
3.05	1V	20.5	1.2
2.44	111	20.6	1.2
2.74	1V	21.0	1.8
2.74	11	21.3	0.55
2.13	111	21.3	0.16
3.05	1	22.1	1.4
2.44	11	22.1	1.1
3.66	111	22.8	1.3

TABLE A3.5

Analysis of interaction effects, Expt. 106 Bowenia.
Height (m) of all trees, select stems and other than select stems.

ALL TREES				SELECT STEMS				OTHER THAN SELECT STEMS			
SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
2.13	111/T	14.6	2.2	2.13	111/T	16.2	1.3	2.13	111/T	14.3	2.2
2.13	1/U	16.4	1.9	2.13	1/U	18.0	1.2	2.13	1/U	16.1	1.9
2.44	1V/U	16.8	1.9	2.44	11/T	18.6	1.0	2.44	1V/U	16.4	1.8
2.44	11/T	17.2	1.5	2.44	1V/U	18.7	1.1	2.44	11/T	16.7	1.4
3.05	11/T	17.5	1.7	3.05	1/U	18.7	1.2	3.05	11/T	17.0	1.7
2.74	1V/T	17.6	1.7	3.05	11/T	18.8	1.1	2.74	1V/T	17.1	1.5
2.74	11/U	17.6	2.0	2.74	11/U	18.9	1.2	3.05	1/U	17.3	1.4
3.05	1/U	17.7	1.5	2.74	1V/T	19.1	1.2	2.74	11/U	17.3	2.0
3.66	1/U	18.2	2.1	3.66	11/T	19.4	0.9	3.66	1/U	17.6	2.3
3.66	11/T	18.6	1.3	3.66	1/U	19.4	1.1	3.66	11/T	18.2	1.3

TABLE A3.6

Analysis of interaction effects. Expt. 106 Bowenia. Height to LGB(m) of all trees, select stems and other than select stems.

ALL TREES				SELECT STEMS				OTHER THAN SELECT STEMS			
SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
2.13	111/T	8.2	1.6	2.13	111/T	8.6	1.2	2.13	111/T	8.1	1.7
3.66	1/U	9.0	1.7	3.66	11/T	9.9	1.2	3.66	1/U	8.4	1.7
2.74	1V/T	9.4	1.3	3.66	1/U	10.0	1.3	2.74	1V/T	9.1	1.3
3.05	1/U	9.6	1.3	2.74	1V/T	10.1	1.0	3.05	11/T	9.3	1.6
3.05	11/T	9.6	1.5	3.05	1/U	10.2	1.1	3.05	1/U	9.4	1.3
3.66	11/T	9.7	1.3	2.44	1V/U	10.2	1.4	3.66	11/T	9.5	1.3
2.44	1V/U	9.7	1.6	3.05	11/T	10.5	1.0	2.44	1V/U	9.6	1.6
2.44	11/T	10.0	1.3	2.74	11/U	10.9	0.85	2.44	11/T	9.9	1.4
2.74	11/U	10.1	1.7	2.44	11/T	11.1	0.85	2.74	11/U	9.9	1.8
2.13	1/U	10.6	1.7	2.13	1/U	11.4	0.84	2.13	1/U	10.5	1.8

Appendix 3 Cont'd

TABLE A3.7

Analysis of interaction effects. Expt. 106 Bowenia. Height to LGW (m) of all trees, select stems and other than select stems.

