Variation in root density of poplar trees at different plant densities

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Abstract

Poplars (*Populus* spp.) play an important role in soil stabilisation on farmed hill slopes, principally because they can be established quickly from poles and are reported to have an extensive root system able to stabilise large soil masses. Planting densities ranging from 25-256 stems ha^{-1} have been recommended but little is known of how the root system develops chronologically and what root densities different planting densities achieve.

Root density was determined in the soil surrounding two 9-year-old *P. x euramericana* 'Tasman' poplars growing in a fan nelder planting design, one at a high density (770 stems ha$^{-1)}$ and the other at a low density (84 stems ha^{-1}). This was conducted by digging trenches to a depth of 1m at different distances from the trees on all four sides and measuring root number and cross-sectional area in the soil profile using a 90 x 90 cm quadrat comprising 15 x 15 cm squares set against the smoothed face of the trench. Most of the roots were in the top 45 cm and the number of roots decreased exponentially with depth. At the high density planting, the tree root network at any point was contributed by more than one tree. At the low density planting, there were no roots found at the midpoint between adjacent trees.

For tree plantings at this age the ideal planting density to sustain pasture production and good soil protection is likely to be between these two densities.

Additional keywords: root distribution, tree spacing, soil conservation.

Introduction

Soil conservation is a significant concern for landowners farming hillslopes in New Zealand. Soil conservation on hillslopes is threatened by a mixture of high rainfall, short periods of heavy rainfall, steep slopes, fragipans, deforestation, intensive farming and unstable soils. The influence of each of these factors varies from region to region but the most significant impact is from short periods of heavy rain (between 100 mm and 300mm in 24 hours) falling on already saturated soils. Typically this is expected to occur in winter when rainfall is generally higher, but may occur at any time of the year.

Prior to the introduction of pastoral farming the hilly landscape was forested. Removal of forest has increased the rate of soil erosion on hillslopes. For example, the sediments analysis of Lake Tutira in the southern East Cape region, showed that the rate of natural erosion was 2.1 mm per year before pastoralisation, compared with 14 mm per year in the 1990's, contributed by climate change, land use and vegetation (Trustrum and Page, 1991).

Poplars are planted extensively throughout North Island farmed hill country to stabilise soil and reduce the impact of erosion (Wilkinson, 1999). Attributes of poplars that have favoured their use are their early growth rate (which is higher than other cool temperate trees except for a few *Eucalyptus* spp.), their ease of vegetative propagation from poles, their extensive root system able to stabilise large soil masses, their capacity to provide shade, shelter and supplementary fodder for stock, a high evapo-transpiration rate depleting soil moisture and the opportunity of maintaining pasture productivity. Since annual pasture production is reduced by up to 40% under conservation trees like poplars (Guevara-Escobar *et al.*, 1997; Douglas *et al.*, 2001), predominantly because of shading, it is important to know what tree spacing is needed to retain the soil on the slopes, and how this changes as the trees grow. Such data will enable farmers to develop a management plan that includes removal of trees and increasing spacing as the trees grow, thereby retaining soil conservation capability, shade and shelter, and at the same time increasing pasture production. Knowledge of structural root development in space and time, particularly on slopes, is needed to determine how management plans should proceed. This knowledge is laborious to obtain and involves some form of excavation. Previous root studies relevant to this study have investigated the relationship between root diameter and tensile resistance (Davidson *et al.*, 1989; Stokes and Mattheck, 1996; Nilaweera and Nutalaya, 1999; Watson *et al.*, 1999), fine root production and turnover in *Populus* (Coleman *et al.,* 2000), and effect of slope on root system architecture (McIvor and Douglas, 2005; Di Iorio *et al.*, 2005). Slopes are complex environments that subject plants to several mechanical stresses, such as the turning movement induced by the combination of the inclination and the weights of the stem and the soil (Di Iorio *et al.*, 2005). It is not possible to state with certainty when there is sufficient soil root density to ensure soil stability. However, it should be possible to collect data on root extension in time and space at different tree densities to give landowners planting and management guidelines for retaining soil conservation capacity over the lifetime of a wide-spaced silvopastoral planting.

This study aimed to compare the spatial root density in soil surrounding poplars planted at high and low densities in a silvopastoral system.

