POPLARS AND WILLOWS IN HILL COUNTRY – STABILISING SOILS AND STORING CARBON

[1]Ian R. McIvor and [2]Grant B. Douglas

[1] The New Zealand Institute for Plant & Food Research Limited,
Private Bag 11030, Palmerston North
[2]AgResearch Limited, Private Bag 11008, Palmerston North
ian.mcivor@plantandfood.co.nz

Abstract

Poplar and willow trees are effective in preventing or reducing a range of soil erosion processes on pastoral slopes. They achieve this through the development of an extensive root system which achieves its maximum potential when it interconnects with root systems of adjoining trees to form a reinforcing network across a slope. A consideration of spacing is important to achieve soil stability in the shortest possible time. These trees contribute to the soil carbon pool and are eligible for carbon credits under the New Zealand Government Emissions Trading Scheme (ETS) providing the area planted exceeds one hectare and the trees are sufficiently close to achieve 30% canopy cover. Trees planted to achieve 30% canopy cover will reduce pasture production by around 10% during the period the trees are in leaf. At maturity, poplar and willow trees can stabilise soil on slopes at a canopy cover less than 30%, the amount depending on the clone. Trees vary in form, so a consideration of canopy spread will assist in choosing appropriate species and clones for the complementary purposes of soil conservation and carbon storage.

Keywords: spaced trees, soil conservation, carbon farming, erosion, tree roots

Introduction

In New Zealand poplars (*Populus* spp.) and willows (*Salix* spp.) and to a lesser extent *Eucalyptus* and *Acacia* spp. have been planted on erosion-prone pastoral hill slopes for more than 50 years (Van Kraayenoord and Hathaway 1986a; Hicks 1995; Wilkinson 1999; McIvor *et al*. 2011). Poplars and willows are best suited to sites where erosion is mediated by surplus soil water, whereas the other species are more tolerant of sites prone to summer dryness. Trees established well and maintained effectively enable the continuation of pastoral livestock enterprises on land that might otherwise be best retired from grazing to facilitate indigenous forest regeneration, or used for exotic plantation forestry. In the last few years, there has been research interest in determining and understanding the root development of poplar and willow, their effectiveness in reducing soil slip (shallow landslide) occurrence, and implications for tree spacing (Basher *et al*. 2008; McIvor *et al*. 2008; McIvor *et al*. 2009; Douglas *et al*. 2010; Douglas *et al*. 2011; Marden and Phillips 2011).

The New Zealand Government has chosen the Emissions Trading Scheme (ETS) (http://www.climatechange.govt.nz/emissions-trading-scheme/about/basics.html) as the cheapest way of putting a price on greenhouse gas emissions. The purpose of the scheme is to reduce the amount of greenhouse gases emitted in New Zealand. The New Zealand ETS is the system in which New Zealand Units (NZUs) are traded. One NZU is the right to emit one tonne of carbon dioxide, or the equivalent amount of certain other greenhouse gases, e.g. methane. There are a number of incentives to offset carbon emissions, including the planting of exotic and indigenous trees in plantations (Crofoot 2009; Davis *et al*. 2009; Parsons *et al*. 2009). The eligibility of spaced soil conservation trees such as poplars and willows for gaining NZUs (carbon credits) from the Government has been discussed in various forums and discussion groups. However, there is a lack of published scientific information on this potentially important additional income source for farmers, including aspects such as optimum tree size and density, and timeframes for eligibility.

The objectives of this paper are to 1) briefly review recent key New Zealand literature on root development of spaced trees and their effectiveness for erosion control, and 2) develop relationships for attributes of spaced poplar and willow trees that are useful for appraising eligibility for carbon credits under the ETS.

Poplars and willows reduce soil slipping and sediment loss

Plantings of poplar and willow on farms have been used to stabilise gully, earthflow and slope erosion (Thompson and Luckman 1993; National Poplar and Willow Users Group 2007; Basher *et al*. 2008). Depending on the situation, the extent of planting and the spacing of trees have varied. As many as 700,000 ha of pastoral land remains unplanted or underplanted with protective trees and so this land area continues to be susceptible to slipping or collapse or gravitational creep, depending on the erosion issue. Major storm events e.g. Manawatu 2004, Wairarapa 2005, Hawke's Bay 2011, lead to significant erosion of pastoral hill country without woody vegetation cover. However, the strategic planting of poplar and willow trees can significantly reduce the extent and severity of slipping, earthflow movement and gully scouring (Hawley and Dymond 1988; Thompson and Luckman 1993). Douglas *et al*. (2011) reported that spaced conservation trees of various sizes on slopes of mostly 25-30° reduced the extent of soil slipping at 65 sites by an average of 95% compared with slipping on nearby pasture control sites (Figure 1). Furthermore, they found that slipping occurred on 10 tree sites (nearly all slip areas < 3.5% per site) compared with 45 of the 65 pasture sites.

