FRST Programme: Knowledge based tools for environmental action.
Objective 3 Sustaining soil – production and protection

2. Silvopastoral management of 'Veronese' poplars on an erosion-prone hillslope

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Summary

Soil stabilisation of farmed hill country continues to be a significant issue for both farmers and Regional Councils. Poplars planted as poles are making an important contribution to soil stabilisation, both through soil anchorage by means of their extensive lateral root system, and through dewatering of the soil during the growing season. A three-year research programme designed to quantify the effects of managing hill country poplars for both soil conservation and timber production began in October, 2000.

The project was carried out at AgResearch's Ballantrae Hill Country Research Station near Woodville, on a widely-spaced (8 m x 8 m) stand of 'Veronese' (*Populus deltoides* x *P. nigra*) poplars planted in 1995 on a wet, east-facing hillslope. Three plots were selected; a control open area in the middle of the paddock, and two tree blocks, one of which was high-pruned as a timber stand in March 2002 (P), and one which remains unpruned (UP). Meteorological data were collected from an automated weather station on site. The hydrological impact of the trees was determined by directly measuring soil water content, runoff, rainfall, stemflow and tree water use within the treatment sites.

Trees had a modest effect on rainfall interception, and also re-directed a small percentage of rainfall to the ground as stemflow. An estimated 4% of rainfall was intercepted and evaporated from the tree canopies during the period Sept '01 – Apr '02, and 10% during Sept '02 – Apr '03. These losses, along with tree water use, contributed to the lowering of soil water content under trees. Soil water content at the shallowest depth (0-200 mm) in the tree sites did not differ greatly from water content in the open sites. However, deeper in the soil profile (200-800 mm) soil water content was significantly lower under trees, particularly from late summer through until leaf fall. The influence of the trees in reducing soil moisture over the growing season extends the capacity of the soil to absorb water during the wetter winter months, when plant water use is very low and the risk of erosion is highest.

Tree water use for two trees averaged 75 L/day (dbh=13.0 cm) and 110 L/day (dbh=16.8 cm), equating to 1.2 and 1.7 mm per day. Pruning of the larger tree to a height of 5 m reduced water use by 28%. Pruning the trees increased mean canopy openness under P trees from 50% in January 2002 to 59% in March 2002, while canopy openness under UP trees decreased from 65% to 60% over the same period. Simulations showed that the percentage of transmitted direct and diffuse radiation reaching the understorey also increased from 61% to 72% following pruning. Mean pasture production under trees was approximately 10-15% lower than in the open site.

Two unpruned trees were excavated to measure root biomass and distribution. For both excavations the majority of the roots were within 2 m of the root bole and 50 cm of the soil surface. Structural (>2 mm) root biomass for the excavated trees was 0.56 kg at age 5 (height=6.3 m, dbh=7.0 cm in 2000) and 7.82 kg at age 7 (height=9.0 m, dbh=14.0 cm, in 2002), the latter being 26% of the total tree biomass. The roots extended to 9 m from the tree in 2000 and to 15 m in 2002. These results show that root biomass has dramatically increased over a two year period. Combined with the results above, we suggest that these young trees are mostly contributing to erosion control by the binding and re-enforcing role of the tree roots, however their impact on site hydrology will become increasingly important over time.

Introduction

Soil stabilisation on farmed hill country is a significant issue for farmers, landowners and Regional Councils throughout New Zealand. Since the 1950s poplars (*Populus* spp.) have been extensively planted to reduce soil erosion (Wilkinson, 1999). Poplars are ideally suited to this role due to their extensive root system, which anchors the soil to the underlying substrate, and a high water use that reduces water logging. Coupled with these characteristics is their relative ease of propagation, and the ability to establish from poles within a grazed environment.

Poplars provide other notable benefits such as shade and fodder for stock, and enhancement of the visual appeal of a farm. An additional, but commonly neglected benefit of poplars is their potential to provide a high-grade timber source. Indeed, the management of hill country poplars for purposes other than soil stabilisation has been largely ignored. The need to manage conservation plantings is highlighted by frequent major limb breakage and toppling when the trees get older and suffer from wind damage. As poplar and willow clones with improved timber and pulp wood properties are bred and planted into hill country for erosion protection, farmers may increasingly choose to increase the asset value of the trees whilst maintaining erosion protection.

Several studies have already been conducted on pastoral farms to determine the effect of intermediate-and mature-aged widely-spaced poplars on the surrounding environment (e.g. Douglas *et al*., 2001; Gilchrist, 1993; Guevara-Escobar, 1997). However as was noted at a recent workshop (Westbroke, 2002), few experiments have addressed the impact of silviculture regimes on the soil conservation role of the trees. Of particular interest is the trade-off involved in form-pruning to maximise understorey pasture production and create a usable butt-log, whilst still maintaining the ability of the tree to improve soil strength. Therefore the ongoing objective of this study was to determine the impact of pruning young widely-spaced poplar trees on the surrounding environment, particularly those physical changes likely to affect soil conservation, such as:

- The site water balance – rainfall, throughfall, stemflow, runoff, soil water content and water uptake by the trees and pasture.
- The site light environment and pasture production.
- Tree root mass and distribution.

