A farm level assessment of a novel drought tolerant forage: Tedera (*Bituminaria bituminosa* C.H.Stirt var. *albomarginata*).

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Tedera (*Bituminaria bituminosa* C.H.Stirt var. *albomarginata*) is a drought tolerant perennial legume originating in the Canary Islands. This study evaluates the potential role and value of tedera in dryland mixed crop and sheep production systems in southern Australia. Regional variants of the bio-economic model MIDAS are used to assess tedera in farming systems at two locations. The analysis considers the quantity and quality of feed produced by tedera, the ability of other forages to complement or substitute for tedera and its impact on meat versus wool-producing sheep flocks. The results indicate that tedera offers the potential to increase farm profits by up to 26% and be grown on ~28% of a low rainfall mixed enterprise farm. On a high rainfall mixed enterprise farm tedera may boost profit by up to 58% and be grown on ~75% of the farm. The increase in profit is attributable to savings in supplementary feed and higher stocking rates.

Keywords: tedera; drought tolerant; forage; legume; Mediterranean-type climate; autumn feed gap; bio-economic modelling; whole farm modelling; technology evaluation; MIDAS; model of dryland agricultural system.

Introduction.

Tedera (*Bituminaria bituminosa* C.H.Stirt var. *albomarginata*) is an herbaceous deep rooted perennial legume that has been used by farmers in the Canary Islands for hundreds of years where it is grazed in-situ or is cut and fed green to dairy goats (Méndez 2000). In the last decade tedera has attracted attention from the scientific community (Gintzburger and le Houérou 2003; Ventura *et al.* 2004; Sternberg *et al.* 2006; Mendez *et al.* 2006; Ventura *et al.* 2009). Of particular interest are tedera's extreme drought tolerance and its ability to produce relatively high quality feed throughout the year. Tedera remains green in summer and autumn in Mediterranean-like climates with minimal loss of leaves and it grows on a wide variety of soils.

Tedera was introduced to Australia in 2005 and it is being evaluated experimentally for potential release as a commercial forage crop. The assessment of tedera is still at a relatively early stage and there remain uncertainties about its ability to contribute to Australian farming systems. The experimental plantings of tedera in Australia have mostly been in Western Australia where a number of experiments have considered issues such as: the risk of tedera becoming a weed; its ability to grow on a range of soils and with varying temperature and rainfall conditions; its palatability for sheep and whether it adversely affects meat quality and animal health. Other research has involved breeding and selecting tedera for characteristics such as forage and seed yield, drought tolerance, and pest and disease tolerance.

One of the experiments assessed the effect of planting density and frequency of defoliation on the yield and quality of tedera at three sites over two years (Suriyagoda *et al.* 2011). The sites were located at Buntine, Merredin and Newdegate in Western Australia (see Figure 1). These sites have similar annual rainfalls (~300 mm) but differ in their length of growing season, summer and winter temperatures and soils. Although considerable experimental and breeding work is still needed, the trial demonstrated that tedera has potential to contribute to dryland farming systems in southern Australia.

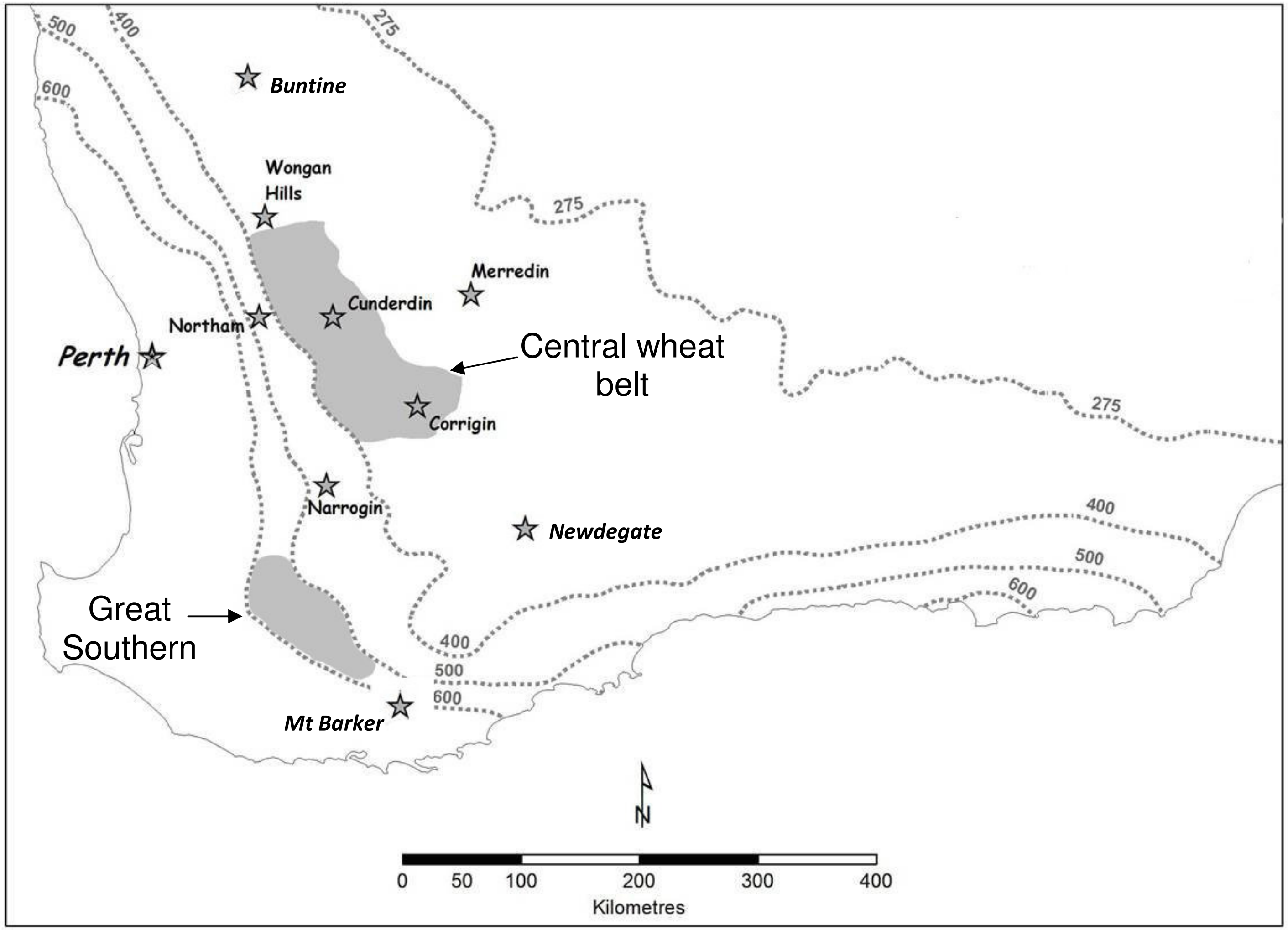

Figure 1. Location of central wheat belt and Great Southern regions in Western Australia.

Additional grazing experiments are proposed in Western Australia, New South Wales and Victoria, leading to further selection of accessions for traits suited to the range of target environments. To assist researchers in selecting tedera it is important to understand what attributes contribute most value when incorporated into farming systems. In this study bio-economic modelling was used to provide information about the value of tedera, and its traits, in different environments and farming systems. An advantage of bio-economic modelling is that it enables the traits of most and least economic importance to be quickly identified, thereby helping researchers to better target their selection and prioritise measurements to be made in field experiments. In this way costly and wasteful experimental programs can be avoided and issues with critical economic and agronomic importance can be prioritised.

The modelling approach in this study relies on MIDAS (Model of an Integrated Dryland Agricultural System) (Bathgate et al. 2009, Kingwell and Pannell 1987, Kingwell 2002 & 2011, Morrison et al. 1986, O'Connell et al. 2006). The model and its application to the assessment of tedera are described in the next section.

