Stemflow runoff contributes to soil erosion at the base of macadamia trees

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Abstract
Soil erosion in macadamia orchards on the north coast of New South Wales (NSW) is a major issue due to several erosive forces. Stemflow (water flowing down a tree trunk) is a potential contributor that has not been assessed for macadamias. Observational studies were established to measure soil movement from beneath trees and stemflow volumes from macadamia trunks. Soil micro-topography around the base of eight trees was measured using the distance from an elevated platform at monthly intervals over 16 months. Stemflow volume was measured using a plastic vessel attached around each of eight trees. The water captured was funnelled into a tipping bucket flow gauge that continuously logged for the same period. Soil movement away the base of trees averaged 6.5 mm/m^2/year, with the development of surface gullies and root exposure evident. Stemflow volume was highly and positively correlated with rainfall volume in a close to linear relationship (r^2 = 0.83 to 0.99). The percentage stemflow captured varied from 0 to 28% with an overall average stemflow of 7% and a monthly range of 5 to 10%. This study confirms that stemflow runoff contributes to the redistribution of soil away from beneath macadamia trees. With tree spacings typically used by the industry, this soil movement could amount to 3.8 t/ha/year.

Key Words
Micro-topography, root exposure, soil surface monitoring, electronic fluid level.

Introduction
Soil erosion is a major issue in macadamia orchards, especially on the Acidic, Dystrophic, Red Ferrosol (Isbell 2002), or Nitisol (IUSS WRB 2006) soil of northern NSW where several erosive processes contribute to the problem. Trees in orchards older than 15 years generally have dense canopies that shade a large proportion of the orchard floor. In many cases there is insufficient light to maintain any groundcover species and the orchard floor is mostly bare. Where enough light is present in the inter-row region, sweet smothergrass (*Dactyloctenium australe*) has been selected as an effective groundcover (Firth *et al.* 2002). Harvesting nuts from the orchard floor is typically mechanised with powerful blowers or sweepers used to move nuts into the path of the harvester. Both of these harvest aids also displace soil from beneath trees. Overland water flow during intense rainfall events in this subtropical region also contributes to soil erosion in orchards. One study measured soil losses at 2 t/ha/yr on a 5 degree slope with bare soil (Reid 2002).

Another process that may contribute to the movement of soil from under macadamia trees and subsequent erosion of soil is stemflow. Stemflow can be defined as canopy intercepted rainfall that flows down and runs off the base of the plant and has been reported as high as 56% for some plant species (Crockford and Richardson 2000). In one study conducted in a tropical forest, stemflow was recorded at 6 000 to 70 000 litres per tree from 7800mm of rainfall over two wet seasons (Herwitz 1986). In tropical forest (Herwitz 1986) and eucalypt tree forests (Zhou *et al.* 2002) stemflow has been shown to contribute to substantial soil erosion with up to 9.1 kg/ ha soil lost per mm rainfall (Zhou *et al.* 2002). In older macadamia orchards, soil loss leading to severe root exposure at the base of trees is frequently observed. The extent to which stemflow contributes to this phenomenon for macadamias has never been investigated. This paper reports on the observational studies carried out over 16 months to quantify soil movement around macadamia trees and to assess the contribution of stemflow to soil erosion and tree root exposure.

Methods
Soil erosion
Micro-topographical measurements were made to assess soil erosion resulting from stemflow in a macadamia orchard at the Centre for Tropical Horticulture, Alstonville, NSW. These measurements were made using a purpose-built aluminium elevated measurement platform which was designed to permit 220 measurements at 10cm intervals across a 1.4m x 1.5m grid. At each of eight, nine year old trees, the

platform was set up in exactly the same vertical and horizontal position at monthly intervals over 16 months. On each occasion, a laser distance meter (Leica *DISTO™*) and electronic fluid level (Technidea *ZIPLEVEL™*) were used to position the platform accurately using permanent reference markers. Distances from the platform to the soil surface were measured with the laser distance meter with readings electronically transferred to a handheld computer (Hewlett Packard Pocket PC). Soil surface topographical maps were created from the data.

