An economic review of key land management systems on the South Coast of Western Australia

Prepared for:

SOUTHCOAST NATURAL RESOURCE MANAGEMENT INC.

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Executive Summary

South Coast Natural Resource Management Inc. is conducting a project funded by the Australian Government's Carbon Farming Futures Program which is designed to assist on-farm trial and demonstration of practices aimed at increasing the carbon potential of the soil and to mitigate carbon loss in the South Coast of Western Australia. Advanced Choice Economics Pty Ltd has been contracted by South Coast NRM to conduct an economic review of seven trialled farming systems and practices. The main findings of the review for each of these systems and practices are provided below.

1. Annual pasture

Pastures play an important role in agricultural enterprises through animal production, improvements to crop rotations, and conserved fodder. Economic review of annual pastures indicates that gross margins of annual pastures are heavily influenced by output prices, the control of feed demand (especially stocking rate) and net pasture production. Generally, higher output prices, stocking rate and rainfall are associated with more profitable mixed or continuous pasture rotations. Continuous annual pasture is really only economically competitive on marginal soils or in high (450 – 550 mm/year) or very high rainfall zones (> 550mm/year). Pasture gross margins can range from $40 – 326/ha/year depending on stocking rate, rainfall zone, rotation used and wool/livestock farmgate prices.

2. Perennial pasture – Kikuyu

Perennial pastures have two key benefits: (a) they have a deep root system which enables them to use water and nutrients from deeper soil layers than annual plants, and (2) they can extend the growing season at both ends when conditions are favourable. Kikuyu is very well suited to the conditions of the South Coast of Western Australia. Economic review of perennial pastures indicates that the gross margin of kikuyu pasture is heavily influenced by the rainfall zone and area of perennial pasture in the system. Profitability of kikuyu paddocks is approximately $65/ha/year in the medium rainfall zones, $126/ha/year in the high rainfall zone, and $242/ha/year in the very high rainfall zone. This is approximately $10 – 15/ha/year more than annual volunteer pastures in the high and very high rainfall zones, and is similar to improved pastures in the very high rainfall zone. On average, the optimal area of the farm sown to perennials is approximately 50% of grazing area although this depends on rainfall zone.

3. Perennial pasture - Native grass

Many native grass species are drought-resistant and require low input costs. These characteristics make them suitable for inclusion in a balanced and sustainable grazing system, particularly in low rainfall areas. Little is known about the economic performance of native grasses. In Western Australia, the cost of seed is prohibitively high. Sowing rates are approximately 2 kg/ha for pasture, at a cost of $120/ha. Hence, establishment is approximately $240/ha. Native pastures are rare in Western Australia and are unlikely to be widely adopted due to the lack of established markets for the supply of seed. The current economic viability of non-native perennial pastures in the medium to very high rainfall zones, and the increase in cropping areas in all parts of the South Coast, means that large scale commercial seed markets for native pasture are unlikely to be established in the short to medium term.

4. Pasture cropping

Pasture cropping is a zero tilling technique of sowing annual crops into living perennial pastures. On the South Coast, pasture cropping is being trialled by some farmers with few farmers fully adopting as yet. Economic review of pasture cropping indicates that its profitability is heavily influenced by yield penalties due to competition between the arable crop and host perennial, the number of crop and pasture phases, and the pasture species. Yield penalties due to competition are approximately 30%. It is estimated that “non-thatchy” kikuyu pasture has an indicative equivalent annual profit of $65 – 242/ha/year, a “thatchy” kikuyu pasture has an indicative equivalent annual profit of $53 – 205/ha/year, and that pasture cropping a “thatchy” kikuyu pasture has an indicative equivalent annual profit of $89 - 183/ha/year (depending on the rainfall zone). Pasture cropping “thatchy” kikuyu increases pasture gross margins in the medium rainfall zone by approximately 45% and in the high rainfall zones by approximately 24%. It was not found to increase gross margins in the very high rainfall zone unless stocking rates from the declining quality of kikuyu decrease by more than approximately 25%.

5. Canola cropping

Canola is a profitable cash crop. The main rotational advantage of canola in the South Coastal Region is the ability to grow a profitable break crop on a pasture, with or without any pasture manipulation in the previous year. For most farmers on the South Coast, selection of rotation is driven by profitability, cereal diseases, stubble handling and impacts on stocking rates. Economic review of canola indicates that gross margins are heavily influenced by input costs, time of sowing, rainfall, soil type, occurrence of frost or hail, cost of transport, presence of insects or disease, and farm-gate price. Gross margins of canola on the South Coast are approximately $120/ha/year in the low rainfall zone, $245/ha/year in the medium rainfall zone, and $265/ha/year in the high rainfall zone. Canola is still profitable in cropping areas even under conditions of low prices and yields.

6. Agroforestry

Agroforestry is an activity that combines annual agricultural activities (such as crops and pastures) and tree production (for example timber and services) on the same plot of land. There is significant variation in the literature regarding the economic costs (establishment and maintenance) and benefits of agroforestry depending on whether the tree stands are in blocks or belts, the species of tree, and the management of the trees within the agriculture competition zone (i.e. pruning, thinning, coppicing or a combination). Tree-crop competition for water and nutrients from tree belts presents a significant cost to farmers. In general, agroforestry in the context of integrated farming enterprises is rare on the South Coast, and is not economically viable in the absence of a carbon market, although forage shrubs have economic potential on marginal soils.

7. Soil amelioration – claying

Claying involves incorporating clay into the profile of sandy soils to ameliorate issues such as poor water holding capacity, water repellence, inherent low fertility, extremes of pH, low levels of microbial activity and vulnerability to wind erosion. The biggest overall cost of claying is fuel and labour. Costs of claying are between $300 – 900/ha but benefits can last for more than 15 years. Claying increases profitability for crop dominant rotations where the impacts of claying are moderate (greater than approximately 10%) and the cost of claying is moderate (less than approximately $700/ha). Assuming a cost of claying of $400/ha, a 20% increase in crop yields and stocking rates and a wheat-barley-canola-pasture rotation, claying increases the indicative equivalent annual profit by approximately $20/ha/year (15%) in the low rainfall zone, $50/ha/year (24%) in the medium rainfall zone and $60/ha/year (25%) in high rainfall zone. Crop yield increases from clay addition are most likely to occur where sands are deep (> 60 cm), soils are highly repellent (MED > 2.5), cation exchange capacity (CEC) is low (< 3) and potassium is marginal or deficient (< 50 ppm).

Contents

1. Introduction

Action on the Ground is a component of the Australian Government's Carbon Farming Futures Program that assists farmers and land managers to undertake on-farm trials of abatement technologies, practices and management strategies to measure and demonstrate how they can reduce agricultural greenhouse gas emissions or increase the sequestration of carbon in soil while maintaining or improving farm productivity. South Coast Natural Resource Management Inc. (South Coast NRM) secured Action on the Ground funding for the project "Empowering farmers to adopt behaviour change in a carbon economy". The project is designed to assist on-farm trial and demonstration of practices aimed at increasing the carbon potential of the soil and to mitigate carbon loss in the South Coast of Western Australia.

As part of this project, South Coast NRM contracted the author to conduct an economic review of each of these trial sites in terms of productivity and production costs for implementing the different land management systems and practices. The purpose of the review is to collect and collate economic information and assess the production value and costs associated with implementing these different land management systems and practices. This review is intended to add value to the scientific review of soil carbon data and to highlight the costs, benefits and outcomes of trialled land management systems and practices in a format that enables production decisions to be easily made by farmers.

The economic review involves review of economic impacts of each of the following land management systems and practices conducted at the trial sites:

a. Annual pasture,
b. Perennial pasture - Kikuyu,
c. Perennial pasture - Native grass,
d. Pasture cropping,
e. Canola cropping,
f. Agroforestry, and
g. Soil amelioration – claying.

The methodology for conducting the review is provided in Section 2, and the economic review itself is contained in Section 3.

2. Methodology

The review of each management system or practice includes a summary of a survey of the relevant literature, including (where appropriate) review of the potential production advantages and disadvantages of each system/practice, potential environment advantages, and the risks associated with each practice/system.

Additional to the survey of literature, an economic analysis using current production and market variables is also conducted to provide economic information to farmers who may be making production decisions regarding these practices/systems. This economic information includes indicative costs of establishment and maintenance, indicative expected income and indicative profit over time. The economics of any practice or system is variable and uncertain depending on location along the South Coast, seasonal and market conditions. Hence, economic information provided in this report can only be considered as indicative measures.

The economic analysis is conducted for four regions within the South Coast depending on rainfall:

- Low Rainfall Zone (LRZ): < 325mm/year,
- Medium Rainfall Zone (MRZ): 325 - 450mm/year,
- High Rainfall Zone (HRZ): 450 - 550mm/year, and
- Very High Rainfall Zone (VHRZ): > 550mm/year.

If a farmer's location is close to one of the rainfall thresholds above (i.e. close to 325, 450 or 550mm/year), it is recommended that the information from both adjacent regions be considered.

The economic analysis for each system or practice is conducted using the established model RIM (a decision tool for integrated management of herbicide-resistant annual ryegrass). RIM is used for the following reasons:

1. It is a spreadsheet tool that is flexible and simple enough to apply to new regions and to analyse new management practices, but has enough detail to capture the relevant biological and economic relationships,
2. It is relevant to the paddock scale,
3. RIM represents a number of years (we will apply it to 10 years). The value of manipulating soil carbon requires a long-term view as the economic benefits depends on carbon levels over time,
4. It includes a number of user-specified crop and pastures sequences, rather than fixed rotations. Enterprise options include wheat, barley, canola, lupins, volunteer pasture, subterranean clover pasture, and perennial pasture,
5. RIM includes fuel and machinery costs,
6. It includes quantification of some aspects of environmental benefits and costs,
7. It is a simulation, not an optimisation, model, and
8. RIM evaluates the benefits of management practices on weed control, specifically ryegrass. This is a significant benefit given that many of the land management systems and practices listed above have weed management benefits.

RIM utilises the well-accepted methodology of discounting the future benefit and cost stream over a time horizon (10 years), and an Annual Equivalent Profit (AEP) is calculated. The AEP is the annual amount if a constant profit per ha per year could be earned over the 10 years, allowing for interest and tax.

Results derived from a model such as RIM are contingent upon the assumptions driving them and should be interpreted accordingly. They key assumptions that affect the results of this study or are required by the reader for their accurate interpretation are discussed below.

RIM does not represent year to year variation in weather or price. Yields in the model vary from year to year due only to the sequence of crops and pastures selected. It is recommended that results are considered as indicative only, and that a grower consider further information and their farm-specific variables before adopting any of these practices or systems.

Seven enterprise options are available for selection: wheat, barley, canola (with the default of triazine-tolerant canola), legumes (lupins, chickpeas, field peas or faba beans), regenerating pasture (assumed to be subterranean clover), perennial pasture and volunteer pasture. Almost any sequence of these enterprises can be specified with the exception that legumes or canola cannot be selected for two or more consecutive years due to the very high yield losses that would occur from disease.

