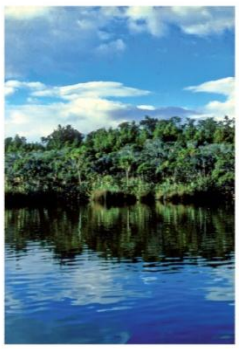

Poplar and willow growth during their formative years: preliminary findings from new field trials

Envirolink advice grant:

907-GSDC83

Landcare Research
Manaaki Whenua

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February 2011

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Landcare Research Contract Report:	LC 135

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Contents

Summary

Project and Client

- Gisborne District Council supported a Landcare Research initiative seeking FRST Envirolink funding to collate and compare data on the above- and below-ground growth performance of 1-year-old poplar and willow poles from two trials and one field site in the North Island.

Objectives

- Collect a representative sample of 1-year-old poplar and willow poles from an East Coast hill slope typical of the most difficult land classes considered treatable with space planted poles. Partition the material by stem, branches, and roots; oven dry, weigh and for the roots separate into diameter size classes and measure root length.
- Compare with equivalent data for 1-year-old pole material of poplar and willow clones established as part of two field trials located on alluvial terraces with contrasting soil types and in climatically different regions: East Coast of the North Island and Manawatu.
- Summarise the findings, highlight knowledge gaps and recommend future research needs.

Methods

- One-year-old poplar (Veronese) and willow poles (Moutere) were retrieved from Puketoro Station, an East Coast hill country property for partitioning into above-ground (stem and branches) and below-ground (root bole and roots) components before oven drying and weighing. The distribution of root biomass and root length (of roots >1 mm), relative to the root bole, was recorded by 50-cm radius × 50-cm deep concentric disc (similar to growth rings) to the maximum extent of root growth. Roots within each concentric disc were segregated into diameter size classes and total root length was measured. Growth performance was then compared with one-year-old poles of two poplar and two willow clones excavated from a controlled field trial site in Gisborne and with one pole of a poplar clone from a similar trial site in Palmerston North.

Results

- At Puketoro, for all parameters measured one year after establishment, willow (Moutere) appears to outperform poplar (Veronese). Measured data for new growth produced since planting (e.g., branches and roots) indicate that willow produced ~twice more branch and ~three times more new root biomass than did poplar. At this stage in growth the mass of the fine root fraction (< 2mm) was greater for both poplar (54%) and willow (66%) than the structural root (>2 mm) mass. Willow produced more than twice the total length of structural roots than did poplar, contributing to its superior root spread. Of that total root length, most is in the finer roots and located closest to the stem, with willow having more root length and root biomass than poplar. Nonetheless,

for both species, the mass of new roots after one year's growth comprises just 7% of the total below-ground biomass.

- Mean tree height of willow at both the Gisborne and Puketoro sites was greater than for poplar and for both species was significantly greater at the Gisborne site where Tangoio outperformed Hiwinui and, Veronese outperformed Kawa. The mean tree height of poplar at the Puketoro site was similar to that of the Veronese poplar at the Palmerston North site. The differences in above-ground parameters are generally less within and between sites than are below-ground parameters.
- There was no significant difference in root spread between poplar at Puketoro and the Palmerston North site, averaging just over 0.8 meter diameter. This contrasts markedly with the mean root spread of ~10 m for similar aged poplar and willow at the Gisborne site. At this age root depth is heavily influenced by the depth to which the pole is planted. In the denser soils at Puketoro Station and the Palmerston North trial site the maximum root depth was little more than the base of the pole at 70 cm. However, in the less dense soils at the Gisborne trial site, the roots that developed from the base of the root bole and the sinker roots that descended from surficial lateral roots both penetrated to a maximum depth of ~1 m.
- At both the Gisborne and Puketoro sites, the total length of roots (> 1-mm diameter) was greater for willow than for poplar and for both species was significantly greater at the Gisborne site where Tangoio and Hiwinui were similar and Kawa outperformed Veronese. Here, both poplar species had two to three times more root length than Veronese at the Aokautere site, which in turn outperformed the poplar at Puketoro Station.
- The same general trend was evident for the biomass of roots >1 mm in diameter with the exception that for the willow clones, Tangoio outperformed Hiwinui.
- Total tree biomass follows similar patterns to many of the other parameters. The ratio of above-ground biomass (stem and branches) to below-ground biomass (root bole and structural roots i.e. including fibrous roots) varied from 0.39 to 1.21 but at this stage of growth is largely a function of differences in the size of the planting material.
- While relationships between DBH and total root length for roots >2-mm diameter and between DBH and below-ground biomass, including data collected for 5-, 7- , 9.5-, and 11.5-year old poles from Ballantrae Station, can be derived with relatively good R^2 values, these relationships should be used with caution as they have been derived from small sample numbers of each clone.

Conclusions

- Irrespective of site and for many of the growth parameters measured, willow appears to outperform poplar during their early stages in growth reflecting their overall greater hardiness and suitability to wet sites including earthflows and along gullies, typical of locations where they are the preferred soil conservation species.
- For both poplar and willow there are clear differences in growth performance between sites. Growth performance at the Gisborne site was superior to that of the Puketoro and Aokautere sites but for the latter two sites was of a similar order of magnitude.
- Regression relationships established using growth performance data collected from trees at different stages of growth and growing in different physiographic sites, where growth performance can be markedly different, will be less than ideal for developing

robust relationships between above- and below-ground growth parameters. These relationships, however, are critical for determining planting density requirements for situations where poplar and willow plantings are the preferred means of soil conservation. The scarcity of data has limited our ability to develop predictive models. The completion of time series data on the growth performance of poplar and willow is required for Manawatu and East Coast hill country sites where partial time series data already exist.

Recommendations

- It is recommended that the annual excavation of pole material, preferably from Puketoro Station or from other nearby hill slope locations on the same land class, be continued for a minimum of another two years, but preferably for four years, in order to establish a time series of growth performance for poplar and willow poles to at least year-5. Alternatively, continue annual excavations of poles for a further 2 years (2012) , and randomly select a representative number of trees for annual re-measurement of above-ground growth parameters until these plantings are 5-years old (2014).
- For the Manawatu region, it is recommended that the existing time series data for 5-, 7-year, 9-year and 11.5-year old Veronese poles extracted from Ballantrae Research Station be extended to include the collection of additional data for younger aged Veronese poles established on sites with similar land/soil/slope class and within the general vicinity of Woodville.
- It is recommended that parties interested in research specifically on poplar and willow root systems convene a workshop that focuses on formulating a research strategy for the future that will address some of the risk management issues associated with hill country subject to one or a combination of erosion types and for which poplar and willow plantings are the preferred means of soil conservation.

1 Introduction

Poplars (*Populus* spp.) and willows (*Salix* spp.) are commonly used in New Zealand for soil conservation on erosion-susceptible pasture-covered hill country (Douglas et al. 2010) and river bank protection. Mostly they are established on hill country as widely spaced plantings at 25–150 stems ha^{-1} (spha) but occasionally they may be established in high density "plantations" up to 1500 spha. There are a number of advantages that make poplar and willows useful for soil conservation on moist unstable hill country including: rapid establishment from stem cuttings, ease of establishment in the presence of grazing livestock, extensive lateral root development, high evapotranspiration rates during the growing season, and tolerance of seasonally wet soils (Wilkinson 1999). Plants are predominantly established from 3-m-long un-rooted stem cuttings, referred to as poles. Occasionally, where livestock are not present, smaller diameter and shorter length materials are used (wands and cuttings).

