A bio-economic evaluation of the profitability of adopting subtropical grasses and pasture-cropping on crop-livestock farms.

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Abstract

Pasture-cropping is a novel approach to increase the area of perennial forages in mixed livestock and cropping systems. It involves planting annual cereals directly into a living perennial pasture. There is interest in using subtropical grasses for pasture-cropping as they are winter dormant and their growth profile is complementary with winter crops. However, a wide range of factors can affect the uptake of such systems. This paper evaluates the farm-system economics of subtropical grasses and pasture. The research question is: what factors affect the profitability of a new technology such as (1) subtropical grass and (2) subtropical grass that is pasture-cropped. The analysis uses the MIDAS model of a central wheatbelt farm in Western Australia. The results suggest the profitability and adoption of subtropical grasses is likely to be strongly influenced by the mix of soil types present on the farm; the feed quality of the subtropical grass; whether the production emphasis of the farm is for grazing or cropping and whether the sheep flock is structured primarily for meat or wool production. The same factors are relevant to pasture-cropping, with the addition of yield penalties due to competition between the arable crop and the host perennial. The results were not sensitive to changes in the winter production of subtropical grass but production in summer and early autumn did influence profitability.

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1. Introduction

Intercropping, or planting two or more crops to the same ground at the same time, is practised in a wide range of environments and in many parts of the world (Vandermeer 1992). Recent work has shown it can provide higher annual yields than conventional cropping (Willey, 1979). One reasons for this is that the component crops often complement each other and make better overall use of resources when growing together (Natarjan and Wiley 1986).

Pasture-cropping is a form of intercropping which involves planting a winter cereal into a summer-active (C4) native grass pasture (Millar and Badgery 2009). The summer versus winter dominance of the pasture and cereal are complementary and this reduces the competition between crops planted in the same ground at the same time. Rather than storing water in soils for extended periods, which can be subject to high losses and increases in summer weeds, pasture-cropping avoids the need for summer fallows and allows summer rainfall to be utilised when it occurs (Howden *et al*. 2005). The technology is relevant for both grain- and forage-dominant farming systems (Badgery and Millar 2009).

The use of deep-rooted perennial pastures in mixed farming systems has attracted interest as perennials can increase farm profit and diversity amongst farming enterprises, assist with controlling weeds and crop diseases, provide summer feed for livestock and improve ecosystem sustainability (Byrne *et al*. 2010; Harris *et al*. 2007; Millar and Badgery 2009; Monjardino *et al*. 2010; Moore *et al*. 2007, 2009). The environmental advantages of perennial pastures include reduced nitrate leaching and reduced deep drainage below the root zone (Kemp and Dowling 2000) with attendant salinity and water logging benefits (Ewing and Dowling 2003, Ward 2006), reduced soil erosion from all year round ground cover, improved soil structure and improved water infiltration (Nutall 2008).

Despite these advantages, growing perennial pastures in phase rotations with annual grain crops and pastures can be problematic. The financial consequences of poor establishment are greater for perennials than for annual pastures and it can be difficult to remove perennials when switching back into cropping (Davies and Peoples 2003). The increased use of winter active perennial forages such as lucerne (*Medicago sativa*) can exacerbate the risk of drought resulting in increased feed shortages in summer and autumn.

Pasture-cropping has been trialled on lighter soils in New South Wales (Millar and Badgery 2009). In this region there is a relatively high chance of crop establishment failure in conventional phase rotations that include cereals and sown pasture. Typically these soils do not support long cropping phases due to low fertility and poor moisture-holding capacity and introduced perennials rarely persist beyond a few years (Li *et al*. 2004; Mullen *et al*. 2006). In these circumstances pasture-cropping is thought to be a useful way to retain or rehabilitate perennial grasses and reduce the consequences of cereal-establishment failure. In north central Victoria farmers have sown cereals into lucerne stands for environmental and sustainability benefits and because the economic returns from growing a cereal crop are perceived to be higher than grazing the lucerne itself (Harris *et al*. 2003).

Although pasture-cropping was initially 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). A variety of perennial species, such as lucerne, summer-active (C4) native and subtropical grasses, serradellas (*Ornithopus sativas*), medics (*Medicago ssp*.) and a range of cereal and pulse crops including wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oats (*Avena sativa*), faba-beans (*Vicia faba*), vetches (*Vicia sativa*), triticale (*Triticale hexaploide* Lart.) and canola (*Brassica napus*), are candidates for pasture-cropping systems (Egan and Ranson 1996).

In Western Australia research into perennial pasture production has focused on lucerne-based systems under favourable conditions of rainfall and soil types (Latta *et al*. 2001; Robertson *et al*. 2004). Until recently there has been relatively little success with farming perennial pastures in lower-rainfall areas and on marginal soils. Pasture-cropping is seen as a way to increase the perennial pasture component on farms while still producing a profitable cereal crop in these areas. While most farms have some land that is unproductive (Lawes and Dodd 2009), poor sands do not occupy large areas of the central wheatbelt. In the northern agricultural region of Western Australia there is interest in subtropical grasses as pasture-cropping potentially provides opportunities to crop land that has not historically grown cereals.

The yield of both the crop and the pasture components of a pasture-cropping system are affected by the resource requirements of growing the plants together. In particular the pattern of resource use by the plants can contribute to shortfalls at critical times (Egan and Ransom 1996; Humphries *et al*. 2004; Robertson *et al*. 2004). The extent to which yield is affected relates to factors such as soil fertility, water-holding capacity and weather conditions as well as the characteristics of the plants and planting parameters such as row spacing, spatial arrangement and plant density. Competition for water, nutrients and light can also reduce grain protein and contribute to increased grain contamination (Harris *et al*. 2007).

The evaluation of such systems via traditional field experimentation is difficult due to the presence of multiple interacting factors, high levels of seasonal variability, and differential performance of crops and pastures on different soils (Pannell *et al*. 2006). In these circumstances bio-economic modelling provides a cost-effective alternative to identify research and development priorities for systems evaluation. This is particularly the case for novel technologies such as pasture-cropping where there is little experimental information on the biological performance of the components or the value these might have in a complex system.

This study considers alternate ways to include pasture-cropping in mixed farming systems and identifies farm, management and agronomic factors that will contribute to or impede its uptake. The potential for pasture-cropping to allow better utilisation of poor soils is of particular interest in this study. We targeted poor soils as continuous cropping is currently more profitable on better soils in the central wheatbelt of Western Australia

(Robertson *et al.* 2010). Unless there are large changes in prices and productivity levels, cropping is unlikely to be substantially displaced on these soils by grazing systems. For this reason it seems likely that the soil make up of the farm and the enterprise choices (area cropped, livestock characteristics such as meat based versus wool based flock) will influence the area suitable for subtropical grasses.

