EFFECTIVENESS OF CONSERVATION TREES IN REDUCING EROSION FOLLOWING A STORM EVENT

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Summary
On the 25th of April 2011 a severe storm hit parts of coastal Hawke's Bay, resulting in major slipping, infrastructure damage, and stock and pasture losses. The effectiveness of soil conservation plantings of poplar and willow in reducing slipping in the affected areas was evaluated during the period January – May 2013. Eleven of the farms that suffered severe slipping were visited. For each farm, sites with trees and comparable sites without trees were identified from aerial maps. The sites were visited and mapped for slipping, tree spacing and distance of slips from the nearest tree. Other data collected were aspect of the site, mean slope, number of trees, species of tree and tree size (trunk diameter). Calculations were made of the area of protection extended by the trees and the effectiveness of the conservation trees was linked with tree size, tree species, and tree spacing.

Data were collected from 86 sites with trees (treed sites) and 25 sites with pasture only (control sites). The pasture only sites were close to a treed site. Numbers of trees at treed sites were usually between 3 and 8, but ranged from 1 to 14.

Slipping was reduced by 78% on treed sites compared with control sites. Mature plantings of groups of both poplar and willow reduced slipping within a zone of ~10 m of the trees to almost zero. Where plantings had a mean DBH of <20 cm, their effectiveness was reduced dependent on spacing. For trees with a mean DBH of ~10 cm effectiveness was negligible regardless of spacing. Despite this, trees with DBH of ≥10 cm were generally able to withstand shallow slipping without being totally dislodged. Where trees were planted in gullies the same criteria applied for their effectiveness in halting the advancement of the gully upslope.

The findings strongly suggest that below a particular tree size (DBH of ~10 cm), spacing matters little since the roots are not sufficient to resist the downward movement of saturated soil. However, as the trees grow their effectiveness is enhanced by their size (increase in root thickness and root distribution), and by their spacing (the intermeshing with root networks of adjacent trees, particularly the weaker extremities). The effectiveness of the trees in reducing erosion is increased when more trees are present.

Introduction
When Hawke's Bay was first settled, large expanses of forest and bush land were cleared for pasture production and animal grazing. With the removal of the native bush and trees the hill country is susceptible to widespread erosion. This is due mainly to soil type, lack of woody vegetation and severity and duration of rain (Feng et al. 2008).

On the 25th of April 2011 a severe storm hit Hawke's Bay and lasted for 72 hours. Anecdotally over 700mm of water fell in some localities over this period. The worst hit localities included

Wairoa (39.0° S, 177.4° E), Waimarama (39.82°S, 176.99°E) and Pourerere (40.10°S, 176.87°E). The terrain comprises steep hill country (over 45° slope angle in some parts), gentle slopes and flatlands.

This prolonged period of severe rain resulted in major slipping, infrastructure damage, and stock and pasture losses. The water flooded buildings, fences fell and tracks disappeared overnight. Loss of tracks meant it was near impossible to reach certain areas on quad bike. Without fences paddocks were unmanageable and stock had to be moved. As a result of loss of fences and grazing, farmers had to relocate or sell stock. Lambs had to be sold early resulting in a loss of opportunity profit i.e. sold before they reached optimum weight, or grazed off the farm. Stock losses also occurred as a direct result of the storm. Stock were buried in slips, washed out to sea, or drowned against fences in flood waters on the flats.

On slipped sites all grass cover was lost. The slip tail brought debris to the pasture below, making the pasture unusable until the ground had been re-sown or pasture recovered. Flat land was not exempt from damage as floodwaters brought stock loss, fence damage and sediment deposits that buried the crop or pasture.

The storm also affected residential properties and infrastructure. Bridges were washed away, homes were flooded and roads were covered in slips. The government labelled the storm as a medium adverse event and this allowed extra funds for relief work.

An earthquake centred 10.65 km southeast of Pourerere occurred at 10:28pm on 26th of April (Geonet 2011). This caused more damage as unstable slopes gave way and some previously stable slopes were damaged. Slipping on upper steep slopes was attributed by farmers to the earthquake as much as the rainstorm. Their relative contribution remains conjectural.

Soil conservation plantings of poplars and willows have been promoted since the 1950s to reduce the impact of such storm events. Poplars and willows are grown successfully in the presence of grazing stock using protected poles. Pasture growth occurs to the base of the trunk, and the trees provide shade, shelter and fodder for stock animals. Strategic plantings of these trees in gullies, across slopes, along stream and river banks and above and below tracks have been effective in reducing slipping on hills, silt deposition on flats, bank erosion along waterways and maintaining track access. The protection of infrastructure is a significant cost saving in the aftermath of major rainstorms in pastoral hill country.