In 2008, a joint Ministry of Agriculture and Forestry (MAF) and Gisborne District Council workshop (Poplar and Willow Planting on Land Overlay 3A, Gisborne, East Coast Region) addressed a number of concerns regarding the efficacy and effectiveness of regimes of wide-spaced poplar and willow plantings as an erosion control strategy on unstable East Coast hill country (MAF 2008). This workshop brought current practitioners, with significant experience in soil conservation (4 regional councils represented), together with scientists knowledgeable in the causes and solutions for erosion types typical of hill country, to explore if a consensus could be reached on the process of selecting the most effective and practical erosion control solution for different erosion types. The aim was to develop written guidelines outlining specifications for the treatment of eroding areas where poplar/willow pole planting could result in a successful erosion control outcome. A general consensus was reached on indicative plant spacing for earthflows, linear gullies and slumps based largely on post-storm landslide damage assessments and personal experiences. While these species have long been recognised by soil conservation practitioners for their ability to provide a soil conservation benefit in New Zealand (Hawley & Dymond 1988; Hicks 1989; Thompson & Luckman 1993), concern was raised that there is limited quantitative knowledge and understanding of the rates and patterns of root development particularly during their formative years (1–5 years old) to underpin the workshop recommendations on wide-spaced plantings (Phillips et al. 2008).

Previous attempts at evaluating the 'effectiveness' of soil conservation efforts include 'whether the works have survived a number of years later' to post-storm, field-based surveys of fresh erosion relative to land class, tree age, spacing and condition of plantings (Hicks 1989); modelling of the fraction of ground eroded relative to distance from trees (Hawley & Dymond 1988); assessing plant performance for erosion control (Phillips et al. 2000); and development of a "decision support system" for assessing the effectiveness of wide-spaced trees based on vegetation parameters derived from limited data sets of commonly planted trees (Phillips et al. 2008; Douglas et al. 2009).

In his assessment of the effectiveness of soil conservation efforts in the Waihora catchment Hicks (1989) identified that 66% of farm conservation measures undertaken before a major storm in 1988 (Cyclone Bola) had failed. Reasons included (i) plantings established to control one but not all erosion types present, (ii) installation of appropriate measures but over an insufficient area required to stabilise a hillslope, (iii) well-executed but poorly maintained plantings, and (iv) non-replacement of dead trees. These studies highlight that the ongoing

incidence of slope failures in areas considered to have been well-treated and planted at spacings deemed appropriate for particular land classes and type of erosion are in fact symptomatic of insufficient trees in good health at the time of the initiation of new slope failures. While recent work by Douglas et al. (2009, 2010) indicates that mature plantings of 30–60 stems per hectare (13–18-m spacing) were effective in controlling shallow slip erosion on slopes up to 20° in the Manawatu and Wairarapa, of increasing concern is the assumption and general acceptance that a successful treatment reported for a particular land class/slope category/erosion type is applicable to other land classes and erosion types. On the contrary, questions of plant spacings and time (years) required to achieve a measureable improvement in slope stability and thereby 'effectively' minimise the risk of further landslide damage on different land classes (steeper slopes) and combinations of erosion type other than shallow landsliding (e.g. deeper-seated failures such as earthflow and slump) and small gullies (see Figs 4–6) remain largely unanswered.

To date , there have been few New Zealand-based field studies that involve the systematic measurement of both the above- and below-ground plant components of poplar and willow trees at varying ages and from which time series regression analyses of relationships between above-and below-ground growth parameters can be established (McIvor et al. 2005, 2010) . In particular, time series data of the growth rate of root systems of **modern** clones of poplar and willow are essential for understanding how soon (years after planting) root occupancy (depth, spread and root mass per volume of soil) and thus root reinforcement of slopes occurs. This understanding would then enable the development of models or tools to determine effective planting strategies and provide soil conservators with a scientific basis to support the development of guidelines for appropriate spacing of poplar and willow on eroding hill country with differing stabilities and/or combinations of erosion types. Had there been data available on tree age and knowledge of the architecture and distribution of roots of poplar and willow at the time of the earlier studies by Hicks (1989) and Hawley and Dymond (1988) these authors would have been better able to substantiate their findings.

This report summarises current research efforts aimed at improving the knowledge base of growth rates and patterns of root development for poplar and willow poles during their formative years. In addition, we highlight knowledge gaps and recommend future research needs.

2 Background

In recognition of the paucity of quantitative time series data of poplar and willow growth, particularly of their root systems, two trial sites were established as part of the FRST-funded SLURI programme in 2009 with the aim of documenting the relative growth rates of clones typically used for erosion control in two regions of the North Island: the East Coast and the Manawatu. Both trials are located on flat land (alluvial terraces) in Gisborne and Palmerston North, respectively.

While these data will be useful for modelling purposes, a potential shortcoming of these trials is that the expected growth rates may represent the upper end of growth possible in the two respective regions and will therefore over-represent that on hill slopes susceptible to erosion where growing conditions are likely to be less than optimum in maintained experimental trial sites. With this in mind, and the coincidental opportunity to collect 1-year-old poplar and willow poles from actively eroding slump terrain in the Gisborne region (Puketoro Station),

we are able to contrast growth rates of poplar and willow poles between an 'ideal' and a 'typical hill slope' site in the same region with that for two alluvial terrace sites in climatically different regions and on contrasting soil types.

While the data presented in this report will fall far short of improving our understanding of the intricate relationships between plant growth, site, soil and climatic influences, it is the first step towards compiling a time-series database of measureable growth paramaters for modern clones of poplar and willow that will eventually permit scientifically validated comparisons to be made with older age classes of these and other tree species commonly used for soil conservation. The information gained will fill a key gap in data required to advance our understanding of how soon after planting, poplar and willow poles increase soil reinforcement in a field situation. Such data are proving increasingly essential to support the continued use of pole planting for soil conservation through policy development and to promote landowner participation in the goal of long-term sustainability of pastoral farming on soft rock hill country (not just Gisborne) where afforestation is not the only soil conservation option. In addition, it is anticipated that in future years these data will help establish the 'effectiveness-limitations' of space-planted soil conservation strategies on different classes of land and/or erosion types and, perhaps, where species more suited to close-planting would afford the required level of soil reinforcement and slope stability. With increased knowledge of the growth performance of poplar and willow species over time, particularly of their root systems, conflicts over which soil conservation strategy is most appropriate for different hill slope situations can then be addressed.

This information can then be used by Councils as part of their one-to-one advocacy programmes with farmers, interaction with MAF, and for education initiatives. It could lead to changes in willow and poplar clone recommendations for particular site conditions, revised planting standards and spacings, and ultimately result in increased interest and uptake of pole planting opportunities. Pole planting is integral to the success of Gisborne District Council's regulatory-based Sustainable Hill Country Project, which is itself complementary to MAF's East Coast Forestry Project.

3 Objectives

Collect representative samples of 1-year-old poplar and willow poles from an East Coast hill slope typical of the most difficult land classes considered "treatable" with space-planted trees. Partition the material by stem, branches, and roots; oven dry, weigh and, for the roots, separate into diameter size classes and measure root length.