The aims of this study are two-fold: (1) to assess the profitability and potential adoption of subtropical grasses and pasture-cropping on representative mixed crop-livestock farms and consider how this may be affected by the distribution of soil types, the type of livestock production system, and the productivity of crops and pastures in the pasture-cropping system, and (2) to identify priorities for agronomic research into the pasture-cropping system through the analysis of factors that most strongly influence the bio-economic performance of pasture-cropping.

2. Methods

2.1 Study area

The study area is the central wheatbelt of Western Australia, which is centred on the town Cunderdin (31°39'S 117°14'E) approximately 160 km east of Perth in Western Australia (see Figure 1). The central wheatbelt receives an average of 350 to 400 mm of rainfall per year and the weather is characteristic of a Mediterranean-type climate with hot dry summers and cool wet winters (see Figure 2). The growing season for annual crops and pasture is typically from April/May until October when two-thirds of the annual rainfall occurs. The remainder of the year is characterised by low rainfall and an associated decline in the quality and quantity of feed available for livestock. This often culminates in an autumn feed-gap, with consequences for live weight gain, wool growth and quality, and reproductive performance (Robertson *et al*. 2010). During the autumn feed-gap sheep are often fed supplements such as grain and conserved fodder.

FIGURE 1 about here

FIGURE 2 about here

The area of most farms ranges from 900 to 2500 ha and they are run as family-owned enterprises with some external labour. In this study the modelled farm is comprised of 2000 ha. Most farms produce a mix of grain, wool and meat. It is common for 50 to 70 percent of arable land to be sown to crops with the balance being in annual pasture. Pastures usually consist of subterranean clover with volunteer annual grasses and herbs. Sheep are the predominant livestock enterprise, but in the past, cattle were important on some farms (Morrison *et al*. 1986).

Perennial pastures, including forage shrubs, are sometimes grown as they are able to extract water from deeper in the soil profile than annual pastures and they normally produce more feed in summer than annual pastures. The ability of perennial pastures to produce summer feed reduces the autumn feed-gap but perennials can still be drought-affected and their yield is variable (Moore *et al*. 2009). The autumn feed gap has important implications for the profitability of alternate feed sources and the timing of feed supply can be as important as the quantity and quality of the feed that is produced (Moore *et al*. 2009).

Sheep production systems in the region are mainly based on the Merino breed and range from wool- to meat-dominant systems with meat production being more prevalent. In wool-dominant systems, ewes are replaced by lambs that are produced on farm and castrated male animals (wethers) are sold as prime lambs, to other graziers or as live sheep exports (18 months or older). Mixed wool-meat enterprises are self-replacing, and surplus ewes (cast-for-age and surplus ewe hoggets) are used for crossbred lamb production. On meat-dominant farms, income is mainly from merino ewes producing crossbred lambs for meat, and replacement ewes are bought in.

Cropping systems are based around wheat, and to a lesser extent barley, in rotation with canola (*Brassica napus*) and grain legumes including narrow-leafed lupin (*Lupinus* *angustifolius*) and field peas (*Pisum sativum*). Perennial pastures are typically grown for 2-7 years as a monoculture in rotation with crops. The productivity of crops and pastures varies depending on their position in a rotation due to carryover effects on soil fertility, weed burdens and plant diseases.

2.2 MIDAS Model

The whole-farm bio-economic model MIDAS (Model of Integrated Dryland Agricultural System) was used to address the study objectives for a representative farm system in the central wheatbelt of Western Australia. The crop and pasture sequences, livestock enterprises, stocking rates, soil types, and the labour and capital requirements represented in MIDAS are typical of the region. MIDAS is a 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). The objective function of the model is to maximise whole-farm profit and the model does this by allocating resources between enterprises subject to various resource, environmental and managerial constraints (Pannell 1996).

MIDAS uses a comparative static framework in which the initial state of the modelled system is incompletely defined, and consequently changes from an initial to a final state are not captured. MIDAS is a deterministic model that does not endogenously consider variations in prices and productivities. However, the model can be run with a range of price and production levels to assess their influence on the selected mix of enterprises and on the level of farm profit (Pannell 1997).

Temporal interactions that occur between farm components have important implications for the structure and function of the farming system (Pannell 1987). One of the strengths of MIDAS is that a variety of these types of interactions are represented. For example changes in cereal yields that are the result of growing pulse crops for disease break purposes and the influence of crop sequences on herbicide and fertiliser requirements are included in MIDAS. Another example is the selection of an optimal grazing strategy, as this depends on the availability and quality of pasture on different parts of the farm, and at different times of the year. The choice to graze one part of the farm directly affects pasture growth on the land that is grazed but it also indirectly affects pasture growth on land that is not grazed. MIDAS simultaneously considers how such choices affect stocking rate, wool growth and quality and sheep live weight in assessing optimal grazing strategies.

Time periods are included in MIDAS to represent the supply and demand for time-critical resources. For example the value of forage production and consumption by animals varies depending on the time of year. To account for this MIDAS considers 10 feed periods in a year (see Table 1). Decisions with cash flow implications are also modelled in terms of the time of year they affect a farms funding situation. In addition MIDAS includes time limits that relate to crop sowing. To model the effect of sowing timeliness on crop yield MIDAS includes yield penalties that become progressively larger as sowing becomes later.

TABLE 1 about here

MIDAS includes the livestock system as a categorical variable that can be varied between model runs. In any particular model run the number of livestock on the farm is an endogenously modelled variable but the model structure requires the type of livestock system to be specified before the model is run.

The model accommodates eight land management units (LMU) or soil types that are treated as homogeneous units in terms of crop yield and response to management inputs (see Table 2). Approximately 80 crop-pasture sequences are represented on each land management unit. The production parameters associated with each rotation include grain yield, quality and protein (wheat and barley), oil content (canola), quantity of crop residues and spilt grain, and germination rates of pasture. The livestock parameters 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.

TABLE 2 about here

2.3 Including pasture-cropping in MIDAS

MIDAS was modified to include subtropical grass and pasture-cropping on each of the 8 soil types or land management units. The pasture-cropping system in this study includes Rhodes grass (*Chloris gayana*) and wheat. Rhodes grass is a hardy and relatively low-quality summer-active subtropical perennial. In winter the feed production from Rhodes grass is relatively low (< 10 kg DM per ha per day), but in summer and autumn (December to May), it is likely to produce a higher yield than lucerne or annual pasture (Lawes and Robertson 2008).

