PHYSICAL PROPERTIES, RESIN CONTENT, AND TRACHEID LENGTH OF LODGEPOLE PINE GROWN IN NEW ZEALAND

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ABSTRACT

Two increment cores were taken at breast height from 50 trees of **Pinus contorta** Dougl. on each of 16 sites, to assess variations in outerwood density between trees and between sites. On the basis of this preliminary survey five trees, stratified with respect to stem diameter and wood density, were felled on each of eight selected sites for detailed examination of wood physical properties, resin content and tracheid length. Most attention was directed towards two "green strains" (of subspecies **contorta** Critchfield) derived from Cpt 2 Waiotapu Forest (origin unknown) as one seed source, and from seedlot R26/26 (Manning Seed Co., Washington) as the other, though other stands of the same subspecies and of "yellow" strains (subspecies **murrayana** Critchfield) were also examined. No other seed source is producing wood with properties markedly superior to that of the two preferred "green" strains. Of the two, the "Manning green strain" is producing consistently denser wood than the "Waiotapu green strain", and the wood is not inferior in other respects. In general the wood density of trees grown on sites with low mean annual temperatures is lower than that produced on warmer sites: densitometer studies show that this is mainly due to the production of low density latewood on cold sites. The resin content of **P. contorta** is rather high (average more than 3%) which may restrict its use for groundwood pulp. In other respects its wood properties are those of a general-purpose softwood very suitable for sawn timber or chemical pulping.

INTRODUCTION

Present plantings of lodgepole pine (*Pinus contorta* Dougl.) in New Zealand occupy more than 26,000 acres in pure and mixed stands. Historically the species was used fairly extensively during the planting boom of the thirties as an alternative to radiata pine (*Pinus radiata* D. Don) on cold wet sites. About 80% of the present crop was established between 1926 and 1945. Later plantings were less extensive, averaging less than 150 acres per annum between 1945 and 1960. Nevertheless good growth of some seed lots in high altitude forests such as Karioi has revealed the value of lodgepole pine on cold sites and some conservancies have indicated that it could amount to 10% of future plantings.

The mixed results obtained with the species in the past have arisen in part from the use of an ill-defined range of subspecies and provenances, that has given rise to very broad phenotypic variation. Stands from inland origins within the USA — the so-called "yellow" forms*, tending towards subspecies *murrayana* (Critchfield, 1957) — are usually unimpressive in rate of growth, though some are of good general form. The "green" strains, derived from the Pacific coast and low elevations, corresponding to Critchfield's subspecies *contorta,* are more vigorous, but often show malformation on hard sites and are prone to windthrow. However, superior individuals are not uncommon even on the hardest sites.

Experience overseas (Panshin *et al.,* 1964) indicates that the wood properties of *P. contorta* qualify it for the category "general-purpose softwood". Sawn timber has been used for light timber construction, railway sleepers, and dressing lines. The timber also pulps satisfactorily by the sulphate, sulphite, and mechanical processes, though the proviso "if of low resin content" has sometimes been applied to its use for processes other than kraft pulping. Some limited tests of lodgepole pine timber in New Zealand have indicated similar properties (Hinds and Reid, 1957) but it is obvious that the complexities of provenance and the reactions of trees to a wide range of growing conditions require much more work to be done before an adequate assessment can be made.

This paper describes a survey of the physical properties of New Zealand-grown lodgepole pine timber, produced from several seed sources and growing on as wide a range of sites as could be found amongst existing stands (Table 1). In the course of the survey sufficient material was collected for limited mechanical testing and for studies of pulp and paper making characteristics: these two aspects will be reported separately.

In selecting trees and stands for examination it seemed realistic to concentrate on the two "green" forms that appear to have the greatest forestry potential. "Yellow" forms were also examined in a number of forests in case they should prove to have wood properties that would meet some outstanding need, so that their continued use in forestry might be justified despite their less vigorous growth. The two green forms are:

(a) Seed lot R26/26, supplied by the Manning Seed Co. of Washington, and first planted in 1928. This is the strain of the formally approved seed stand R/B18. It is a vigorous but fairly coarse tree, reputed to be frost resistant. The origins of this seed lot are believed to be coastal and probably more northerly than
(b) Seed derived from Compartment 2 Waiotapu Forest (origin unknown). This form is almost certainly of low elevation coastal origin though its large, serotinous, and knobby cones are atypical of the coastal subspecies described by Critchfield (1957). On favourable sites its form is somewhat superior to (a) above, but it is reputed to be more prone to malformation on cold sites. This is the strain of seed stand R/B9.

Besides assessment of physical properties such as wood density, moisture content, shrinkage, growth rate and latewood development, two other properties were examined and are reported in this paper. The first of these, resin content, appears to be an

* The terms "form" and "strain" will be used for convenience in this paper to refer to broadly grouped geographical origins that occur as commercial seed collections.

TABLE 1—Details of sites examined

Site No.	Forest	Cpt	Age yr	Latitude °S	Altitude m	"Green" or "Yellow" strain	Source of Seed	Remarks
1	Kaingaroa	51	40	38.30	400	Green	Manning Seed Co., Wash.	Light thinning
2	"	115	32	38.30	450	"	Waiotapu	Unthinned
3	"	211	32	38.30	550	Yellow	Klamath	"
4	"	274	38	38.40	600	Green	Manning Seed Co., Wash.	"
5	"	275	36	38.40	600	Yellow	Canada	"
6	Karioi	8	40	39.20	650	Green	Manning Seed Co., Wash.	"
7	"	19	32	39.20	650	"	Waiotapu	Heavily thinned
8	"	25	39	39.20	850	"	Manning Seed Co., Wash.	Light thinning
9	Golden Downs	56a	33	41.30	250	"	Waiotapu	Mixture with redwood
10	"	56b	35	41.30	250	Yellow	Shuswap Lake	Unthinned
11	"	7	33	41.30	650	"	Klamath	"
12	Eyrewell	23	39	43.20	150	Green	Manning Seed Co., Wash.	
13	"	38	37	43.20	150	Yellow	Shuswap Lake	Open grown
14	Naseby	17c	33	45.00	750	Green	Waiotapu	Thinned 4 yr
15	Beaumont	33	32	45.50	50	"	—	Unthinned
16	"	14c	33	45.50	550	"	—	Thinned 1 yr

important intraspecific variable of lodgepole pine grown in North America, and was therefore included in this study because of its importance for pulp and paper manufacture as well as for its influence on wood density. The other property, tracheid length, was included in this part of the study mainly because it is recognised as an important source of wood quality variation, and the wide range of material collected during the survey provided an excellent opportunity to examine this feature at the same time.