In order to provide a complete summary, some sections are duplications of the results presented at the WPRC 2002 AGM, however here we include new information on the effects of pruning on tree water use and light interception, as well as the results from a second root excavation study.

Methods

Site description

A south-east facing hill slope at AgResearch ‘Ballantrae’ Research Station near Woodville was planted with 3 m 'Veronese' poplar (*Populus deltoides x P. nigra*) poles in 1995, spaced 7-8 m apart in a grid pattern (160 stems per hectare). In winter 2001 the trees had a mean height of 8.9 m and a mean diameter at breast height (dbh) of 13.2 cm. In winter 2002, mean height was 10.2 m and mean dbh was 16.4 cm. The resident pasture was grazed by sheep every 3-4 weeks during summer.

Meteorological data

An automated weather station was installed in the open pasture block at the beginning of the experiment to record direct and diffuse radiation, air and soil temperatures, rainfall, wind speed and direction, and relative humidity. The climate is temperate with mean daily air temperature ranging from 6.8 ^{o}C in July to 18.1 ^{o}C in February (data not shown). Annual rainfall at the site was 1250 mm in 2001, and 1210 mm in 2002.

Pruning treatment

In November 2000 two uniform sites were selected at opposite ends of the paddock, one for a pruning treatment (P) and another for an unpruned control treatment (UP). A third "open" pasture treatment (O) was created by removing several trees to create a 25 m x 25 m open area in the middle of the site. The trees in the P treatment were pruned to a height of 4-5 m on March 6th 2002. During pruning, the diameters of the branches at the intersection between the branch and the central leader were recorded. The approximate leaf area removed from each tree was calculated using a known relationship between branch diameter and leaf area.

Soil water content

Soil water content was measured fortnightly in summer and every 3-4 weeks in winter around a selected tree in each of the P and UP treatments. Time Domain Reflectometry (TDR) probes were installed at 2, 4 and 5 m distances in four directions from the tree trunks, and soil water content was measured at 4 depths (0-200 mm, 200-400 mm, 400-600 mm and 600-800 mm) at each of these locations. Additional probes were buried at the same depths at four randomly chosen locations in the open treatment.

Rainfall and Stemflow

Rainfall was collected in troughs constructed of spouting set at 1 m above ground level, with outflows collecting the water through a tube into sealed 20 L containers. Seven troughs were arranged within each tree treatment (P and UP) to measure the effect of the trees at different locations within the grid. Four troughs were randomly placed within the open treatment for comparison. Approximately fortnightly, or following significant rainfall events, the volume of rain collected in each trough was recorded. The meteorological station also logged rainfall to an accuracy of 0.2 mm in the open treatment. Stemflow was measured on four trees, two in each of the P and UP treatments. Flexible plastic tubing (11 mm diameter) was wrapped in a slight downwards spiral around the tree trunks, starting at breast height, for one complete 360° rotation. The tubes were fixed to the tree using a non-toxic silicon-based sealant, and grooves were cut in the plastic to allow "stemflow" water to enter the tube and flow into a sealed 50 L container at the base of the trees. Stemflow volumes were measured and recorded following rainfall events.

Surface runoff

Runoff collectors were constructed from 40 cm diameter hard PVC drainage pipe sawn into 30 cm lengths. 21 lengths of this pipe (8 sites in the P and UP treatments and 5 sites in the open) were installed vertically in the ground to a soil depth of 25 cm soil to prevent subterranean inflow. Eleven mm tubing was inserted into a hole drilled flush with the soil surface on the downslope of the pipe, and the runoff was collected through this tubing into 10 L containers.

Tree water-use

Tree water use was ascertained from measures of sap flow using heat pulse technology (Swanson & Whitfield, 1981). On the 5th February 2002 instrumentation to measure tree sap flow was installed in one tree in each of the P and UP treatments. This equipment was connected to a Campbell data logger and continuous measurements until 12th March 2002 enabled us to calculate the change in water use following pruning of one of the trees on the 6th March. Tree water use for the same two trees was measured again during February 2003.

Light Environment

Canopy photos were taken in January 2002 and April 2002 using a Nikon SLR camera mounted on a tripod 30 cm above the ground. A hemispherical lens was attached to the camera to capture the entire 360° above-ground image. The photos were taken from the same fixed positions as the pasture cages (see below) and were scanned and analysed using the Gap Light Analyzer (GLA) software (http://www.rem.sfu.ca/forestry/gla/index.htm) to predict canopy openness and global and diffuse short-wave radiation at these locations.