A 12-year phase of subtropical grass was included as a conventionally managed forage and as a pasture-crop with wheat every second, third or fourth year. We did not allow wheat to be pasture-cropped every year as we judged it unlikely that such an intensive rotation could be sustained on soils where pasture-cropping would be competitive. We assume that animals are excluded from pasture-cropped land between cereal planting and harvesting (periods 1 to 7, see Table 1). As such, the frequency of cropping has implications for the area of forage that can be accessed by animals in winter. This contrasts with the summer months (periods 8 to 10) when all subtropical grass is available for grazing regardless of its management (see Figure 3).

The main assumptions relating to subtropical grass growth involve its growth at different times of the year, on different soils, and in the presence of pasture-cropped wheat. Estimates of feed quality and the quantity of forage produced at different times of the year were estimated using the APSIM model (Lawes and Robertson 2008). The subtropical grass sward was assumed to have a sub-clover content of 20 percent and under standard assumptions there was a yield penalty of 15 percent for companion wheat crops relative to conventionally managed (i.e. not pasture-cropped) cereals (Ferris *et al.* 2010). The yield penalty is considered further in the sensitivity analysis (see section 2.5).

FIGURE 3 about here

An important assumption in this study is that subtropical grass is less affected by poor soils than is lucerne or annual pasture (see Table 3). This was modelled by assuming that on poor sands (LMU 1) the potential yield of lucerne is only 50 percent of what is achieved on a more favourable soil but for subtropical grasses the yield is relatively higher at 65 percent of the yield on an ideal soil (Moore *et al*. 2007). Depending on the soil, the yield of subtropical grass varies from 65 percent to 100 percent of its maximum yield of 4200 kg DM per ha; lucerne varies from 50 percent to 100 percent of its maximum yield of 3600 kg DM per ha and annual pasture varies from 40 percent to 100 percent of its potential yield of 4800 kg DM per ha.

TABLE 3 about here

The crop husbandry associated with pasture-cropping involves applying 2.0 litres per ha of paraquat and diquat (135 and 115 g per litre, respectively) prior to direct drilling wheat into subtropical grass and 0.5 litres per ha glyphosate and 0.8 litres per ha of paraquat and diquat at the time wheat is sown. 20 kg N fertilizer per ha is applied annually to conventionally sown subtropical grass, and 30 to 70 kg N fertilizer per ha is applied to companion wheat crops. Subtropical grass seed is sown at a rate of 4 kg per ha (Bagshaw *et al*. 2004). The machinery requirements to establish and harvest a companion wheat crop are otherwise identical to conventionally sown wheat.

The MIDAS model outputs used in this analysis include farm profitability ($ per ha) and the area of conventionally managed and pasture-cropped subtropical grass. Numerous other outputs including the area and yield of other crops and forages and the soil types these were planted on, the numbers and types of livestock, the source of animal feed at different times of the year were generated and inspected, but are not reported here.

2.4 Standard runs

In the standard model runs we consider the area selected and implications for farm profitability of conventionally sown and pasture-cropped subtropical grass. The runs were performed for both a wool- and meat-dominant sheep and cropping farm. In these runs the value to the farm system of subtropical grass was compared to lucerne. The first scenario excludes lucerne, subtropical pasture and pasture-cropping from the model solution. The individual and joint contributions of lucerne, subtropical grass and pasture-cropping are then considered.

2.5 Sensitivity analyses

In any economic model there is uncertainty about the parameter values. The modeller is unsure of the current values of parameters and even less sure about their future values (Pannell 1997). A sensitivity analysis provides a means of determining the influence of parameters on the conclusions that can be drawn and provides insight into the robustness of solutions and the factors influencing them. A sensitivity analysis was performed to assess the outputs of a variety of MIDAS runs in which the attributes of the farm; the enterprise mix or management choices; and the agronomic characteristics of subtropical grass and pasture-cropping were varied. Altogether, eight factors were considered at two levels to form a balanced factorial comprised of 2^8 or 256 model runs (see Table 4).

Table 4 ABOUT HERE

The first attribute to be evaluated relates to the suitability of a farm for subtropical grass and pasture-cropping. As discussed above the relative yields of crops vary between land management units or soil types. As such, the distribution of different soil types on a farm is likely to influence the value of different cropping and pasture systems. The area of poor sands was of particular interest as subtropical grass and pasture-cropping perform relatively well on this soil type. The reduced costs reported from the standard runs were used to rank the different soils in terms of their favourability for pasture-cropping. These rankings were then used to apportion differing areas of land to different soils. The soils where pasture-cropping was most competitive, and which achieved the highest rankings occurred on soils where pasture-cropping was selected or the opportunity cost of selecting pasture-cropping was small.

Two soil distributions were considered. These both involved a triangular distribution with the area of individual soils being between 0 percent of the farm for the lowest ranked soil and 25 percent of the farm for the highest ranked soil. The areas of soils with an intermediate rank were interpolated between these extremes. The first distribution had a "low" or small area of soils that favoured subtropical grass and pasture-cropping and a large area of soils where they were less competitive. The second distribution reversed this order and a "high" or large area of soils was allocated to soils where pasture-cropping had a high ranking. In the remainder of this paper, these soil distributions are referred to as "low" and "high" poor sands (see Figure 4). The apportioning of land in this way was somewhat arbitrary as it does not reflect the distribution of soils found on any particular farm but it allowed the sensitivity of the model to be assessed for a wide range of soil type distributions.

FIGURE 4 about here

The next group of attributes involved farmers' management decisions or enterprise choices. These included the area of land that is cropped: low or 25 percent of the farm and high or 75 percent of the farm; and whether the farmer runs a wool- or meat-dominant sheep system. These factors involve decisions or choices available to a farmer and they were varied to explore the circumstances where pasture-cropping might offer the greatest advantage to a farming system. For example, meat-dominant systems require high-quality feed in early summer to produce prime lambs. Consequently, the ability of a pasture-cropping system to produce feed at this time of the year is likely to confer a greater advantage to a meat-dominant system than to a wool system.

The remaining runs with the MIDAS model assess the importance of different agronomic attributes of pasture-cropping. The first of these was forage quality or the digestibility of subtropical grass. In the MIDAS model, the digestibility of subtropical grass ranges from 63 percent in summer to 66 percent in winter. This compares to annual pasture (45 to 81 percent) and lucerne (64 to 82 percent). This suggests Rhodes grass produces feed whose quality does not vary much during the year although its peak digestibility is relatively low (Moore *et al*. 2007). The sensitivity of the model to the feed quality of subtropical grass was tested by including digestibility at a high (79 to 83 percent) and a low level (47 to 49 percent). These reflect changes from the default values of plus and minus 25 percent, respectively. These are relatively large changes in digestibility but the resulting digestibility's are within the range of other forages. The inclusion of this factor allowed us to consider whether changes in digestibility, such as through breeding or by selecting other pasture species, might be an important determinant of the value of subtropical grass.