ALL TREES				SELECT STEMS				OTHER THAN SELECT STEMS			
SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
2.13	111/T	9.6	1.7	2.13	111/T	10.1	1.5	3.66	1/U	9.4	1.6
3.66	1/U	10.0	1.7	3.66	11/T	10.7	0.88	2.13	111/T	9.5	1.8
2.74	1V/T	10.4	1.3	3.66	1/U	11.0	1.3	2.74	1V/T	10.1	1.3
3.05	11/T	10.6	1.5	2.44	11/T	11.0	1.1	3.05	11/T	10.2	1.5
3.05	1/U	10.6	1.1	3.05	1/U	11.1	0.83	3.05	1/U	10.4	1.2
2.44	1V/U	10.6	1.6	2.74	1V/T	11.2	0.52	2.44	1V/U	10.5	1.6
3.66	11/T	10.7	1.1	3.05	11/T	11.5	1.3	3.66	11/T	10.7	1.2
2.74	11/U	10.9	1.6	2.44	1V/U	11.6	1.3	2.74	11/T	10.7	1.7
2.44	11/T	11.0	1.3	2.74	11/U	11.8	0.98	2.44	11/T	10.9	1.4
2.13	1/U	11.5	1.6	2.13	1/U	12.2	0.88	2.13	1/U	11.4	1.6

Appendix 3 Cont'd

TABLE A3.8

Analysis of interaction effects. Expt. 106 Bowenia. Crown depth based on LGB (m) of all trees and other than select stems.

ALL TREES				OTHER THAN SELECT STEMS			
SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
2.13	1/U	5.8	1.4	2.13	1/U	5.6	1.4
2.13	111/T	6.4	1.5	2.13	111/T	6.2	1.4
2.44	1V/U	7.0	1.5	2.44	1V/U	6.8	1.3
2.44	11/T	7.2	1.7	2.44	11/T	6.8	1.6
2.74	11/U	7.5	1.6	2.74	11/U	7.4	1.6
3.05	11/T	7.8	1.6	3.05	11/T	7.6	1.7
3.05	1/U	8.1	1.3	3.05	1/U	8.0	1.4
2.74	1V/T	8.2	1.6	2.74	1V/T	8.0	1.6
3.66	11/T	9.0	1.5	3.66	11/T	8.7	1.6
3.66	1/U	9.3	1.8	3.66	1/U	9.2	2.0

TABLE A3.9

Analysis of interaction effects. Expt. 106 Bowenia. Green crown per cent (%) based on LGB of all trees, select stems and other than select stems.

ALL TREES				SELECT STEMS				OTHER THAN SELECT STEMS			
SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
2.13	1/U	35.2	7.6	2.13	1/U	36.7	4.9	2.13	1/U	35.0	7.9
2.44	11/T	41.8	8.1	2.74	11/U	42.0	5.4	2.44	11/T	40.6	8.7
2.44	1V/U	42.0	7.7	3.05	11/T	44.1	6.1	2.44	1V/U	41.4	7.7
2.74	11/U	42.8	7.8	3.05	1/U	45.1	5.7	2.74	11/U	43.0	8.2
2.13	111/T	44.0	8.3	2.44	1V/U	45.2	7.4	2.13	111/T	43.5	8.5
3.05	11/T	44.8	7.7	2.44	11/T	45.6	4.6	3.05	11/T	45.0	8.3
3.05	1/U	45.7	6.7	2.13	111/T	46.5	7.1	3.05	1/U	46.0	7.1
2.74	1V/T	46.7	6.8	2.74	1V/T	46.9	5.5	2.74	1V/T	46.6	7.3
3.66	11/T	48.1	6.8	3.66	11/U	48.5	5.9	3.66	11/T	47.6	7.3
3.66	1/U	50.9	7.5	3.66	1/T	48.9	6.1	3.66	1/U	52.2	8.0

Appendix 3 Cont'd

TABLE A3.10

Analysis of interaction effects. Expt. 106 Bowenia. Green crown per cent (%) based on LGW of all trees and other than select stems.