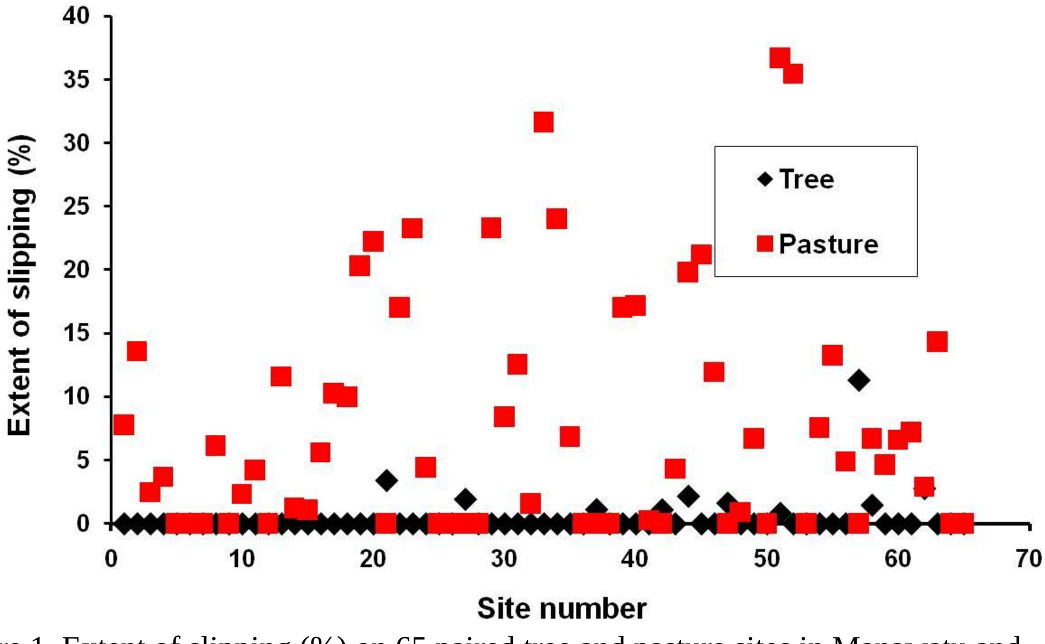


Figure 1. Extent of slipping (%) on 65 paired tree and pasture sites in Manawatu and Wairarapa in winter 2007 (*Populus* (53 sites), *Salix* (6), *Eucalyptus* (6)) (modified from Douglas *et al*. 2011).

Soil slipping occurred at six of the 53 sites with *Populus* trees and at four of these, trees had an average diameter at breast height (DBH; measured at 1.4 m above ground on upslope side of the tree) of <30 cm (Douglas *et al*. 2011). The relatively low DBH values suggest that slipping at these sites was predominantly because of inadequate root development of individual trees (McIvor *et al*. 2008) or failure of adjoining tree root systems to interlock significantly, perhaps because spacings were too wide (Douglas *et al.* 2011). Even with treed areas, slipping may occur over a short distance, but major slipping with a debris tail to the bottom of the slope was never observed to have originated from within a treed site.

Conservation trees enhance the pastoral environment through erosion reduction, stream protection, shelter, fodder, increased soil carbon (C) and nitrogen (N), flood mitigation, summer moisture retention, shade and shelter, and wood products. They therefore have the potential to add significant value and improve returns from pastoral enterprises.

Tree root systems take time to develop to the extent that they effectively stabilise saturated soil (http://www.poplarandwillow.org.nz/files/poplar-root-developing-and-tree-spacing.pdf). McIvor *et al.* (2009) showed that root development is related to DBH and Douglas *et al.* (2011) suggested that poplar or willow trees with a DBH >30 cm will stabilise soil within 10 m of the trunk.

If trees were planted at 20 m (2 m x 10 m) spacing, the time taken to achieve slope protection, as judged by attainment of DBH >30 cm, would probably be 9-13 years depending on site characteristics (soil depth, available moisture, wind exposure etc.) and clonal attributes (tolerance to drought and wind, growth rate). Closer spacing at planting time followed by progressive thinning as the trees grow will achieve rapid soil stabilisation while having minimum impact on pasture production.

