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HARVESTING MECHANISATION AND SILVICULTURE

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ABSTRACT

The stem and branch characteristics of managed new crop radiata pine will impede the introduction of fully mechanised harvesting systems into New Zealand, if their introduction is to be decided on economic criteria.

Current silvicultural practices in New Zealand of relatively low initial stockings, early and heavy thinning to waste to low final crop stockings, encourage large tree sizes, and also large branches and heavy whorls in unpruned logs. Field measurement and analysis confirm this condition which is also supported by predictions using computer modelling systems.

Modification to silvicultural practices would be required to allow the successful introduction of fully mechanised harvesting systems on a large scale. If that is not economically acceptable, then other harvesting systems and options must be investigated if logging costs are to be contained.

INTRODUCTION

The prime factors in logging that are manipulated to reduce the cost of production are the capital and labour inputs. Another most important variable that can be influenced, and which has a very significant effect on production, is piece size. Generally, small piece size is associated with low production and high cost, while large piece size is linked with high production and low cost. Other important cost factors include the terrain types, average extraction haul distances and transport lead distances.

Increased mechanisation of harvesting operations is commonly put forward as another method of reducing labour inputs and increasing production. In New Zealand the substitution of capital for labour has not been overly successful (Terlesk and Walker, 1982). In some cases, this failure is attributable to the tree form characteristics of our major plantation species, radiata pine.

This report discusses the characteristics of radiata pine that impede the successful introduction of highly mechanised harvesting systems to the New Zealand forest industry. The effect of early silvicultural operations on tree and branch size and the impact of these factors on mechanised delimbing are emphasised.

Table 1 - Stocking rates (stems/ha)

Stocking rate	1	2	3
Initial stocking	1400	1000	600
At age 4 years	1330	950	570
After first thinning*	700	500	300
Final crop stocking	350	250	150

* To waste.

CURRENT SILVICULTURAL PRACTICES

West (1990) presented a table showing three stocking levels (Table 1) which were considered to include most of the managed radiata pine plantations.

West added, *"In broad terms stocking rate 1 would be indicative of companies supplying their own combined sawmill/pulpmill complexes, stocking rate 2 is usually followed by companies which do not have supply commitments, and stocking rate 3 is used where livestock grazing is important in agroforestry ventures. These three regimes show the relatively low initial stocking rates, and the early and heavy thinning schedules. Both of these practices are likely to lead to large branches."*

The Ministry of Forestry publication, (Turland and Nuemann, 1990) presented a graph (Figure 1), showing the age class distribution of the net productive stocked area of exotic forest as at 1 April, 1989. At this time, over 68% of the stocked area was in age classes 15 years or less. The survey claimed to cover 85% of the exotic national resource by area.

A second graph from the same source showed the type of silviculture practices by age classes. (Figure 2). Four categories were recognised:

- minimum tending with production thinning
- minimum tending without production thinning
- intensive tending with production thinning
- intensive tending without production thinning

Intensive tending refers to pruning carried out prior to age 12, with more than 50% of the final crop stems containing a pruned butt log of not less than 5 m in length. The minimum tending regimes are those with little or no pruning. Initial stockings will be lower, and thinning to waste or final crop will occur at an early age.

The data contained in a National Exotic Forest Description showed that over 800,000 ha of the exotic forest resource had already been committed to one or other of the four tending categories and that the resultant tree characteristics at harvest had already been decided.

The trend towards lower initial stocking and heavy early thinnings is most obvious in the agroforestry research field, where the following tree management schedules given in Table 2 were suggested.