The rotational impacts captured within RIM that are dependent on the sequence of crops and pastures and which may affect yields are as follows:

1. A non-legume crop (wheat, barley or canola) grown after a legume (pulse or legume pasture) is expected to achieve a higher yield than if grown after a non-legume crop or volunteer pasture,
2. It is expected that canola or legumes grown after a break of only one year (i.e. after a single year of wheat, barley or canola) will realise a lower than average yield due to the increased risk of disease occurrence, and
3. The set of available weed control options differs depending on the selected crops and pastures. This selection in turn has a bearing on the number of weed seeds in the soil in autumn and the number of weed plants setting seed in spring, resulting in varying levels of weed competition on crops and hence varying crop yields.

It is assumed that a no-tillage crop establishment system is used (knife/narrow points) with minimal soil disturbance. For mixed crop-livestock systems, knock-down, pre-emergent and post-emergent herbicides vary depending on the crop selection and region, and are chosen to keep the number of ryegrass seeds in soil the following autumn at levels less than $100/m^2$. For continuous pasture systems, ryegrass is considered to be a valuable food source and is not controlled.

All crop stubble is retained and harvest weed control is achieved through use of a Harrington seed destructor or narrow windrows burning. Canola is swathed and sprayed with a non-selective herbicide. Machinery costs include purchase and repayment costs, and are only included if a strategy that requires the machinery is selected. The cost is then distributed across all 10 years of the analysis.

RIM is calibrated for each of the three rainfall regions within the South Coast largely from published literature as cited where appropriate. Fertiliser and farm-gate prices are constant across zones according to Table 1. Key standard assumptions that differ across focus regions are presented in Table 2.

Table 1: Fertiliser and farm-gate prices (net of selling costs except transport) used in RIM

	Price ($/t)
Fertiliser prices	
DAP/MAP	750
Urea	570
Farm-gate prices (net of selling costs except transport)	
Wheat	270
Barley	275
Canola	460
Legume	270

Sources: AWB (2015a-c) and Glencore Grain (2015a-c).

Table 2: Summary of key assumptions that differ across the three South Coast rainfall regions (5-year averages)

	LRZ	MRZ	HRZ	VHRZ
	Average yields (t/ha)			
Wheat	1.5	2.3	2.5	2.0
Barley	1.8	2.4	2.7	2.2
Canola	0.7	1.1	1.2	1.0
Legume	1.0	1.5	1.4	1.2
DAP or MAP rates for cereals (kg/ha) [a]	26	46	52	52
Urea rates for cereals (kg/ha)	38	73	89	89
	Other variables			
Stocking rate (DSE/ha)	3	6	9	17
Sheep Gross Margin ($/DSE) [b]	15	27	30	30
Average arable area (ha)	5,500	4,000	2,000	500

Source: Planfarm and Bankwest (2009 - 2013) and discussions with various experts within the Department of agriculture and food, Western Australia (DAFWA)
LRZ = low rainfall zone (< 325mm/year), MRZ = medium rainfall zone (325 – 450mm/year), HRZ = high rainfall zone (450 – 550mm/year), and VHRZ = very high rainfall zone (> 550mm/year)
[a] DAP = Di-ammonium phosphate and MAP = mono-ammonium phosphate
[b] The return expected per dry sheep equivalent, excluding the costs specific to pasture implementation and maintenance.

The results of the indicative standard solution from RIM are summarised in Table 3. Annual gross margin is provided for each phase of the crop/pasture sequence over a 10-year time horizon, as well as the equivalent annual profit. These results are relevant on a paddock-scale, rather than a whole-farm scale. Rotations used differ across regions on the South Coast. Results are provided for a crop-pasture rotation in the low to high rainfall zones (wheat-barley-canola-pasture), and for continuous volunteer pasture in the medium to very-high rainfall zones. For those farm management systems or practices where data is available for estimation of their profitability (i.e. annual pasture, perennial pasture, pasture cropping, canola cropping and claying), an indicative equivalent annual profit is estimated using RIM and compared with the standard solution in Table 3. Estimation of the profitability of two management systems/practices are not included in this report; native grass (due to the lack of knowledge about native pasture characteristics, establishment, management and harvesting and therefore economic performance) and agroforestry (where there is significant variation in the literature regarding the economic costs (establishment and maintenance) and benefits depending on whether the tree stands are in blocks or belts, the species of tree, and the management of the trees within the agriculture competition zone).

Table 3: RIM ANALYSIS - Indicative standard solution for two rotations, including annual gross margins ($/ha/year) and the equivalent annual profit

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Rotation	W	B	C	Pv	W	B	C	Pv	W	B
LRZ	167	269	132	5	220	308	125	-1	246	294
MRZ	323	393	265	54	397	438	247	48	427	425
HRZ	353	454	286	90	433	502	265	84	464	489
Equivalent annual profit* ($/ha/yr)					LRZ: 186		MRZ: 323		HRZ: 365	
Rotation	Pv	Pv	Pv	Pv	Pv	Pv	Pv	Pv	Pv	Pv
MRZ	40	72	72	58	72	72	58	72	72	58
HRZ	76	120	120	103	120	120	103	120	120	106
VHRZ	156	227	227	212	227	227	212	227	227	212
Equivalent annual profit* ($/ha/yr)					MRZ: 67		HRZ: 115		VHRZ: 224	

Note: W = Wheat, B = Barley, C = Canola, Pv = volunteer pasture
* If you could earn a constant profit per ha per year over the 10 years, this is the annual amount that would result in the final balance after 10 years after allowing for interest and tax.

3. Economic review of land management systems and practice

The economic review of key land management systems and practices is presented in this section as follows:

- Annual pasture (Section 3.1),
- Perennial pasture – Kikuyu (Section 3.2),
- Perennial pasture - Native grass (Section 3.3),
- Pasture cropping (Section 3.4),
- Canola cropping (Section 3.5),
- Agroforestry (Section 3.6), and
- Soil amelioration – claying (Section 3.7).

3.1 Annual pasture

Pastures play an important role in agricultural enterprises through animal production, improvements to crop rotations, and conserved fodder. Improved pastures are increasingly being used to play a more comprehensive role in farming systems to address emerging challenges for environmental protection and food production.

A wide range of annual grasses and legumes are available for rain-fed pasture production systems along the South Coast of Western Australia. Legume species in particular are valued for their high quality feeding value and ability to improve soil fertility through nitrogen fixation. The selection of which pasture species to grow is based on climate (amount and reliability), soil conditions (texture) and feed demand as determined by the type of livestock and cropping system. Pastures in the South Coast of Western Australia are typically dominated by annual species, particularly annual ryegrass and subterranean clover (DAFWA 2015a).

Subterranean clover is the dominant annual legume for most pasture mixes (including varieties such as Dalkeith, Coolaman, Riverina, Gosse, Goulburn and Denmark). Including several annual legume varieties allows growth of pastures at different times of the year, and therefore the potential for increased profitability, especially in difficult conditions.

Serradella and medic are other annual legumes that can be used for specific soil types and climatic conditions. Serradella will survive on more acidic and sandier soils where other annual legumes and medics tend to perform poorly. Medics are more suited to heavy loam soils, but are very susceptible to low pH (acidic) soils.

There is a large range of annual ryegrasses; including Dargo, Missile, Progrow, Pronto, Safeguard, Surrey, Abundant and New tetila. Annual ryegrass toxicity (ARGT), can be a livestock health problem associated with some annual ryegrasses

The number of stock a pasture can support without becoming overgrazed and degraded is called its 'carrying capacity'. Carrying capacity is expressed as the number of adult dry sheep equivalents (DSE) that can be grazed on a year round basis on the land without soil degradation, and with only minimal hand feeding in the late summer/autumn period. Some analyses report winter stocking rates (on a winter-grazed hectare basis), which is almost double what can be expected year-round in most areas.

A list of the potential productivity advantages and disadvantages of annual pastures is provided in Table 4, and their environmental advantages and risks are highlighted in Table 5.

Economic review of annual pastures indicates that gross margins of annual pastures are heavily influenced by output prices, the control of feed demand and net pasture production. Feed demand is dependent on stocking rate, lambing date and per head feed demand. Net feed production is the balance between new growth and the senescence of older tissue, which is dependent on soil nutrient levels (nitrogen, phosphorus and potassium), pH, temperature, moisture and drainage (Westwood 2008). The main findings of this economic review are summarised as follows:

- Sanford (2013a) estimated the gross margin of a farm with annual, rather than perennial, pastures to be $150 – 330/ha/year, depending on the stocking rate (8 – 19 DSE/ha) in Wellstead,
- Sanford (2013b) found that whole-farm gross margins of annual perennials depends on the rainfall, and are approximately $50/ha/year in the medium rainfall zone, $200/ha/year in the high rainfall zone, and $600/ha/year in the very high rainfall zone, depending on stocking rate,
- McDowell *et al.* (2003) estimated the equivalent annual net return of annual pastures on the South Coast of Western Australia to be $121/ha/year. This estimate was made assuming a stocking rate of 9.9 DSE/ha, supplementary feeding costs of $19/ha/year, total variable costs $110/ha/year, and a total income of $231/ha/year,
- Masters *et al.* (2006) estimated whole-farm profit to be $10/ha/year in the Albany Eastern Hinterland, assuming a stocking rate of 8.1 DSE/WG ha, supplementary feeding costs of $19/ha/year, 70% of the farm in annual pasture with the rest in crop, wool income of $148/ha/year and sheep sales of $42/ha/year,
- Byrne (2006) estimated that whole-farm profit is approximately $11/ha/year for a self-replacing Merino flock for wool only, and $36/ha/year for a self-replacing Merino flock with crossbred lamb production, when 70% of the farm is allocated to annual pasture production, and the remaining 30% is in crop,
- Sanford and Young (2005) estimate that farm profit is approximately $32/ha/year for a farm in the Albany Eastern Hinterland catchment with an annual rainfall of approximately 600mm/year, with 30% crop and 70% annual subterranean clover pasture, a stocking rate of 8.5 DSE/ha, and assuming a livestock enterprise that is a self-replacing Merino flock utilising surplus ewes for crossbred lamb production, and
- Young *et al.* (2004) report that the profitability of a farm with 70% annual pasture (defined as sub-clover based annual pasture with volunteer grasses and herbs) and 30% crop, to be $10/ha/year for a self-replacing Merino flock (assuming a stocking rate of 8.1 DSE/WG ha) and $32/ha/year for a self-replacing cross bred flock (assuming a stocking rate of 8.4 DSE/WG ha).

Most publically-available studies on the economics of annual pastures are ten or more years old. Few studies have considered the economics of annual pastures in recent years due to the increased research attention given to perennial pastures and increased sowing of crops in traditionally grazed areas. This has largely been the result of reduced economic profitability of livestock relative to crops along the South Coast.

