The potential contribution of forage shrubs to economic returns and environmental management in Australian dryland agricultural systems

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Abstract

In face of climate change and other environmental challenges, inclusion of perennial forage shrubs in Australian agricultural systems has the potential to deliver multiple benefits: increased whole-farm profitability and improved natural resource management. The profitability of shrubs was investigated using MIDAS (Model of an Integrated Dryland Agricultural System), a bio-economic model of a mixed crop/livestock farming system. We found that including forage shrubs could increase farm profitability by over 20% for an optimal 10% of farm area in shrubs. The impact of shrubs on whole-farm profit accrues primarily through the provision of a predictable supply of "out-of-season" feed, thereby reducing supplementary feed costs, and through the deferment of grazing of pastures, allowing a higher stocking rate and improved animal production. The benefits for natural resource management include improved water use through summer-active, deep-rooted plants, reduced risk of soil erosion through year-round ground cover and/or wind breaks, reduced soil acidification, increased habitat for biodiversity, and effective carbon storage. Forage shrubs also allow for the productive use of marginal soils. Finally, we discuss other benefits of shrubs such as the effect on lambing and on livestock gut health. The principles revealed by the MIDAS modelling have wide application beyond the region.

Keywords: Whole-farm modelling; economics; perennial species.

Introduction

Agricultural systems in the Mediterranean regions of Australia currently face a broad range of environmental challenges. Finding ways to cope with drought and unseasonable rainfall, soil salinity, soil erosion, soil acidification, herbicide resistance, reduced biodiversity, and pressure to reduce greenhouse gas emissions will likely require adoption of novel technologies and modified farming systems. Agricultural systems will also need to continue to be responsive to changing market trends and consumer demands. The *Enrich* project is intended to contribute to these various challenges. It aims to develop innovative, profitable and sustainable farming systems in the low-medium rainfall zones (300-650 mm) of southern Australia, based around grazing of novel shrubs and shrub-based systems. In this target zone there are currently few perennial plant options available.

This project focuses on a range of mostly Australian native forage shrubs (e.g. *Atriplex* sp., *Acacia saligna, Rhagodia preisii, Chenopod* sp.), which are especially well adapted to the climatic challenges of this land and appear to contain unique bioactive compounds. They are generally being assessed for their ease of establishment, growth performance, nutritive and anti-nutritive value, and impact on the gut health of livestock. This information is supported by farmer experiences and by computer modelling through the use of MIDAS (Model of an Integrated Dryland Agricultural System), a bio-economic model of a mixed crop/livestock farming system.

This analysis investigates the potential benefits of integrating forage shrubs in a farming system by evaluating shrub biological and management data in a whole-farm economic context. *Enrich* was built on the assumption that shrubs alone will not provide sufficient edible biomass to support productive livestock systems. This has directed our research towards the incorporation of shrubs into forage systems for multiple benefits, including a pasture understorey.

The MIDAS model

The circumstances under which novel forage shrubs are likely to be profitable and thus potentially adopted into the farming system are being investigated with the help of MIDAS (Kingwell and Pannell, 1987). MIDAS was chosen because its complex framework allows for the integration of biological, physical and financial information relevant to whole-farm economics. The model uses linear programming (LP) to select a farm strategy that maximizes an equilibrium farm profit in the medium term. Its detailed representation of the farming system allows us to assess the overall change in profit when a new farming option is included in the system in an optimal way.

Here we use the Central Wheatbelt version of MIDAS (CWM) (Blennerhassett *et al.,* 2002), which represents a typical crop/livestock farming system in a region of south-west Western Australia (Figure 1). This region has average annual rainfall of 350 mm, of which less than 20% falls outside the relatively short growing season (May to October). The summer maximum daily temperature is over 30 ºC on average. Farms are heterogeneous in terms of soil types, so the model describes eight main land management units (LMU) for the typical 2000 hectare farm. Mixed crop-livestock farms make up the majority of farm businesses. Typically, farms in the region allocate 50-60% of their farm area to crops (and the remainder to pasture production for livestock grazing) although this varies with the mix of soil types present and with farmer preference. Crops grown in the region include wheat, barley, lupins, triticale, canola or rape seed, and a range of pulse crops. Sheep are the dominant livestock and are grazed mainly on annual pasture, which vary widely in composition, some improved by planting of high-quality pasture species (e.g. yellow serradella), some dominated by species that may have been planted for feed purposes decades ago (e.g. subterranean clover or annual ryegrass (*Lolium rigidum*)) and some consisting largely of volunteer weeds. There is also a relatively small area of improved perennial pasture (e.g. lucerne or alfalfa). Historically, wool production made up the majority of the sheep enterprise, by value of production, but prime lamb production for meat has increased in recent years as a result of improved prices. The model also includes an option for oil mallee trees, a novel enterprise that provides energy, oil and activated carbon, but is not yet firmly established as an economic enterprise in the region. In addition, the CWM accounts for:

- Over 60 crop-pasture rotations and their inter-year biological effects (e.g. plant nutrition and disease effects);
- Ten pasture growing periods within the year;
- Four major feeding periods within the year;
- A range of supplementary feeding options (pasture, grain, stubble, hay, forage shrubs);
- 86 categories of sheep with distinctive characteristics and management options (depending on race, gender, age, bodyweight, reproductive status, feeding regimes, and lambing/shearing/sale times);
- Different energy and volume intake requirements for each sheep category;
- Several grain, stubble and wool quality classes;
- Soil nitrogen balance and fertilization options;
- Deferment of pasture grazing from one time period to the next, allowing for degeneration in terms of both quality and quantity of feed;

- Groundwater recharge;
- Machinery specifications (crop establishment method, machine type, fuel use, contracts, repairs and maintenance);
- Chemical control of diseases, pests and weeds;
- Labour (fixed, casual);
- Finance (credit, debt limit, interest rates, operation costs, depreciation costs, bi-monthly overhead costs, cash return, profit).

MIDAS selects the set of activities that maximize the objective function (usually long-term farm profit), subject to acreage, biological, technical, labour and financial constraints. Model outputs include:

- Rotations for each LMU
- Enterprise areas for each LMU
- Sheep stocking rates and flock structure
- Supplementary feed
- Fertilizer rates
- Groundwater recharge volume
- Expected annual profit
- Shadow prices and costs (which indicate second best options)

Being an optimisation model, MIDAS is not amenable to the sort of validation processes advocated for, say, a biological simulation model. However, it has undergone an extensive process of verification, of expert assessment of input parameters, and of comparison with actual farming practice.