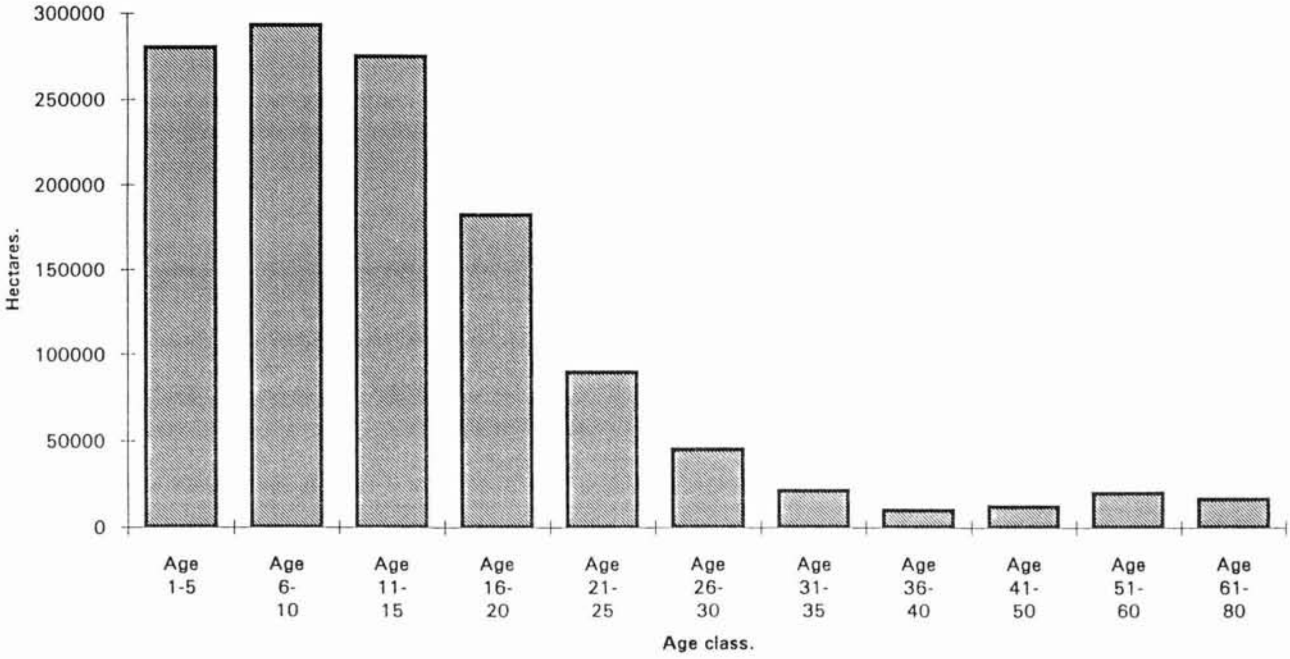

Figure 1 - Net productive exotic stocked forest area

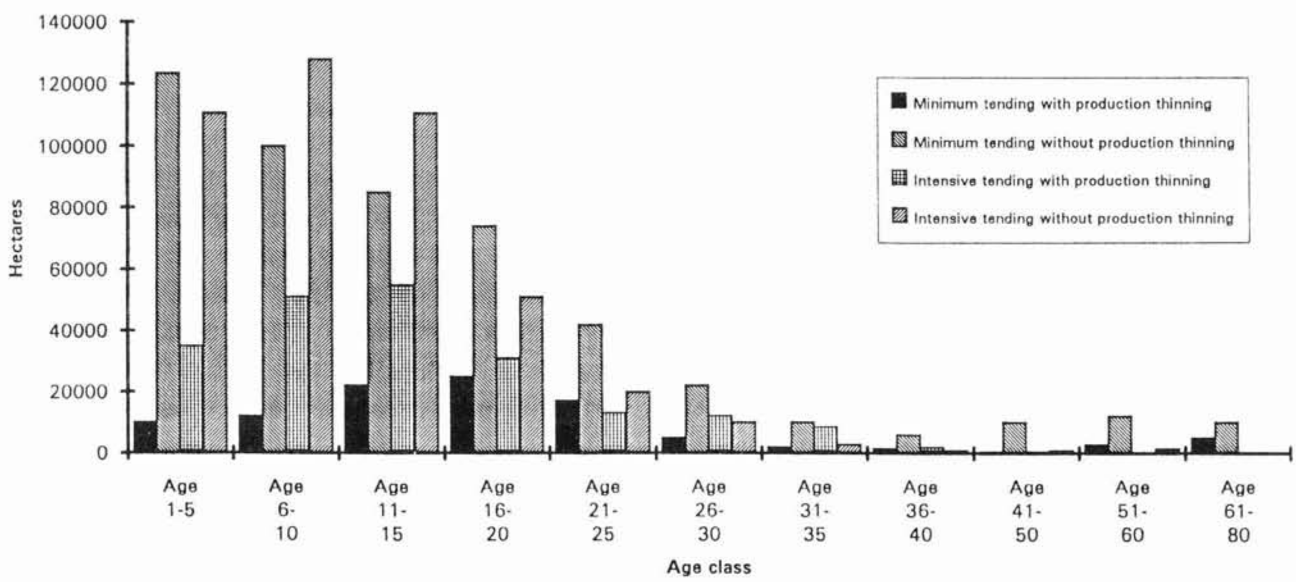

Figure 2 - Net productive exotic stocked forest area by age class and silvicultural type