ALL TREES				OTHER THAN SELECT STEMS			
SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.	SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
2.13	1/U	29.9	5.8	2.13	1/U	29.6	5.9
2.13	111/T	34.1	7.9	2.13	111/T	33.3	8.0
2.44	11/T	36.0	8.0	2.44	11/T	34.4	8.1
2.44	1V/U	36.5	7.2	2.44	1V/U	36.2	7.3
2.74	11/U	38.0	7.0	2.74	11/U	38.1	7.2
3.05	11/T	39.4	8.0	3.05	11/T	39.7	8.4
3.05	1/U	40.0	6.5	3.05	1/U	39.9	7.2
2.74	1V/T	40.9	6.9	2.74	1V/T	40.9	7.7
3.66	11/T	42.6	6.3	3.66	11/T	41.4	6.9
3.66	1/U	45.4	6.7	3.66	1/U	46.5	6.8

Appendix 3 Cont'd

TABLE A3.11

Analysis of interaction effects. Expt. 106 Bowenia. Branch angle (degrees) of sample trees.

SAMPLE TREES			
SPACING (m)	BLOCK/ THINNING	$\bar{X}$	S.E.
3.66	1/U	61.2	13.3
2.44	11/T	64.4	11.0
2.13	111/T	64.6	11.6
2.44	1V/U	65.6	13.6
2.74	11/U	67.8	13.8
3.05	11/T	67.9	11.0
3.66	11/T	68.0	9.3
2.13	1/U	68.8	13.3
2.74	1V/T	70.9	15.4
3.05	1/U	71.5	11.9

APPENDIX 4

TABLE A4.1

Effect of orientation on branch diameter (cm) - Expt. 106 Bowenia.

ALL SPACING COMBINED									
OCTANT	5	3	4	2	1	6	8	7	SIG#
$\bar{X}$	2.35	2.39	2.41	2.42	2.52	2.56	2.61	2.79	*
S.E.	0.80	0.65	0.68	0.54	0.77	0.62	0.60	0.69	
2.13m×2.13m									
OCTANT	5	2	4	3	6	1	8	7	
$\bar{X}$	1.94	2.07	2.11	2.18	2.29	2.32	2.37	2.66	N.S.
S.E.	0.60	0.46	0.69	0.66	0.33	0.16	0.40	0.58	
2.44m×2.44m									
OCTANT	5	6	4	8	2	3	7	1	
$\bar{X}$	1.90	2.24	2.27	2.30	2.34	2.42	2.61	2.62	*
S.E.	0.49	0.25	0.61	0.27	0.27	0.30	0.45	0.85	
2.74m×2.74m									
OCTANT	3	1	2	4	8	6	5	7	
$\bar{X}$	2.08	2.29	2.51	2.53	2.62	2.68	2.70	2.99	N.S.
S.E.	0.38	1.04	0.62	0.70	0.75	0.46	0.61	0.79	
3.05m×3.05m									
OCTANT	4	3	6	1	5	2	8	7	
$\bar{X}$	2.38	2.40	2.52	2.52	2.65	2.78	2.79	2.88	N.S.
S.E.	0.55	0.45	0.76	0.74	0.77	0.68	0.51	0.71	
3.66m×3.66m									
OCTANT	2	4	1	7	5	8	3	6	
$\bar{X}$	2.47	2.64	2.76	2.81	2.89	3.05	3.08	3.12	N.S.
S.E.	0.62	0.83	0.81	0.85	0.97	0.73	0.94	0.83	

#significant levels: N.S., not significant; *, 0.05.

N.B. Values not underlined by the same line are significantly different at 0.05.

Appendix 4 cont'd.

TABLE A4.2

Effect of orientation on branch angle (degrees) - Expt. 106 Bowenia.

