EFFECTIVENESS OF SPACE-PLANTED TREES FOR CONTROLLING SOIL SLIPPAGE ON PASTORAL HILL COUNTRY

Grant B Douglas[1], Ian R McIvor[2], Andrew K Manderson[1], Malcolm Todd[3], Stan Braaksma[4], Ross AJ Gray[1]

[1]AgResearch Grasslands, PB 11008, Palmerston North
[2]Plant and Food Research, PB 11030, Palmerston North
[3]Horizons Regional Council, PB 11025, Palmerston North
[4]Greater Wellington Regional Council, PO Box 41, Masterton

Abstract

Spaced trees, predominantly species of *Populus* (poplar) and *Salix* (willow), but also species of other genera (e.g. *Eucalyptus*), have been grown to stabilise erodible pastoral hillslopes in New Zealand for more than 40 years. *Populus* and *Salix* spp. are most suitable for relatively moist sites whereas *Eucalyptus* spp. are more tolerant of summer-dry sites. Despite the widespread use of these tree species, there is negligible quantification of the effectiveness of different densities and sizes of trees for reducing mass movement erosion, such as common and unsightly soil slippage, which can significantly alter sediment/nutrient distribution on slopes and reduce pasture productivity. This study determined in winter 2007 how much groups of 5-10 spaced trees reduced soil slippage at 65 sites in Manawatu (40 sites) and Wairarapa (25) following the most recent storms in February 2004 and July 2006, respectively. There were 53 sites with *Populus* trees and six sites each with *Salix* and *Eucalyptus* trees. Sites had a mean slope of 27^{o} (mostly 25-30^{o}) and soils were predominantly silt or sandy loams. Diameter at breast height (DBH) of all trees averaged 52 cm and ranged from 18 cm to 99 cm. Over all sites, trees (three genera) reduced the extent of slippage by an average of 95% (98% in Manawatu, 90% in Wairarapa) compared with slippage on nearby (< 1 km) pasture control sites of similar aspect and slope. On sites with trees, slippage (up to 11% of assessed area) occurred at 10 of the 65 sites, and the greatest extent of slippage occurred where trees had a DBH of < 30 cm. It is concluded that spaced trees dramatically reduced the incidence and severity of soil slippage on erodible slopes, and that they were even more effective when their average DBH exceeded 30 cm. Established trees at 30-60 stems per hectare (13 m to 18 m spacing) were very effective in reducing soil slippage. Regional Councils recommend planting 3 m poles of *Populus* and *Salix* at a spacing of 12–15 m on erodible pastoral slopes. If all poles survive to produce trees, the results suggest that tree thinning could be conducted to increase understorey pasture production without compromising slope stability, providing retained trees have DBH > 30 cm and are no further apart than 18 m.

Introduction

Erodible pastoral hill country has been stabilised for more than 40 years with spaced plantings of various tree species including one or more of the genera *Acacia*, *Eucalyptus*, *Pinus*, *Populus*, and *Salix* (van Kraayenoord and Hathaway 1986a,b; Hicks 1995; Wall et al. 1997; Wilkinson 1999; Hicks and Anthony 2001; Basher et al. 2008). These species have been planted predominantly to enable the continuation of livestock enterprises, rather than changing land use to retirement/conservation blocks, or plantation/protection forestry. In many cases, spaced planting of species of the genera *Populus* and *Salix* is preferred, particularly where sites are relatively moist and it is desired to continue (sheep) grazing during early tree establishment (Wilkinson 1999). In addition to erosion control, these deciduous tree species provide other benefits including shade and shelter for grazing livestock, supplementary forage (prunings and leaf fall), vista enhancement, and timber production (Douglas et al. 2006).