Table 2 - Example of an agroforestry regime

Years	Mean height (m)	Operation	Prescription
0	-	Plant	400-600 stems/ha *(Pinus radiata)* onto sprayed spots. Use the best genetically-improved seedlings or rooted cuttings available.
			Hand release from autumn pasture growth
4.1	5.5	Prune	250 stems/ha to 2.2 m to achieve 16 cm diameter over stubs. Thin to waste to 250 stems/ha.
5.4	7.6	Prune	225 stems/ha to 4.2 m to achieve 17 cm diameter over stubs. Thin to waste to 225 stems/ha.
6.9	10.0	Prune	225 stems/ha to 6.3 m to achieve 17 cm diameter over stubs.
Final yield from 211 stems/ha at age 27 years: 625 m^3/ha (219 m^3/ha pruned sawlogs, 347 m^3 unpruned sawlogs, 59 m^3 pulp).			

This schedule will inevitably lead to large tree sizes with many whorls having multiple large branches. This will effectively preclude the economic use of technologically advanced but complex multi-function harvesting machines.

A paper to the 1989 IUFRO Symposium on spacing and thinning (James 1990), documented the trend towards earlier thinning in New Zealand plantations and gave the reason as increased emphasis on the economics of plantation forestry.

Whiteside (1989) presented a base regime as being typical of those being practised in the Central North Island region in 1980 (Table 3). The table also describes a new regime scenario which takes into account changes made in silvicultural practices since 1980. Although there are significant differences between different organisations and also within one organisation, the regimes in the table represent the average trends that have taken place during the 1980s, namely; lower initial stocking, lower final crop stockings, lower initial stocking/final stocking ratios, reduced pruning height, reduced number of pruning lifts, earlier pruning to reduce the defect core and in direct regimes, a reduced number of thinnings with thinning completed earlier.

Lower initial stockings, lower final crop stockings and a reduced number of thinnings carried out in an early age inevitably result in a greater number of large branches and heavy whorls.

This conclusion is supported by Manley and Wakelin, 1990. Four regimes were presented and the log outurns from the four regimes at age 30. These showed significant quantities of L type (large branched) logs. This type of log contains branches greater than 6 cm in diameter.

These results were generated by a stand evaluation model (STANDPAK) and a forest estate modelling system (FOLPI). The results reinforce the effect that silvicultural regimes have on branch size.The effect of silvicultural practice on log grade outturn is shown in Table 4.

Table 3 - A base and new regime scenario

	Base		New	
	Stems/ha	Crop height	Stems/ha	Crop ht
(a) Direct regime				
Plant	1650	-	1000	-
Prune	650 to 2.2 m	6 m	250 to 2.7 m	6 m
Thin	to 650	6 m	to 250	6 m
Prune	450 to 4.2 m	9.5 m	250 to 5.2 m	9 m
Prune	330 to 6 m	13 m		
Thin	to 330	13 m		
Clearfell		age 30		age 30
(b) Production thin regime				
	1650	-	1000	-
Plant	650 to 2.2 m	6 m	350 to 2.7 m	6 m
Prune	to 650	6 m	to 500	6 m
Thin	450 to 4.2 m	9.5 m	250 to 5.2 m	9 m
Prune	330 to 6 m	13 m		
Prune	to 330	18 m	to 250	18 m
Production thin		age 30		age 30
Clearfell				

Table 4 - The effect of silvicultural practice on log grade outturn

Operation	Log grades	Regime			
		*Base	NOPR	PTHIN	NOTEND
		Log Volume produced at age 30 (m^3/ha)			
Clearfelling	P1/P2	164	-	148	-
	S1	10	67	50	61
	S2	25	95	80	232
	S3	13	36	36	229
	L1	150	182	77	65
	L2	150	183	94	53
	Residual	124	161	95	186
Total clearfelling		636	724	580	826
Production thinning		-	-	112	-
Total		636	724	692	826

* Base Regime	a direct pruned sawlog regime with heavy early thinning
NOPR	a direct unpruned sawlog regime with heavy early thinning
PTHIN	a production thinning regime
NOTEND	a minimum tending regime

From a harvesting mechanisation viewpoint it seems that the proposed regimes, in many cases, will result in large trees and branches that may be beyond the capacity of both current and future felling and delimbing machinery.

