Predicting mallee biomass yield in the Western Australian wheatbelt

Dan Huxtable and John Bartle Department of Environment and Conservation February 2007

The Department of Environment and Conservation (DEC) is working with a range of partners to develop mallee eucalypts as a broad scale crop for the production of low cost biomass feedstock for industrial products and bioenergy (Bartle 2006). This development is motivated by the potential to create a new profitable crop that will improve the environmental performance of wheatbelt agricultural systems. WA wheatbelt farmers were quick to see the potential of mallee and have made a major contribution to the development by planting some 13,000 ha since 1994.

Mallee productivity will be a major determinant of commercial success. Therefore, methods for predicting yields are required to evaluate commercial potential. Such methods use mathematical models to link biomass production to site attributes. There are two broad types of yield models:

- Empirical models: where sufficient data on site attributes and actual growth performance are correlated.
- Process models: where some simplification of actual physical and biological processes is used to predict yield at a specified location.

The first large scale, systematic work on mallee yield commenced in 2000. Several conceptual and practical factors delayed initiation of this work including:

1. There had been no research or cultivation of mallee species on any scale prior to 1994. It took several years before differences in soil/climatic preferences and performance could be recognised. This is not surprising because six species from four groups of mallee were selected as candidates for large scale use. A general understanding of what constituted good performance for each species across the range of sites was necessary to be able to select representative stands for detailed investigation.
2. Development of management techniques took priority over performance measurement. For particular species, it was necessary to develop an understanding of what constituted good management practice before representative, well managed stands could be selected for detailed investigation.
3. Yield over the first several years of growth is strongly influenced by the availability of stored soil water. It is necessary to deplete this initial water storage before sustainable yield can be observed.
4. Mallee has always been planted in belts, often on the contour, to passively capture surface run-off and improve both yield and salinity control. Recently the sensitivity of mallee yield to water supply has become more apparent (Cooper et al 2005). It follows that the high variability of run-off observed in the wheatbelt climate will strongly influence yield over time, further complicating yield estimation.
5. Coppice crop productivity will be strongly influenced by harvest regime factors such as the season and frequency of harvest. Since commercial harvest will occur all year round we must understand harvest regimes and their impact on yield. However, no large scale commercial harvest has yet commenced and no extensive coppiced stands are available to provide research sites.

The main publicly funded projects on mallee biomass production since 2000 have been:

- A Natural Heritage Trust sponsored project commencing in 2000 on the effect of season and frequency of harvest (Carslake and Bartle 2003). This project provided useful empirical data on first and some data on second harvests of mallee (i.e. the second harvest being the first coppice harvest) but it omitted looking at competition effects in the lateral root zone and was subsequently superseded by another project (listed below).

- Dan Wildy commenced a PhD study in 2000 funded by Joint Venture Agroforestry Program (JVAP) to look at the water use physiology of mallee at Kalannie (Wildy et al 2003 and 2004). His work included detailed investigation of coppicing in *Eucalyptus kochii* spp *plenissima*. This study is the current major source of physiological data for process modelling.
- The CRC for Plant-based Management of Dryland Salinity commenced several projects on mallee water use in the period 2002-04 and this will soon provide a larger body of data for process models.
- JVAP funded a study to predict nutrient removal in harvest of mallee biomass by Tim Grove from CSIRO. This has been submitted to JVAP for publication.
- In 2005 JVAP, Avon Catchment Council, DEC, Department of Agriculture and Food, Oil Mallee Association and CRC for Plant-based Management of Dryland Salinity commenced a second study to look at season and frequency of harvest. The project has established 19 representative mallee belt sites across a range of species, soils and climates with the objectives to:
    - Measure the impact of two seasons and two frequencies of harvest on mallee yield.
    - Measure competition by the lateral roots of mallee with the adjacent annual crop or pasture.
    - Test the efficacy of root ripping to manage competition.
    - Provide a large empirical dataset for validation of process models.

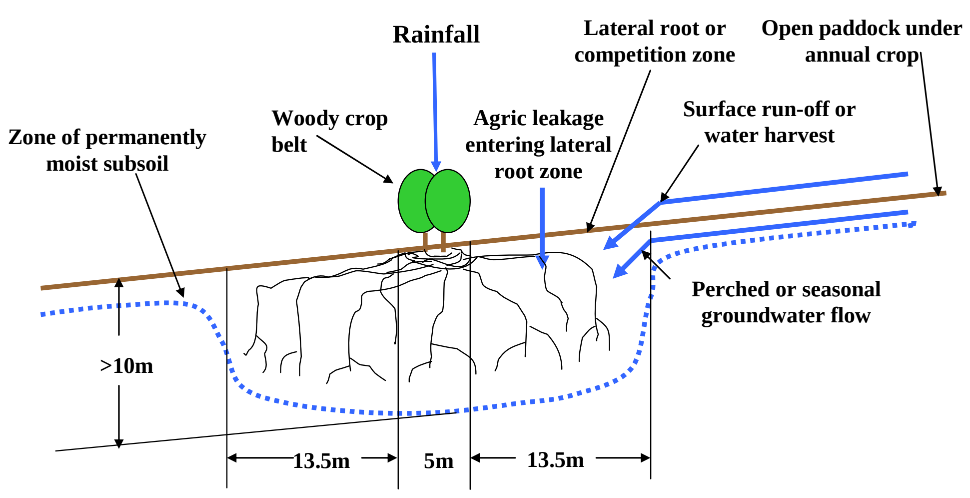
  The project will follow some 7,131 individual mallees over several harvest cycles (12-15 years) to provide hard data on long term sustainable yield in the Narrogin-Toolibin and Kalannie districts. At this stage the project is funded for the first 5 years. The first full set of harvests of the seedling crop at ages 7 to 11 years have been completed. Biomass yields range from 5-10 dry tonnes/ha/year. Progress results will be made available at the completion of each harvest cycle, but final results will not be available for more than a decade.