Pasture Production

Pasture production was measured monthly from March 2001 to May 2003 using a standard pre-trimming technique involving 0.2 m^2 grazing exclusion cages (Radcliffe, 1974). The cages were located at seven midpoints between 12 trees in both the P and UP treatments (Figure 2), and at 4 locations in the open site. At each harvest, herbage in the caged areas of all plots was cut with electric shears to a residual sward height of 1-2 cm. The dry weights of the herbage cut from each cage were determined following drying for 12 hrs at 80 ^oC.

Structural Root Biomass and Distribution

Excavation of the structural roots of one 5-year old tree (height=6.3 m, dbh=7.0 cm) was conducted in 2000, and this procedure was repeated on an adjacent tree in 2002, at tree age 7 (height=9.0 m, dbh=14.0 cm). Excavation was carried out by digging around the base of the tree and collecting all roots with a diameter greater than 2 mm. Root distribution and approximate depths were recorded.

Results and Discussion

Quantifying the Water Balance

Soil water content

Figure 1 shows the mean soil water content in the P and UP treatments combined, at different depths and distances from the two trees. Mean water content within the open site is also shown. At the shallowest depth seasonal soil moisture levels ranged from 20-50% of total soil volume but large differences between the tree and open sites were not apparent. However, at depths of 200-400, 400-600 and 600-800 mm, summer and autumn soil moisture levels within the tree sites were consistently lower than those in the open site. For example, on April 3, 2002, mean soil water content at 2 m from the trees was 36.1%, 34.7% and 38.1% at depths of 200-400, 400-600 and 600-800 mm respectively (data not shown). Mean water content measured on the same day and at the same depths in the open sites was 40.3%, 39.7% and 42.2%.

In autumn 2002, mean stored water across all depths (0-800 mm) was significantly lower under trees, and this difference was maintained until October (Figure 2). The influence of the trees in reducing soil moisture over the growing season extends the capacity of the soil to absorb water during the wetter autumn and winter months when plant water use is very low and risk of erosion is highest. No obvious changes in soil water content followed pruning, however the timing of the pruning and slight differences in mean tree height for the P and UP treatments are likely to make any difference difficult to detect.

