DEVELOPMENT OF MALLEE EUCALYPTS AS A WOODY BIOMASS CROP IN SEMI-ARID AUSTRALIA

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SUMMARY

Australian agriculture in the 300mm to 600mm mean annual rainfall zone is at a turning point. Known as the "wheatbelt", this region contains the bulk of Australia's arable land. Wide spread replacement of natural vegetation with short lived, winter grown annual crops for agriculture over the last 120 years.

These cultures have a reduced capacity for transpiration and direct interception of rainfall. Gradual accumulation of water in the deep subsoil profile results in rising ground water. The rising groundwater intercepts and mobilises previously stable deposits of salt to the surface resulting in the degradation or loss of arable land. The problem is accentuated by a land profile which is relatively flat and by poor drainage in the soil.

Currently in Australia some 6 million ha of land are mapped to be at risk or affected by dryland salinity. By 2050 it is estimated that the area of regions with high risk may triple. About 75% of the area at risk of dryland salinity in Australia occurs in Western Australia, vast areas of the southwest region have a high potential of developing salinity from shallow water tables and this is predicted to rise to 9 million ha by 2050.

Mitigation of the problem is recognized as requiring extensive change in agricultural practice. Primary management tools will include deep drainage and establishment of deep rooted woody perennials. One interesting alternative is the development of mallee eucalypts as extensive woody crops for biomass production, integrated into crop or pasture systems.

Key words: Eucalyptus, mallee, integrated systems, semiarid zones.

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DESARROLLO DE EUCALIPTOS *MALLE* PARA LA OBTENCIÓN DE BIOMASA LEÑOSA EN ZONAS SEMIARIDAS DE AUSTRALIA

RESUMEN

La agricultura en las zonas semiáridas de Australia está encontrando crecientes problemas. Grandes extensiones de terrenos entre los 300 y 600 mm de precipitación anual, conocidas como el cinturón de trigo y en las que se encuentra una parte importante de los suelos arables del país, han sufrido durante los últimos 120 años el reemplazo de la vegetación natural por cultivos agrícolas anuales.

Estos cultivos tienen una menor capacidad de transpiración y también de intercepción directa de las precipitaciones. Gran parte del agua de las lluvias escapa en profundidad del alcance de sus raíces y se produce una gradual acumulación de agua en el subsuelo. Las napas freáticas empiezan a subir y movilizan depósitos salinos, antes estables, hacia la superficie. Se degrada o se pierde de este modo tierra arable, situación que se ve agravada por condiciones de topografía plana y pobre drenaje de los suelos.

Actualmente unos 6 millones de hectáreas están afectadas o en riesgo de ser afectadas por esta salinidad en zonas semiáridas y se estima que para el año 2050 el área en serio riesgo puede verse triplicada. Tres cuartas partes del área de riesgo se encuentra en Western Australia, grandes áreas tienen el potencial de desarrollar salinidad desde napas poco profundas y se estima que para el año 2050 unos 9 millones de hectáreas podrían presentar este problema.

La mitigación del problema requiere de importantes cambios en las prácticas agrícolas y las primeras herramientas de manejo de manejo disponibles son el uso de drenajes profundos y el establecimiento de cultivos perennes de raíces profundas. Una interesante alternativa para esto es el desarrollo de cultivos extensivos de eucaliptos *mallee* (especies del género *Eucalyptus* de carácter más bien arbustivo, de múltiple fuste y buena capacidad de retoñación), para la producción de biomasa para diferentes usos, combinados con cultivos agrícolas o praderas.

Palabras claves: Eucaliptos, *malle*, sistemas integrados, zonas semiáridas

INTRODUCTION

Australian agriculture in the 300mm to 600mm mean annual rainfall zone is at a turning point. Known as the "wheatbelt", this region contains the bulk of Australia's arable land. Projected drying trends as a result of global warming (Hennesy *et al.*, 2007) combined with encroaching dryland salinity have brought unprecedented pressures to bear on traditional agriculture.

Wide spread replacement of natural vegetation with short lived, winter grown annual crops for agriculture over the last 120 years has lead to reduced capacity for transpiration and direct interception of rainfall. Between 1% and 29% of rainfall escapes below the root zone of short rooted annual crops and pastures to deep drainage, depending on annual rainfall, and soil type. By contrast, deep water drainage under native vegetation ranges from less than 0.2% up to 1.6% (Asseng *et al.*, 2001).

Gradual accumulation of water in the deep subsoil profile (known as recharge) results in rising ground water. Eventually the rising groundwater intercepts and mobilises previously stable deposits of salt in the soil profile. Where the water table intersects the surface, saline water is discharged into surface soils, streams and river systems resulting in the degradation or loss of arable land (George *et al.*, 1997). The problem is accentuated by a land profile which is relatively flat with broad shallow valleys and poor drainage. As a result, large areas can be affected.

