FUTURE ROLES FOR NATIVE WOODY SPECIES IN AUSTRALIAN AGRICULTURAL LANDSCAPES

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Abstract

Australian broadacre agricultural lands are dominated by annual crop and pasture species with relatively shallow root depths compared to perennial species and low accumulation of above ground biomass. Deterioration of the environment in these landscapes by dryland salinity, nutrient losses, soil degradation, emission of greenhouse gases and loss of biodiversity may be averted by phases of native woody species and shrubs. Recently, lucerne and other herbaceous perennials have begun to be incorporated into broadacre cropping systems for hydrological control. There are indications, however, that lucerne may not be as efficient as woody species in dewatering the soil profile. Some recent studies in America have shown that mitigation of net global warming potential by lucerne was significantly less than woody species, due to nitrous oxide emissions and lime requirements in the lucerne and resistance of woody species to decomposition in the soil. Pastures such as lucerne have different biodiversity values compared with native woody species. Phases of different ages of native woody species are likely to provide multiple niches for enhanced biodiversity, provided biological assets are maintained when cropping and/or pasture phases are resumed. Problems perceived with use of woody species often centre on loss of income during the early years of their growth. However, forecast markets for emerging bio-energy industries, and ecosystem services incentives could provide worthwhile returns. This hypothetical approach using native woody species is untested scientifically and research is needed to ascertain their utility in a range of Australian environments. The selected examples we have shown focus on environmental outcomes and would depend on favourable socio-economic structures for implementation. We envisage that optimisation of overall environmental gains could be achieved in a six year time frame.

Introduction

Lucerne is increasingly being used to restore perennial growth regimes to Australian landscapes that were previously shaped by native vegetation and other geographic factors that restricted loss of nutrients and water (Specht 1990). Annual crops and pastures that have been introduced into 95% of these landscapes are incapable of maintaining the ecological functions of the original vegetation they replaced (Anon. 2001). These functions include nutrient cycling, maintenance of soil structure balanced hydrology sequestration of carbon and conservation of biodiversity.

One approach that has been suggested in order to achieve satisfactory hydrological control is a return to an 18-22% cover of native woody vegetation in the landscape (Dunin 2002). In addition to providing hydrological control, phases of native vegetation in farming systems are likely to have a significant role in reduction of global warming potential by a combination of factors that includes reduction in nitrous oxide emissions from the soil (Robertson *et al.* 2000). A mixture of different woody species in these phases may substantially increase biodiversity values and a 30% cover of native vegetation has been suggested (Wilson and Lowe 2002). Preliminary trials of phases of woody perennials in rotations have showed that mallee eucalypts in a low rainfall environment (< 300 mm) of WA produced 26 t/ha of standing dry matter after five years (Harper *et al.* 2000).

In this paper we examine the scope for capturing multiple environmental benefits from phase farming with a mixture of native woody species compared with lucerne. We have drawn on local data in recent experiments and selected reports from elsewhere to illustrate these concepts. A hypothetical rotation of native woody-phases is presented for optimising hydrological control, greenhouse gas mitigation and improved biodiversity.

What native woody plants are likely to have a role in Australian agricultural landscapes?

We considered the definition of woody native perennials to range in size from that of the low growing shrubs of the arid plains such as *Atriplex* spp. (saltbush), *Solanum* spp. (includes kangaroo apples), *Acacia* spp., *Allocasuarina* and *Callitris* spp., to a range of eucalypt species (Anon. 1993). The latter would include mallee eucalypts in the drier areas and *E. camaldulensis* and *E. globulus* in wetter environments (>450 mm annual rainfall). Selection of an appropriate species mix would need to optimise desired environmental benefits with risks (eg. disease, pests and fire) and economic alternatives. These mixes could be based on historical records, and remnants of local native vegetation (eg. road-side reserves and bordering waterways), which are the likely sources of endemic seeds.