The presence of woody vegetation on hill slopes significantly decreases the incidence of erosion events (Bergin et al. 1993, Marden 2004, Benavides et al. 2009, Douglas et al. 2009, Douglas et al. 2013) and also decreases infrastructure damage to fences, tracks and water systems and buildings. Soil health benefits are reported to accrue from planting poplars and willows (Guevara-Escobar et al. 2002, Dunlop et al. 2010). As reviewed by Benavides et al. (2009) poplars are able to act as soil bioremediators in de-acidifying the soil, thereby improving pasture growth. The pH and plant production potential of the soil in poplar silvopastoral systems were identified as being higher when compared with soil in open pasture (Guevara-Escobar et al. 2002). But the growth of the grass and its nutritive quality is directly affected by the density and age of the plantings. Hussain et al. (2009) showed that densely planted poplars and willows reduce pasture growth, mainly through shading. However without their soil protection pasture growth on the slip-prone slopes would reduce.

Poplars and willows have been widely planted at various times in the localities affected by the April 2011 storm. Plantings have been concentrated in gullies and on historic earth flows, and the trees found in these places are mature trees planted 20-30 years previously, or trees planted from poles within the last 5 years. Poplar and willow trees space-planted across a slope to protect against slipping, are less common than gully and earth flow plantings. Most properties visited in this field study were considered under-planted as evidenced by the slipping resulting from the storm. Establishing trees on most of the steep slopes is challenging with key limiting factors being soil depth and available soil moisture during the growing season. However, despite these limiting factors, most properties require tree plantings to reduce lower slope slipping and protect infrastructure such as tracks and dams.

Work had been conducted previously in Wairarapa and in Manawatu on the effectiveness of soil conservation trees in reducing slipping during a major storm event (Douglas et al. 2013) Following storms in 2004 and 2005, centred in Manawatu and Wairarapa respectively, the study determined the ability of space planted trees (*Populus*, *Salix* and *Eucalyptus*) to prevent soil erosion. Sites with trees showed a reduction in landslide occurrence, dependent on the size of the tree. The data set included few trees below 30cm DBH, so this present storm gave us an opportunity to assess effectiveness of smaller diameter poplar and willow trees in reducing slipping and to reaffirm previous findings for older poplar and willow trees.

Methodology

Site selection

Farmers in Hawke's Bay from the Blackhead Beach area to Waimarama, and in the vicinity of Wairoa, who were affected severely by the storm completed a questionnaire containing information about present and future erosion mitigation practices. Of the properties of those questioned, 26 properties were selected based on planting details and examined using the GIS database at the Hawke's Bay Regional Council offices. Aerial photography taken in 2008 was used to identify possible plantings of poplars and willows on sloped land. This was cross referenced to aerial photography taken after the storm in 2011 to determine whether the trees were still standing and if there were slips present nearby. Groups of trees were chosen by:

- Location on upper and mid slope and the presence of slips nearby.
- Trees with small canopy indicating a young age.

No cabbage trees or native bush were included as the study was only focussed on intentional spaced plantings for soil stabilisation. Pine trees were excluded because they are generally planted as forestry blocks. Eucalyptus trees were excluded because their use for erosion mitigation was rare.

Field measurements were taken on eleven farms, chosen because they had been exposed to the highest rainfall amounts, showed severe slope damage, and had substantial plantings of both old and more recent poplars and willows. Two farms were located at Waimarama and seven farms were located near Pourerere (Figure 1). Two farms were located 10 km north of Wairoa. Farmers were most co-operative, supplying a quad bike, taking us over the property to locate the treed areas, providing historical information on plantings and in other ways supporting the research.