Compare with equivalent data for 1-year-old pole material of poplar and willow clones established as part of a wider field trial that included cuttings and wands planted on alluvial terrace sites with contrasting soil types and in two climatically different locations Gisborne and Palmerston North (SLURI trial).

Summarise the findings, highlight knowledge gaps and recommend future research needs.

4 Methods

4.1 Site details

4.1.1 Gisborne trial site

The trial site is located on a low-lying, even-surfaced alluvial terrace adjacent to the Taraheru River, in Gisborne City, North Island, New Zealand (Fig. 1).

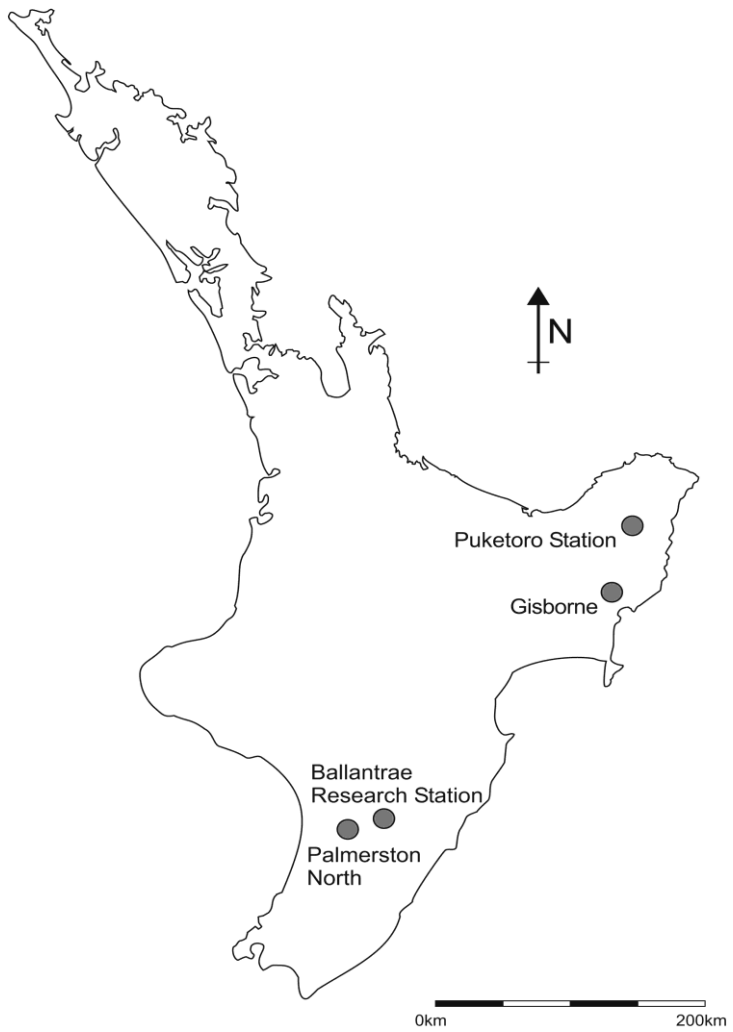

Figure 1 Map of study sites.

The soil is free draining, Te Hapara Typic Sandy Brown Soil (Hewitt 1998) and is irrigated in summer. The site (50 m × 30 m) is subdivided into three blocks, tilled and to minimise weed competition, matting was laid down before planting in September 2009 (Fig. 2).

Poles, stakes and wands of two clones of poplar and two of willow were sourced from local nurseries and all three blocks were planted in a day. Within each block, the three types of material(poles, stakes and wands) were planted in a pre-determined random pattern at 3-m spacing. Poles 3 m long were inserted into the ground to a depth of 0.7 m; 1 m wands to 0.4

m; and 0.5 m stakes to 0.3 m. Diameter at breast height and root colar diameter were measured at the time of planting but not the mass of the planting material.

Species selected were two clones of poplar (Veronese and Kawa) and two clones of willow (Tangoio and Hiwinui), these being the species most often used for soil conservation in this Region.

Figure 2 Trial site at Gisborne. Poplar and willow are 9 months old. (Photo: Mike Marden, Landcare Research).

In May 2010, 9 months after planting, three of each planting type (poles, wands, stakes) of each of the four species were removed for processing however, only one root system of each planting type was excavated and processed. Using an air lance at 240 kPa, soil surrounding each root system was removed allowing them to be extracted undamaged and a high percentage of the total root mass to be recovered (Fig. 3).

Figure 3 Air lance using compressed air to remove soil and expose root system of 9-month-old poplar pole intact. (Photo: Chris Phillips, Landcare Research).

4.1.2 Puketoro Station

In July 2010, seven Veronese poplar and nine Moutere willow poles were excavated from the 'Horse paddock' on Puketoro Station, inland of Tokomaru Bay (Fig. 1). Most of the sample trees were located close to an actively eroding gully where they had toppled and were partially exhumed as a consequence of localised slumping of the gully sides (Figs 4–8). The site is west facing, LUC Class VIIe 15 land with slopes 21–35 degrees and averaging 28 degrees (NWASCO 1975). Soils are Orthic Brown Soils transitioning to Allophanic BrownSoils and related skeletal steepland soils (Hewitt 1998). They comprise clay-rich, greywacke colluvial subsoil overlain by thin volcanic ash and a residual organic topsoil. Slopes show evidence of past and present moderate to severe gully erosion and moderate slump and earthflow with a potential for gully erosion to become very severe (NWASCO 1975). Willow (Moutere) pole material was grown in a nursery on Wharekaka Road, Tolaga Bay and poplar (Veronese) poles were sourced from Puketoro nursery. The Veronese parent material for this nursery was sourced from the Gisborne District Council nursery at Waerenga-o-kuri. The 'Horse paddock' site was planted in August 2009. Diameter at breast height, root colar diameter and pole mass were not measured at the time of planting.

Figure 4 One year old poplar and willow plantings in 'Horse Paddock', Puketoro Station. (Photo: Nick Pollock, MAF, Gisborne).

The location of approximately 1200 poplar and willow poles planted at this 9.7-ha site has been georeferenced by GPS (Global Positioning System) to an accuracy of ± 3.0m. The Ministry of Agriculture and Forestry intend to repeat this survey in 2014 to assess pole losses (mortality); results will form the basis for determining the amount of grant payout to the landowner.

Figure 5 One-year-old poles planted along the sides of a small gully are toppling as a consequence of gully deepening and subsequent collapse of the adjacent slopes. (Photo: Nick Pollock, MAF, Gisborne).

Figure 6 Advanced gullying following heavy rainfall in February 2010 resulting in slump failure with consequent toppling and ultimately the loss of one-year-old poles. (Photo: Nick Pollock, MAF, Gisborne).

