Live root-wood tensile strength of *Populus × euramericana*, 'Veronese poplar'

by

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Introduction

Root system architecture and stand density are major factors that influence the degree to which trees enhance the mechanical reinforcement of soils (Phillips & Watson 1994). Soils containing roots have the ability to undergo larger shear displacements before reaching failure conditions than soils without roots (Ekanayake & Phillips 1999; Ekanayake *et al*. 2004). The extent to which roots improve soil stability depends not only on attributes such as root to soil volume and root area ratios (Wu *et al*. 1979; Abernethy & Rutherfurd 2001; Easson & Yarbrough 2002), but also on the specific root-system characteristics of the vegetation involved. Roots impart resilience to the soil, a component of which is the magnitude of the live root-wood tensile strength.

Shear stresses set up within the soil mobilise the tensile resistance of the enclosed roots (Abernethy & Rutherfurd 2001). If the soil fails, roots can respond in a number of ways:
(1) The roots may pull out. The full reinforcement potential, of particularly shallow roots, is often not realised as soil failure occurs before peak tensile strength is reached. Under these circumstances the resistance provided by the roots is supplied by the cohesion of the root-soil interface.
(2) The roots rupture at or near the shear plane. In this scenario the reinforcement provided by the root-wood tensile strength is fully utilised.
(3) The roots rupture at some point within the soil regolith. During soil failure the full reinforcement potential of the roots is realised, and after root rupture there remains some residual reinforcement as the roots are pulled through the soil.
In summary, roots provide reinforcement to soils through a combination of their tensile strength, frictional resistance, and soil bonding properties.

Live-root tensile strength (Watson and Marden, 2004) and root development (Marden et al, 2005) have been measured for several endemic species. There is a need to quantify the root contribution to soil shear resistance and this contribution is in part dependent on the root tensile strength of the plant species involved. Knowledge of a range of root-wood tensile strengths provides important information that is often required in root-soil assessment analysis, and can be useful when selecting plant species for erosion control (Watson and Marden 2004).

Currently there is great interest throughout New Zealand in revegetating hill slopes, roadside cuttings and riverbanks with endemic plant species, rather than the traditionally used exotic tree species. As poplars are currently the species most widely used for slope stabilisation in pastoral hill country and in riverbank stabilisation behind the front-line willow protection, this study sought to provide some comparison of live-root tensile strength of 'Veronese' poplar with the endemic tree and shrub species previously tested.

Method

Undamaged roots with over-bark diameters of between 1-13 mm and 150-250 mm long, lying at depths of 0-250 mm were extracted from manually excavated root systems of ‘Veronese’ poplar trees growing on a slope of 23-27° (McIvor et al 2008). The fresh weight of the roots was recorded, they were then sealed in plastic bags to preserve root-moisture content, and kept in cool storage until tested.

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; Watson *et al*. 1997). The root ends were clamped and a strain rate of 20 mm/min was applied until rupture occurred. The applied force required to break the root was taken as the measure of root strength. The location and form of the break was noted and the unstressed mean under-bark diameter of the root at rupture point was measured using digital callipers. Tensile strength (MPa) was calculated by dividing the applied force (MN) required to break the root by the under-bark cross-sectional area (m^2) of the root at its rupture point. Tests subject to slippage, or those roots that broke because of crushing at the jaw faces were disregarded.

Data analysis

The allometric relationships developed during the course of this study were generated by the curve fitting software package " TABLECURVE 2D, Version 4".

Results

Mean live root-wood breaking force and mean live root-wood tensile strength values (Table 1) were obtained from 123 roots ranging from 0.90- to 8.51 mm under-bark diameter (1.16- to 12.63 mm over-bark diameter). The tested roots had a mean bark thickness, as a %age of under-bark root diameter, of 60%.

Root dia. class	Mean root dia.	max : min dia	Mean breaking force	max : min force	Mean tensile strength	max : min tensile str	n
<1	0.93	0.90 : 0.95	0.06	0.04 : 0.08	90.8	114 : 69	3
1<2	1.53	1.97 : 1.07	0.11	0.51 : 0.21	56.9	107 : 27	31
2<3	2.47	2.01 : 2.99	0.19	0.30 : 0.07	40.1	68 : 11	43
3<5	3.89	3.02 : 4.77	0.29	0.45 : 0.11	24.3	37 : 15	34
5<7	6.15	5.23 : 6.85	0.57	0.82 : 0.32	19.0	26 : 15	7
7<9	7.71	7.13 : 8.51	0.98	1.19 : 0.82	20.9	22 : 20	5
All roots	3.02	0.90 : 8.51	0.246	1.19 : 0.04	39.2	114 : 11	123

Table 1. Mean live root-wood breaking force (kN), mean live root-wood tensile strength (MPa) over a range of u.b. diameter classes (mm) of ‘Veronese’ poplar.