2. Methods

2.1 Study area

The role and value of tedera for mixed crop and livestock farms was assessed in two regions in Western Australia. The central wheat belt is centered on the town Cunderdin (31°39'S 117°14'E) ~160 km east of Perth. It has an area of ~5.2 million ha and receives an average annual rainfall of 350-400 mm/year. The other region is the upper Great Southern region which is ~300 km south west of Perth and it has an average annual rainfall of 500-600 mm (see Figure 1) and an area of ~1.0 million ha.

Both regions have Mediterranean-type climates with hot dry summers and cool wet winters. The growing season for annual crops and pasture is normally from April/May until October in the central wheat belt, or November in the upper Great Southern region. The rainfall and temperatures that occur in these regions are typical of much of southern Australia.

In both regions sheep are the main livestock enterprise and in current production systems the most critical time of year for feed is at the end of summer when the quality of dry annual pasture and crop residues from the preceding winter tend to be low (Robertson *et al*. 2010). The existence of an autumn feed-gap has important implications for farm profitability, with sheep often being fed supplements such as grain and conserved fodder in autumn (Moore *et al*. 2009; Young *et al*. 2011).

In the central wheat belt, farming systems are dominated by cropping while in the Great Southern region, sheep provide the majority of income. Rainfall and consequently production per hectare is lower in the central wheat belt, but farms are generally larger than in the Great Southern region. In both regions the sheep systems mainly involve Merinos and include both wool and meat-dominant systems, with meat production being more prevalent in the Great Southern region. On meat-dominant farms, income is mainly from merino ewes producing crossbred lambs for meat, and replacement ewes are purchased.

In the central wheat belt, annual pasture usually consists of the sown species subterranean clover (*Trifolium subterraneum* L.) and/or seradella (*Ornithopus sp.*) with volunteer annual grasses and herbs such as capeweed (*Arctotheca calendula* (L.) Levyns*)* on acidic soils. On neutral and alkaline soils, annual species of *Medicago* are sown and occur with volunteer species. In the Great Southern region subterranean clover is the dominant annual legume with volunteer grasses such as annual ryegrass (*Lolium rigidum* Gaud.), barley grass (*Hordeum leporinum* Link) and herbs such as capeweed and geranium (*Erodium sp.*).

Lucerne (*Medicago sativa* L.) is sometimes grown with the aim of producing feed in late spring and summer which is outside the normal winter growing period for annuals. The ability of lucerne to produce summer feed reduces the autumn feed-gap but it can still be drought-affected. Leaf drop by lucerne occurs in summer in both regions but particularly in the central wheat belt where the summers are hotter and drier. Lucerne is regarded as moderately suitable forage in the central wheat belt and highly suitable in the Great Southern region (Robertson 2006). However, the variable yield of lucerne and its susceptibility to drought means the area of lucerne in Western Australia is small compared to its potential (Bennett 2009).

In the central wheat belt, cropping systems are based around wheat (*Triticum aestivum* L.), and to a lesser extent barley (*Hordeum vulgare* L.) and oats (*Avena sativa* L.), in rotation with canola (*Brassica napus* L.) and grain legumes including narrow-leafed lupin (*Lupinus angustifolius* L.) and field peas (*Pisum sativum* L.). In the Great Southern region, cropping traditionally involved growing barley and oats for grain to feed sheep. More recently grain sales from lupins, canola and wheat have become more important (Young *et al.* 1995, ABS 2008).

The role of crop and pasture rotations in mixed farming systems are described by Reeves and Ewing (1993) and Loi *et al.* (2005). They distinguish short sequences of annual pastures, that self regenerate, from longer periods of perennial pasture (typically lucerne) that are re-sown. In both cases the pasture phase alternates with single or multiple years of cropping. In the remainder of this paper the term 'pasture' refers to mixes of annual species and the term 'lucerne' is used in its conventional sense.

2.2 MIDAS model

MIDAS is a whole-farm bio-economic linear programming model which represents the biological, physical, technical and managerial relationships of a mixed farm in a specified region (Kingwell and Pannell 1987; Morrison *et al.* 1986) for an average weather year. There are a number of regional versions of MIDAS across southern Australia, each of which represents crop and pasture sequences, livestock enterprises, soil types, prices, production responses, labour, machinery and capital requirements at typical levels for the respective regions (Ewing and Flugge 2004; Finlayson *et al.* 2010).

The model maximizes farm profit subject to various environmental, managerial and resource constraints (Pannell 1996). MIDAS is a deterministic model and variations in prices and productivities are not endogenously considered. However, prices and production levels can be varied to assess their influence on the selected mix of enterprises and farm profit (Pannell 1997). Time periods are included in MIDAS to represent the supply and demand for time-critical resources with forage production and consumption, cash flow and the effect of time of sowing on crop yield, being examples of variables whose level varies during the year.

The central wheat belt model and Great Southern models include ~80 rotations or sequences of crops and forages and a number of soil types (see Table 1 and Table 2). Crops on these soils are responsive to phosphate and superphosphate which are normally applied annually (Young *et al.* 1995). Crop yields are modeled as a function of the rotation, soil, and management inputs such as fertilizer and time of sowing. The livestock variables include wool cut, wool fibre diameter, hauteur and live weight. Input costs include fertiliser, chemicals for weed, pest and disease control, machinery, seasonal labour, crop insurance, seed costs, selling costs, transport, ownership costs of capital assets and sheep husbandry. Commodity prices are averages of the last 5 years, adjusted using the Consumer Price Index, to reflect current values (see Table 3).

Table 1. Description of soils in the central wheat belt version of the MIDAS model. Soils are described by Lantzke N. 1992. Soils of the Northam Advisoy District-The Zone of Ancient Drainage, Bulletin No.4244.

	Name	Description	Modeled area (ha)
1	Poor sands	Loose, white and pale yellow sands. Low moisture and nutrient availability.	140
2	Average sand-plain	Yellow sandy soils with topsoil.	210
3	Good sand-plain	Often contains large percentages of ironstone gravel.	350
4	Shallow duplex soil	Occurs down slope from good sand-plain and extends towards the valley floor.	210
5	Medium heavy	Above average quality soil suitable for cereals, lupins and pasture.	200
6	Heavy valley floors	Contains heavy red and grey soils. Can produce good cereals, field pea crops and medic based pastures.	200
7	Sandy surfaced valleys	Shallow soils are good quality and suitable for cereal and pasture production and deep soils are of average to good quality and suitable for cereals, pastures and lupins.	300
8	Deep duplex soil	Generally a productive soil with good moisture and nutrient availability.	390
	Total area		2000

Table 1. Description of soils in the Great Southern version of the MIDAS model.

	Name	Description	Modeled area (ha)
1	Saline soils	Shallow saline soils over heavy gleyed or mottled clay.	100
2	Waterlogged soils	Deep sands often waterlogged over grey gleyed clay.	150
3	Deep sands	Deep sands but not waterlogged over mottled clay.	50
4	Sandy gravels	Gravels and sandy gravels to 500 mm over clay or gravelly clay.	500
5	Sandy loams	Sandy loam, loamy sand over clay. Rock outcropping in landscape.	200
	Total area		1000

Table 2. Farm gate prices. The cost of transporting inputs and outputs is assumed be the same in the central wheat belt and Great Southern versions of MIDAS

Commodity	Price at farm gate	
Canola	512	$/tonne
Lupins	240	$/tonne
Wheat	250	$/tonne
Wool	9.70	$/kg
Cull for age ewes	54	$/head
Shippers	77	$/head
Merino Prime Lambs	4.00	$/kg dead weight
Hired labour	1,200	$/week
Diesel	1.27	$/litre
Di-Ammonium Phosphate	1,030	$/tonne
Super Phosphate	430	$/tonne
Urea	740	$/tonne

2.3 Yield of crops and forage in MIDAS.

The annual yields of selected arable and forage crops are included in Table 4. These were estimated by ensuring at least a hectare of each crop occurred on each soil when solving the model. The yields reflect a range of factors including climate, soils, level of fertilizer use, timeliness of sowing, the selected rotation, and grazing management. It can be seen that the yields of canola and forages are higher in the Great Southern model while wheat and lupin yields are similar in the two regions. The results are consistent with the relatively better performance of forage, and hence animals, in the Great Southern region. The Great Southern region experiences a longer growing season with higher rainfall that particularly benefits forages and canola.