Methods

Study site and plant material

The trial was located on slightly sloping ground (2.5-6º) at AgResearch's Ballantrae Hill Country Research Station, near Woodville. Measurements were conducted on two 9-year-old *P.* × *euramericana* 'Tasman' poplars selected from within a fan nelder planting design. This is a design in which trees are planted in a fan generating a changing tree density as the fan extends outwards. One tree (T1) was selected in a high-density area (770 stems ha^{-1}) and the other (T2) in a low-density area (84 stems ha^{-1}). Height and diameter at breast height (DBH; 1.4 m above ground on the upslope side of the tree) of both trees are presented in Table 1. T1 was representative of the trees growing at that density but T2 had a smaller DBH than other trees growing at the same density. The reasons for this were unclear. The soil type was a Kumeroa hill soil classified as Typic Dystrochrepts related to yellow-brown earth and yellow-grey earth intergrades. The soil had a pH 5.4, Olsen P of 17-22 mg/kg and an organic content of 7-9%. The understorey vegetation comprised perennial ryegrass / white clover pasture and dense patches of rush (*Juncus* spp.)

Table 1. Description of the two *P.* × *euramericana* 'Tasman' trees around which trenches were dug.

Tree	Density (stems/ha)	Height m	DBH cm	Slope (degrees)
T1	770	14.9	19.2	3.5
T2	84	11.5	17.3	5.5

Excavation procedure

Trenches were dug perpendicular to each tree to a depth of 1 m and a length of 1.2 m on four sides corresponding to N, S, E and W directions. The upslope and down-slope sides were in the N and S directions, respectively. Trenches around both trees were excavated at half and a quarter the mean distance to the four nearest trees, these distances being 1.8 m and 0.9 m from T1 and 5.5 m and 2.8 m from T2. Trenches were also excavated at 0.9 m and 1.8 m around T 2.

The side of the trench nearest the tree was smoothed with a spade and a 90 cm x 90 cm steel reinforcing mesh organised in 15 cm x 15 cm squares was positioned against the smoothed side so that the centre of the mesh was nearest to the tree. The number of cut root ends within each square was recorded together with the root diameter. In this way roots were mapped over a 90 cm x 90 cm area for each trench face. Root diameters were grouped into the diameter classes <2mm, 2-5 mm, 5-10mm, 10-20 mm, >20 mm. Neither the direction of root growth nor the tree from which a root originated was determined.

Three soil cores 50 mm high and 45 mm in diameter were taken at 17.5 cm, 35 cm, 50 cm and 80 cm from the distal face of the 1.8 m trench in each direction to determine the bulk density of the soil surrounding the trees at different depths. The cores were stored in plastic bags, weighed immediately on returning to the laboratory and then dried at 90 ºC for 72 hours before reweighing.

Single factor ANOVA was used to determine if there were significant differences in root and soil data between directions around a tree, and between slopes. The roots were assumed to be circular and cross-sectional areas were calculated using $A = (\pi * d^2)/4$ where d = root diameter.

Results

Root number and root cross-sectional area varied ($p<0.05$) between different depths but not between different squares at the same depth, nor when root data at the same depth were compared in different directions ($p>0.05$). Consequently, data recorded both at the same depth (0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-75 cm and 75-90 cm) for trenches in each compass direction and at the same distance (0.9 m, 1.8 m, 2.8 m and 5.5 m) from the tree were aggregated for subsequent analysis.

Over 70% of roots surrounding both trees were found in the top 30 cm of the soil profile (Table 2), and over 90% of the root cross-sectional area was found in the top 30 cm (Table 3). The percentage of roots in the top 30 cm increased with trench distance from the tree trunk. No roots were found at the trench equidistant between T2 and its nearest neighbours (Table 3). The roots found at the 2.8 m trench were almost certainly from T2 only.

Table 2: Total number of roots per m^2 at 0.9 m. 1.8 m and 2.8 m (T2 only) from the tree trunk at different depths for high and low tree density locations (% distribution in brackets).

	Distance of trench from tree				
	High density tree (T1)		Low density tree (T2)		
Depth in cm	0.9 m	1.8 m	0.9 m	1.8 m	2.8 m
0-15	398 (52)	269 (55)	165 (42)	26 (52)	12 (52)
15-30	175 (25)	133 (27.5)	106 (26)	14 (26)	8 (35)
30-45	103 (15)	56 (11)	69 (17)	9 (16)	3 (13)
45-60	42 (6)	25 (5)	45 (11)	2 (4)	1
60-75	13 (1.7)	3 (1)	16 (3.6)	1 (2)	0
75-90	6 (0.3)	2 (0.5)	2 (0.5)	0	0

The greater root numbers surrounding T1 (Table 2) were because of the larger size of T1 resulting in more and longer roots (the lesser contribution) and the protrusion of roots from adjacent trees. Root numbers per m^2 around T2 (Table 2) reduced to 13-16% in the top 45 cm of soil from the 0.9 m trench to the 1.8 m trench. Around T1 the value was 54-76% indicating that the roots extended from a number of adjacent trees as well as the tree around which the trench was dug, and contributed to the root numbers at 0.9 m as well. Root cross-sectional area in the top 30 cm of soil moving from the trench at 0.9 m to the 1.8 m trench (Table 3) around T1 reduced to 32-60%, and around T2 reduced to 2-15%.