In the initial runs the default yield of companion wheat crops was 85 percent of the yield of a conventionally sown crop. However, there is uncertainty about the competition effects of the host pasture on a companion wheat crop and the associated yield penalty is potentially important to the profitability of pasture-cropping (Ferris *et al*. 2010, Harris 2007). In the sensitivity analysis the yield of a companion wheat crop was varied from a low of 75 percent to a high of 95 percent relative to wheat that was not pasture-cropped. This was plus or minus 10 percentage points relative to the default yield of 85 percent.

The other factors to be considered relate to the yield or availability of subtropical grass in different periods of the year. In the initial runs grazing animals were excluded during the wheat phase (periods 1 to 7) of a pasture-cropping rotation. This restriction was relaxed in the sensitivity analysis. The first of these involves the availability of pasture-cropped forage in autumn. The “low scenario” uses the same assumptions as the initial model runs but in the second or “high scenario”, animals were allowed to graze wheat during the early periods of the wheat phase of a pasture-cropping rotation (periods 1 and 2, see Table 1). It was assumed this did not affect the subsequent yield of the grazed wheat crop. The importance of subtropical grass yield at different times of the year was evaluated by varying production in the winter (periods 1 to 7) and summer (periods 8 to 10) from 75 to 125 percent of the standard yields.

3. Results and Discussion

3.1 Results of standard model runs

In the majority of the standard model runs, approximately three-quarters of the farm area (total area = 2000 ha) was planted to crops (see Table 5). This reflects the value of forages to the cropping rotations and the benefits of maintaining a mixed farming system. Pasture-cropping was planted on a smaller area and made a smaller contribution to farm profit than lucerne but the benefits of pasture-cropping became larger when lucerne and a meat-dominant system were present. The results indicate pasture-cropping is profitable but it is a complementary technology rather than one that is likely to dominate the farm system. In all cases where pasture-cropping could be planted the rotation involving wheat every two years was selected. This was the most “crop” intensive of the pasture-cropping rotations and was consistent with the value of additional wheat exceeding the value of increased winter forage production from the less “crop” intensive pasture-cropping rotations.

TABLE 5 about here

A farm with meat-dominant livestock system tended to be more profitable and involved a smaller area of crop than a wool-based sheep production system. Similarly, the inclusion of additional forages resulted in larger increases in profit for the meat-dominant than the wool-dominant system. This is shown in the baseline scenarios (scenarios 5 and 10). These both allow lucerne, subtropical grass and pasture-cropping but scenario 5 includes a wool-dominant flock and scenario 10 refers to a meat-dominant flock. Compared to scenario 5, scenario 10 involves an increase in profit of 26 percent, a decline in crop area of 12 percent, and an increase in lucerne and sub-tropical grass of 50 percent and 230 percent, respectively. This suggests that both lucerne and subtropical grass are more valuable when meat producing animals are present.

In the non-baseline scenarios (scenarios 2 to 5 and 7 to 10), there was some uptake of the introduced forage, an increase in profit, and declines in cropping area and supplementary feeding compared to the baseline scenarios (scenarios 1 and 6). However, the area of annual pasture and changes in stocking rate were dependent on the scenario being considered. For example, 498 ha of annual pasture were included in the baseline solution for the meat flock, and this declined by 32 percent to 340 ha with the adoption of lucerne (scenario 7). This is in contrast to about a 28 percent increase in the area of annual pasture to approximately 635 ha in the meat-dominant system if subtropical grass or pasture-cropping are introduced (scenarios 8 and 9). In these scenarios, lucerne competes for land with annual pasture but subtropical grass appears to be complementary to annual pasture. A possible explanation for this result is the growth profile, or the timing of the dormancy, of annual pasture is more closely matched by lucerne than by subtropical grass.

In the majority of the additional forage or pasture-cropping scenarios, there was an increase in stocking rates relative to the baseline scenario. However, in the case of the meat flock “with subtropical grass” and “with pasture-cropping” (scenarios 8 and 9) there was a small decrease in stocking rate relative to the baseline scenario. It should be noted that scenarios 8 and 9 are associated with relatively large increases in annual pasture, thus despite lower stocking rates (expressed in dry stock equivalents per winter grazed ha), these scenarios involved an increase in the number of grazing animals relative to the baseline scenario. Because meat-dominant systems were more profitable and pasture-cropping was found to have greater value in meat dominant systems, the results hereafter refer to meat producing systems only.

Subtropical grass was only selected on LMU 1 or poor sands (see Table 6). This was despite the relatively low yield of subtropical grass and pasture-cropped wheat on LMU 1. This result occurs because subtropical grass is less adversely affected than competing land uses on this soil. Although pasture-cropping grass was not selected on other soils in the standard runs, the opportunity cost associated with adopting subtropical grass or pasture-cropping on soils 2, 4 and 5, was less than $5 per ha. This suggests that relatively small improvements in the performance of pasture-cropping, such as through increased digestibility, increased forage production or increased yield by the companion wheat crop, might favour increased adoption of pasture-cropping. On the remaining soils (LMU's 3, 6, 7 and 8) the opportunity cost of additional pasture-cropping ranged from $20 to $85 per ha and reflects the dominance of other land uses on these soils.

TABLE 6 about here

The marginal value of animal intake was estimated using the shadow prices that are reported in the linear programming solution. The value of intake tends to be high if the demand for feed is high relative to supply and the alternatives to meet demand are expensive (see Figure 5). In Western Australian mixed farming systems, the supply of feed is often scarce in autumn and early winter, from March until June. This is referred to as the "autumn feed gap" and the majority of supplements are fed at this time. In these months the marginal value of metabolisable energy exceeds $20 per GJME which reflects the cost of feeding supplements to animals. There was little difference in the marginal value of feed between "with subtropical grass" and "with pasture-cropping" (scenarios 7 and 8) and the results from scenario 7 are not presented in Figure 5.

FIGURE 5 about here

From July until September animal intake is mainly derived from annual pasture. This corresponds to a period when feed is relatively abundant and the marginal value of animal feed is low. Lucerne becomes the major source of feed in October and November when it is available but in the scenarios where lucerne was not grown the farmer must rely on annual pasture, which is declining in quantity and quality, and on provision of costly supplementary feeds (e.g. hay and grain). The inclusion of lucerne causes a large reduction in the marginal value of feed in these months as it eliminates the feed-gap. The presence of lucerne allows a smaller area of annual pasture to be planted and results in annual pasture being more highly utilised when it is growing most actively and its quality is highest.