MATERIALS AND METHODS

An extensive survey of wood density variation using increment cores followed the techniques described by Harris (1965). This was followed by felling and detailed analysis of selected trees using the methods of Harris and Orman (1958). As a brief summary the main features of this sampling system were:

(1) Two increment cores were taken from each of 50 randomly selected trees in each stand, avoiding only extremely malformed or moribund stems. In the laboratory the 10 outer growth layers were dissected from each core, measured for radial width, and basic wood density estimated either as oven-dry weight divided by green volume, or by the method of maximum moisture content.

(2) On the basis of this preliminary survey five trees from each of eight selected stands were chosen to provide a sample stratified with respect to wood density and stem diameter, e.g., the trees could include one with high wood density, one with low density and three about the mean value for the stand: at the same time their diameters should be representative of those in the stand, and their mean diameter was required to be within $\pm$ 1 cm of the mean for the stand.

(3) Detailed measurements were made on all selected trees and, after they had been felled, cross-sectional discs were cut from the butt, from breast height (b.h. = 1.4 m) and from stem internodes corresponding to the level of the apical shoot at 5, 10, 15 etc, yr after planting. These discs are hereafter referred to as the 5th, 10th, 15th, etc. internodal samples.

(4) Diametrically opposed sectors cut from butt, 10th, 20th, etc. internodal samples were divided into heartwood and sapwood sections.

(5) Similar sectors cut from breast height, 5th, 15th etc. internodal samples were divided from the pith outwards into 5-ring sections. These were made rectangular in shape to facilitate measurements of dimensional shrinkages that were made on these sections only.

(6) Wood density in the green condition was measured only on samples from the North Island trees that could be examined immediately after felling. The time required to transport South Island material to the laboratory made measurements of green density impractical. Basic density and air-dry density were measured on all samples as were volumetric shrinkages to the air-dry and oven-dry conditions. Detailed analyses of density variations within annual growth layers were made with a beta ray densitometer (Harris, 1969).

(7) Tracheid length (average of 50 tracheids — Harris, 1966) was measured at regular intervals across one stem from each stand, but only at the mid-point of the corewood and at the 25th growth layer in the remaining four trees.

(8) Resin content was determined by methanol extraction of finely ground wood pre-

pared from matched sectors of heartwood and sapwood, which were extracted separately.

(9) Botanical specimens were collected from all felled trees and were preserved to provide identification if the systematic position of the species or subspecies should be revised at some future time.

The use of stem sectors for many of the measurements described above is a device used to ensure that sample dimensions are proportional to the volumes of the wood they represent in the total stem or log. Thus, when properties such as density or resin content have to be summarised, disc average values can be weighted by volume, and an average value for the entire commercial stem can be derived quite simply.

RESULTS

The stem and growth characteristics of trees felled for detailed examination of wood properties are summarised in Table 2. Besides the conventional stem measurements, details of the heights from which internodal samples were cut are also tabulated in the five right hand columns of Table 2. These approximate to height increments by five-yearly intervals up to 25 yr after planting. The data suggest that the "Waiotapu green strain" (sites 2, 7, 9 and 14) grows more slowly over the first five years than the "Manning green strain" (sites 1 and 18). After this initial period both green forms show approximately equal height increments. This feature of growth rate over the first five years after planting could be of importance on sites where weed competition necessitates frequent release cuttings.

TABLE 2—Average stem and growth characteristics of trees felled for testing on each site

Site No.	Total Height m	D.b.h. o.b. mm	Crown Depth m	Height (m) to i.b. diameter (mm) 200	150	100	Height (m) to centre of internodes above ground 5	10	15	20	25
1	30.5	330	10.1	14.0	19.8	23.5	3.0	8.8	13.7	18.0	22.3
2	24.4	287	9.8	7.6	12.2	18.6	1.5	5.2	10.4	15.5	20.7
8	18.9	206	8.8	0.9	5.8	10.7	2.1	6.1	9.8	13.1	15.8
7	19.8	376	10.7	11.9	14.9	16.5	1.8	6.1	11.3	15.5	17.7
8	25.3	338	13.4	8.8	15.2	18.5	2.4	6.4	10.7	14.3	17.4
9	22.9	246	9.4	5.2	10.4	16.8	2.4	7.6	12.2	16.8	20.1
10	20.1	203	9.4	2.1	6.4	11.9	2.1	7.0	10.4	13.7	16.5
14	18.3	325	11.3	8.5	11.5	14.3	1.2	6.1	9.4	12.2	15.2

The small dimensions of trees of the "yellow" strains on sites 3 and 10 are also apparent from Table 2, though both of these stands were, in fact, selected to represent the more vigorous forms of subspecies *murrayana.*

Wood Density

Results of the initial survey of wood density using increment cores are summarised in Fig. 1. Differences between stands revealed by this study strictly relate only to the density of the outer 10 growth layers of trees at breast height although it is usually assumed that this value is related to the average density of the merchantable stem. The