Table 4: Review of potential productivity advantages and disadvantages of including annual pastures in South Coast farming systems

Productivity advantages	Productivity disadvantages
Legume pastures improve soil fertility through nitrogen fixation resulting in higher productivity (due to improved plant health and vigour) and/or reduced input costs in subsequent years	Synchronising peak periods of feed demand for stock with peak periods of annual pasture growth can be challenging, especially on low-productivity soils and where rainfall limits productivity
The inclusion of annual pastures in cropping rotation provides a disease break as pastures are not hosts of many cereal diseases. Well managed, weed-free pastures remove the cereal disease green bridge and may remove the disease residue bridge depending on the environment	Livestock may have limited performance when fed pasture with nutrient imbalances including high or low levels of structural or non-structural carbohydrates, crude protein, trace elements and minerals, and the presence of ant-nutritional compounds
Dense stands of well-adapted annual pasture species compete against weeds, reducing weed numbers and weed seed-set. Competitive pastures greatly improve the effectiveness of other tactics to manage weeds in the pasture phase	Pastures, and their associated livestock enterprise, are more complex in their management requirements compared with cropping only systems, and additional capital investment are required
Pastures provide an effective feedbase for livestock enterprises, which provide diversification of income in a mixed crop-livestock system	Terminating the pasture phase can be difficult when it contains persistent pasture species
The peak periods of feed demand for stock can be synchronised with peak periods of annual pasture growth	Pastures may have potential herbicide residue problems
Pasture can provide a relatively low-cost feed source compared with alternative livestock management systems such as feed-lotting	Livestock grazing on pasture may cause soil compaction and pugging on heavy soils
Pastures can restore compacted soils in some areas	Pastures may reduce moisture in the soil profile for following crops
Pastures can lead to increased soil organic matter levels, leading to an increase in the level and variety of soil organisms. This has the potential agricultural benefits of improving plant productivity, soil structure and disease management, as well as reducing input requirements	Often, potential liveweight gain and reproductive performance of pasture-fed livestock is below genetic potential unless offered high quality supplements

Sources: Collett and McGufficke (2005), GRDC (2011a), Westwood (2008)

Table 5: Review of potential environmental advantages and risks of including perennial pastures in South Coast farming systems

Environmental advantages	Risks
Pastures do not have extensive manure disposal issues compared with feed lotting	Poor and/or inconsistent pasture production may result from drought, hot or cold climatic conditions, limitations of soils, drainage issues and/or inappropriate pasture species
Pastures provide ground cover, reducing the risk of erosion and providing greater water infiltration, potentially preventing running off which can result in soil erosion and sedimentation problems	Pasture-fed livestock may be at risk of bloat and other livestock disorders
Pastures can lead to increased soil organic carbon levels, storing carbon underground and potentially slowing global warming issues	

Sources: Collett and McGufficke (2005), GRDC (2011a), Westwood (2008)

Costs specific to pasture implementation and maintenance for volunteer pasture are generally negligible, especially in the lower rainfall zones. Pastures are generally only improved by some farmers in the high and very high rainfall zones. Costs of improving pastures depend on the region, and include seed (approximately $50 - 100/ha/year), fertiliser ($30 - 60/ha/year), herbicide costs (approximately $5/ha/year) and other additional costs additional costs including insecticides, fungicides, and broadleaf weed control (approximately $10 - 20/ha/year).

Indicative equivalent annual profit from select crop-pasture rotations and continuous annual pasture on a paddock scale (not the whole farm) across rainfall zones is provided in Table 6. Indicative gross margins of the pasture phase within these rotations are provided in Table 7. Generally, the more crop phases in a rotation, the higher the profitability. An exception is the very high rainfall zone where continuous pastures, especially improved pasture, is more profitable than a wheat-pasture rotation.

Table 6: RIM ANALYSIS - Indicative equivalent annual profit for various annual pasture rotations ($/ha/year)

	LRZ	MRZ	HRZ	VHRZ
WBCPv	186	323	365	n/a
CBPvPv	130	233	276	n/a
WPvPvPv	47	146	189	216
Pv	2	67	115	224
P	n/a	54	111	239

W = wheat, B = barley, C = canola, Pv = voluntary pasture, P = improved pasture in year 1 and then volunteer pasture in subsequent years. Stocking rate is higher in first five years of improved pasture.
n/a = not applicable (rotation not used in that rainfall zone)

Table 7: RIM ANALYSIS - Indicative gross margin of pasture phases ($/ha/year) under a number of rotations

	LRZ	MRZ	HRZ	VHRZ
WBCPv	2	51	87	n/a
CBPvPv	2	57	99	n/a
WPvPvPv	-9	48	91	183
Pv	4	64	111	215
P	n/a	56	110	230

W = wheat, B = barley, C = canola, Pv = voluntary pasture, P = improved pasture in year 1 and then volunteer pasture in subsequent years. Stocking rate is higher in first five years of improved pasture.
n/a = not applicable (rotation not used in that rainfall zone)

As highlighted by the earlier economic review, the profitability of annual pastures is dependent on output prices, feed demand and net pasture production. A sensitivity analysis of animal gross margin (which captures fluctuations in output price) and stocking rate (which is an indicator of the paddock's feed demand and net pasture production potential) is presented in Table 8. Results for the low rainfall zone show that including continuous pasture rotations in this region has significant potential to be unprofitable. This reflects reality where farmers rarely use continuous pasture, but are planting unproductive soils to other enterprises such as saltland pasture, lucerne and tagasaste. The sensitivity analysis results from the medium, high and very high rainfall zones show significant fluctuations in profitability depending on gross margin and stocking rate, with opportunities for very high profitability of continuous pasture in the very high rainfall zones with high stocking rates and gross margins.

Table 8: RIM ANALYSIS - Sensitivity analysis on the effect of animal gross margin and stocking rate on indicative gross margins of continuous annual volunteer pasture ($/ha/year)

		LRZ			MRZ		
		Animal Gross Margin ($/DSE)					
		-20%	**Standard**	**+20%**	**-20%**	**Standard**	**+20%**
Stocking rate	**-20%**	-5	-2	1	40	52	64
	Standard	-2	2	6	52	67	81
	+20%	1	6	11	64	81	99
		HRZ			**VHRZ**		
		Animal Gross Margin ($/DSE)					
		-20%	**Standard**	**+20%**	**-20%**	**Standard**	**+20%**
	-20%	71	140	111	141	178	215
	Standard	91	115	140	178	224	270
	+20%	111	91	169	215	270	326

KEY FINDINGS: ANNUAL PASTURES

- Pastures play an important role in agricultural enterprises through animal production, improvements to crop rotations, and conserved fodder,
- Economic review of annual pastures indicates that gross margins of annual pastures are heavily influenced by output prices, the control of feed demand (especially stocking rate) and net pasture production,
- Generally, higher output prices, stocking rate and rainfall are associated with more profitable mixed or continuous pasture rotations,
- Continuous pasture is really only economically competitive on marginal soils or in high (450 – 550 mm/year) or very high rainfall zones (> 550mm/year), and
- Pasture gross margins can range from $40 – 326/ha/year depending on stocking rate, rainfall zone, rotation used and wool/livestock farmgate prices.

3.2 Perennial pasture - Kikuyu

DAFWA (2015b) defines perennial pastures as plants that live for more than two years and include herbaceous legumes, herbs, grasses and fodder shrubs. Perennial pastures have two key benefits:

(1) they have a deep root system which enables them to use water and nutrients from deeper soil layers than annual plants, and
(2) they can extend the growing season at both ends when conditions are favourable.

The interest in perennial pastures in south-western Australia grew from the understanding that there are sustainability constraints to agricultural systems associated with annual pastures and crops (Moore 2006). These sustainability constraints include rising groundwater and the spread of salinity, herbicide resistant weeds, soil acidity and wind erosion. Farmer experience and research have since shown that incorporating well adapted perennial pastures into these systems can improve production, protect natural resources and build the capacity of these systems to adapt to future production and environmental challenges (DAFWA 2015b).

The focus perennial pasture of this review is kikuyu - a sub-tropical grass. Sub-tropical grasses have moderate winter production, good summer production and moderate autumn and spring production. Kikuyu is very well suited to the conditions of the South Coast of Western Australia which are characterised by nil to low frosts, cool winters, mild springs, medium to long growing season (6 – 8 months) and warm to hot summers with 25-35% out-of-season rainfall (Moore *et al.* 2006). Kikuyu has proven to be one of the most widely adopted perennials on the South Coast of WA with an estimated area of more than 150,000ha sown in 2010 (Sanford 2010).

A list of the potential productivity advantages and disadvantages of including perennial pastures in South Coast farming systems are provided in Table 9, and their environmental advantages and risks are highlighted in Table 10.

Economic review of perennial pastures indicates that gross margins of perennial pastures is heavily influenced by the rainfall zone and area of perennial pasture in the system, and have significant impacts on stocking rate, optimal lambing time and supplementary feeding required. A review of the literature of these impacts is provided in Table 11. Key economic findings are as follows:

1. Inclusion of perennial pastures can increase gross margins by 5-10% in the higher rainfall zones of the South Coast (650mm/year) to 400% in the lower rainfall zones (350mm/year),
2. The optimal area sown to perennial pastures depends on the livestock enterprise and the mix of perennial pastures,
3. On average, the optimal area of the farm sown to perennials is approximately 25% of grazing area, although the proportion is higher in the lower rainfall zones (75%) than the higher rainfall zones (25%),
4. Profit can be insensitive to pasture area within a significant range, especially where a mix of perennial pastures is used to provide a range of feed availability due to their different seasonal growth patterns,
5. The inclusion of perennial pastures allows an increase in stocking rate (20 – 30%), pasture use and pasture growth, and

6. Perennial pastures help fill the summer/autumn feed gap and so reduce the amount of supplementary feeding required per animal by approximately 50 – 100%.

Table 9: Review of potential productivity advantages and disadvantages of including perennial pastures in South Coast farming systems

Productivity advantages	**Productivity disadvantages**
Out of season green feed, especially in summer	Higher establishment costs for perennial pastures, compared with annual pastures, with a time-lag until they can be grazed
Increased carrying capacity due to improved seasonal distribution of feed and pasture use	More intensive grazing management to ensure the pastures persist and their quality is maintained
Recognising that as the focus of the livestock enterprise shifts towards meat production, then the value and optimal area of perennial pastures increase	Perennial forages use more of the water within the annual crop rooting zone. The drier soil profile at the end of the pasture phase can result in lower yields of following crops.
Ability to reduce or replace supplementary feeding in autumn	Perennial pastures exacerbate problems with worm control in sheep
Ability to increase production from land with a low carrying capacity	Perennial pastures become difficult weeds to control in crops
Ability to turn-off animals at target liveweights all year round	The 'green bridge' created by perennial pastures increases the incidence of pests and diseases in annual crops and pastures
Reduced wool faults and maintenance of wool fibre diameter and stable strength	A possible need to change rotations on other soil types to achieve the best enterprise mix
Reduced fodder conservation	
Increased winter feed	
Opportunity to rest annual pasture paddocks after the break of the season	
Provision of feed during false break events, where annual pastures suffer reduced seed bank	
Replaced weed burden in pasture due to displacement by perennials	

Sources: Byrne (2006), Dobbe *et al.* (2013), Moore (2006) and Sanford (2010).

Table 10: Review of potential environmental advantages and risks of including perennial pastures in South Coast farming systems

Environmental advantages	**Risks**
Increased water use and reduced deep drainage to groundwater, and therefore reduced risk of dryland salinity or waterlogging	Establishment failure or poor establishment
Maintenance of plant cover in summer to reduce wind erosion. Kikuyu pastures maintained more than 50% ground cover through summer and autumn, even in the driest years	Failure to survive a dry summer
Overcoming water repellent soils by creating preferred pathways which move water in to the soil profile that can subsequently be used for perennial plant growth	Can overwhelm native plants, particularly around creek lines. Care should be taken to manage kikuyu in these circumstances to maintain the environmental and production benefits
Increased perennial cover for waterways	
Slowing the rate of soil acidification via a reduction in nitrate leaching by deep-rooted non-leguminous perennials	
Perennial pastures are generally expected to store more soil carbon than annual pasture due to their extensive root system which persists all year round	

Sources: Byrne (2006), Dobbe *et al.* (2013), Moore (2006) and Sanford (2010).