4.1.3 Palmerston North site

This trial is located on an elevated alluvial terrace at the site of the former Ministry of Works Aokautere plant nursery, Palmerston North (Fig. 1). The soil, Weathered Recent Fluvial Soils (Hewitt 1998), consists of an uppermost compacted 30 cm layer of silt loam overlying loosely compacted sands. The site, protected by shelter belts, was cultivated 2 months before planting and weeds sprayed soon after planting and again during summer. It is not irrigated. As part of the larger SLURI study on the relative growth rates of different types of poplar plant material, poles, wands and cuttings were planted in August 2009 at 2 m (within row) × 2.5 m (between rows) spacing (Fig. 7). Poplar clones included Veronese, Fraser, Kawa, NZ 5026, NZ 5034, and Trichocarpa but only Veronese was planted as a pole. In May 2010, 5 Veronese poplar poles were extracted for procesing and measuring. Diameter at breast height, root colar diameter and pole mass were not measured at the time of planting. Willow clones were not trialled at this site.

Figure 7 View of Palmerston North trial site. Veronese poplars 17 months old when photgraphed. (Photo: Ian McIvor, Plant & Food, Palmerston North).

4.2 Partitioning and measurement

The methods used to process root systems and the scope of the data collected by different researchers varies between studies. Nonetheless, many of the basic parameters used to quantify growth performance are standard and conform to well-established procedures (e.g., Watson et al.1999; Marden et al. 2005; McIvor & Douglas 2005; Douglas et al. 2010).

Measurements made at each of the 3 sites (Puketoro, Gisborne and Palmerston North) in the contemporary studies are reasonably consistent, while those from older studies are less so. Above-ground growth parameters measured included height, canopy spread, root collar diameter (sometimes referred to as ground-line diameter) and diameter at breast height (DBH). Canopy spread is the mean of the canopy measured in two directions. Below-ground growth measurements included maximum root depth and lateral root spread. The latter was taken as the mean of the distance from root tip to root tip measured in two directions. The root system of each plant was photographed before being partitioned into its biomass components.

Above-ground biomass was segregated into branches and stem. There was no foliage on the trees at the time of sampling. Total stem and branch green weight were recorded, sub-samples of which were weighed before drying until there was no further decline in weight. To calculate total dry weights the respective weight loss ratios for branches and stem were applied to the total sample.

Below-ground components were partitioned into root bole (stump), tap, lateral and sinker roots. Roots were further partitioned into diameter size classes (<1 mm (fibrous), 1–2 mm, 2–5 mm, 5–10 mm, 10–20 mm) (Watson & O'Loughlin 1990), and the total length of roots in each diameter size class (excluding fibrous roots) was measured. Relative to the root bole, a measure of the distribution of root biomass and root length (of roots >1 mm), by diameter size class, was recorded for each 50-cm radius by 50-cm deep concentric disc (similar to growth rings) to the maximum extent of root growth (Figs 8 and 9).

Figure 8 Intact 9-month-old willow root system from Gisborne trial site before measuring root distribution relative to the root bole. (Photo: Chris Phillips, Landcare Research).

Figure 9 Partitioning of a 9-month-old willow root system from the Gisborne trial to measure the distribution of root length and biomass in 50-cm radial increments relative to the root bole starting from the outermost extent of the longest root. (Photo: Chris Phillips, Landcare Research).

The total amount of each below-ground biomass component (root bole and roots) was oven-dried at 80°C until there was no further weight loss then weighed to the nearest 0.1 g.

In this report we present selected measurements of above- and below-ground plant components for pole material of poplar and willow (where available) excavated from each of the three field sites approximately one growing season after planting.

Where relevant, and to enable comparisons with older trees, we incorporate selected growth data for older poplar trees excavated from Ballantrae Research Station, near Woodville (Fig. 1).

5 Results and Discussion

5.1 Puketoro site

At Puketoro, for all parameters measured one year after establishment, willow (Moutere) appears to outperform poplar (Veronese) (Tables 1 and 2). However, as no measurements of root collar diameter, DBH or of the the mass of the planting material (pole) were recorded at the time of planting, some of the apparent differences in growth performance between poplar and willow are to some unknown degree likely to reflect size differences in the initial planting material itself (i.e. the pole). Measured data for new growth (excluding pole) produced since planting (e.g., branches and roots) indicate that willow produced ~twice more branch (Table 1) and over three times more new root biomass (Table 2) than did poplar. At this stage in growth the mass of the fine root fraction (< 2 mm) was greater for both poplar (54%) and willow (66%) than the structural root (>2 mm) mass (Table 2). Willow produced three times the total length of structural roots (> 2 mm) than did poplar, which contributed to its superior root spread (Table 2). Of the total root length most is in the finer roots and located closest to the stem (Fig. 10), with willow having more root length and root biomass than poplar (Fig. 11). Nonetheless, for both species, the mass of new roots after one years growth comprise ~7% of the total below-ground biomass.

Table 1 Mean above-ground parameters for 1-year-old Veronese poplar (n=7) and Moutere willow (n=9) poles from Puketoro Station

	DBH (mm)	Root collar diameter (cm)	Tree height (m)	Canopy spread (cm)	Stem biomass (g)	Branch biomass (g)	Total above-ground biomass (g)
Poplar	34	42	2.99	33	833	86	919
Willow	54	70	3.0	53	2547	162	2709

Table 2 Mean below-ground parameters for 1-year-old Veronese poplar (n=7) and Moutere willow (n=9) poles from Puketoro Station. Total root biomass includes fine and coarse roots. Total below-ground biomass includes roots plus root bole

	Maximum root spread (cm)	Maximum root depth (cm)	Root bole biomass (g)	Total new root biomass (g)	Root biomass >2mm (g)	Total below ground biomass (g)	Total structural root length (>2 mm) (m)	Total root length (>1 mm) (m)
Poplar	85	70	355	26	12	381	4	12
Willow	132	70	1202	87	38	1289	12	29

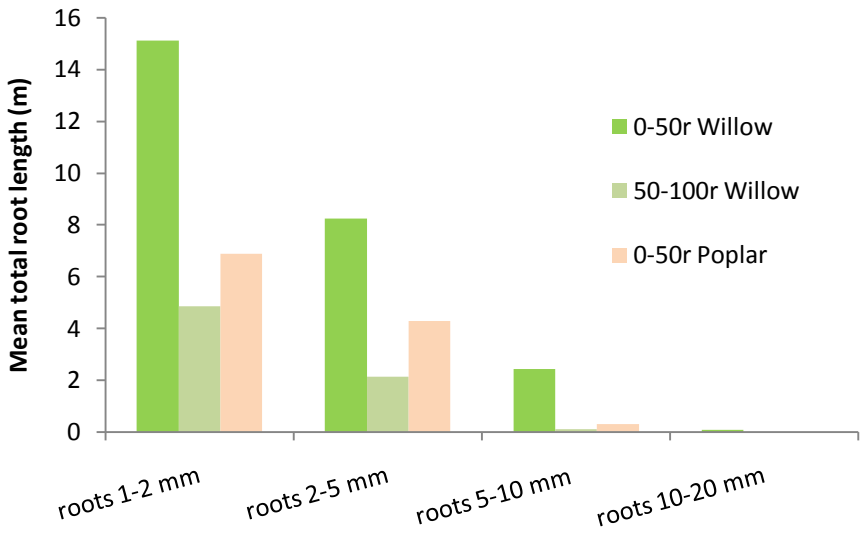

Figure 10 Distribution of mean total root length by root diameter at 50-cm radial increments from the root bole.