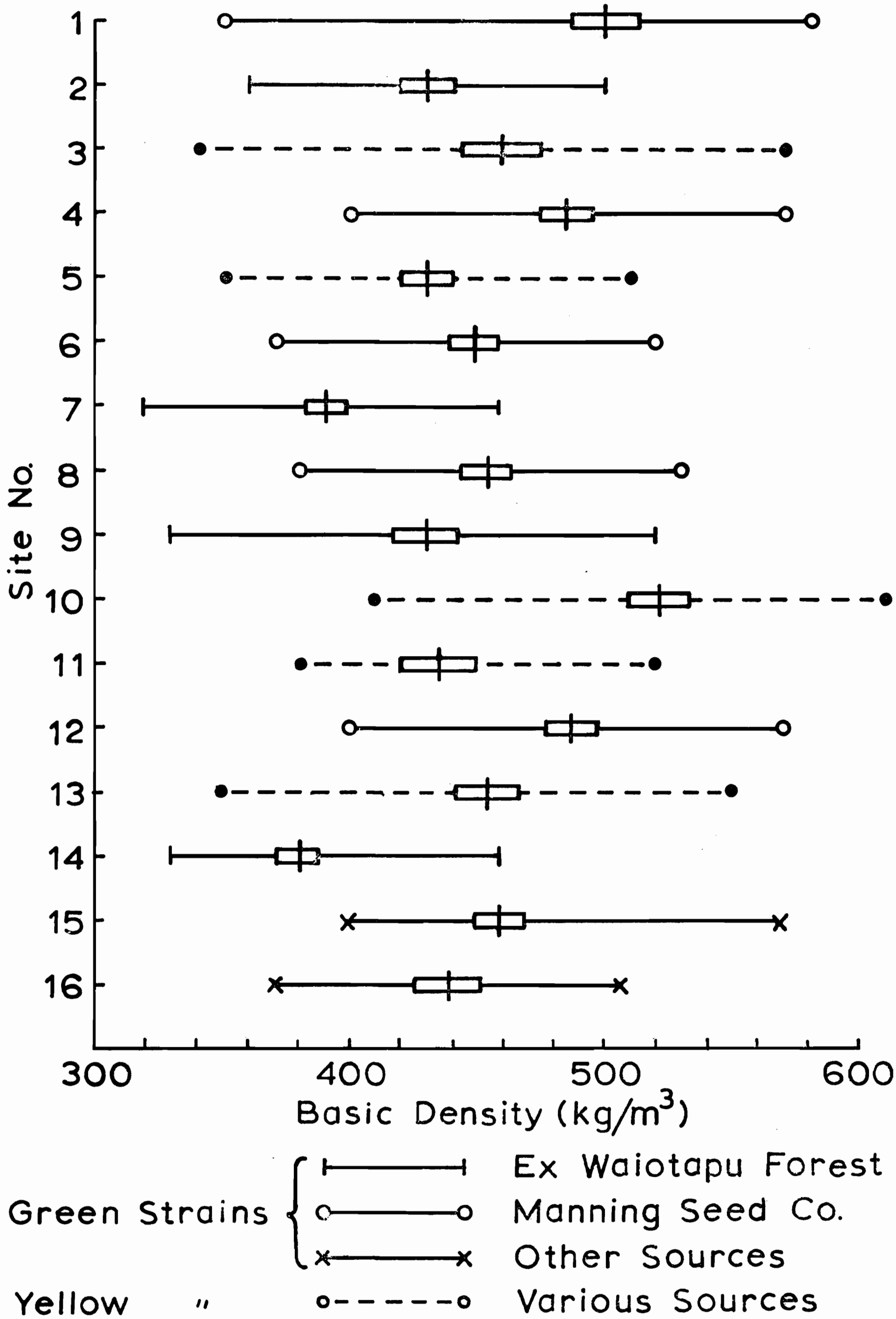

FIG. 1—Range of wood density of the outer 10 growth layers at breast height for each site. Each vertical line is at the mean value: the boxes represent two standard errors on either side of mean values.

justification for this assumption is provided by Fig. 2 in which average stem density to 100 mm diameter inside bark is related to outer wood density at breast height for all trees so examined.

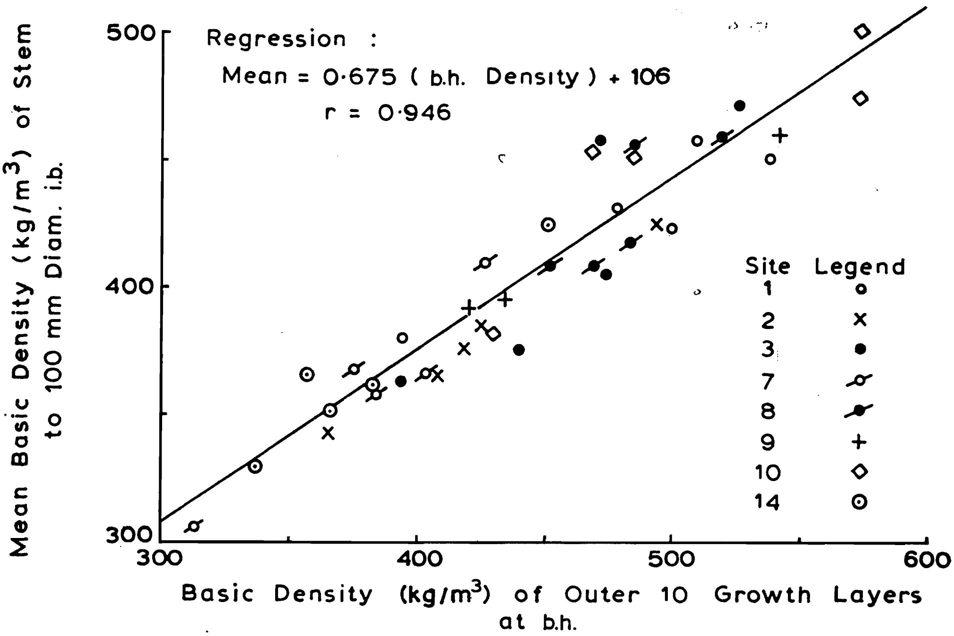

FIG. 2—Relationship between density of the 10 outer growth layers at breast height and weighted average density of the merchantable stem to 100 mm diameter i.b.

Not only is there a close relationship between these two parameters within each group of five trees, but analysis of the regression coefficients for individual sites showed that there was no significant difference between stands in this respect, irrespective of seed source or environment, and therefore the common regression line can be used for all.