THE INFLUENCE OF SILVICULTURAL TREATMENT ON TREE CHARACTERISTICS

Branch Measurements - Current Operations

Data were collected during three harvesting operations, one each in a transition crop, young crop and agroforestry crop, and consist of measurements of the number, location and the diameter of all the branches to a 10cm SED. These data are summarised in Figures 3, 4 and 5. They are shown as a distribution by branch size and by branch cross-sectional area (BCA).

These data are from Compartment 1036 in Kaingaroa Forest and are considered to be reasonably representative of the transition crop (Figure 3). The term "transition crop" describes a tree crop which received some silvicultural pruning and thinning treatment (Table 5). This silvicultural treatment distinguishes the transition crop from the untended old crop stands. Numerically a high percentage (50%) of the branches are in 1 and 2 cm classes. However, they make a relatively small contribution to the total BCA. Total BCA of a whorl is the amount of wood that has to be cut in order to remove all the branches. Some large branches are present, and in combination, present formidable whorl cross-sectional areas. However, previous silvicultural operations and regimes have resulted in some degree of branch control. Total BCA in a whorl rather than the number of branches is the limiting factor to mechanised delimbing.

Figure 4 represents a "young crop" stand in Compartment 110, Rotoehu Forest (Hall and Terlesk, 1990). "Young crop" radiata is considered to be a stand planted post-1960 and having received extensive silvicultural treatment. Again, a high percentage of the branches are in the 1 and 2 cm classes.

Butt diameters in the "young crop" stand averaged 55 cm (range 31-77 cm, SD 11.1 cm). This is close to the maximum felling capacity of commonly available felling machines and is beyond their capacity in the upper diameter sizes.

Table 5 - Transition crop stand details

Treatment	Year	Comment
Regeneration	1953	Not Known
Low Pruned (0 - 4.2 m)	1960	600 stems/ha.
Thin-to-waste	1960	Residual 400 stems/ha
High pruned (0 - 6.1 m)	1965	300 stems/ha
Production thinned	1972	Residual 300 stems/ha
Clearfelled	1984	Total live vol 722 m^3/h

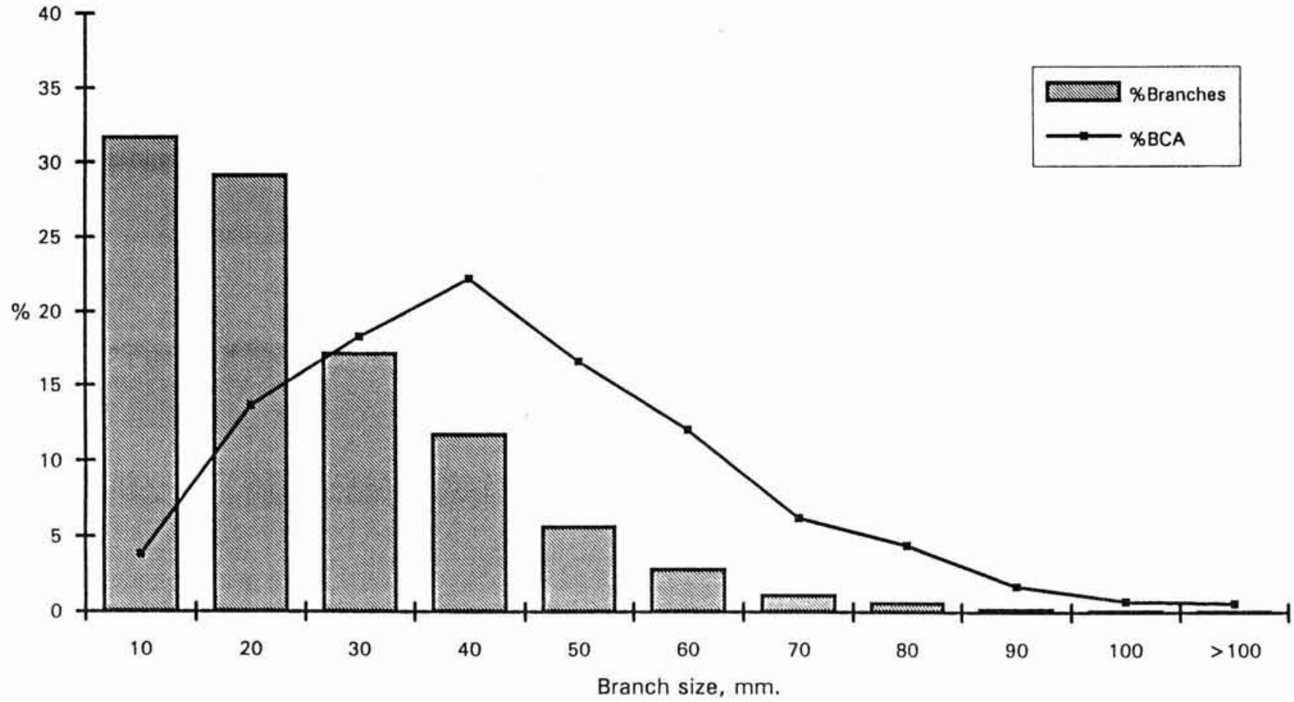

Figure 3 - Transition crop - branch size and branch cross-sectional area distribution