Despite the extensive use of spaced trees in hill pastoral systems (variously named silvopastoralism, tree-pasture systems, agroforestry, 2-tier systems), there has been limited quantification of their effectiveness for reducing erosion. One of the few evaluations, with respect to spaced *Populus* spp., was the estimation of the average (radial) range of influence of individual trees of *Populus* x *euramericana* aged 14-17 years on the occurrence of landslides on erodible slopes near Gisborne (Hawley and Dymond 1988). They estimated trees reduced pasture production losses by 13.8% and an average tree saved 8.4 m^2 of ground from failure. This work was extended by Hawley (1988) to determine the influence of root encroachment from neighbouring trees on slope stability. At a spacing of 11.5 m (75 sph), Hawley (1988) estimated that land slippage around one tree, including the contribution from a neighbouring tree, reduced from 8.2% to 1.4%. Following the results of vegetation surveys after storms in various regions, and other experiences, Hicks (1995) concluded that mature trees of *Populus* and *Salix* spp. and other broadleaved species, at spacings of 12 m (70 sph) or less, can reduce mass movement in pasture by 50-80%. Partial planting of erosion-prone slopes with trees can reduce mass movement by 10-20%, and similarly for areas where older tree stands have not been maintained (Hicks 1995). An extensive vegetation survey was conducted after the Manawatu-Rangitikei storm in February 2004 (Hicks and Crippen 2004), but there was no vegetation category specifically for spaced tree plantings. Using their presented data, Basher et al. (2008) estimated that spaced trees in the surveyed area possibly reduced erosion by 34% compared with under open pasture.

A feature of numerous post-storm soil conservation effectiveness studies is the lack of information on the characteristics of the spaced trees. Data have usually been limited to likely or confirmed tree age and sometimes tree density, so that it is not possible to objectively appraise and describe those tree plantings that retained slope intactness, or failed, and understand why. Several recent storms e.g. Manawatu/Wanganui 2004, South Taranaki 2005, East Coast 2006, Wairarapa 2006, severely eroded hill landscapes and disrupted infrastructure, and with a changing climate, the severity and frequency of storms are predicted to increase. Information on tree size and spacing, and micro-topographical features, is essential for predicting those tree-pasture systems that are likely to be resilient in the face of future storm events, and the information will be used to refine recommendations for future planting and tree management programmes.

Recent storms gave the ideal opportunity to determine how effective spaced trees of various species, size and density were in maintaining slope intactness. This paper reports selected measurements on tree-pasture systems in Manawatu and Wairarapa conducted in winter 2007 (Douglas et al. 2008). It focuses on *Populus* plantings because of their widespread use in grazing systems, but also includes spaced trees of *Salix* and *Eucalyptus* spp., the latter because of their potential usefulness in summer-dry environments.

Materials and Methods

Site selection

Sites were selected in Manawatu and Wairarapa, where the most recent severe storms occurred in February 2004 and July 2006, respectively. Aerial photography was used to select sites with groups of space planted trees before field visits. In Manawatu, ortho-corrected black and white photography (scale 1: 6000) taken in 1998/99, and colour photography (1:2700 to 1:8300) taken in 2004 within a few months after the February storm, were accessed from Horizons Regional Council's collection. Photography was obtained for farms where plantings of *Populus* and *Salix* had been conducted over a range of years, sites were within 80 km of Palmerston North, and the storm had caused mostly moderate to extensive soil slippage in the area. Groups of spaced trees (mostly 5-10 trees) were identified on the black and white photography using the following criteria:

- trees located approximately mid- to upper-slope, and on a range of aspects
- trees at various spacings and of various sizes/ages, and
- no evidence of fresh slip scars within land covered by each tree group.

Forty sites were selected across 13 farms, of which 39 sites comprised spaced *Populus* trees and 1 site comprised spaced *Salix* trees. Soils were mostly Mottled Immature Pallic Soils (NZ Soil Classification) with predominant textures of sandy loam or fine sandy loam.