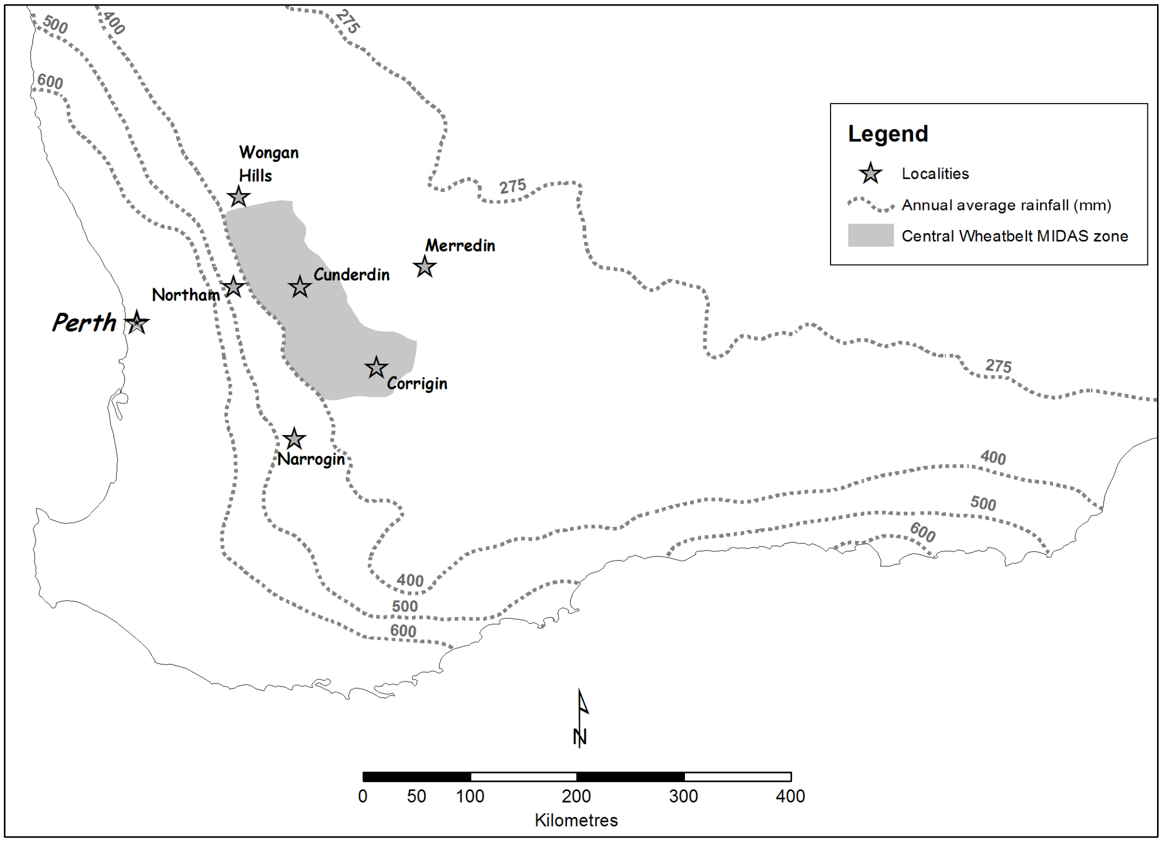

Figure 1. The central agricultural region (grey shade) of south-western Australia.

Methods

The CWM was adjusted to include multi-purpose perennial shrubs and is being used to test a range of parameters and scenarios of the new mixed system. Due to the novelty of forage shrubs on Australian farms and lack of specific data, sensitivity analysis is required to explore changes in many of the model's parameters and assumptions that are subject to uncertainty or to change over time and space. A list of approximately 40 shrub, pasture, sheep, environmental and economic parameters and their value ranges used in the sensitivity analyses are shown in the Appendix. Results are presented below only for some parameters to which results were most sensitive.

Results and Discussion

Initially, results focus on the economic net benefits of including shrub-based grazing systems on the farm from the base-case modelling scenario. Later, results from sensitivity analyses are presented for a range of parameters, starting with an important set of basic economic and production parameters: nutritive value, biomass production, and commodity prices (wheat, wool and prime lamb). As part of the analysis, results are presented for shrub areas up to 60% of the farm.

Base-case scenario

This section presents an example of standard results from the CWM model. These results are meant to provide a reference for more detailed analyses carried out in the following sections. Four sets of standard model results are presented in Table 1. The first two sets show an optimal default farm strategy with and without the incorporation of shrubs. The last two scenarios are similar, but the proportion of poor sandy soils (LMU 1) in the model was increased from 7 to 15%. Where shrubs are allowed into the system, a series of assumptions are made regarding biological characteristics as well as benefits for animal health and natural resource management (NRM) (see Appendix for default parameter values).

Table 1. Key features of the optimal farm plan, with and without shrubs, also for a farm with a higher proportion of poor sandy soils.

		Default[1]		**+ Poor soils[2]**	
	Farm strategy	**No shrubs**	**Shrubs**	**No shrubs**	**Shrubs**
Enterprise	Shrub area (% of farm)	0	7	0	9
	Crop area (% of farm)	55	54	50	51
	Pasture area (% of farm)	45	39	50	40
	Stocking rate (DSM/ha)	6.0	7.0	5.7	6.8
Receipts	Total grain sale and protein payments ($/ha)	140	129	122	123
	Total wool sale ($/ha)	58	68	56	66
	Total sheep sale ($/ha)	44	51	43	50
Costs	Supplementary feed ($/ha)	13	5	12	7
	Crop and pasture inputs ($/ha)	85	78	76	75
	Sheep husbandry and replacements ($/ha)	37	43	36	42
NRM	Groundwater recharge (ml/ha)	20	16	22	18
	Farm emissions (t CO_2-e/yr)	1571	994	1510	774
	CO_2 sequestered (t CO_2-e/yr)	0	700	0	865
	Farm profit ($/ha/yr)	**84**	**102**	**75**	**93**

[1] 7% of poor sandy soils (LMU 1)

[2] 15% of poor sandy soils (LMU 1)

As Table 1 shows, the optimal farm plan allocates 7% of the area to shrubs, mainly at the expense of pasture. For a farm with a larger proportion of poor soils, an extra 2% of shrubs is profitable as they are better suited to those conditions than the pasture species represented in MIDAS. Cropping is clearly the most profitable enterprise on this farm, with only 1% change occurring in either case after inclusion of shrubs. The range of benefits from shrubs considered in the model led to a 22% increase in farm profit relative to the strategy with no shrubs. The gain was even more significant (24%) for a farm with a higher proportion of poor soils, despite overall lower profits. The results indicate that the main economic value of shrubs flows from:

1. Deferment of grazing of annual pastures, allowing them to establish well and, as a result, allowing a higher stocking rate (by 1 DSE/ha) and improved animal production (12% of the total benefits of shrubs are due to increased wool sales and 8 to 9% are due to increased sheep sales);
2. Provision of valuable feed after the break of the season (feed gap), reducing the need for costly supplementary feed such as grain and hay during summer and autumn (6 to 9% of all shrub benefits);
3. Profitable use of marginal and poor land, reducing the opportunity cost of growing less crops and pasture in those soils.