ALL SPACING COMBINED									
OCTANT	7	3	8	2	1	4	6	5	SIG#
$\bar{X}$	64.0	65.1	65.3	65.8	65.8	69.4	69.8	70.9	N.S.
S.E.	13.0	11.3	10.4	12.1	14.1	16.7	9.8	12.3	
2.13m×2.13m									
OCTANT	7	1	8	2	3	5	4	6	
$\bar{X}$	63.8	65.2	65.3	65.9	66.1	68.7	69.0	71.4	N.S.
S.E.	19.8	13.0	10.5	14.0	12.3	11.4	13.0	8.5	
2.44m×2.44m									
OCTANT	3	7	4	2	8	1	6	5	
$\bar{X}$	60.0	62.3	63.2	63.2	64.3	65.7	66.7	71.6	N.S.
S.E.	4.6	10.2	21.6	12.8	6.6	18.7	4.1	13.4	
2.74m×2.74m									
OCTANT	1	7	3	8	2	6	4	5	
$\bar{X}$	65.1	65.5	65.8	67.2	67.9	70.2	75.4	75.9	N.S.
S.E.	17.5	13.0	13.5	12.9	13.1	11.8	19.1	13.3	
3.05m×3.05m									
OCTANT	2	1	8	7	3	6	4	5	
$\bar{X}$	64.9	67.0	67.0	69.0	71.8	72.0	72.2	72.7	N.S.
S.E.	11.2	10.3	9.5	14.1	9.6	13.4	11.2	14.3	
3.66m×3.66m									
OCTANT	3	8	7	4	1	5	2	6	
$\bar{X}$	60.4	61.1	61.2	63.4	65.6	67.2	67.4	68.2	N.S.
S.E.	10.9	11.2	8.6	18.5	14.2	10.4	11.3	9.9	

#significant level: N.S., not significant.

Appendix 4 cont'd.

TABLE A4.3

Effect of orientation on potential knot sectional area (cm^2) - Expt. 106 Bowenia.

ALL SPACING COMBINED									
OCTANT	5	2	3	6	4	8	1	7	SIG#
$\bar{X}$	5.38	5.50	5.70	5.98	6.08	6,45	6.50	7.80	N.S.
S.E.	4.2	2.6	3.2	3.5	5.3	3.7	4.4	4.8	
2.13m×2.13m									
OCTANT	5	2	4	6	3	1	8	7	
$\bar{X}$	3.62	4.20	4.32	4.40	4.78	4.80	4.95	7.68	N.S.
S.E.	2.6	2.3	3.0	1.5	3.2	1.1	1.8	4.4	
2.44m×2.44m									
OCTANT	5	6	8	2	4	3	7	1	
$\bar{X}$	3.32	4.35	4.72	5.10	5.32	5.40	6.55	7.30	N.S.
S.E.	1.9	1.0	1.2	1.4	2.6	1.0	2.6	4.2	
2.74m×2.74m									
OCTANT	3	2	6	5	4	1	8	7	
$\bar{X}$	4.02	5.80	6.40	6.58	6.62	6.68	6.80	9.18	N.S.
S.E.	1.5	3.0	2.6	3.4	5.8	7.0	5.0	7.4	
3.05m×3.05m									
OCTANT	3	4	6	1	5	8	2	7	
$\bar{X}$	5.02	5.08	6.00	6.20	6.50	7.10	7.42	7.82	N.S.
S.E.	1.8	2.5	4.3	4.4	3.8	2.9	4.0	4.5	
3.66m×3.66m									
OCTANT	2	1	7	5	4	3	6	8	
$\bar{X}$	5.55	7.22	8.02	8.18	8.42	9.00	9.05	9.20	N.S.
S.E.	2.7	3.7	5.2	6.1	8.7	5.5	4.8	4.6	

#significant level: N.S., not significant.

Appendix 4 cont'd.

TABLE 4.4

Effect of orientation on number of branches in each octant - Expt. 106 Bowenia.

ALL SPACING COMBINED								
OCTANT	3	1	6	2	8	5	4	7
$\bar{X}$	0.42	0.44	0.45	0.47	0.47	0.49	0.51	0.55
2.13m×2.13m								
OCTANT	1	2	4	6	7	5	3	8
$\bar{X}$	0.30	0.40	0.45	0.50	0.50	0.55	0.60	0.60
2.44m×2.44m								
OCTANT	3	1	4	8	6	5	2	7
$\bar{X}$	0.30	0.35	0.35	0.35	0.45	0.55	0.60	0.60
2.74m×2.74m								
OCTANT	5	6	2	3	7	1	4	8
$\bar{X}$	0.30	0.30	0.40	0.40	0.40	0.45	0.60	0.60
3.05m×3.05m								
OCTANT	2	5	3	6	8	7	1	4
$\bar{X}$	0.35	0.35	0.40	0.45	0.45	0.50	0.55	0.60
3.66m×3.66m								
OCTANT	8	3	6	1	4	5	2	7
$\bar{X}$	0.35	0.40	0.40	0.55	0.55	0.55	0.60	0.75

Appendix 4 cont'd.