Table 6 - Young crop stand details

TREATMENT	YEAR	COMMENT
Planted	1962	2670 stems/ha
Low pruned (0 - 2.4 m)	1967	667 stems/ha
Medium pruned (2.4 - 4.2 m)	1970	395 stems/ha
High pruned (4.2 - 6.1 m)	1971	300 stems/ha
Thin-to-waste	1972	Residual 370 stems/ha
Production thinned	1980	Residual 210 stems/ha
Clearfelled	1989	Merchantable volume 588 m^3/ha

Based on data from Compartment 110 Rotoehu Forest.

The average merchantable tree size in the stand was 2.8m^3.

More of the larger branches are present, and reflect, to a degree, the previous silvicultural treatment (Table 6). The large branches and the increasing cross-sectional area of the branches at many of the whorls show that a proportion of trees within the stand are beyond the capacity of many of the Scandinavian and North American feed roll and stroke delimbers currently available.

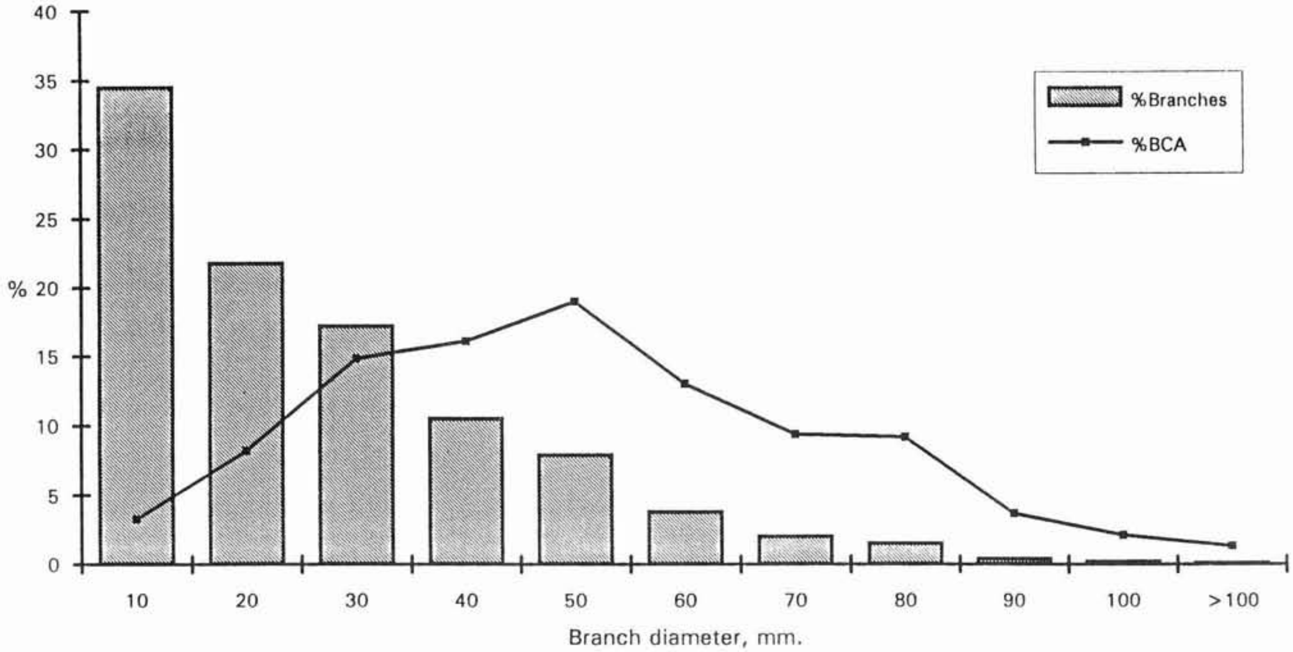

Figure 4 - Young crop - branch size and branch cross-sectional area distribution

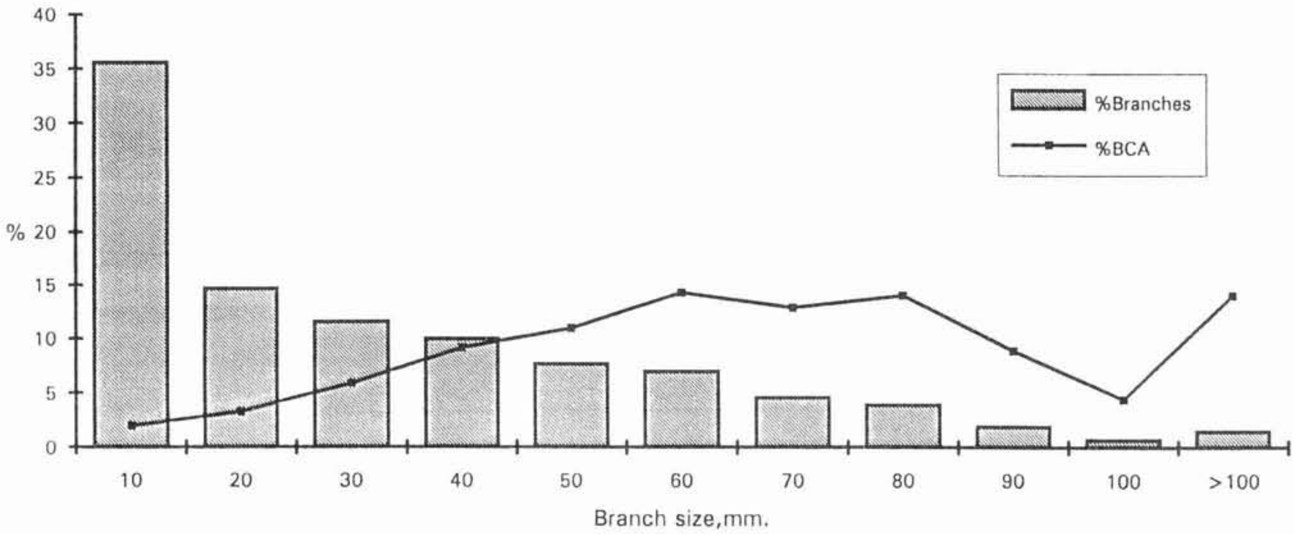

Figure 5 - Agroforestry stand - branch size and branch cross-sectional area distribution

Figure 5 shows the branching characteristics of trees grown under the regime described as agroforestry (Table 7). Agroforestry is "dual agricultural and forestry production on the same unit of land". This data was based on measurements of an agroforestry block in the coastal Bay of Plenty. The final crop stocking was variable, with low stocking on the ridges. Large numbers of small 1 and 2 cm branches were present, but the trees also contained a much higher percentage of very large branches than was shown in either Figure 3 or 4.

