ROOT-WOOD STRENGTH DETERIORATION IN KANUKA AFTER CLEARFELLING

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ABSTRACT

Significant areas of indigenous kanuka (*Kunzea ericoides* var. *ericoides* (A.Rich.) J.Thompson) growing on the unstable East Coast hill-country north of Gisborne, New Zealand, are under threat of replacement by exotic plantation tree species. A knowledge of the strength and decay properties of kanuka root-wood would increase understanding of the potential impacts of clearfelling kanuka in this region. About 30 trees were felled and their roots sampled at 6-monthly intervals over the following 48 months to determine tensile strength, rate of decay, and elastic properties of kanuka root-wood. Roots were excavated using high-pressure water and tested in tension on an Instron Universal Testing Machine.

Mean live kanuka root-wood strength and modulus of elasticity were 32.5 MPa and 830 MPa, respectively. Mean tensile root-wood strength increased 33% to a maximum of 43.1 MPa 12 months after cutting, and did not decline below live root-wood strength until 24 months after the death of the parent tree. To demonstrate that the root decay pattern of kanuka was not unique, additional information was collected and added to the dataset of a previous study of root-wood strength deterioration in southern rata (*Metrosideros umbellata* Cav.). Mean live southern rata root-wood strength was 50.8 MPa, which increased 27% over 15 months after cutting to 64.7 MPa. The root-wood strength of both species declined exponentially. The calculated time for kanuka and southern rata to lose half their live root-wood strength was 39 and 45 months, respectively.

It was concluded that the strength and elastic behaviour of roots impart resilience to the soil by allowing a greater magnitude and range of slope shear-displacement before failure occurs. Kanuka root-wood has a greater live strength and a lower decay rate than the main exotic plantation species, *Pinus radiata* D.Don. From a purely root strength/ root decay stand-point, kanuka would at least for the first 4 years, provide a clearfelled slope with greater stability than a similar slope clearfelled of *P. radiata*. Consequently, kanuka can be seen as an effective stabiliser of slopes and thus has a very important role to play in the maintenance of slope stability.

Keywords: tree roots; root strength; root decay; root elasticity; *Kunzea ericoides*.

INTRODUCTION

The size of the rooting system and stand density are major factors influencing the degree to which trees enhance slope stability. If trees are removed by clearfelling, slope stability is likely to decline at a rate largely determined by the magnitude of the live root-wood strength and the rate at which this strength is lost after the death of the parent tree.

This important soil protection function is provided by mono-specific stands of the indigenous myrtaceous species kanuka (Bergin *et al.* 1995) on approximately 140 000 ha of erosion-susceptible hill country from Banks Peninsula to East Cape (Watson & O'Loughlin 1985). Throughout the East Cape, significant areas of these stands are under threat of clearance as part of the Government's promotion of large-scale commercial forestry to help control the severe soil erosion associated with the region (Ministry of Forestry 1994).

Information on the live root-wood strength of kanuka and the rate at which roots of this tree species lose their tensile strength after felling are prerequisites to a better understanding of the potential impacts of clearfelling kanuka in the East Cape region and the development of predictive models on relationships between vegetation and slope stability. The objectives of the research outlined in this paper, therefore, were to:

(1) Determine the mechanical tensile strength and elasticity of root-wood taken from live kanuka trees, then use a negative exponential relationship developed by O'Loughlin & Watson (1979) to identify the rate at which kanuka root-wood strength declines after the felling of the parent tree;

(2) Demonstrate, using southern rata, that other tree species could have a root decay pattern similar to kanuka;

(3) Use the results of soil shear strength tests (Ekanayake *et al.* 1997) to describe the significance of live kanuka root-wood strength, elasticity, and root decay to the mechanical aspects of soil reinforcement and slope stability.

SITE DESCRIPTION

Root samples were collected from a stand of regenerated kanuka (Table 1) growing on well-drained mid-slope sites on pastoral land in the Waimata Valley (38°30' S, 178°04' E) in the East Coast hill country, approximately 20 km north of Gisborne in the North Island of New Zealand. The area is representative of terrain where kanuka is likely to be clearfelled and replaced by exotic plantations.