In Wairarapa, 25 sites were selected on two adjacent farms, approximately 40 km south of Masterton. One farm had extensive plantings of *Populus*, *Eucalyptus* and *Salix* species, some dating to the 1970s, whereas the second farm had more recent plantings comprising mostly *Populus* and *Salix* species. Collectively, the farms provided examples of trees of a range of sizes/ages on similar topography. Colour photography of both farms taken in 2002, residing in Greater Wellington Regional Council's collection, was used to select appropriate sites using the criteria used to select sites in Manawatu. Across both farms, there were 14 sites with *Populus*, 6 sites with *Eucalyptus*, and 5 sites with *Salix*. Soils were mostly Mottled Argillic Pallic Soils or Typic Orthic Brown Soils (NZ Soil Classification) with predominant texture of silt loam.

Site and tree measurements

Topographic data collected at each site were aspect, slope, and the location of fresh soil slippage within 10 m radius of any tree in the measured group. Aspect of a site was characterised as north, south, east, or west, or any binary combination of these. Slope was measured within 2 m of each tree using an electronic level placed on ground representative of the surrounding area, excluding stock camps. The location of fresh soil slippage at each site was mapped on graph paper.

All trees at each site were measured for height (m), trunk diameter at breast height (DBH; cm), and canopy radius (m), and the spacings (m) between all trees at each site were recorded (Douglas et al. 2008). Site positions were confirmed and polygons digitised on the aerial photographs. A diagram of the trees at each site was prepared using computer aided design software, and areas of the site, including the area of any slippage within 10 m of any tree, estimated.

For each of the 65 sites with trees, a nearby (< 1 km) site with open pasture of similar slope and aspect was identified on aerial photographs to enable valid comparisons between sites with and without trees. The area (m^2) of each open pasture site, and the area of fresh slippage within, were estimated from visual inspection of the aerial photographs.

Data analysis

The percentage of soil slippage at each tree (T_slip) and corresponding pasture (P_slip) site was calculated. The percentage of non-zero T_slip values was compared with the percentage of non-zero P_slip values across the 65 data pairs and within each region (Manawatu – 40 data pairs; Wairarapa – 25 data pairs). Differences between T_slip and P_slip across all sites and within each region were tested using a one-sample t-test. Means of T_slip and P_slip were calculated for each region and for each region x tree species combination.

The number of trees at each site was expressed as stems per hectare. Means were calculated for height, DBH, canopy radius, and stems per hectare for each region x tree species combination. T_slip data for the 65 sites were plotted against DBH.

Results

The most frequent aspect of sites was NE to NW in Manawatu (22 of 40 sites) and SE to SW in Wairarapa (9 of 25 sites). Slope of the 65 tree sites averaged 27^{o} (s.e. = 0.5^{o}) and mean slope of sites with each species in each region was 24-29^{o} (Table 1).

Table 1. Site and tree characteristics at 40 sites in Manawatu and 25 sites in Wairarapa in August 2007 (*n* = sample size; mean and standard error in brackets).

Region	**Species**	***n***	**Slope (^{o})**	**Slippage (%)**	**Height (m)**	**DBH (cm)**	**Canopy radius (m)**	**Stems per hectare**
Manawatu	*Populus*	39	28 (0.6)	0.2 (0.1)	28.6 (1.1)	58.3 (3.0)	5.5 (0.4)	43 (1)
	Salix	1	24	0.0	20.6	53.0	5.7	52
Wairarapa	*Populus*	14	27 (0.8)	1.1 (0.8)	17.5 (1.9)	36.0 (3.2)	3.9 (0.3)	50 (2)
	Eucalyptus	6	29 (1.0)	0.3 (0.2)	18.8 (1.7)	69.1 (5.5)	5.9 (0.5)	37 (1)
	Salix	5	26 (0.9)	0.8 (0.6)	10.9 (1.1)	26.7 (3.5)	3.6 (0.4)	55 (5)

DBH = diameter at breast height

Soil slippage

The presence of spaced trees on a site dramatically reduced (P < 0.001) the extent of slippage compared with sites of similar aspect and slope with pasture only (Table 2). In Manawatu, the 40 sites with trees had an average of 98% less slippage than sites supporting pasture, and in Wairarapa, the average reduction was 90%. Across the 65 sites, average reduction was 95%. Slippage occurred on fewer sites with trees (10 of 65 sites) than on those with pasture (45 of 65 sites) (P < 0.001). Mean slippage beneath any tree species in either region was 1.1% or less (Table 1). At each of the 10 sites with trees where slippage occurred, its extent was less than 4% except at one site with *Populus* where it was 11.3%.