Table 11: Review of economic benefits from perennial pastures

Factor affecting gross margin	**Economic review**
Area sown to perennial pasture	**Dobbe *et al.* (2013):** • For an average farm on the South Coast, gross margin can increase by approximately \$100/ha/year (or 45%) when 25% of the grazing system is based on perennials with a stocking rate of 8DSE/WG[a] ha, • In a medium rainfall environment (370mm/year), it is optimal to have a higher proportion of perennials in the pasture base (75%, specifically kikuyu) which can lead to an average 65% increase in gross margin at a stocking rate of 4 DSE/WG ha, • In a very high rainfall environment (650mm/year), smaller proportion of perennials (25%) in the pasture base are optimal, leading to a 5 - 10% increase in gross margin with a stocking rate of 12 DSE/WG ha, **Young *et al.* (2004):** • Compared with a system of 70% annual pasture and 30% crop, sheep gross margins can increase by 300% (from \$10/ha/year to \$30/ha/year) if kikuyu replaces 45% of farm that would otherwise be in annual pasture, **Masters *et al.* (2006):** • Compared with a system of 70% annual pasture, a system of 25% annual pasture and 45% kikuyu can increase sheep gross margin by 400% (from \$10/ha/year to \$40/ha/year), **Stanford and Young (2005):**

	• Compared with a system of 70% annual pasture, a system of 23% annual pasture and 47% kikuyu can increase sheep gross margin by 115% (from $32/ha/year to $69/ha/year), **McDowall *et al.* (2003):** • Replacing an annual pasture mix with a kikuyu-annual pasture mix on deep sands near Esperance can increase the gross margin of a cattle enterprise by 20%.
Rainfall zone	• Sanford (2013b) found that including 25 – 75% perennials in South Coast systems can increase whole-farm gross margins by approximately 80% in the medium rainfall zone, 50% in the high rainfall zone, and 13% in the very high rainfall zone.
Stocking rate	• On average, stocking rate can lift from 6.5 to 8.0 DSE/WG ha when perennials are introduced. However, the risk of financial loss in some years was also increased with this higher stocking rate. Also, this stocking rate is highly dependent on rainfall zone (Dobbe *et al.* 2013), • Young *et al.* (2004) and Masters *et al.* (2006) report an annual change in stocking rate of 8.1 to 10.7 DSE/WG ha. • McDowall *et al*. (2003) report a carrying capacity of 0.64 cows/ha for the annual pasture compared with 0.55 cows/ha for the kikuyu mix.
Optimal lambing time	• The optimal lambing type for perennial pasture systems with >75% perennials was June or July in relatively high rainfall areas and May in relatively low rainfall areas (Dobbe *et al.* 2013).
Supplementary feeding	• Perennials typically reduce supplementary feed costs. When supplementary feeding is required, kikuyu is able to tolerate high stocking rates and prevents soil erosion (Dobbe *et al.* 2013), • Young *et al.* (2004) and Masters *et al.* (2006) report a decrease in supplementary feeding from 18.5kg/DSE to 8.3kg/DSE, • McDowall *et al.* (2003) found that the increase in growth margin of a kikuyu mix pasture with an annual pasture is largely due to the elimination of in supplementary feeding costs (from $19/ha/year).
Enterprise type	• Sanford (2013) found that the value of perennial pastures depended significantly on the type of livestock enterprise. For example, a prime lamb enterprise on annual pasture could support a stocking rate of 11 DSE/ha whereas a fine wool enterprise could support a stocking rate of 12 DSE/ha. Gross margins ranged from $50/ha/year for fine wool to$500/ha/year with prime lamb (depending on the cost structure). Perennial pastures were able to increase these gross margins by $50 – 200/ha/year.
Establishment cost	• Perennial pasture establishment costs vary with different species and economies of scale. It is estimated that the cost of establishing kikuyu sown at 1kg/ha is $110 - $190/ha based on the following assumptions: o Chemicals: 0 – 40kg/ha o Kikuyu seed: $40 – 60/kg o Contract seeding: $45 – 65/ha o Own gear: $30 – 90/ha These costs should be annualised over the life of the sward (e.g. approximately 30 years for kikuyu) (Dobbe *et al.* 2013). The above costs do not include lost grazing time during establishment (usually 6 months) and the cost of any additional fertiliser above normal maintenance to establish the sward.

[a] DSE/WG ha = dry sheep equivalent per winter grazed hectare

Current indicative profitability of a continuous perennial pasture paddock is presented in Table 12. This profitability assumes a kikuyu establishment cost of $130/ha/year and fertiliser costs after establishment (to encourage the annual components of the kikuyu sward) of $30/ha/year in the very high rainfall zone and $10/ha/year in the high and medium rainfall zones. These results assume that stocking rate increases above the standard (see Table 2) by 25% in the second and subsequent years after establishment. Indicative equivalent annual profit starts at $65/ha/year in the medium rainfall zones, and approximately doubles for the high rainfall zone ($126/ha/year) and the very high rainfall zone ($242/ha/year). On a paddock basis, this compares favourably with continuous annual volunteer and improved pasture in the high and very high rainfall zones. On a whole-farm basis, this profitability will depend on the percentage of crop and pasture in the system, which is not considered in this analysis.

Table 12: RIM ANALYSIS - Indicative equivalent annual profit ($/ha/year) for continuous perennial pasture compared with continuous annual pasture

	MRZ	HRZ	VHRZ
Continuous perennial pasture	65	126	242
Continuous annual volunteer pasture	67	115	224
Continuous annual improved pasture	54	111	239

Potential profitability given a 20% increase and decrease in animal gross margin and stocking rate is shown in Table 13.

Table 13: RIM ANALYSIS - Sensitivity analysis on the effect of gross margin per DSE and stocking rate on indicative gross margin of continuous kikuyu perennial pastures ($/ha/year)

		MRZ			HRZ			VHRZ		
		Animal Gross Margin ($/DSE)								
		-20%	Standard	+20%	-20%	Standard	+20%	-20%	Standard	+20%
Stocking rate	-20%	31	46	61	71	95	120	138	184	231
	High	46	65	83	95	126	157	184	242	300
	+20%	61	83	105	120	157	194	231	300	370

KEY FINDINGS: PERENNIAL PASTURES - KIKUYU

- Perennial pastures have two key benefits:
    - they have a deep root system which enables them to use water and nutrients from deeper soil layers than annual plants, and
    - they can extend the growing season at both ends when conditions are favourable,
- Kikuyu is very well suited to the conditions of the South Coast of Western Australia and has proven to be one of the most widely adopted perennials on the South Coast of WA,
- Economic review of perennial pastures indicates that the gross margin of kikuyu pasture is heavily influenced by the rainfall zone and area of perennial pasture in the system. Kikuyu has significant impacts on stocking rate and supplementary feeding required,
- Profitability of kikuyu paddocks starts at $65/ha/year in the medium rainfall zones, and approximately doubles for the high rainfall zone ($126/ha/year) and the very high rainfall zone ($242/ha/year). This is approximately $10 – 15/ha/year more than annual volunteer pastures in the high and very high rainfall zones, and is similar to improved pastures in the very high rainfall zone, and
- On average, the optimal area of the farm sown to perennials is approximately 50% of grazing area, although the proportion is higher in the lower rainfall zones (75%) than the higher rainfall zones (25%).

3.3 Perennial pasture - Native grass

Native grasses are, by definition, those grasses that are indigenous (native) to Australia. This is in contrast to how grass species that have their origins in Europe, Asia, Africa and other parts of the world. Over the time of white settlement in Australia and the pastoral development of the country, native grasses have to a large extent been denigrated and replaced by other species. Many of the introduced species are considered to be more nutritious and hence have been accepted and used extensively. Unfortunately, those native grasses that have survived have often been the non-productive and less palatable species. However, many native grass species are drought-resistant and require low input costs. These characteristics make them very suitable for inclusion in a balanced and sustainable grazing system, particularly in low rainfall areas. Examples of native grass species that are suitable for pastures include kangaroo grass, red grass, spear grass, wallaby grass, weeping grass, wheat grass and windmill grass.

The particular focus of this review is Kangaroo grass (*Themeda triandra / Themeda australis*). It is one of the most widespread native grasses in Australia. It is a warm season, deep rooted perennial grass with a soft, erect or sprawling tussocky habit. The leaves of Kangaroo grass are long and thin and as they mature, turn from green to red/brown/purple. Kangaroo grass can grow to a height of 40-90 cm. It spreads by seed, not by root growth, and after harvest, the seed is dormant for six months. Kangaroo grass doesn't grow during winter. It grows on sandy soils to heavy clays and is often common in areas where moisture collects and grazing is infrequent. It also grows in soils of low to moderately-high pH. Kangaroo grass has high drought and heat tolerance, low to moderate frost tolerance, and moderate to good feed value when actively growing. When actively grown, it is best when intermittently grazed (Native Seeds 2015). Kangaroo Grass is a C4 perennial native grass (see definitions of C3 and C4 grasses in Table 14) that grows well on floodways, flood fringes, sands and loams. It is drought tolerant and is best suited for < 400mm/year rainfall zone. It grows well in fresh or saline conditions.

Table 14: Features of C3 and C4 plants

	C3	C4
Initial molecule formed during photosynthesis	3 carbon	4 carbon
Growth period	cool season or yearlong	warm season
Light requirements	lower	higher
Temperature requirements	lower	higher
Moisture requirements	higher	lower
Frost sensitivity	lower	higher
Feed quality	higher	lower
Production	lower	higher
Examples	weeping grass and common wheatgrass	kangaroo grass, red grass and wire grass

Note: Perennial grasses can be classified as either C3 or C4 plants which refer to the different pathways that plants use to capture carbon dioxide during photosynthesis.
Source: NSW DPI (2015)

A list of the potential productivity advantages and disadvantages of including native pastures, in particular kangaroo grass, in South Coast farming systems are provided in Table 15. The main environmental advantages of including native pastures is that they provide a permanent ground cover and therefore have a role in reducing soil erosion, runnoff and increasing water infiltration, and they encouragement of the native plant species within agricultural systems. The lack of knowledge about native pasture characteristics, establishment, management and harvesting is a risk. Little is known about the economic performance of native grasses. In Western Australia, the cost of seed is prohibitively high. Sowing rates are approximately 2 kg/ha for pasture, at a cost of $120/ha. Hence, establishment would be approximately $240/ha.

