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Sap flow in *Searsia pendulina* and *Searsia lancea* trees established on gold mining sites in central South Africa

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ABSTRACT

The Witwatersrand Basin Goldfields (WBG) have seen over a century of continuous mining that has generated extensive tailings storage facilities (TSF), together with "footprints" remaining after the residue has been removed for reprocessing or consolidation into larger TSFs. These are now believed to number several hundred and cover a total area of 400–500 km^2. Acid mine drainage (AMD) from these structures is widespread and has resulted in contamination of soils, groundwater and surface water systems. Sustainable and long-term control measures are required to limit environmental contamination. The Mine Woodlands Project, initiated by the University of the Witwatersrand and AngloGold Ashanti Ltd, aims to investigate the use of trees for hydraulic control of mine seepage, as well as contaminant immobilization. A variety of exotic and indigenous tree species was planted in high density stands within site species trials located close to TSFs in the Orkney and Carltonville districts. The aim is to evaluate their survival and growth, as well as water use and contaminant uptake or immobilization.
This paper describes a study of the annual pattern of sap flow rates in two species of indigenous tree (*Searsia lancea* (L. F.) F.A. Barkley and *S. pendulina* (Jacq.) Moffett, comb. nov.) established in plantation form. These species occur naturally in central and western South Africa. Sap flow was monitored continuously over a full year in eight stems representing each species, using the heat ratio version of the heat pulse velocity technique. Plot sap flow was estimated by scaling up according to the number and size of stems, and utilizing functions relating leaf dry mass and leaf area to stem diameter. The deciduous species *S. pendulina* was found to use 591 mm of water over a full growing season, while the evergreen species *S. lancea* was found to use 1044 mm over a full year. Differences in sap flow patterns between these species are attributed largely to different leaf dynamics. We conclude that *S. lancea* has potential for the hydraulic control of mine seepage water in phytoremediation systems in the WBG.

1. Introduction

The Witwatersrand Basin Goldfields (WBG) comprise an area of approximately 25,000 km^2 in north central South Africa. Gold deposits were discovered in 1886, and have been mined continuously since then, yielding approximately 50,000 tonnes of gold, equivalent to about 31% of all gold ever mined anywhere throughout history (McCarthy and Rubidge, 2005). Gold mines are located along the northern and western margins of this basin. Tailings are pumped in the form of a slurry and deposited on large unlined tailings storage facilities (TSF). These TSFs number several hundred (many are now being reprocessed and consolidated into fewer larger dumps) and total approximately 400–500 km^2 in area (Marsden, 1986; Blight, 2011). After more than a century of mining, they contained an estimated 6 billion tonnes of tailings (Blight, 2011), which was estimated to include 430,000 tonnes of low grade uranium (Winde et al., 2004) and 30 million tonnes of sulphur (Witkowski and Weiersbye, 1998). Additional gold tailings are produced in the WBG at an estimated rate of 105 million tonnes per annum (Chamber of Mines of South Africa, 2004).

Many years of acid mine drainage (AMD) from the saturated core of gold tailings dams has resulted in artificially elevated groundwater levels and extensive contamination of soils, streams, sediments and groundwater (Rudd, 1973; Funke, 1990; Coetzee, 1995; Hodgson

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et al., 2001; Rösner et al., 2001; Naiker et al., 2003; Coetzee et al., 2004; Winde et al., 2004; Tutu, 2005; Coetzee and Winde, 2006; Sutton et al., 2006; Chevrel et al., 2008). Levels of contaminants sometimes exceed environmental standards (Coetzee and Venter, 2005; Coetzee and Winde, 2006) and therefore pose a potential danger to humans, farm animals, and both crop and natural ecological systems. Public awareness of the pollution threat is growing as the media increasingly draw attention to pollution threats (Earthlife Africa, 2011). Many mines are nearing the end of their lives, and closure planning is assuming more importance. A prerequisite of Government closure certificates is that sustainable and long term control measures are in place to limit environmental contamination. Engineering solutions are costly and unlikely at this stage to offer sustainable long term answers by themselves. Phytoremediation measures are far less costly (Weiersbye, 2007), and experience globally has shown that this approach may be effective and sustainable.

The Mine Woodlands Project (MWP) was initiated by the University of the Witwatersrand and Anglogold Ashanti Ltd. in 2001, with additional funding and support from the South African Department of Trade and Industry (THRIP programme) and NRF, and in-kind support from the DWAF: Directorate of Participatory Forestry. The intention of this phytoremediation research programme is to show the effectiveness of woodlands in taking up contaminants from soils and groundwater, and reducing or preventing the spread of mine drainage water from tailings dams, to provide a sustainable, low cost and long term solution to the pollution threat. As an example of the potential of trees to take up contaminants, research has shown that the hyper-accumulator species *Tamarix usneoides* can take up large quantities of salt which is exuded through salt glands and deposited on the leaf surface (Wilson and Mycock, 2014). Periodic harvesting of stems with their foliage will allow the contaminants to be disposed of at a safe site.