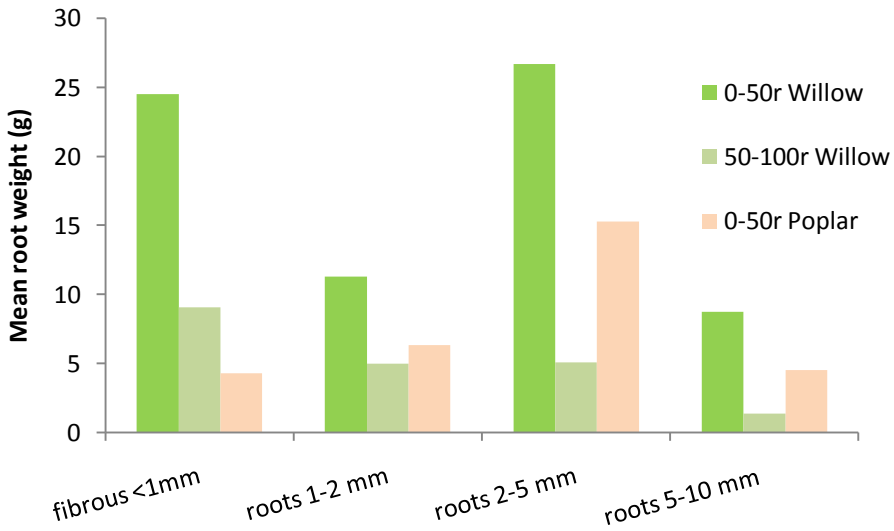

Figure 11 Distribution of mean root weight by root diameter at 50-cm radial increments from the root bole.

5.2 Site comparisons

Comparisons of the early growth performance of poplar with willow poles across and within sites was limited to Puketoro and Gisborne sites because willow were not planted as part of the trial at Aokautere. Furthermore, comparisons of root length and biomass with data collected for older poplar poles were complicated by researchers using different root size classes. Thus for comparisons of root length and biomass for 1-year-old poplar (current research – Puketoro, Gisborne and Palmerston North) with that for older poplar poles (previous studies) to be valid, the results include only root size classes >2 mm in diameter.

Another limitation, particularly with data from studies of older poplar poles, is the small number of sample trees and as a consequence most graphs do not have error bars.

5.2.1 Mean tree height

At both the Gisborne and Puketoro sites, tree height was greater for willow than for poplar and for both species was significantly greater at the Gisborne site where Tangoio outperformed Hiwinui and, Veronese outperformed Kawa (Fig. 12). Mean tree height of poplar at the Puketoro site was similar to that of the Veronese poplar at the Palmerston North site. The differences in above-ground parameters are generally less within and between sites than are below-ground parameters.

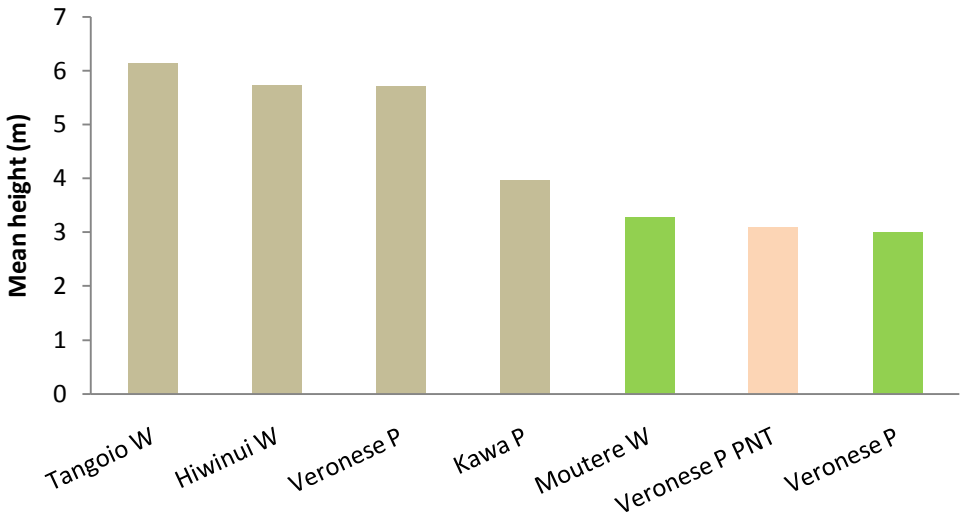

Figure 12 Comparison of mean tree height of 1-year old poplar poles at each of the three trial sites and of willow poles at the Gisborne (brown bars) and Puketoro sites (green bars). Symbols – W = Willow, P = Poplar, PNT = Palmerston North Aokautere (pink bar).

5.2.2 Root spread and depth

There was no significant difference in root spread (diameter) between poplar at Puketoro and the Palmerston North site, averaging just over 0.8 m diameter. This contrasts markedly with the mean root spread of ~10 m for similar aged poplar and willow at the Gisborne site. At this age, root depth is heavily influenced by the depth to which the pole is planted. In the denser soils at Puketoro Station and the Palmerston North trial, the maximum root depth was little more than the base of the pole (0.7 m). However, in the less dense soils at the Gisborne trial site, the roots that developed from the base of the root bole and the sinker roots that descended from surficial lateral roots both penetrated to a maximum depth of ~1m.

5.2.3 Total structural root length and root biomass

At both the Gisborne and Puketoro sites, the total length of roots (> 1-mm diameter) was greater for willow than for poplar and for both species was significantly greater at the Gisborne site where Tangoio and Hiwinui (willow) were similar and, for the poplars, Kawa

outperformed Veronese (Fig. 13). At Gisborne, both poplar species (Kawa and Veronese) had between two and three times more root length than Veronese poplars at the Aokautere site, which in turn outperformed the Veronese poplars at Puketoro Station.

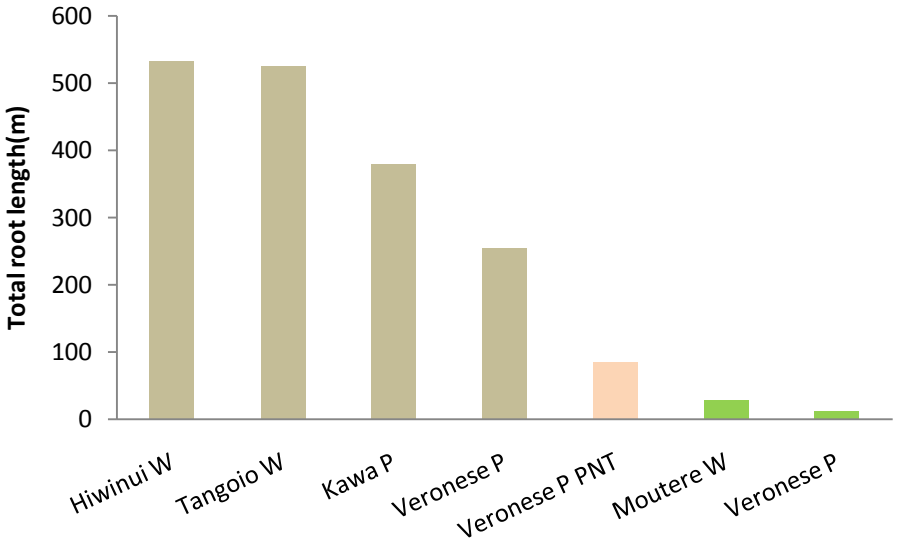

Figure 13 Comparison of total root length (>1 mm) (means where appropriate) between 1-year-old poplar poles at each of the three trial sites and of willow poles at the Gisborne (brown bars) and Puketoro sites (green bars). Symbols – W = Willow, P = Poplar, PNT = Palmerston North Aokautere (pink bar).