Table 7 - Agroforestry stand details

TREATMENT	YEAR	COMMENT
Planted	1972	400-500 stems/ha
High pruned, 6 m	Not known	Late scheduling
Thin-to-waste	Not known	150-200 stems/ha
Clearfelled	1991	Merchantable volume 300-350 m^3 ha.

Table 8 - Summary of tree characteristics (Mean ± SD). Transition, young and agroforestry crops

Stand type	Length to ca. 10 cm SED	DBHOB (cm)	Pruned height (m)	No. whorls (tree)	Av.distance whorls (m)
Transition	35.7 ± 4.3	49.9 ± 8.8	6.1 ± 0.8	44.6 ± 15.0	0.64
Transition	29.5 ± 5.7	41.7 ± 10.6	1.6 ± 2.4	47.2 ± 14.3	0.59
Young Crop	23.7 ± 4.6 *1	48.6 ± 10.5	5.2 ± 1.2	44.6 ± 9.4	0.57
Agroforestry	20.5 ± 2.5*2	44.4 ± 5.6	6.3 ± 1.2	25.2 ± 6.7	0.56

*1 Length not to a 10 cm top, but to trim length and head off at larger sed

*2 Contractors headed off at an average of 26.43 cm SED @ length 13.57 m

Table 9 - Feller/trimmer production rates - minutes/m^3

Crop type	Production (minutes/m^3)	Average extracted stem volume/m^3
Old crop	0.7	2.7
Transition (1)	3.7	1.9
Transition (2)	2.8	2.2
Young crop	2.9	2.8
Agroforestry	6.7	1.7

A summary of the average tree characteristics of two transition stands, one young crop and one agroforestry stand are shown in Table 8. The data is variable as are the stands sampled, and reflect the diverse silvicultural regimes that are current in New Zealand. The relatively short distances between branch whorls and the accompanying nodal swelling pose some additional problems for economic mechanised delimbing.