TABLE A4.5

Effect of orientation on number of live branches in each octant - Expt. 106 Bowenia.

ALL SPACING COMBINED								
OCTANT	3	1	8	2	5	6	4	7
$\bar{X}$	0.31	0.39	0.41	0.42	0.43	0.43	0.47	0.49
2.13m×2.13m								
OCTANT	1	2	4	7	3	6	5	8
$\bar{X}$	0.30	0.35	0.40	0.40	0.45	0.45	0.50	0.50
2.44m×2.44m								
OCTANT	3	1	8	4	6	7	5	2
$\bar{X}$	0.20	0.30	0.30	0.35	0.45	0.50	0.55	0.60
2.74m×2.74m								
OCTANT	3	5	1	2	6	7	4	8
$\bar{X}$	0.30	0.30	0.35	0.35	0.40	0.40	0.50	0.55
3.05m×3.05m								
OCTANT	2	5	3	8	6	7	1	4
$\bar{X}$	0.30	0.30	0.35	0.40	0.45	0.45	0.50	0.60
3.66m×3.66m								
OCTANT	3	8	6	1	2	4	5	7
$\bar{X}$	0.25	0.30	0.40	0.50	0.50	0.50	0.50	0.70

Appendix 4 cont'd.

TABLE A4.6

Effect of orientation on number of dead branches in each octant - Expt. 106 Bowenia.

ALL SPACING COMBINED								
OCTANT	6	4	1	2	5	7	8	3
$\bar{X}$	0.02	0.04	0.05	0.05	0.06	0.06	0.06	0.11
2.13m×2.13m								
OCTANT	1	2	4	5	6	7	8	3
$\bar{X}$	0	0.05	0.05	0.05	0.05	0.10	0.10	0.15
2.44m×2.44m								
OCTANT	2	4	5	6	1	8	3	7
$\bar{X}$	0	0	0	0	0.05	0.05	0.10	0.10
2.74m×2.74m								
OCTANT	7	2	6	8	1	3	4	5
$\bar{X}$	0	0.05	0.05	0.05	0.10	0.10	0.10	0.15
3.05m×3.05m								
OCTANT	4	6	1	2	3	5	7	8
$\bar{X}$	0	0	0.05	0.05	0.05	0.05	0.05	0.05
3.66m×3.66m								
OCTANT	6	1	4	5	7	8	2	3
$\bar{X}$	0	0.05	0.05	0.05	0.05	0.05	0.10	0.15

APPENDIX 5

Importance of Knots in the Visual Grading of Honduras pine Timber for Structural Purposes.

(Adapted from:

Australian Standard 2099-1977
Visually stress-graded seasoned Australian-Grown Softwood (Confiers) for Structural Purposes (Excluding radiata pine and cypress pine)
Standards Association of Australia (1977)).

Honduras pine timber for structural purposes is visually graded into one of four main grades

(i) Structural Grade No. 1 - F11

(ii) Structural Grade No. 2 - F8

(iii) Structural Grade No. 3 - F7

(iv) Structural Grade No. 4 - F5

For each of the four timber grades, each piece of timber has to be free from decay, compression failures and other fractures and splits but may contain the following imperfections to varying extents:- knots, cone holes, bores holes, resin pockets, bark pockets and overgrowths of injury, bow, spring and twist, surface checks, sloping grain, insect galleries, wane or want, heart shakes, pith and stain.