Consequently, differences between the outer wood densities of stands shown in Fig. 1 are in fact also indicative of their average wood densities. From this it can be deduced that the "Manning green strain" (on sites 1, 4, 6, 8 and 12) consistently produces denser wood than the "Waiotapu green strain" (on sites 2, 7, 9 and 14). The other seed sources (green or yellow forms) also show considerable variability between sites, but none is producing wood of such outstanding density that it merits special consideration on this account. Even the very dense wood of the yellow strain on site 10 comes from trees so small that they would have no advantage in terms of "weight of wood per acre" over the more vigorous green forms.

There are some indications within the two main green forms that wood density is lower on the colder sites, i.e. sites at higher altitude or southerly latitude—a similar situation to that demonstrated for radiata pine in New Zealand (Harris, 1965).

Details of basic, air-dry, and green densities of wood from each site are presented in Table 3, and in Table 4 the radial development of four wood properties is examined

TABLE 3—Average physical properties of trees felled on each site

Site No.	Volume m^3	Heart %	Late-wood %	Moisture Content %	Weighted Mean Density kg/m^3			Percentage Shrinkage from Green							
								to Air-Dry				to Oven-Dry			
					Basic	Air Dry	Green	Vol.	Tan.	Rad.	Long.	Vol.	Tan.	Rad.	Long.
1	0.91	41	28	95	429	523	835	8.6	4.8	3.2	0.04	13.2	7.8	4.6	0.07
2	0.62	32	25	136	379	463	893	6.9	4.4	2.2	+ 0.11	13.1	7.0	3.6	0.02
3	0.19	18	29	117	425	517	914	6.9	4.1	2.4	0.00	12.0	7.4	4.4	0.11
7	0.91	23	20	146	362	439	889	7.6	4.5	2.0	+ 0.09	11.9	7.4	3.5	0.04
8	0.77	38	23	99	431	527	857	8.2	4.6	2.5	+ 0.09	12.9	7.7	4.3	0.04
9	0.46	29	28	—	416	496	—	5.9	3.9	2.0	+ 0.02	10.9	7.2	4.2	0.13
10	0.22	27	32	—	453	550	—	7.8	4.4	3.0	+ 0.17	12.3	7.6	5.3	+ 0.10
14	0.59	20	21	—	367	439	—	6.5	4.2	2.0	+ 0.21	10.7	6.6	3.6	+ 0.03

TABLE 4—Variation of wood properties from pith to bark

	No. of Growth Layers from the Pith					
Site No.	1-5	6-10	11-15	16-20	21-25	26-30
A. Basic density (kg/m³)						
1	420	410	430	440	450	480
2	390	380	390	410	430	
3	400	410	420	440	470	
7	380	360	360	380	380	
8	420	400	420	440	460	460
9	410	400	420	450	480	
10	430	440	450	480	510	
14	390	370	360	380	400	370
B. Radial growth rate (ring width in mm)						
1	7.1	5.3	3.4	3.0	2.0	1.5
2	6.4	6.0	3.6	2.9	2.8	
3	4.9	4.4	2.4	2.0	1.2	
7	6.9	6.5	5.8	5.8	5.8	
8	5.8	4.4	3.5	3.0	2.6	2.5
9	5.3	5.0	3.0	1.8	1.3	
10	4.5	3.3	2.0	1.6	1.5	
14	6.1	5.1	4.7	3.3	3.2	7.3
C. Percentage of latewood						
1	19	24	28	29	32	37
2	17	21	27	30	34	
3	22	29	29	32	30	
7	12	18	19	26	23	
8	14	18	21	24	26	27
9	19	23	28	34	37	
10	23	30	31	38	38	
14	16	19	20	25	27	24
D. Volumetric shrinkage from green to air-dry (%)						
1	7.3	7.6	8.3	9.0	9.6	9.8
2	5.9	6.0	6.8	7.7	8.5	
3	5.5	6.1	7.2	7.5	8.2	
7	6.9	7.3	7.4	8.3	8.0	
8	7.1	7.7	7.9	8.3	8.6	9.1
9	4.7	5.3	5.9	6.6	6.8	
10	6.6	7.2	8.0	8.4	8.6	
14	5.4	6.0	6.4	6.4	7.8	7.3
E. Latewood ratio (and within-ring density range (kg/m³))*						
1	0.34	0.31	0.39	0.42	0.45	0.50
	(390-690)	(310-720)	(350-710)	(380-700)	(390-690)	(400-680)
2	0.36	0.36	0.41	0.47	0.56	
	(390-670)	(340-690)	(360-700)	(390-710)	(400-720)	
7	0.33	0.33	0.33	0.33	0.34	
	(390-590)	(320-640)	(300-650)	(300-650)	(290-650)	
8	0.30	0.26	0.35	0.38	0.41	0.42
	(410-680)	(340-680)	(370-660)	(400-660)	(400-660)	(400-650)
9	0.31	0.37	0.45	0.44	0.46	
	(330-600)	(300-660)	(300-620)	(310-600)	(320-600)	
14	0.33	0.33	0.35	0.38	0.47	0.27
	(350-500)	(310-510)	(320-510)	(330-520)	(360-520)	(300-530)

* Estimated at centre of each group of five growth layers

from pith to bark by the summarised results of all internodal samples. That is to say that "1-5 growth layers from the pith" refers to the average value for this growth zone at all heights in the stem.

Pith to bark trends in the development of average wood density provide useful information on the extent of corewood formation and the variability that will be encountered in wood products of all sorts. The limitation to this form of analysis is that the basic causes of density variation are largely obscured by the use of "whole ring" values. The true nature of differences in wood density between the "Manning" and "Waiotapu" green forms of lodgepole pine showed up very clearly under detailed analysis with the beta-ray densitometer. This permits the contributions of earlywood and latewood densities and also the ratio of latewood in each annual growth layer to be considered separately (Harris, 1969).