Table 15: Review of potential productivity advantages and disadvantages of including native pastures in South Coast farming systems

Productivity advantages	Productivity disadvantages
Adaptability to local environmental conditions such as low rainfall, infertile soils and acid soils.	Generally considered to be less productive than introduced pastures (but their adaption can enable them to be more productive and persistent than introduced species in marginal areas)
Low input (fertiliser) requirements	Prone to overgrazing
A sustainable, resilient pasture. Can cope with adverse climate conditions such as droughts, heavy rains and frosts	Wild species have diverse genetic traits, flower over a long period, have lower seed yields or do not yield commercial quantities of viable seed
Potential alternate source of income from the collection and sale of seed	Difficult to establish through sowing with traditional sowing technologies
Deep-rooted and can draw on moisture reserves from deep in the soil profile	Potentially less palatable to stock due to coarse hairy leaves and have lower nutritive values and herbage yield
Can help control dryland salinity due to their deep root systems, summer activity and perennially, reducing recharge to groundwater	Under conditions where improved pasture species perform adequately, native grasses are unlikely to be more productive or be able to compete with improved pasture species
Disease-resistant	
Native grasses respond well to periods of rest and rotational grazing regimes	
Native grasses store soil nitrogen and therefore there is reduced amounts of nutrients available for weeds	
Summer growing pasture providing an option for year-round green feed	

Sources: Bennett (2006), Butler (2008)

Currently, native pasture seed is collected by hand for industries smaller than agriculture, such as mine site rehabilitation and use by council to support local amenities. Native pastures are not mainstream in Western Australia, and are unlikely to become so as there are no established markets for the supply of seed. Demand for this market is low in the south coast given the economic viability of non-native perennial pastures in the medium to very high rainfall zones, and the increase in cropping areas in all parts of the South Coast. Some farmers on the South Coast stop fertilising paddocks to allow local grass species to grow, but these situations are rare given the increasing popularity of crops and perennial pastures.

KEY FINDINGS: PERENNIAL PASTURES – NATIVE GRASSES

- Many native grass species are drought-resistant and require low input costs. These characteristics make them suitable for inclusion in a balanced and sustainable grazing system, particularly in low rainfall areas,
- The lack of knowledge about native pasture characteristics, establishment, management and harvesting is a production risk. Little is known about the economic performance of native grasses,
- In Western Australia, the cost of seed is prohibitively high. Sowing rates are approximately 2 kg/ha for pasture, at a cost of $120/ha. Hence, establishment is approximately $240/ha,
- Native pastures are rare in Western Australia and are unlikely to be widely adopted due to the lack of established markets for the supply of seed. The current economic viability of non-native perennial pastures in the medium to very high rainfall zones, and the increase in cropping areas in all parts of the South Coast, means that large scale commercial seed markets for native pasture are unlikely to be established.

3.4 Pasture cropping

Pasture cropping is a zero tilling technique of sowing annual crops into living perennial pastures (BCG 2015). It combines species with complementary growth periods to improve overall productivity and environmental benefits. Growth of summer active perennial pasture occurs in late spring and summer while winter annual crops grow over winter and early spring. Pasture cropping systems exploit this dynamic and can be used to boost overall feed or grain production (Finlayson *et al.* 2012). The shading crop delays the growth of the pasture until the crop senesces and the canopy opens. After harvest, the pastures respond to removal of the covering crop with reduced "thatchiness" and therefore increased productivity for subsequent years.

In Western Australia, pasture cropping is being trialled on introduced C4 perennials (Kikuyu, Panic and Rhodes grass) (see definitions in Table 14). Although pasture cropping was initial regarded as a means to better utilise poor soils (Hacker *et al.* 2009, Millar and Badgery 2009) it is increasingly being evaluated for use on better soils and at a wider range of locations (Bruce *et al.* 2005, Harris *et al.* 2003, 2007). These perennials have been sown on deep sandy soils which are generally unprofitable to crop, due to poor yields and the need for high inputs. On the South Coast, very few farmers are pasture cropping, and these farmers are still in the trial phase. The benefits of pasture cropping are dependent on seasonal conditions, and hence the trial phase can take a number of years.

A list of the potential advantages of pasture cropping in South Coast farming systems are presented in Table 16, and the potential disadvantages, environmental advantages and risks are reviewed in Table 17.

Economic review of pasture cropping indicates that its profitability is heavily influenced by yield penalties due to competition between the arable crop and host perennial, the number of crop and pasture phases, and the pasture species.

A review of the literature of these impacts is provided in Table 18. Key economic findings are as follows:

1. Pasture cropping has the potential to improve whole farm profitability on poor quality soils that are not generally suited to a high number of cropping phases in a rotation (Hagan *et al.* 2014),
2. The length of the pasture phase has a strong impact on profitability, with a 3-year phase pasture phase before pasture cropping appearing to be the point at which perennials show significant benefits from pasture cropping (Hagan *et al.* 2014),
3. On soils that are consistently unproductive for cropping purposes, pasture cropping can increase whole-farm profitability by between \$1 and \$11/ha/year when three years of perennial pastures are supplemented with a fourth year of pasture cropping (Hagan *et al.* 2014),
4. Pasture cropping is likely to have a niche role on poor sands (the soil type for which subtropical grasses are best suited) rather than becoming ubiquitous on the South Coast of Western Australia,

5. Pasture cropping increased farm profitability in the central wheatbelt of WA by approximately 10% (Findlayson *et al.* 2012), through use on poor sands,

Table 16: Review of potential productivity advantages of pasture cropping in South Coast farming systems

Productivity advantages
Increased productivity of subsequent pastures phases due to decreased "thatchiness" of pasture, especially kikuyu
Resting of the perennial pastures during winter improves their persistence
Potential for pasture density to improve from pasture cropping as new plants can recruit under a weed-free crop
Rejuvenation of clover in subsequent pasture phases
Potential financial benefit from the cash, hay or fodder crop
The supply of nitrogen to the perennial pasture is increased if the crop is a legume, from nitrogen released from the thatch of the perennial pasture, or from fertiliser nitrogen applied to cereal or canola crops. Deep rooted perennials can use nitrogen which has leached below the crop root zone
Where the pasture species is a legume, the pasture adds nitrogen to the soil resulting in reduced nitrogenous fertiliser requirements for the crop
Control of silver grass in perennial pasture
Reduced herbicide costs of cropping as perennial pastures minimise annual weed problems
Even when seasonal conditions results in crop failure, rotational benefits are still achieved from improved pastures and silver grass
Up to six months extra grazing is available during the cropping phase, compared to traditional cropping systems, as little ground preparation and weed control is required before cropping
Perennial grasses are tolerant to a range of herbicides, particularly broad leaf herbicides, allowing weeds to be controlled in the cropping phase
Potential for increased number of crop phases, especially on lighter soils or soils with low fertility and/or poor moisture holding capacity, compared with conventional phase farming
Improved business flexibility and reduced risk. Decision of cropping a perennial pasture can be made once seasonal conditions regarding the break of season is known. Similarly, a cropped perennial pasture can be grazed or cut for hay depending on seasonal conditions and commodity prices.

Sources: Borger and Ferris (2012), Barrett-Lennard *et al.* (2012), Seis (2006), Ward (2012).

Table 17: Review of potential productivity disadvantages, environmental advantages and risks of pasture cropping in South Coast farming systems

Productivity disadvantages	**Environmental advantages**	**Risks**
Loss of grazing area during crop phase	Improved soil health as inputs of carbon and nitrogen from crops can increase soil microbe diversity and quantity.	The crop may not be profitable as perennials are generally sown on poor soils with inherently low crop yield potential (low water and nutrient holding capacities)
Crops may be unprofitable in dry years due to competition from pasture	Pasture cropping reduces incidence of soil erosion compared to annual crop and pasture paddocks.	Poor seasonal conditions can increase the risk of crop failure
Spraying out weeds and sowing a crop may cause a decline in perennial pasture density and productivity	Increased stability of soil supporting the crop. This is especially an advantage for canola on the South Coast	
Knife points can remove perennial plants from the ground		
Specialist equipment may be needed for sowing crops (e.g. a disc machine may be required)		
Producers might compromise effective in-crop weed control to guarantee the survival of their perennials, leading to weedy crops and weed problems in future years		
By spraying out annual pastures to undertake pasture cropping, a years' worth of annual pasture seed production is been removed, reducing productivity of the paddock.		

Sources: Borger and Ferris (2012), Barrett-Lennard *et al.* (2012), Seis (2006), and Ward (2012).

6. Thomas *et al.* (2014) found that pasture cropping was favourable in Jerdacuttup (a South Coast town in the local government area of Ravensthorpe) due to its cold growing season, plant-available water holding capacity at anthesis and winter-spring rain. The crops did not rely on stored soil moister, growing instead on incident rain, and
7. High levels of inputs do not enhance crop yield in a pasture-cropping system. Grain yield losses are lower in the low input system as competition between species is reduced in a nitrogen-limited environment and the extent of the competition is dependent on season (Lawes *et al.* 2014).

Table 18: Review of economic benefits from pasture cropping

Factor affecting gross margin	Economic review
Yields penalty experienced during the crop phase	**Hagan *et al.* (2014)** – Northern agricultural region • The yield penalty of lupins sown into a perennial pasture compared with a conventional lupins crop is approximately 30%, • The yield penalty of wheat sown into a perennial pasture compared with a conventional wheat crop is approximately 40%, **Badgery and Millar (2009)** – New South Wales • The yield penalty of wheat sown into a perennial pasture compared with a conventional wheat crop is approximately 30 – 50%, **Ferris (2015)** – Northern agricultural region • The yield penalty of lupin sown into a perennial pasture compared with a conventional wheat crop is approximately 30%, • The yield penalty of wheat sown into a perennial pasture compared with a conventional wheat crop is approximately 30-40%, depending on pasture species **Ferris *et al.* (2010)** • Yield penalty for wheat was 15% when pasture-cropped **Thomas *et al.* (2014)** - Jerdacuttup • Yield penalty of barley was 10% when pasture-cropped **Lawes *et al.* (2014)** - Moora • Under high-input conditions, the yield penalty for cereals was 26% and lupins was 29% • In Moora, under low-input conditions, there were no yield penalties. In fact, yields can increase for barley by 10 – 40% and lupins by 15%.
Number of pasture phases	• Hagan *et al.* (2014) found that profit is maximised with three years of perennial crops and one year of pasture cropping. This system lead to a $15/ha/year increase in gross margin compared with three years of annual pastures and one year of conventional cropping in 2012 but no economic benefit in 2013.
Pasture species	**Ferris (2015)** • The yield penalty of pasture cropping of wheat was: o 3% for Burgundy bean, o 16% for Consol lovegrass, o 18% for Premier digit grass, o 30% for low density Gatton panic grass, and o 36% for higher density Gatton panic grass.

[a] DSE/WG ha = dry sheep equivalent per winter grazed hectare

Indicative assumptions regarding receipts, expenses and annual gross margins of pasture cropping are shown in Table 19. In our analysis, we assume that pasture cropping is only conducted on kikuyu perennial pasture systems which have become "thatchy". Stocking rates are assumed to decrease by 25% in years 5 to 10 due to this thatchiness. Canola is assumed to be swathed and followed by a non-selective herbicide. While growers may prefer to feed the hay to their livestock, the benefit of the hay is considered to be the value of replacing the purchase of supplementary feeding at the value of the hay if it were sold. Yield penalties due to competition between the crop and host perennial are 30% for both the canola and wheat-hay crops.