Poplar root systems and effectiveness

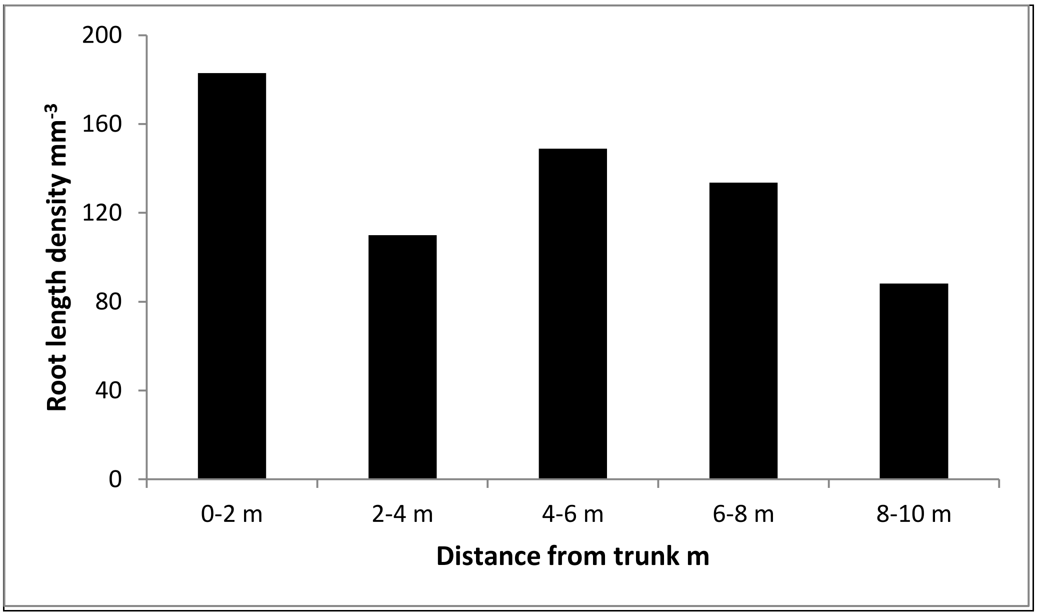


Figure 2. Root length density for coarse (≥2 mm diameter) roots of a single 9-year-old ‘Veronese’ poplar tree grown on a pastoral hill slope (from McIvor *et al*. 2008).

Poplar root systems extend a long way from the tree and anchor themselves at regular intervals by growing vertical roots called sinker roots into the deeper soil horizons. Figure 2 shows the horizontal distribution of coarse roots for a 9-year-old ‘Veronese’ poplar tree with a DBH of 21.3 cm. While the coarse roots of the single tree extend out beyond 10 m, Douglas *et al.* (2011) suggested that there is insufficient root presence or root strength past 10 m to prevent soil slipping.

However, this does not take account of the contribution of adjacent trees to root presence and hence soil stabilising. For poplar trees aged 9-11 years growing at a range of densities at the same location, a tree density of about 160 stems per hectare (SPH), approximately 8 m x 8 m spacing, was recommended for being likely to provide enhanced soil strength through lateral root development, whilst enabling satisfactory understorey pasture production (Douglas *et al.* 2010). Figure 3 shows how spacing influences root length density around each tree, by adding in the contribution of all trees surrounding that tree and assuming they are space-planted across the slope, either 8 m, 10 m or 15 m apart. Two aspects are notable: the closer the spacing, the greater the slope protection; and the closer the spacing, the earlier slope protection is achieved. The distribution and extent of the root system of a tree species are not as important in stabilising soil and reducing landsliding as the evenness and density distribution of roots across a slope.

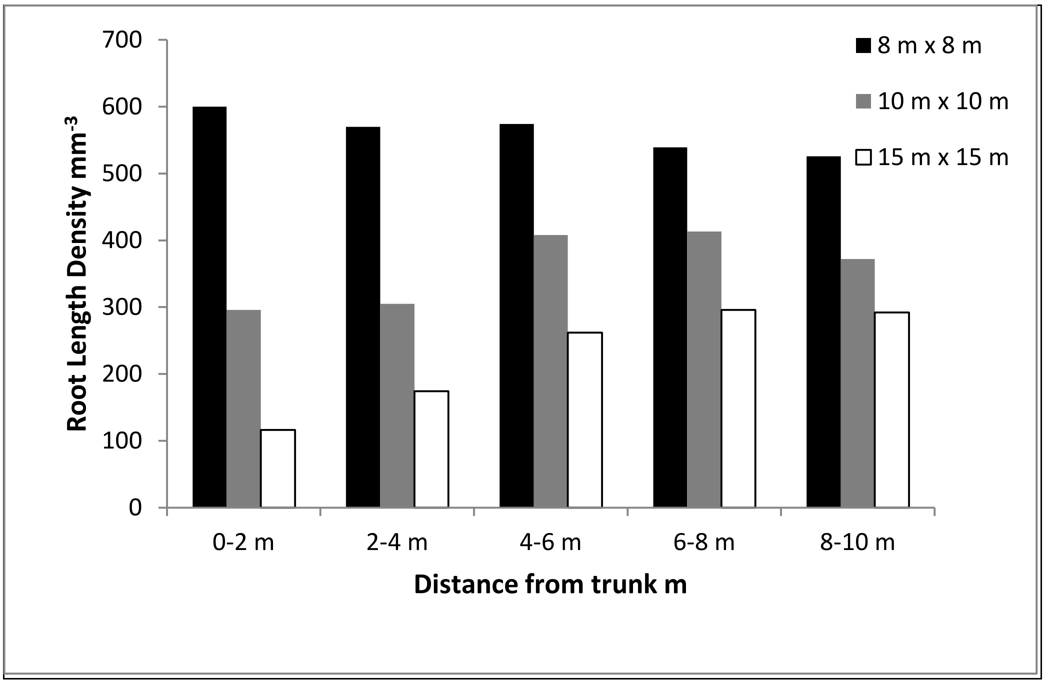


Figure 3. Root length density for coarse (≥2 mm diameter) roots at different distances from the trunk of a 9-year-old ‘Veronese’ poplar tree grown at different spacings (from McIvor *et al.* 2008).