Three density values were measured for each growth layer. These were the maximum density (normally recorded in the outermost latewood), minimum density (usually in the first-formed earlywood), and mean density. When plotted against the number of the growth layer counted from the pith (Figs. 3 and 4) the data provide a graphical illustration of the "limiting envelope" of wood density about the line for radial variation in "whole ring" mean density. All samples were extracted with methanol before they were run through the densitometer.

As experience accumulates in interpreting graphs of this type, certain features are found to be common to most pines (Harris, 1969):

(1) Maximum (latewood) density values increase more or less abruptly from the pith outwards but soon tend to settle at some value that remains nearly constant from the corewood outwards. Values for maximum density usually show much greater variability between adjacent growth layers than do the corresponding values for minimum density.

(2) Minimum (earlywood) density values usually decrease over the first two to four growth layers from the pith but thereafter remain constant or may slowly increase and settle at some value which remains fairly constant outside the corewood.

(3) As might be expected from the general appearance of the wood, sites in which physiological stress is a recurrent feature produce wood with greater density variations between successive growth layers, than sites with near-optimum growing conditions. In New Zealand, stands likely to suffer "physiological stress" would include those in Canterbury subject to föhn winds and those in central Otago subject to frosts during the growing season.

These various features can be seen as recurrent themes in the graphs of Figs. 3 and 4. The four graphs of Fig. 3 are all of the "Waiotapu green strain" but each graph represents a different site. Despite the superficial similarities there are important differences among the graphs that can be interpreted in terms of environmental variables:

Site 2. Unthinned but vigorous trees: a steep increase in mean density implies high "latewood ratio" (Harris, 1969) as the mean value approaches the line for maximum density in outer growth layers. (Note that all trend lines have been drawn as smoothed curves and short-term variations in density have been ignored.)

Site 7. A very fast-grown stand: minimum density remains low; latewood ratio

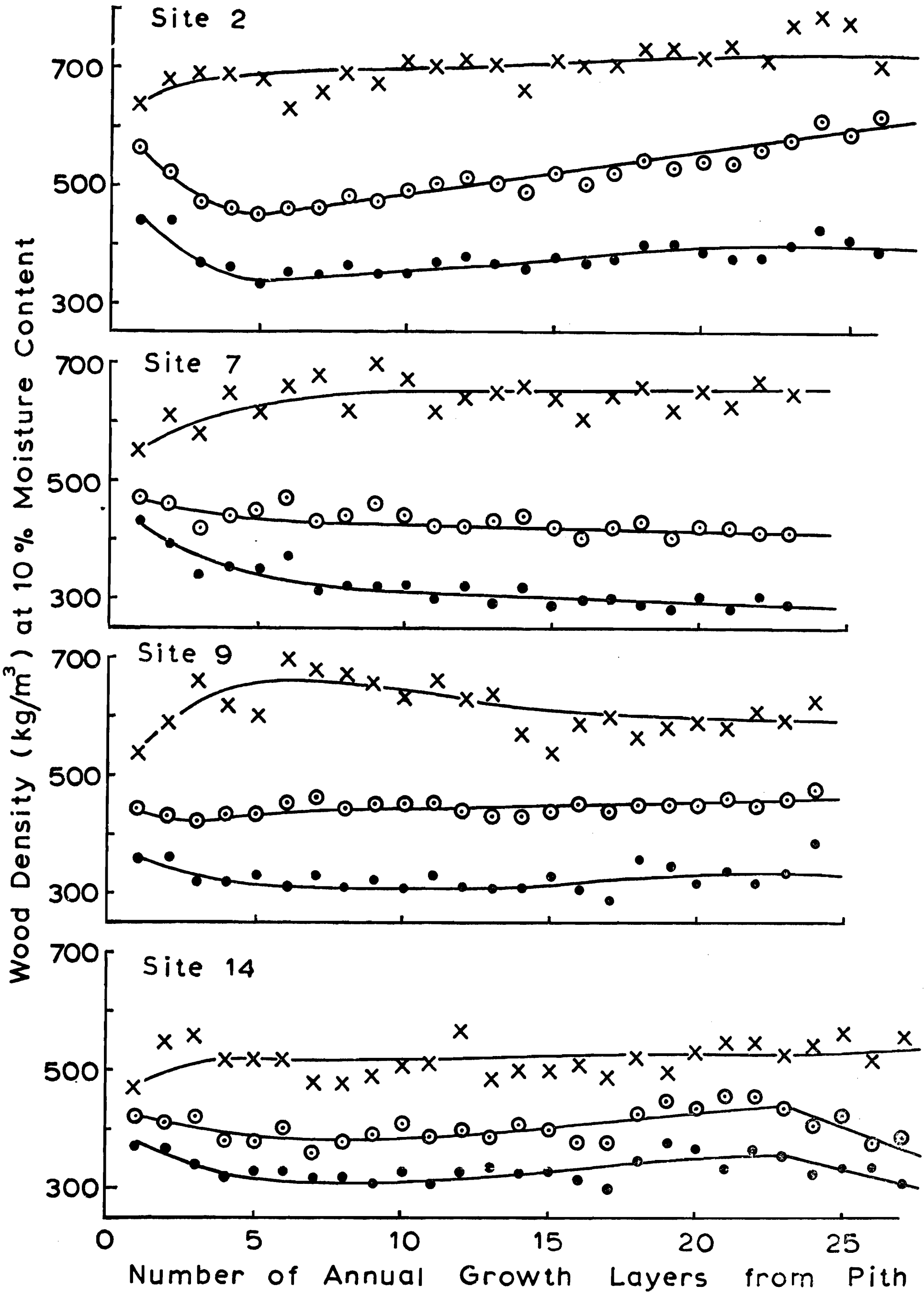

FIG. 3—Radial patterns of (methanol extracted) wood density variation on four sites planted with the "green" strain of lodgepole pine from Cpt 2 Waiotapu Forest. The upper line of each set represents maximum density, the centre line mean density, and the lower line minimum density of each growth layer: average values for five trees on each site.