For each grid of observations, broad scale trends and features such as slope and relatively large valleys were approximated by using a function of cubic splines of the spatial coordinates (x,y). Local variability was modelled by a nugget effect plus an exponential covariance function based on the distance between pairs of coordinates. The two components were combined to form a predicted soil surface (Lark *et al.* 2006). A numerical integration algorithm used the models to provide predicted heights at specific points on the surface in order to estimate the volume of air in the space enclosed by the elevated platform. The space occupied by the tree trunk was not included in the calculation. Change in air volume was assumed to correspond exactly to change in soil volume relative to the initial observation on each tree. Thus gain or loss in air volume was used to indicate decrease or increase in soil volume over time. All analyses and graphical presentations were conducted in the R environment (R Development Core Team 2008). The spatial modelling component was managed by use of the asreml-r package (Butler *et al.* 2007). The adapt package was employed for the numeric integration of the modelled surfaces.

Stemflow

Stemflow was intercepted using cylindrical-shaped vessels built from thick polyurethane and fitted to the trunks of seven macadamia trees. Each vessel was set 25 mm from the tree trunk, was 175 mm deep and attached approximately 1 m from the ground. The vessels were designed to transfer the stemflow resulting from a rainfall event of 50 mm in a 15 minute period, assuming the tree canopy diameter did not exceed 4 m and that 20% of the intercepted rainfall was stemflow. Stemflow was directed from the vessels into a tipping-bucket flow gauge (Unidata, Australia) with data logged (Starlog, Unidata, Australia) every 15 minutes. Stemflow data was compared with rainfall data recorded by the Alstonville Automatic Weather Station (located 400m from the study area) for the same period.

Results

An average 6.5 mm/m^2/year net soil loss from around the base of the trees occurred in the orchard over 16 months (Figures 1 and 2). Soil loss was gradual and small gullies were observed developing over this time. Preferential flow lines also became visible along tree roots radiating out from the base. Where an orchard contained the standard 312 trees/ha, the calculated soil movement would equate to 3.8 t /ha /year.

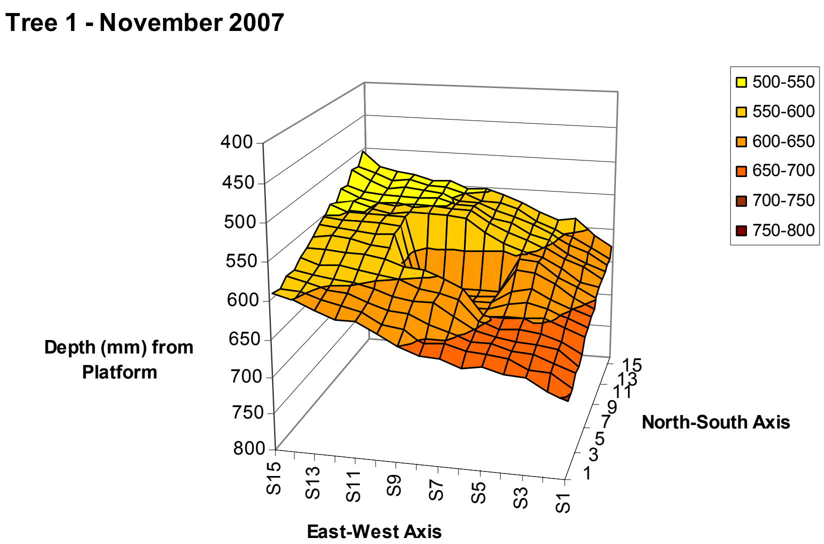

Figure 1. Soil surface topographical map (1.5 x 1.4m) around the base of a 9 year old macadamia tree at the start of monitoring at Alstonville, NSW, Australia.