The same general trend was evident for the root biomass, except that for the willow clones, Tangoio outperformed Hiwinui (Fig. 14).

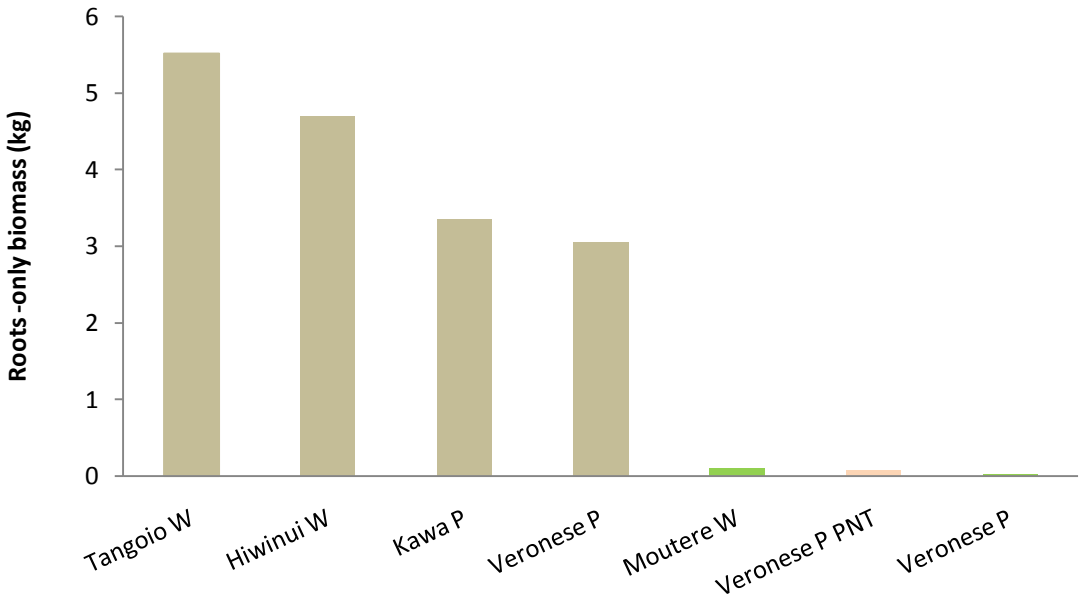

Figure 14 Comparison of roots-only biomass between 1-year-old poplar clones (poles) at each of the three trial sites and of willow poles at the Gisborne (brown bars) and Puketoro sites (green bars). Symbols – W = Willow, P = Poplar, PNT = Palmerston North Aokautere (pink bar).

5.2.4 Total tree biomass and root:shoot ratio

Total tree biomass (Fig. 15) follows similar patterns to many of the other parameters. The ratio of above-ground biomass (stem and branches) to below-ground biomass (root bole and structural roots, i.e. including fibrous roots) represents the root:shoot ratio, which varied from 0.39 to 1.21 (Table 3). Irrespective of species type or clones within a species, differences in the root:shoot ratio at this stage in growth largely reflect differences in the size of the planting material.

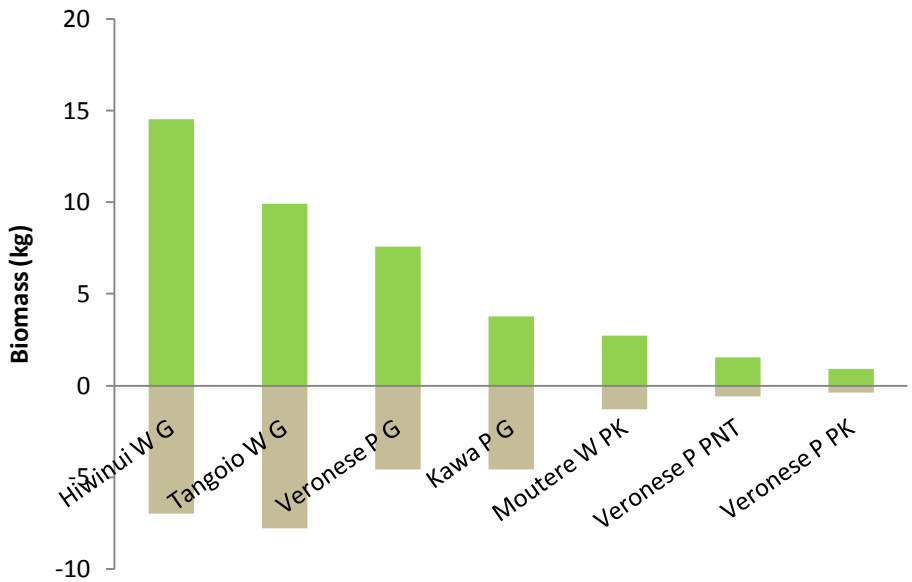

Figure 15 Comparison of mean above- (green bar) and below-ground (brown bar) biomass of 1-year-old poplar poles at each of the three trial sites and of willow poles at the Gisborne and Puketoro sites. Symbols – W = Willow, P = Poplar, G = Gisborne, PK = Puketoro, PNT = Palmerston North. Below-ground biomass shown as negative values on graph.

Table 3 Mean root:shoot ratios for 1-year-old poplar (n=7) and willow (n=9) from Puketoro Station, Gisborne trial site (n=1) and Palmerston North site (n=5). Symbols – W = Willow, P = Poplar, PNT = Palmerston North

	Gisborne Trial				Palmerston North	Puketoro Station	
	Hiwinui W	Tangoio P	Kawa P	Veronese P	Veronese P PNT	Moutere W	Veronese P
Root:Shoot	0.48	0.78	1.21	0.6	0.60	0.48	0.41

5.3 Comparisons with data from older poplar poles

5.3.1 Relationship between DBH and total root length

Figure 16 shows the relationship between total root length (for roots > 2-mm diameter) and DBH including data collected for 5-, 7- , 9.5-, and 11.5-year-old Veronese poplar trees from Ballantrae Station (McIvor & Douglas 2005; McIvor et al. 2008, 2009). A linear relationship fitted to the data shows a relatively poor fit with an r^2 of 0.8. A polynomial fit provides a better r^2 value of 0.96. While such curves can be fitted, with so few data points the equations should be used with caution. Further, because materials are planted as poles, any fitted curve should not intersect the origin but intersect the x-axis at the DBH of the planted pole which is likely to be around 4–5 cm.