Table 2. Mean extent of soil slippage (%) on sites with spaced trees and comparable sites without trees (pasture) in Manawatu and Wairarapa in August 2007 (*n* = sample size; mean and standard error in brackets).

Region	*n*	Extent of slippage (%)	
		Tree sites	Pasture sites
Manawatu	40	0.2 (0.1)	7.8 (1.4)
Wairarapa	25	0.9 (0.5)	8.2 (2.1)

Tree characteristics
Tree height ranged from 10.9 m for *Salix* spp. in Wairarapa to 28.6 m for *Populus* spp. in Manawatu (Table 1). *Populus* trees at 39 sites in Manawatu averaged approximately 11 m taller than those at 14 sites in Wairarapa. The average height of *Salix* trees at the site in Manawatu was twice that of those growing at five sites in Wairarapa (Table 1). Trees of *Eucalyptus* in Wairarapa had the thickest trunks with an average DBH of 69.1 cm (Table 1). The DBH of *Populus* trees in Manawatu was 22 cm greater than for those in Wairarapa and *Salix* trees in Manawatu had an average DBH twice that for trees in Wairarapa (Table 1).

Trees of all species had an average canopy radius of less than 6.0 m, with the narrowest crowns being recorded for *Populus* (3.9 m) and *Salix* (3.6 m) in Wairarapa (Table 1). Estimated plant spacing for species across the regions varied from 37 stems per hectare (sph) for *Eucalyptus* to 55 sph for *Salix* in Wairarapa (Table 1).

Association between slippage and tree characteristics
Six sites with *Populus* had slippage and at four of these, average DBH was 26-30 cm, whereas at the other two sites, DBH averaged 67 cm and 69 cm. The average DBH of *Populus* trees at sites without slippage was 54 cm. Slippage occurred at two sites with *Salix* trees which had an average DBH of 18 cm and 30 cm (Figure 1). In contrast, the average DBH of *Salix* trees at the four sites without slippage was 35 cm. The DBH of *Eucalyptus* trees at two sites where slippage occurred averaged 61 cm and 74 cm, and the average for trees at the four sites without slippage was 70 cm.