Deep root zone activity of native woody species compared with lucerne and annual systems

Role of native woody species in hydrological control compared to lucerne and annual species

The broadacre cropping and pasture systems in Australian Agriculture are generally shallow rooted compared with the previous native woody vegetation. Extraction of water from the soil profile by annuals such as wheat, canola, pulses and annual pastures (eg. sub-clover, medic) is often limited to a metre or less, depending on the soil type and phenology of the crop and the perennial lucerne has demonstrated deeper water extraction due to summer and autumn activity (Fig. 1) (Whitfield *et al.* 1992; Ridley *et al.* 2001, Angus *et al.* 2001). Depending on the intensity of rainfall events, and the capacity of these systems to both store and extract water, mobile nutrients are either leached (shallow root zone) or captured within the root zone (Figure 1).

Native woody perennials have deep roots capable of penetrating heavy subsoils and can extract a larger amount of water from the soil profile than shallow-rooted annual crops. Woody eucalypt communities have been shown to extract water from depths of 6 m (Talsma and Gardner 1986). Water penetration to 28 m depth beneath mixed mallee eucalypts and heath via the soil-root interface was found with dye tracing experiments in WA (Nulsen and Bligh 1986). Thus, deep-rooted characteristics can enable water uptake from shallow groundwater systems (Bari and Schofield 1991).

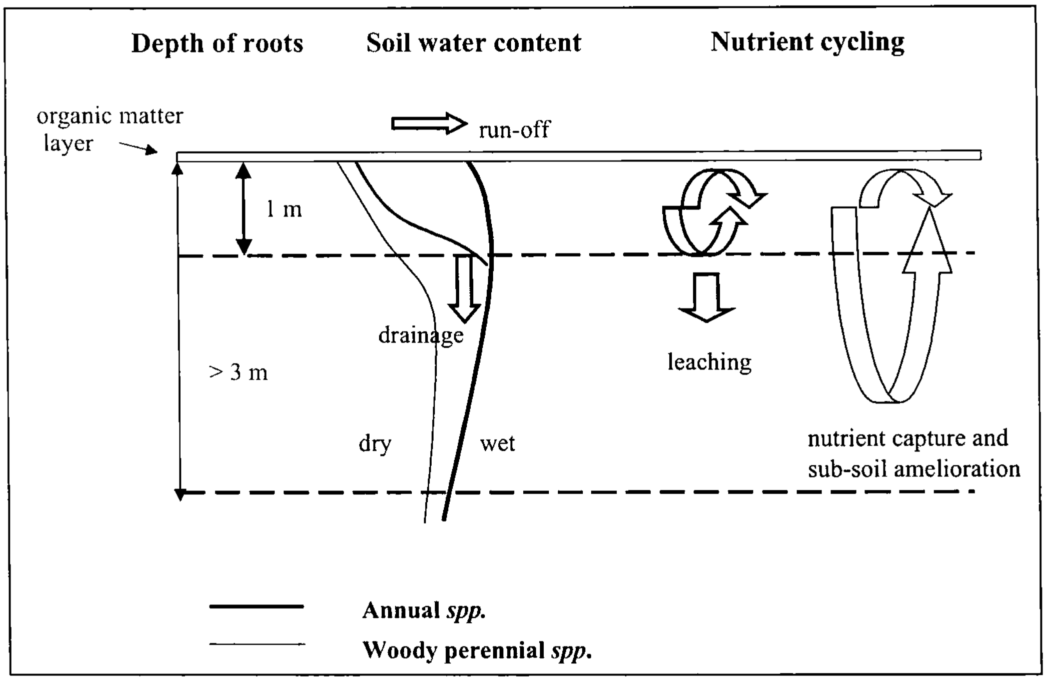

Figure 1.Schematic diagram of soil profile representing depth of roots, drying cycles and nutrient cycling below annual crops compared with deeper cycling when amended to include native woody species.

In evergreen native systems, year–round water extraction occurs in native woody communities, and although the leaf area as a whole may be less than that of lucerne, overall water use is not dissimilar due to low winter activity in lucerne (Dunin 2002). The leaf area index of lucerne is reduced to negligible levels at times under rotational grazing (Crawford and M^{c}Farlane 1995), cutting for hay under irrigation (Whitfield *et al.* 1986) and dryland (Hirth *et al.* 2001).