The area is underlain by Orthic Recent Soils, which on well-drained sites vary from dark brown silt loam to light yellow brown gravelly silty clay loam at the base of the rooting zone. These soils are typically associated with land that has been eroded or has received sediment as a result of slope processes (Hewitt 1992). Mean annual rainfall is 1409 mm (1983–96, data collected by J. & S.Hall, Waimata Valley).

TABLE 1–Site and mean stand parameters

Area (ha)	Density (stems/ha)	Age (yr)	Height (m)	Dbh* (mm)	Slope (°)	Aspect (°)
35	3900	32	13.6	127	23	280

*Dbh = Diameter at breast height measured at 1.4 m on uphill side of tree.

METHOD

Root Sampling

About 30 kanuka trees were felled, then root samples were collected at 6-monthly intervals over the following 48 months. The roots were excavated using a high-pressure water technique (*see* Watson *et al.* 1995). Root samples were sealed in plastic bags to preserve root-moisture content and when necessary kept in cool storage until testing.

An existing root decay dataset from an earlier study was available for another myrtaceous species, southern rata (Phillips & Watson 1994), which with an additional sample point had the possibility of showing that other tree species have a root decay pattern similar to kanuka, i.e., a temporary increase in tensile strength immediately after felling. Roots were sampled from a southern rata cut 15 months previously, located in Camp Creek on the western slopes of the Alexander Range, Westland.

Root Tensile Strength

Tensile strength testing was carried out using a Floor Model 1195 Instron Universal Testing Machine, equipped with a 5-kN maximum capacity, reversible, load cell. Type 3D pneumatic-hydraulic clamps with flat, non-serrated, jaw faces were used to grip the root ends (O'Loughlin & Watson 1979). The gape of the jaw faces was approximately 18 mm, which governed the maximum diameter of the roots tested. Both ends of the root were clamped and a force was applied. The resistance to being pulled apart was taken as the measure of the tensile strength of the root. The root was strained in tension at a rate of 20 mm/min until rupture occurred. The location and form of break were noted and the mean diameter near the rupture point was measured using Vernier callipers. Results were recorded as applied force *v.* root deformation plots on a paper strip chart recorder set at 20 mm/min. Maximum tensile strength (MPa) was calculated by dividing the applied force ($kN/10^3$) required to break the root by the cross-sectional area (m^2) of the root at its rupture point. Roots that broke because of crushing or slippage between the jaw faces were disregarded. Of the 858 roots tested, 708 were considered satisfactory for analysis.

Root Elasticity

When a material is put in tension, the stress is linearly proportional to the strain during the initial portion of the stress-strain curve. This proportional region of the curve is where the material shows elastic behaviour. Beyond the proportional limit the relationship no longer holds and the material undergoes plastic deformation. The length of root section between the clamps was measured and for each root tested a tangent was drawn to the resulting stress-strain curve. The point where the tangent deviated from the curve was taken to be the position of the proportional limit.

The modulus of elasticity is defined by

$$E = \text{Stress}/\text{Strain}$$

where

Stress $= F_p/A$

Strain $= l_p/l$

E = modulus of elasticity (MPa)

F_p = applied force at the proportional limit (MPa)
A = cross-sectional area of the root (m^2)
l = original root length (m)
l_p = root deformation at the proportional limit (m)

RESULTS AND DISCUSSION

Tensile Strength of Live and Decaying Root-wood

The mean maximum live tensile strength of 64 small-diameter (1.1–13.5 mm) kanuka roots was 32.5 MPa (Table 2), similar to that measured in two other indigenous tree species, beech (*Nothofagus* spp.) 32.6 MPa (O'Loughlin & Watson 1981) and manuka (*Leptospermum scoparium* J.R. et G.Forst.) 34.2 MPa (Watson & O'Loughlin 1985). Mean tensile root-wood strength increased by 33% to reach a maximum of 43.1 MPa, 12 months after the cutting of the parent trees, and did not decline below the mean live root-wood strength until about 24 months after tree felling (Fig. 1).