Currently in Australia some 5.7 million ha of land are mapped to be at risk or affected by dryland salinity. By 2050 it is estimated that the area of regions with high risk may triple. In addition, infrastructure of some 200 towns is threatened and up to 20 000 km of streams could be significantly affected by salinity by 2050 (Australian Dryland Salinity Assessment, 2000). About 75% of the area at risk of dryland salinity in Australia occurs in Western Australia. An estimated 4.3 million ha (16%) of the southwest region have a high potential of developing salinity from shallow water tables and this is predicted to rise to 8.8 million ha (33%) by 2050. Mitigation of the problem is recognized as requiring extensive change in agricultural practice (Clarke *et al.*, 2002). Primary management tools will include deep drainage (Ali *et al.*, 2004) and establishment of deep rooted woody perennials (Pannell *et al.*, 2004).

Figure 1
DRYLAND SALINITY WESTERN AUSTRALIA

The challenge is to develop economically attractive woody biomass crops which can be integrated into existing agricultural systems on a large scale (Bathgate and Pannell, 2002).

At present tagasaste (*Chamaecytisus palmensis* (H.Christ) F.A.Bisby & K.W.Nicholls) is the only woody perennial profitably integrated into farm systems, however its use is restricted to deep infertile soils with poor water holding capacity. New woody perennial crops are needed to make it possible for extensive use of woody crops integrated into crop or pasture systems (Pannell *et al.*, 2004).

Evaluation of prospective tree crops in the early 1990's pointed to mallee eucalypts as having the highest potential for commercial development (Bartle and Shea, 2002). The existence of several well adapted species to the region combined with drought tolerance, vigorous coppicing ability and established history of commercial utilisation for eucalyptus oil suggested good potential for success.

Mallee development commenced in 1992 with the screening of populations of *Eucalyptus polybractea* and *E. kochii* subsp. *borealis* for high leaf cineole content. Resource establishment commenced in 1994 at 6 regional centers selected to represent the full range of wheat belt conditions from the northern wheat belt to the southeast. To date some 12 000 ha of mallee have been established with a view to building a resource for potential industry.

PRODUCTS

It was always recognized that no single product will generate sufficient revenue to drive a mallee industry (Bartle, 2006). Large scale viability of the industry requires the utilization of the entire tree (Bartle and Shea, 2002) to produce diverse products such as panel boards, charcoal, activated carbon, renewable energy and chemical extracts such as eucalyptus oil from the leaves.

The raw chipped biomass consists of wood, leaf, twig and bark fractions. The challenge is to maximize the value of each. Potential products which may be derived from the chipped mallee biomass fractions are outlined in table 1.

TABLE 1
POTENTIAL PRODUCTS DERIVED FROM CHIPPED MALLEE BIOMASS

Biomass Fraction	**Potential Products**
Large wood fraction	Wood panels
	Activated Carbon
	Charcoal
	Bioenergy including electricity and liquid fuels
Twig and bark fraction	Charcoal
	Bioenergy including electricity and liquid fuels
Leaf Fraction	Chemical extracts e.g. cineole, phloroglucinols
	Charcoal
	Bioenergy including electricity and liquid fuels

Additional product value may be derived from environmental services such as carbon sequestration of below ground biomass, biodiversity protection and stock shelter.

Wu *et al.* (In press) studied the overall balance of mallee biomass production using a model assuming five years until first harvest followed by fifteen coppice cycles of three years. They considered all energy inputs from the nursery through to establishment in the field, harvest and delivery to the factory gate. They found that the ratio of energy outputs and total non-renewable energy inputs was 41.7 with an energy productivity of 206.3 GJ/(ha year). This compared favorably with the energy ratio of 7 and an energy productivity of less than 40 GJ/(ha year) achieved by other energy crops such as canola grown in Australia. This makes mallee an attractive crop for production of biofuels.

PROCESSING

Efficient conversion of raw biomass into useful commodities is most likely to be achieved using integrated processing i.e. the biorefinery concept (Ragauskas, 2006). Integrated processing enables efficient partitioning and direction of the biomass fractions into the most economically viable products. Enecon Pty Ltd. (2001) conducted a commercial feasibility study for the integrated production of activated carbon, eucalyptus oil and electricity from chipped mallee biomass. Based on economic modeling at the time, that study indicated that the concept should be financially viable for the investors in the integrated processing plant as well as providing sufficient economic returns to farmers and others to justify planting, harvesting and transporting the chipped product to the factory.

Following the feasibility study a 20% scale demonstration plant was constructed at Narrogin by the stated owned Verve Energy Pty Ltd in Western Australia and successfully trialed during 2006. The trial demonstrated that integrated processing to produce activated carbon, eucalyptus oil and electricity was a viable process (Verve Energy, 2006). Later economic modeling work by Cooper *et al.* (2005) showed that the potential scale of biomass crops and therefore regional capacity to support an industry such as the integrated mallee processing plant at Narrogin, was highly dependant on biomass prices, water availability and the rate of conversion of water to biomass.