Reported savings in crop and pasture input costs as more shrubs grow on the farm are generally off-set by reduced grain sales and protein payments, as well as by higher sheep husbandry and replacement costs. Likewise, an increased sheep carrying capacity is likely to result in higher farm greenhouse gas emissions under the shrub strategies, even though perennial vegetation plays a role in off-setting those emissions. Shrubs also have a positive effect on groundwater recharge (on sandy soils), as will be considered later.

Nutritive value

We looked at the impact of low, standard and high levels of shrub nutritive value (7, 8, 9 MJ ME per kg edible DM) (Figure 2) and biomass production (1, 2, 3 kg DM per plant) on whole-farm profit. These ranges allow for likely variation among species. For shrubs with a standard nutritive value (8 MJ ME/kg edible DM), profit is maximised with shrubs on 10% of the farm, and remains higher than with no shrubs until shrub area reaches 25% (over 50% for high nutritive value). At higher shrub nutritive value, much larger shrub areas can be established profitably as more and better quality feed supplement becomes available during a great proportion of the year.

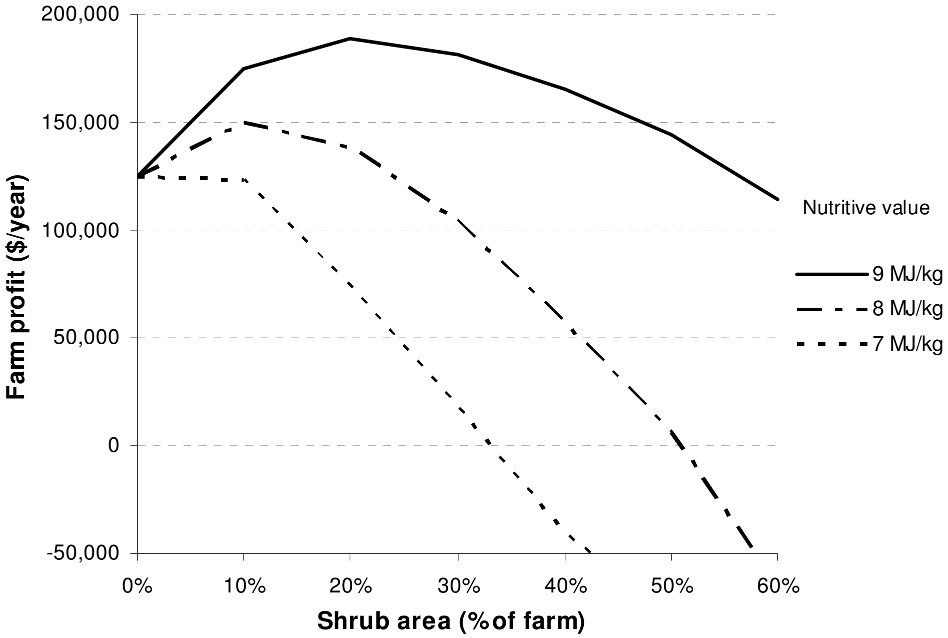

Figure 2. Whole-farm profit for a standard, high and low nutritive value of shrubs.

Commodity prices

The impact of a change in wheat, wool and prime lamb prices on whole-farm profit and optimal strategies was also examined (see Appendix for price ranges), due to uncertainty about future prices and the likelihood that they will fluctuate (Figures 3 to 5). The optimal area of shrubs remained unchanged across the range of price scenarios, indicating that there is some robustness to the finding that allocating approximately 10% of land to shrubs is profit-maximizing. The decline in profit from moving beyond 10% area of shrubs increases as the price of wheat goes up (Figure 3). At low wheat price, profit at 40% shrubs is similar to no shrubs and only slightly below 10% shrubs. However, at the high wheat price, a strategy with 40% shrubs is substantially inferior to either zero or 10%, due to the higher opportunity cost of reallocating crop land to shrubs. This suggests that it could be valuable to develop cropping systems within shrub alleys, allowing shrubs to be utilized even when there is a reduced demand for feed. The "penalty" for having too many shrubs on the farm changed little as the prices for wool and prime lamb varied (Figures 4 and 5).