TABLE 2–Root-wood tensile strength and diameter of kanuka

Months since cutting (n)	Tensile strength (MPa) Mean (sd)	Tensile strength (MPa) Max.	Tensile strength (MPa) Min.	Root diameter (mm) Mean (sd)	Root diameter (mm) Max.	Root diameter (mm) Min.
0 (64)	32.45 (12.71)	79.98	15.54	4.7 (2.7)	13.5	1.1
6 (74)	36.36 (11.66)	73.66	15.61	5.6 (3.2)	15.8	1.1
12 (80)	43.13 (12.69)	79.43	17.46	5.9 (2.6)	13.9	1.5
18 (89)	34.94 (14.69)	95.10	11.46	5.2 (2.7)	16.2	1.3
24 (100)	31.64 (13.81)	88.97	4.54	6.1 (2.9)	17.6	1.4
30 (79)	28.30 (12.50)	72.12	8.82	6.1 (2.5)	12.1	2.7
36 (67)	24.20 (13.66)	54.71	2.29	7.0 (2.9)	14.8	2.2
42 (68)	19.15 (8.57)	39.24	3.03	5.3 (1.8)	11.5	1.8
48 (87)	15.53 (8.77)	44.76	2.18	6.3 (2.0)	10.4	2.7

Southern rata showed a similar pattern. The mean maximum live tensile strength of southern rata root-wood was 50.8 MPa (Table 3), which increased by 27% over the 15 months after felling to a maximum of 64.7 MPa. Tensile strength did not fall below that of live root-wood until about 27 months after the death of the parent tree (Fig. 2).

The initial increase in root tensile strength and the delay in the onset of root decay can be explained in the following way.

In general, after tree felling the roots lose moisture until an equilibrium is reached with the surrounding soil. This loss of root moisture is assumed to be accompanied by a decrease

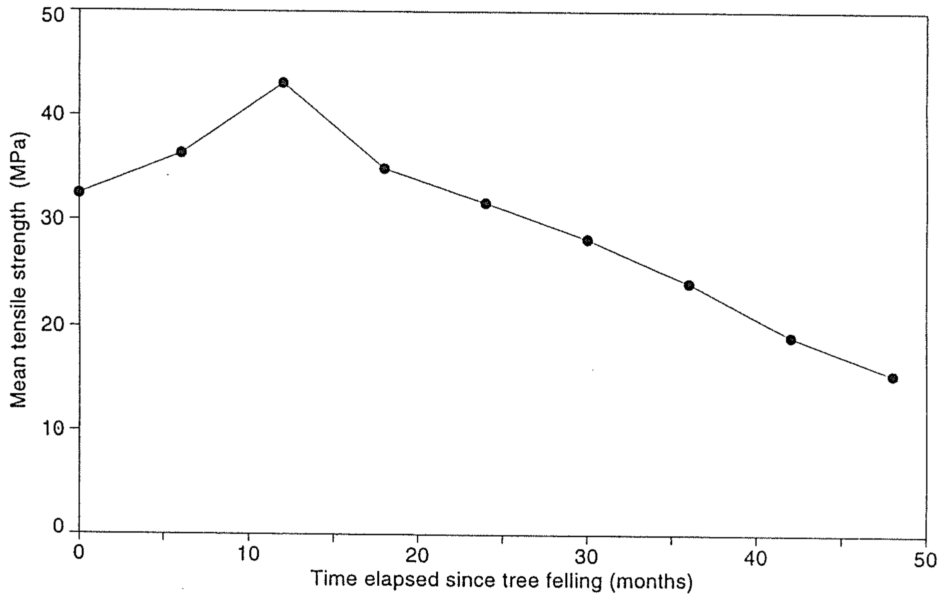

FIG. 1–Plot of mean tensile strength against time elapsed since tree felling for kanuka roots <20 mm diameter.

TABLE 3–Root-wood tensile strength and diameter of southern rata

Months since cutting (n)	Tensile strength (MPa)			Root diameter (mm)		
	Mean (sd)	Max.	Min.	Mean (sd)	Max.	Min.
0 (58)	50.81 (29.72)	139.91	10.60	4.6 (2.5)	10.1	1.1
15 (46)	64.73 (29.40)	153.91	14.81	3.1 (1.6)	7.3	1.3
30 (65)	45.31 (23.35)	102.17	6.31	4.2 (2.3)	11.3	1.3
39 (42)	36.71 (22.38)	98.46	7.49	5.1 (2.1)	12.2	2.0
72 (67)	18.62 (17.18)	83.23	2.94	6.7 (2.4)	12.5	2.5

in root diameter. If the same force is required to break two roots of different diameters the smaller diameter root would be considered the stronger, i.e., would have the greater tensile strength. The same reasoning can be applied to a root before and after moisture loss. Therefore it is the loss of root moisture that is the mechanism behind the increase in the root-wood tensile strength of the two tree species studied in this paper.

