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Competition for water between annual crops and short rotation mallee in dry climate agroforestry: The case for crop segregation rather than integration

Robert A. Sudmeyer*, David J.M. Hall [1]

Department of Agriculture and Food Western Australia, RMB 50, Esperance, WA 6450, Australia

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ABSTRACT

Crop and mallee (*Eucalyptus kochii* subsp. *plenissima* (C.A.Gardner) Brooker and *Eucalyptus horistes* L.A.S. Johnson & K.D. Hill) growth and water use were measured in an alley system from 1999 to 2003. The aims of this study were; to quantify the growth and water use of agricultural crops and mallee belts grown as a short rotation woody crop and to test the hypotheses that a mallee agroforestry system is more productive than annual crop or mallee monocultures, and that managing competition in a mallee agroforestry system by root pruning can increase the productivity of the annual crop component.

Mallee growth was typical of values reported for the Western Australian wheatbelt. Root pruning or harvesting mallees reduced mallee growth and water-use and partitioned more water to annual crops, but didn't increase the overall productivity of the system. As the mallees had exhausted stored soil water and didn't have access to fresh groundwater there was little complementarity in resource use.

Rather than planting mallees in alley configurations (integration) there is a case for block planting (segregation) with longer harvest intervals for the mallees. The results suggest that biological productivity of mallee monocultures harvested on a rotation of five or more years > crop monoculture > mallee agroforestry. Ultimately the relative economic returns from cropping and mallees will determine where they are grown and the degree of integration.

1. Introduction

Agroforestry systems using mallees (*Eucalyptus* species that are multi-stemmed and coppice from a lignotuber) as short rotation woody crop (SRWC) for bioenergy feedstock and CO_2 sequestration in the lignotuber are being actively researched and promoted in Australia [1–5]. The current interest is the culmination of three decades of research. In the early 1980s mallee agroforestry was identified as a way of ameliorating secondary salinity on dryland farms in Western Australia (WA). It was suggested that the wide-scale establishment

* *Corresponding author*. Tel.: +61 8 9083 1129; fax: +61 8 9083 1100.
E-mail addresses: rsudmeyer@agric.wa.gov.au (R.A. Sudmeyer), david.hall@agric.wa.gov.au (D.J.M. Hall).
[1] Tel.: +61 8 9083 1142; fax: +61 8 9083 1100.
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required could be funded by the production of eucalyptus oil [6,7]. By the late 1980s the economic focus had expanded from just producing eucalyptus oil, to the complete utilisation of the above-ground biomass for activated carbon, biofuel, wood fibre and oil [8,9]. Research over the last decade has provided a better understanding of the hydrological impacts and productivity of mallee agroforestry systems [3,5] and development now focuses on growing mallees in two row belts in fully integrated alley systems to produce bioenergy feedstock and for CO_2 sequestration. While around 15,000 ha of mallees have been planted to date, commercial harvesting has been limited.

This changing focus of mallee research has also reflected global concerns about energy security, rising oil prices and climate change that have driven an expansion in the use of biomass to generate power and produce transport fuels [10–12]. Between 2000 and 2010 the global trade in solid biofuels and production of liquid biofuels grew six and five-fold respectively [12,13]. Biofuels now contribute around 3% of global transport energy, with the International Energy Agency predicting this increasing to 27% by 2050 [12].

The rapid increase in demand for biofuels has highlighted concerns about food security associated with direct land use change and biodiversity loss and greenhouse gas emissions associated with indirect land use change [13–17]. Growing woody energy crops such as mallees in agroforestry systems that are designed to complement conventional agriculture and provide a range of environmental services has been identified as a way to address these concerns [2,18]. This has been termed the "intelligent" use of biofuel [19], "multifunctional bioenergy systems" [20] and "integrated food and energy systems" [16,20]. Ideally there is greater resource capture in agroforestry systems and in consequence the productivity of these systems is greater than the productivity of either agricultural or biomass crops grown as monocultures (sole crops) [20–22].

