MORPHOLOGY, STRENGTH, AND BIOMASS OF MANUKA ROOTS AND THEIR INFLUENCE ON SLOPE STABILITY

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ABSTRACT

Manuka (**Leptospermum scoparium** J.R. et G. Forst.) root systems growing in shallow, stony, hillslope and terrace soils consisted of shallow lateral structural roots up to 275 cm long, and rapidly tapering sinker roots which extended to 120 cm below the ground surface. Mean tensile strength of manuka root wood (34.2 MPa) was similar to that of **Nothofagus** root wood. Total root biomass averaged 25 tonnes/ha. Manuka roots provide good soil protection against shallow landslides, but this protection diminishes quickly after clearing of manuka scrub.

Keywords: root wood; morphology; root strength; biomass; slope stability; **Leptospermum scoparium**; **Kunzia ericoides**.

INTRODUCTION

The myrtaceous species manuka and kanuka (*Kunzia ericoides* (A. Rich.) J. Thompson) grow in areas throughout New Zealand where low fertility or dry soils tend to limit competition from other pioneering tree species. At present, stands dominated by manuka-kanuka occur on 140 000 ha of erosion-susceptible hill country, predominantly on the east coast of both the North and the South Island (Fig. 1). Pure or mixed stands of kanuka are also found along stream banks and on river and stream terraces where they provide protection and stability. Large areas of manuka-kanuka stands have been cleared over recent decades for plantation forestry and pastoral development.

In some steepland locations where manuka and kanuka stands have been crushed and burnt, the frequency of small, shallow, translational landslides has increased. It is known that slope stability generally decreases after forest-clearing as the root systems gradually decay, especially when the soils are partly or completely saturated (e.g., O'Loughlin 1974a; Wu & Swanston 1980; O'Loughlin & Ziemer 1982), but the specific contribution of manuka roots to slope stability has not been studied. In response to queries from forest and farm management in areas where manuka is being removed, this study was set up to describe the morphology of manuka and kanuka root networks, and to determine their biomass and the degree of their mechanical contribution to slope stability.