While root distribution around a single tree may be asymmetrical (McIvor *et al.* 2008), the contribution of surrounding trees, while not necessarily removing any asymmetry, may create a more even spatial distribution of roots, and the root density across a slope is a function of spacing.

Poplars, willows and pasture production

Poplar and willow trees reduce pasture production (Figure 4), the extent depending on canopy spread which, in turn, depends on the clone (the narrower the canopy, the less the reduction in annual pasture production). For instance, *P. deltoides* × *nigra* × *nigra* 'Crowsnest' poplars produce the least reduction in pasture growth. Tree shade has a positive effect on pasture growth in late summer through greater retention of soil moisture and cooling of the pasture. Pruning of the trees allows more light to the pasture. Following pruning of the trees in Figure 4 (spaced 8 m apart), radiation to the pasture under the tree canopy increased from 66% to 77% of the radiation available to the open pasture. Wider spacing of the trees will also enhance pasture production. Assuming 30% canopy cover (required by the ETS), overall annual pasture production would decrease by 7% beneath pruned trees and 11% beneath unpruned trees compared with adjacent open pasture.

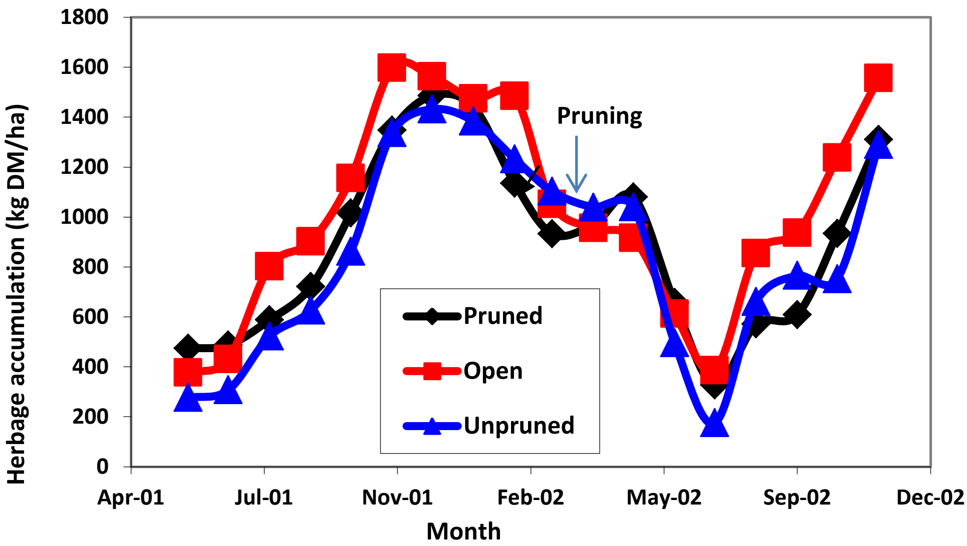
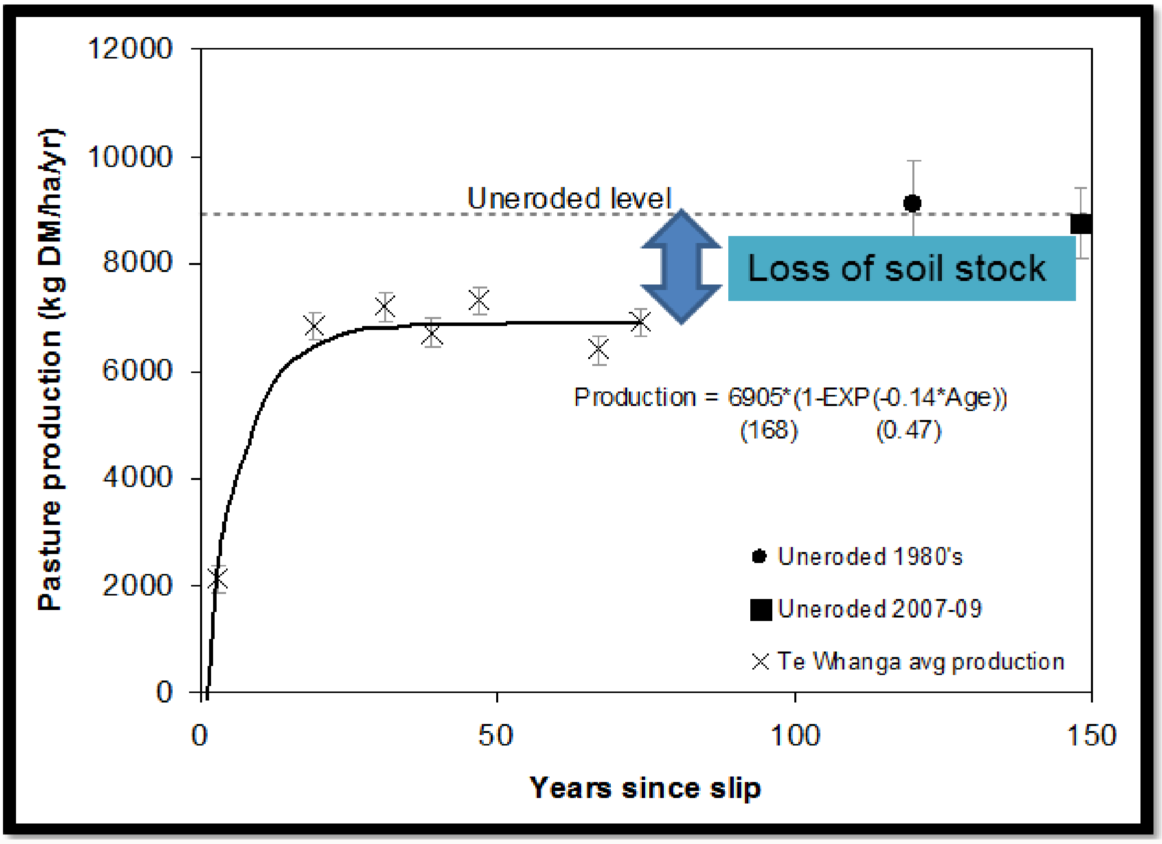