Crop harvesting occurs in late November and early December and the associated crop residues are an important source of feed in the summer months. Initially the residues are comprised of high-quality (spilt grain and green plant material) and low-quality (straw) material. However, the quantity and quality of these residues decreases as they are grazed and their feed value declines during summer. This is reflected by an increase in the marginal value of feed that occurs in this period. Subtropical grass also provides feed in summer and if subtropical grass is present it reduces the length and severity of the autumn “feed gap”. The results indicate that, even in the presence of subtropical grass, autumn is still a critical feed period.

3.2 Results of sensitivity analysis.

The results of the sensitivity analysis are summarised in Figures 6 and 7. In these figures, the average increase in profit and the average area of pasture-cropping for the 256 treatments are included as horizontal lines. In the sensitivity analysis, subtropical grass could be planted conventionally or as a pasture-cropping system, but in all treatments pasture-cropped subtropical grass was selected in preference to non pasture-cropped subtropical grass. The average percentage of the farm that was pasture-cropped was 16 percent and this contributed to an average increase in annual profit of ~$12 per ha. The bars show the increase in profit for low and high values of each of the eight factors examined (Figure 6) or the corresponding areas of subtropical grasses (Figure 7). In each case, a bar represents an average of 128 model solutions, or half of the total number of solutions, which represent all possible combinations of factors.

FIGURE 6 about here

FIGURE 7 about here

If a large difference in profitability or area occurred due to changes in a factor then the model is considered to be sensitive to the factor. For example, the inclusion of subtropical grass and pasture-cropping resulted in a mean change in profit of ~$9 and ~$15 per ha for the farm for the "low" and "high" sand treatments (i.e. high and low areas of sandy soils on the farm). This indicates pasture-cropping was likely to make greater contributions to farms with larger areas of sand. The model results were sensitive to the farmers' choice of enterprises (crop area and flock structure), feed quality, the yield penalty to a companion wheat crop and the production of subtropical grass in summer. The factors of least importance include early grazing, or the ability to graze immediately after a companion wheat crop is planted, and the winter production of subtropical grass.

The factor with the largest individual effect on the profitability of subtropical grasses and pasture-cropping systems was feed quality. In the "low" feed quality treatment subtropical grass and pasture-cropping only made a small contribution to profitability (<$3 per ha of the farm) and they were not widely planted in the optimal farm solutions. In contrast the "high" feed quality treatment involved a large increase in farm profit (>$22 per ha of the farm) and high levels of adoption were optimal (~20 percent of the farm). The inclusion of subtropical grass that occurred in the low-feed-quality treatments was likely to be related to its ability to reduce the cost of supplementary feeding in autumn. In contrast, the high-feed-quality treatments had a larger effect on the farm system with pasture-cropping successfully competing for land that would otherwise be cropped.

This is an important result as a number of subtropical grass species are being trialled in the central wheatbelt and northern agricultural regions of Western Australia. Rhodes grass was considered in this study but Panic grass (*Panicum maximu*) and Digit grass (*Digitaria eriantha*) are more palatable and they are potentially suitable for pasture-cropping in Western Australia (Ferris *et al*. 2010). In addition, increasing the digestibility of subtropical grasses through breeding will likely improve its value.

Pasture-cropping was selected on a greater proportion of the farm and made a larger contribution to farm profit when large areas of poor sand were present. However, the higher profitability of cropping compared to sheep systems did limit the uptake of subtropical grass systems. For example, subtropical grass appeared to have a comparative advantage on poor sands, but in the high-sand treatments not all of these were allocated to subtropical grass or pasture-cropping.

Subtropical grass and pasture-cropping tended to be more valuable with less cropping (25 percent of the farm). The "low" crop-area treatment resulted in ~20 percent of the property being planted to subtropical grass and pasture-cropping and a mean increase in profit of ~$18 per ha for the farm. This compares with a ~$6 per ha increase in profit for the farm and ~12 percent of the farm being pasture-cropped in the "high" crop area treatment. This indicates that the value a farmer can derive from pasture-cropping systems varies depending on the emphasis the farmer places on cropping versus sheep production.

In the sensitivity analysis, pasture-cropping made a larger contribution to profit when meat rather than a wool flock was present. This finding was consistent with the initial model runs. There was also an interaction between feed quality and flock structure, with high feed quality having a larger effect when a meat-dominant system was present. This suggests that subtropical grass and pasture-cropping are more likely to be selected when enterprises exist that can take advantage of the forage and deliver a profitable return.

The yield penalty associated with pasture-cropped wheat had a large effect on the profitability and adoption of pasture-cropping. In the treatment with low yield for companion wheat, the average area of the farm associated with pasture-cropping was ~9 percent and this compares with ~24 percent in the high-yield treatments. There was also an interaction between the companion-wheat yield treatments and the area of poor sands. On poor sands, pasture-cropping was competitive but the yield of the accompanying wheat crop tended to be low. Therefore, the margin between conventional and pasture-cropped subtropical grass was small but on better quality soils the differential between conventional and pasture-cropped subtropical grass tended to be larger.

The early grazing treatment considered the value of allowing animals to graze pasture-cropped wheat in the early period after planting. Although the marginal value of feed tends to be relatively high at this time of year (see Figure 5) the results were not responsive to this factor. There was a similar lack of response to the level of winter production. A likely explanation for this relates to the relatively low feed quality of Rhodes grass during the winter months compared with annual grasses and lucerne. In contrast, an increase in the yield of subtropical grass in the summer months resulted in an increase in farm profit and a decrease in the area of subtropical grass. The association between an increase in yield and a decrease in area implies the production of forages at other times of the year become the limiting factor in terms of increases in livestock numbers.

4. Conclusions

The objective of this study was to ascertain what factors affect the profitability and predispose a farmer in the central wheatbelt of Western Australia to adopt subtropical grass and pasture-cropping. The intent of the simulations was to encompass the breadth of variables that were likely to influence this decision. The analysis indicates that not all of the variables are important, and the decision space can be reduced to just a few. These include the soil types present on the farm, enterprise choice, forage quality, and the level of summer production. Of these variables, the quality of feed produced by subtropical grass had the largest effect on the profitability and adoption of subtropical grass and pasture-cropping systems. In the low-feed-quality treatments, subtropical grass did not enter the farm plan or only entered at low levels.

In the initial model runs the inclusion of subtropical grass and pasture-cropping in a meat-dominant system increased farm profitability by ~10 percent. The scale of this increase suggests pasture-cropping is worthwhile. In spite of subtropical grasses and pasture-cropping contribution to increases in farm profit, they did not dominate the farming system and were primarily selected on LMU 1 or poor sands. To the extent that subtropical grasses are best suited to poor sands, pasture-cropping is likely to have a niche role rather than become ubiquitous in the central wheatbelt. In the northern agricultural region of Western Australia more livestock are run and poor sands are more prevalent and, while additional experimental data are needed, these technologies are perhaps better suited to this region.