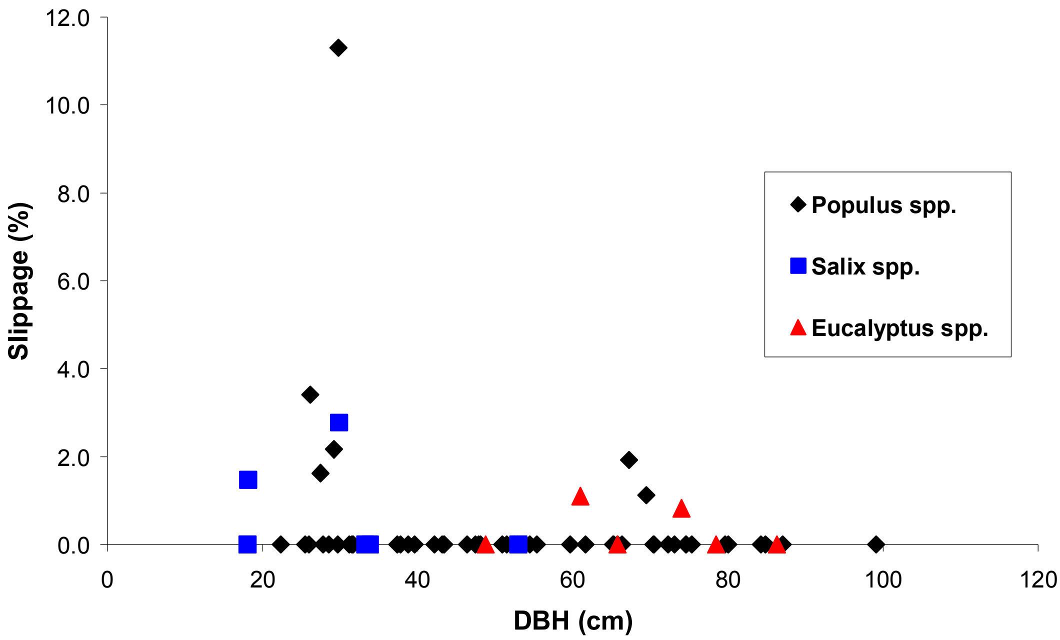

Figure 1. Association between extent of slippage (%) and diameter at breast height (DBH; cm) for spaced trees growing at 65 sites in Manawatu and Wairarapa in winter 2007.

Slight slippage (<4%) around trees occurred at nine sites at which tree density ranged from 32 sph (1.9% slippage at a site with *Populus* trees) to 62 sph (2.8% slippage at a site with *Salix* trees). The only other site with slippage (11.3%) had *Populus* trees at 43 sph. There were 45 sites with trees at densities of 32 – 50 sph and 39 of these sites had no fresh slippage.

Discussion

Space-planted trees are widely acknowledged as a key option for conserving soil on eroding hill country, where it is desired to maintain a pastoral cover for livestock grazing (Hathaway 1986; Wilkinson 1999; Basher et al. 2008). This is supported by the considerable experience and knowledge in the land management fraternity in Regional Councils and elsewhere, and a number of farmers, who frequently regard wide-spaced tree planting as effective for slope stabilisation because sites with healthy spaced trees often remain intact or suffer relatively low damage, compared with nearby unplanted areas. This study has quantified the effectiveness of spaced trees and shown unequivocally that on slopes of approximately 27^{o}, they reduced the amount of soil slippage compared with open pasture sites by an average of 95%.

One of the key ways trees contribute to slope stability is through their development of an extensive root network, the extent of which depends on tree age/size, spacing, and site factors such as soil type, depth, and position on slope. Diameter at breast height (DBH) was a key attribute recorded as a measure of tree size. It is easy to measure and has biological significance. For example, for individual *Populus* trees aged 5-9.5 years (DBH 8-21 cm) on a slope near Palmerston North, root mass and root length increased linearly with DBH (McIvor et al. 2008) and there was a log relationship between these attributes when data for larger trees (DBH up to 29 cm) were included (McIvor et al. 2009). Root development of a tree aged 5 years (DBH = 8.4 cm) was negligible compared with that of trees aged 7 years (DBH = 14 cm) and 9.5 years (DBH = 21.3 cm), and it was concluded that a tree was unlikely to contribute significantly to slope stability until it was aged at least 5 years (McIvor et al. 2008). Apart from the study of McIvor et al. (2009), no data are available on relationships between root attributes and DBH for larger (likely older) *Populus* trees on slopes. Tree age has often been used as an indicator of size in the past but the size of trees of the same age can vary considerably with position on a slope and other factors.

Populus trees in this study varied in DBH from 26 cm to 99 cm, and it is suggested that their root systems were at least as well developed as the oldest trees excavated by McIvor et al. (2008; unpubl.). Soil slippage occurred at six of the 53 sites with *Populus* trees and at four of these, trees had an average DBH of < 30 cm. The relatively low DBH values suggest that slippage at these sites was predominantly because of inadequate root development of individual trees or the failure of the root systems of neighbouring trees at each site to interlock significantly, perhaps because spacings were too wide. A possible relationship between slippage and tree size (DBH) can only be confirmed by further data collection at similar sites in the same and different regions, and a larger data set will be very useful for identifying thresholds for DBH beyond which soil slippage is highly unlikely.