Lucerne's role for controlling dryland salinity derives from its deep rooting habit and ability to extract water beyond depths of 3 m (Ridley *et al.* 2001). However, the processes are not clear as lucerne tends to degenerate after a few years as a result of plant mortality and progressive reduction in vigour, which then exposes significant areas of the soil surface to direct impact of rain and consequent degradation of surface structure of the soil. This would tend to increase runoff (Rob Harris *pers. comm.* 1996), and it is possible that the hydrologic balance often reported under lucerne (eg. Ridley *et al.* 2001, Angus *et al.* 2001, Taylor and Olsson 1984) may be the result of increased partitioning of rainfall through runoff. This process could reduce the amount of water infiltrating into the soil matrix and may result in deep drainage elsewhere in the landscape. Hence, anecdotal comments from lucerne farmers who have referred to the soil between grazed lucerne plants as either "mud or dust". A simple soil water storage and winter rainfall model has showed effective de-watering by lucerne in the 300-600 mm zone in SE Australia (Whitfield 1998). While this study was based on limited water extraction data, it showed that deep drainage was still probable under lucerne when rainfall exceeded 700 mm per year and persistence and survival of lucerne was likely to be limited in very arid environments such as the Mallee (< 300 mm rainfall). A lucerne stand typically lasts 5-10 years, which is comparable with a six-year rotation of native woody species.

Role of native woody species in nutrient cycling

Opportunities for increased leaching of nutrients beneath the annual crop/pasture systems pose environmental risks, including groundwater contamination. High applications of macronutrients in current farming systems have increased concentrations near the surface of the soil. This has recently been shown in the case of phosphorus (P) in pasture systems, where increased loses of dissolved P originating from the topsoil were found in runoff water (Nash *et al.* 2000). Commensurately high levels of mineral nitrogen in the soil that favour leaching of nitrate and associated cations have resulted in a widespread decline in surface soil pH and often subsoil pH, with corresponding loss in the overall buffering capacity of the soil (Ridley *et al.* 1990a; Ridley *et al.* 1990b). A phase of native woody vegetation may have the potential to recover nutrients in farming systems by capturing nitrate and other nutrients leached from the surface organic matter layer beyond the root zone of the annual phase and by amelioration of the subsoil for subsequent annual phases (Fig. 1). Micronutrients extracted from within these deep rooting zones can be cycled through the plant and deposited back to the surface organic matter layer (Noble and Randall 1998). A belt of native vegetation has been shown to influence cation uptake in a comparison with annual crops in NE Victoria as shown in Table 1 (Mele *et al.* 2003).

Table 1. Concentration of calcium in the soil as affected by either seven years of continuous annual crop rotations (cropping), six years of native woody species followed by one year of crop (native vegetation) or permanent grassy annual pasture (pasture) in Fan/Feb 2000 at Rutherglen.

Soil horizon	Management			
	Cropping	Native Vegetation	Pasture	Mean
	Ca (cmol kg^{-1})			
A-horizon	2.99	2.81	1.77	2.52
B- horizon	6.72	4.74	5.15	5.15

Reliance of current annual systems on organic carbon and associated nutrients built up under the previous woody systems has been shown by sources of mineralised nitrogen for crops (Angus 2001; Newton 2000). A return of native woody phases into rotation with annual crops will help to restore sustainable levels of organic carbon and nitrogen as complex hydrocarbons in the roots of woody species are not readily degraded by microorganisms in the soil (Rodriguez *et al.* 1996).

Role of native woody species in subsoil amelioration

Macropores are an important part of the air-filled pores in the soil as they drain under zero suction (White 1997). Reduced infiltration and aeration of the subsoil via macropores is apparent where pastures have replaced native vegetation 80 years previously and produced high peak runoff volumes, whereas a woody forested catchment produced no runoff below 60% of soil storage (Burch *et al.* 1987). This was due to subsoil hydraulic conductivities twice that of the cleared grassland. Amelioration of impermeable subsoils has been indicated by increased formation of macro-pores as roots decayed following removal of a six year phase of native woody perennials (Yunusa *et al.* 2002a) (Table 2). Increased macroporosity of the sub-soil following native woody species is due to a combination of factors such as the interfacial space between the root and the soil, cracks on upheaval of soil around large roots and deep cracks on drying of clay in the soil.