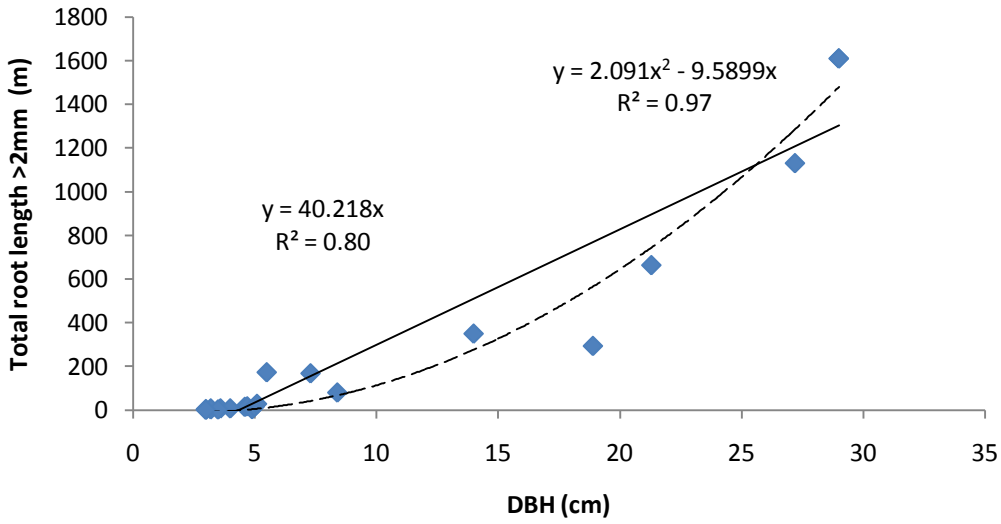

Figure 16 Relationship between DBH and total root length (roots >2mm diameter) using 1-year-old poplar poles from Puketoro, Gisborne and Aokautere (current trials) and data collected for 5-, 7- , 9.5-, and 11.5-year-old poles from Ballantrae Research Station (McIvor & Douglas: 2005, McIvor et al. 2008, 2009). Linear regression solid line, polynomial dashed line.

In earlier studies, McIvor et al. (2008) derived a linear relationship for poplar based on the Ballantrae data:

Structural root length (m) = 45.1 * DBH (cm) – 293.4

(R2 = 0.99, P <0.001, SE (regr.) = 9.4)

However, this was later revised to be:

Log_{10} structural root length (m) = 2.26 * Log_{10} DBH (cm) – 0.18

(R^2 = 0.95, P <0.01, SE (regr.) = 0.19)

As an example of the similarity between this and the earlier study of McIvor et al .(2008), Figure 16 is repeated showing the two linear relationships (Fig. 17).

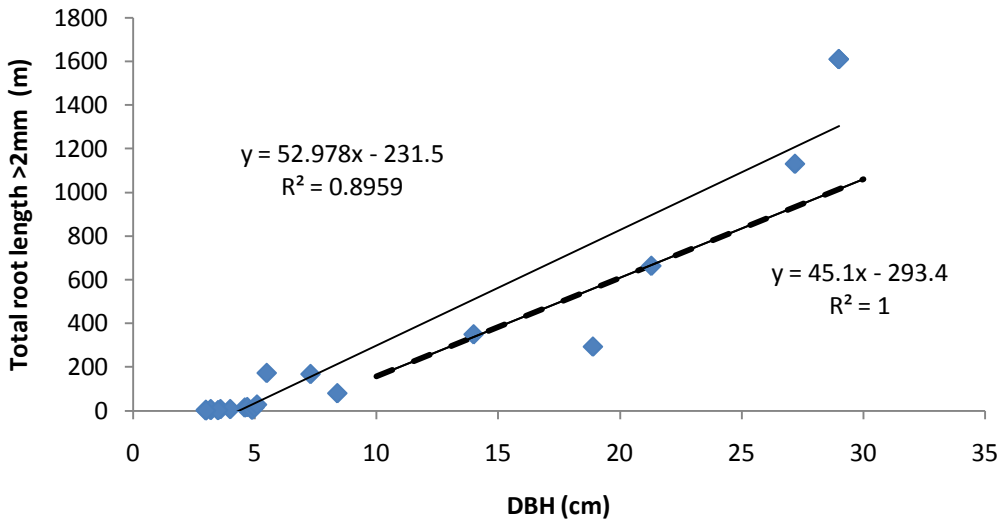

Figure 17 Relationship between DBH and total root length (roots >2mm diameter) using 1-year-old poplar poles from Puketoro, Gisborne and Aokautere (current trials) and data collected for 5-, 7- , 9.5-, and 11.5-year-old poles from Ballantrae Research Station (McIvor & Douglas 2005: McIvor et al. 2008, 2009). Linear regression fitted to data points is solid line and linear regression derived from McIvor et al. (2008) is dashed line.

Rather than a linear relationship, it is more likely that the growth relationship between DBH and total root length at smaller DBHs is curvi-linear, as shown in Figure 16. Curves derived from data from trees older than 5 years may well follow more linear relationships. In general, development of allometric relationships are confounded because the plants are grown initially from poles and, depending on how much pole was above ground when planted, any relationship is likely to be less reliable at smaller values of DBH.

5.3.2 Relationship between DBH and below-ground biomass

As for root length, it is possible to derive relationships between DBH and root biomass, below-ground biomass and total tree biomass, as shown for example in Figure 18. However, because of the difficulties already alluded to between comparing data sets, these relationships should be used with caution. Figure 18 demonstrates the relationship between below-ground biomass and DBH using the 1-year-old poplar poles from Puketoro, Gisborne and Aokautere (current trials) and data collected for 5-, 7- , 9.5-, and 11.5-year-old poles from Ballantrae Station (McIvor & Douglas 2005; McIvor et al. 2008, 2009). Even though a general trend is evident, these relationships should be used with caution because of the limited sample numbers. For comparison, using just the older trees at the Ballantrae site, McIvor et al. (2009) derived the following relationship:

$$\text{Log}_{10} \text{ root mass (kg)} = 3.62 * \text{Log}_{10} \text{ DBH (cm)} - 3.52$$

$$(R^2 = 0.95,\ P < 0.01,\ \text{SE (regr.)} = 0.19)$$

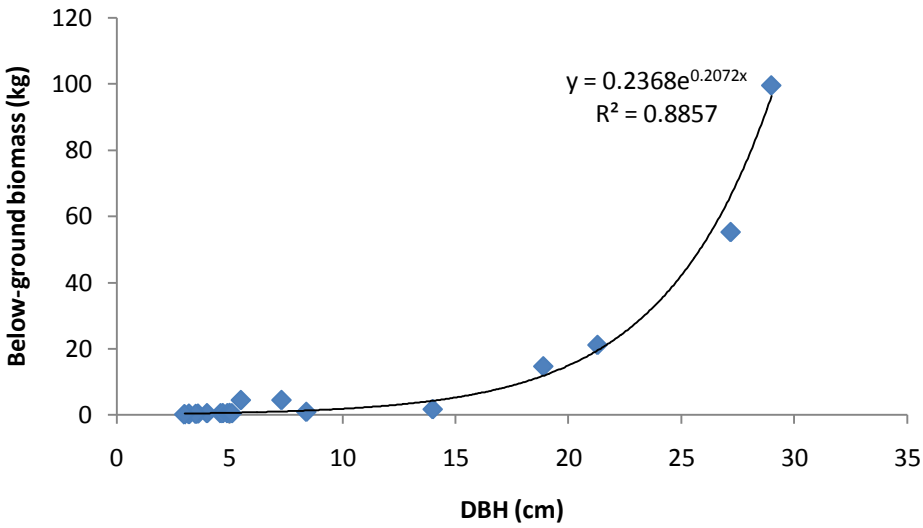

Figure 18 Below-ground biomass (roots plus root bole) and DBH for 1-year-old poplar poles from Puketoro, Gisborne and Aokautere (current trials). Also, included are 5-, 7- , 9.5-, and 11.5-year-old poles from Ballantrae Station (McIvor & Douglas 2005; McIvor et al. 2008, 2009).