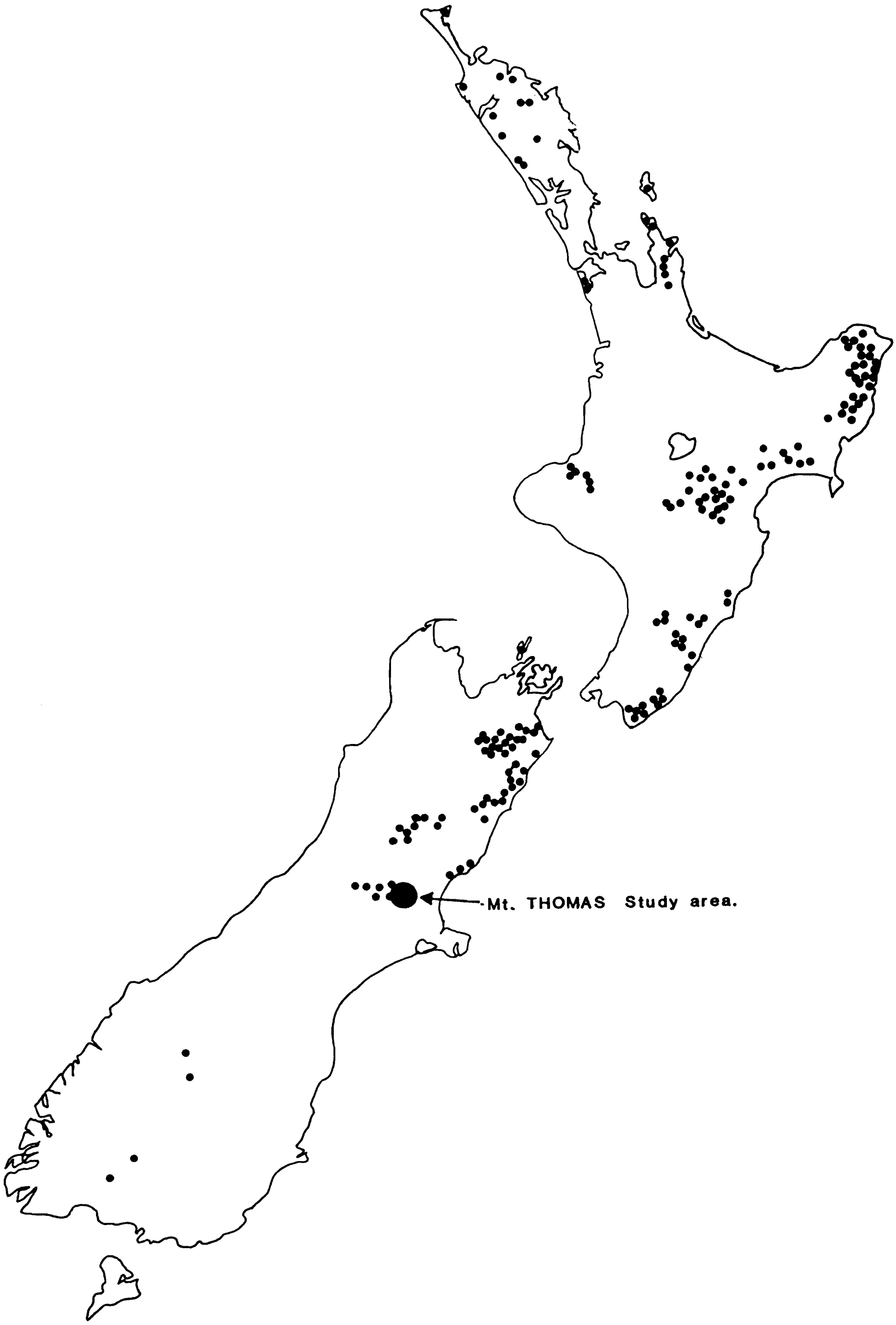

FIG. 1—Location of study area and distribution of manuka/kanuka-dominated vegetation growing on land with an erosion severity of severe to extreme. (Extracted from Land Resource Inventory Data Files, Ministry of Works and Development, Wellington.)

STUDY AREA

Two contrasting sites at Mt Thomas in Canterbury were selected for the study of manuka-kanuka roots. Site 1 was representative of well-drained, lower mountain slopes of inland Canterbury and Marlborough where the original *Nothofagus* forests have been removed by burning and manuka scrub dominates the replacement seral vegetation. Site 2 was representative of valley bottom, well-drained, river terrace edges where soils are shallow, stony, and drought-prone – typical habitat for manuka scrub. Rainfall in the area is moderate (900 mm/yr).

Site 1 was in a dense stand of 7-m-tall manuka in a small gully on the northern flanks of Mt Thomas at 500 m a.s.l. Associated species were *Pseudopanax arboreus* (Murr.) Philipson, *P. crassifolius* (A. Cunn.) C. Koch, *Carpodetus serratus* J.R. et G. Forst., *Coprosma parviflora* Hook. f., and *Astelia nervosa* Hook. f. The site faced north-west (310°), with an average slope of 27°. The following soil profile was typical:

0–10 cm	Dark greyish-brown, organic-rich silt loam with a block structure. Few gravels up to 2 cm diameter.
10–30 cm	Greyish-brown silt loam with slightly more massive structure, less organic matter. Some stones, a few up to 10 cm diameter.
30–40 cm	Greyish-brown silt loam with many angular stones. Tight massive structure.
40–100+ cm	Light yellowish-brown, very stony silt loam, with angular stones up to 20 cm diameter. Stones made up 40% of this part of the profile.

Site 2 was on the edges of two alluvial and gravel terraces on the true left side of the Okuku River at 250 m a.s.l. The low terrace supported closely spaced, even-aged manuka up to 3 m tall over a ground cover of herbs and mosses. On the higher terrace, associated tree species were *Nothofagus solandri* (Hook. f.) Oerst. and *Cyathodes fasciculata* (Forst. f.) Allan.