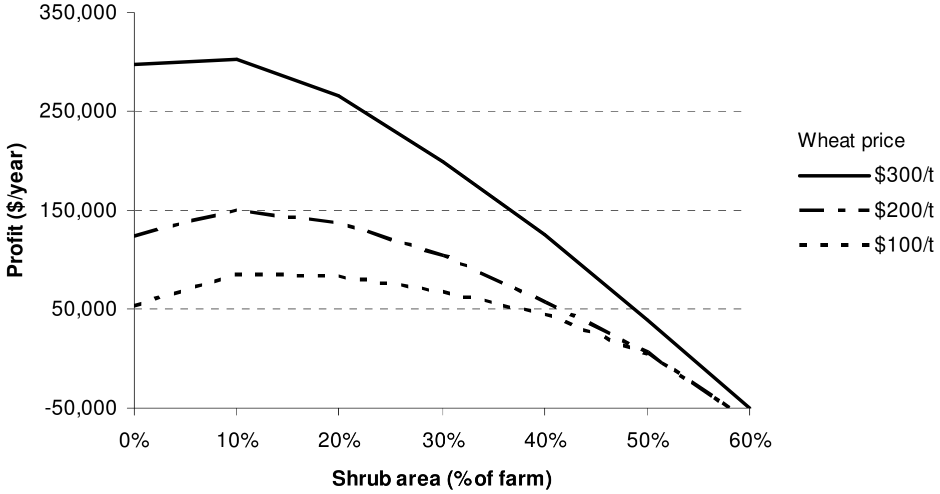

Figure 3. Whole-farm profit for a range of wheat prices (Australian Standard White wheat at 10% protein).

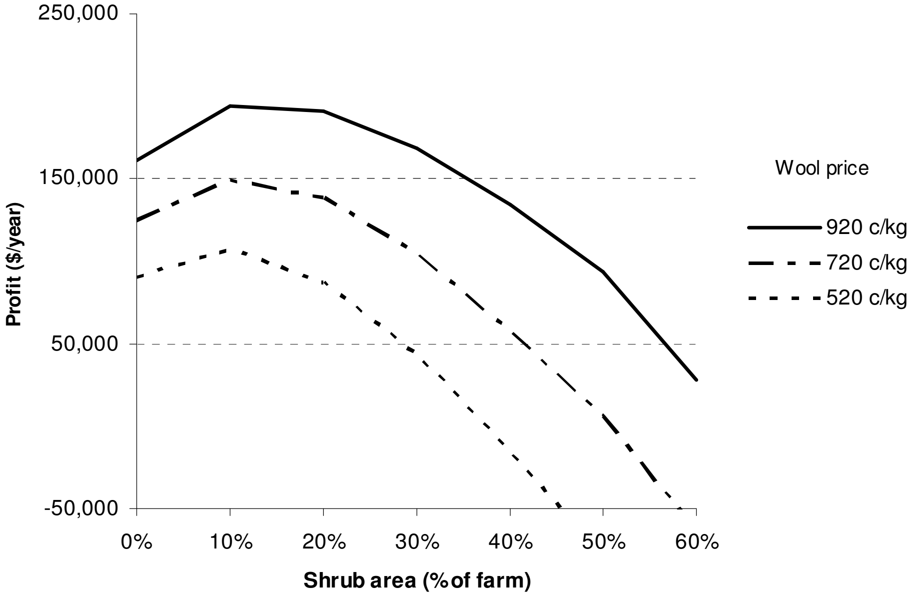

Figure 4. Whole-farm profit for a range of wool prices (Wool Market Indicator).

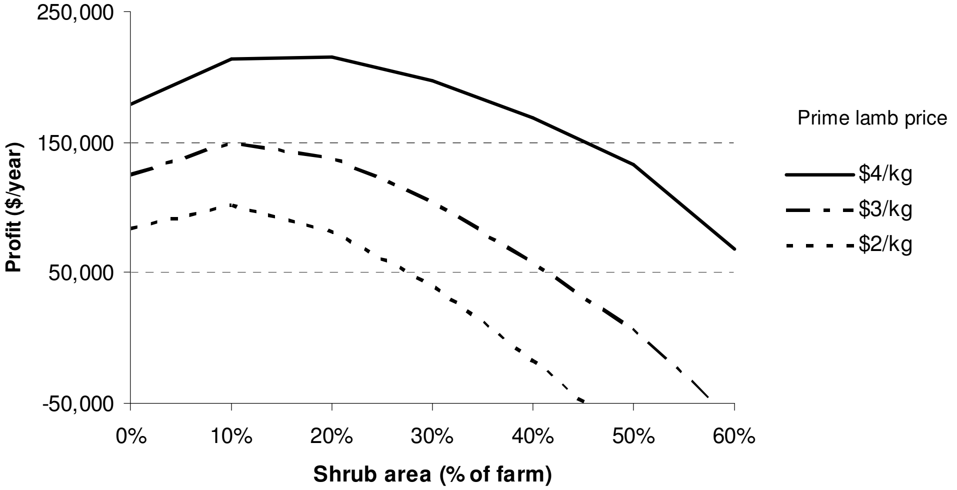

Figure 5. Whole-farm profit for a range of prime lamb prices (dressed weight).