Table 2. Changes in soil structural variables at Rutherglen (34° 26'S, 147° 32'E) under different land-use systems and after removal of woody species in south-eastern Australia (from Yunusa *et al.* 2002a).

Soil structural variable (B horizon > 20 cm depth)	1 year after removal of woody species under oats		20 months after removal of woody species under wheat	
	Continuous cropping	Woody species	Continuous cropping	Woody species
Pores > 2.0 mm (number m^{-2})	97	161	268	415
$K(\theta)$ (mm d^{-1})	128	310	na	na
Mean θ (m^3 m^{-3}) at planting of following crop	0.31	0.18	0.26	0.26

na: data not available

Carryover benefits of subsoil improvements after woody species for following crops are likely to be subject to trade-offs such as the opportunity time while being removed, depletion of stored soil water for following crops and low initial levels of mineral nitrogen (Yunusa *et al.* 2000b).

Reduction in global warming potential by woody species

Agricultural systems have the potential to play a key role in abatement of greenhouse gasses due to their ability to either sequester carbon or contribute large emissions of carbon dioxide (CO_2), nitrous oxide (NO_2; 314 times more potent than CO_2) and methane (CH_4; 30 times more potent than CO_2), respectively. This has already resulted in large tracts of the agricultural landscape being returned to trees. In relatively permanent plantations of native woody species, however, the potential for carbon sequestration slows as trees mature to a much reduced level determined largely by the tree species and prevailing soil conditions, such as soil moisture and temperature. The net effects on reduction in Global Warming Potential (GWP) of native woody species grown in phases with annual crops are untested under Australian conditions. However, the carbon compounds in woody species are likely to remain more resistant to decomposition in the soil due to complex lignin structures (Wedderburn and Carter 1999). The standing biomass produced is not considered in these greenhouse gas calculations as it represents a temporary pool of carbon whose stability over time will depend on its end-use (IPCC 1997).

Little has been published on greenhouse gas emissions from different vegetation types or agricultural systems in Australia, but studies elsewhere have indicated that depending on the period of time considered, woody species can be more efficient in abating these gases than herbaceous ones. For instance, Robertson *et al.* (2000) found that fluxes of nitrous oxide (N_2O) was largely similar for lucerne and annual crops (3.5 – 6.5 g/ha/day). These were much larger than those observed from woody species either in pure stands of plantation or in mixed communities (0.6 – 1.5 g/ha/day). Robertson *et al.* (2000) related high N_2O fluxes to high levels of available soil nitrogen caused by legumes and nitrogen fertiliser application rather than species or crop type *per se*. Under woody perennials, fluxes of N_2O are likely to be low because of low levels of nitrate and conservative cycling of nitrogen.

A positive or negative GWP in terms of net CO_2 equivalents arises from changes in soil organic matter, greenhouse gas emissions, nitrogen fertiliser inputs, application of lime and fuel requirements (Table 3). Although lucerne has shown a capacity to store large amounts of soil C, these gains are likely to be offset by CO_2 released from lime and from N_2O emissions (Robertson *et al.* 2000). Annual cropping systems are unlikely to sequester enough CO_2 to match the cumulative effect of early-to-mid successional communities of mixed woody species, and hence be able to offset the GWP of N_2O production arising from fertiliser use. Carbon in the surface soil (0-10 cm) accumulated to 1.58% under a six-year-old belt of mixed woody natives that included acacia, melaleuca and callistemon, compared with 1.10% under annual crops at Rutherglen (Yunusa *et al.* 2002a).

Table 3. The relative GWP for different land management (equivalent to $gCO_2/m2/yr$) (from Robertson *et al.* 2000) Negative values indicate a global warming mitigation potential.

Land-use types	Soil C	N fertiliser	Lime	Fuels (diesel)	N_2O	CH_4	Net GWP
Conventional cropping[1]	0	27	23	16	52	-4	114
No-Till	-110	27	34	12	56	-5	14
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

Woody species in mid successional communities had the lowest net GWP due to less tillage, little use of fuel and a low inorganic nitrogen content in the soil, which restricted the amount of N_2O produced (Robertson *et al.* 2000). The sequestration of carbon in the soil is likely to continue to increase over the proposed six-year duration of a woody phase. An example of the accumulation of organic carbon and mineral nitrogen under annual and perennial land use systems in Australian conditions is shown in Table 4.