There is a time lapse between the death of a parent tree and the onset of root fungal decay. The time lapse will depend on tree species. In soft-wood species such as *P. radiata* the time will be short, possibly a few weeks (O'Loughlin & Watson 1979), but in more durable

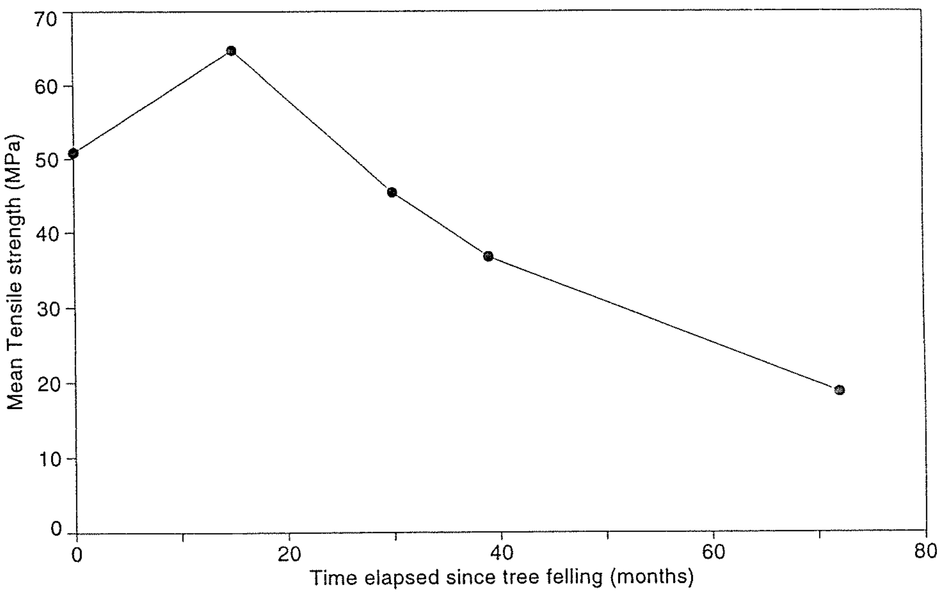

FIG. 2–Plot of mean tensile strength against time elapsed since tree felling for southern rata roots <15 mm diameter.

timbers it will be much greater. For kanuka the time lapse between felling and the onset of root decay is of the order of 12 months (Fig. 1).

Development of Root-wood Strength Decline Curves

The decline in tensile root-wood strength can be approximated by a negative exponential curve of the general form

$$y = ae^{-bx}.$$

where $y = TS_t$ = tensile strength of root-wood sampled at t months;
$a = TS_m$ = maximum tensile strength of root-wood;
b = probability of decay;
$x = t$ = time of root sampling minus time, since felling, to reach maximum tensile strength.

This gives

$$TS_t = TS_m e^{-bt}.$$

If the term e^{-b} is an expression for the decline in root-wood strength, it follows that the time taken for the root strength to decline to half live root-wood tensile strength is :

$$t_{0.5} = \log 0.5 / \log e^{-b} \cdot \text{(Martin 1973)} \qquad (1)$$

where $t_{0.5}$ = the half-strength period.

With regard to the two tree species described in this paper, if the maximum root-wood strength occurred some time after tree felling, that time must be added to Eq. (1) to obtain the corrected value of the half-strength period.

These relationships are used to determine the parameters of the strength decline curves.

For kanuka the strength decline curve (Table 4 and Fig. 3) is

$$TS_t = 42.73e^{-0.026t} \qquad r^2 = 0.98$$

Considering that the maximum root-wood strength occurred 12 months after felling, the half-strength period is

$$t_{0.5} = 26.7 + 12 = 38.7 \text{ months}$$

For southern rata the revised strength decline curve (Table 4 and Fig. 3) is

$$TS_t = 64.26e^{-0.023t} \qquad r^2 = 0.99$$

The maximum southern rata root-wood strength occurred 15 months after felling, giving a half-strength period of

$$t_{0.5} = 30.1 + 15 = 45.1 \text{ months}$$

TABLE 4–Exponential relationships between root-wood tensile strength and months after clearfelling of parent tree ($y = ae^{-bx}$)