The following soil profile from the terrace was typical:

0–7 cm	Dark brown sandy loam with a weak nut structure. Boulders up to 50 cm diameter common.
7–40 cm	Brown loamy sand with a loose consistency. Many stones and boulders.
40–80 cm	Pale brown loamy sand containing many stones and boulders.
> 80 cm	Grey, loose sand pockets amongst abundant boulders.

METHODS

Root Excavation

The root systems of 10 trees (nine manuka and one kanuka) were hydraulically excavated from the two study sites. The trees were selected for proximity to water for excavation, relative isolation from other trees, and favourable ground surface configuration for excavation. After felling, tree heights and stem diameters were measured. Discs were cut from the lower stems for age determination from annual rings. Stumps and root systems were excavated using a Gorman-Rupp fire pump (capacity 360 *l*/min at 1700 kPa) fitted with a 5-mm non-adjustable nozzle. The excavated structural roots and root bole were propped in their original positions until their morphology had been described.

Root Biomass

The intact, excavated root systems were transported to the laboratory, cut up, and sorted into the following components:

fine roots	$<$ 2 mm diameter
medium roots	2–20 mm diameter
coarse roots	$>$ 20 mm diameter
central root bole at the base of the stems	

The root wood was dried for 6 days at 75°C, then weighed, and the total length of medium and coarse roots for each individual system determined.

To estimate total root biomass per hectare, six 10 × 10-m plots were established on the northern slopes of Mt Thomas. They were located over a 300-m altitudinal range in the same manuka population as the study sites, and therefore had similar age distribution and structure. Individual tree diameters (d.b.h.) were measured. Equivalent diameters of multiple-stemmed trees were obtained by summing the cross-sectional areas of the individual stems and then calculating the corresponding diameter. Estimation of root biomass per hectare was based on the basal area of each manuka tree (or summed basal area of multi-stemmed trees) measured in the six plots and a regression of root weight (kg) on tree basal area (cm^2) for the nine sampled manuka trees and one kanuka tree.

Tensile Strength

Straight root sections of approximately 25 cm length were cut from roots up to 1 cm diameter taken from the excavated root systems. These were trimmed and tested in a floor model 1195 Instron Universal Testing Machine equipped with a 5 kN maximum capacity reversible load cell, using techniques described by O'Loughlin & Watson (1979).

RESULTS

General Root Morphology

Site 1 – Root systems were excavated for seven manuka trees. Five trees with pronounced downslope butt-sweep and one tree with no butt-sweep had asymmetric root systems in plan view, with the bulk of the root development in the upslope direction (Fig. 2, 3). Few structural roots developed downslope from the manuka root stumps, except in Tree 5 (Fig. 3) which showed minor butt-sweep and was growing on a relatively gentle, sloping site.

In general, the root systems consisted of a few main structural roots of small diameter which gave rise to a dense network of fine roots. The largest vertical roots originated from directly under the tree stumps, but many others grew from the underside of the larger lateral roots within 0.5 m of the stump. The structural verticals tapered rapidly, and many twisted and curved in an apparently erratic or random manner, undoubtedly to avoid the many stones and boulders. Many did not penetrate beyond 50 cm because of the stony soil. The few roots that did, tended to develop a weak second tier of lateral roots, as shown in Fig. 3. The growing tips of some vertical roots that had grown back towards the soil surface proliferated into many, fine, surface-feeding roots (Fig. 2).