Table 3. Annual yield of selected crops on different soils (kg/ha). The table values refer to the yield of saleable product (canola, lupins and wheat), and dry matter production (pasture, lucerne and tedera). Yield estimates were estimated by ensuring at least one hectare of crop was grown on each soil.

			Central Wheat Belt			
Soil	Canola	Lupins	Wheat	Pasture	Lucerne	Tedera
1	-	554	871	832	1,628	1,302
2	747	1,187	1,517	1,677	2,117	1,693
3	1,121	1,286	2,103	2,768	2,931	2,344
4	883	791	1,845	1,874	2,380	1,954
5	1,050	989	1,992	2,763	3,256	2,605
6	1,000	-	2,164	1,886	2,442	1,954
7	900	-	1,967	1,801	2,442	1,954
8	1,000	1,123	2,006	2,039	3,253	2,605
			Great Southern Model			
Soil	Canola	Lupins	Wheat	Pasture	Lucerne	Tedera
1	-	-	113	1,560	2,468	1,974
2	-	160	847	4,319	2,468	1,974
3	-	848	1,411	5,028	4,936	3,949
4	1,979	1,348	2,126	6,197	5,560	4,442
5	1,979	1,348	2,218	6,627	6,178	4,936

In the following discussion the seasons are referred to as autumn (March-May), winter (June-August), spring (September-November), and summer (December-February). The beginning of the growing season is normally in late autumn. Annual pasture grows from May until October and it is typically the main source of feed in winter and spring. Compared to the other forages annual pasture achieves its maximum growth rate early in the growing season. In terms of regional differences, the maximum growth rate of annual pasture is less and it occurs earlier in the central wheat belt than the Great Southern region (see Table 5).

Lucerne is usually grown in phase rotations with annual crops and in Western Australia a stand of lucerne typically lasts three to five years before it is renewed. As a stand becomes older it becomes prone to invasion by weeds. A relatively high level of weed control is often applied. To renew lucerne, the stand is typically sprayed out, and the land is cropped for several years, before it is replanted.

Lucerne is beneficial to the following crops, due to its nitrogen fixation, its role as a weed and disease break and as a salinity management tool (Robertson 2006), but it is relatively expensive to establish and remove. Lucerne is intermediate in its seasonality and in the timing of its maximum growth relative to pasture and tedera. Most lucerne production (~60-70%) occurs between late September and November and there is some growth in all of the modeled periods.

The production of tedera at different times of the year was estimated by extrapolating the yield from two trials in Western Australia (Suriyagoda et al. 2011) which included four cutting dates (January, May, August, November) to the ten periods considered in MIDAS. The data that describe the seasonal pattern of production for tedera were relatively limited, but our estimates suggest Tedera was less seasonal than pasture or lucerne, and its maximum growth rate did not occur until after the other forages.

The annual dry matter production of tedera was assumed to be 80% of the average annual yield of lucerne on each soil. We believe this was a conservative assumption as the yield of tedera was similar to lucerne in a number of experiments involving different soils, seasonal patterns of rainfall, soils and planting densities (Real et al. 2011; Suriyagoda et al. 2011). The yield of lucerne was recorded but not reported in Suriyagoda et al. Their data suggest tedera had the same or higher annual yield as lucerne at Buntine and Merridin, but at the most southerly site, Newdegate, the yield of tedera was ~80% of lucerne.

Another reason the estimated yield of tedera might be conservative relates to the removal of weeds and annual species in Suriyagoda et al.'s (2011) experiment. Removing weeds is labour intensive, but it eliminated a source of experimental error, and it was consistent with recommended practice to control weeds in lucerne. However, tedera may be more tolerant than lucerne weed competition and winter active pasture species (Suriyagoda, pers comm.). If this is the case, annuals might be grown in a mixed sward with tedera and contribute useful feed in winter, without adversely affecting tedera production in summer and autumn. Clearly, there is considerable uncertainty about the best management of tedera that will only be resolved with additional experimentation. The point here is Suriyagoda *et al*. may have underestimated the amount of dry matter production that can be achieved from a mixed tedera sward relative to conventionally managed lucerne.

The final reason we believe the yield of tedera might be higher than we estimated was the tedera plants in Suriyagoda *et al*.'s experiment were grown from unselected accessions. Tedera is now subject to a breeding program so the variability between individual plants should decline and the average yield increase as the breeding program progresses. Balanced against this the analysis does not consider anti-nutritional factors that could reduce the value of tedera. Anti-nutritional factors are relatively common amongst forages. For example, lucerne and clover contain chemical compounds that cause bloat while phalaris and ryegrass can cause staggers.

It is known that tedera contains furanocoumarins in its leaves, stems and fruit. These are of concern as similar compounds have been linked to photo-sensitisation in grazing animals (Oertli *et al.* 1984; Oertli *et al.* 1983). However, furanocoumarins may protect the plant from pests (Ivie 1987) and to date there are no reports in the scientific literature, or by farmers, that tedera has caused health problems in grazing animals. This will continue to be assessed carefully by scientists as this could affect the breeding program or place limitations on the use and management of tedera by farmers.

Table 4. Growth of forage in different periods (kg/ha/day) on highest yielding soil.

Period	Starting date	Number of days	Central Wheat Belt			Great Southern		
			Pasture	Lucerne	Tedera	Pasture	Lucerne	Tedera
1	10-May	14	18.2	4.4	4.4	22.0	7.1	8.3
2	24-May	21	7.3	5.2	3.9	16.9	7.1	7.3
3	14-Jun	35	8.7	5.0	3.9	11.3	7.7	7.3
4	19-Jul	56	11.1	9.1	5.3	35.2	9.5	10.0
5	13-Sep	28	50.3	21.1	6.6	65.7	36.9	12.5
6	11-Oct	21	1.1	37.9	6.6	83.8	79.0	12.5
7	1-Nov	35	-	14.4	12.5	-	51.9	23.7
8	6-Dec	85	-	3.7	10.6	-	5.0	20.0
9	1-Mar	56	-	2.5	5.3	-	2.4	10.1
10	26-Apr	13	-	4.0	5.3	-	4.8	10.1

2.4 Including tedera in MIDAS

Currently there is little information about the long term persistence of tedera. Similarly, it is not clear if tedera can be immediately replanted to form a continuous sward, or if tedera needs to be managed as a phase rotation (much like lucerne) where tedera is grown for a number of years alternating with several years of crops. Compared to a permanent stand of tedera, removal and replanting involves additional costs without (at this point) identifiable financial benefits. In this study we included tedera as a continuous forage rather than as a rotational phase as farmers are time-pressed (Kingwell 2011). We assumed the financial costs of establishing and maintaining tedera are the same as for lucerne. Because lucerne is relatively expensive to manage, we believe this is a conservative assumption, albeit it involves uncertainty.

Tedera is likely to have implications for the labour requirements of a farm. To the extent that tedera reduces the need to hand feed supplements it will reduce the need for labour. However, if tedera is associated with increases in sheep numbers, these are more labour intensive than crops. We did not explicitly analyze the implications of tedera for labour but mention labour requirements could affect the uptake of tedera particularly in remote areas (Doole et al. 2009, Rose 2011).

The dry matter production of tedera (*T*, kg/ha) at different times of the year was expressed as follows:

$$\sum_{t=1}^{m} T_{t,s} = \sum_{t=1}^{m} L_{t,s} \cdot a \qquad (1)$$

where *t* identifies the time period, *m* is the number of time periods in a year, *s* is the soil type, *L* is dry matter production of lucerne (kg/ha) and *a* scales the yield of tedera relative to lucerne. The amount of dry matter increases with growth (*G*, kg/ha/period) and it can be grazed by animals (*I* , kg/ha/period) or transferred to a subsequent period.

$$T_t = T_{t-1} b_{t-1} + G_t - I_t \qquad (2)$$

The proportion of forage transferred to the next period, *b*, reflects senescence and decay with *b* varying between regions, the time of year the transfer occurs, and the type of forage being considered (see Table 6). The tedera sub-model has a similar structure to annual pasture and lucerne. The model allows pasture to be grazed throughout the year but the quantity and quality of summer-grazed pastures are lower than winter-grazed pastures. In the case of lucerne, inter-period transfers occur in winter but not in summer. The assumptions reflect declines in the quantity and quality of annual pasture and leaf shedding by lucerne in summer.