Groundwater recharge

Dryland farming systems of southern Australia are predominantly based on annual crops and pastures. These use less water than native vegetation did prior to clearing and, as a consequence, naturally saline watertables have risen in many areas, resulting in salinisation of soils and waterways. Inclusion of perennials in the system, with their deeper roots and increased water use, has the potential to reduce the extent of salinity by reducing recharge of groundwater.

In the CWM we represented groundwater recharge for shrubs, based on a 20-year average of unpublished data for each Land Management Unit. An increase in the farm area under shrubs (or any other perennials such as lucerne and trees) is likely to decrease deep flow and have a positive impact on the sustainability of the farm by reducing future salinity. Here, we use the predicted reduction in groundwater recharge only as an indicator of reduced dryland salinity. Results are shown in Figure 6.

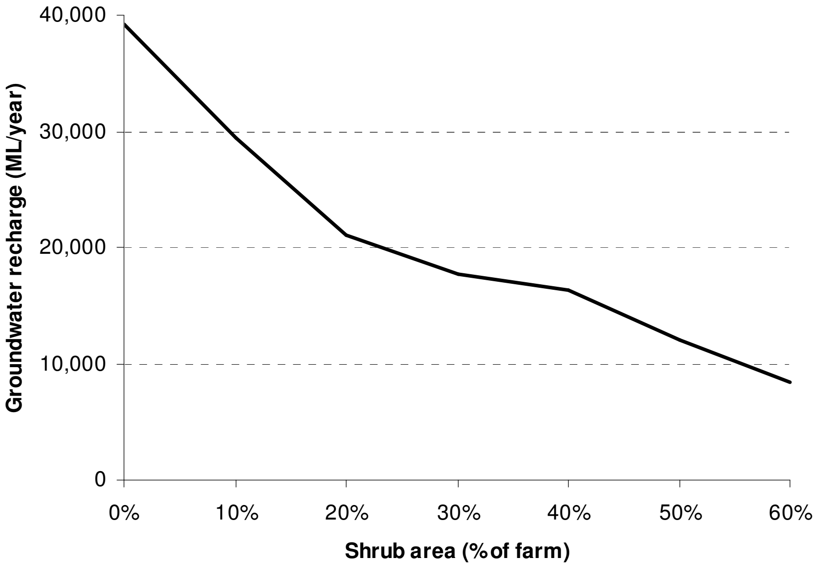

Figure 6. Total groundwater recharge over the whole farm.

For the first 10-20% of the farm allocated to shrubs, average recharge across the farm falls disproportionately as the area of shrubs in increased (Figure 5). This reflects that the soil types on which shrubs are most economically attractive are also those on which recharge is highest. If 10% of the farm is sown to perennials (the optimum based solely on short-term financial considerations), average recharge falls by 25%.

Greenhouse gas emissions

Australia has recently ratified the Kyoto Protocol, committing the country to the restriction of CO_2-equivalent emissions to 108% of 1990 levels in the first commitment period of 2008-2012 (UNFCCC, 1997). Agriculture is responsible for approximately 16% of Australia's total greenhouse gas emissions (AGO, 2005a). Table 2 outlines the main sources of emissions that are relevant to established farms that have no potential to clear further native vegetation (AGO, 2005a; NGA, 2008).

Table 2. On-farm sources of greenhouse gases, global warming potential relative to CO_2 and proportions of total farm emissions.

GHG	**On-farm emission source**	**GWP**[1]	**% of CO_2-eq farm emissions**
Methane (CH_4)	Livestock rumen fermentation	21	42%[2]
Nitrous oxide (N_2O)	Livestock excretions in field	310	
	Nitrogenous fertilization		7%
	Nitrogen-fixing legume crops and pastures		28%
	Crop residues		17%
Carbon dioxide (CO_2)	Fuel use	1	5%
	On-farm electricity use		1%

[1] Global Warming Potential

[2] Includes all livestock emissions (i.e. also N_2O from livestock excretions in field)

Establishment of woody perennials provides an opportunity to offset some or all of these emissions through sequestration of organic carbon. However, the accreditation of forests and other plantations as carbons sinks under the Kyoto Protocol remains a contentious issue as their contributions are uncertain, difficult to measure and possibly temporary (UNFCCC, 2000). Nevertheless, there is wide agreement that using perennials like forage shrubs to sequester greenhouse gas emissions (Murdoch, 2004) will at least “buy time” until less-polluting technologies such as alternative energy sources can be developed or improved (Shea, 1999).

