Ecological and productivity potential of native woody species in Australian cropping systems

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Abstract

Herbaceous perennials, especially lucerne, may be effective in dewatering the soil to mitigate salinisation, but may be limited in their ability to improve soil structure and abate greenhouse gas emissions. A cropping landscape consisting of a mosaic of herbaceous crops and woody perennials is proposed as a means of getting approximately 20% of the landscape under permanent vegetation cover to impart hydrological control and also to enhance biodiversity values. We propose that in phase farming systems, woody perennials be used as an alternative to lucerne, because of greater dewatering benefits with native woody species than with lucerne. We discuss how net greenhouse gas abatement of actively growing woody species could be much less than that of mature lucerne. Arguments against inclusion of woody species in cropping systems often centre on loss of potential income during their growth phase. Careful management of species mix, future environmental service subsidies, and opportunities in emergent bio-energy industries may help growers obtain economic returns from short-phases of native woody species.

Key Words

woody perennials, lucerne, land degradation, greenhouse gases, salinity, biodiversity

Introduction

Land degradation is the major environmental challenge facing broadacre cropping in southern Australia and includes dryland salinity and soil structural decline, emission of greenhouse gases and loss of biodiversity. These adverse processes tend to co-exist in the same landscapes, since they are all largely associated with replacement of the original native vegetation with ‘exotic’ annual crops (1). In addressing salinity, attention is increasingly being focussed on re-establishing perennial vegetation to extend the duration of the use of soil water by plants. Also, the frequency of tillage operations in farming systems needs to be minimised to conserve soil carbon and prevent soil structural decline.

Numerous studies have demonstrated effective control of the water balance with lucerne (*Medicago sativa* L.) through reduced drainage beneath the rooting depth (1, 2). Lucerne may behave as a seasonal crop when its growth is limited during extended dry summers and by its partial to complete dormancy in winter. These constraints may limit its capacity to hydrologically mimic the woody and grassy native vegetation formerly dominant in southern Australia. It is also doubtful whether lucerne can ameliorate soil structural degradation and abate greenhouse gas emission to the same degree as native woody species. In this paper, we briefly discuss the potential of short-phases of native woody species in rotation with cereal crops using selected examples associated with salinity, greenhouse gas abatement and loss of biodiversity.

Land degradation

Salinity

Development of dryland salinity is associated with an imbalance between rainfall and plant water-use, leading to increased accessions to the watertable. Perennials such as lucerne ensure continued use of soil water in summer resulting in an increased capacity to store more of the rainfall within the rooting depth of most seasonal crops during winter. It is, however, possible to achieve greater dewatering of soil with evergreen native woody species because their higher rates of water-use through autumn to early winter creates a greater soil capacity to store winter rainfall than is possible with lucerne. This was demonstrated a study at Rutherglen (36? 08’S, 146? 28’E) in south-eastern Australia (3). This study found that a 3 year-old mixed stand of acacia (*Acacia melanoxylon*, *A. dealbata,* and *A. pravissima*), eucalypts (*Eucalyptus botryoides, E. camaldulensis,* and *E. campara*) and casuarina (*Casuarina cunninghamiana*) used more soil water than lucerne over an 18-month period. The woody species created a soil water-storage buffer of 248 mm, which was 16% larger than that formed under lucerne (213 mm). This was despite the soil being only marginally drier at any depth under the woody species than under lucerne (Figure 1), as the total difference in water content over the 2.6 m depth was significantly less in the woody species soil. In contrast, the soil under annual crops was close to field capacity below a depth of 1 m. Simulation studies (4) showed that recharge to ground water can be prevented within 4 years with woody species, while resumption of recharge could be delayed for up to 10 years after the removal of the trees.