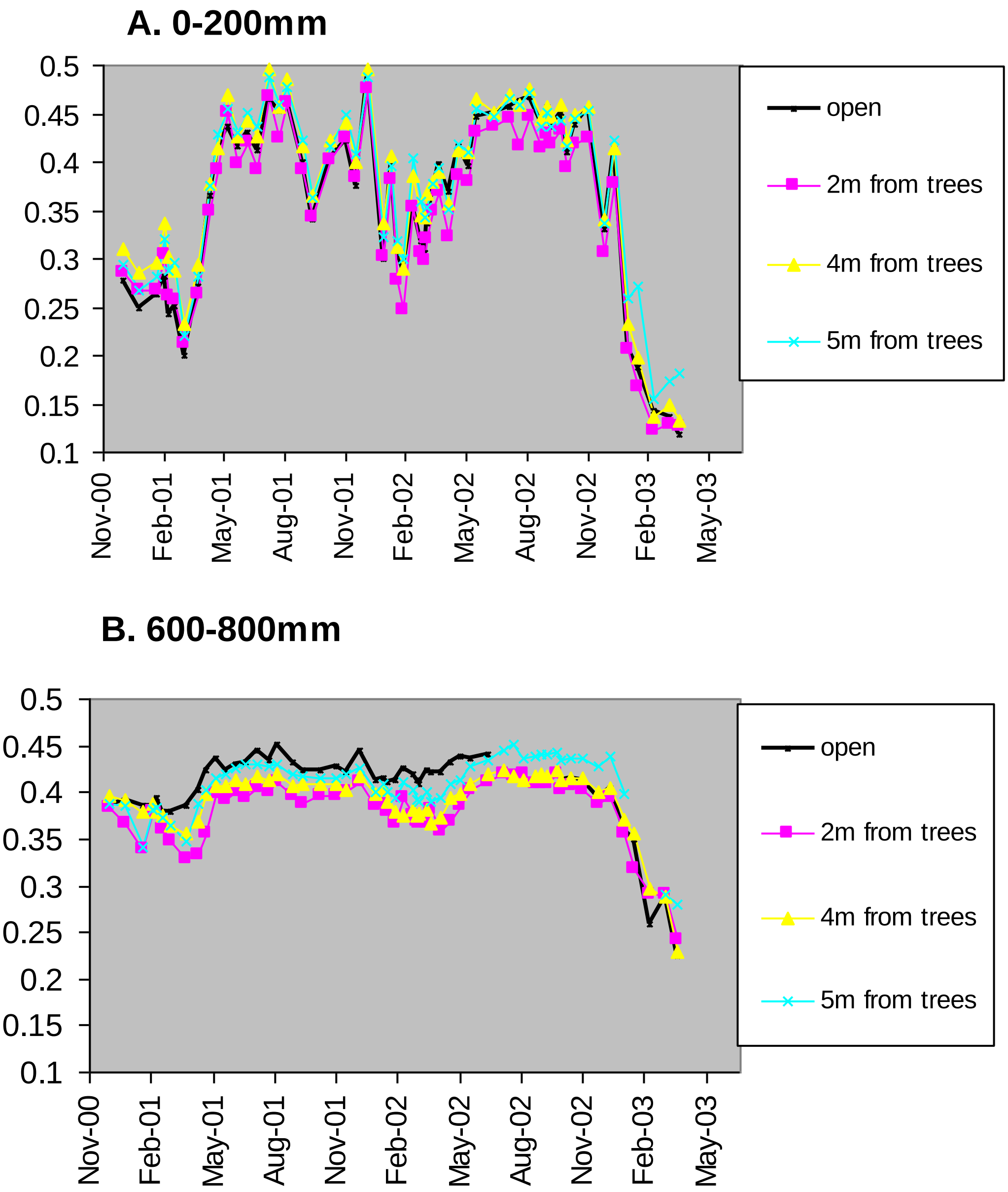

Figure 1. A. Mean soil water content at 0- 200 mm, and B at 600-800 mm at distances of 2 m, 4 m and 5 m from the UP and P trees (includes both) and in the open site.

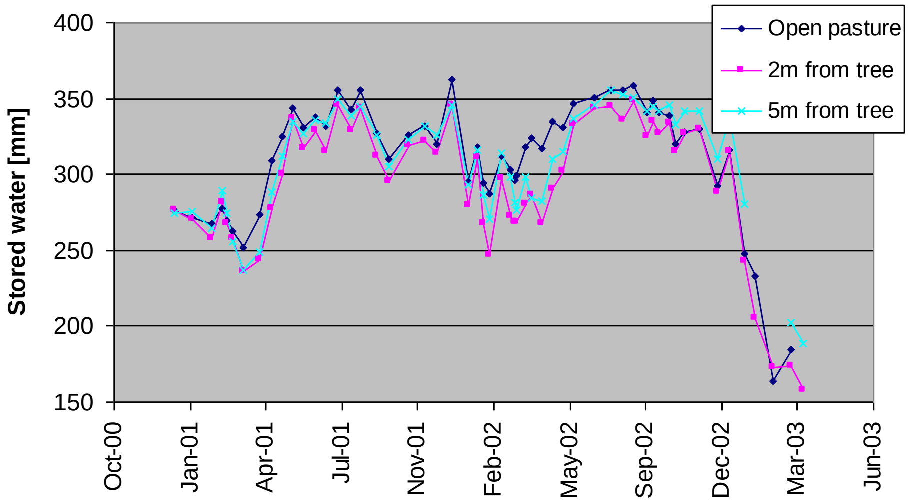

Figure 2. Mean stored water from 0-800 mm at 2 m and 5 m from the trees, and in the open site.

Rainfall and Stemflow

Rain troughs in the P and UP sites measured the effect of the trees at different locations within the plantations. Total rainfall collected within the P and UP sites from Sept 01- Apr 02, and Sept 02 – Mar 03 , compared with that in the open site, is shown in Table 1.

Table 1. Average throughfall-rainfall totals for two seasons in each tree site location and the percentage of these rainfalls compared to the open site rainfall of 822 mm in season one (Sept 01-Apr 02) and 415 mm in season two (Sept 02-Feb 03).

	P site before pruning (Sept 01- Apr 02)			**P site after pruning (Sept 02- Feb 03)**		
Trough (s) location	N	rainfall (mm)	% of open rainfall	n	rainfall (mm)	% of open rainfall
1m from tree	4	721	88	4	373	90
4m from tree (N/S)	1	786	96	1	373	90
4m from tree (E/W)	1	790	96	1	364	88
5m from tree	1	845	103	1	368	89

	UP control site (Sept 01- Apr 02)			**UP control site (Sept 02- Feb 03)**		
Trough (s) location	N	rainfall (mm)	of open rainfall	N	rainfall (mm)	% o open rainfall
1m from tree	4	721	88	4	333	80
4m from tree (N/S)	1	788	96	1	384	93
4m from tree (E/W)	1	808	98	-	-	91 est
5m from tree	1	844	103	1	408	99

During the 2001-02 poplar growing season, the average rainfall volumes from both groups of four troughs located 1 m from the trees was only 88% of the 822 mm recorded in the open site (Table 1). The total rainfall volumes 4 m from the tree in North/South and East/West directions were also reduced by canopy interception. However rainfall in the centre of the four trees was actually higher than in the open by 3%. By combining these averages we estimated the overall effect of trees on rainfall at this site. For the purposes of calculation we assumed that each trough location in Table 1 represents a good approximation of the rainfall over a quarter of the tree site. On the basis of these assumptions, the percentages of rainfall collected in the P and UP sites when compared with the open sites, were 96% and 97% respectively in 2001-02.