While it is not within the scope of this report to identify which site factor or combination of factors contributed to differences in growth performance between sites, it is generally accepted that the morphology and distribution of roots in the soil are greatly affected by the immediate soil environment as well as by above-ground influences. In particular, soil type and soil density have a major influence on the development and distribution of adventitious roots within the soil profile (Davis et al. 1983; Sands & Bowen 1978). In addition, the anchorage of adult *Populus sp.* grown from live poles depends on whether soil is frictional (sandy) or cohesive (clayey) with anchorage improved in the latter (Dupuy et al. 2007). The uniformly textured and fertile sandy loam at the Gisborne site proved ideal conditions for the development of an extensive lateral root network, and with no other obvious soil constraints the distribution of roots tended to be highly symmetrical (Fig. 8). In contrast, the denser, clay-rich, heterogeneous soils at Puketoro and Palmerston North sites, with soil constraints including elevated soil moisture levels limiting root growth by hypoxia under wet conditions, the presence of stones as a mixed colluvium/soil (Puketoro) or a compacted layer such as alluvial gravel/volcanic ash (Palmerston North) have likely restricted root growth and induced a sharply asymmetric distribution of lateral roots.

Climatic influences likely to influence differences in the relative growth performance of these species between sites include the overall warmer temperatures and generally frost-free environment of the Gisborne region. However, the Puketoro site does experience occasional snow, and at 400–450 m above sea level is cooler and at times exposed to severe wind. Additional factors that likely contribute to differences in early growth performance between sites include the size and condition of the planting material, the soil moisture levels and general climatic conditions at the time of planting and planting aftercare.

6 Conclusions

Irrespective of site and for many of the growth parameters measured, willow appears to outperform poplar during their early stages in growth, reflecting their overall greater hardiness and suitability for wet sites including earthflows and along gullies, typical of locations where they are the preferred soil conservation species.

For both poplar and willow there are clear differences in growth performance between sites. Growth performance at the Gisborne site was superior to that of the Puketoro and Aokautere sites but for the latter two sites was of a similar order of magnitude.

Regression relationships established using growth performance data collected from trees at different stages of growth and growing in different physiographic sites, where growth performance can be markedly different, will be less than ideal for developing reliable relationships between above- and below-ground growth parameters. These relationships, however, are critical for determining planting density requirements for situations where poplar and willow plantings are the preferred means of soil conservation. The scarcity of data has limited our ability to develop predictive models that would benefit from the completion of time series data on the growth performance of poplar and willow for Manawatu and East Coast hill country sites where partial time series data already exist.

7 Information Gaps and Recommendations

The excavation and processing of 1-year-old poplar and willow plant material from Puketoro Station was proposed as a 'one-off' exercise for which funding was made available through the East Coast Forestry Project.

It is recommended that poplar and willow poles are excavated annually for the next 2 years, preferably from Puketoro Station or from other nearby hill slope locations on the same land class, to enable a 3-year time series of growth performance for these pole species to be established. This would correspond with the completion of data collection in 2012 from existing trials at Gisborne and Aokautere and provide a short-term time series comparison of growth performance for these species at three contrasting North Island locations.

For the longer term, it is recommended that excavations at the Puketoro site be continued until 2014, thereby extending this time series to include data for trees up to 5 years old. Year-5 (2014) coincides with MAF's reassessment of the condition of plantings (largely based on the number and spread of surviving trees) established at this site with funding assistance provided through the East Coast Forestry Project and on which final pay-out is based. The location of surviving poles at this site will be recorded using GPS. Rudimentary evidence suggests that the root spread and mass of poplar planted as poles on hill country in the Manawatu doesn't increase appreciably until the trees are ~5 years old (McIvor & Douglas 2005). The proposed continuation of root extractions from the Puketoro site to compile a 5-year time series for root spread, biomass and length would go some way towards validating this previous finding. These data could then be used in conjunction with MAF's GPS database of ~1200 pole locations in the 'Horse paddock' to model the rate of root occupancy over a 5-year period based on (i) actual locations and thus spacings between trees at the time of planting (2009) and (ii) surviving trees and their spacings 5 years after planting (2014).

Alternatively, should the extraction of root systems for plantings 3 to 5 years old at this site prove impractical and/or too expensive, a fall-back option would involve using MAF's GPS database of pole locations within the 'Horse Paddock' to randomly select a representative number of trees for annual re-measurement of above-ground growth parameters only and until these plantings are 5 years old. From these data, the allometric relationships established between above- and below-ground growth parameters for poles 1–3 years old, in combination with annual above-ground measurements of poles up to 5 years old from the same site, could be developed to predict potential root development in trees up to 5 years old.

Either option would provide MAF and soil conservators alike with greater surety/assurance of the potential effectiveness of space planted poplar and willow for a range of plant spacings that existed at the time of planting and again after 5 years. The latter repeat measurement is particularly important as there are few reliable records of the rate of mortality of pole plantings, a primary contributing reason as to why a high percentage of earlier plantings failed to provide the anticipated level of protection against slope failure.

For the Manawatu region, it is recommended that the existing time series data for 5-, 7-, 9- and 11.5-year-old Veronese poles extracted from Ballantrae Research Station be extended to include the collection of data for younger aged (e.g., 1–4 years) Veronese poles established on the same land/soil/slope class.

This report highlights the dearth and incompleteness of existing time series data sets, the fragmented nature of current data collection across different sites and by different researchers using different measurement strategies, and the apparent absence of any clearly formalised and consistent research goals for the future.

It is recommended that all parties interested in research specifically on poplar and willow root systems convene a workshop that focuses on formulating a specific research strategy for the future that will address some of the risk management issues associated with hill country subject to one, or a combination of, erosion types and for which poplar and willow plantings are the preferred means of soil conservation.

8 Acknowledgements

This report has been prepared as part of an Envirolink grant GSDC83 funded by FRST. We acknowledge the support of Gisborne District Council, in particular Trevor Freeman, who supported the application leading to this work. We also acknowledge the support of the Tairawhiti Polytechnic Rural Studies Unit Gisborne, on whose land the SLURI trial is located, and the owners and management of Puketoro Station for allowing us to excavate pole material. Thanks to the Ministry of Agriculture and Forestry for financial assistance to enable the Puketoro trees to be excavated and processed. Kaisa Valkonen, Richard Hemming, Suzanne Lambie, Ian McIvor, and Nathan Arnold are thanked for assisting with various plant excavations, processing and assembling data. Comments on a draft were provided by Trevor Freeman (Gisborne District Council), Ian McIvor (Plant & Food) and Grant Douglas (AgR esearch).We thank Caroline Hedley, Landcare Research, Palmerston North, for reviewing a draft of this report. The final version of this report was edited by Anne Austin and formatted by Mandy Cains. The current comparative data used in this report were from trials carried out as part of the Sustainable Land Use Research Initiative (SLURI) funded by the Foundation for Research Science and Technology, New Zealand under Contract No. C02X0813.

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