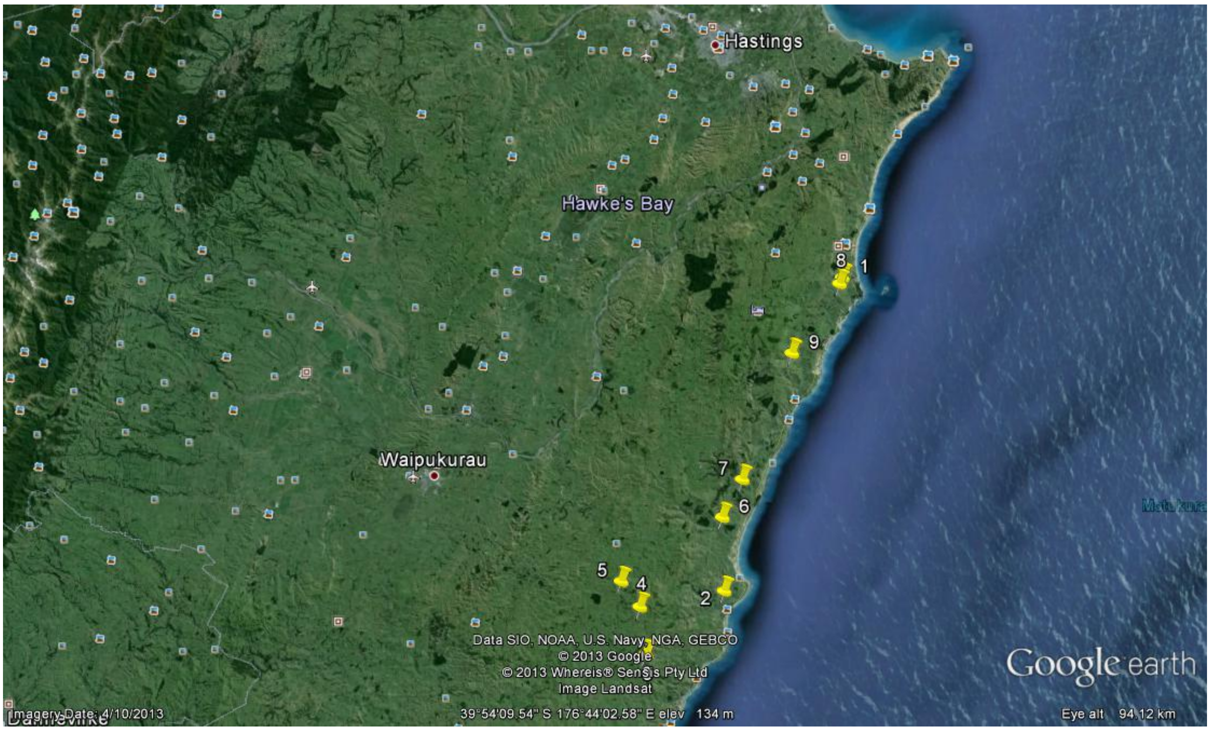

Figure 1 Locations of the nine farms in Southern Hawke's Bay where field sites were visited. A total of 86 sites with trees were assessed, 40 with willow (*Salix*) trees only, 37 with poplar (*Populus*) only, and 9 with both species, along with 25 non-planted 'controls'.

Field methodology

Topographic data collected for each site were aspect, slope and area of any nearby slipping. Aspect was measured as a compass bearing 0-359°. Slope was measured using an electronic level positioned inside the area bounded by the trees (subsequently called the polygon) excluding stock camps or slip tails. Five measurements of slope were taken at various locations within the polygon and a mean calculated. Slips were measured for height and width and their slope and distance to the nearest tree recorded and shape sketched on graph paper.

The trunk diameter of the trees at each site was measured at breast height (DBH), being 1.4m above ground on the upslope side of the tree.

The distances to all other trees (m) within the group of trees at that site were measured and recorded. Using these measures, the polygon (P - area of the site bounded by the trees) was calculated. The area of protection (A) for a treed site was calculated as the sum of the circular protection areas around each tree (using a radius of protection of 10m) excluding those fractions of the areas already contained within the polygon (Figure 2). Ten metres was taken as a proxy radius of protection as found by Douglas et al. (2013), unless the distance to the slip was less than 10 m, in which case the lesser distance was used. The area (S) of any slip scar present within the polygon was subtracted from the polygon. The area of the slip and the slope of the slip were calculated only if the slip was within 15 m of the treed site. Measurements were also taken at sites where there were trees planted and where there was no notable slipping but where there was ground disturbance such as cracks opened up, or an upward advance of the gully.