Knots, for the purposes of grading, are classified into four groups:-

Appendix 5 Cont'd

(a) Sound knots (round, oval or spike; intergrown or partially intergrown; single or in clusters)-

(i) face knots

(ii) margin knots

(iii) through knots

(iv) edge knots

(b) Knots in groups

(i) on the face

(ii) on the edge

(c) Arris knots

(d) Unsound and defective knots.

For my purposes I examined only the effect of sound face knots and sound edge knots on timber grading. I accepted branch diameter as the index of knot size. The size of a sound knot is the width measured between lines enclosing the knot and parallel to arrises of the piece.

Each timber grade may contain sound face knots and edge knots to the following extent:

(a) Structural Grade No. 1 (F11)

(i) face knots - width not exceeding one-quarter of the width of the piece.

(ii) edge knots - width not exceeding one-quarter of the thickness of the piece.

(b) Structural Grade No. 2 (F8)

Appendix 5 Cont'd

(i) face knots - width not exceeding one-third of the width of the piece.

(ii) edge knots - width not exceeding two-fifths of the thickness of the piece.

(c) Structural Grade No. 3 (F7)

(i) face knots - width not exceeding two-fifths of the width of the piece.

(ii) edge knots - width not exceeding half the thickness of the piece.

(d) Structural Grade No. 4 (F5)

(i) face knots - width not exceeding half the width of the piece.

(ii) edge knots - width not exceeding three-fifths of the thickness of the piece.

BIBLIOGRAPHY

Anderson, M.L. 1958. Effect of site and silvicultural treatment upon timber quality. Q. J. For. 52(4):272-290.

Bacon, G.J. 1979. Interim summary - Experiment 106 Bowenia. File S107/33 : Spacing in plantations, Expt. 106 Bowenia. Dept. of For., Qld.

Baker, F.S. 1950. Principles of silviculture. McGraw-Hill Book Co. Inc. N.Y. 414pp.

Beekhuis, J. 1965. Crown depth of radiata pine in relation to stand density and height. N.Z. J. For. 10(1):43-61.

Bella, I.E. and de Franceschi, J.P. 1974. Early results of spacing studies of three indigenous conifers in Manitoba. Canad. For. Serv., Dept. of Environment. North. For. Res. Cent. Inf. Report NOR-X-113.

Bramble, W.C., Cope, H.N. and Chisman, H.H. 1949. Influence of spacing on growth of red pine in plantations. J. For. 47(9):726-732.

Brazier, J.D. 1977. The effect of forest practices on quality of the harvested crop. For. 50(1): 49-66.

Brown, A.G. 1967. A branch protractor. Sil. Gen. 16(1):34.

Brown, A.G. 1970. Improvement in log quality - A review. Paper 3A in *Pinus radiata*, Volume 1, Proc. of Symp. held at Dept. of For., A.N.U., Canberra, August, 1970.

Bibliography Cont'd

Brown, G.S. 1962. Stages in branch development and their relation to pruning. N.Z. J. For. 8(4):608-622.

Bryan, W. 1978. Queensland Department of Forestry Annual Report 1977-78. Govt. Print., Qld.

Carron. L.T. 1968. An outline of forest mensuration with special reference to Australia. A.N.U. Press, Canberra. 224pp.

Cromer, D.A.N. and Pawsey, C.K. 1957. Initial spacing and growth of *Pinus radiata*. Forest. and Timber Bur. Bull. No. 36., Canberra. 42pp.

Dempster, Q. 1980. Wood pulp project go-ahead 'likely'. Telegraph 8th Jan., 1980. Brisbane, Qld.

Evert, F. 1971. Spacing studies - A review. Forest Management Inst. Ottawa, Ontario. Inf. Rep. FMR-X-37., Canadian Forest. Serv., Dept. of Environment. 95pp.

Fenton, R.J. 1971. Silviculture and management of *Pinus radiata* for framing timber production. N.Z. J. For. Sci. 1(1):60-73.

Fenton, R.J. and Familton, A.K. 1961. Tending *P. radiata* for optimum timber grade recovery. N.Z. J. For. 8(3):415-439.