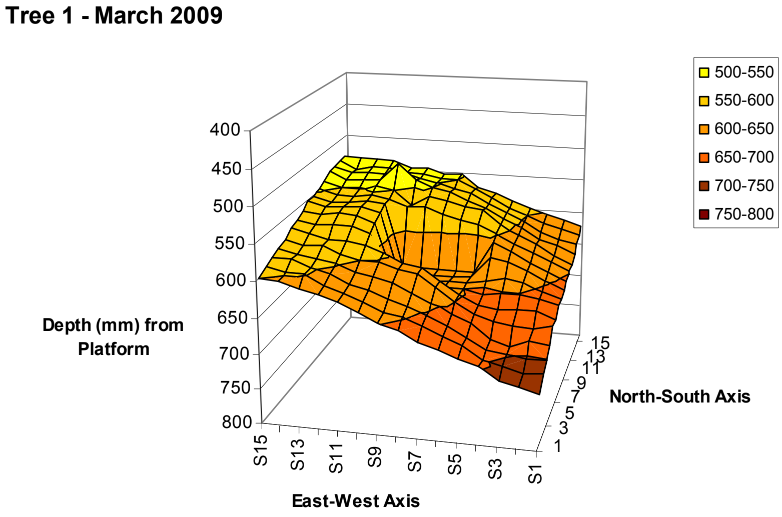

Figure 2. Soil surface topographical map (1.5 x 1.4m) around the base of the same tree from figure 1, 16 months after commencing monitoring at Alstonville, NSW, Australia.

Stemflow volume was highly and positively correlated with rainfall volume (r^2 ranged from 0.83 to 0.99 per month, data not shown). Every month, as daily rainfall increased, the amount of stemflow increased and although the relationship was close to linear, polynomial functions more accurately described the relationship. On 21 May 2009, a major flood event in the region registered 217 mm rainfall in 32 hours. The corresponding average stemflow was 1,100 L for that time. Overall, stemflow as percentage of rainfall captured by each tree increased with increased rainfall up to a point where further rainfall did not generate further stemflow (Figure 3) as the tree reached its capacity. Percentage stemflow varied from 0 to 28% with an overall average stemflow of 7% and a monthly range of 5 to 10%.

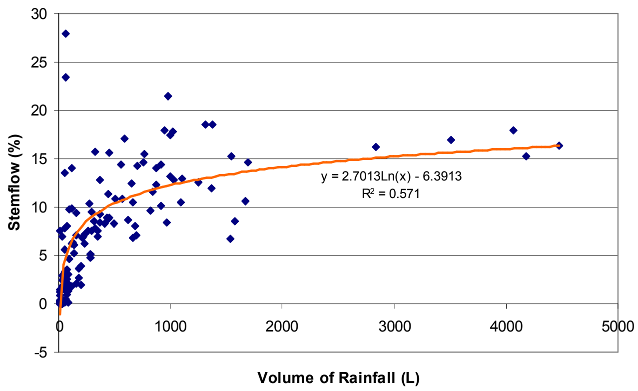

Figure 3. Stemflow as a percentage of rainfall captured by the tree canopy (L/tree/day) for November 2008 to June 2009. A volume of 1000L is equal to 29mm rainfall, and 3000L to 88mm over average canopy area of 36 m^2.

Conclusion

The results of this study indicate that stemflow runoff made a substantial contribution to soil movement away from the base of macadamia trees. We measured 6.5 mm/m^2/year net soil loss from the base of the trees (2.1m^2) which in orchards with typically 312 trees/ha, could equate to soil movement of 3.8 t /ha/yr. The extent of the soil movement was unexpected, although confined to small areas of the entire orchard. Several factors may have accentuated the severity of soil redistribution, including inherently erodible soil type, bare soil management, tree canopy architecture and storm intensity in this region. Soil particles may not have moved far beyond the under tree area, but as they have become detached from the bulk soil, they are at a higher risk of subsequent movement by future erosive events (Rose 1994). The outcomes of this study suggest that management of soil erosion in macadamia orchards should focus on protecting soil within the tree row to reduce the impact of stemflow. Mulches of a suitable size fraction could be used by growers to buffer against stemflow and to also contribute organic matter back into the soil (Cox *et al.* 2004). The industry is now aware of the extent to which stemflow contributes to redistribution of soil and subsequent development of tree root exposure and will explore alternative management practices.

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