We assumed the value of *b* was the same for tedera and lucerne in winter, and in summer the value of *b* for tedera was 0.8 or equivalent to a 20% loss per period. The summer transfers of tedera are equivalent to losses of existing plant material of ~0.5% per day (Wilson and t'Mannetje 1978). The losses in the quantity of tedera in summer are greater than annual pasture losses at the same time of the year. However, the quality of dry pasture residues in summer is lower than tedera (see Table 8). This is consistent with quality, rather than quantity, limiting the value of pasture as a summer feed (Brown 1977; Rossiter et al. 1994).

Table 5. Proportion of forage transferred to the next period (b, see equation 2).

Period	Central Wheat Belt			Great Southern		
	Pasture	Lucerne	Tedera	Pasture	Lucerne	Tedera
1	0.99	0.96	0.96	0.99	0.96	0.96
2	0.98	0.97	0.97	0.97	0.96	0.96
3	0.97	0.96	0.96	0.91	0.96	0.96
4	0.81	0.95	0.95	0.87	0.97	0.97
5	0.86	0.94	0.94	0.88	0.96	0.96
6	0.89	0	0.80	0.88	0.95	0.95
7	0.84	0	0.80	0.74	0.94	0.94
8	0.81	0	0.80	0.85	0.94	0.94
9	0.90	0	0.80	0.93	0	0.80
10	0.96	0	0.80	0.80	0	0.80

Animal intake is calculated as a function of the animal's energy requirements and the maximum amount the animal can eat. This ensures animals are not able to consume unrealistic quantities of low quality feed. This is expressed as:

$$A \cdot E_t^R < \sum_{f=1}^{n} \left(I_t^f E_t^f \right) \tag{3}$$

and

$$A \cdot R_t > \sum_{f=1}^{n} \left(I_t^f C_t^f \right) \tag{4}$$

where A is the number of animals in dry sheep equivalents (DSE); E^R is the energy requirement of the animal (MJME/DSE); I is intake (kg); f identifies the feed source (pasture, lucerne, tedera, stubble, and supplement); n is the number of feed sources; and E^f is the energy content of the respective feed (MJME/kg); R reflects a physical constraint on the amount of feed an animal is able to ingest (kg); and C^f relates to the digestibility and availability of a feed and determines the maximum amount an animal can consume (see Tables 7 and 8). It should be noted animal feed is represented for three classes of animals (ewes, wethers, and lambs), each of which has differing energy requirements and abilities to ingest feed at different times of the year.

2.4 Modeling Approach

2.4.1 Standard runs

The implications of differing tedera yields, for wool and meat-dominant sheep and crop farms, in the central wheat belt and Great Southern regions was evaluated. In the first scenario, tedera was excluded as an option from the farm plan. Tedera was then included with its annual dry matter production at 40, 60 and 80% of the annual yield of lucerne. As discussed earlier in this paper we consider the highest yielding treatment to be a conservative estimate of the expected yield of tedera. The inclusion of the lower yielding

Table 6 Metabolisable energy requirement and rumen capacity of selected livestock classes in the Central Wheat Belt Model.

Period starting	Metabolisable energy requirement (E^R, MJME/day/DSE)			Rumen capacity (R)		
	Composite merino ewe and lamb (18 - 65 months)	Merino ewe hogget	Merino wether hogget (sold at 17 months)	Composite merino ewe and lamb (18 - 65 months)	Merino ewe hogget	Merino wether hogget (sold at 17 months)
10-May	14.6	6.0	4.2	1.9	1.6	1.8
24-May	15.0	8.3	9.4	2.4	1.6	1.8
14-Jun	18.5	13.6	15.3	2.1	1.6	1.8
19-Jul	15.5	15.9	18.0	1.5	1.6	1.8
13-Sep	15.9	13.8	13.8	1.5	1.3	1.3
11-Oct	13.7	12.6	12.6	1.6	1.4	1.4
1-Nov	9.1	8.7	8.7	1.5	1.5	1.5
6-Dec	8.9	8.8	8.8	1.5	1.5	1.5
1-Mar	8.8	7.1	6.6	1.6	1.6	1.6
26-Apr	11.1	7.2	6.1	1.7	1.7	1.7

Table 7 Metabolisable energy content and digestibility of pasture, lucerne and tedera in the Central Wheat Belt Model.

Period	Metabolisable energy content (E^f , MJME/kg)			Forage digestibility (%)		
starting	Pasture	Lucerne	Tedera	Pasture	Lucerne	Tedera
10-May	11.8	11.8	11.5	81	81	74
24-May	11.8	11.8	11.5	81	81	75
14-Jun	11.8	11.8	11.5	81	81	77
19-Jul	11.8	11.8	13.0	81	81	78
13-Sep	10.9	11.9	13.0	78	82	78
11-Oct	9.6	10.6	12.2	72	74	75
1-Nov	8.2	10.8	11.4	64	75	71
6-Dec	6.7	9.7	11.4	55	69	71
1-Mar	6.2	9.4	11.4	52	67	71
26-Apr	5.1	8.9	11.4	48	64	73

treatments allowed the limits of tedera's ability to contribute profitably to farm plans to be explored. A treatment with a higher than expected yield was not considered as it was unclear how useful this would be given the current uncertainties about the yield potential of tedera.

The seasonal pattern of feed requirements varies between different flock structures. This implies the value of forage will vary during the year depending on the flock structure being considered. For example the feed requirements of a wool flock are relatively low in summer and autumn and consequently their requirement for supplementary feed is lower than a meat flock. As such meat flocks are expensive to feed but they are potentially more profitable than a wool flock. The inclusion of flock structure as an experimental treatment allowed such tradeoffs to be evaluated. The last treatment was the region; the farm was in the central wheat belt or the Great Southern region.

2.4.2 Sensitivity analysis

The value of tedera depends on its ability to provide high quality feed when it is most valuable. On mixed sheep and cropping farms in southern Australia feed shortages tend to be most acute during the autumn feed gap. At this time of the year feed shortfalls are usually overcome by feeding purchased supplements or retained grain. However, supplementary feeding is labour intensive and expensive and it adversely affects farm profitability (Rose 2011). The drought tolerance of tedera and its ability to remain green in summer and autumn means it is potentially well suited to reduce the need for supplementary feeding. The sensitivity analysis explores factors that affect tedera's ability to provide feed in summer and autumn.

The ability of tedera to feed animals at this time of year relates to its growth in summer and autumn, the transfer of forage grown in the preceding months, and the quality of the feed. In the sensitivity analysis the summer inter-period transfers (b, see equation 2 and Table 6) and feed quality (E^f, see equation 3) were varied. In the standard runs the default value of b for tedera in summer was 0.8 and the mean E^f of tedera in summer was 11.5 MJME/kg. In the sensitivity analysis b was varied from 0 to ~90% while E^f was varied from 0 to ~13.1 MJME/kg.

3. Results and Discussion

The role and value of tedera in the different farming systems and regions was sensitive to the yield assumptions. The area of tedera and farm profit both increased when the yield of tedera was higher, more so in the Great Southern region than the central wheat belt, and when a meat rather than a wool flock was considered (see Table 9 and Table 10). In the Great Southern region when the yield of tedera was 80% of the yield of lucerne, the proportion of the farm devoted to tedera was >70% and tedera's contribution to farm profit was ~$130/ha. This compares with tedera being planted on ~25% of the farm and profit increasing by ~$20/ha in the central wheat belt.