In the 2002-03 poplar growing season, average throughfall 1 m from the pruned tree was 90% of open site rainfall, compared to 80% for the unpruned tree (Table 1). However, average throughfall percentages for the P and UP site across all distances were not significantly different in 2002-03, at 89% and 91% respectively.

The "missing " rainfall (3-4% in ‘01-‘02 and 10% in ‘02-‘03) is attributed to both interception and evaporation from the tree canopy, and movement of water down the tree trunk (stemflow). Investigation of the latter was carried out on four trees. Stemflow expressed as a percentage of the rainfall during the period Sept 01-Apr 02 was 0.8% of total rainfall across the site. We assume that the remaining rainfall evaporates from the tree canopy before reaching the understorey. The greater interception by the trees in the 2002-03 growing season is likely to be due to a combination of greater canopy area and less intense rain events. While measurable, the low percentages of stemflow and evaporation from the canopy indicate that other factors such as tree water uptake have a more important impact on the site water balance in young wide-spaced plantations.

Runoff

Runoff followed large rain events and was very variable across the slope, although mean runoff was usually lower in treed blocks (Figure 3). We would expect that in summer the land under the trees has a greater capacity to take up precipitation because of the lower soil moisture levels. However soil hardening under very dry conditions may create the opposite effect. The study hillslope is not uniform in grade, and previous slump history of the site is likely to be as significant as root channels in contributing to runoff variability. Topographical features such as catchment size, gullies and hillocks will also affect total runoff volumes under wide-spaced plantations of young trees.

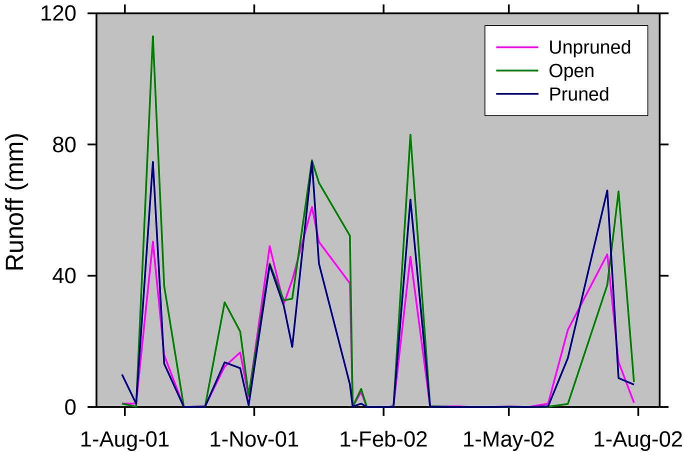

Figure 3. Average surface runoff (L/m2) measured on 8 (P and UP treatments) or 4 (Open treatment) circular plots from July 01-May 02.

Tree water use and pruning

A tree from the edge of the P treatment was felled in February 2002, and the leaf area was measured for each branch. From this data numerical relationships were established between branch diameter and leaf area, and tree whorl (the ring of branches off the main trunk formed in one growing season) and cumulative leaf area (Figure 4). The latter relationship was used to estimate the leaf area removed from each pruned tree.

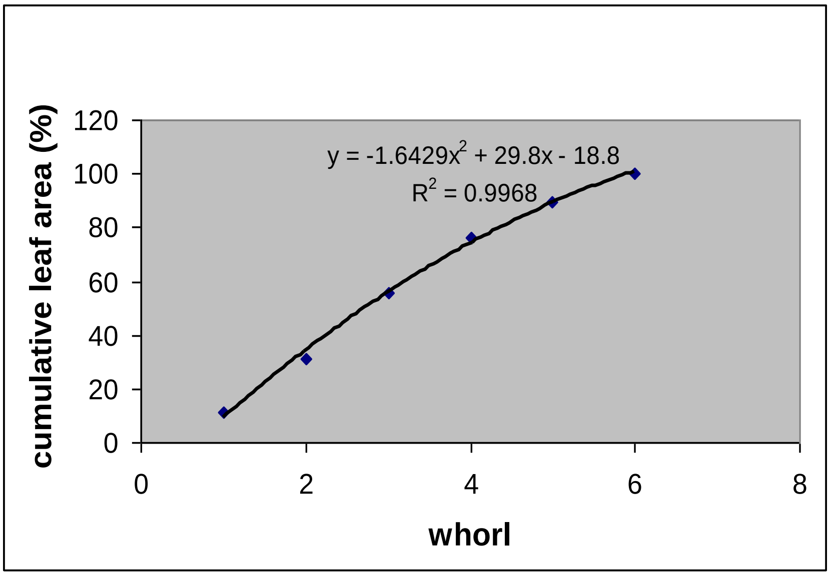

Figure 4. Relationship between whorl and cumulative leaf area for a tree felled in February, 2002