A power function relationship between applied breaking force and under-bark root diameter of the form $Y = aX^b$ was developed, where Y = applied force (kN), X = under-bark diameter (mm), a = 0.05, b = 1.51, $r^2 = 0.88$ and n = 123 (Fig. 1).

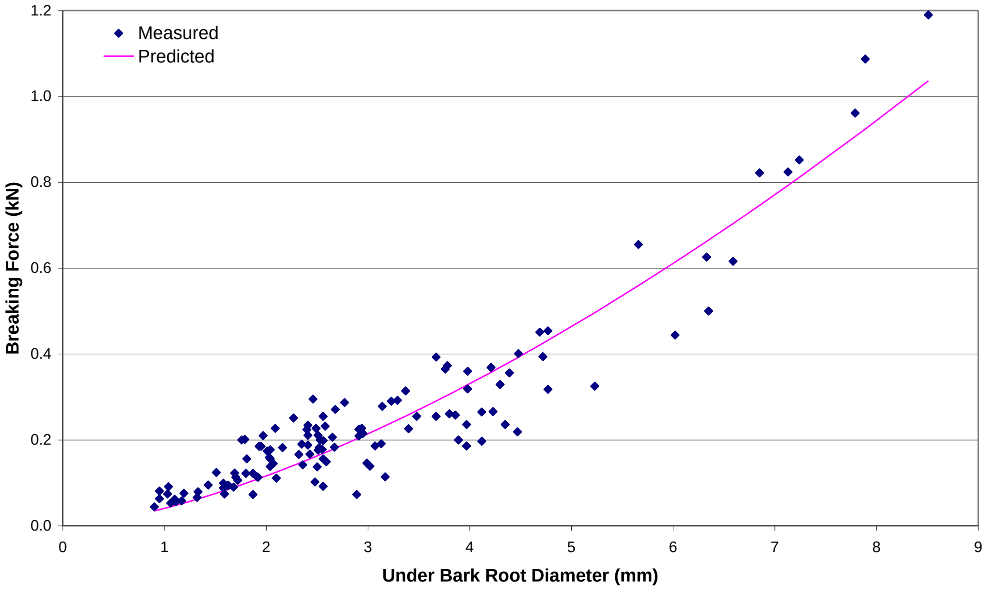

Figure 1. Relationship between applied breaking force of 'Veronese' poplar roots and their under-bark root diameter.

Similarly, another power function relationship was developed, this time between live root-wood tensile strength and under-bark root diameter. The form of the relationship was $Y = aX^b$, where Y = tensile strength (MPa), X = under-bark diameter (mm), a = 80.79, b = -0.82, $r^2 = 0.69$ and n = 123 (Fig. 2).

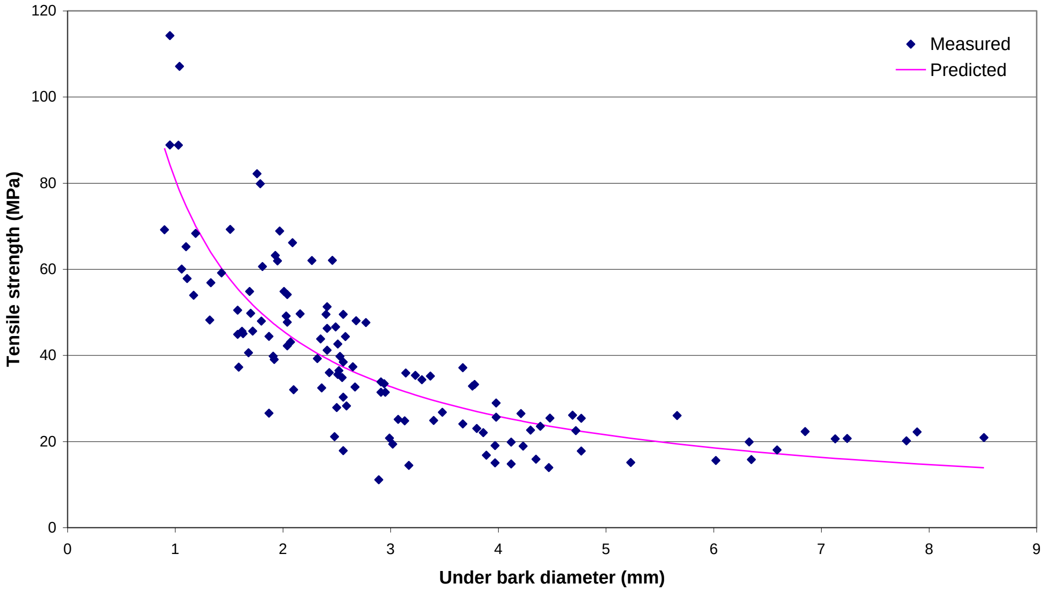

Figure 2. Relationship between 'Veronese' poplar live root-wood tensile strength and their under-bark root diameter.