Total area of protection (T) for a treed site was calculated using the following formula:

$$T = A + P - S$$

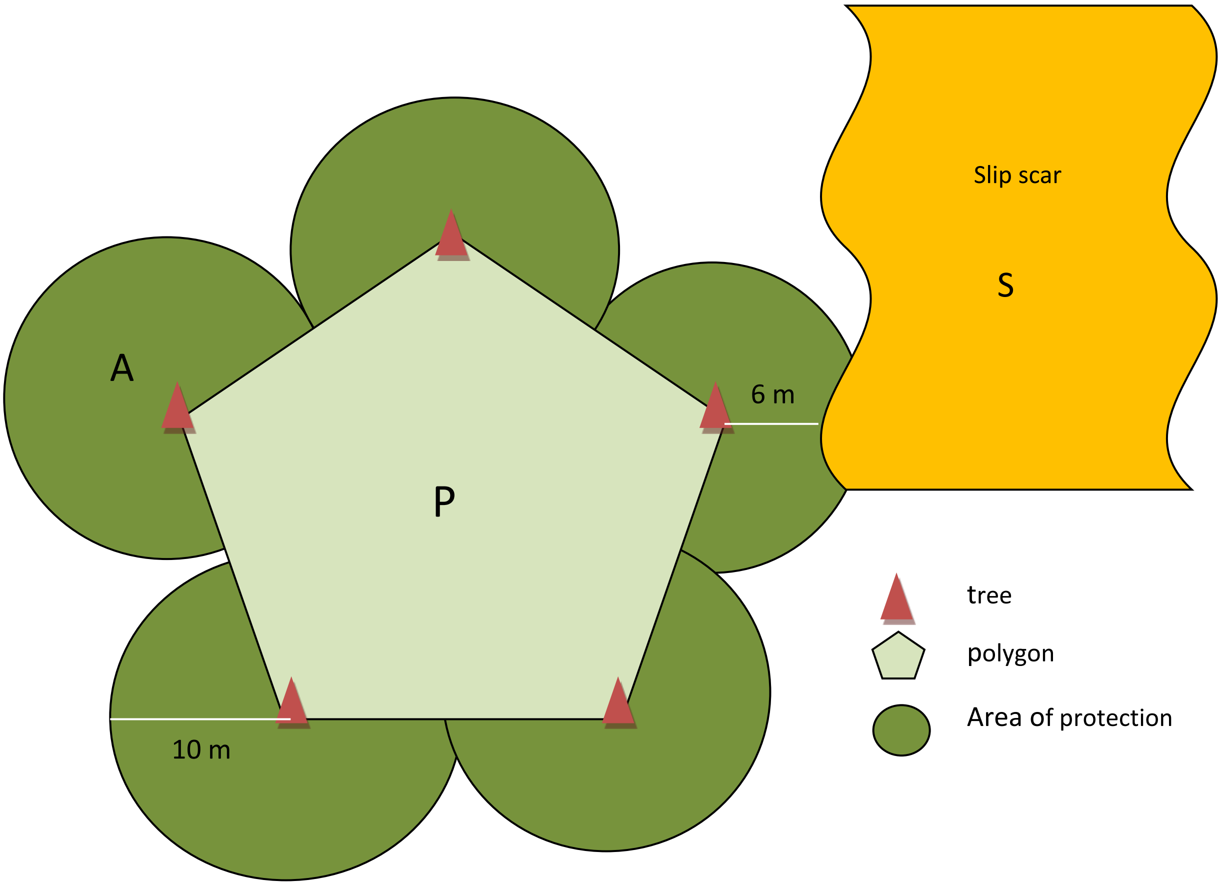

Figure 2 Diagrammatic representation of the total protection afforded by a treed site. The polygon (P) is shown as light grey area, and the area of protection (A) is shown as green. Any intersection areas were only counted once. Total protection area (T) is all the shaded area excluding the slip. Where the slip scar (S) approached closer than 10 m, that distance was used as the radius of protection (in this diagram it is 6 m).

Data were collected from 86 sites with trees (treed sites) and 25 sites with pasture only (control sites). The control sites were close to a treed site. Numbers of trees at treed sites were usually between 3 and 8, but ranged from 1 to 14.

Sites with 1 or 2 trees (N = 17) were used to determine the area of protection afforded by a single tree varying in DBH.

Data were graphed and fitted using a natural logarithmic model.

Results and discussion

Site characteristics

The treed sites favoured E and S facing aspects (Figure 3). The majority of the control sites were N facing. Slipping from the storm was not noticeably directional, as determined from aerial photomaps taken immediately following the storm.