Table 4. Organic carbon and mineral nitrogen (nitrate and ammonium nitrogen) content in the top 0.1 m of the soil under a range of land-use systems at Rutherglen in October 2002.

Land-use system	Organic carbon (%)	Mineral nitrogen (ppm)
Non-tilled annual cropping	0.97	54.4
7-year old lucerne	1.02	62.2
5-year old mixed woody species	1.71	12.8

Source: P. Newton and I. Yunusa (unpublished data).

Enhanced biodiversity from increased cover of native woody vegetation

A phase of mixed native trees and shrubs is not an exact replica of a naturally regenerated native vegetation habitat but in terms of habitat values could represent an intermediate habitat quality between native remnants and plantations, such as a mid-successional stage following recovery from severe bushfire. The extent to which this mixture represents a native phase can be assessed relative to local or historic vegetation remnants taking into account generic quality attributes such as species representation, large trees, understorey species and canopy cover using the 'habitat hectares' approach (Parkes *et al.* 2002).

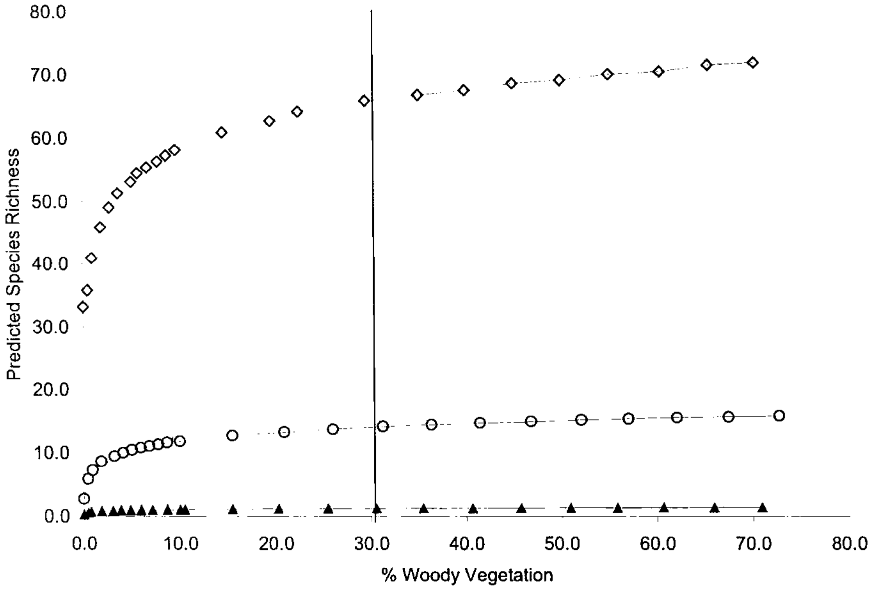

Figure 2. Predicted change in species richness of birds as a function of decreasing vegetation cover for different biodiversity classes (all species = open diamonds, at risk species = open circles and threatened species = solid triangles: adapted from Reid In Wilson and Lowe 2002).

Potential for enhancing the richness of native biodiversity using phases of mixed natives tress and shrubs is increased with the size and connectivity of the area (Lowe *et al.* 2002). Bird species provide indicators of habitat diversity and food supply, with some species having specific requirements for size of habitat (Wilson and Lowe 2002). Modelling of bird species in the northern plains of Victoria has shown that the predicted species richness in diversity of bird species increases rapidly from zero tree cover and rises rapidly to 20%, with a gradual increase thereafter (Fig. 2) (Wilson and Lowe 2002). Surveys of bird populations conducted in the Lachlan catchment of NSW have showed that the presence or absence of woodland birds was associated with remnant area, shrub cover, number of vegetation species, pine cover, ground habitat and the number of remnants within a 2-5 kilometre radius (Seddon *et al.* 2001). The diversity of woodland bird species was lower in small areas and higher in larger areas where there were more tree-hollows. Phases of mixed native woody species in rotation with crops and pastures could theoretically provide a semi-permanent cover of around 30% in the landscape, if quality was sufficient for conservation of biodiversity as indicated by classes of bird fauna (Wilson and Lowe 2002).