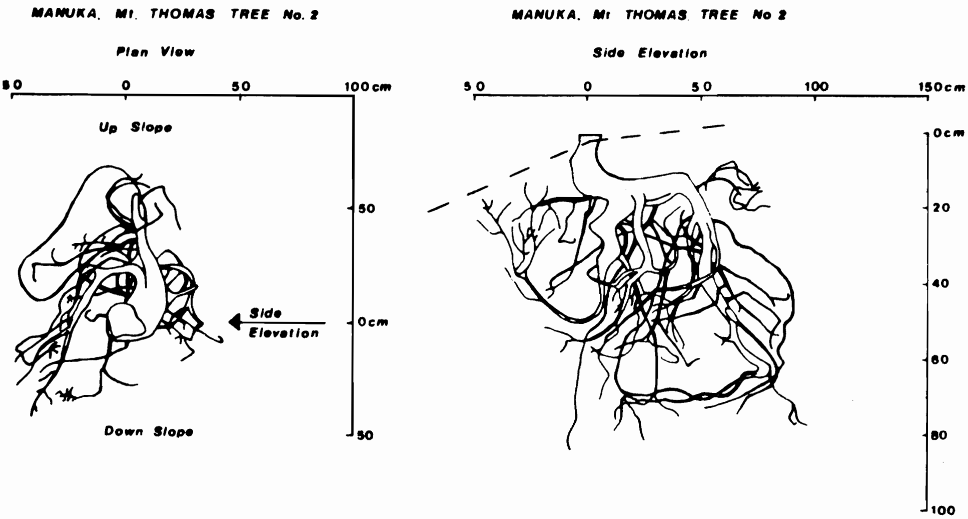

FIG. 2—Plan and side elevation of root system of Tree No. 2.

The lateral roots (coarse and fine roots which had developed more or less parallel to the slope surface) were confined mainly to the upper 25 cm of soil. The roots which extended furthest from the tree stumps were generally within 10 cm of the ground surface and tended to follow the humus-horizon/upper-mineral-soil interface. Occasionally laterals changed their direction of growth and became oblique vertical roots.

Site 2 – On the alluvial terrace edges, root systems were excavated for three trees (two manuka and one kanuka) (Table 1). The root systems were more symmetrically developed around the central root bole (Fig. 4) than for Site 1 trees, reflecting the level terrain. They also had greater radial spread and penetrated more deeply into the lighter sandy soils of the terraces than on Site 1 (Table 1).

Vertical root development was dominated by a central taproot which tapered rapidly and developed multiple branches which, in the large kanuka tree, formed deep laterals between 40 and 80 cm below the surface. Many of the structural roots were distorted.

The lateral roots were confined to the top 20 cm of soil, and most of the branching took place within 0.75 m of the stump. Consequently, mean root diameter declined rapidly as distance from the stump increased up to about 0.75 m, and a dense mat of fine roots (< 2 mm diameter) developed. The longest lateral roots were confined to the upper 10 cm of soil.

Many roots at both sites were in direct contact with other roots of the same tree or roots of adjacent manuka trees, but no examples of root grafting were observed.

Biomass

Individually excavated root systems showed that about 44% of the total weight of the root biomass was contained in the central root stump, and less than 2% in roots less than 2 mm (Table 2). Over 90% of the total length of roots greater than 2 mm