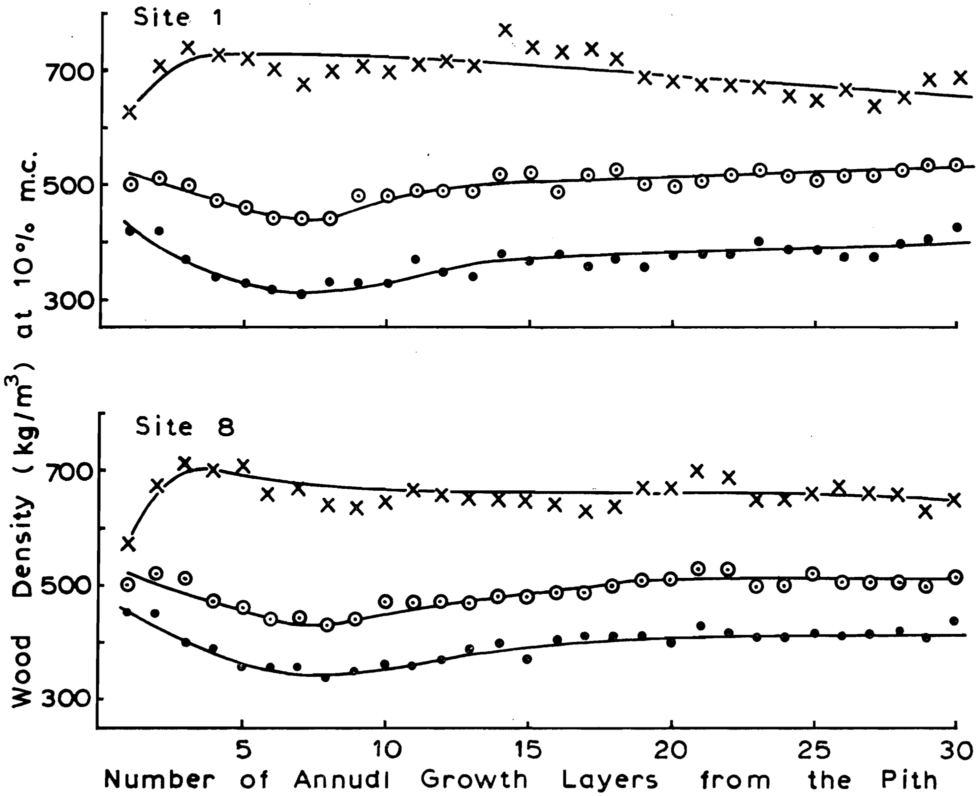

FIG. 4—Radial patterns of (methanol extracted) wood density variation on two sites planted with the Manning "green" strain of lodgepole pine. The upper line of each set represents maximum density, the centre line mean density, and the lower line minimum density of each growth layer: average values for five trees on each site.

increases less rapidly and maximum density values are lower than on site 2.

Site 9. Trees unthinned and slow-grown over the last 10 yr: the densitometer may fail to register maximum density in narrow growth layers (Harris and Polge, 1967) so that the apparent decrease in maximum density of the outer growth layers could be exaggerated. Otherwise site 9 resembles site 2.

Site 14. The "hardest" site of all: all density values are very variable; maximum values remain low; minimum and mean density decrease sharply following the thinning which was done four years before felling.

These results suggest the following broad trends in development of wood density:

(1) Earlywood (minimum) density tends to remain lower in the outer wood of fast-grown trees than in slow-grown trees. It also decreases as rates of growth increase following thinning.

(2) Maximum density values tend to vary widely in successive growth layers. This probably reflects the differences that appear visually in seasonal development of latewood. Maximum density is lower on cold sites than on warm ones, but is

apparently less affected by growth rates than is minimum density (assuming that the apparent decrease on site 9 is attributable to the limitations of the apparatus).

(3) Mean density is obviously affected by the other two values but tends to approach the maximum value when growth is slow, which indicates an increase in latewood ratio (Harris, 1969). This also implies that fast growth is achieved by the formation of proportionately more earlywood than latewood.

The graphs of Fig. 4, which are both for the "Manning green strain", substantiate these general observations, yet at the same time they have a family resemblance which differentiates them from those of the other green form in Fig. 3. The trees of site 12 (Eyrewell) were unfortunately clearfelled between the time of the initial survey and the return visit when they would have been examined in greater detail, so that no record is available of the effect of föhn winds on green strains of lodgepole pine.

Radial Growth Rates (Rings per inch)

Lodgepole pine is often regarded as a species in which initial growth is reasonably fast, but in which both height and diameter growth slow down abruptly after 15-20 yr. The data of Table 2 confirm that some reduction of height increment can be expected after 20-25 yr, but some of the stands examined in this study equally suggest that the full potential of this species for diameter growth has been realised in very few instances. This may be partly due to the natural reluctance of foresters to open up stands of a species known to be prone to windthrow. The large diameters produced on site 7 have arisen almost by accident—in that a green strain was under-planted to an under-stocked area of a yellow strain, which acted as a nurse crop but offered no competition once the green strain had achieved dominance. The remarkable response to thinning on site 14 (Table 4b) was achieved through more deliberate silviculture: all malformed stems in the stand were poisoned, leaving about 120 well-formed stems per acre which responded immediately. These two instances clearly illustrate the readiness with which the Waiotapu green strain, at least, will respond to silviculture.

Effect of Radial Growth Rates on Wood Density

The effect of growth rates on wood density has already been referred to when interpreting the response to thinning shown on the densitometer records for site 14.

The short term response to silvicultural treatment often differs from the effect of growth rate in the long term. Short term effects may be due to a sudden increase in available soil water (e.g. via root grafts with a felled tree) or to a sudden increase in wind sway and so on. A more general analysis of the relationship between growth rate and outer wood density at breast height for 50 trees in each stand was made possible by comparing the lengths of increment cores obtained in the course of the initial survey with basic density of the wood.

The results are summarised in Table 5 and show a situation somewhat similar to that in radiata pine (Harris, 1965; Table 2). Although growth rate can be shown to be significantly and inversely related to wood density on the majority of sites, the relationship is nowhere so strong that reduction of growth rates would be recommended in the interest of increasing wood density. Considering all sites together, rather less than 20% of the total variation in wood density can be accounted for in terms of radial growth rate ($r^2 = 0.18$).