In the sensitivity analysis the area of poor sand was an important driver in terms of the area of pasture-cropping, ~13 to ~20 percent of the farm and its contribution to farm profit \$9.55 to \$15.10 per ha of the farm, for low versus high sand treatments, respectively. Enterprise choice (area of cropping and presence of meat sheep), the yield penalty to a companion wheat crop due to pasture-cropping and the level of summer production were also important. Changes in feed quality resulted in the area of pasture-cropping varying from ~13 percent to ~21 percent of the farm and increases in profit varied from $2.30 to $22.30 per ha of the farm between the low and high feed quality treatments, respectively. The level and availability of feed production in winter was less influential to the value of subtropical grass systems.

It is unlikely that research or changes in management to increase out-of-season feed production will have a high value as alternative feed sources are available at this time of the year. The differences in profitability between conventional subtropical grass and pasture-cropping depended on the soils that pasture-cropping was selected on. In this analysis, subtropical grass was primarily grown on poor sands and on these soils there was little difference in profitability between conventional subtropical grass and pasture-cropping. However, in the treatment with low areas of sandy soils, pasture-cropping was selected on soils other than poor sands and on these soils pasture-cropping was more profitable than conventional subtropical grass. The yield penalty to a companion wheat crop was more important in the low-sand treatment than in the high-sand treatment.

The analysis provides information that is useful for farmers, researchers and policy makers. The value to farmers of subtropical grass and pasture-cropping is likely to depend on the characteristics of their farms and their management choices. Farmers who develop livestock enterprises that are able to capitalise on subtropical grass systems should profit from their adoption.

Acknowledgements

The project was funded by the Future Farming Industries CRC. This study would not have been possible without this funding or discussions and collaboration with other colleagues from the FFI CRC, CSIRO, University of Western Australia and DAFWA. The authors particularly wish to thank Andrew Bathgate, Michael Burton, Rohan Sadler, Clinton Revell, David Pannell, Phillip Ward, Tim Wiley, Diana Fedorenko, Perry Dolling, Phillip Barrett-Leonard and Rick Llewellyn for their assistance in the preparation of this paper.

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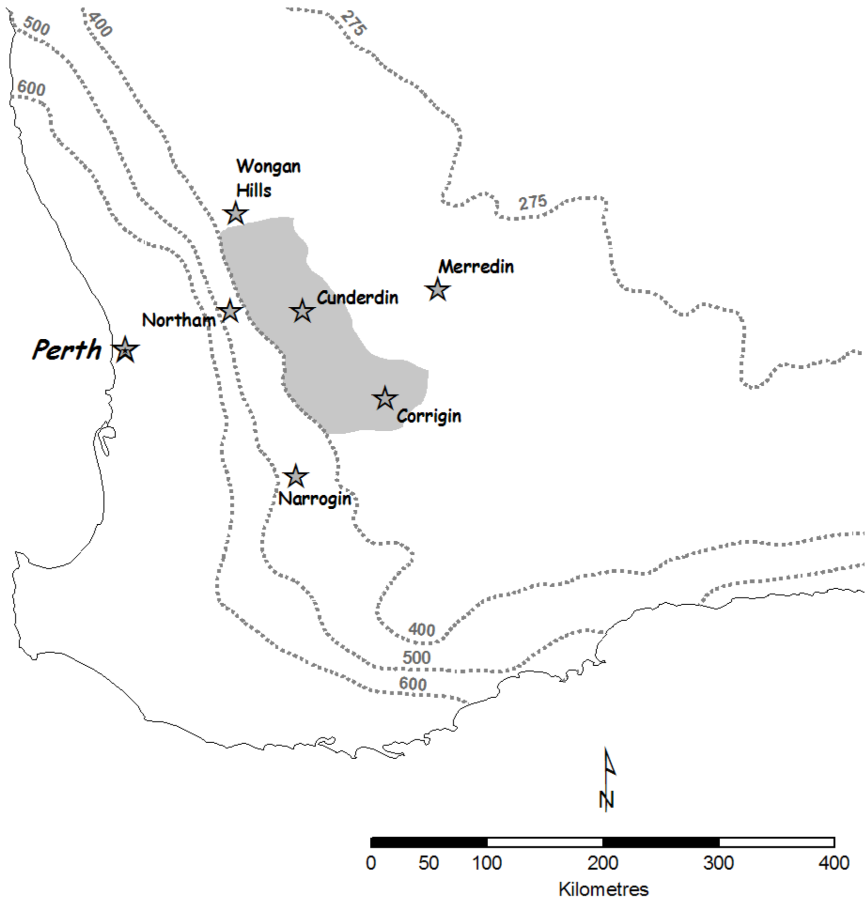

Figure 1. Central wheatbelt region in Western Australia.

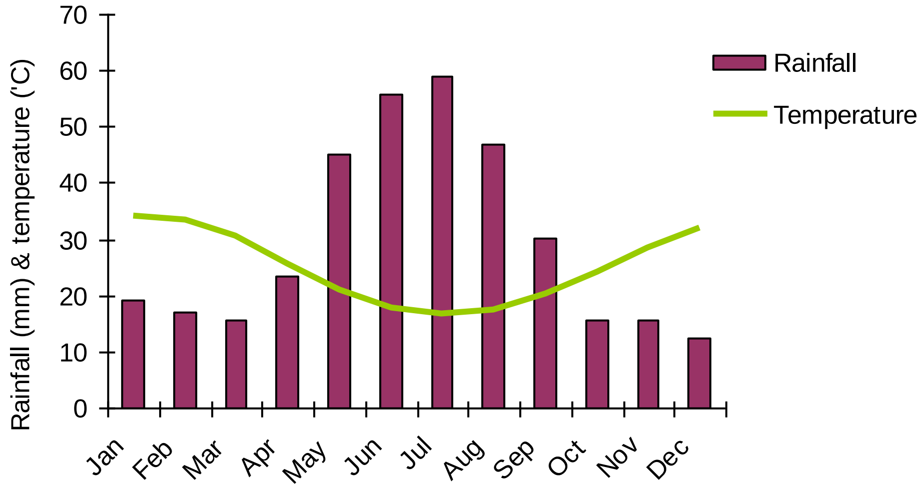

Figure 2. Average monthly rainfall (mm) and average maximum temperature (°C) for the central wheatbelt town of Cunderdin (Bureau of Meteorology, 2009)