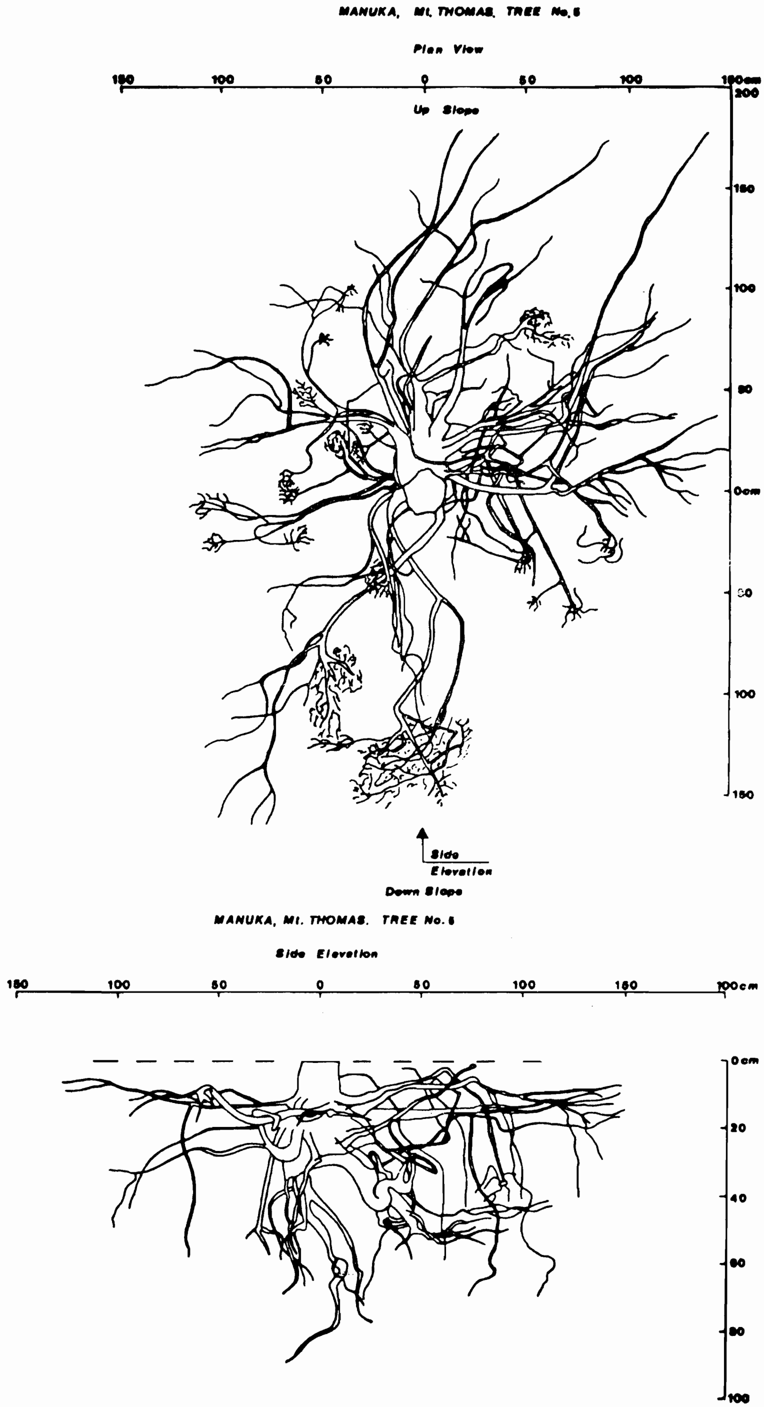

FIG. 3—Plan and side elevation of root system of Tree No. 5.

TABLE 1—Age and size of sampled trees and dimensions of their root systems

Tree No.	Age (yr)	Diam. (cm)	Height (m)	Maximum radial spread (cm)	Maximum depth (cm)	Maximum depth taproot (cm)
Site 1						
1	23	7.0	6.8	167	45	45
2*	24	6.5	6.4	70	85	82
3	26	6.8	5.1	108	55	Nil
4	27	7.5	7.1	100	70	58
5*	48	21.0	7.2	207	90	59
6	18	6.2	4.7	125	45	43
7	13	3.1	1.7	97	34	Nil
Site 2						
8†	50	20.5	9.5	275	118	118
9	25	10.0	2.7	230	95	75
10*	30	13.5	3.1	210	67	65

* Illustrated in Fig. 2, 3, and 4 respectively.
† Kanuka tree

in diameter occurred in the 2- to 20-mm-diameter root class. Only about 6% of the total length of roots occurred in the coarse root (> 20-mm-diameter) class.

Mean stand density on the six 100-m^2 plots was 7050 trees/ha, and mean basal area was 44.7 m^2/ha (Table 3). The regression equation, $Y = 0.065X - 0.613$ ($r = 0.995$), for root weight (kg) on tree basal area (cm^2) (Fig. 5) gave root biomasses of 16.0 to 36.9 tonnes/ha and an average of 24.9 tonnes/ha (Table 3).