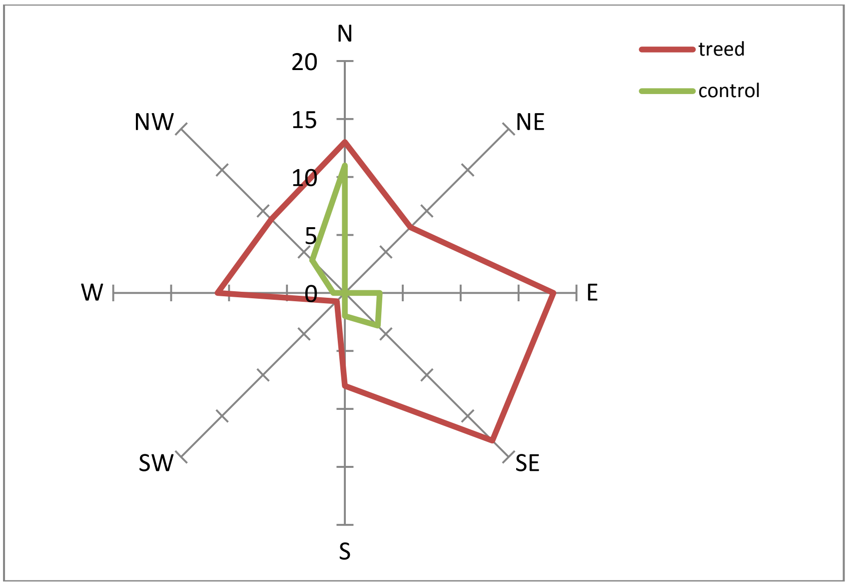

Figure 3 Distribution by site aspect of treed sites (N = 86) and control sites (N = 25).

The mean slopes for poplar sites (sites with poplar trees only) and willow sites (sites with willow trees only) were 22.3° and 24.2° respectively (Table 1). The control sites had a steeper mean slope of 27.9°. Most slips near a treed site initiated on a steeper slope above the treed site. The poplar sites had a mean tree DBH of 31.1 cm compared to the mean DBH of 18.0 cm for trees at willow only sites. The greater proportion of the smaller trees (lowest treed site mean DBH) were willows.

Table 1 Site and tree characteristics of both the treed and control sites. Data are presented as means and SEM in brackets. N = sample size: DBH = diameter at breast height.

Species	**N**	**Mean Slope (°)**	**Mean spacing (m)**	**Mean DBH (cm)**	**Area of Polygon (m^2)**	**Area of Protection (m^2)**	**Total Protection (m^2)**	**Area of Slip (m^2)**	**Slip Slope (°)**
Poplar	37	22.3 (1.1)	11.1	31.1 (4.1)	147.5 (33.8)	373.1 (77.6)	521.6 (104.0)	98.1 (29.4)	23.5 (2.5)
Willow	40	24.2 (1.2)	9.3	18.1 (2.8)	94.9 (17.7)	361.2 (84.7)	419.9 (98.3)	55.7 (78.4)	24.4 (1.1)
Both	9	22.5 (2.1)	10.3	13.3 (1.5)	183.5 (31.9)	24.6 (21.7)	199.9 (53.6)	39.3	22.9
Control	25			27.9				174.8 (22.2)	27.9 (1.1)

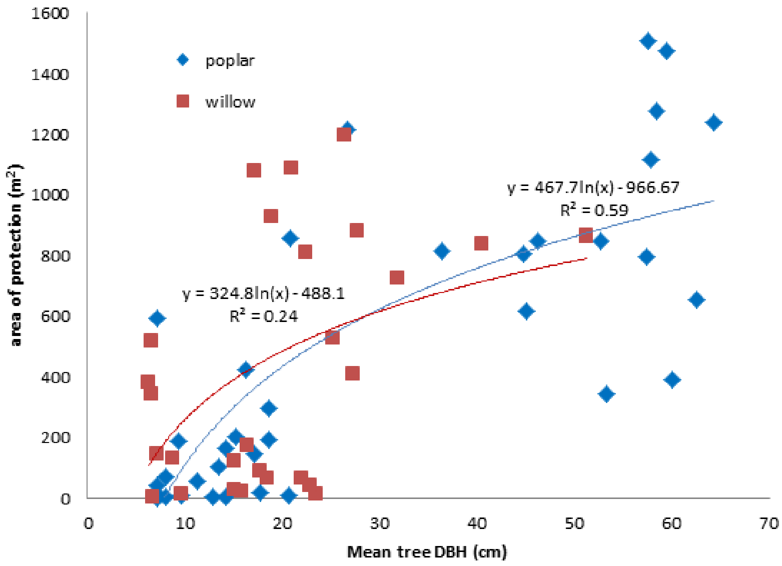

Figure 4 Area of protection for each site compared against the mean DBH of the trees present at the site separated for species (N = 32, poplar; N = 24, willow). Both data sets are fitted with a log model.