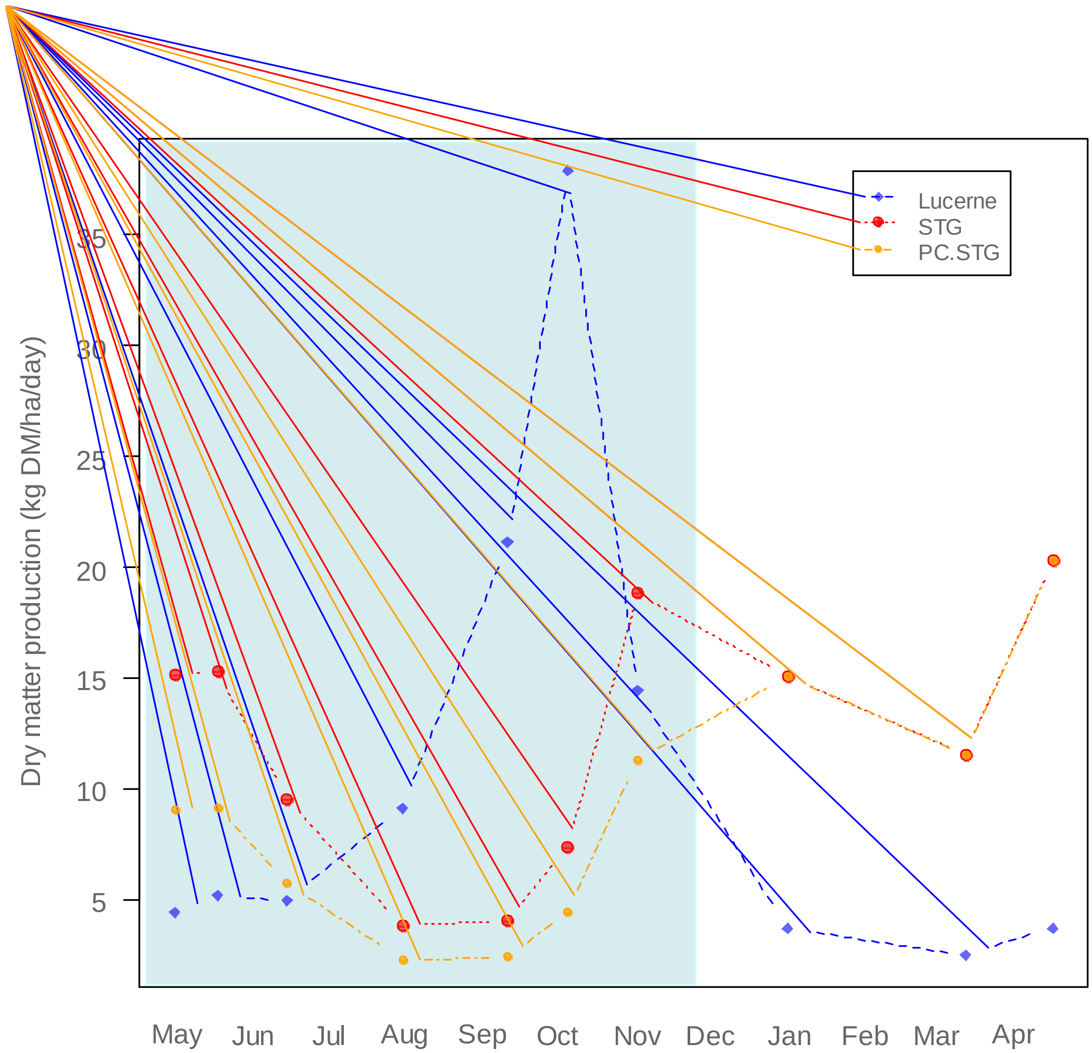

Figure 3. Daily dry matter production of lucerne, conventional subtropical grass (STG) and pasture-cropped subtropical grass (PC.STG)[6].

[6] Shaded area refers to the period of animal exclusion.

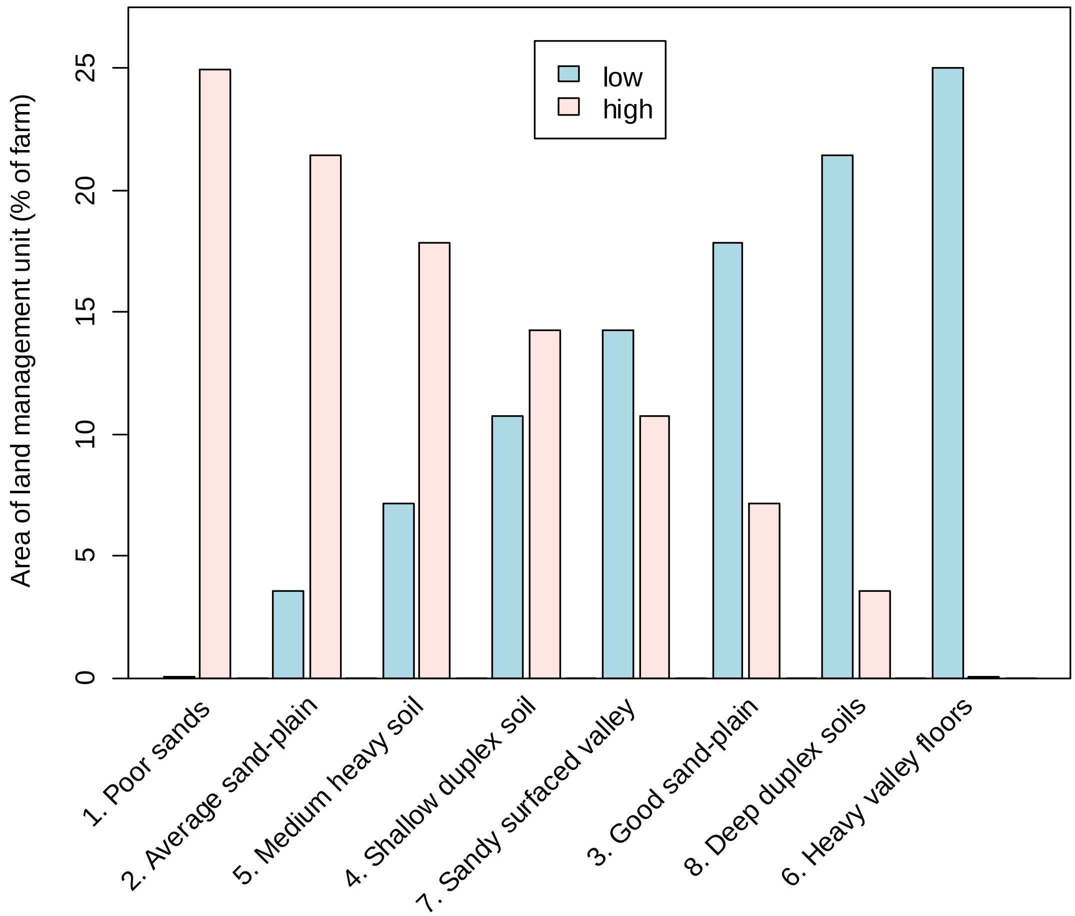

Figure 4. Area of individual land management units associated with the "low" and "high" sand treatments.