Tensile Strength of Live Root Wood

The mean tensile strength of manuka root wood (34.2 MPa) was not significantly different from the measured mean strength of *Nothofagus fusca* (Hook. f.) Oerst. and *N. truncata* (Col.) Ckn. root wood (32.5 MPa) (Table 4). Manuka root wood was considerably weaker than root wood of *Metrosideros* spp., but was stronger than *Pinus radiata* D. Don root wood.

DISCUSSION

Studies in the United States, Japan, and New Zealand (Gray & Megahan 1981; Endo & Tsuruta 1969; O'Loughlin *et al.* 1982), have suggested that tree root systems increase slope stability by:

(1) Bonding unstable soil mantles to stable subsoils or bedrock where roots penetrate through surface soil layers, across potential failure planes, and into failure-resistant substrates;

(2) Providing a reinforced surface layer of soil, usually less than 1 m deep, which gives a type of membrane strength or lateral acting strength that holds the underlying regolith in place;

TABLE 2—Root system biomass data by root size-class for 10 sampled trees

Tree No.	< 2 mm	2–20 mm		> 20 mm		Stump	Totals	
	wt (kg)	wt (kg)	length (m)	wt (kg)	length (m)	wt (kg)	wt (kg)	length (m)
Site 1								
1	0.02 (1)*	0.37 (24)	22.8 (96)	0.35 (23)	1.0 (4)	0.81 (52)	1.55	23.8
2	0.02 (1)	0.28 (19)	23.1 (95)	0.56 (39)	1.2 (5)	0.59 (41)	1.45	24.3
3	0.05 (2)	0.71 (34)	33.1 (97)	0.44 (21)	1.2 (3)	0.86 (42)	2.06	34.3
4	0.06 (3)	0.45 (25)	26.0 (95)	0.64 (36)	1.4 (5)	0.63 (35)	1.78	27.4
5	0.23 (1)	2.90 (14)	208.0 (95)	5.29 (26)	10.7 (5)	12.06 (59)	20.48	218.8
6	0.02 (1)	0.32 (21)	35.4 (97)	0.39 (26)	1.1 (3)	0.77 (51)	1.50	36.5
7	0.01 (8)	0.08 (61)	6.2 (100)	No roots in this class		0.04 (31)	0.13	6.2
Mean	0.06 (2)	0.73 (28)	50.7 (96)	1.28 (29)	2.8 (4)	2.25 (45)		
Site 2								
8†	–	5.74 (25)	111.7 (91)	6.02 (27)	11.5 (9)	10.85 (48)	22.61	123.2
9	–	1.19 (33)	27.6 (96)	0.91 (25)	1.2 (4)	1.54 (42)	3.64	28.8
10	–	1.75 (20)	55.6 (92)	3.92 (44)	4.9 (8)	3.29 (37)	8.96	60.5
Mean		2.89 (26)	65.0 (93)	3.62 (32)	5.9 (7)	5.23 (42)		

* Figures in parentheses represent percentage of totals.
† Kanuka tree.

