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Examination of the consistency of plant traits driving oil yield and quality in short-rotation coppice cultivation of *Eucalyptus polybractea*

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Abstract

The value of eucalyptus oil for medicinal purposes is based largely on its cineole content. The prime commercial species for cineole production in Australia is *Eucalyptus polybractea* (blue mallee). Despite the long history of blue mallee harvesting in Australia, there has been little research on the establishment of plantations of the species or on the efficacy of short-rotation coppice cultivation with respect to the consistency of oil yield and quality from rotation to rotation. This study aims to assess if subsequent coppice oil traits reflect sapling traits and if the coppice oil traits under short-rotation cultivation are consistent from one rotation to the next. A trial plantation was established in a key eucalyptus oil harvesting district in Victoria. Firstly, the oil-related traits of 20 saplings harvested 3.5 years after planting were compared with those of their subsequent coppice harvested after 12 months regrowth. Despite the expected differences in total biomass, the oil-related traits of blue mallee saplings were mostly well reflected in their subsequent coppice. Total above ground biomass and foliar oil concentration were significantly related between saplings and coppice, and cineole proportion showed a Pearson's correlation of 0.93 between harvests. Nevertheless, the mean foliar oil concentration in the coppice was 148 mg g^{-1} dw compared with 107 in the saplings, and the coppice foliage, on average, showed significantly reduced cineole with a mean of 87% in the saplings (maximum of 95.6%) compared to a mean of only 80% in the coppice (maximum of 87.0%). Secondly, the oil traits of 20 coppice plants from one 12-month harvest rotation to the next were compared. Again, total above ground biomass, foliar oil concentration and cineole proportion were significantly related between the harvests, with cineole proportion having a Pearson's correlation of 0.90 between rotations. The coppice between rotations were remarkably consistent in terms of biomass and oil traits and indeed mean coppice cineole yields were 28.6 and 29.7 g in rotations 1 and 2, respectively. The results support the screening of key oil-related traits in saplings for the selection of elite genotypes for plantations, and the use of short-rotation cultivation of the plantations for continued oil harvesting. Furthermore, no relationship was observed between biomass and oil concentration in the blue mallee saplings or coppice, suggesting selection gains in a given key oil trait will not result in losses in another.

Keywords: Eucalyptus oil; Cineole; Coppice; Mallee; Short-rotation forestry

1. Introduction

Eucalyptus oil has been harvested and traded for medicinal, perfumery and industrial uses since 1852 (Doran, 1991). In recent times the pharmaceutical trade has driven the demand for eucalyptus oil, with market prices for pharmaceutical grade eucalyptus oil ranging from USD 4.30–4.40 per kilo in late 2006, with its key constituent, 1,8-cineole (cineole or eucalyptol) priced around USD 5.70 per kilo (cost, insurance and freight; George Uhe Company Inc., 2006). The value of eucalyptus oil for medicinal purposes, and therefore the major determinant of its market price, is based largely on its cineole content, although physical characteristics such as colour, specific gravity and optical rotation may also be important for non-medicinal uses (see Doran, 1991). National and international standards exist which specify the minimum cineole content of pharmaceutical grade eucalyptus oil to be 70% (v/v; Coppen, 2002). These standards also set strict limits on the content of the undesirable eucalyptus oil components phellandrene and isovaleraldehyde which must be negligible (see Warren, 1991). For only a few species of *Eucalyptus* does the crude oil from the primary distillation of leaves readily meet these requirements.

Eucalyptus polybractea (blue mallee) is the prime commercial candidate of these species for a number of reasons. Firstly, the oil extracted from blue mallee foliage generally contains between 80 and 88% cineole (Abbott and Abbott,

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2005), but levels as high as 92% (Brophy et al., 1991) and 93.4% cineole (King et al., 2004) have been recorded. Secondly, blue mallee oil has very low levels of undesirable components with isovaleraldehyde not detected in the species (Brophy et al., 1991; Wang et al., 1997; Wildy et al., 2000b; King et al., 2006b) and only negligible amounts of α-phellandrene (Wang et al., 1997; Wildy et al., 2000b) and β-phellandrene (King et al., 2006b) recorded. Thirdly, blue mallee foliage gives greater oil yields than many other commercial eucalyptus oil producing species with levels as high as 5% fresh weight (Brophy et al., 1991) recorded, and means of 2.12% fw (Wildy et al., 2000b) and 3.64% dry weight (King et al., 2004) observed in leaf-only samples from plantation and wild populations, respectively. Finally, blue mallee is suitable for mechanical harvesting when grown in short-rotation coppice cultivation which vastly increases the potential scale of oil production and therefore reduces the cost (Davis, 1997; Abbott and Abbott, 2005).