Tree density across all sites and species varied mostly between 30 stems per hectare (sph; equivalent to approximately 18 m x 18 m spacing) and 60 sph (13 m x 13 m), which is within the normal range of densities/wide spacings recommended for slope stabilisation (Hathaway 1986; Wilkinson 1999). This study confirmed that these densities of established trees are effective in controlling soil slip erosion. The variability measured in spacings between trees at each site, for example average minimum spacing of 10 m and average maximum spacing of 24 m, likely reflected variation in slope micro-relief and perceived need by the land manager or farmer for treatment of particular parts of the area at the time of planting, as well as subsequent possible tree mortality. Initial pole mortality without blanking was more likely, although there might also have been initial under-planting. Regional Councils recommend planting 3 m poles of *Populus* and *Salix* at a spacing of 12–15 m on erodible pastoral slopes, and if their survival is 100%, the results suggest that later thinning of trees could be conducted to increase understorey pasture production without compromising slope stability. This is providing retained trees have a DBH of > 30 cm and are no further apart than 18 m.

There were a number of tall trees with wide canopies assessed, particularly the *Populus* trees in Manawatu and the *Eucalyptus* trees in Wairarapa. Large trees may topple during severe storms with high wind velocities, and when soils are saturated, as was observed for a few trees near those assessed at several sites in Manawatu/Rangitikei, and reported by land managers at some other locations in the region following the February 2004 storm. From observations made during this study, the incidence of tree toppling was very low, with breakage of large branches being more characteristic of storm damage. Most of the trees were estimated to be aged around 25-30 yrs.

Different species or clones of *Populus*, and perhaps of the genera *Salix* and *Eucalyptus*, were assessed in this study but their identification was often difficult. For *Populus* and *Salix* trees, this was partly because they were assessed in winter when leaves were absent. Many of the *Populus* trees at the sites in Manawatu, particularly the older/larger trees, were imported clones with parent *Populus deltoides* (e.g. I214, I78, 'Flevo') bred for a forestry environment, not wide spaced planting. *Populus deltoides* is renowned for its brittleness and propensity to develop very heavy and sprawling crowns. Trees of narrow crowned *Populus nigra* 'Lombardy' were assessed at three sites in Manawatu. Most of the *Salix* trees assessed were likely *Salix matsudana*, which has similar problems to *Populus deltoides* of brittleness and heavy, spreading crowns. Some practitioners regard trees with these characteristics as potentially unstable because of the weight of their crowns. New species/clones with narrower form and less brittle crowns (National Poplar and Willow Users Group 2007), products of the national poplar and willow breeding programme now based at Plant and Food Research, are being propagated by Regional Councils to overcome some of the disadvantages of germplasm used earlier.

Conclusions

Conservation trees of various size at densities of 30-60 stems per hectare (13 m to 18 m spacing) on slopes of mostly 25-30^o, reduced the extent of soil slippage at 65 sites by an average of 95% compared with slippage on nearby pasture control sites. Most of the trees were *Populus*, but similar significant reductions in slippage occurred beneath *Salix* and *Eucalyptus* spp. The occurrence and extent of slippage at sites with spaced trees were reduced when trees had a diameter at breast height exceeding 30 cm. This was more pronounced for *Salix* trees, but also for those of *Populus*. Tree height and canopy width covered the range found for many spaced tree plantings for slope stabilisation on pastoral hill country, and results are likely applicable to plantings at other locations.

Acknowledgements

This research was conducted under the Sustainable Land Use Research Initiative (SLURI) programme (FRST Contract CO2X0405). We are most grateful to all farmers who granted access to their farms for assessment of one or more groups of trees. Comments from some farmers on their experiences with spaced trees, either specific trees assessed or otherwise, were also appreciated.