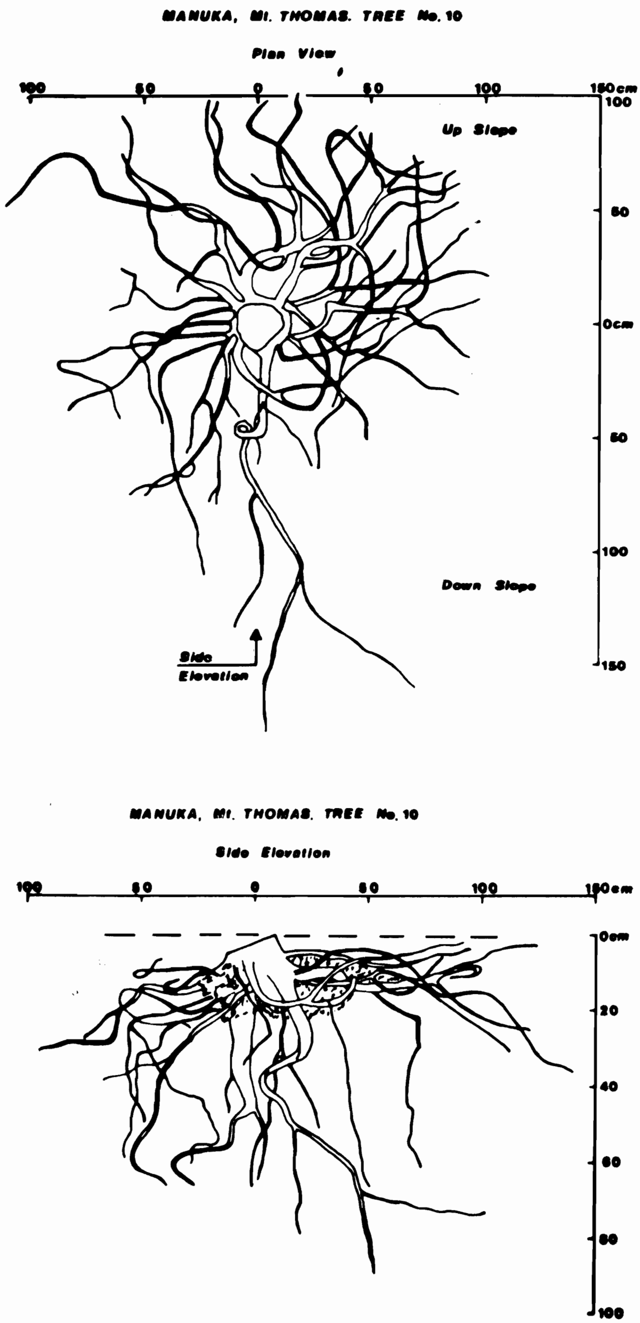

FIG. 4—Plan and side elevation of root system of Tree No. 10.

TABLE 3—Mean diameter, basal area, tree density, and estimated tree root biomass for six 100-m^2 manuka plots

Plot	Average diam. (cm)	Basal area (m^2/ha)	Stand density (trees/ha)	Root weight* (tonnes/ha)
1	7.2	39.5	7400	21.2
2	6.7	31.1	7000	16.0
3	6.8	41.3	7500	22.3
4	11.7	59.3	3700	36.9
5	7.0	50.2	7100	28.4
6	6.8	46.6	9600	24.4
Mean	7.7	44.7	7050	24.9
s.d.	1.8	8.9	1734	6.5

* Estimated from regression of root weight on tree cross-sectional area (Fig. 5).

TABLE 4—Live tensile strength (TS) of root wood of manuka, **Pinus radiata**, **Nothofagus** spp., and **Metrosideros umbellata**

	N	Mean		Max.		Min.		s.e.	
		TS (MPa)	Diam. (cm)	TS (MPa)	Diam. (cm)	TS (MPa)	Diam. (cm)	TS (MPa)	Diam. (cm)
Manuka	62	34.2	0.49	89.9	0.99	9.6	0.15	2.3	0.03
Pinus radiata*	188	17.6	0.53	37.5	1.39	7.7	0.13	0.5	0.02
Nothofagus spp.†	97	32.5	0.38	82.9	0.84	8.4	0.11	1.6	0.02
Metrosideros spp.‡	58	50.8	0.46	139.9	1.01	10.6	0.11	3.6	0.03

* O'Loughlin & Watson (1979)
† O'Loughlin & Watson (1981)
‡ A. J. Watson (unpubl. data)