When the area of protection was compared with the mean tree DBH, a logarithmic function fitted the data for the poplars moderately well ($R^2 = 0.59$), whereas it was a poor fit of the data for the willow sites ($R^2 = 0.24$) (Figure 4). For the three poplar outlier sites with mean DBH >40 cm and furthest below the trend line, a low area of protection could be accounted for at each site. Two of the three sites were gully plantings with the side slopes exposed resulting in slipping close to the sites. The site with the least protection (53, 344) was on the steepest measured slope of 34.9° (mean). There were only three trees present at the site and cracking was present inside the polygon. If the outliers were removed the model has a better fit with $R^2 = 0.76$. These data do not consider the number of trees at the site which, in turn, influences the area of protection. When the pattern of protection is allocated on a per tree basis for each site (Figure 5), again the data are a moderately good fit for poplar ($R^2 = 0.64$) but a poor fit for willow ($R^2 = 0.33$).

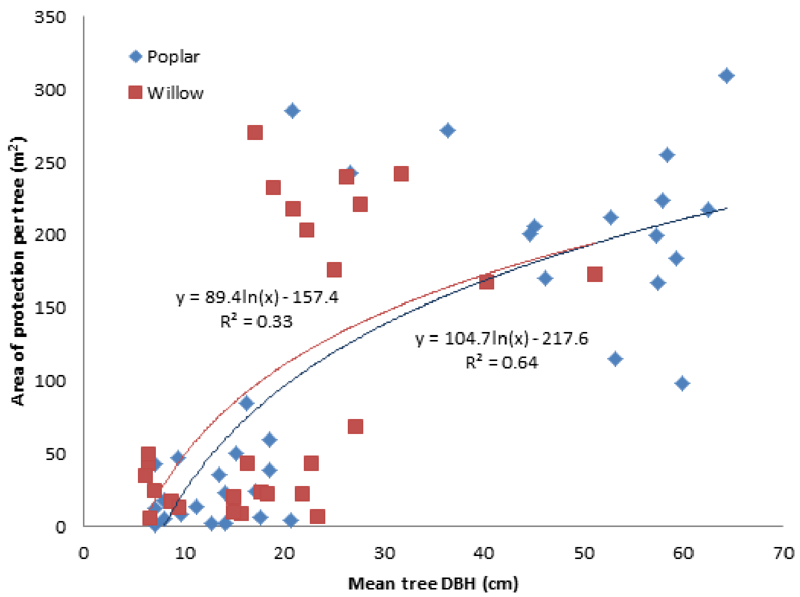

Figure 5 Area of protection per tree at each site compared with mean tree DBH (N = 32, poplar; N = 24, willow). Both data sets are fitted with a natural log model.

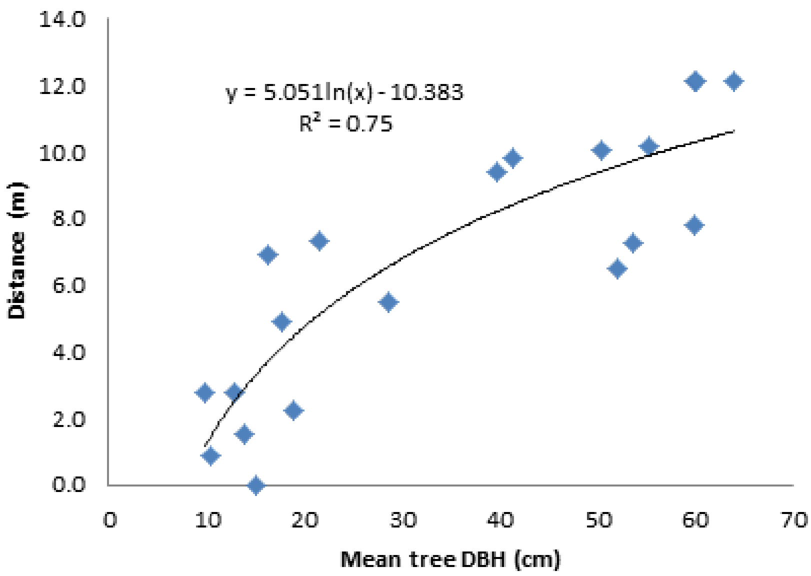

Figure 6 Relationship between DBH of the closest tree to a slip (at a treed site) and distance from that tree to the slip edge (N = 19). Data are fitted with a natural log model.