Cooper et al (2005) developed a combined process and economic model using results of mallee water use efficiency (WUE) and water availability from Wildy et al 2004. Wildy et al (2004) determined that mallee has a WUE to be between 1.2 and 1.8 grams/litre (conversion for available water to above-ground biomass) in their study. The Cooper model applied this conversion to estimates of the amount of water available to mallee belts to derive biomass production, i.e.

available water x water use efficiency = biomass production

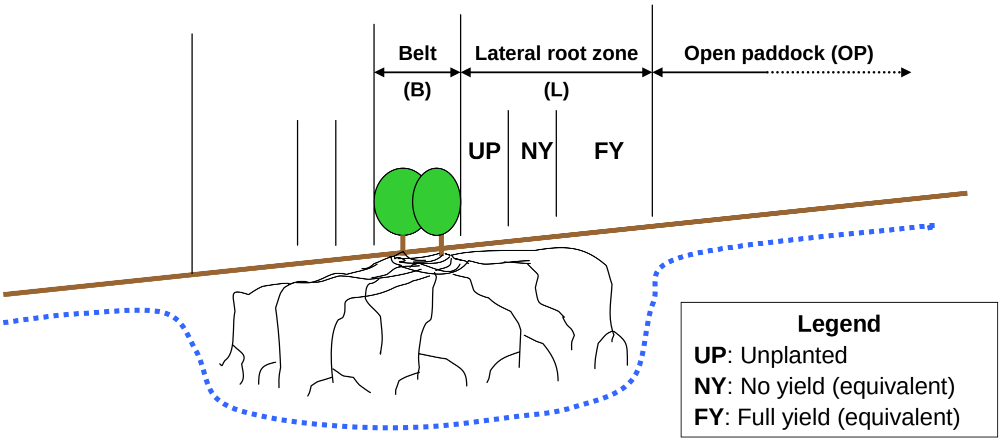
Fig 1 shows all potential sources of water supply to a mallee belt.

Figure 1: Water capture by woody crop belts



On suitable soil types mallee belts generate a wide, deep zone of soil water deficit creating conditions for efficient capture of incoming water (Robinson et al 2006, Sudmeyer and Goodreid in press). Fig 2 shows the 5 water source zones used in the Cooper model to estimate potential water supply to a mallee belt. The Cooper model explicitly links biomass production to available water and limits the area to be planted to that which will be economically competitive with conventional agriculture.

Figure 2: Cooper model water source zones



In this short review we have adapted the Cooper model to make predictions of sustainable mallee yields based only on the availability of water from rainfall incident on the belt and lateral root zone, i.e. sources B, UP, NY and FY in Fig 2. The amount of water coming from these 4 sources is comparatively easy to estimate and forms a larger and more consistent water supply than OP. The latter requires run-off generating rainfall events, the amount is more difficult to estimate and its potential is not included in this estimate of available water. This method should provide a conservative estimate of the mean annual increase in mallee biomass. All assumptions about belt configuration and water availability come from Cooper et al (2005).

Table 1 shows estimates of the proportion of incident rainfall that is likely to become available from each of the four zones of a mallee belt.

Table 1: Proportion of rainfall available by zone within a mallee belt

Rainfall in mm/yr	B	UP	NY	FY
350	44%	51%	51%	10%
450	54%	62%	62%	10%
550	61%	70%	70%	10%

Table 2 converts these proportions of rainfall to quantities of available water in megalitres/ha corrected for the relative area of each zone.

Table 2: Amount of available water from each zone in megalitres/ha/yr

Rainfall in mm/yr	B	UP	NY	FY	Total
350	1.5	1.8	0.8	1.4	5.5
450	2.4	2.8	1.2	1.8	8.3
550	3.3	3.8	1.7	2.2	11.1

Table 3 converts the water in Table 2 to dry biomass (WUE = 1.5 g/litre) and expresses this in terms of tonnes/ha of belt area (B), even though the belt captures water from a greater area than the belt alone.