Fenton, R.J. and Sutton, W.R.J. 1968. Silvicultural proposals for radiata pine on high quality sites. N.Z. J. For. 13:220-228.

Fielding, J.M. 1960. Branching and flowering characteristics of montery pine. For. and Timber Bur. Bull. No. 37. Govt. Printer, Canberra.

Bibliography Cont'd

Fisher, W.J. 1978. Spacing, branch size, branch longevity and wood quality in plantations of hoop pine at Yarraman. Qld. Dept. For., Tech. Pap. No. 12., 17 pp.

Forward, D.F. and Nolan, N.J. 1961. Growth and morphogensis in the Canadian forest species - IV Radial growth in branches and main axis of *Pinus resinosa* Ait., under conditions of open growth, suppression and release. Can. J. Bot. 39:385-409.

Gevorkiantz, S.R. and Hosley, N.W. 1929. Form and development of white pine stands in relation to growing space. Harvard Uni. Forest Bull. No. 13.

Hamilton, G.J. and Christie, J.M. 1974. Influence of spacing on crop characteristics and yield. For. Comm., England. Bull. No. 52.

Hawkins, P.J. 1969. Commencement report - Experiment 106 Bowenia. File S107/33 : Spacing in plantations, Expt. 106 Bowenia. Dept. of For., Qld.

Hawkins, P.J., Nikles, D.G. and Smith, W.J. 1978. Management, wood properties and genetic improvement of Caribbean pine in Queensland. Dept. of For., Qld. Tech. Paper No. 4.

Hawkins, P.J. and Muir, J.D. 1968. Aspects of management of plantations in tropical and sub-tropical Queensland. Paper prepared for the 9th Comm. For. Conf. Dept. of For., Qld.

Helmers, A.E. 1946. Effect of pruning on growth of western white pine (*Pinus monticola*). J. For. 44(9): 673-679.

Bibliography Cont'd

Jacobs, M.R. 1938. Notes on pruning *Pinus radiata* - Part 1. Observations on features which influence pruning. Comm. For. Bur. Bull. No. 23. 47pp.

James, R.N. 1970. In "Discussion Section" in Pruning and Thinning practice - Vol. 1 : Proceedings. Ed. by Tustin, J.R. and Bunn, E.H. Proc. of N.Z.F.S. F.R.I. Symp. No. 12. Rotorua. 16-20 March, 1970.

Kozlowski, T.T. 1971. Growth and development of trees. Volume II. Academic Press, N.Y. 514pp.

Lamb, A.F.A. 1973. *Pinus caribaea* - Volume 1. Fast growing timber trees of the lowland tropics. No. 6. Uni. of Oxford. Dept. of For. Comm. For. Inst. 254pp.

Larson, P.R. 1962. A biological approach to wood quality. Tappi 45(6):443-448.

Larson, P.R. 1963. Stem form and silviculture. Proc. Soc. American Foresters Meeting, Boston, Massachusetts. Oct. 20-23. pp.103-107.

MacDonald, J. 1933. The form of the stem in coniferous trees. For. 7(1):32-42.

Meney, S. 1976. Knot characteristics and occlusion in low pruned *Pinus radiata* D. Don. Honours Thesis, Dept. of For., A.N.U., Canberra.

Miller, W.D. and Maki, T.E. 1967. Planting pines in pocosins. J. For. 55(9):659-663.

Bibliography Cont'd

Nikles, D.G. 1979. Genetic improvement of tropical lowland conifers. Inst. For. Aust. Newsletter 20(4):28-30.

Powell, M.B. 1979. Effect of spacing on tree and crown parameters, branch growth and longevity in improved slash pine. Honours Thesis, Dept. of For., A.N.U., Canberra.

Reilly, R. 1979. Memo - Spacing trial : Diameter of branches and green crown levels. File S107/33 Experiment 438 Atherton. Dept. of For. Qld.