Table 8. Impacts of various yield scenarios for tedera: Central Wheat Belt[1,3]

Flock	Yield of Tedera (percent of lucerne yield)	Crop (percent of farm)	Annual pasture (percent of farm)	Lucerne (percent of farm)	Tedera (percent of farm)	Stocking rate (DSE/ha)	Meat sales (kg/ha)	Wool sales (kg/ha)	Supp. feed (kg/DSE)	Farm profit ($/ha)	Increase in farm profit due to Tedera ($/ha)
Wool	0	82.3	7.9	9.8	-	1.2	3.7	4.1	18	86	-
	40	79.0	5.0	8.7	7.2	1.3	4.0	4.3	17	86	0.5
	60	66.8	8.1	5.7	19.4	2.1	18.9	5.6	0	93	6.9
	80	64.5	9.4	1.6	24.5	2.5	23.5	6.9	0	103	16.9
Meat	0	78.8	6.9	14.3	-	2.0	25.9	5.6	66	95	-
	40	70.1	6.9	14.0	9.0	2.2	28.6	6.2	44	97	2.0
	60	65.5	8.1	7.9	18.6	2.2	28.6	6.2	0	106	11.0
	80	56.9	10.4	4.8	27.9	2.9	38.6	8.3	0	120	25.2

Table 9. Impacts of various yield scenarios for tedera: Great Southern Model[2,3]

Flock	Yield of Tedera (percent of lucerne yield)	Crop (percent of farm)	Annual pasture (percent of farm)	Lucerne (percent of farm)	Tedera (percent of farm)	Stocking rate (DSE/ha)	Meat sales (kg/ha)	Wool sales (kg/ha)	Supp. feed (kg/DSE)	Farm profit ($/ha)	Increase in farm profit due to Tedera ($/ha)
Wool	0	42.4	32.7	24.8	-	6.3	45.3	19	25	205	-
	40	36.1	18.9	17.8	27.1	7.0	49.6	22	17	238	33.2
	60	24.3	18.7	16.8	40.2	8.1	57.0	25	0	273	68.3
	80	10.2	14.1	4.5	71.2	11.6	81.5	35	0	325	119.5
Meat	0	32.7	37.6	29.7	-	9.1	94.0	29	43	260	-
	40	28.9	20.0	21.0	30.1	8.2	88.1	26	24	287	27.3
	60	19.0	24.2	20.8	35.9	8.9	95.7	28	0	326	66.1
	80	3.8	17.9	3.6	74.7	12.3	136.8	40	0	403	143.1

1: Farm area is 2000 ha
2: Farm area is 1000 ha
3: All "per ha" values are "per ha of the farm"

The area of tedera selected in the Great Southern model was initially surprising as we expected the drought tolerance of tedera would confer a greater advantage in the central wheat belt which is more prone to dry summers. However, in the Great Southern region sheep contribute a greater proportion of income, and in spite of having relatively wetter summers; autumn is still a critical period for feed. In particular, the wetter summers in the Great Southern region cause the quality of deferred grazing of annual pastures and crop residues to decline more rapidly than in the central wheat belt. The smaller area of crops in the Great Southern region also means there are less crop residues available for animals to graze (see Figures 2 and 3).

Another reason why the area of tedera selected in the central wheat belt model was less than perhaps anticipated, may be due to the steady-state nature of the MIDAS model. The model describes average seasonal conditions rather than capturing weather-year sequences. Hence tedera's role as a drought-tolerant feed source is not easily captured in the model's steady-state framework and so its value in a variable climate is under-represented. However, sensitivity analysis, as described later, does allow the worth of tedera's productive capacity to be explored.

Perennials such as lucerne provide summer feed and they are better suited to the higher summer rainfall in the Great Southern region. However, leaf shedding by lucerne still occurs and this reduces its quality in summer and autumn. Lucerne production increases with summer rainfall but it may be less efficient at converting summer rainfall to dry matter than tedera (Foster K., *pers comm.*). Summer rainfall can contribute to weed growth, but these generally have little feed value, and in cases such as caltrop (*Tribulus terrestris* L.) weeds can be toxic for livestock.

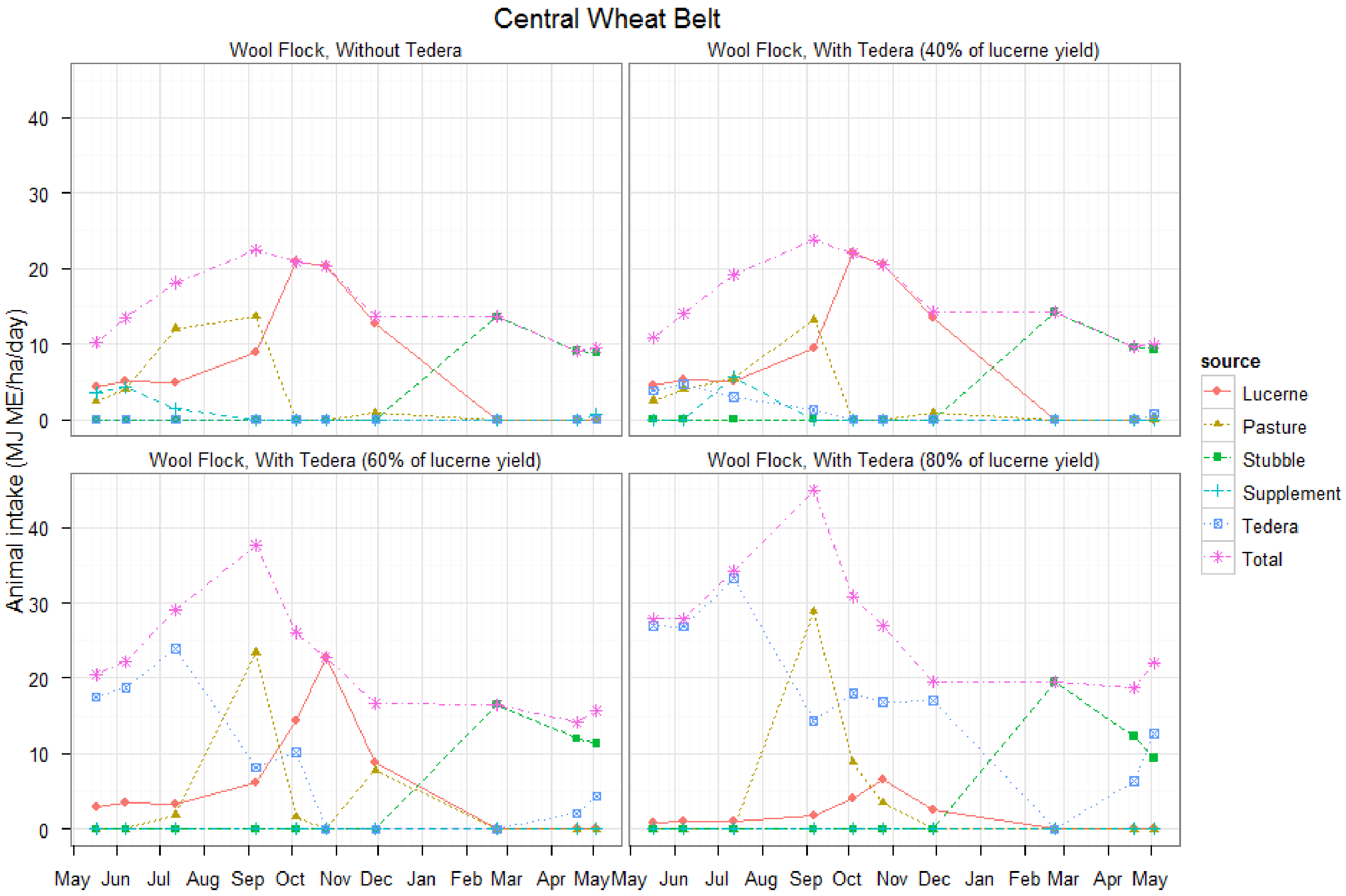

Figure 2. Sources of animal feed at different times of the year and different yields of tedera. Central wheat belt, wool flock.