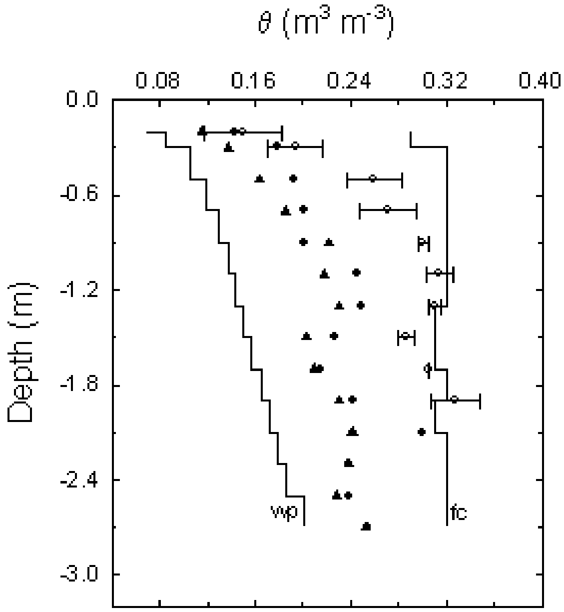

Figure 1. Distribution of soil water content under woody species (triangles), lucerne (black circles) and annual crop rotations (open circles) on 7 May 1997 at Rutherglen (3). Nominal water contents at field capacity (fc) and wilting point (wp) are also shown. The woody species and lucerne were planted in September 1993.

Soil structure

Water-use efficiency of winter crops is lower on duplex soils, largely because of the strong textural contrast between the A and B horizons (5) and the dense and impermeable nature of the B horizon. The subsoil is now largely devoid of macropores because few roots now penetrate this horizon and because the effects of the original deep roots of the native species had long been long lost. Penetration of these subsoils by the roots of annual crops and pastures is, therefore, constrained by their low macroporosity, and this often results in low yields. Yields on most of these soils generally increase significantly with depth of soil loosening (6, 7) (Figure 2).

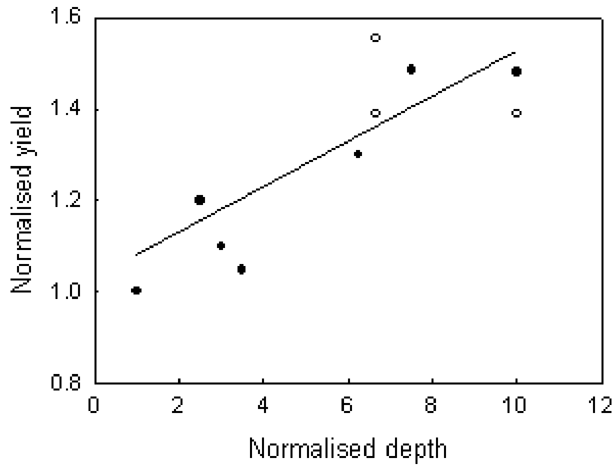

Figure 2. Normalised productivity in response to normalised depths of tillage for grain yield in wheat (closed symbols) and dry matter production in perennial ryegrass pasture (open symbols). Data for wheat from Schmidt and Bedford (6) and for pasture from Olsson *et al*. (7). Fitted line: $y = 0.05x + 1.03$, $r^2 = 0.62$.

The routine use of deep tillage is deterred by its high energy cost, as well as the loss of organic carbon, causing eventual deterioration of soil structure. It is feasible, however, to restore the permeability of these dense subsoils with the roots of plant species capable of penetrating them, to create pores following their death and decomposition. Following generations of roots use these biopores to explore a greater volume of soil and achieve enhanced water uptake (8). Perennial species with thick roots are noted to be effective in penetrating dense layers and creating biopores (8). It is not known if lucerne, despite its perenniality, can create large enough pores to mimic native plants because of its relatively thin roots and semi-seasonal growth in many Australian environments.

A study on soil with an underlying claypan showed that unlike the thick roots of soybean (*Glycine max* L.) and maize (*Zea mays* L.), lucerne roots failed to penetrate the dense layer and so did not create significant numbers of pores (9). Lucerne was found to create pores only when the soil was deep ripped and treated with gypsum (10). This was in contrast to the study with woody species that showed they were effective in opening up a dense subsoil (11). Two years after their removal, the number of large pores found in the subsoil of a redbrown earth was almost twice that found under annual crop rotations (Table 1). No yield increases were observed for the first crop after the woody species due to the dry soil profile. This water deficit was gradually overcome during the following seasons with the pre-sowing soil water content after woody species reaching parity with soil under continuous annual crops by the third season. The yield of the third crop after woody species was 16% greater than that in the continuous cropping sequence (3).

Table 1. Selected structural and chemical characteristics of the subsoil under woody species and continuous annual crops measured in February 2000 by Yunusa *et al*. (11).