Species	n	a	b	r^2	e^{-b}	$t_{0.5}$
kanuka	7	42.73	0.026	0.98	0.974	38.7
southern rata	4	64.26	0.023	0.99	0.977	45.1

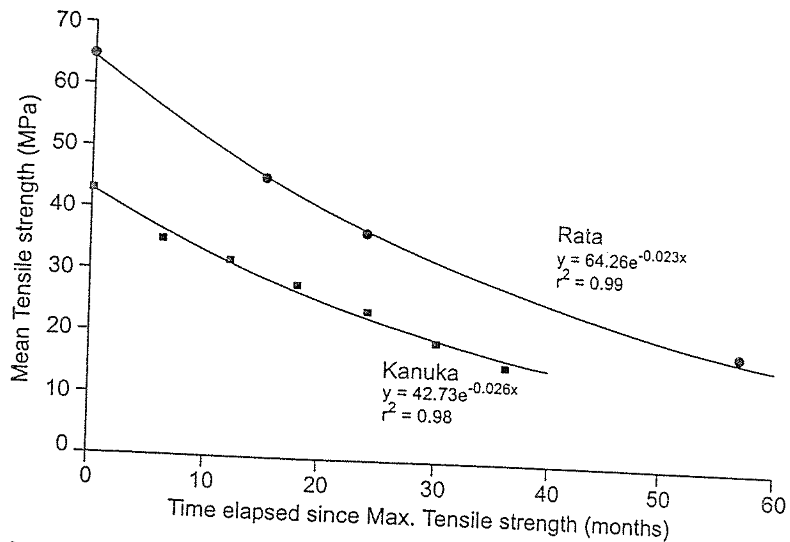

FIG. 3–Root-wood strength decline curves. Negative exponential relationship between mean tensile strength (MPa) and time elapsed since occurrence of maximum tensile strength (months) for root-wood of kanuka and southern rata.

Elastic Behaviour of Kanuka Roots

More-or-less mirroring the trend displayed by the mean tensile strength data (Fig. 1), the mean modulus of elasticity of kanuka roots reached a peak 12 months after the cutting of the parent tree and declined somewhat erratically thereafter (Table 5).

TABLE 5–Modulus of elasticity and maximum elongation of kanuka root-wood

Months since cutting (n)	Modulus of elasticity (MPa)			Max. root elongation (mm)		
	Mean (sd)	Max.	Min.	Mean (sd)	Max.	Min.
0 (64)	830 (335)	1933	317	6.9 (2.8)	20	3
6 (74)	866 (393)	2284	339	11.0 (3.8)	21	4
12 (80)	1151 (410)	3151	315	7.8 (2.5)	16	3
18 (89)	949 (537)	2948	343	5.9 (1.8)	11	2
24 (93)	925 (415)	2159	128	6.1 (3.5)	21	2
30 (73)	868 (450)	1953	223	7.2 (2.5)	15	3
36 (57)	909 (461)	1960	131	4.0 (1.9)	8	1
42 (68)	631 (349)	1814	81	4.5 (1.7)	10	2
48 (87)	673 (395)	2119	81	4.2 (1.6)	11	2

The stress-strain relationship of kanuka roots changes as they decay and lose their elastic properties (i.e. flexibility), becoming increasingly brittle with time. This loss of elasticity is illustrated by the gradual decrease in the distance between the rupture point (RP) and the proportional limit (PL) and the gradual decrease in value of PL (Fig. 4).

Root Contribution to Soil Reinforcement

The contribution of roots to soil strength can be evaluated by using the results of direct shear box tests on soils with and without roots to determine shear stress-displacement curves. The increase in soil strength can be estimated as the vertical difference between the two shear stress-displacement curves (Fig. 5).

The shear box tests show that the maximum shear strength of soils with roots occurs at greater shear displacements and remains at or near maximum peak resistance over a greater range of shear displacements than soils without roots (Ekanayake *et al.* 1997). It is the elastic properties of the live roots, and in particular their flexibility, which allow soils to maintain their stability over a broader range of slope displacement.