References

Basher, L.R.; Botha, N.; Dodd, M.B.; Douglas, G.B.; Lynn, I.; Marden, M.; McIvor, I.R.; Smith, W. 2008. Hill country erosion: a review of knowledge on erosion processes, mitigation options, social learning and their long-term effectiveness in the management of hill country erosion. Landcare Research Contract Report: LC0708/081. Prepared for MAF Policy (POL/INV/0708/03). 199p.

Douglas, G.; McIvor, I.; Manderson, A.; Todd, M.; Braaksma, S.; Gray, R. 2008. Effectiveness of space-planted trees for controlling soil slippage on pastoral hill country. AgResearch Client Report. June 2008, 39p.

Douglas, G.B.; Walcroft, A.S.; Hurst, S.E.; Potter, J.F.; Foote, A.G.; Fung, L.E.; Edwards, W.R.N.; van den Dijssel, C. 2006. Interactions between widely spaced young poplars (*Populus* spp.) and the understorey environment. *Agroforestry Systems 67*: 177-186.

Hathaway, R.L. 1986. Plant materials for slope stabilisation. Pp. 39-47 *In* Plant Materials Handbook for Soil Conservation. Volume 1 Principles and practices. Van Kraayenoord, C.W.S.; Hathaway, R.L. *eds*. Water and Soil Miscellaneous Publication No. 93, MWD, Wellington.

Hawley, J.G. 1988. Measuring the influence of trees on landslip. Proceedings of the New Zealand Association of Soil and Water Conservation Annual Conference, Havelock North, August 1988.

Hawley, J.G.; Dymond, J.R. 1988. How much do trees reduce landsliding? *Journal of Water and Soil Conservation 43*: 495–498.

Hicks, D.L. 1995. Control of soil erosion on farmland: a summary of erosions' impact on New Zealand agriculture, and farm management practices which counteract it. MAF Policy Technical Paper 95/4. Ministry of Agriculture and Forestry, Wellington.

Hicks, D.L.; Anthony, T. 2001. Soil Conservation Technical Handbook. Prepared for the Ministry for the Environment by the New Zealand Resource Management Association, Ministry for the Environment, Wellington.

Hicks, D.; Crippen, T. 2004. Erosion of Manawatu-Wanganui hill country during the storm on 15-16 February 2004. Report prepared for Horizons Regional Council (Manawatu-Wanganui Regional Council). 56p.

McIvor, I.R.; Douglas, G.B.; Hurst, S.E.; Hussain, Z.; Foote, A.G. 2008. Structural root growth of young Veronese poplars on erodible slopes in the southern North Island, New Zealand. *Agroforestry Systems 72*: 75-86.

McIvor, I.R.; Douglas, G.B.; Benavides, R. 2009. Coarse root growth of Veronese poplar trees varies with position on an erodible slope in New Zealand. *Agroforestry Systems 73*: (in press).

National Poplar and Willow Users Group 2007. Growing Poplar and Willow Trees on Farms, Guidelines for establishing and managing poplar and willow trees on farms.

Compiled and prepared by the National Poplar and Willow Users Group as part of the Sustainable Farming Fund's Poplar and Willow Project (Grant No. 04/089). 72p.

van Kraayenoord C.W.S.; Hathaway, R.L. (eds.) 1986a. Plant materials handbook for soil conservation, Volume 1: Principles and practices. Water and Soil Miscellaneous Publication No. 93, National Water and Soil Conservation Authority, Wellington.

van Kraayenoord C.W.S.; Hathaway, R.L. (eds.) 1986b. Plant materials handbook for soil conservation, Volume 2: Introduced Plants. Water and Soil Miscellaneous Publication No. 94, National Water and Soil Conservation Authority, Wellington.

Wall, A.J.; Mackay, A.D.; Kemp, P.D.; Gillingham, A.G.; Edwards, W.R.N. 1997. The impact of widely spaced soil conservation trees on hill pastoral systems. *Proceedings of the New Zealand Grassland Association 59*: 171-177.

Wilkinson, A.G. 1999. Poplars and willows for soil erosion control in New Zealand. *Biomass and Bioenergy 16*: 263-274.