Figure 4. Herbage accumulation under pruned (to 4 m, in March 02) and unpruned 7-year-old 'Veronese' poplar trees growing on a hillslope compared with on open ground. Tree spacing was 8 m x 8 m. DM = dry matter.

Once slipping has occurred on a pastoral slope, annual pasture production is unlikely to recover to beyond 80% of that on adjacent un-eroded ground (Figure 5, taken from Rosser and Ross 2011), such a recovery taking up to 80 years (Lambert *et al.* 1984; Douglas *et al.* 1986; Rosser and Ross 2011). Topsoil, once lost, takes a long time to re-form. Investment in strategic planting of poplars and willows will retain the topsoil, which is a primary capital asset. It is well to consider other benefits conferred by the trees, in addition to soil stabilisation. They maintain and enrich soil carbon and contribute to soil nitrogen (Sivakumaran unpubl.) through root breakdown, root exudates, leaf litter and the action ofendophytic nitrogen fixing bacteria (Doty *et al.* 2005). Lateral roots aerate the soil assisting root penetration by pasture grasses, legumes and herbs, and increasing water storage. Tree shelter promotes grass growth and shelter, and shade eases environmental stresses on stock, reduces maintenance feed requirements, and promotes growth. Cattle with shade grazed longer mainly in the afternoon, whereas cattle without shade spent 4% less time feeding and 4% more time lying down during the hours of 10 a.m. to 4 p.m. (Betteridge *et al.* 2012, in these Proceedings). Stock water requirements are considerably reduced when shading is available.



Rosser B, Ross C ***2011****. Recovery of pasture productivity on landslide scars in erodible siltstone hill country, Wairarapa. New Zealand Journal of Agricultural Research 54: 23–44.*

Figure 5. Recovery of pasture production following slipping on erodible hill country in Wairarapa.

Conservation trees and soil properties

Soil pH is increased in a poplar-pasture system compared with open pasture. This effect is more pronounced with older trees than with younger trees. Soil pH under 5-year-old poplar was 5.9 compared with 5.4 under open pasture and for 29 to 40-year-old poplar was 6.0-6.6 compared with 5.4–5.7 under open pasture (Guevara-Escobar *et al*. 2002). These differences were maintained to depths of 300 mm. Soil calcium and magnesium concentrations were higher under the poplar-pasture system, most notably at soil depth of 0-75 mm. While less N is fixed under trees because of shading reducing the legume component of the pasture, the N-fixing capability and contribution of the bacterial endophytes of poplars have not yet been determined and compared in poplar–pasture and open pasture systems.

Total carbon pool measured in a mature poplar-pasture system (55.5 t/ha) was 26% higher (Figure 6) than in an open pasture system without trees (44.0 t/ha), with the extra carbon residing in poplar biomass (Guevara-Escobar *et al*. 2002).