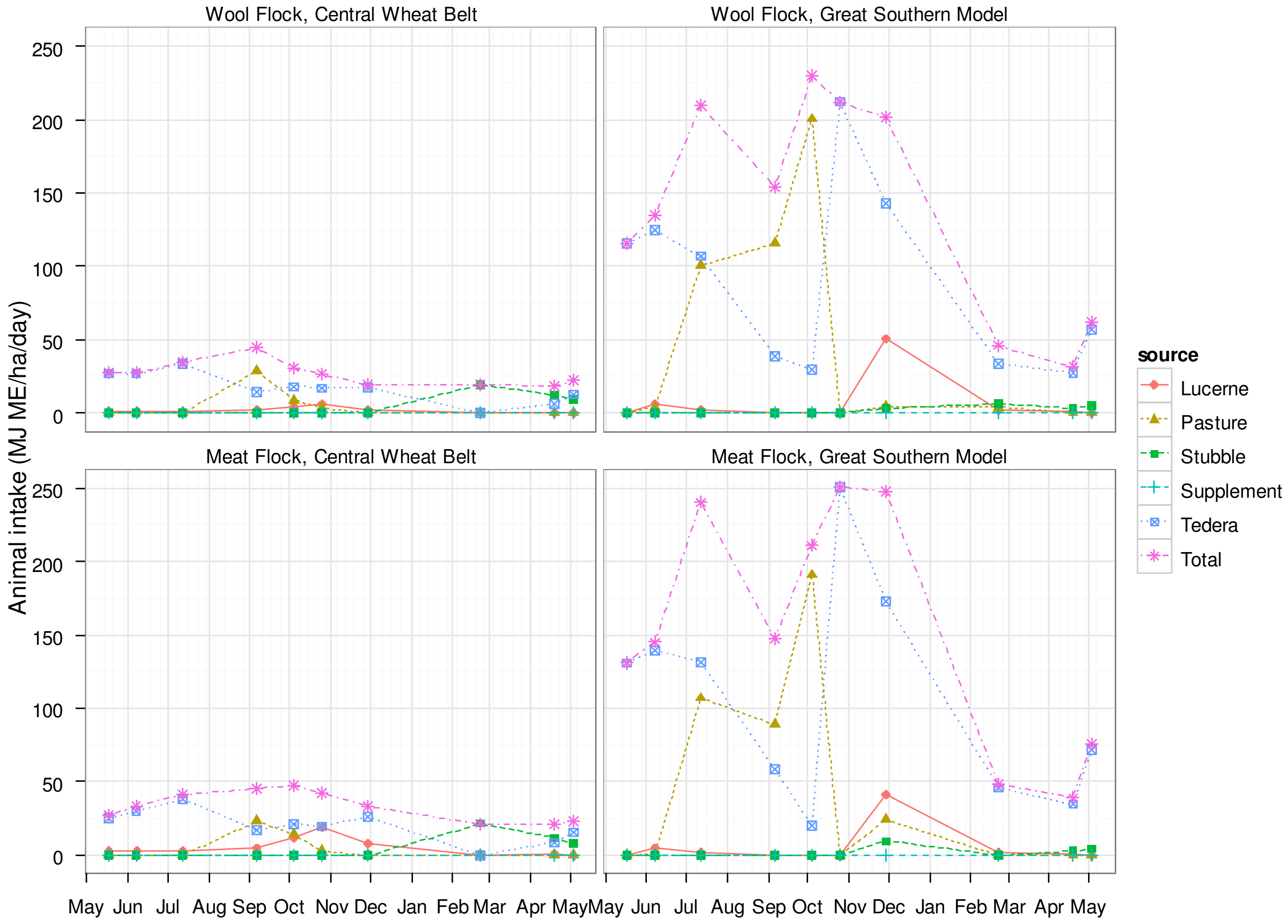

Figure 3. Sources of animal feed at different times of the year for wool and meat flocks in two regions. Tedera yield = 80% of lucerne yield.

The stocking rate, meat and wool sales and farm profitability were at, or close to their lowest levels, and supplementary feeding and the area of lucerne were at their highest levels when tedera was not included in the farm plan. In the absence of tedera, ~80% of the central wheat belt farm was cropped, with the balance in pasture and lucerne. This compares with ~30-40% cropping in the Great Southern region. In contrast the area of cropping declined to ~57-65% in the central wheat belt and ~4-10% in the Great Southern region when tedera could be grown.

The estimates of the area of lucerne were higher than are normally observed in the "without" tedera treatments (Robertson et al. 2009). This most likely relates to MIDAS's inability to account for stochastic variations in the yield or the success of establishing and removing lucerne. Farmers are sensitive to such factors (Abadi Ghadim and Pannell 1998) but as the model is unable to account for these factors this can bias the model results. To the extent that lucerne competes with tedera, an overstatement in the value of lucerne will cause the value of tedera to be understated. However, it is unlikely this had a large effect on the results. For example a "with" versus "without" comparison of tedera, in the presence of lucerne and a meat flock in the central wheat belt, yields a $25.2/ha return (see Table 9). This compares with $32.9/ha, if tedera can be selected, but lucerne was excluded from the farm plan.

In the central wheat belt, increases in the yield of tedera resulted in declines in the area of lucerne and arable crops and increases in the area of tedera and pasture. This implies that lucerne and arable cropping compete with tedera while annual pasture and tedera were complementary. The complementarity between tedera and annual pasture may be related to annual pasture's competitiveness in winter relative to tedera and lucerne; while in summer and autumn lucerne was less competitive than tedera. This contrasts with the Great Southern region where increases in the yield of tedera were accompanied by declines in the area of both annual pasture and lucerne. This implies that in the Great Southern region, tedera was able to compete with both annual pasture and lucerne to provide feed throughout the year.

In the central wheat belt where farming systems are typically crop dominant, the area of cropping declines as the yield of tedera increases. However, a very large increase in the relative profitability of sheep production is required for cropping to be completely displaced by sheep. In the scenarios involving the highest tedera yield and a meat flock, the area of crop was >55% in the central wheat belt farm compared with ~4% or the Great Southern farm. These differences reflect the relative advantage of cropping in the central wheat belt and the high level of complementarity between crops and animals in the region.

In the central wheat belt pastures provide advantages to the cropping phase of a rotation by creating a break for weeds and diseases, and additional opportunities for nitrogen fixation (Loi *et al.* 2005). Another example of crops being more profitable, in the presence of animals, involves sheep grazing crop residues including spilt grain that would otherwise be wasted. Increased diversity of income and reduced peak labour and capital requirements are also commonly cited reasons why the central wheat belt is mainly comprised of mixed rather than specialized farming systems (Ewing and Flugge 2004). In contrast, cropping is more marginal and specialized sheep farms are more likely to occur in the Great Southern region.

For a the central wheat belt farm based on a meat dominant flock, and subject to the lowest versus highest tedera yield treatment, meat sales increased from ~26 to 39 kg/ha, and wool sales went from 5.6 to 8.3 kg/ha, respectively. The same comparison in the Great Southern region shows meat sales increasing from ~94 to 137 kg/ha and wool sales from 29 to 40 kg/ha. Tedera's contribution to increased animal production and profitability relate to its ability to increase stocking rate and reduce supplementary feeding, with these effects occurring even in the scenarios where tedera's annual yield was only 40% of lucerne. These findings reflect tedera's value stemming from its ability to provide high quality feed in summer.

As previously mentioned, the feed requirements of wool compared to meat flocks are better matched to the pattern of feed supplied at different times of the year. This reduces the need for supplementary feeding and is probably the main reason that tedera-related increases in profit are less for wool flocks than meat flocks. The remaining discussion relates to meat flocks as these were more profitable and more responsive to tedera.

In the central wheat belt "without tedera" treatment, supplements and lucerne are fed in late autumn and early winter. The principle feedstuffs in winter are pasture and lucerne and the period of maximum daily intake occurs in spring when lucerne is the main feed source. In summer, crop residues provide the majority of feed with the balance coming from supplements. This compares with no supplementary feeding and less lucerne being fed to animals in the "with tedera (80% of lucerne yield)" treatment. In the "with tedera" treatments a larger amount of pasture was fed, and tedera was grazed most of the year. Tedera intake was at a maximum on either side of the winter periods when lucerne and annual pasture were actively growing. The only period when tedera was not grazed in the central wheat belt was in the period starting on the 6th of December (see Table 5) when crop residues were available post harvest (see Figures 2-4).