Table 3: Amount of available water converted to biomass in t/ha/yr

Rainfall mm/yr	Available water in Ml/ha/yr	Above-ground biomass t/ha/yr	Total biomass t/ha/yr*
350	5.46	8.20	11.71
450	8.25	12.37	17.67
550	11.03	16.55	23.64

* Assumes that above ground-biomass is 70% of total biomass

This estimate of annual biomass increment is process based and generates above ground biomass estimates that are more than 50% higher than that observed in the empirical first harvest results (expressed as an annual increment) from the mallee harvest regime projects mentioned above. These two results are derived independently which gives some confidence that they extend over the right range. However, the size of the difference between the two is too great for practical purposes. The capacity to refine and validate models will be enhanced by results from current water use work by the CRC PBMDS and the continuing empirical research.

In the meantime several factors that may contribute to the difference can be proposed:

- The harvest results were for 7-11 year old mallee that had not been previously harvested. They are therefore not representative of long term sustainable biomass production because:
    - The first harvest has grown through the slow initial seedling and root system establishment stages whereas the coppicing cycle is based on an established root system. This suggests that a first harvest assessment of biomass production will under-estimate the sustainable level of above-ground production from regular coppice harvests.
    - The seedling crop has access to stored water that accumulated in the soil profile during the previous period of agricultural use of the land. Robinson et al (2006) and Sudmeyer and Goodreid (in press) showed that this may be a substantial amount, i.e. between 1300 and 1800 mm to a depth of 10 m. In contrast to the previous point this suggests that first harvest yield will be higher than could be sustained permanently.
- The model estimates long term sustainable yield based on a set of plausible assumptions. Further investigation of mallee water use and growth may show that some assumptions should be modified. The model also assumes average rainfall inputs. Rainfall data from the locations where the empirical data were collected could be assessed to see if this might explain some of the observed difference.
- The potential supply of water from the OP source was not included in the Cooper model estimates. This indicates that the model predictions and the empirical data are even further apart.
- The model shows that extra water from the OP zone, or from adjacent paddocks with no planted trees, could increase biomass productivity, thereby improving commercial viability and environmental benefit.

This brief review of current unfinished research suggests that the mallee growth increment will lie in the range 5-15 dry tonnes/ha/yr across the rainfall range 350-550mm/yr. The Cooper model economic analysis shows that this range of yield would generally fall short of being competitive with conventional agriculture based on economics alone.

It is therefore important that mallee R&D continue to focus on increasing productivity and revenue. The new Future Farm Industries CRC plans to investigate the potential for productivity gains from better designed planting configuration and water harvest systems that more efficiently capture surface and shallow subsurface run-off. DEC has made substantial investment in genetic improvement and seed production and this should be reflected in greater revenue particularly by increasing oil content. There is also an increasing likelihood of revenue from carbon sequestration. Finally, there are many other benefits from mallees, both on-farm and off-farm, that are difficult to measure as revenue but which can help improve mallee competitiveness.

Acknowledgements

The work reported here has involved several collaborators most notably Don Cooper, Graeme Olsen and Rob Sudmeyer, with funding and assistance from several organisations, including the Natural Heritage Trust, Joint Venture Agroforestry Program, Avon Catchment Council, CRC for Plant-based Management of Dryland Salinity and the Department of Agriculture and Food. The Oil Mallee Association has helped with introductions to many farmers who willingly provided experiment sites.

References

Bartle JR (2006). New non-food crops and industries for Australian dryland agriculture. Proceedings, Green Processing 2006, Third International Conference on the Sustainable Processing of Minerals, Newcastle NSW, Australasian Institute of Mining and Metallurgy. Pp 63-68.

Carslake J and Bartle JR (2003). Demonstration of biomass productivity and carbon sequestration in oil mallee. Natural Heritage Trust Project 003127 final report.

Cooper, Olsen and Bartle (2005). Capture of agricultural surplus water determines the productivity and scale of new low-rainfall woody crop industries. Australian Journal Experimental Agriculture, 45/11 pp 1369-1388.

Robinson N, Harper RJ, Smettem KRJ (2006). Soil water depletion by Eucalyptus spp integrated into dryland agricultural systems. Plant and Soil. 286:141-151

Sudmeyer RA and Goodreid A (in press). Short rotation woody crops: a prospective method for phytoremediation of agricultural land at risk of salinisation in southern Australia. Ecological Engineering.

Wildy, D. T., Pate, J. S. and Bartle, J. R. (2003) *Silviculture and water use of short-rotation mallee eucalypts. A report to the RIRDC/Land & Water Australia/FWPRDC/MDBC Joint Venture Agroforestry Program.* Publication number 03/033, Rural Industries Research and Development Corporation, Canberra, Australian Capital Territory. 55 p. http://www.rirdc.gov.au/reports/AFT/03-033.pdf

Wildy, D. T., Pate, J. S. and Sefcik, L. (2004) 'Water use efficiency of a mallee eucalypt growing naturally and in short-rotation coppice cultivation', *Plant and Soil,* **262,** 111-128.