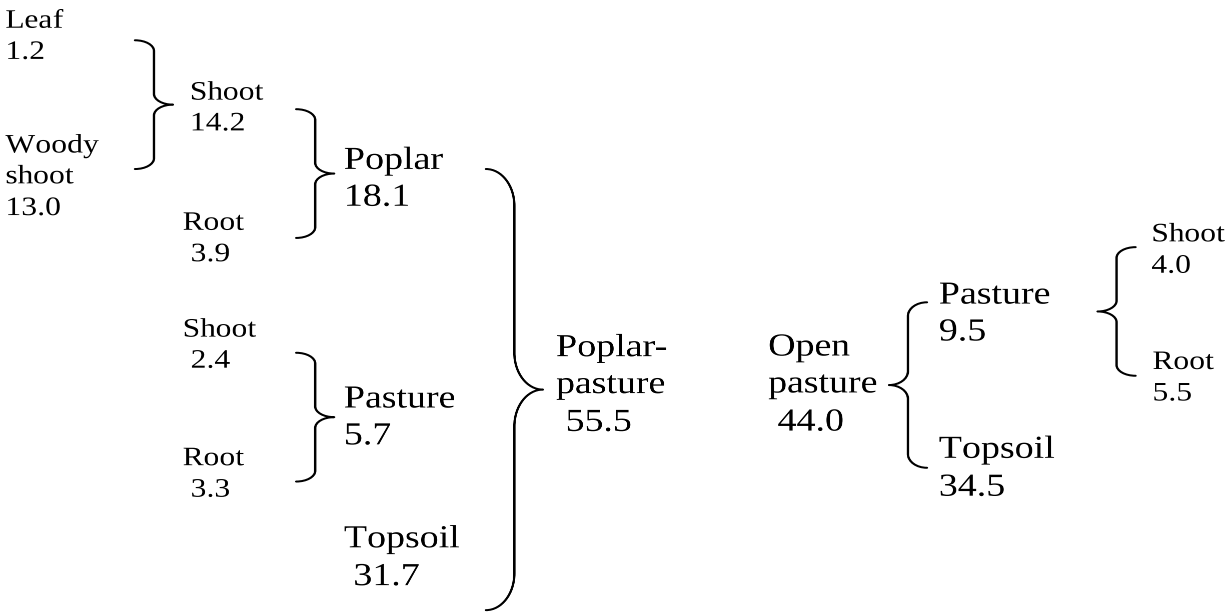


Figure 6. Carbon pools (t/ha) in poplar-pasture and open pasture systems. Topsoil is 0-75 mm depth. (Guevara-Escobar *et al.* 2002).

Poplars, willows and the Emissions Trading Scheme

Established soil conservation plantings of both poplars and willows provide an opportunity to claim carbon credits under the Emissions Trading Scheme. The requirements are well documented on the MAF website (http://www.maf.govt.nz/forestry/forestry-in-the-ets).

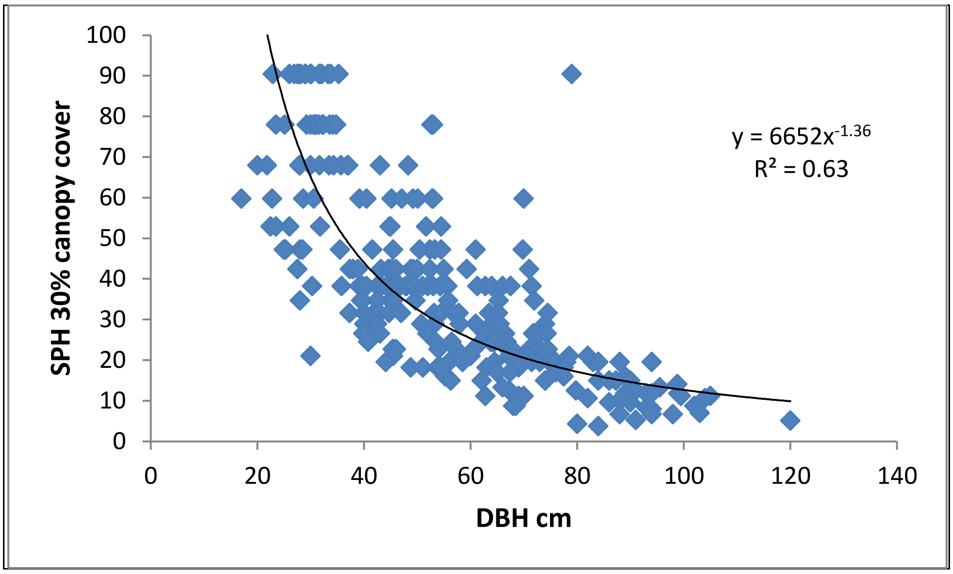


Figure 7. Poplar planting density required to achieve 30% canopy cover at differing diameter at breast height (DBH) (N= 282). SPH = stems per hectare.