Fell and Trim Times

The effect of previous treatment, and silvicultural regimes on felling and trimming production is demonstrated in Table 9. This data was collected from time studies of motor-manual clearfelling operations in the Bay of Plenty over a number of years. Preparation time per m^3 using a motor manual system, rises from less than one minute for old crop radiata, to just under 7 minutes in an agroforestry type block. The range spans low work content due to older age, large piece size and little silvicultural management, through to high work content in young, widely-spaced, heavily-branched trees growing on highly fertile sites. Clearfelling of old crop will cease in the Bay of Plenty region in the near future and therefore will be omitted from further consideration.

MECHANISED PROCESSING

As discussed, a proportion of stands of trees grown under current management regimes are beyond the capacity of many delimbers on the market today. As an example, a Scandinavian publication (Skogsarbeten, 1985) presented information on tree size and the capacity of a number of Scandinavian two grip harvesters. The average tree size in final felling in large scale operations in Sweden was estimated to be 0.27 m^3, and in thinnings 0.13 m^3. Felling capacity of the machinery ranged from 56-60 cm, and their crosscutting capacity 50-56 cm. These machines are used in Australia for production thinning in radiata pine but not in clearfelling. Other delimbing machines that have been used in clearfell operations in Australia and may have potential here are the Koehring 618 and 628, Denis 3000 and DM 3000 and the Harricana Can-trac.

However, the regimes commonly practised in Australia differ from those in New Zealand as they are held at higher stocking longer and often include multiple production thinnings. In New Zealand, machines successfully operating in radiata pine thinnings are mainly Waratah DFBs, processors and harvesters. In clearfell radiata pine Denis DM3000 delimbers and the larger Waratah harvester have been successfully introduced. However, operations to date have been in stands of smaller tree size and lighter branching than typical young crop stands.

TREE CHARACTERISTICS THAT INFLUENCE HIGHLY MECHANISED SYSTEMS

Sophisticated harvesting machinery operate at an optimum within a very narrow range of conditions. Outside their optimum range, production will be affected and costs will increase. Continued operation at or near the machine's maximum capacity may lead to increased repair and maintenance costs. Limiting factors influencing production are tree size, stem characteristics and terrain conditions.

Variations in the management practices for radiata pine can reduce the available volumes for a dedicated harvesting system. This reduces the opportunity to consistently optimise machine performance. A review of these practices in New Zealand (Williams 1982), revealed that nearly 70 different silvicultural regimes were being applied. These many variations, coupled with site and fertility differences, together with varying abilities to meet silvicultural standards and prescriptions from establishment to final thinning have resulted in major differences between trees within a stand, and between forests and regions. These differences will manifest themselves in a number of ways, for example, pruned and unpruned, diameter range (piece size), size and location of branches, and degree of malformation. In total, these differences indicate a non-standard product.

Accurate detailed descriptions of the varied resource to be harvested appear to be a prerequisite for the successful introduction of full mechanisation.

Observations in Scandinavia, United Kingdom and Australia clearly show that

Table 10 - Number of whorls and internodal lengths in young crop radiata pine

No. trees	Height to 10 cm SED (m)	Pruned height (m)	No. whorls	Distance between whorls (m)
30	30.63 (SD 4.04)	5.17 (SD 1.19)	44.6 (SD 1.19)	0.57 m

stem straightness (lack of malformation) and light to moderate branch size (often dead) are positively correlated with the successful introduction of sophisticated highly mechanised harvesting systems. As an example, in Sweden the silvicultural regimes restrict branch growth and produce a piece size under 1.00 m^3 at clearfelling, conditions which suit the successful introduction of mechanised harvesting systems (Gilfillan et al, 1990). This approach has not been widely practised in New Zealand. The Scandinavian machines designed to process this crop are unlikely to succeed in one that is substantially different.

The incidence of sweep and malformation is likely to be less in future crops of genetically improved stock in New Zealand. However, current and proposed silvicultural regimes encourage large branches and branch whorls above the pruned zone in the direct pruned sawlog regime, and the development of relatively large branches to the forest floor in the minimum tending regime. Wider initial spacings and early thinnings are likely to compound the branch size problem.

Other radiata pine characteristics that may inhibit mechanised delimbing are nodal swelling and short average internodal distances. The following data were derived from field measurements in "young crop" radiata Compartment 110 Rotoehu Forest (Table 10).