The different feed sources were grazed, at similar times of the year, in both regions. In the Great Southern region "without" tedera treatment, pasture provided the main feed source in winter and early spring with lucerne being important from mid spring to early summer, and supplements were fed from April until July. Stubble was grazed in summer and autumn but it was the least important feed source. In the "with" tedera treatment, pasture was the main source of feed in late winter and early spring, but at all other times of the year tedera was the main feed source.

The transfer of forage from one time of the year to another can be seen in Figure 4 and Figure 5. Pasture is the least flexible forage with the model suggesting it is optimal to graze pasture when it is actively growing rather than allowing dry matter to accumulate in the paddock to be grazed at a later time. Lucerne is more flexible than pasture with a proportion being deferred rather than grazed immediately. By comparison tedera enables a relatively large amount of dry matter to be transferred for later grazing.

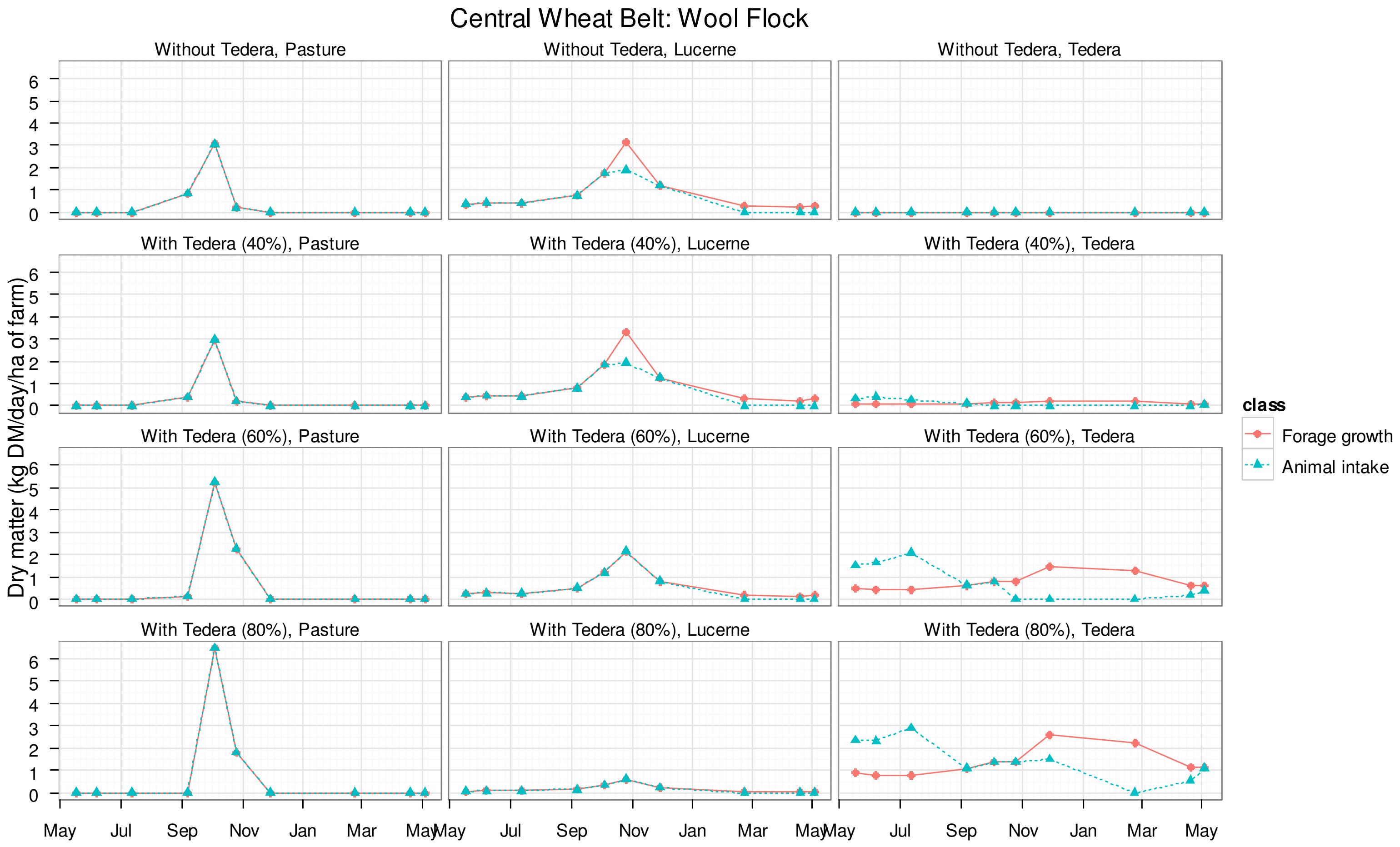

Figure 4. Production and intake of pasture, lucerne and tedera at different times of the year given different tedera yields. Central wheat belt, wool flock.

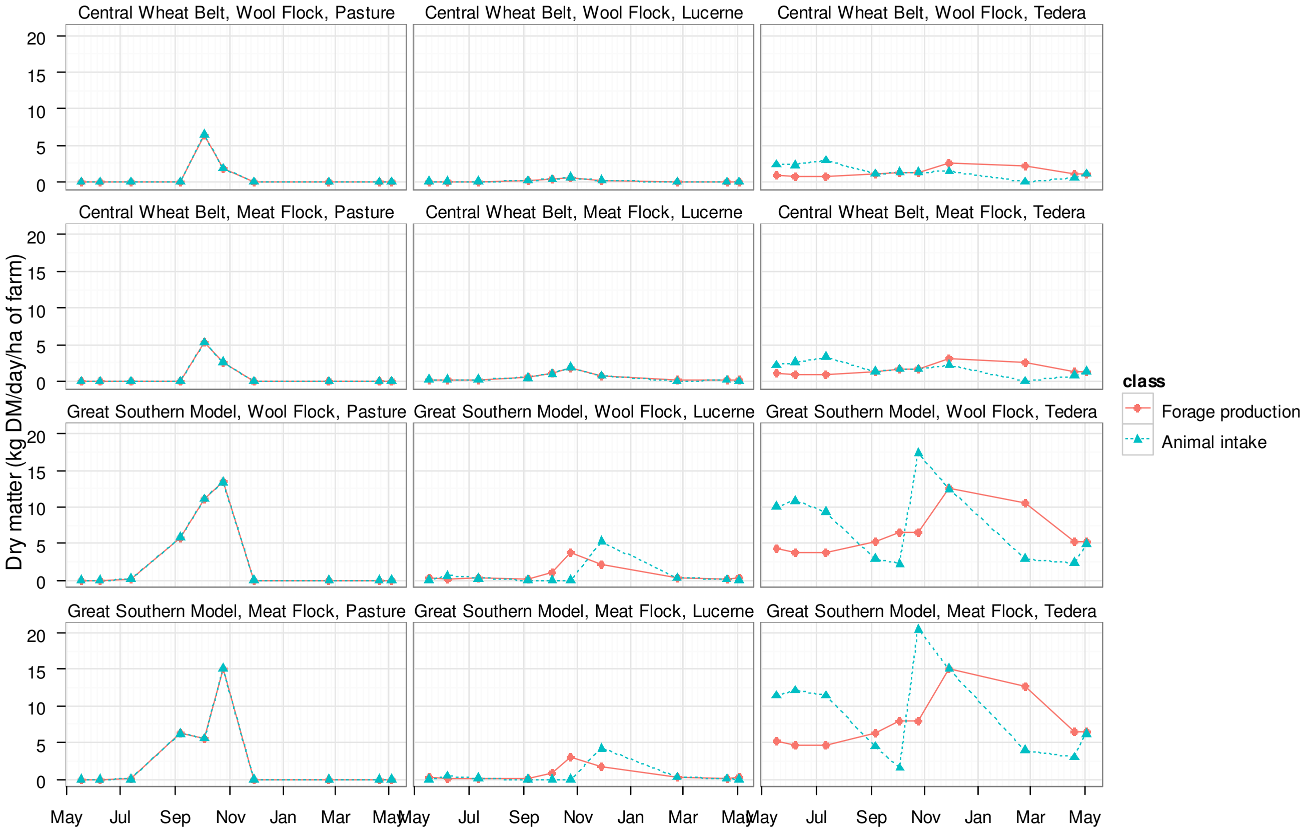

Figure 5. Production and intake of pasture, lucerne and tedera at different times of the year given different regions and flock structures. Tedera yield = 80% of lucerne yield.