Table 19: RIM ANALYSIS - Indicative receipts, expenses and annual gross margin of pasture cropping ($/ha/year)

	Kik	**Kik**	**Kik**	**Kik**	**Kik**	**Canola**	**Hay**	**Kik**	**Kik**	**Kik**
VHRZ										
Receipts	283	170	292	292	227	336	246	243	292	292
Weed control costs	19	0	0	0	56	65	41	0	0	0
Other costs	111	30	30	30	30	179	178	30	30	30
Annual gross margins	**153**	**140**	**262**	**262**	**141**	**92**	**27**	**213**	**262**	**262**
HRZ										
Receipts	150	90	155	155	120	575	439	129	155	155
Weed control costs	19	0	0	0	56	65	41	0	0	0
Other costs	111	10	10	10	10	179	178	10	10	10
Annual gross margins	**20**	**80**	**145**	**145**	**54**	**332**	**220**	**119**	**144**	**144**
MRZ										
Receipts	90	54	93	93	72	527	404	77	93	93
Weed control costs	19	0	0	0	56	65	41	0	0	0
Other costs	111	10	10	10	10	158	161	10	10	10
Annual gross margins	**- 40**	**44**	**83**	**83**	**6**	**305**	**202**	**67**	**83**	**83**

Table 20 provides indicative profitability estimates of pasture cropping and associated stocking rates in the medium to very high rainfall zones on the South Coast. Pasture cropping systems as outlined above are found to increase the indicative equivalent annual profit from $53/ha/year to $89/ha/year in the medium rainfall zone, and from $107/ha/year to $141/ha/year in the high rainfall zone. This is a 45% increase in the medium rainfall zone, and a 24% increase in the high rainfall zone. The pasture cropping system was found to decrease profitability in the very high rainfall zone by 12%. This pasture cropping system would break-even if the kikuyu pasture lost productivity due to thatchiness leading to a reduction in stocking rate from 21 to 17DSE/ha or more. In that case, pasture cropping would become economically viable.

Table 20: RIM ANALYSIS - Indicative equivalent annual profit under various ($/ha/year)

	MRZ	HRZ	VHRZ
Indicative equivalent annual profit ($/ha/year)			
Non-thatchy kikuyu – high stocking rates in year 3 to 10	65	126	242
Thatchy kikuyu – stocking rates reduce to standard in year 5 to 10.	53	107	205
Pasture cropping – Kikuyu pasture with a canola crop in year 5 and hay crop in year 6, followed by high stocking rates	89	141	183
Stocking rates (DSE/ha)			
High stocking rate	7	11	21
Standard stocking rate	6	9	17
Breakeven stocking rate	n/a	n/a	15

W = wheat, B = barley, C = canola, Pv = voluntary pasture, P = improved pasture in year 1 and then volunteer pasture in subsequent years. Stocking rate is higher in first five years of improved pasture.
n/a = not applicable as pasture cropping has a higher profitability than a thatch perennial kikuyu.

KEY FINDINGS: PASTURE CROPPING

- Pasture cropping is a zero tilling technique of sowing annual crops into living perennial pastures,
- In Western Australia, pasture cropping is being trialled by farmers on introduced C4 perennials (Kikuyu, Panic and Rhodes grass). Few farmers have fully adopted it,
- Economic review of pasture cropping indicates that its profitability is heavily influenced by yield penalties due to competition between the arable crop and host perennial, the number of crop and pasture phases, and the pasture species.
- Yield penalties due to competition between the crop and host perennial are approximately 30%,
- Pasture cropping has the potential to improve whole farm profitability on poor quality soils that are not generally suited to a high number of cropping phases in a rotation,
- Pasture cropping kikuyu pastures that have become “thatchy” increases pasture gross margins in the medium rainfall zone by approximately 45% and in the high rainfall zones by approximately 24%. It was not found to increase gross margins in the very high rainfall zone unless stocking rates from the declining quality of kikuyu decrease by more than approximately 25%.

3.5 Canola cropping

Canola is Western Australia's third largest crop after wheat and barley, with production reaching 1.8 million tonnes in 2013 valued at just over 1 billion dollars (DAFWA 2014). Almost all canola produced in Western Australia is exported to Asia for human use and to Europe for biofuels. Approximately 8% of the State's total canola production is crushed locally (in Pinjarra and Kojonup). The rest is exported unprocessed (DAFWA 2014). Although canola is a profitable cash crop for farmers, it is valuable for other reasons. It is an important break crop for cereal production, replacing lupins in many areas due to a higher farm-gate price and cheaper weed control options. Both conventional and genetically modified canola varieties are grown in Western Australia, with strict segregation in the supply chain allowing the two systems to co-exist.

The vast majority (87%) of the Western Australian canola crop is Triazine Tolerant (TT). All Roundup Ready® (RR) canola is genetically modified and is grown on the remaining 13% (DAFWA 2014). The most popular canola varieties grown last year were Crusher TT, ATR Stingray, ATR cobbler, Hyola 404RR and ATR Snapper. These five varieties made up over 70% of hectares sown to canola in the 2013/14 season (DAFWA 2014).

For most farms on the South Coast, selection of rotation is driven by profitability, cereal diseases, stubble handling and impacts on stocking rates. The main rotational advantage of canola in the South Coastal Region is the ability to grow a profitable break crop on a pasture, with or without any pasture manipulation in the previous year (Eksteen 2000). Successful rotations rely on canola being sown onto pasture to make the best use of the fixed nitrogen, and to prepare the paddock for a high yielding wheat or barley crop in the following year.

Some common rotation options for canola on the South Coast include (W = wheat, L = lupins, C = canola, P = pasture, B = barley, O = Oats):

- PCWBPC
- PCWLOBPC
- PCWLBOPC

Other options are:

- PCWBCP (suitable for heavy soils where stubble can be removed without risk of erosion)
- PCWBPPC
- PCWLWP

OIAWA provides gross margins for yields 0.4 – 1.8 and prices \$320 – 420/t ranging from -\$141 to \$425/ha/year.

A list of the potential productivity advantages and disadvantages are listed in Table 21. Risks of canola cropping include yield failure due to drought, insects, disease, frost or heat stress, and potential high input costs.

Table 21: Review of potential advantages, disadvantages and risks of including canola in South Coast farming systems

Productivity advantages	**Productivity disadvantages**
Profitable with high-value established markets.	Disease susceptibility
An more profitable alternative to pasture with similar break crop advantages	Not as drought tolerant as wheat, requiring good conserved moisture and good finishing rains
Reduced incidence of disease in subsequent winter cereal crops due to removal of their grass weed hosts	Susceptible to insects in early seedling stage
The rotation of hervicide groups reduces the potential for herbicide resistance to develop and for herbicide residues to accumulate in the soil	Canola seedlings are particularly vulnerable to sand blasting
Canola leaves a more friable topsoil which is well suited to the direct drilling of the following cereal crop	High demand for disease, pest and weed monitoring and control
Can be produced in most arable areas of Australia where winter crops are currently grown	Higher nutritional requirements than cereals
Can be grown on a wide variety of soil types (does best in areas where spring rains are reliable and high)	
Allows pasture paddocks to be cropped with or without the need for severe pasture manipulation to control grass weeds and root diseases	
Spreads the time available to use machinery and labour because of canola's earlier sowing and harvest timing relative to cereals	
Compared to cereals, canola is very resilient to frost	
Canola provides a range of grain delivery and marketing options. Selling grain off the header at harvest can give growers an early cashflow and reduce on-farm storage demand, while storing or warehousing canola can spread price risk and provide marketing flexibility.	
GM technology provides opportunities for development of functional foods, improved pest, weed and/or disease tolerance, oil and/or protein modification	
Strong domestic consumption and role as healthy alternative oil	
Has potential for price increases with increased demand (e.g. opportunities for biodiesel with increasing petroleum price or for human use as a healthy alternative oil) and potential for improving quality (e.g. oil, chlorophyll, protein, amino acids, saturates)	

Sources: AOF (2015), Eksteen (2000), Parker (2009).

Economic review of canola indicates that gross margins are heavily influenced by input costs, time of sowing, rainfall, soil type, occurrence of frost or hail, cost of transport, presence of insects or disease, and farm-gate price.

Input costs

Knowckdown herbicides are recommended before seeding canola as weeds can reduce yield potential dramatically. Atrazine and Simazine is recommended before or after seeding. Fertiliser inputs to canola are recommended by OIAWA (2006) according to Table 22.

Table 22: Canola fertiliser input requirements by rainfall zone

	HRZ	MRZ	LRZ
Yield potential (t/ha)	1.8 – 2.5	1.2 – 1.8	0.8 - 1.2
	Rate of nitrogen (kg/ha)		
Canola following a cereal	80 - 110	50 – 80	30 - 60
Canola following a legume or pasture	50 - 80	30 – 50	20 - 40
	Rate of phosphorus (kg/ha)		
	15 - 20	10 – 15	10 - 15

Source: OIAWA (2006)

Canola crops are very susceptible to pest attack in the early seedling stage. Some of the problem insects include redlegged earth mite, bryobia mite, balaustium mites, cutworms and brown pasture loopers, cabbage white butterfly, diamondback moth, vegetable weevil, vegetable beetle larva, false wireworm, snails and slugs and aphids.

Canola can be infected by a number of pathogens in Australia, ranging from root rots to leaf disease and crown to stem infections. As with all diseases, their presence and severity depends on plant susceptibility, presence of the pathogen and favourable climatic conditions (Marcroft and Hind-Lanoiselet 2009). Generally, fungal diseases such as blackleg and Sclerotinia are more damaging in higher rainfall regions, but if unseasonably high rainfall occurs in lower rainfall regions these areas may also experience high disease levels. Disease control varies for each pathogen but generally variety resistance, crop production practices and fungicides are used, either alone or in combination to reduce economic losses.

Time of sowing

Sowing time is a compromise between sowing too early, which may increase the risk of frost damage and, and sowing too late which increases the risk of the crop undergoing seed development in increasingly hot and dry conditions, reducing the yield potential and oil content of the grain.

In general, sowing at the earliest time within the optimum window pays off in a number of ways, as earlier sown crops:

- generally have higher seed and oil yields as the crop finishes under cooler, moister, conditions. A premium is paid for oil content above 42 per cent;
- allow for better coordination of sowing and harvesting, as these operations for canola are well ahead of wheat;
- grow faster initially and so compete better with weeds; and
- normally have fewer problems with insect pests, such as aphids, in spring.

Time of sowing should be ideally mid-April to late May for most parts of the South Coast. In the low rainfall area it is recommended to sow in early April if possible but not in March. Dry sowing is not recommended on the South Coast because of sand blasting risk and large areas of non-wetting soils.

Soil type

Canola grows well on most soil types, but it prefers well drained gravel soils, red loams, sandy loams and deeper duplex soils. Soil pH levels (in $CaCl_2$) of 4.5 to 8.0 are suitable. In acid soils (< 4.5 pH), canola has shown yield responses to applications of lime (Eksteen 2000).

Rainfall

Rainfall has a significant impact on yield and the farm area with which growers are choosing to plant canola (Table 23).

Table 23: Canola yield and farm areas on the South Coast from 2009 to 2013

	2009	2010	2012	2013	Average
High rainfall					
Yield (t/ha)	1.04	0.97	1.45	1.53	**1.25**
Area of farm (ha)	469	681	430	1015	**649**
% of farm in canola	25	25	20	26	**24**
Medium rainfall					
Yield (t/ha)	1.05	0.79	1.05	1.50	**1.10**
Area of farm (ha)	853	801	855	875	**846**
% of farm in canola	19	24	23	21	**22**
Low rainfall					
Yield (t/ha)	0.65	0.39	0.59	1.30	**0.73**
Area of farm (ha)	493	560	777	683	**628**
% of farm in canola	10	10	14	12	**11**

Note: 2011 data not available.
Source: Planfarm and Bankwest (2009 - 2013)

Table 24 displays the results of a sensitivity analysis on the impact of farmgate price and yield on the indicative gross margin of canola under two rotations. Canola remains profitable even with low yields and farmgate price. A 20% decrease or increase in yield has a greater impact on gross margin than the same percentage change in price. Hence, farmers stand to profit considerably by improving the yields on their farm.