Prior to pruning, tree water use averaged 75 L/day for the UP tree (dbh=13.0 cm) and 110 L/day for the P tree (dbh=16.8 cm), equating to 1.2 and 1.7 mm/day respectively at these tree spacings (Table 2). These results are consistent with other studies, for example Guevara-Escobar et al (2000) measured the water-use of mature *Populus deltoides* trees and showed that an average of 188 L/day was transpired, which equated to 0.92 mm/day at 37 stems per hectare.

Using the relationship between branch diameter and leaf area (Figure 4), we estimated that approximately 40% of the tree leaf area was removed from the P tree on March 6th 2002. Following pruning water use dropped to 77 L/day in the P tree, a relative decrease of 28% when compared with the UP tree for the same period (Figure 5). This discrepancy between leaf area removed and change in water use suggests that the removed leaves in the lower canopy may have a lower water use than those in the upper canopy. However, predicted water use as determined by our 3D array model (Green, 1993) closely followed actual water use for the trees prior to pruning.

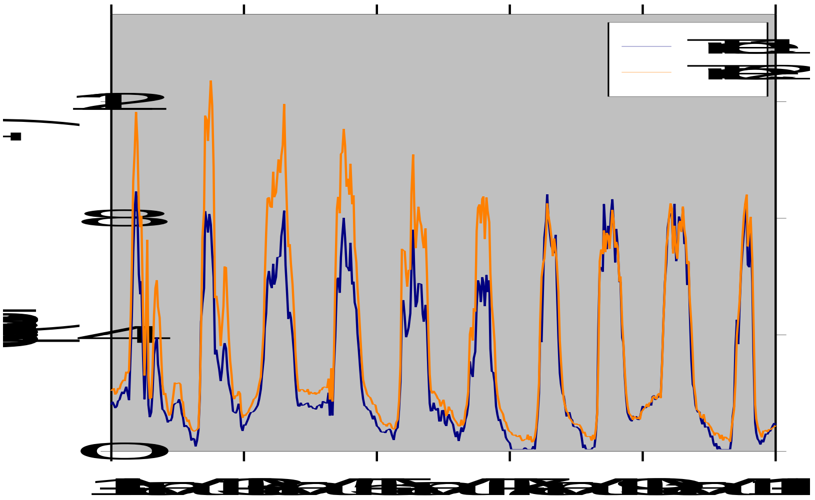

Figure 5. Daily water use of two trees during February and March, 2002. Tree 1 was in the UP treatment, while Tree 2 (upper trace) was in the P treatment and was pruned on March 6th 2002.

The pruned tree in the following season, 2003, has already shown evidence of a greater sap flow equating to water use consequent on a greater increase in leaf area (Figure 6). A summary of the mean daily water use measured over the same time period in 2002 and 2003 is given in Table 2. Tree water use in 2003 equates almost exactly to tree leaf area (1.29 c.f. 1.31). Water use has increased by 78% in the pruned tree but only 41% in the unpruned tree. It can be seen that by 2003 the pruned tree has recovered around two thirds of the water use (0.29 of 0.47) that was lost by pruning. This difference reflects the greater size of the pruned tree, but also reflects the low impact that pruning at the end of the growing season has on the storage of the tree.