TABLE 5—Effect of growth rate on wood density of the outer 10 growth layers at breast height

Site	Mean D(1)	Mean L(2)	No. of Trees	Regression	Residual Mean Square	F
1	500	23.9	50	D = 466 + 1.40L	2.08	—
2	430	37.0	50	D = 491 — 1.66L	0.99	8.6
3	460	26.7	50	D = 438 + 0.83L	2.82	—
4	484	21.0	50	D = 542 — 2.73L	1.48	3.8
5	429	21.9	50	D = 429 — 0.00L	1.08	—
6	450	34.2	50	D = 505 — 1.65L	1.17	5.6
7	392	71.9	50	D = 399 — 0.10L	0.09	—
8	455	36.0	50	D = 463 — 0.22L	1.36	—
9	428	25.6	50	D = 540 — 4.35L	1.15	25.7
10	522	25.1	50	D = 589 — 2.74L	1.93	4.0
11	434	21.2	49	D = 392 + 1.96L	2.67	1.4
12	487	24.0	50	D = 584 — 4.05L	1.16	15.2
13	455	26.8	50	D = 541 — 3.20L	1.35	23.4
14	380	39.8	50	D = 420 — 1.01L	0.77	5.4
15	461	30.5	50	D = 480 — 0.64L	1.23	1.2
16	439	34.7	50	D = 526 — 2.50L	1.37	9.6
All Sites	450	31.3	799	D = 500 — 1.64L	2.34	173.9

(1) D = Basic density (kg/m³) of the outer 10 growth layers at breast height
(2) L = Length (mm) of increment cores from bh containing the outer 10 growth layers

Moisture Content

The average moisture content of the merchantable stems of all North Island trees felled for examination of physical properties is presented in Table 3. Trees of the Waiotapu green strain (sites 2 and 7) appear to have a much higher moisture content than those of the Manning green strain (sites 1 and 8), but this is partly due to the greater age and higher heartwood content of the latter. The moisture content of heartwood is similar for all the sites examined (average 48%), but the sapwood of the Manning green strain does have a lower moisture content (134%) than that of the Waiotapu strain (170%). This may be related directly to differences in density, and when the water in sapwood is expressed as "percentage saturation" the value (85% saturated) is the same for both.

Shrinkage

The data in Table 3 summarise volumetric and dimensional shrinkages from green to the air-dry and oven-dry conditions. Transverse shrinkage values (tangential and radial) are slightly greater than in radiata pine but rather less than in *P. nigra* Arnold (laricio) (Hinds and Reid, 1957). Longitudinal shrinkage is usually very small, and slight longitudinal expansion ("+" values in Table 3) is not uncommon on drying to 12% moisture content (air-dry). Longitudinal shrinkage was never observed to exceed 1% in wood adjacent to the pith, although corewood shrinkage was larger than outerwood shrinkage in a few stems so that some distortion on drying could occur. Overall shrinkage values do not, however, suggest that any great difficulties will be encountered during seasoning. The most likely source of distortion is one that is not readily assessed in the laboratory — that which arises from grain deviations around knots and nodal swellings. As some forms of lodgepole pine are rather prone to these defects (Hinds and Reid, 1957) their possible effect on dimensional stability in sawn timber should not be overlooked. Variations in shrinkage across the stem radius from pith to bark (Table 4D) are small. This feature also favours minimal degrade as the result of drying.

Latewood

Percentage latewood, measured visually on the cut surface of sample discs, is summarised in Table 4C. The value of measuring percentage latewood in soft pines and species lacking an abrupt transition from earlywood to latewood has been questioned by several writers recently (e.g. Harris, 1967; Elliott, 1970). The use of "latewood ratio" derived from densitometer records and expressed as,

(Mean density — minimum density) ÷ (Maximum density — minimum density)

has been suggested as an alternative (Harris, 1969). This essentially descriptive parameter requires to be used in conjunction with data for the density range to which it is applicable if correlations are sought with other properties, hence the maximum and minimum density values in the corresponding growth layers are also included in Table 4E.

Heartwood

The heartwood content of lodgepole pine is greater than that of the other major exotic pines grown in New Zealand with the possible exception of *P. strobus* L. The values summarised in Table 3 are difficult to compare because trees of the Manning green strain on sites 1 and 8 are older than trees of the Waiotapu green strain. If rate of heartwood formation approximates 1% per annum in trees of this age, which is not unlikely, then the trees of the Waiotapu strain on site 2 will contain as much heartwood as trees of the other strain when they reach the same age. However, differences between stands of the Waiotapu strain, all aged 32 or 33 yr, are quite considerable. Sites 7 and 14 have produced much less heartwood than sites 2 and 9, but there is insufficient evidence to decide whether this is a direct consequence of the greater degree of exposure and lower mean temperatures on the two former sites.

Resin Content

The results of methanol extraction of heartwood and sapwood samples from all felled trees are given in Tables 6 and 7. Variability between trees within any site was large enough to prevent any firm conclusions concerning differences between seed sources or between sites, but the following features are worth noting:

(1) The high average resin content recorded from all sites may lie towards the limit of what is acceptable for mechanical pulping.

(2) The two yellow strains examined (sites 3 and 10) have the highest heartwood resin contents.

(3) Both sites in Karioi Forest (7 and 8) are producing very resinous sapwood, though there is no obvious reason why this should be so, and it may be a fortuitous result of the rather limited sampling.