As roots decay and lose both strength and elasticity, the shape of the stress-displacement curve representing soils with roots will gradually change. As root reinforcement of the soil deteriorates, this curve will eventually coincide with the curve representing soils without roots. The magnitude of the maximum shear stress, the elasticity and rates of decay are species dependent.

CONCLUSIONS

The presence of tree roots imparts a resilience to the soil. It is not only root strength that provides increased soil stability, but also the increased magnitude and greater range of shear

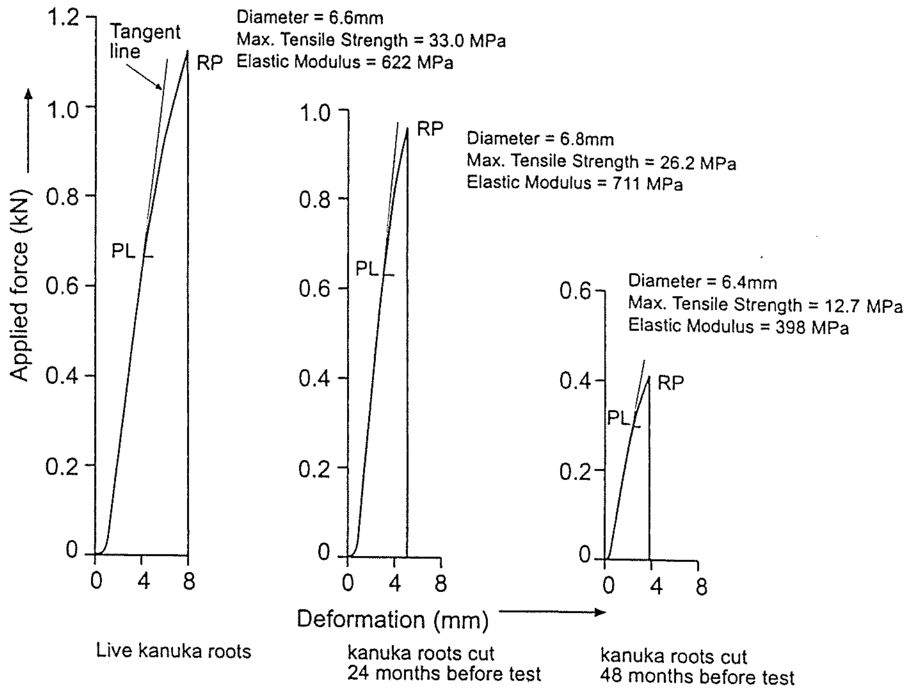

FIG. 4—Applied force-deformation curves resulting from tensile wood strength tests on three kanuka roots at different stages of decay. RP = Rupture Point, PL = Proportional Limit.

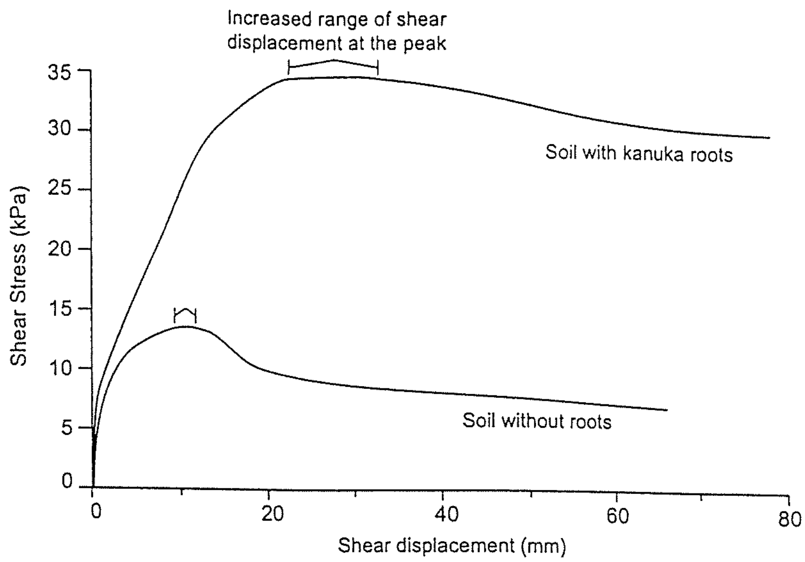

FIG. 5—Shear stress-displacement curves for soil containing 24-year kanuka roots and for soil, at the same site, without roots (modified from Ekanayake *et al.* 1997)

displacements provided by root elasticity that enable the soil-root layer to undergo greater movement before slope failure occurs.