If a slip was present adjacent to a treed site then the distance from the slip to the nearest tree was measured and this was plotted against that tree's DBH (Figure 6). As the DBH of the nearest tree increases so does the distance to the slip, which fits strongly ($R^2 = 0.75$) with the natural logarithmic model (Figure 6). This further supports the findings of Douglas *et al*. 2013 as the distance begins to level at ~10m.

Where slips originated within the area bounded by trees planted for soil conservation (Figure 7) it was apparent that groups of trees where the mean DBH was ~≤20 cm were not able to hold the soil. This analysis does not consider spacing between the trees or the number of trees in the group. The closer trees are to each other the greater the degree of root overlap between adjoining trees and the greater the root reinforcement of the slope. For the 4 groups of willows in Figure 7 where both the mean DBH was ~≤20 cm and slipping occurred within the polygon, the spacings (mean DBH, no. of trees) were 7 (15.1, 6), 7.3 (17.8, 4), 8.1 (18.4, 3) and 18.2 (15.8, 3) m. For the 4 groups of poplars in Figure 7 where both the mean DBH was ~≤20 cm and slipping occurred within the polygon, the spacings (mean DBH, no. of trees) were 3.9 (12.8, 3), 7 (20.7, 2), 14.5 (14.2, 3) and 18.8 (9.4, 4) m. The wide variation in tree spacings may be due to tree deaths in the first two years, or differences in landowner approaches to tree placement. While tree deaths are the more likely explanation, the benefits of having other trees close by when trying to reduce slipping may not always be understood by landowners.

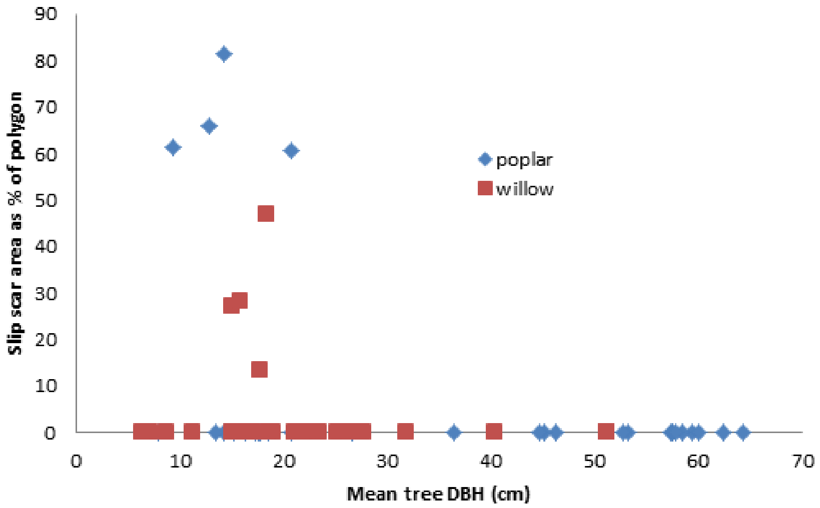

Figure 7 Slip scar area within the tree polygon as a % of the polygon area (see text for how this was calculated) for treed sites (N=60).

For the 60 sites shown in Figure 7, the mean number of trees present per site was 4.3 with a mean spacing between trees of 11.2 m. The data suggest that smaller trees (DBH < 20 cm) are more likely to be uprooted by slips, and when they are present in smaller groups. Young trees that have died should be replaced to maintain the original root reinforcement plan for stabilising the soil. The rate of growth (of the root system) of poplar and willow trees on slopes is much slower than on the flat, being reduced by shallower soil depth, less water availability and often increased wind run.

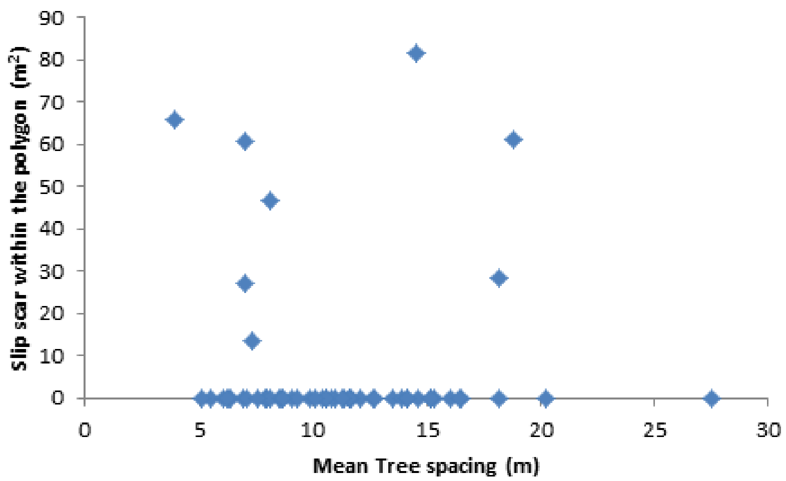

Figure 8 Relationship between slip scar area within treed site polygon and the tree spacing (N = 60).