Scenarios to include woody phases in rotations for landscape values

Australian cropping landscapes often resemble a mosaic of well-distributed crop and pasture paddocks interspersed with remnant native vegetation. Commonly, the type of enterprise and size of the farm, which in turn depends on the soil type, rainfall supply and location to regional infrastructure, determines the sizes of paddocks. Paddock sizes tend to range from 10-40 hectares for intensive farming systems in the high rainfall zone (> 500 mm) and from 20-100 hectares in the more extensive farms from arid broadacre cropping areas.

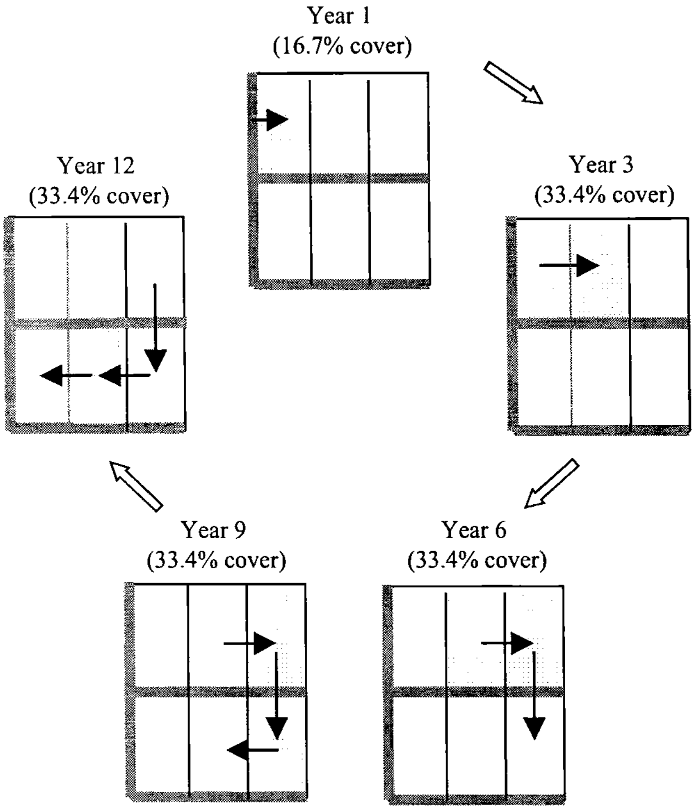

Figure 3. Diagram of the area distribution of a hypothetical woody phase (dots) rotation at a planting interval of three years (arrows indicate clockwise planting sequence), with removal (shaded) every six years and interconnecting shelterbelts (heavy lines).

The arrangement of paddocks can be subdivided into a rotation of woody phases with adjacent permanent tree belts. A hypothetical scenario is to commence planting native woody species in the first year on 16.7% of the available 'farm' land and carry out a three-year planting cycle (Fig. 3). This approach slows the lead-time and always results in trees or shrubs of three years or older being present after the third year, with 33.4% of the land area covered (Fig. 3). This coverage corresponds to the suggested minimum requirement in species richness for sustaining high biodiversity values (Wilson and Lowe 2002). Inter-connectively between paddocks, remnants and phases can be addressed by sequential planting of permanent shelterbelts around the paddocks that represent approximately a further 10% of the land area

(Yunusa *et al.* 2002b) (Fig. 3). After six years the height of dominant trees would be close to six meters at an average annual growth rate of 1 m/yr and a density of 1000 trees/ha (spacing of 3.0 m x 3.3 m), and achieve significant light interception. Thus, the tallest species (eg. Eucalypts) projecting a canopy volume for greater light interception after three years will tend to extract more water from the soil profile.