Live root-wood strength of kanuka (32.5 MPa) is comparable to that of other indigenous tree species and is nearly twice as strong as that of *P. radiata* (17.6 MPa) (O'Loughlin & Watson 1979). The mean rate of loss of tensile strength of kanuka root-wood over the 4-year post-felling period was 4.2 MPa/yr, about a third lower than that of *P. radiata* at 5.9 MPa/year (Watson *et al.* 1995).

There was a period of approximately 40 months after felling before kanuka root-wood strength fell below the live root-wood strength of *P. radiata*. In a comparable root-wood deterioration investigation of *P. radiata* (O'Loughlin & Watson 1979) it was found that in a similar period after felling most of the pine roots less than 30 mm diameter had disappeared, while roots larger than 50 mm diameter showed advanced decay and often consisted only of empty fragile bark sheaths.

As kanuka has a greater live root-wood strength and a lower decay rate, then from a purely root strength / root decay stand-point, kanuka would at least for the first 4 years provide a clearfelled slope with greater stability than a similar slope clearfelled of *P. radiata*. Consequently, kanuka can be seen as an effective stabiliser of slopes and thus has a very important role to play in the maintenance of slope stability.

A continuous undisturbed cover of kanuka will provide an on-going stabilising effect. A managed stand of *P. radiata* or other commercial forest species, however, will provide a much reduced level of stability for several years after clearfelling and will not reach its maximum stabilising potential until the maturing trees approach canopy closure, the timing of which depends on the planting density. Whether a constant soil stabilising effect is more desirable than a cyclic stabilising effect which is determined by the harvesting regime, is a judgement land managers will need to consider carefully for slopes of uncertain stability.

Finally, the initial increase in the mean tensile strength of kanuka root-wood does not imply that dead kanuka are as beneficial as live ones. Trees increase slope stability not only by the root reinforcement of the surrounding soils, but also by their modification of the soil moisture regime. It is the combined effect of the above- and below-ground components of vegetation that ultimately leads to the drier, stronger soils that tend to promote increased slope stability. The beneficial attributes of the above-ground vegetation cease as soon as the trees are felled. Until some remedial action is taken, all that remains are the decaying root systems.

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REFERENCES

BERGIN, D.O.; KIMBERLEY. M.O.; MARDEN, M. 1995: Protective value of regenerating tea tree stands on erosion-prone hill country, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science 25(1)*: 3–19.

EKANAYAKE, J.C.; MARDEN, M.; WATSON, A.J.; ROWAN, D. 1997: Tree roots and slope stability: A comparison between *Pinus radiata* and kanuka. *New Zealand Journal of Forestry Science 27(2)*: 216–233.

HEWITT, A.E. 1992: New Zealand Soil Classification. *DSIR Land Resource Scientific Report No. 19.* 133 p.

MARTIN, G.N. 1973: Characterization of simple exponential baseflow recessions. *Journal of Hydrology (NZ) 12(1)*: 57–62.

MINISTRY OF FORESTRY 1994: "A Guide to the East Coast Forestry Project". Ministry of Forestry, Wellington, New Zealand.

O'LOUGHLIN, C.L.; WATSON, A.J. 1979: Root-wood strength deterioration in radiata pine after clearfelling. *New Zealand Journal of Forestry Science 9(3)*: 284–293.

———1981: Note on root-wood strength deterioration in *Nothofagus fusca* and *N. truncata* after clearfelling. *New Zealand Journal of Forestry Science 11(2)*: 183–185.

PHILLIPS, C.J.; WATSON, A.J. 1994: Structural tree root research in New Zealand. *Manaaki Whenua Press, Landcare Research Science Series No. 7.* 71 p.

WATSON, A.J.; O'LOUGHLIN, C.L. 1985: Morphology, strength and biomass of manuka roots and their influence on slope stability. *New Zealand Journal of Forestry Science 15(3)*: 337–348.

WATSON, A.J.; MARDEN, M.; ROWAN, D. 1995: Tree species performance and slope stability. Pp.161–171 *in* Barker, D.H. (Ed.) "Vegetation and Slopes". Thomas Telford Press.