TABLE 6—Average resin content of the wood examined from each site

Site No.	Resin Content (%) Heart	Sap	Average
1	4.8	2.2	3.3
2	3.6	1.8	2.4
3	7.0	2.4	3.2
7	6.0	3.8	4.3
8	4.2	3.8	4.0
9	5.4	1.9	2.9
10	7.2	2.9	4.0
14	5.6	2.1	2.8

TABLE 7—Variation in resin content with height in the stem (Average values for all sites)

	Resin Content % at					
	Butt	BH	5th internodes	10th	15th	20th
Heartwood	8.4	5.9	5.5	3.9	2.8	—
Sapwood	2.7	2.3	2.2	2.1	2.0	2.2

Variation of resin content at different heights in the stem (Table 7) follows a pattern common to many species of pine. Highest values for both sapwood and heartwood are found in the butt log. This feature may be of value when segregating logs for uses in which high resin content is undesirable.

Tracheid Length

In one tree from each stand tracheids were measured at the 2nd, 5th, 10th, 15th, 20th, and 25th growth layers at breast height, and at the 2nd, 5th, 10th and 15th growth layers in the 15th internode sample. This indicated the radial pattern of tracheid length development, and trees from all stands were found to behave similarly (Table 9). Tracheid length increased most rapidly over the first 10 growth layers and very little change was recorded outside the 15th growth layer from the pith. Consequently it was thought sufficient to examine the tracheids of the remaining four trees in each stand in the centre of the core wood (5th growth layer) at breast height and at the 15th internode, and in the 25th growth layer at breast height (Table 8).

TABLE 8—Tracheid length (mm) of corewood (5th growth layer) at b.h. and at 15th internode, and of 25th growth layer at b.h.

Internode:	Breast Height						15th		
Ring from Pith:	5th			25th			5th		
Site No.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.
1	2.4	2.1	2.7	3.5	3.0	4.1	2.4	2.2	2.7
2	2.1	1.7	3.3	3.0	2.6	3.5	2.8	2.4	3.4
3	2.0	1.8	2.3	2.8	2.5	3.4	2.2	1.9	2.6
7	2.3	2.0	2.6	2.9	2.3	3.2	2.5	2.2	2.7
8	2.4	2.1	2.7	3.1	2.9	3.4	2.4	2.3	2.8
9	2.2	1.9	2.5	3.4	3.3	3.4	2.7	2.4	3.0
14	2.7	2.4	2.9	3.5	3.3	3.7	2.4	2.1	2.7

TABLE 9—Radial variation in tracheid length (mm) at b.h. and at 15th internode — average of all sites

Internode	Growth Layer from the Pith					
	2	5	10	15	20	25
Breast height	1.5	2.1	2.9	3.2	3.1	3.2
15th	1.5	2.4	2.9	3.0		

The results from all sites are quite similar, though it may be noted that the only yellow strain examined (site 3) had the shortest tracheids of all. As compared with radiata pine (Harris, 1965; Table 6) the tracheids of lodgepole pine are slightly shorter, but it is doubtful if this difference will be of any great technological significance. Whereas tracheid length in radiata pine shows a definite decrease with increasing latitude, no such trend was observed in lodgepole pine.

DISCUSSION

This section will be concerned mainly with the two green strains represented by sites 1 and 2, since no other seed source looks more promising from a forestry viewpoint and the yellow strains examined were not superior in density, had higher resin content in heartwood, and had shorter tracheids — in other words they had no desirable properties to compensate for their inferior volume production.

If a choice has to be made between the Waiotapu and Manning green strains on the basis of wood properties alone, the higher wood density of the latter (and equality in other properties examined) would probably lead to a decision in its favour. Though low wood density might be favoured for mechanical pulping, the rather high resin content common to all seed sources makes this appear an unlikely form of utilisation. Consequently sawn timber and chemical pulp appear to be the most likely products from this species, and low density wood of the type produced by the Waiotapu strain on cold sites would result in timber of low intrinsic strength and low yields of pulp.

In favour of the Waiotapu strain are its stem form and response to silviculture. These features may be available in selected trees of the Manning strain though this remains to be proven. Alternatively there are sufficient trees producing high wood density within the Waiotapu strain to justify the inclusion of wood density in the criteria for plus tree selection if this appears desirable.

One reputed feature of the Waiotapu strain—its alleged frost tenderness—now seems to require reassesssment. Even on the hardest of sites, such as site 14 in the present study, sufficient stems of superior form survive to seriously raise the possibility that this first rotation selection may have eliminated many of the unsuitable genotypes that were originally present. It would be interesting to see whether the progeny of seed that has set since the poison thinning might reproduce the phenotypic superiority of their parents on this site.

In the long term it may well be that knowledge of intraspecific variability gained from this study will find its greatest usefulness when we are able to review the broader perspective that will be provided by extensive provenance trials established in 1961. On the basis of the densitometer records in Figs. 3 and 4, a useful assessment of wood properties should be possible shortly after these trials reach an age of 15 yr. At this age trends of wood density can be predicted for outer wood and extrapolation towards future wood quality production becomes possible.

CONCLUSIONS

(1) *Pinus contorta* is a species of wide genotypic and phenotypic variation with considerable potential for tree improvement, and with a definite place in planning future afforestation.

(2) Under New Zealand conditions it is capable of producing a general purpose softwood timber which appears suitable for sawn timber production or chemical pulping. Resin content of the wood may lie towards the upper limit of what is acceptable for mechanical pulping.

(3) Of the various seed sources used to establish the older stands in New Zealand, two appear to have the greatest forestry potential. These are the two "green" strains (subspecies *contorta*) represented by Cpt 2 Waiotapu Forest (origin unknown) and by Cpt 51 Kaingaroa Forest (ex Manning Seed Co., Washington).

(4) No other seed source examined is producing wood with properties markedly superior to these two.

(5) Of the two, the "Manning green strain" is producing denser wood than the "Waiotapu strain", and is not inferior in respect of the other properties examined (shrinkage, resin content, tracheid length).

(6) Trees of the Waiotapu strain have rather superior stem form and respond very readily to silvicultural treatment (e.g. diameter growth responds rapidly to thinning). There are sufficient trees producing dense wood within this strain to justify the investigation of wood density as a criterion for plus tree selection if further development seems desirable.

(7) Based on developmental trends within stems examined for this study, a useful assessment of the wood properties within provenance trials of lodgepole pine should be possible soon after they reach the age of 15 years (in 1976).

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