Table 24: RIM ANALYSIS - Sensitivity Analysis of the effect of farmgate price, yield and rotation on the indicative gross margin of canola ($/ha/year)

	LRZ	**MRZ**	**HRZ**	**LRZ**	**MRZ**	**HRZ**	**LRZ**	**MRZ**	**HRZ**
	20% reduction in farmgate price ($368/t)								
	20% reduction in yield			Standard yields			20% increase in yields		
WBCPv	20	86	91	68	162	173	116	237	255
CBPvPv	13	75	80	58	146	157	103	217	234
	Standard farmgate price ($460/t)								
	20% reduction in yield			Standard yields			20% increase in yields		
WBCPv	68	162	173	128	256	275	188	350	378
CBPvPv	58	146	157	114	235	254	171	323	350
	20% increase in farmgate price ($552/t)								
	20% reduction in yield			Standard yields			20% increase in yields		
WBCPv	116	237	255	188	350	378	260	463	501
CBPvPv	103	217	234	171	323	350	141	430	466

W = wheat, B = barley, C = canola, Pv = voluntary pasture

KEY FINDINGS: CANOLA CROPPING

- Canola is Western Australia's third largest crop after wheat and barley, with production reaching 1.8 million tonnes in 2013 valued at just over 1 billion dollars,
- Canola is a profitable cash crop for South Coast farmers,
- The main rotational advantage of canola in the South Coastal Region is the ability to grow a profitable break crop on a pasture, with or without any pasture manipulation in the previous year
- The vast majority (87%) of the Western Australian canola crop is Triazine Tolerant (TT),
- For most farms on the South Coast, selection of rotation is driven by profitability, cereal diseases, stubble handling and impacts on stocking rates,
- Economic review of canola indicates that gross margins are heavily influenced by input costs, time of sowing, rainfall, soil type, occurrence of frost or hail, cost of transport, presence of insects or disease, and farm-gate price,
- Gross margins of canola on the South Coast are approximately $120/ha/year in the low rainfall zone, $245/ha/year in the medium rainfall zone, and $265/ha/year in the high rainfall zone, and
- Canola is still profitable in cropping areas even under conditions of low prices and yields.

3.6 Agroforestry

Removal of native vegetation to facilitate traditional agriculture practices has been shown to reduce ecosystem health, and restricts the native habitat. The subsequent change in water use patterns has altered the catchment water balance and hydrology, resulting in land degradation through salinisation and water logging. More recently, moves toward more sustainable farming practices have been taken to help re-establish catchment hydrological equilibrium and improve catchment ecosystem services. Agroforestry is one such vehicle for this reestablishment. Agrofrestry is an activity that combines annual agricultural activities (such as crops and pastures) and tree production (for example timber and services) on the same plot of land. This is achieved either by planting trees on agricultural land or by cropping forested land.

Agroforestry is seen as a potential opportunity to develop new agricultural landscapes that interlace ecosystem services (such as carbon mitigation via carbon sequestration), the production of biofuels, biodiversity restoration and watershed management while maintaining food production (George *et al.* 2012). Active markets are developing for some of these ecosystem services. However a lack of predictive metrics and a sufficient regulatory environment are impeding the adoption of several ecosystem services.

Bennett & George (2008) identify the species best suited for the south-west of Western Australia due to their adaptation to site conditions, high water use and multiple uses. They include blue gum (*Eucalyptus globulus*, *E. saligna*), maritime pine (*Pinus Pinaster*), red river gum (*E. camaldulensis,* salt river gum (*E. sargentii*), swamp sheoak (*Casuarina obesa*), swamp yate (*E. occidentalis*), and river red gum (*E. camaldulensis*).

A list of the potential production advantages and disadvantages of agroforestry in South Coast farming systems are presented in Table 25, and environmental advantages and overall risks are presented in Table 26.

Flugge and Abadi (2006) estimate the establishment expenses for a natural revegetation (based on *Eucalypt* spp) plantation in Kojonup to be $840/ha which includes fencing, land preparation, seedlings and planting, weed management and insurance. Maintenance costs are $25/ha which includes general maintenance and monitoring, and insurance. They argue that in the absence of a carbon market, agroforestry is not economically viable. The carbon price would need to be $25 – 46/t CO_2-e higher than expected for forestry to be economically viable.

The effect of alternating native perennial tree belts with traditional broad acre agriculture in the alleys is referred to as alley farming. Of the alley farming designs tested, the optimal planting density and belt/alley design, from an economic perspective, is identified as 4m belt width to generate the greatest biomass.

Sudmeyer and Simons (2008) investigated tree-belts in the Neridup catchment, north of Esperance, which occupied 10% of the catchment and the lateral spread of outer tree roots meant recharge was effectively eliminated over 20% of the catchment. However, groundwater at the site continued to rise for 13 years after the trees were planted. Tree growth was poor and the estimated economic returns from the pulpwood production were less than from agriculture. There was reduced crop and pasture growth in the adjacent 15-20m wide competition zone where agriculture production was less than breakeven. There was no economic advantage in growing pulpwood in belts rather than in blocks. Thinning the trees to 125 stems/ha allowed improved crop and pasture production and reduced wind erosion in the cropping zones, and facilitated greater growth rates of the remaining trees. It remains to be determined whether increased economic returns from the trees will compensate for the cost of thinning and pruning. Sudmeyer and Simons argued that E. globulus is not a suitable agroforestry tree species for medium rainfall sites with deep sands and brackish groundwater. Other tree species may be more suited to these sites and achieve better economic and hydrological outcomes for landholders.

Table 25: Review of potential productivity advantages and disadvantages of including agroforestry in South Coast farming systems

Productivity advantages	**Productivity disadvantages**
Diversification of agricultural activities	Can introduce tree/crop competition for water
Potential build-up of an inheritance of valuable trees	Agricultural returns can be reduced for two to three years after the trees are harvested because of reduced plant-available water and nutrients
Protection of intercrops and livestock from wind, sun and rain	Management for fodder could be in direct conflict with timber production
Recover of some of the leached nutrients from deep roots of the trees	Agroforestry reduces availability of land for agricultural or other uses
Enrichment of soil organic matter by tree litter and by the dead roots of the trees	Shading has been shown to reduce the level of soluble carbohydrate in pasture which reduces palatability and this may reduce utilisation of the shaded pasture
Possible remuneration from sale of tree products	
Provision of some fodder extending the grazing calendar	
Increased use of stored water during establishment. Agroforestry can increase the depth to groundwater within the area planted and therefore mitigate salinity	
Food and fibre production is maintained in a new sustainable agricultural landscape	
Protection from chemical drift from neighbouring paddocks	

Sources: Abel *et al.* (1997), Sudmeyer and Daniels (2008), Sudmeyer & Simons (2008), Bennett & George (2008), George *et al.* (2012) and Young *et al.* (2004).

Table 26: Review of potential environmental advantages and risks of including agroforestry in South Coast farming systems

Environmental advantages	Risks
Reduced incidence of wind erosion or sand blasting	Not all agroforestry species are tolerant of waterlogged or saline soils
Protection of fauna from wind, sun and rain	Grazing needs to be managed carefully to reduce damage to trees by stock
Stimulation of soil microfauna and microflora	Heaving grazing or lopping would reduce effectiveness of shade and shelter aspects of agroforestry
Carbon sequestration from tree rows	
Increased build-up of soil organic carbon under tree and cultivated land	
Improvement of habitat biodiversity and act as corridors for some species	
Control of soil losses due to overland flow of water runoff	
Potential impact on scenic quality	

Sources: Abel *et al.* (1997), Sudmeyer and Daniels (2008), Sudmeyer & Simons (2008), Bennett & George (2008), George *et al.* (2012) and Young *et al.* (2004).

Hut *et al.* 2003 argues that in the low to medium rainfall areas of Australia the availability of water is likely to exert greater influence on crop productivity than variations in light or temperature due to the presence of the trees (Huth *et al.* 2003). Noorduijn (2008) suggests that the benefits of alley farming as a means of controlling recharge is limited in some areas due the shallow saline water table which limits perennial growth.

Of late, most of the attention on tree-based alley farming has been on mallee-based agroforestry which has potential to provide farmers with new income sources derived from biofuels, biofeedstocks, and carbon sequestration (e.g. Smith 2009, He *et al.* 2012). Although mallees are planted on greater than 12,700ha across the south-west of Western Australia, very little commercial harvesting of mallee has occurred to date. Sudmeyer *et al.* (2012) found that mallee–crop competition was negatively correlated with rainfall and positively correlated with mallee age and size, and greater for crops than pasture. On average, mallee–crop competition extended 11.3m from unharvested belts and reduced crop and pasture yields by 36% within 2 to 20m of the mallee belts relative to open paddock yields. Harvesting mallees reduced competition such that crop and pasture yield was reduced by 22 to 27% relative to open paddock yields. The opportunity cost of competition was equivalent to forgoing agricultural production for 14m on each side of unharvested mallee belts, or 9 to 10m on each side of harvested belts. This research shows that mallee–crop competition presents a significant cost to farmers and must be considered when designing mallee agroforestry systems.

Sudmeyer and Flugge (2005) investigated the effect of agroforestry on annual equivalent return (or annual equivalent profit), from crops and pastures within the competition zone of trees with various management treatments (Table 27). They found that windbreaks can have a negative impact of crop-pasture profits, timber belts may have a positive impact, and mallee hedges generally have smaller positive impacts.

Table 27: Increase in annual equivalent return (ER) from crops and pasture within the competition zone of trees with various management treatments.

Planting type	Increase (over control) in AER due to management of competition ($/kg)				
	Root-pruned every 3 years	Root barrier or pruned annually	Trees thinned	Coppiced	Coppiced and pruned
Windbreak	-14 – 193	-1,309	-	-	-
Timber belt	-	-	104	-	-
Mallee hedge	13 - 79	72	-	4 – 16	-5 - 51

Source: Sudmeyer and Flugge (2005). Note: Values for one side of the trees only.

Monjardino *et al.* (2010) consider the potential contribution of forage shrubs to economic returns and environmental management in Australian dryland agricultural systems. Their modelling indicated that including forage shrubs had the potential to increase farm profitability by an average of 24% for an optimal 10% of farm area used for shrubs in the central wheatbelt of Western Australia. 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 deferment of use of other feed sources on the farm, allowing a higher stocking rate and improved animal production. The benefits for natural resource management and the environment include improved water use through summer-active, deep-rooted plants, and carbon storage. Forage shrubs also allow for the productive use of marginal soils.

KEY FINDINGS: AGROFORESTRY

- Agrofrestry is an activity that combines annual agricultural activities (such as crops and pastures) and tree production (for example timber and services) on the same plot of land,
- Agroforestry has been considered as a sustainable farming system that helps re-establish catchment hydrological equilibrium and improved catchment ecosystem services,
- There is significant variation in the literature regarding the economic costs (establishment and maintenance) and benefits of agroforestry depending on whether the tree stands are in blocks or belts, the species of tree, and the management of the trees within the agriculture competition zone (i.e. pruning, thinning, coppicing or a combination),
- Tree-crop competition for water and nutrients from tree belts presents a significant cost to farmers which should be considered when designing agroforestry systems, and
- In general, agroforestry in the context of integrated farming enterprises is rare on the South Coast, and is not economically viable in the absence of a carbon market, although forage shrubs have economic potential on marginal soils.