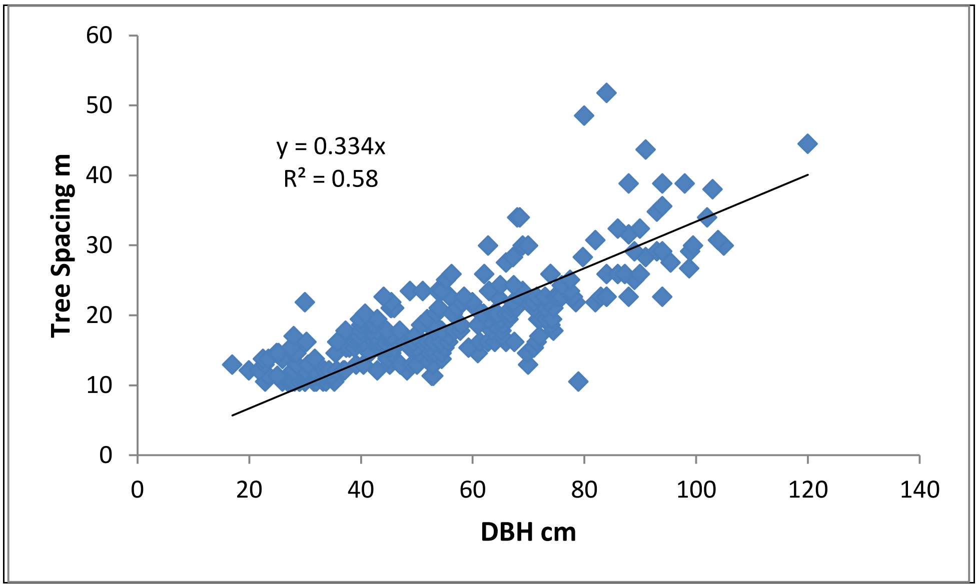


Figure 8. Poplar tree spacing required to achieve 30% canopy cover at differing diameter at breast height (DBH) (N=282). SPH = stems per hectare.

Poplars (Figures 7, 8) show greater variation in canopy cover than willows (Figures 9, 10). The poplar data excluded the very narrow form Lombardy-type poplars, which distorted the graphs and reduced the R^2 values. There are many more poplar species and hybrids present in the landscape than there are willow species and hybrids. Almost all willows on farms are *Salix matsudana* or *Salix matsudana* x *alba,* which have a relatively uniform shape. The earlier poplar clones released for on-farm planting were developed for the plantation timber industry in Europe. As it turned out, their branching pattern produced a wide canopy, which is favourable for gaining carbon credits but not so favourable for pasture production. New Zealand-bred clones were selected for narrower canopy to improve light to pasture and consequently more trees per hectare will be required to achieve 30% canopy cover (http://www.poplarandwillow.org.nz/pages/breeding-&-research/breeding/strategy/). The poplar data include both earlier and New Zealand-bred clones.

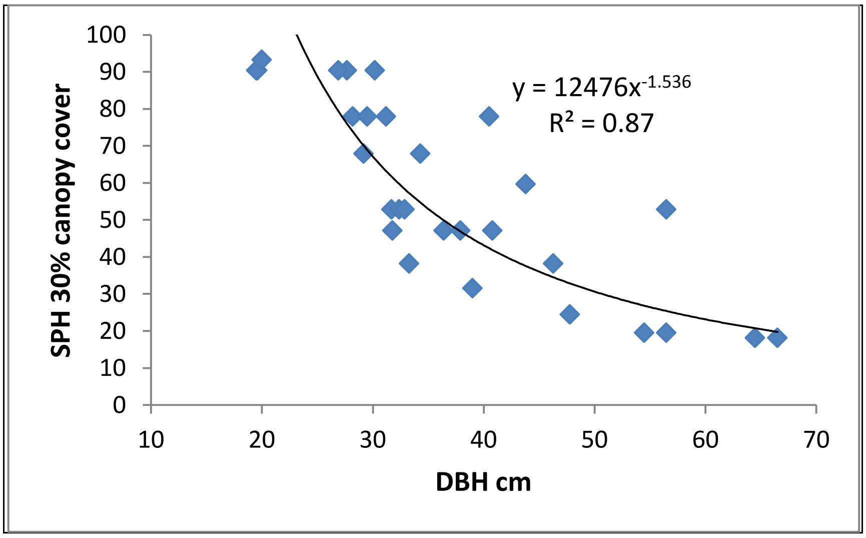


Figure 9. Willow planting density required to achieve 30% canopy cover at differing diameter at breast height (DBH) (N= 60). SPH = stems per hectare.