Mechanical harvesting is possible because 'mallee' eucalypts are characterized by multiple woody stems that arise from an underground lignotuber (Wildy and Pate, 2002). The lignotuber houses a large store of potential bud-forming sites that enable rapid regeneration of a canopy (coppice) after loss of above ground biomass (Noble, 2001). This trait combined with the long-lived nature of these perennials means that coppice can be harvested over many years on a relatively short-rotation basis (Davis, 1997). In general, blue mallee is harvested on a 1–2-year rotation basis depending on the rate of growth, with some individual blue mallee trees having been continually harvested in this manner for 60 years in New South Wales (Milthorpe et al., 1998) and 100 years in Victoria (Abbott and Abbott, 2005).

Although most of the eucalyptus oil produced in Australia comes from blue mallee, the species is not the main commercial source of cineole-rich eucalyptus oil in the world. Lower production costs particularly in China, and to a lesser extent in Portugal and Spain, have resulted in species with inferior oil and cineole yields to blue mallee such as *Eucalyptus globulus*, *E. smithii* and *E. dives*, being planted and non-mechanically harvested on much larger scales (Warren, 1991; Coppen, 2002). Nevertheless, the overall superiority of blue mallee as a commercial source of cineole-rich eucalyptus oil makes the species an attractive candidate for improved selection strategies and plantation development in Australia. Maximising blue mallee leaf oil yields and establishing plantations of blue mallee have been identified as powerful means of expanding and increasing the profitability of the eucalyptus oil industry in Australia (Barton et al., 1991; Bartle et al., 1996). Moreover, the traditional production areas of natural stands in state forest and public land are diminishing, especially in Victoria where the state government recently introduced severe restrictions to the harvesting of *Eucalyptus* leaves from Crown land (Parliament of Victoria, 2002). Under this legislation, the eucalyptus oil harvesting industry in Victoria has been given several years to move their harvesting operations out of public lands and preferably into plantations. Therefore the establishment of commercial blue mallee plantations has become a necessity.

The yield of cineole-rich oil is determined by a number of factors: the concentration of oil in the leaves, the proportion of cineole in the oil, and the rate at which biomass (particularly leaves) accumulates between successive harvests. Research has shown that leaf oil concentration and biomass production are poorly correlated and that both attributes need to be measured if the highest producing lines are to be selected for a plantation (Grant, 1997; Milthorpe et al., 1998 and see Doran, 2002). Indeed, Milthorpe et al. (1998) proposed that if selection is based solely on leaf oil concentration then reduced oil yield may occur, although contrary to this (King et al., 2006a) recently showed a small but significant positive correlation between foliar oil concentration and growth of blue mallee seedlings.

Biomass production in oil plantations is likely to be strongly influenced by the climatic and edaphic features of a given planting site, and the quality of establishment of plantings (Wildy et al., 2000b). Early plantation establishment obviously requires adequate rainfall or irrigation, and weed control has also been described as a key management task in the first few years of establishment (Department of Primary Industries Victoria, 2002), but evidently little or no fertilizers are required for mallee species (see Wildy et al., 2000a). The influence of environmental factors on plantation yields is less clear. Leaf oil concentration and quality in terms of specific constituents such as cineole are generally regarded as being largely genetically determined, heritable traits (Leach and Whiffin, 1989; Barton et al., 1991; Doran and Matheson, 1994; King et al., 2006a). Indeed oil content can vary considerably when plants of a given species are grown under uniform environmental conditions, arguably due to genetic variation (Doran, 1991). However, the environment in which a particular genotype is grown may also exercise appreciable effects on oil yields (Brooker et al., 1988; Doran and Bell, 1994). Thus the level of phenotypic control of oil yield and quality remains uncertain and few if any clear trends have been established (Koricheva et al., 1998; King et al., 2004).

There has been relatively little research on the basic biology of blue mallee (see recent articles King et al., 2004, 2006a,b). Moreover, little research has been conducted on the establishment of plantations of the species (but see Milthorpe et al., 1994; Wildy et al., 2000a,b; Davis, 2002) or on the efficacy of short-rotation coppice cultivation with respect to the consistency of oil yield or quality from rotation to rotation (but see Milthorpe et al., 1998; Davis, 2002). A study on plantation establishment by (Wildy et al., 2000a,b) on a number of mallee species including blue mallee found a decrease in mean foliar cineole concentrations from 2.5-year-old saplings in December 1995 to the subsequent coppice in December 1996 (summer harvest), but an increase in mean cineole when 3-year-old saplings were harvested in June 1996 and the subsequent coppice harvested June 1997 (winter harvest). Nevertheless, variability in cineole levels was apparently not quantified, so it is not possible to say whether significant changes in cineole concentration were detected between the saplings and subsequent coppice. Moreover, cineole was presented on a leaf fresh weight basis, hence differences in water content may account for the apparent seasonal trends observed. Therefore,