Table 3. Root cross-sectional area (mm^2 per m^2) around the high and low-density trees at a quarter and half the distance to the next nearest tree (percentage distribution in brackets).

	Distance of trench from tree					
	High density tree (T1)		Low density tree (T2)			
Depth (cm)	0.9 m	1.8 m	0.9 m	1.8 m	2.8 m	5.5 m
0-15	9400 (86)	3071 (74)	5973 (77)	923 (94)	57 (17)	0
15-30	1130 (10)	682 (16)	1283 (17)	32 (3)	188 (56)	0
30-45	269 (3)	317 (8)	276 (4)	23 (2)	70 (21)	0
45-60	91 (1)	40 (1)	150 (2)	2 (<1)	20 (6)	0
60-75	17 (<1)	3 (<1)	31 (<1)	7 (<1)	0	0
75-90	14 (<1)	26 (<1)	2 (<1)	0	0	0

Table 4. Mean cross-sectional area (mm^2) per root at different depths and at different distances from the trunk for the high and low-density trees.

	Distance of trench from tree					
	High density tree (T1)		Low density tree (T2)			
Depth (cm)	0.9 m	1.8m	0.9 m	1.8 m	2.8 m	5.5 m
0-15	23.5	11.4	36.2	35.5	4.8	
15-30	6.5	5.1	12.1	2.3	23.5	
30-45	2.6	5.7	4	2.6	23.3	
45-60	2.2	1.6	3.3	1	20	
60-75	1.3	1.0	1.9	7		
75-90	2.3	13	1			

Table 5: Number of roots (%) as a function of their diameter around low and high density trees at 0.9 m and 1.8 m from the tree trunk.

	Percentage high density		Percentage low density	
Root diameter (mm)	At 0.9 m from the trunk	At 1.8 m from the trunk	At 0.9 m from the trunk	At 1.8 m from the trunk
<2	41.7	49.2	37	42.3
2-5	46.5	42.4	48.9	48.1
5-10	12.6	6.1	8.4	3.8
10-20	3.3	2	4.7	3.8
>20	1.1	0.2	1	2

Table 6. Soil bulk density (g/cm^3), volumetric soil water content (g/cm^3) and saturated soil water content (g/cm^3) at four depths at 1.8 m from trees in high (T1) and low (T2) density plantings (mean and sd). N = 12 for each tree at each depth except 80 cm (N for T1 = 1, N for T2 =3).

	Soil bulk density (g/cm^3)		Volumetric water content (g/cm^3)		Saturated water content (g/cm^3)	
Depth (cm)	T1	T2	T1	T2	T1	T2
17.5	1.18±0.12	1.35±0.12	0.36±0.05	0.35±0.11	0.55±0.05	0.49±0.05
35	1.47±0.10	1.57±0.12	0.34±0.07	0.37±0.05	0.44±0.04	0.41±0.04
50	1.59±0.09	1.68±0.04	0.30±0.05	0.35±0.03	0.40±0.03	0.37±0.02
80	1.75	1.67±0.10	0.33	0.28±0.02	0.34	0.37±0.04

Roots with the greatest cross-sectional area were mostly close to the surface (Table 4). While the occasional large root occurred deeper in the exposed soil profile most of the roots at depth were smaller. Over 85% of roots sampled were 5 mm or less in diameter (Table 5). Soil data collected in the directions N, S, E and W were not significantly different ($p>0.10$) so they were bulked together in Table 6.

Discussion and conclusions

Trees grown on pastoral hillslopes for soil retention influence the microclimate of the hillslope in a number of ways most of which are not well quantified. The trees have the capacity to influence pasture productivity through such factors as canopy shading, and reduced wind run, and to influence animal productivity through creating shade and shelter. Since soil retention depends on the extension of the root system and this in turn depends on the photosynthetic productivity of the tree and its genetic potential, the most suitable planting density for conservation trees on hillslopes at different growth stages or ages is a statistic that is most useful to know. In New Zealand poplars are used extensively in this role. Nelder design plantings enable the distribution of root systems through time and space to be measured with a high degree of confidence.