In MIDAS, we model carbon sequestration by the non-edible components of the woody shrubs (above- and below-ground) through an annual carbon sequestration value. This is included in an emissions budget for the farm, including a parameter for each gas-emitting activity (converted in CO_2-equivalents); sequestration of 5 to 10 tonne of CO_2/ha/year over at least 10 years is judged to be realistic, based on predictions by AGO (2005b). The model is also used to estimate the impact of an emissions trading scheme on the optimal level of total emissions (from the farmer's perspective) and on the profitability of forage shrubs.

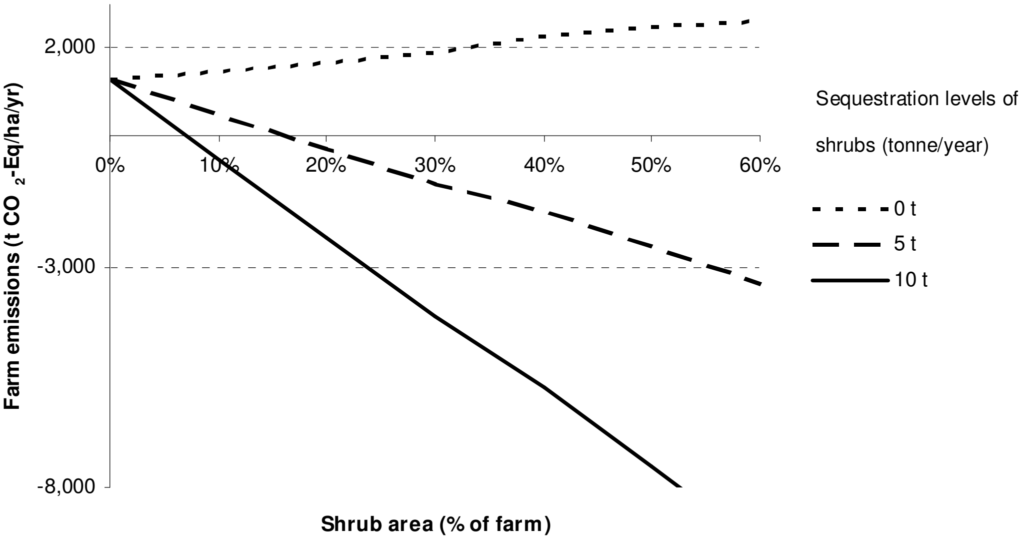

Figure 7. Farm emissions of CO_2-equivalents for a range of carbon sequestration levels over 10 years.

The results shown in Figure 7 indicate that shrubs are potentially good carbon sinks, with the sequestration rate having a substantial impact on net emissions. If carbon is sequestered at a high rate of 10 tonne of CO_2-Eq/ha/year, net farm emissions over ten years can be fully offset with only 7% of the farm area allocated to shrubs. At the base-assumption rate of 5 tonne of CO_2/ha/year a neutral emissions status was reached at approximately 16% of the farm in shrubs.

Assuming a price for CO_2 of $25, no significant difference in farm profit was observed across the carbon sequestration levels analyzed for the default parameters, as the annualized payment for carbon sequestration by shrubs represents only a very small contribution to the farm budget. The effect on farm profit and emissions was further investigated for a range of economic parameters such as the price of emissions, price of nitrogenous fertilizer, and fuel price (see Appendix for parameter levels). None of these factors significantly affected profit or the level of emissions generated on this farm, except for the slight impact of a higher fuel price. For the default result, there were nearly 1000 tonne of CO_2-e emitted and 700 tonne of carbon sequestered every year. The optimal area of shrubs stayed around 10% for all cases.

An additional benefit of shrubs is that they provide a reduction in methane emissions from livestock. In fact, 20% of all native shrub plants investigated in the *Enrich* project have been shown to reduce methane production from microbial fermentation (without affecting other normal fermentation parameters). This offers an additional prospect for shrubs to help reduce agricultural greenhouse gas emissions.