Of the 60 treed sites, only 8 (13.3%) experienced slipping. Figure 8 inform why there are sites with trees and also with slipping, because there is no information on tree size. Perhaps it is not surprising that where trees are 15-20 m apart the protection is insufficient to prevent slipping. Slipping at spacings of 4-8 m occurred where the mean DBH of the trees was <20 cm (see Figure 7).

Considering both Figures 7 and 8 (data from same sites), effectiveness of conservation trees in reducing slipping reduced at high tree spacings and when the trees are young (even at low tree spacings). Whereas mature poplar and willow trees are able to resist slipping and reduce the impact of slip debris (Figure 9, upper photos), smaller trees may have limited effectiveness ((Figure 9, lower photos; Figure 10). This is largely attributed to the root system not having the extension to bind soil, or the individual root strength supported through thickness, branching and sinker roots, to resist distortion through soil slipping. However, holding saturated soil can be challenging, even to a dense root network (Figure 10, right).

Figure 9 Mature poplar and willow plantings located on lower slopes (upper left); or in gullies (upper right). Younger willow and poplar planted for a mixture of slope and gully protection (lower left, centre); but with a weakly developed root system showing limited capacity to resist slipping or gullying (lower centre, right).

Figure 10 Gully head erosion interrupted by roots of a young willow (Left); contributed by the mass of fine roots developed in a moist environment (Centre). Rooting depth was 170 cm. Even dense forest tree root networks may not prevent slipping, but will reduce its severity (Right) (Photo M Schwartz).

Data presented in the results were largely from slope plantings. However, where young (mostly) willows were planted in or close to gullies, the greater soil depth and availability of soil moisture enabled the trees to develop a deeper and more extensive root system after ~3 years which often interrupted advancement of the gully, even though the root system was usually exposed (Figures 9 and 10). Slipping occurred but its severity was reduced sufficiently that the trees providing the protective measures remained largely intact and future events will be expected to generate less erosion.

This study identified the lag period between planting a poplar or willow pole for erosion control and when the resulting tree becomes effective in binding soil against erosion agents such as severe rainstorms. The lag period is best described in terms of tree size rather than time since growth rates differ with environmental conditions (soil depth, soil moisture, exposure to wind etc). During the lag period the tree is growing a root system, and the dimensions (mass and length) of the root system become sufficient to be described as effective at around 20 cm DBH. This stem diameter was identified in root studies of the poplar clone *P. ×euramericana* 'Veronese' as corresponding with a linear phase in root development transforming to an exponential phase by McIvor et al. (2009) and the increase in effectiveness of trees at this growth stage on hill slopes can now be correlated with the developmental stage of the root system.

Conclusions

Mature plantings of groups of both poplar and willow reduced slipping within a zone of ~10 m of the trees to almost zero. Where plantings had a mean DBH of <20 cm, their effectiveness was reduced, and for plantings with a mean DBH of ~10 cm effectiveness was negligible regardless of spacing. This is considered to result from insufficient development and strength of the root system for trees of this size range (McIvor et al. 2008). Despite this, trees with DBH of ≥10 cm were generally able to withstand shallow slipping without being totally dislodged. Where trees were planted in gullies the same criteria applied for their effectiveness in halting the advancement of the gully.

Which is the more significant factor in reducing slipping? Tree size (DBH) or tree spacing? It is clear from these findings that below a particular tree size, spacing matters little since the roots are not sufficiently strong to resist the downward movement of saturated soil. However, as the trees grow in size their effectiveness is contributed both by their size (strong root network) and their spacing (the intermeshing of adjacent root networks, particularly the weaker extremities). The effectiveness of the trees in reducing erosion is increased when more trees are present.

Effectiveness of these trees in holding soil against erosion has been correlated with the start of an exponential growth phase of the root system at DBH of ~20 cm.

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