Shelbourne, C.J.A. 1970. Genetic improvement in different tree characters of radiata pine and the consequences for silviculture and utilisation. in Pruning and Thinning Practice, Volume 2, Papers. pp.44-58. Ed. by Sutton, W.J.R. Proc. of N.Z.F.S. F.R.I.Symp. No. 12. Rotorua. 16-20 March, 1970.

Sjolte - Jørgensen, J. 1967. The influence of spacing on growth and development of coniferous plantations. Int. Rev. Forest. Res., N.Y. 2:43-94.

Slee, M.U. and Nikles, D.G. 1968. Variability of *Pinus caribaea* (Mor.) in young Queensland plantations. Paper prepared for 9th Comm. For. Conf. Dept. of For., Qld.

Smith, D.M. 1962. The practice of silviculture. John Wiley and Sons, N.Y. 7th Edition. 578pp.

Smith, J.H.G. 1961. Comments on "Relationships between tree spacing, knot size and log quality in young Douglas-fir stands". J. For. 59(9):682-683.

Bibliography Cont'd

Spurr, S.H. 1962. A measure of point density. For. Sci. 8(1):85-96.

Standards Association of Australia. 1977. Visually stress-graded seasoned Australian-grown softwood (conifers) for structural purposes (excluding radiata pine and cypress pine). Australian Standard 2099-1977.

Stevenson, D.D. and Bartoo, R.A. 1939. The effect of spacing on the growth of Norway pine plantations - a progress report. J. For. 37(4):313-319.

Stiell, W.M. 1962. Crown structure in plantation red pine. Dept. of For., Canada. For. Res. Branch. Tech. Note No. 122.

Stiell, W.M. 1964. Twenty-year growth of red pine planted at three spacings. Dept. of For., Canada. For.Res. Branch.Publ. No. 1045.

Stiell, W.M. 1966. Red pine crown development in relation to spacing. Dept. of For., Canada, Publ. No. 1145.

Stiell, W.M. and Berry, A.B. 1977. A 20-year trial of red pine planted at seven spacings. Canad. For. Serv. Dept. of Environment. For. Manage. Inst. Inf. Report FMR-X-97.

Sutton, W.R.J. 1968. Initial spacing and financial return of *Pinus radiata* on coastal sands. N.Z.J. For. 13:203-219.

Bibliography Cont'd

Vanclay, J.K. 1977. Growth and change in a managed hardwood forest. S.F.R. 537, NSW. Honours Thesis, Dept. For., A.N.U., Canberra.

Wardle, P.A. 1967. Spacing in plantations - A management investigation. For. 40:47-69.

Whitesell, C.D. 1970. Early effects of spacing on loblolly pine in Hawaii. U.S.D.A. For. Serv. Pac. SW For. and Range Expt. Stn. Res. Note PSW-223.

Whiteside, J.D. 1962. Silvicultural characteristics of radiata pine in Tapanui district. N.Z.J. For. 8(4):594-607.

Whiteside, J.D., Wilcox, M.D. and Tustin, J.R. 1977. New Zealand Douglas fir timber quality in relation to silviculture. N.Z.J. For. 22(1):24-44.

Whyte, A.G.D. 1970. Some considerations in assessing and predicting growth of treated plantations of conifers. Paper No. 28. pp.118-135 in Pruning and Thinning Practice - Vol. 2 : Papers. Ed. by Sutton, W.R.J. Proc. of N.Z.F.S. F.R.I. Symp. No. 12. Rotorua. 16-20 March, 1970.

Wilde, S.A., Giordano, A., Shaw, B.H., Fedkenheuer, A.W., and Seip, W.T. 1968. Tree spacing in forest plantations as related to soils and revenue. Res. Div., Coll. of Agric. and Life Sci., Uni. of Wisconsin. Bull. No. 589.

Wright, J.P. 1970. Site and silvicultural influences on log quality in radiata pine. Paper 3E in *Pinus radiata*, Volume 1. Proc. of Symp. held at Dept. of For., A.N.U., Canberra. Aug. 1970.