Nodal swelling in the above stand averaged 2.06 cm (SD 1.48). Stem shrinkage 10cm from the top side of the nodal swelling averaged 0.58cm (SD 0.17 cm). At delimbing machine feed speeds of 3 m/second, frequent variations in stem diameter may make it difficult, if not impossible to achieve consistent flush trimming, and high levels of production. Other malformations will compound this problem.

DISCUSSION

Tree characteristics which will affect the efficiency of mechanisation are the degree of malformation, (stem straightness, multileaders), size of branches and whorls, total tree weight, nodal swelling and the presence or absence of pruning (influencing access by the processor head to the base of the stem).

By the turn of the century, logging operations in many future tree crops will be difficult to mechanise fully. The tree size and weight are likely to make controlled tree felling by feller buncher difficult to achieve and stem breakage will continue.

Many of the transition and "young" crop stands in parts of Kaingaroa Forest are about 40m in height at clearfelling. Felling by motor manual methods leads to stem breakage, and a high number of small, but merchantable pieces. From a recent sample of 50 felled trees in a transition crop stand in Kaingaroa Forest, 132 merchantable pieces were available for extraction. The fifty butt pieces amounted to 93.3% of the merchantable volume, and

38% of the pieces to be extracted. The remaining logs, after the first major break point, amount to only 6.7% of the volume but 61.7% of the merchantable pieces to be recovered. This result is similar to that of a study by Twaddle (1987). Mechanised felling and bunching may reduce the amount of breakage due to its greater ability to control the direction of the tree's fall.

The cost of processing the large number of short lower logs will be high, and probably outside the capabilities, physically and economically, of current mechanical delimbing equipment as many of them are not designed to process short lengths (less than 6.0 m). In any clearfelling operation the processing and handling of multiple small pieces adversely affects production.

Lower initial stockings and heavier earlier thinnings will result, not only in large trees but also large branches and heavy whorls. Whilst it has been observed and noted that some delimbing machines can remove substantial individual branches (70-90 mm), the cumulative effect of several of these branches in one whorl is generally enough to test the limits of the delimber's capabilities. If this type of very heavy work occurs with sufficient frequency, it may adversely affect the level of repairs and maintenance required.

The estimated average size of our future crops of radiata is 2.0 m^3 on a 30-year rotation on medium to high fertility sites. Some trees within the final crop will weigh in excess of 4 tonnes and this weight, together with heavy branching characteristics makes the full mechanisation of harvesting operations seem unlikely. From a health and safety aspect the mechanisation of harvesting is a highly desirable option. To achieve full mechanisation of harvesting operations would require a shift of stance on the part of the silviculturalist.

It also seems unlikely that machinery manufacturers will vary their production lines to accommodate the relatively small New Zealand market. The production of a small number of sophisticated and suitable harvesting machines would be costly.

Wambach (1969) proposed the theory that a discussion on the relationship between mechanisation and silviculture might be approached from two different directions:

1. How can we accomplish our silvicultural goals better by taking advantage of mechanisation? This is, what new equipment is needed, how can we improve our methods, what efficiencies are possible?

Or

2. How will we have to modify our silvicultural goals and practices to accommodate mechanisation? How should we establish, care for, and harvest our forests so that we can reap the maximum benefits from the efficiencies associated with mechanisation?

Wambach continues *"that the distinction between the two approaches is, in fact, quite basic. In the first case we operate from the assumption that silvicultural requirements are known and fixed, mechanisation is a tool which may help accomplish silvicultural objectives. In the second case, silviculture is flexible and adaptable to management goals; mechanisation is a real and controlling factor in management decisions and becomes a management goal which dictates silvicultural practice."*

These are two opposing philosophies. New Zealand forestry has tended towards the first option, hoping that technological advances in harvesting will efficiently process what the silviculture has produced.

CONCLUSIONS

Current silvicultural practice in New Zealand of relatively low initial stockings, followed by early thinnings to waste while ensuring rapid growth rates will also ensure large branch sizes. The branching and form characteristics of radiata pine make it a difficult species to delimb mechanically. This applies to both production thinning and clearfelling.

It is desirable because of economic and social considerations to increase the rate of mechanisation in our harvesting operations. We are faced with a technically difficult task. Our chosen silvicultural path has ensured that our future harvesting system options are limited. The New Zealand forest industry may have to continue with motor manual operations which leave little room for major gains in efficiency and safety.

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