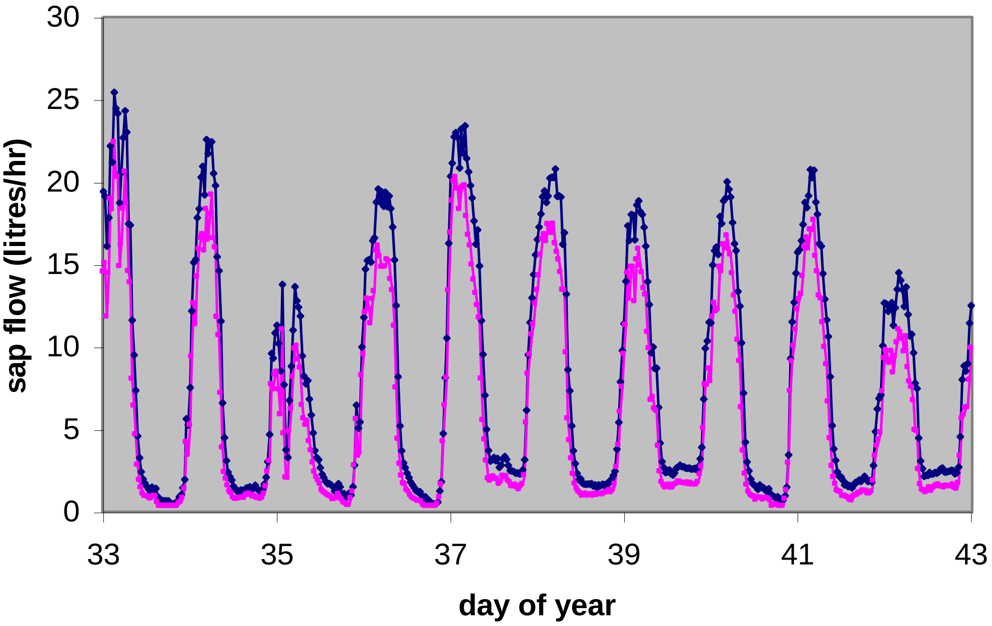

Figure 6. Daily water use of two trees during February, 2003. The lower trace is that of the unpruned tree, while the upper trace was that of the pruned tree.

Table 2. Tree water use for the pruned and unpruned tree (*water use following pruning in 2002) and the ratio of pruned:unpruned for water use and leaf area.

	Unpruned tree (UP) dbh=13.0 cm	Pruned tree (P) dbh=16.8 cm	Ratio of P:UP
2002 Water Use (L/day)	75	110 (*77)	1.47 (*1.03)
2003 Water Use (L/day)	106	137	1.29
2003 Leaf Area (m^2)	81	106	1.31

Light Environment and Pasture Production

Pruning the trees increased mean canopy openness under P trees from 50% in January 2002 to 59% in March 2002, while canopy openness under UP trees decreased from 65% to 60% over the same period (Table 3). The percentage of transmitted direct and diffuse radiation reaching the understorey also increased following pruning, from 61% to 72%. Percentages of radiation received by the open site were high, with slight reductions due to the hill slope masking late afternoon sun, and the presence of trees in the neighbouring sites. The increases observed following pruning should result in corresponding increases in pasture production beneath trees when soil water is not limiting.

Table 3. Percentages of Canopy openness, and Transmitted direct, diffuse and total radiation in the P, UP and Open sites in January 2002 (before pruning) and March 2002 (after pruning). (n=4 (Open) and n=7 (Pruned and Un-pruned)). "Above" radiation is the incident radiation without any effect of topography or forest canopy.

Percentage of "Above" Radiation	P site January	P site March	UP site January	UP site March	Open January	Open March
Canopy openness	50	59	65	60	69	70
Transmitted direct	61	72	80	77	95	94
Transmitted diffuse	61	71	79	76	90	90
Transmitted total	61	72	80	77	94	93

The pasture production under the trees was reduced by 10-15 % over most of the year (Figure 7). The most pronounced differences between sites occurred in spring, when pasture growth in the open exceeded that beneath trees by up to 30%. The immediate effect of pruning was an increase in pasture production under the trees. However in the 2002-03 season this effect is reversed, probably as a consequence of the substantial increase in leaf area and light reduction in the pruned block. Pruning should aim to remove a minimum of 50% of leaf area (the three lowest whorls) if maintaining pasture production is a high priority.

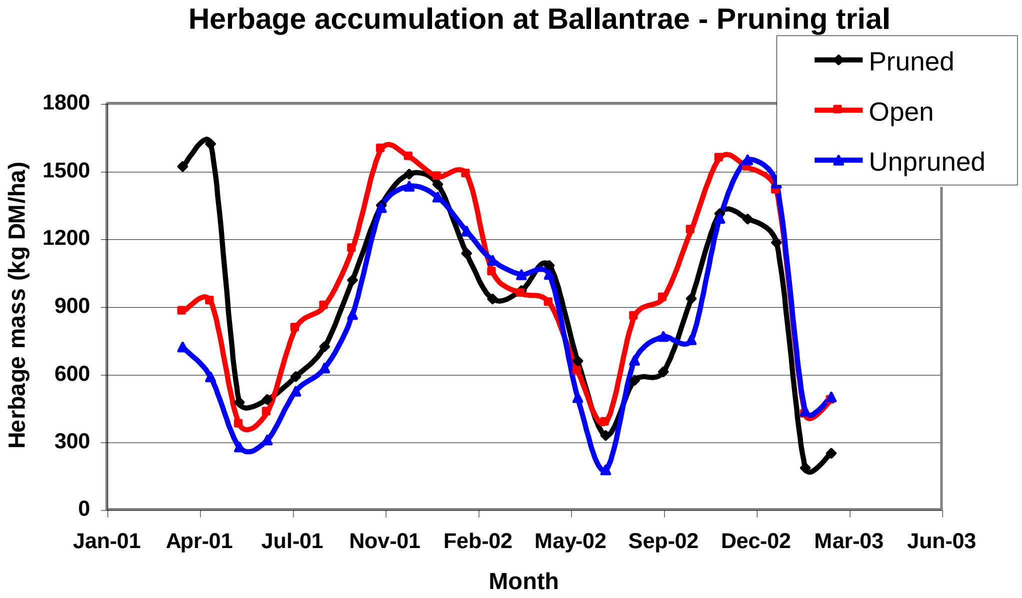

Figure 7. Pasture production during 2001-03 according to treatment (n=4 (Open) and n=7 (Pruned and Un-pruned)).