Discussion

As the tension is applied to a root during testing it is inevitable that the bark within the area of the break will split and detach itself from the root-wood material. This will happen before the break occurs, and hence it is assumed that the bark material does not contribute in any way to the magnitude of the force required to break the root. Therefore whenever root-wood maximum tensile strength values are calculated, it is essential that only the under-bark diameter be used. Subsequently in other studies, if root diameter is not given as an under-bark diameter (Hathaway and Penny 1975; Bischetti *et al.* 2005), it can prove to be difficult if not impossible to compare root-wood tensile strength values in any meaningful fashion. In this manuscript, all root diameters are expressed in terms of under-bark (u.b.) diameter. To enable a conversion from under- to over-bark (o.b.) diameter, a linear relationship of the form $Y = aX + b$ was developed where Y = over-bark, X = under-bark, $a = 1.39$, $b = 0.49$ and $r^2 = 0.95$.

As would be expected, the applied force required to break live roots in tension increases with increase in root diameter (Fig. 1), i.e. the bigger the root the stronger it is. The power function relationship produced is similar in nature to that found by Bischetti *et al.* (2005) and Genet *et al.* (2005) What is not quite so intuitive is why live root-wood strength decreases with increase in root diameter (Fig. 2). It is felt by a number of researchers, typified by Genet et al (2005), that the decrease in tensile strength with increase in diameter is likely to be a function of the changing material properties of the root-wood (e.g. cellulose) with increase in root size (age), rather than the commonly held perception of decreasing tensile strength due to an increase in the number and/or severity of defects with increasing root size. Another possible explanation is that the phenomenon may be at least partially explained as an aberration of how tensile strength is calculated. There is healthy controversy on the subject, with as yet no definitive explanation.

Generally, when root diameter is plotted against root tensile strength (Fig. 2), root tensile strength decreases with increasing root diameter, i.e., a negative power function (Wu 1976; Abernethy & Rutherfurd 2001; Stokes 2002; Bischetti *et al* 2005). Consequently, when comparing root tensile strengths across a number of tree species, all the contributing roots must fall within a set diameter range. In Watson and Marden, (2004) a number of indigenous and plantation tree species were ranked in relation to their live root-wood tensile strengths. As the selected root diameter range in that study was 1- to 4-mm under-bark diameter, only the root tensile strengths values from ‘Veronese’ poplar 1- to 4-mm under-bark diameter roots were used to enable a valid root tensile strength comparison to be made (Table 2).

	Tensile strength (MPa)			**Under-bark root diameter (mm)**			
Common name	Mean	Max	Min	Mean	Max	Min	n
Southern rata	52.06	120.99	24.83	2.49	4.0	1.1	23
Lacebark	51.28	82.53	18.51	2.11	3.6	1.2	23
Hard beech	44.17	62.83	23.02	3.15	4.0	1.2	15
Veronese poplar	44.02	114.29	11.13	2.37	3.98	0.90	98
Kowhai	43.72	70.40	20.68	1.89	3.2	1.1	28
Manuka	41.71	69.63	21.84	2.50	3.6	1.8	22
Red beech	36.13	82.86	17.63	2.64	4.0	1.1	52
Kanuka	34.11	75.82	18.17	2.65	3.9	1.2	32
Kohuhu	29.30	56.08	15.74	1.96	3.9	1.7	18
Kamahi	28.91	37.30	14.99	3.28	4.0	2.5	15
Fivefinger	28.16	42.88	18.78	2.74	3.8	1.3	52
Rewarewa	26.83	52.18	10.00	2.64	3.8	1.6	24
Cabbage tree	26.42	50.18	11.68	2.35	3.5	1.5	48
Mountain beech	25.90	60.26	13.24	2.87	4.0	1.2	37
Douglas fir	25.79	42.75	13.13	2.84	4.0	1.5	22
Ribbonwood	21.59	46.62	10.68	2.30	3.7	1.0	22
Radiata pine	17.52	34.81	8.84	3.20	4.0	1.1	110
Lemonwood	16.44	28.81	8.87	2.77	4.0	1.6	24
Tutu	15.68	30.71	4.65	2.11	3.4	1.1	29
Karamu	8.38	15.23	4.54	2.59	3.8	1.6	13

Table 2 Mean live root-wood tensile strengths from roots of between 1- and 4-mm under-bark diameter, a comparison of Veronese poplar and some common New Zealand indigenous and plantation tree and scrub species. This table has been modified from Watson and Marden, (2004).