3.7 Soil amelioration - claying

Across Western and South Australia there are many millions of hectares of deep sand or sand over clay-rich subsoils that are used for agricultural production. However, these sandy soils present a range of challenges due to their poor water holding capacity, water repellence, inherent low fertility, extremes of pH, low levels of microbial activity and vulnerability to wind erosion.

Raising the clay content changes the soil texture class, which increases the capacity for the soil to store water, nutrients and soil organic carbon. Experience has found that it is feasible and profitable to raise the percentage of clay in the soil to above five per cent through claying. For example, adding 200t/ha of soil containing 30 per cent clay would raise the clay content in the topsoil from 0.5 to about five per cent, if incorporated to 10cm (GRDC 2011b).

The addition of clay to soils has been practised by farmers in the Netherlands since the 1940s and in Australia since the 1960s. Clay is applied to the topsoil by spreading or by delving. Clay spreading involves exposing a clay 'pit' within a 1 km radius of where it is to be applied, using scrapers or carry graders to collect and deposit the clay material in strips or as a compete layer on the soil. The clay is incorporated into the soil through iron bars ('smudged') or tines. Clay delving involves using a delving blade at an angle of 45 degrees to lift subsoil clays to the surface. Clay needs to be within 50 cm of the surface for most delving operations to be effective.

Historically, the addition of claying has been used to ameliorate water repellence in soils. Water repellence occurs where small amounts of particulate organic matter cover the surface of sands. The low surface area of sands renders them more susceptible to repellence than soils with a higher surface area such as clays. In theory, increasing the surface area of a soil by adding clay will 'dilute' and 'mask' the particulate organic matter to the extent that water infiltration is no longer retarded. Water repellent soils generally have clay contents of less than 1% and only exists in the top 100mm cultivated layer (DAFWA 2006). The increase in farming systems which increase soil carbon such as stubble retention and no till farming are contributing to the increase in water repellency.

The aim after clay spreading is to achieve clay content in water repellent topsoil of 3-4 per cent if the soil has an organic carbon content of less than one per cent or, to increase the clay content to 5-6 per cent if the organic carbon content is greater than one per cent (Davies *et al.* 2012). Provided that appropriate methods are followed, remediating sandy soils with clay-rich subsoil can result in substantial yield improvements. Trials in WA and SA have reported yield improvements of 20 to 130 per cent across cereal, lupin and canola crops in the years following clay additions (GRDC 2011b).

Most of the published experiments have shown substantial reductions in repellence and increases in biomass and crop yields where the surface clay content of the topsoil was increased beyond 3 per cent (DAFWA 2009). For example, claying has been shown to increase yields in Dalyup (within the local government area of Esperance) by 23-85%, Esperance Downs by 85% and Woogenellup (in the Shire of Plantagenet) by 27-93%. The improvements in crop yields are principally attributed to wetting and greater water storage within the surface soils.

Claying has other targets, and has shown to provide moderate yield increases and improved weed control in soils not prone to non-wetting. Claying can increase pH (in some soils from 4 to 7), increased cation exchange, and increased potassium and organic cation levels resulting in reduced wind control. Crop yield increases from clay addition are most likely to occur where sands are deep (> 60 cm), soils are highly repellent (MED > 2.5), cation exchange capacity (CEC) is low (< 3) and potassium is marginal or deficient (< 50 ppm).

However, claying has caused yield decreases in some circumstances. It is only beneficial in wet years when the rainfall from April to October is greater than 175mm. It can reduce crop yields in dry years. Also, some clay is naturally low in potassium (< 50 ppm) and has little nutrient benefit. Subsoil compaction will occur during the claying operation as a result of heavy equipment and repeated passes during the 'smudging' and incorporation operations. Also, crop yield reduction often occurs where high rates of clay have been applied without adequate incorporation. This has resulted in surface sealing, poor seedling emergence, stunted root growth and inadequate water infiltration. The combination of reduced water infiltration and root growth results in crops 'haying off' prematurely (DAFWA 2009).

More nutrients need to be applied before and after claying. Approximately 600-700kg/ha of copper, zinc, molybdenum should be applied prior to delving, 5t/ha of lime along with 100 kg/ha of manganese and 2 t/ha of gypsum should be applied post preparation. The cost of applying clay ranges from $300 to $900/ha (DAFWA 2009). The biggest overall cost of claying is fuel and labour, so finding a clay pit as central as possible is the cheapest option. Claying benefits can be realised for more than 15 years after application.

A list of the potential production advantages and disadvantages of including perennial pastures in South Coast farming systems are presented in Table 28 and a list of potential environmental advantages and overall risks is provided in Table 29.

Key economic findings from an economic review of claying are as follows:

- Clay water repellent soils resulting in increases of greater than 50% in crop yields over 15 years (Hall *et al.* 2015),
- Hall *et al* (2010) found crop yields were increased by 0.3 – 0.6t/ha as a result of clay in Dalyup (west of Esperance). Greatest effects on water repellence resulting in highest yields was clay content of 3 – 6% in soils with approximately 1% organic carbon, Longer term effects of claying included increased soil organic carbon by 0.2%, pH by 0.6 units, potassium by 47 mg/kg, soil strength by 250 kPa, and cation exchange capacity by 1.3 $cmol_c$/kg to a depth of 0.1 m,
- The highest clay rates (>3–6%) had cumulative discounted cash returns $100–200/ha/year higher than the unclayed 'control' treatment and $300/ha/year higher than the lowest clay rates. For most of the clay treatments, deep ripping increased discounted returns between 2005 and 2007 by $80–120/ha/year (Hall *et al.* 2010),
- Cost of claying is $500 – 700/ha (Hall *et al.* 2010),
- Davies *et al.* (2012) estimate the wheat yield response to be 0.3 - 0.6t/ha in the central and northern wheatbelt, and
- Davies *et al.* (2012) estimate that clay spreading or delving cost $300 – 900/ha with yield increases experienced over 15 years or more.

Table 28: Review of potential production advantages and disadvantages of claying in South Coast farming systems

Productivity advantages	**Productivity disadvantages**
Significant increases in production (>50% in crop yields which do not diminish with time).	Some clay is naturally low in potassium (< 50ppm) and has little nutrient benefit.
Moisture infiltration increases by 3% with the addition of the clay and the water repellency rating of the soil reduces from high severity to zero in the second year after application. This allows for earlier seeding operations.	Subsoil compaction can occur as a result of heavy equipment and repeated passes during the 'smudging' and incorporation operations
The majority of weeds seeds germinate evenly, and not stagged, as happens with non-wetting soil. This allows better herbicide activity and weed kill	More nutrients need to be applied before and after claying (copper, zinc, molybdenup, lime, manganese and gypsum).
Increasing cation exchange capacity improving retention of nutrients including phosphorus and potassium	High fuel and labour costs associated with applying clay
Increased pH	
Increased soil organic carbon	

Sources: DAFWA (2006, 2009), Davies *et al.* (2012), Hall *et al.* (2010, 2015).

Table 29: Review of potential environmental advantages, and risks of claying in South Coast farming systems

Environmental advantages	**Risks**
Wind erosion is controlled as clayed sands develop a crust after rainfall strong enough to prevent wind erosion when undisturbed.	Crop yield reduction can occur where high rates of clay have been applied without adequate incorporation which results in surface sealing, poor seedling emergence, stunted root growth and inadequate water infiltration. The combination of reduced water infiltration and root growth results in crops 'haying off' prematurely
Soil microbial activity is encouraged during the longer periods of soil wetness.	Clay particles may contain toxic compounds such as salt and toxic concentrations of boron or carbonate, or extremes in pH.
	Heavy clay rich subsoil application rates of 200t/ha or more are difficult to incorporate and more costly to apply given the high volumes that need to be excavated and spread.
	Can cause yield decreases in dry years (when rainfall from April to October is less than 175mm)

Sources: DAFWA (2006,2009), Davies *et al.* (2012) and Hall *et al.* (2010, 2015).

We consider the case where poor performing soils are clayed in the cropping areas of the South Coast (excluding the very high rainfall zone). We assume that these soils have a productivity capacity 20% lower than average[1]. Indicative equivalent annual profit of these below-average-productivity soils is shown in Table 30. We conduct a sensitivity analysis on the cost of claying and the impact of claying in Table 31. We assume two levels of costs; low ($400/ha) and high ($800/ha), and two levels of impact; low (a 10% increase in crop yields and stocking rates) and moderate (a 20% increase in crop yields and stocking rates). The results for which claying increases profitability (the corresponding results in Table 31 are higher than the results in Table 30) are highlighted in yellow. Claying is found to be profitable only for crop dominant rotations where the impacts of claying are moderate and the cost of claying is low. The exception to this statement is crop dominant rotations in the high rainfall zone where claying is beneficial over the 10-year time horizon even with low impacts and high costs of claying.

Table 30: RIM ANALYSIS - Indicative equivalent annual profit under various crop rotations where average stocking rate and crop yields are decreased by 20% ($/ha/year)

	LRZ	MRZ	HRZ
WBCPv	115	218	249
CBPvPv	78	156	188
WPvPvPv	19	98	131

W = wheat, B = barley, C = canola, Pv = voluntary pasture

Table 31: RIM ANALYSIS - Indicative equivalent annual profit with claying ($/ha/year)

	LRZ	MRZ	HRZ	LRZ	MRZ	HRZ
	Low cost of claying ($400/ha)					
	Low impact			Moderate impact		
WBCPv	97	217	254	132	269	312
CBPvPv	51	141	179	76	179	223
WPvPvPv	-20	69	107	-6	93	135
	High cost of claying ($800/ha)					
	Low impact			Moderate impact		
WBCPv	43	164	200	79	216	258
CBPvPv	-3	88	125	23	126	169
WPvPvPv	-74	15	53	-60	40	82

W = wheat, B = barley, C = canola, Pv = voluntary pasture
Low Impact = 10% increase in yield and stocking rate
High impact = 20% increase in yield and stocking rate

[1] Taken as the average decrease in crop yields of the bottom 25% of farms on the South Coast as presented by Planfarm and Bankwest (2009 – 2013).

KEY FINDINGS: SOIL AMELIORATION - CLAYING

- Sandy soils present a range of challenges due to their poor water holding capacity, water repellence, inherent low fertility, extremes of pH, low levels of microbial activity and vulnerability to wind erosion,
- It is feasible to raise the percentage of clay in the soil to above five per cent through claying,
- Claying has been shown to increase yields on the South Coast by 20 to 90% primarily due to wetting and greater water storage within the surface soils, although it has caused yield decreases in some circumstances (e.g. in dry years or where clay has not been adequately incorporated),
- The biggest overall cost of claying is fuel and labour, so finding a clay pit as central as possible is the cheapest option. Costs of claying are between $300 – 900/ha,
- Claying benefits can be realised for more than 15 years after application,
- Claying increases profitability for crop dominant rotations where the impacts of claying are moderate (greater than approximately 10%) and the cost of claying is moderate (less than approximately $700/ha/year). The benefits are greater for higher rainfall zones, and
- Crop yield increases from clay addition are most likely to occur where sands are deep (> 60 cm), soils are highly repellent (MED > 2.5), cation exchange capacity (CEC) is low (< 3) and potassium is marginal or deficient (< 50 ppm).

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