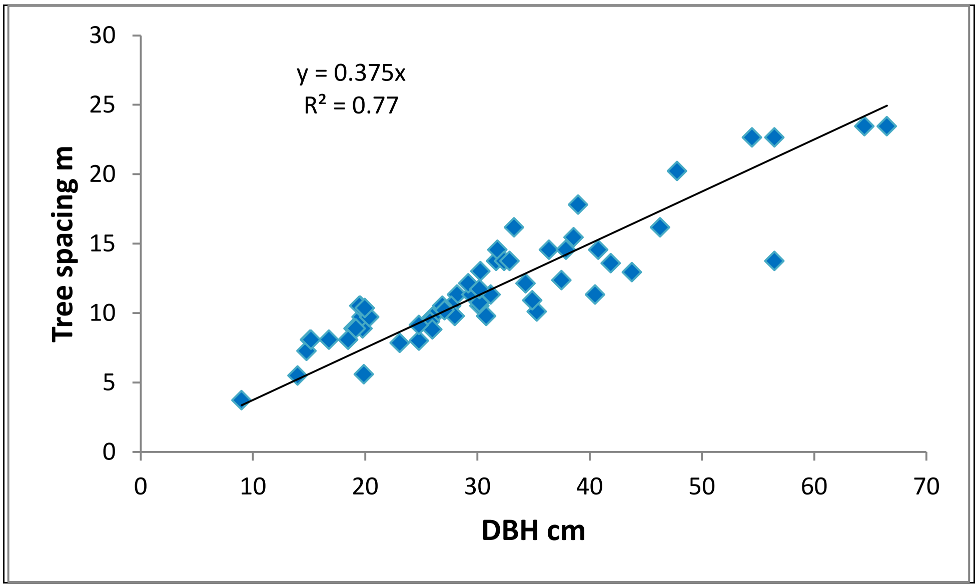


Figure 10. Willow tree spacing required to achieve 30% canopy cover at differing diameter at breast height (DBH) (N= 60). SPH = stems per hectare.

Two examples are given in Figure 11, for *P* .× *euramericana* ×*yunnanensis* 'Toa' and *P. deltoides* × *nigra* 'Tasman' poplar clones.

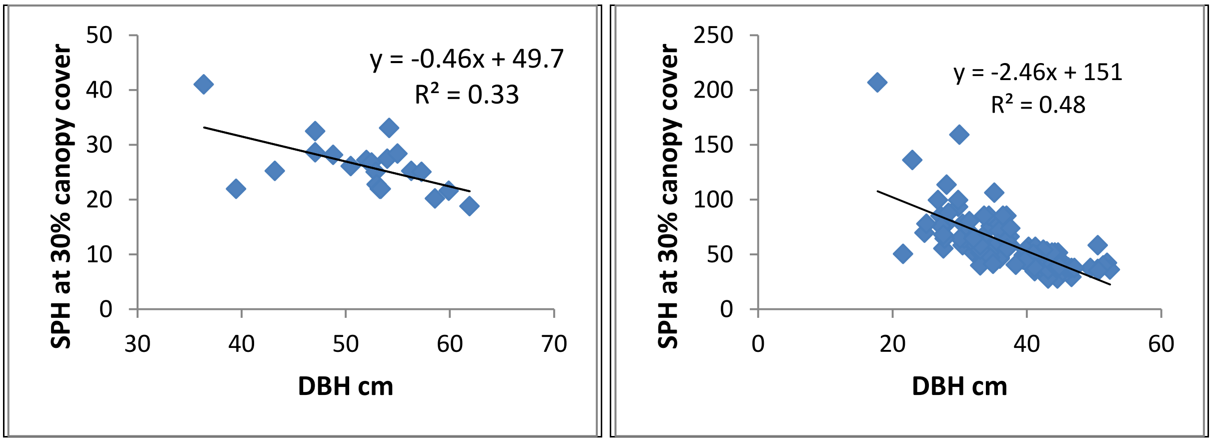


Figure 11. Planting density required to achieve 30% canopy cover at differing diameter at breast height (DBH). for *P* .× *euramericana* ×*yunnanensis* 'Toa' (left) and *P. deltoides* × *nigra* 'Tasman' (right) hybrid poplar clones. SPH = stems per hectare.

While the linear functions differ, a stocking rate of 31 stems per hectare (SPH) for 'Toa' at DBH of 40 cm will achieve 30% canopy cover, whereas for 'Tasman' a stocking rate of 53 SPH is required at that DBH.

Decisions cannot be made based on canopy cover alone, since different clones have different attributes, including soil moisture requirement, drought and wind tolerance, and bark hardiness (Van Kraayenoord and Hathaway 1986b; Wilkinson 1999; National Poplar and Willow Users Group 2007). However, where some extra trees are needed to create corridors between already existing plantings to reach the minimum of one hectare in area of planted trees, selection of a poplar clone with a wider canopy to fill the space could be appropriate.

Soil conservation or carbon credits?

Those land owners who have implemented a policy of increasing the resilience of their farm to rain storm events through progressive planting of trees are now in a position to take advantage of the ETS. This paper raises issues regarding the time taken for a tree to develop the root system required to stabilise slopes to the degree that they will show minimal slipping following a heavy rain event or prolonged rainfall. Achieving the requirements of the ETS for carbon credits will also take considerable time (upwards of 12 years).

To achieve 30% canopy cover, poplar trees will need to be planted at a greater density than would be required to stabilise the soil when they are mature. Assuming all poplar root systems extend out beyond 10 m, regardless of the clone, then at maturity (DBH >30 cm) 30-40 SPH would be sufficient to stabilise a slope, whereas, using the information from Figure 11, 36 SPH ('Toa') or 78 SPH ('Tasman') would be required to achieve 30% canopy cover. It would seem that the greatest priority is soil stabilisation, then pasture production and finally carbon credits. However, there is the opportunity to conduct strategic planting to connect current conservation plantings so they become eligible for carbon credits. Pruning lower branches of conservation poplar trees will increase light to pasture while having little effect on canopy cover, or capacity to stabilise the soil.

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