The potential for deep rooted indigenous trees and shrubs to exert hydraulic control and minimize the lateral flux of contaminants in groundwater is the subject of this paper. It is a well-established technology (ITRC, 2009; Landmeyer, 2011) that relies on the abstraction of water and ions by the living plant, and the phytoimmobilization or sequestration of contaminants in the rhizosphere and biomass, respectively. Suitable species of trees planted at sufficiently high densities are able to increase the rate of evapotranspiration (ET), thereby reducing the water contents in soil and the volume of groundwater (Bari and Schofield, 1992; Schofield, 1992; Salama et al., 1994; Raper, 1998). Substantially higher rates of ET following establishment of trees is predicted for sites in the WBG. The original vegetation surrounding most TSFs is dominated by seasonally dormant, shallow rooted grasslands, which are known to be relatively low water users (Dye et al., 2008). By replacing grasslands with deep rooted trees with higher leaf areas and shorter or no seasonal dormancy, ET can be greatly increased. There is much evidence from South African hydrological catchment experiments (Scott et al., 2000) and from global reviews of such land use change (Bosch and Hewlett, 1982; Zhang et al., 1999; Farley et al., 2005) to show that ET will increase when grasslands are replaced by closed canopy tree species, especially where water availability is high (Zhang et al., 1999). Woodland establishment is expected therefore to reduce the flow of water and contaminants through shallow aquifers and saturated soil horizons into adjacent lands and surface drainage channels.

An important aim of the MWP has been to test the suitability of a range of exotic and indigenous tree species established in high density woodland plots at different site types. Fastest growth and canopy development is shown by several *Eucalyptus* species, but their use for phytoremediation is hampered by legislation and negative public opinion towards alien tree species. The use of indigenous tree species is therefore an important alternative that requires investigation. Little information is available on the water use characteristics of indigenous tree species in South Africa.

Two indigenous tree species belonging to the *Searsia* genus (Family Anacardiaceae; formerly in the genus *Rhus*) have demonstrated good survival and growth. *S. lancea* (L.f.) F.A. Barkley (Karee) is an evergreen, generally multi stemmed tree (Coates-Palgrave, 2002) that is widely planted in mining sites in the WBG. It occurs extensively throughout the relatively dry central areas of South Africa, but shows a preference for drainage lines and riverbanks. *S. pendulina* (Jacq.) Moffett is a semi deciduous to deciduous tree that occurs along riverbanks and wetlands in a narrow band that follows the Orange River from the Free State province to Namibia. This species (known as White Karee, Willow Karee, River Karee) is multi stemmed, and reaches 10 m in height. Both species appear well able to tolerate a wide variety of mine sites (Weiersbye et al., 2006; Weiersbye and Witkowski, 2007), and show tolerance to AMD polluted groundwater. A previous study of sap flow in three size classes of *S. lancea* (Dye et al., 2008) suggested an annual water use rate that is intermediate between grasslands and *Eucalyptus* stands. However, the sample trees occurred in low density woodland. The relevance of the results to high density, closed canopy stands with higher levels of competition among the trees therefore requires investigation.

The purpose of this study was to quantify the total annual sap flow within high density stands of these two species in order to assess their potential for hydraulic control of mine seepage water on mining sites.

2. Site and trial descriptions

Sap flow measurements took place within two site-species trials. The *S. pendulina* plot is situated within the Mispah site-species trial (26° 59′ 20.91″S; 26° 46′ 30.83″E) at Vaal River, while the *S. lancea* plot is situated in the Madala site-species trial (26° 25′ 55.18″S; 27° 20′ 05.03″E) at West Wits. These trial sites are described below.

2.1. Mispah trial (S. pendulina)

This trial is situated approximately 154 km southwest of Johannesburg (Fig. 1). The climate of the region (Table 1) is warm temperate, and characterized by summer rainfall with high summer temperatures, and frequent winter frosts (Schulze, 1997; Mucina and Rutherford, 2006).

Although most of the vegetation growing in the Vaal River mining area is degraded grassland transformed by mining, the natural vegetation type is Vaal Reefs Dolomite Sinkhole Woodland (Gh12), a grassland biome vegetation subunit found in North West and Free State provinces within an altitudinal range of 1280 to 1380 m above sea level (M.A.S.L.) (Mucina and Rutherford, 2006). This vegetation type supports a grassland woodland complex characterized by clumps of woodland that form on dolomite sinkholes. The dominant tree taxa include *S. lancea*, *Vachellia* (formerly *Acacia*) *erioloba* and *Celtis africana* (Mucina and Rutherford, 2006).

The soils at the Mispah trial are deep, red brown, well drained sandy clay loams to sandy loams (Hutton, Hayfield family) derived from highly weathered, largely chert free Malmani Formation dolomite (Herbert, 2003). The equivalent FAO classification is Rhodic Ferralsol. The effective rooting zone observed in deep soil pits is 3.5 to 4.0 m. This overlies weathered dolomite stretching to 10 m below ground (Vivier et al., 2004). Two boreholes (VRM51 and VRM58) situated close to the trial margins revealed a water table at 10.8 and 9.9 m below ground level respectively in January 2007.

The Mispah site-species trial was established in January 2003. It includes 18 tree species, of which 10 are indigenous. Sixty three seedlings were planted in each plot in a 7 by 9 block, and at a spacing of 3 by 2.5 m (1333 stems per hectare). Blanking occurred to replace those trees not surviving the first growing season. Four sample trees were selected within plot 21 based on their healthy growth, absence of fire damage scars and uniformity of canopy cover in adjacent trees.

2.2. Madala trial (S. lancea)

The Madala site-species trial at West Wits is situated approximately 75 km WSW of Johannesburg and 7 km south of the town of Carltonville