Soil variable	Annual crops	Woody species	s.e.d.†
Number of pores (> 1.0 mm) m^{-2}	352	679	226.4*
Estimated air-filled porosity (%)	15.1	19.7	na

Estimated hydraulic conductivity (mm/day)	133	531	na
Total C (%) in top 0.1m of soil	1.11	1.58	0.142**
Mineral N (kg/ha) in top 0.1m of soil	12.3	27.5	4.72**

† difference between treatment means significant at *P< 0.001*(**) or *P<0.01* (**); na,, not applicable

Global warming potential

Global warming potential (GWP) is the net contribution of greenhouse gases measured in equivalents of CO_2. Limited work has been undertaken on greenhouse gas emissions from vegetation systems in Australia, but studies elsewhere have showed that herbaceous species are not as effective as woody species in abating these gases. For instance, Robertson and colleagues (12) found that fluxes of nitrous oxide (N_2O) were largely similar for lucerne and annual crops (3.5–6.5 g/ha.day). These were much larger than those observed from woody species in pure stands or in mixed communities (0.6 – 1.5 g/ha.day) (12). Woody species were also able to oxidise greater amounts of methane (CH_4), ranging from 6.2 g/ha.day in mid-successional communities of woody species (6-10 years) to a maximum of 9.5 g/ha.day in late successional communities (12). High N_2O fluxes are often associated with high levels of soil N caused by applied fertilisers, and the management systems and crop types used. Under woody perennials, fluxes of N_2O and CH_4 are likely to be low because of no tillage and conservative N cycling which maintains low levels of soil nitrate (12).

A positive or negative GWP arises from net CO_2 equivalents as changes in soil organic matter, greenhouse gas emissions, nitrogen fertiliser inputs, application of lime and fuel requirements (Table 2). The major benefit of woody species will derive from low input levels and energy requirements compared with annual crops. Although lucerne has shown a capacity to store large amounts of soil C, these gains will be largely offset by CO_2 released from lime and from N_2O emissions (12). Net primary production (NPP) per annum for eucalypts in cropping areas with an annual rainfall of 350 mm ranges from 15 to 26 t/ha after 5 years (12). Annual cropping systems are unlikely to sequester enough CO_2 to match the cumulative effect of early-mid successional communities of mixed woody species, and offset the GWP of N_2O production (several times that of CO_2 depending on the forecast period). Woody species have potential for the lowest GWP due to a high rate of C storage, the reduced need for tillage and fuel, and low rates of N_2O production due to low levels of soil inorganic nitrogen. However, the initially high rate of C storage in the soil is likely to decline once full canopy cover is achieved after about six years.

Table 2. The relative global warming potential (g/m^2.yr) for different land uses from Robertson *et al*. (12). Negative values indicate a global warming mitigation potential.

Land-use types	Soil C	N fertiliser	Lime	Fuels (diesel)	N2O	CH4	Net GWP
Conventional cropping[1]	0	27	23	16	52	-4	114
5-year old lucerne	-161	0	80	8	59	-6	-20
Early successional[2]	-220	0	0	0	15	-6	-211
Mid-successional[3]	-32	0	0	0	16	-15	-31

Late sessional[4]	0	0	0	0	21	-25	-4

[1]soybean-maize rotation, [2]not used for agriculture for 11 years, [3]abandoned for 50 years, [4]forest >100 years

Biodiversity

With the loss of over 95% of the native vegetation in most cropping regions, there has been a major decline of native biodiversity. A staggered re-planting regime will create a diversity of habitats and provide linkages to and between existing remnants of native vegetation. Approximately 10% of a given landscape area can be planted with mixed species of native perennials to provide a multi-layered canopy in the first year. Further plantings every three years will ensure that at least 30% of the landscape is under woody cover at any given time. The planting of similar species in shelter-belts at least 20 m wide will provide permanent connections between woody phases and any nearby remnants of native vegetation. The prime function of remnant and replanted woody areas is to provide foraging, nesting and refuge sites for native fauna.

Conclusion

We argue that there are potential environmental and productivity benefits of incorporating short-phases of native woody perennials into land-use models that contain mosaics of native woody perennials and annual crops. There are no ready off-the-shelf technology packages for implementing this concept at present. Also, there are several aspects of woody phases that are little understood, including the long-term effects on soil quality, their cost-benefits, potential pest problems, and phase lengths needed to optimise potential benefits.

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