Animal Health

An intention of the *Enrich* project is to capture a range of benefits from secondary plant compounds (SPC) present in many shrub species. A range of animal production benefits are considered likely: higher liveweights and wool growth, a reduced need for antibiotics as a result of parasite inhibition or anthelmintic activity of shrubs, and an increase in the lambing survival rate as a result of improved shade and shelter as well as more permanent and diverse feed on offer supplied by shrubs. The shrubs of interest have relatively high concentrations of crude protein, which should increase digestibility and efficient use of stubble straw. They also have high levels of vitamin E (Norman and Wilmot, 2006), which is likely to protect sheep from nutritional myopathy (CSIRO, 2004) and reduce the animal death rate by around 1% (Barrett-Lennard *et al.*, 2005). Conversely, there may be negative effects of toxic compounds in some shrubs (e.g. high levels of alkaloids, tannins or salt in the leaves).

Existing evidence about the magnitudes of most of these effects is weak, and is the subject of research within the *Enrich* project. Nevertheless, we have included default values for a range of animal health-related parameters (see Appendix), although the impact of each of these on whole-farm profit is relatively minor.

Conclusion

The profitability of including novel shrubs in a typical dryland farm in the mixed farming (crop-livestock) region of Western Australia was evaluated using MIDAS. The results indicate that a perennial forage shrub system can play a substantial role in the region, enhancing economic returns and addressing environmental challenges. For the modelled farm, the analysis estimates an improvement in whole-farm profit by 22% at an optimal area of shrub-pasture sward around 10% of the farm. For a farm with a higher proportion of poor soils, the profit improvement is 24%. It is notable that this positive result occurs despite a number of other potential benefits being omitted from the economic analysis (e.g. increase in soil fertility and biodiversity, reduction in soil erosion, acidity, and salinity). This analysis has helped to support and guide the *Enrich* project, which is currently researching all aspects of these shrub-based systems.

Acknowledgements

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Appendix. Key parameter values and their sensitivity ranges and data sources for a standard forage shrub system (model default values in bold).

Type	Parameters	Sensitivity value range		
		Min	**Std**	Max
Shrubs	Area of shrub-pasture sward (ha)	0	**200**	1200
	Productive life of shrubs (years)	15	**20**	25
	Shrub density (stems/ha)	1000	**2000**	3000
	Probability of establishment success (%)	80	**90**	100
	Re-establishment period (years)	1	**2**	3
	Relative shrub growth in each period/LMU (%)	60	**…**	100
	Nutritive value (MJ ME/kg edible DM)	7	**8**	9
	Biomass production (kg DM/plant)	1	**2**	3
	Crude protein concentration (%)	5	**15**	25
	Vitamin E (mg/kg edible DM)	80	**100**	120
	Salt concentration in the leaves (%)	15	**20**	25
	Anti-nutritional effects on intake (e.g. tannins) (%)	1	**3**	5
Pasture	Understorey pasture density (%)	40	**60**	80
	Potential production (pasture and shrub) (%)	100	**110**	120
	Pasture (only) growth (%)	80	**100**	
	Lucerne production (%)	0	**20**	40
Livestock	Liveweight gain (%)	3	**5**	7
	Increase in lambing rate (%)	0	**5**	15
	Reduction in methane production (% of gas from oaten chaff)	0	**30**	60
Environmental	Proportion of sandy poor soils (% LMU 1)		**7**	15
	Carbon sequestration (t of CO_2-e/ha/year)	0	**5**	10
	Carbon sequestration efficiency (%)	80	**100**	
	Water deep flow (20-year average/LMU) (ml)	0.15	**1.0**	1.4
	Cereal yield reduction due to wind erosion (%)	0	**10**	20
	Pasture conservation standard (kg/ha)	300	**500**	700

	Cereal stubble conservation standard (kg/ha)	500	**750**	1000
	Lupin stubble conservation standard (kg/ha)	1000	**1500**	3000
	Other crops stubble conservation standard (kg/ha)	1000	**2000**	3000
Economic	Shrub establishment cost ($/stem)	0.2	**0.5**	0.8
	Shrub sward maintenance cost ($/ha/yr)	0	**30**	50
	Sale price of wheat ($/t ASW) [1,4]	100	**200**	300
	Sale price of wool (c/kg clean WMI)[2,4]	520	**720**	920
	Sale price of prime lamb ($/kg DW) [3,4]	2	**3**	4
	Cost of antibiotics for sheep ($/hd)	0.13	**0.27**	
	Cost of N fertilizer (urea) ($/t)	400	**500**	600
	Cost of diesel fuel ($/L)	0.6	**1.1**	1.6
	Carbon emissions/sequestration price ($/t of CO_2-e) [5]	0	**25**	50
	Discount/real interest rate (%)	5	**8**	10

[1] Australian Standard White with 10% protein

[2] Western Market Indicator

[3] Dry Weight

[4] Standard default prices for 2002

[5] Annualized over the life of the shrub stand

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