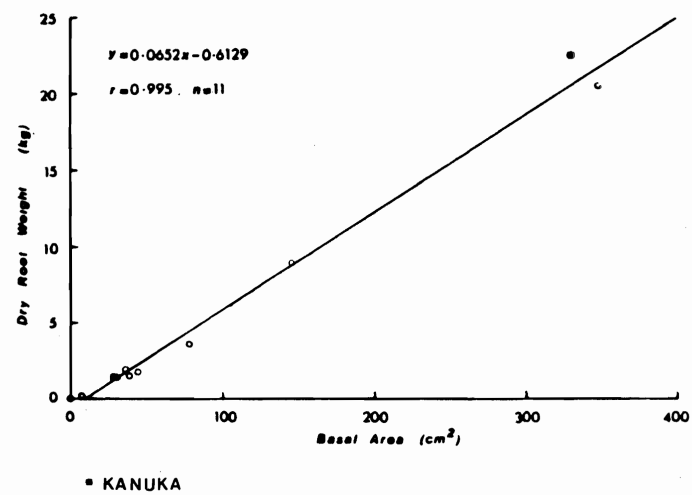

FIG. 5—Regression of root weight (kg) on tree basal area (cm^2) for 10 study trees (nine manuka and one kanuka).

(3) Providing localised centres of great reinforcement in the close vicinity of individual trees, whose large structural roots and central root stumps act as supporting buttresses.

The morphology of the manuka root systems and their strength characteristics measured in this study indicate that manuka stands reinforce the regolith mainly by mechanism (2) above. The relatively small structural roots and root stumps of manuka compared to the massive root systems of tall tree species reduces the importance of mechanism (3). The shallowness of the manuka root systems (mean maximum depth for the 10 study trees was only 66 cm) and the strong tendency for structural lateral roots to concentrate in the top 20 cm of soil limits the significance of mechanism (1).

The reinforcing or soil binding functions of manuka root systems appear to depend primarily on the network of medium-sized vertical and lateral roots and associated fine roots in the upper 50 cm of soil. The spatial density of manuka stems and the distribution of manuka roots found in the 10 root systems studied suggest that, under dense manuka stands of the type growing at Mt Thomas, approximately 5% of the top 50 cm of soil volume is occupied by roots. Under similar circumstances in young conifer stands, the strength provided to the soil by tree roots ranges from about 1 kPa to about 10 kPa (O'Loughlin & Ziemer 1982). This level of reinforcement can be significant in maintaining stability on steep slopes susceptible to shallow translational landslides. Although the mean biomass of manuka roots (24.9 tonnes/ha) measured for this study is not high compared to root biomass of tall tree crops (which often exceeds 50 tonnes/ha on the terrace and mountain soils in inland north Canterbury), it is likely that mature manuka stands provide reinforcement to the soil mantle and inhibit the development of shallow landslides.

However, this mechanical reinforcement is rapidly lost if the manuka stand is destroyed. The rate of loss of root wood strength after tree cutting ranges between 0.40 and 0.52 MPa per month for a number of hardwood and softwood species (O'Loughlin 1974b; O'Loughlin & Watson 1979, 1981; Burroughs & Thomas 1977; Ziemer 1981; O'Loughlin & Ziemer 1982). Although the loss of root wood strength after felling has not been determined for manuka, information on manuka stem wood durability (Forest Research Institute 1982) suggests that kanuka and manuka wood in contact with the ground is susceptible to decay and is much less durable than the stem heartwood of *N. truncata* and *N. fusca*. O'Loughlin & Watson (1981) showed that after clearfelling the small roots of *N. truncata* and *N. fusca* take 33 months to lose half their initial live-wood strength. It is unlikely that manuka root wood would deteriorate more slowly than the root wood of beeches, and the root systems of manuka could be expected to be in an advanced state of decay within 3 years of cutting.

The clearing and replacement of manuka by fast-growing conifer trees on slopes susceptible to shallow landsliding is likely to increase potential instability for a period of 5 years or more, which approximates the time required after planting for young conifer plantations to provide substantial soil reinforcement (O'Loughlin 1984).

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