Structural Root Biomass and Distribution

In an excavation in 2000, structural (>2 mm) root biomass for the excavated tree was 0.56 kg (age 5, height=6.3 m, dbh=7.0 cm). The roots extended to 9 m from the pole, with the laterals typically within 50 cm of the ground surface, occasionally turning sharply downwards to become sinkers. Most vertical roots were within 1 m from the base of the pole. The distribution of roots was roughly symmetrical - mostly concentrated on the NE and SW sides of the tree, with no obvious effect of hill slope.

For the tree excavated in 2002, structural root biomass was 7.82 kg (age 7, height=9.0 m, dbh=14.0 cm), 26% of the total tree biomass. Lateral roots extended to beyond 15 m from the base of the tree, again being concentrated in the top 50 cm. The root biomass was concentrated on the downslope, with 88% of laterals and 85% of sinkers being found there. Almost 99% of sinker biomass was within 1 m of the root bole whereas 46% of lateral root biomass was beyond 1 m. Root biomass distribution for the two trees is shown in Figure 8.

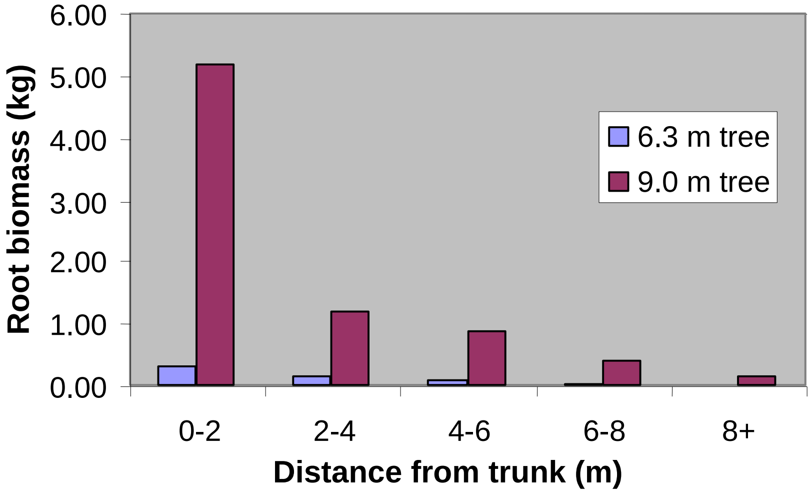

Figure 8. Structural Root Biomass Distribution for the trees excavated in 2000 and 2002.

Conclusions

The trees primarily lower soil water content through transpiration when in leaf. Tree water use for two trees averaged 75 L/day (dbh=13.0 cm) and 110 L/day (dbh=16.8 cm) prior to pruning, which equates to 1.2 and 1.7 mm per day. Pruning of the larger tree to a height of 5 m reduced water use by 28%. Soil water content at the shallowest depth (0-200 mm) in the tree sites did not differ greatly from water content in the open sites. However, deeper in the soil profile (200-800 mm) soil water content was significantly lower under trees, particularly from late summer through until leaf fall. The influence of the trees in reducing soil moisture over the growing season extends the capacity of the soil to absorb water during the wetter winter months, when plant water use is very low and the risk of erosion is highest.

Structural (>2 mm) root biomass for the excavated trees was 0.56 kg at age 5 (height=6.3 m, dbh=7.0 cm in 2000) and 7.82 kg at age 7 (height=9.0 m, dbh=14.0 cm, in 2002), the latter being 26% of the total tree biomass. The roots extended to 9 m from the tree in 2000 and to

15 m in 2002. These results show that root biomass has dramatically increased over a two year period. Combined with the results above, we suggest that these young trees are mostly contributing to soil stabilisation through root anchorage, however their impact on site hydrology will become increasingly important over time.

Benefits emanating from a more managed regime, while continuing to maintain the primary soil stabilisation role, may include: vista enhancement, contributions to several aspects of biodiversity, stock fodder in late autumn, and improved timber qualities. The management practices have consequences both above and below the ground surface. Above ground, the effect is mainly on tree canopy cover, affecting such components as tree and pasture water use, rainfall interception and pasture production. Below ground the effect will be on root structure and biomass affecting soil stabilisation and hence conservation. There is a need for further information on the management of poplar trees for soil stabilisation, timber production, and other uses, and how pasture yield and botanical composition are affected under a silvopastoral operation.

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