Tedera is a flexible feed source and its ability to provide high quality feed in summer seems to be the main reason it makes such a large contribution to farm profits in the Great Southern region. This finding was confirmed in sensitivity analyses mentioned later.

As the yield of tedera increases, the amount of lucerne that is transferred between time periods declines. A possible explanation for this is as tedera becomes more available the need to defer lucerne grazing is reduced, and consequently the losses associated with deferring lucerne grazing can be avoided. This is consistent with a technology contributing to an increase in the efficiency with which other farm resources can be used.

The results of the sensitivity analysis are shown in Figure 6 and Figure 7. Tedera's ability to provide high quality feed in summer was varied by altering its feed quality and the level of inter-period transfers in summer. The results suggest the value of tedera was higher, and more robust to changes in assumptions, in the Great Southern model than the central wheat belt. For example even when the feed quality was ~5 MJME/kg DM, or less than half its expected level, there was some uptake of tedera and a small increase in profit in the Great Southern region. This compares with a minimum feed quality of ~8 MJME/kg DM for tedera to be selected in the central wheat belt.

Tedera was selected, even at low summer inter-period transfers, providing the feed was of sufficient quality. If the inter-period transfers were low, this reduced tedera's flexibility, but tedera still had value possibly because of differences in the seasonality of its production relative to competing forages. The results suggest farm profit is highest, when the feed quality and inter-period transfers in summer are both at relatively high levels.

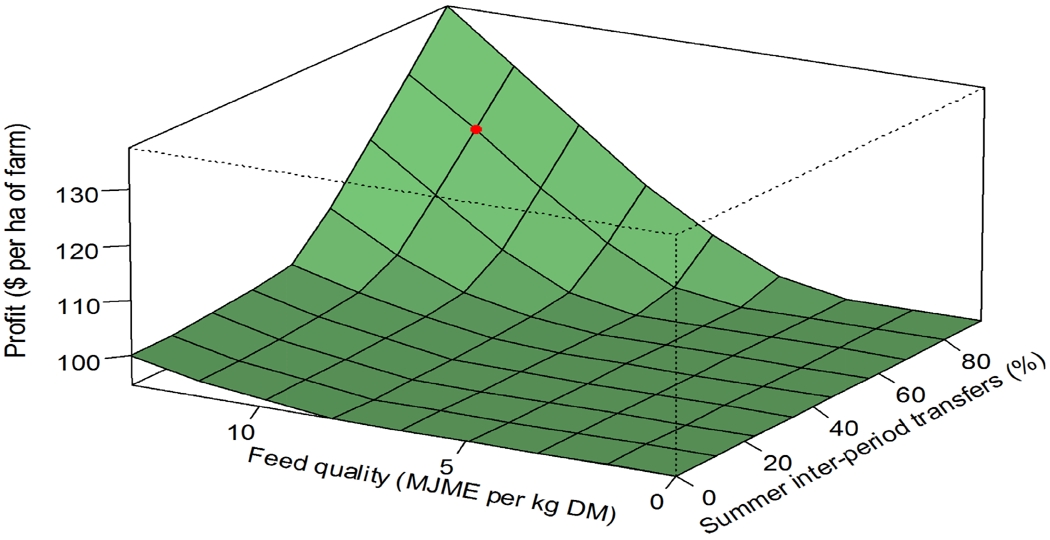

Figure 6. Sensitivity analysis. Profit versus inter-period transfers and feed quality. Central Wheat Belt: Meat flock. ● refers to the default level of feed quality and summer inter-period transfers in the standard runs.

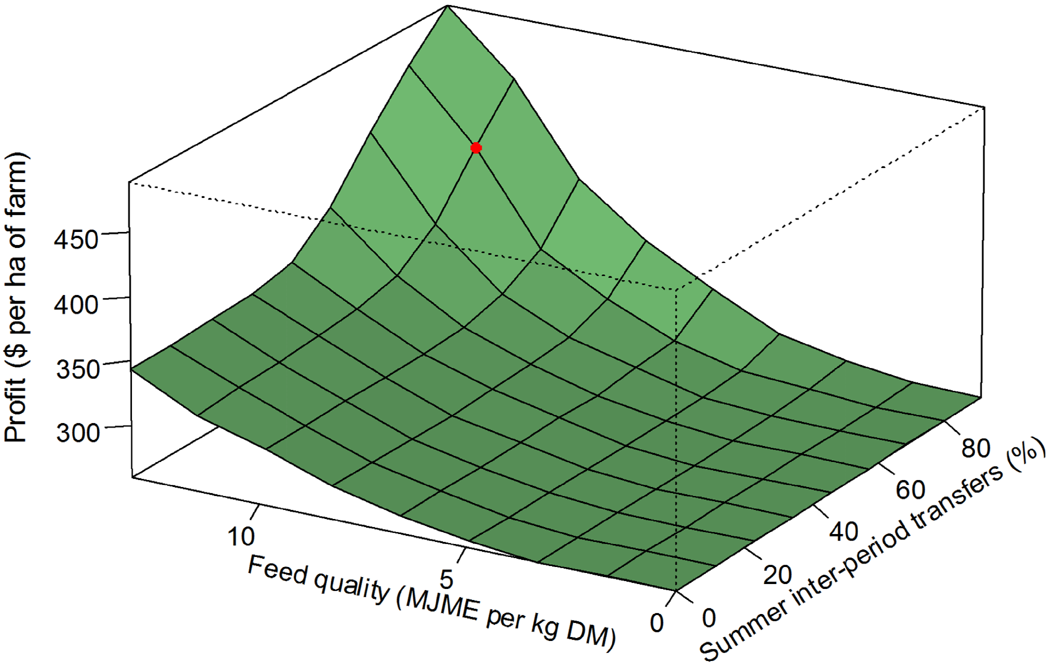

Figure 7. Sensitivity analysis. Profit versus inter-period transfers and feed quality.

Great Southern Model: Meat flock. • refers to the default level of feed quality and summer inter-period transfers in the standard runs.

Conclusions

This paper draws on experimental results and regional variants of the MIDAS model to perform an economic assessment of the role and value of tedera in mixed sheep and crop farming systems. The analysis considered the productivity, value and grazing management possibilities of tedera, a pasture legume, on representative dryland mixed crop and livestock farming systems at two locations in Western Australia. The research and breeding program for tedera is still at an early stage but the experimental and modeling results to date are extremely positive, particularly for higher rainfall mixed farms, and support the case for continued research and breeding. While considerable effort will be needed to reduce uncertainties about tedera's ability to contribute to farm systems in different environments, the potential scale of benefits makes this a high priority activity.

Key areas for additional experimentation include ascertaining: there are no serious anti-nutritional issues with tedera; seasonally-targeted grazing is possible without the need for costly replacement or renovation to deal with thinning of the stand or weed infestation; tedera can provide high quality feed when little else is available; tedera is able to substitute for costly hand feeding in autumn; and labour requirements for using it sustainably are low. These points should be further evaluated under field conditions to gain a fuller understanding of how to best manage tedera.

The analysis indicates that tedera offers the potential to increase farm profits by up to 26% in a low rainfall mixed enterprise farming environment and by up to 58% in a high rainfall mixed enterprise farming environment. The increase in profit was attributable to savings in supplementary feed and higher stocking rates. In this analysis an effort was made to ensure the main assumptions reflect a conservative view of tedera's agronomic potential. Even if these assumptions later turn out to be overly optimistic, tedera seems to confer sufficient advantage, it is likely to have a role in southern Australian farming systems.

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