Extensive work on hillslopes demonstrates that when compared with non-root-permeated soils, even low densities can provide substantial increases in shear strength (Riestenberg, 1994). Assembling tree root data is both time consuming and challenging. Total root excavations have often been considered prohibitive in both time and personnel. Destructive excavation methods such as hydraulic sluicing are often not appropriate where it is important to retain environmental integrity and/or slope stability. A variety of indirect methods have been employed to map the roots of individual trees including soil trenches (Burgess *et al.*, 1997; Tomlinson *et al.*, 1998). In this study the structural root density surrounding trees of the same age planted at differing densities was quantified without distinguishing the source of the roots. The distribution of structural roots largely within the top 30 cm of the soil profile agreed with studies of tree root distribution in both *Populus* and other species (Kellman, 1979; Watson and O'Loughlin, 1990; Puri *et al.*, 1994; Abernethy and Rutherfurd, 2001). Puri *et al.* (1994) found from excavations of *Populus deltoides* growing at spacings of 2m x 2m to 6m x 6m that the root distribution was asymmetrical in some cases and symmetrical in others, and that root:shoot ratio increased with an increase in spacing indicating that trees growing with wide spacing allocated proportionally more carbon to their roots than trees grown with narrower spacing. After thinning, the remaining trees are likely to show reduced above ground growth as more biomass is allocated to structural roots, probably in response to greater forces from wind. Di Iorio *et al.* (2005) found that diameter at breast height is a reliable predictor of root mass but is not necessarily correlated with length and number of roots, these being influenced by such factors as inclination, shallow slides and soil compactness. While not being able to confirm this conclusion in the present study, the high-density tree was taller and had a greater diameter at breast height than the low-density tree and was less exposed to wind. For the two trees sampled in this study the distribution of roots around each tree was symmetrical. For the high-density tree this was a measure of the root distribution of a tree network, whereas for the low-density tree it represented the root distribution of an individual tree since no roots were found in the trenches halfway between the tree and its nearest neighbours. The relative reduction in root cross-sectional area in the top 30 cm of soil from the 0.9 m trench to the 1.8 m trench suggested that 4-6 trees contributed to the root density at 1.8 m from the trunk of T1, compared with the single tree at T2. The many small roots (over 90% were ≤ 10mm in diameter) formed a comprehensive root network that probably had a major role in absorption of water and binding of soil, particularly in the top 45 cm of soil. The high bulk density of this soil (Table 6) likely restricted root penetration as reflected in the low number of roots located deeper in the profile. The lower bulk density of the soil down to 50 cm around T1 was itself probably a result of the soil expanding activity of the higher root density. This would increase water infiltration and reduce runoff. Differences in volume water content of the soil at the depths where roots were concentrated (0-30 cm) between the two trees were small, and further data are needed before comparing the dewatering activity of the tree roots at each density. Large sinker roots are found close to the tree trunk (McIvor and Douglas, 2005) so would not have been measured in this study. The slight slope in this study was atypical of erosion-prone pastoral hillslopes in this region which have gradients up to 25º or more. Other studies found that root distribution around a tree on steeper slopes was greater downslope of the trunk (McIvor and Douglas, 2005; Di Iorio *et al*., 2005). Despite this asymmetry, for wide spaced trees growing on steeper slopes, root distribution around a single tree is likely to be similar to that in this study but with a greater contribution made to upslope root presence from trees above the study tree. Di Iorio *et al*., (2005) found that total root volume at a given DBH was significantly higher in the steep-slope condition, but DBH was not a reliable indicator of root length. Puri *et al.,* 1994 found that root:shoot ratio increased with an increase in spacing in *P. deltoides*. This suggests that trees on steeper slopes and at wider spacings invest more biomass in roots as a response to the greater gravitational and wind forces. However, spacing trees too far apart in the establishment phase will delay effective soil conservation for lack of lateral root coverage (Puri *et al*., 1994; McIvor and Douglas, 2005), or conversely, the trees will take much longer to protect the slope on which they are growing. Effective soil conservation on slopes is likely to require denser plantings at the establishment phase followed by thinning as the trees grow to maximise pasture yields while promoting root coverage of the soil.

At this site 9-year-old *P. x euramericana* ‘Tasman’ root systems were giving complete coverage of the soil between the trees at a planting density greater than 84 stems/ha but less than 770 stems/ha. Further excavations at intermediate tree densities will enable identification of the minimum density of tree plantings required to give complete coverage of the soil between trees at this tree age and slope. At the same time the change in annual pasture yields resulting from the coverage could be estimated.

Acknowledgements

This research was funded by the Foundation for Science, Research and Technology through the Soils and Land Use Initiative (SLURI). The contribution of Lex Foote to the excavations was appreciated.

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