Some economic and management implications of native woody phases and lucerne

The Model of an Integrated Dryland Agricultural System (MIDAS) has been used to partition economic performance from phases of mallee eucalypts for oil (Harper *et al.* 2000). This model partitions the inputs and costs of production on an area basis for each phase of the rotation. The input costs for a phase of woody species could be much higher if planted as seedlings (eg. $500 for 1000 trees/ha at $0.50 per tree) than by direct seeding methods. Cost savings could be achieved by growing seed in the woody phase and by returns from sale of excess seed. An advantage of seedlings is that the requirements for herbicides could be less. Savings in fertiliser and other inputs normally applied on land occupied by woody phases can be re-assigned to other areas of the farm. The balance between the hypothetical environmental and productivity benefits of a native woody phase need to be considered against lucerne as the most viable productive solution for hydrological control and following crops on mixed farms. Examples of these positive and negative aspects are shown in Table 5. Removal of grazing stock during establishment is desirable to protect young native trees and shrubs from grazing animals. However, once young trees are established, selective grazing for forage could help offset lost opportunity costs and provide alternatives during drought that relieve over-grazing on more vulnerable areas of the farm.

Stands of native trees on farms are at risk of fire and disease so that substantial financial losses could occur if they were not insured.

In the future more competitive prices for products derived from woody species are likely, due to products such as bio-fuels (methane, ethanol), oil products, medicines, industrial chemicals (eg. saponins, esters), flowers, bush foods and honey. The value of traditional markets such as firewood and brush fencing materials could also increase. Case studies of different marketing scenarios have shown that the break-even value is most sensitive to product price (Stewart 1999). The costs associated with harvest or mulching of woody materials, however, will be determined by distance from markets, machinery, technology and the value of the their end-use.

Ecosystems services are forecast to increase due to government and private investment in incentive programs for carbon trading, landscape amenity, water supplies and biodiversity assets, which are all favoured by combining the commercial and natural resource protection objectives such as phases of native woody vegetation (Pannell 2002). Increased landscape values associated with phases of mixed native vegetation rotations could also be reflected in higher capital value and flow-on benefits to tourism or small businesses. If market values for either ecosystems services or alternative products do increase significantly in the future, then retaining the woody phase for a longer time interval than six years remains an option.

Table 5. Some estimated positives (benefits), negatives (costs), and trade-offs associated with phases of native woody species relative to lucerne.

Perennial land use system	**Positive**	**Negative**
Native woody species	• Hydrological control through drying the soil profile beyond 1 m and greater than 3 m • Low nutrient requirement during growth through efficient capture • Potentially low levels of nitrous oxide emissions and low GWP • Low level of manual labour needed during first 1-3 years of early growth • Source of pollen for bees • Shelter on lee side for stock from strong winds and cold temperatures • Shading competes with weed growth • Tolerant to low soil water availability once established • Few chemicals needed for weed control once established • High standing biomass and mixed species favours increased biodiversity	• Time taken to develop sufficient leaf area • Few returns from woody production during early years of growth • Shading of adjacent crops could lower overall crop production • Limited opportunity for cost effective grazing during establishment and early growth • Few economic options at present for dry matter utilisation at end of phase • Costs of removal at end of phase unknown • Availability of large numbers of seedlings and seeds is currently limited • Low level of researched to date in native woody phases • Risk of large losses due to fire, pests or disease
Lucerne	• Hydrological control from frying the soil profile beyond 1 m and within 3m • High nutrient requirement if cut for hay or silage • Higher labour requirement for rotational grazing of lucerne • Capacity for summer and autumn water use activity at high temperatures • High quality source of grazing forage • Prolonged nutrient carry over to subsequent crops • Agronomy well researched	• High costs of establishment for seed and fertiliser (phosphorus) and high risk of failure • Cultivation of a seed bed needed for establishment • Exposed soil between plants during winter and after grazing increased risk of erosion • Low winter growth activity • Suffers waterlogging in low lying and poorly drained areas • Productivity relies on continuing weed control • High requirement for lime • High soil N with potential for high nitrous oxide emissions and greater GWP • Low standing biomass, monoculture and intensive management may not favour native biodiversity

Conclusions

Our hypothetical concept of incorporating phases of native woody species into Australian agricultural systems has revealed a potential role for wider environmental benefits that are now the basis of an emerging research effort. This concept has not been presented here as an economic solution, which depends on uncertain future market structures, but to highlight the need to consider a range of outcomes and options in overcoming environmental problems. To devise solutions that apply to differing circumstances on individual farms requires research to understand water movement processes, greenhouse gas emissions and biophysical interactions under Australian climatic conditions.

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