Figure 2
DEMOMSTRATION PLANTA AT NARROGIN WESTERN AUSTRALIA

ECONOMICS

In order for mallee plantings to be adopted by farmers at a scale large enough to influence salinity and support an industry, they need to generate an annual return comparable to that of existing agriculture. Using an adaptation of the "Imagine" model of Cooper *et al.* (2005) and incorporating current data on growth, value of biomass fractions and improved estimation of harvesting costs and competition effects with adjacent crops, Huxtable *et al.* (2007) estimated that mallee would return an annual loss of about $47.60 per effective hectare. The Equivalent Annual Return (EAR) per effective hectare in the target farming zone for agricultural crops was calculated as $66.80. Further sensitivity analysis indicated that the combined effects of optimization of coppice cycle length, improvement of growth by means of site selection and active harvest of water, a reduction in establishment costs, attainment of environmental service payments such as a carbon sequestration, reduction of harvest costs and achieving a higher price for biomass would all contribute to lifting profitability of mallee to a level competitive with existing agricultural crops.

SILVICULTURE

Effective integration of mallee into existing agricultural regimes requires careful planning with regard to soil types and potential to capture surplus water. The most common layout for mallee crops is in the so called alley system. Mallee's are planted in widely separated belts with conventional annual crops and pasture being grown in the alleys between the belts. The distance between mallee belts may range from 80 to 100 meters and is designed to allow easy access for farm machinery whilst maximizing potential for water runoff which may be captured by mallee belts.

Figure 3
MALLE EUCALYPT ROWS

Current recommended composition of a mallee belt consists of two rows of trees spaced at 2 m apart. Within rows trees should also be established at 2 m spacing. The objective with this configuration is to maximize the large woody component of the trees by maximizing "edge effects". Belts of trees with more than two rows often exhibit strong competition effects with the more vigorous edge trees suppressing those trees located on internal rows.

HARVESTING

Efficiency of harvesting is crucial to the success of the mallee industry. Wu *et al,* (In press) found that some 80% of the energy input in production of mallee biomass was due to harvesting operations. Similarly, economic analysis suggests that the supply chain delivering biomass to the factory gate must be able to harvest, chip and transport mallee biomass up to 100 km at a cost of AUS $ 15 per tonne or less (Giles and Harris, 2003).

Size of the mallee trees at harvest is important in maximizing efficiency of harvest and economic returns. If the trees are too small then the cost of harvest per tonne of biomass will rise and the proportion of chip derived from the large woody fraction will be diminished relative to the lower value bark and twig fraction. The higher wood component of older and bigger trees is therefore more desirable for both efficiency of harvest and economic return from the chipped biomass

It is anticipated that first harvest will be at about 5 to 7 years depending on water availability. Subsequent coppice cycles may range from 3 – 5 years, again depending on water availability.

A commercially available woody biomass harvester is not yet available and the Department of Environment and Conservation (DEC) has been developing a prototype over the last 10 years. Significant further investment is required to produce a commercially operational unit.

TREE BREEDING

The first mallee progeny trials of *Eucalyptus polybractea* and *Eucalyptus kochii subsp. borealis* were established in 1993 using seed from high cineole yielding parent trees. Over the next 8 years the mallee breeding program was expanded to include 4 main species and including two subspecies within the *E. loxophleba* group and three within the *E. kochii* group (Table 2).

Selection is conducted on two traits, leaf cineole concentration and whole tree biomass. Early economic modelling indicated that gains in cineole were more profitable than biomass, hence selection indices are weighted more heavily towards cineole production. Heritability of leaf cineole concentration is usually high and ranges from about $h^2=0.2$ to over 0.6. Currently the program has some 50 trials, many of which have been thinned to form seedling seed orchards. Genetic gain trials were established in 2006 and 2007 to measure realised gain. Clonal seed orchards are being developed to maximise gains from the program and enable greater flexibility in the kind of tree that is produced.

Table 2
SPECIES AND SUBSPECIES
IN THE DEC MALLEE BREEDING PROGRAM

Species and Subspecies
Eucalyptus polybractea
Eucalyptus loxophleba subsp. lissophloia
Eucalyptus loxophleba subsp. gratiae
Eucalyptus kochii subsp. borealis
Eucalyptus kochii subsp. kochii
Eucalyptus kochii subsp. plenissima
Eucalyptus angustissima

CONCLUSIONS

Developing a new industry based on woody perennials presents challenges on many fronts. Nevertheless there is good potential to produce energy from mallee with greater efficiency than other bioenergy crop options. Similarly, development of integrated processing technologies opens up new possibilities for efficient use of biomass fractions, thereby maximising the price which may be attained for biomass. Additionally, mallee plantations confer considerable environmental benefits to the wheatbelt including salinity management, carbon sequestration, biodiversity protection as well as rural sector diversification.

DEC and the Future Farm Industries CRC are actively working towards attaining viable growth rates, development of systems of active water harvest and development of a low cost harvest and supply chain. Further opportunity exists for refinement of biomass processing technologies and exploration of markets for mallee derived products.

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