There are any number of reasons why individual plant species are selected for erosion control. When considering below-ground components, species selection for slope and stream channel stability tend to be site specific. The main features of root architecture/morphology that are taken into account when considering root contribution to soil stability are (in no particular order):

(1) Root biomass i.e. root system mass
(2) Root length
(3) Root spread
(4) Rooting depth
(5) Root distribution

The magnitudes of which are controlled by:

(a) Site (geology, climate, topography, soils, water table depth etc)
(b) Stand density
(c) Tree age

In any root-soil stability study, all the above features need to be investigated so site-specific information can be incorporated into the mix of parameters required for analysis. Root-wood tensile strength is important, but is just one of the mix of parameters that should be taken into account throughout any analysis and/or species selection during root-soil investigations.

The mean live root-wood tensile strength of *Populus × euramericana* ‘Veronese’ roots is greater than that of *Pinus radiata* (Table 2). The root systems of ‘Veronese’ poplar have a lower root biomass, but a greater length of root than radiata pine of comparable stem size (McIvor et al, 2008, Watson and O’Loughlin 1990). In other words; ‘Veronese’ poplar root systems are composed of roots of smaller diameter (size) than radiata pine, but there are more of them. The number, size and tensile strength of those roots that cross a potential shear plane are taken as a measure of enhanced slope stability due to root reinforcement (Wu et al. 1979; Abernethy and Rutherford 2001; Easson and Yarbrough 2002). Given the above and the previous paragraph it would seem unlikely that Veronese’ poplars would stabilise slopes at greater spacing distances than radiata pine if the potential is based solely on their greater root length, but smaller over-all root diameter, and a higher mean tensile strength value.

Acknowledgements

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References

References still to be checked

Abernethy, B.; Rutherfurd, I.D. 2001. The distribution and strength of riparian tree roots in relation to riverbank reinforcement. *Hydrological Processes 15*: 63–79.

Bischetti, GB, Chiaradia, EA, Simonato, T, Speziali, B, Vitali, B, Vullo, P and Zocco A. 2005. Root strength and root area ration of forest species in Lompardy (Northern Italy). Plant Soil 278: 11-22.

Coleman MD, Dickson RE and Isebrands JG. 2000. Contrasting fine-root production, survival and soil CO2 efflux in pine and poplar plantations. Plant Soil 225: 129-139.

Cousins WJ. 1976. Elastic modulus of lignin as related to moisture content. Wood Science Technology 10: 9-17

Easson, G.; Yarbrough, L.D. 2002: The effects of riparian vegetation on bank stability. *Environmental & Engineering Geoscience 8(4)*: 63–79.

Ekanayake, J.C.; Phillips, C.J. 1999: A method for stability analysis of vegetated hillslopes. *Canadian Geotechnical Journal 36*: 1172–1184.

Ekanayake, J.C.; Phillips, C.J.; Marden, M. 2004: A comparison of methods for stability analysis of vegetated slopes. Pp. 171–181 *in* Barker, D.H.; Watson, A.J.; Sombatpanit, S.; Northcutt, B.; Maglinao, A.R. (Ed.) “Ground and Water Bioengineering for Erosion Control and Slope Stabilization”. Sciences Publishers Inc., USA.

Genet M, Stokes A, Salin F, Mickovski SB, Fourcaid T, Dumail J-F and van Beek R. 2005. The influence of cellulose content on tensile strength in tree roots. Plant Soil 278: 1-9.

Gray, D.H.; Sotir, R.B. 1996: “Biotechnical and Soil Bioengineering Slope Stabilization: a Practical Guide for Erosion Control”. Wiley, New York. 378 p.
Hathaway, RL and Penny, D. 1975. Root strength in some *Populus* and *Salix* clones. NZ J Bot 13: 333-344.

Hathaway and Penny 1975

Marden, M, Rowan, D and Phillips, C. 2005. Stabilising characteristics of New Zealand indigenous riparian colonising plants. Plant Soil 278: 95-105.

McIvor, IR, Douglas, GB, Hurst, SE and Hussain, Z. 2008. Structural root growth of young Veronese poplars on erodible slopes in the southern north island, New Zealand. Agroforestry Systems 72: 75-86.

O’Loughlin, C.L.1981. Tree roots and slope stability. Whats new in forest research. #77.

O'Loughlin, C.L.; Watson, A.J. 1979: Root-wood strength deterioration in *Pinus radiata* after clearfelling. *New Zealand Journal of Forestry Science 9*: 284–293.

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

Watson, A.J.; Phillips, C.J.; Marden, M. 1999: Root strength, growth and rates of decay: root reinforcement changes of two tree species and their contribution to slope stability. *Plant and Soil 217*: 39–47.

Watson, AL and Marden, M. 2004. Live root-wood tensile strengths of some common New Zealand indigenous and plantation tree species**.** NZ J. For Sci 34: 344–353.

Wu, T.H.; McKinnell, W.P.; Swanston, D.N. 1979: Strength of tree roots and landslides on Prince of Wales Island. *Candian Geotechnical Journal 16*: 19–33.