A recent study examining the sustainability of using mallee biomass to produce aviation fuel in Australia concluded that the "direct and indirect land use impacts are not material" [5]. This is somewhat surprising as the authors estimate that supplying just 5% of the Australian Jet Fuel market would remove at least 12,300 km^2 from agricultural production. This is 5100 km^2 directly planted to mallee belts, with tree/crop competition largely eliminating agricultural production from a further 7300 km^2 immediately alongside the belts in what the authors term the 'no crop zone'. Competition would also have a lesser effect on agricultural production on a further 4000–14,500 km^2 depending on rainfall.

The lack of information regarding the productivity and sustainability of integrated food and energy systems has been identified as a constraint to their widespread adoption [17,20,23]. This study examines the productivity of mallee belts grown as a SRWC with a particular focus on resource capture at the tree/crop interface and aims to;

i. quantify the growth and water use of mallee belts and adjacent agricultural crops growing in an alley system,
ii. test the hypothesis that a mallee agroforestry system is more productive than either annual crop or mallee monocultures and
iii. test the hypothesis that managing competition in a mallee agroforestry system by harvesting or root pruning the mallees can increase the productivity of the annual crop component.

This information will be used to better understand mallee/crop interactions and guide the design of mallee agroforestry systems.

2. Methods

2.1. Site

The trial site was located approximately 48 km north–northeast of the town of Esperance in WA (122:3:58 E, −33:26:17 N). Under the Koppen scheme the climate is classified as Temperate with distinctly dry and warm summers (Csa, Csb) [24]. Crops in the area are typically sown in May or early June and mature in mid-late November. Long term (1907–2009) annual rainfall at Scaddan, 30 km to the west, was 416 mm (SILO Patched Point Dataset). Between 1993, when the mallees were planted, and 1999, when the trial began, the average annual rainfall was 370 mm with a range of 245–598 mm. Annual rainfall 4 km to the east of the site averaged 360 mm between 1993 and 1999 (E. and B. Stewart pers. com.).

After the native mallee vegetation was cleared in 1982 and 1983 the land was used for mixed cropping and grazing enterprises. In 1993, the trial site was planted with two row belts of *Eucalyptus kochii* subsp. *plenissima* (C.A. Gardner) Brooker and *E. horistes* L.A.S. Johnson & K.D. Hill. Both species are mallees. Bynre [25] found there was little differentiation between the two species, suggesting they represent a single widespread and variable species. Within the belts the rows were spaced 2.5 m apart with mallees spaced at 1.5 m along the rows. The belts were oriented WNW–ESE separated by alternating 20 m and 10 m wide alleys (Fig. 1). Crop and mallee measurements were made in the alley and belt system with 20 m wide alleys.

The surrounding area is a gently undulating plain with an extensive system of small playa lakes and low sand lunettes. The mallee belts were planted across one of these lunettes. On the lower (western) side of the site the soil is duplex, with 0.3 m of fine sand topsoil and a sharp texture change to clay subsoil, and is classified as a eutrophic hypernatric yellow Sodosol [26]. Moving east the sandy topsoil becomes progressively deeper, and is about 4 m deep at the crest of the lunette. Where the topsoil depth exceeds 0.8 m, the soil is classified as a deep sand or basic arenic bleached-orthic Tenosol [26]. The subsoil clay is saline (EC_e 9.5–11.1 dS m^{-1}) with potentially growth limiting boron (B) concentrations (B extracted with hot $CaCl_2$ 8.5–10.1 mg kg^{-1}) [27]. The density of vertical mallee roots at 1.5 m depth was 166 m^{-2} in deep sand subsoil and 59–83 m^{-2} in clay subsoil [28]. Two groundwater observation wells were installed in July 2001 and found saline groundwater 1.6 m and 3.6 m below the surface, in the duplex and deep sand soils respectively (Fig. 1).