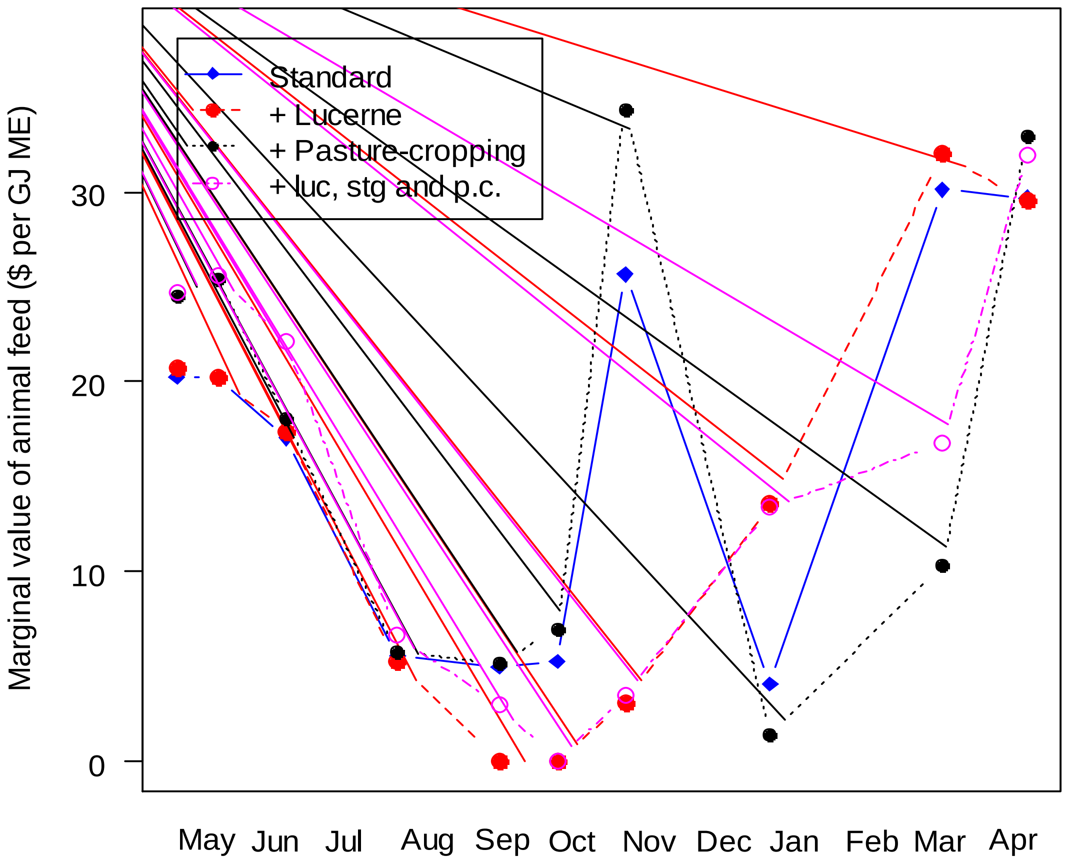

Figure 5. Standard runs: marginal value of animal feed for lucerne, subtropical grass, and pasture-cropping scenarios (meat dominant system).

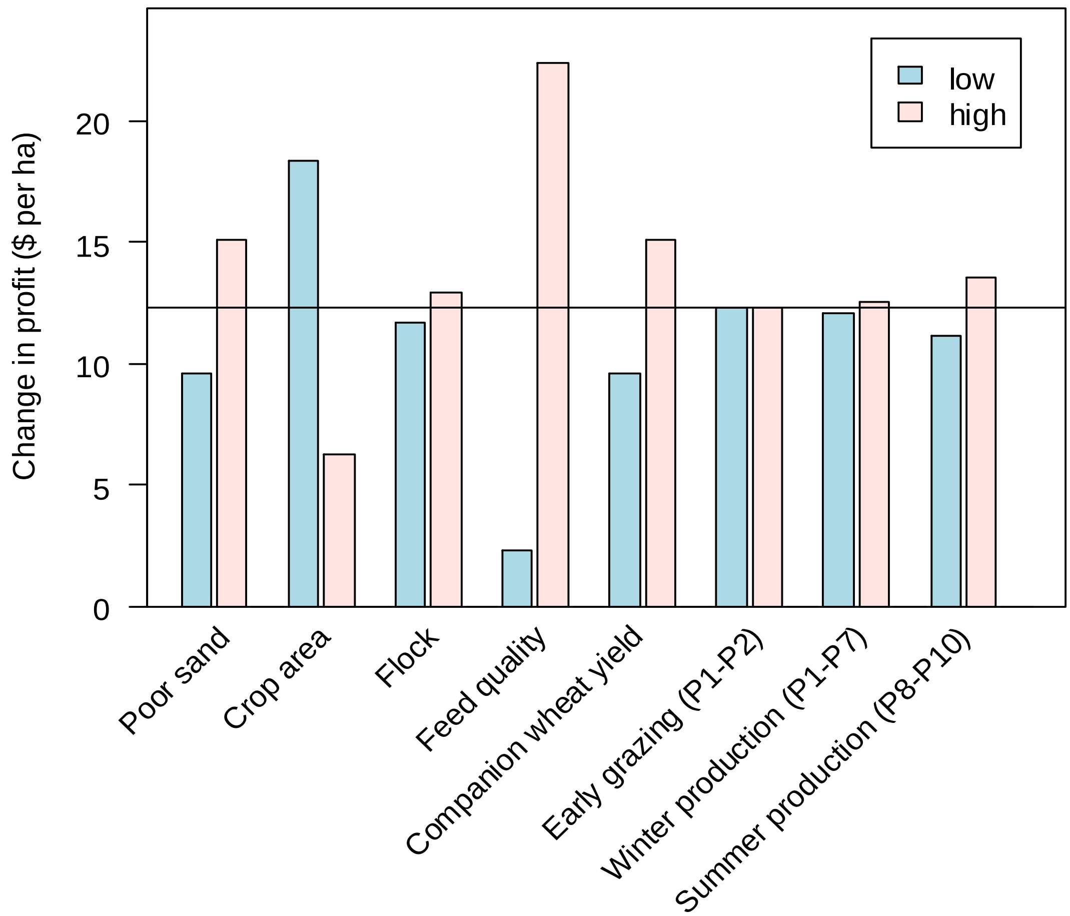

Figure 6. Results of sensitivity analysis: mean profit ($ per ha) associated with pasture-cropping and different factor levels[7].

[7] For a description of the factors that are varied in the sensitivity analysis please see Table 4.

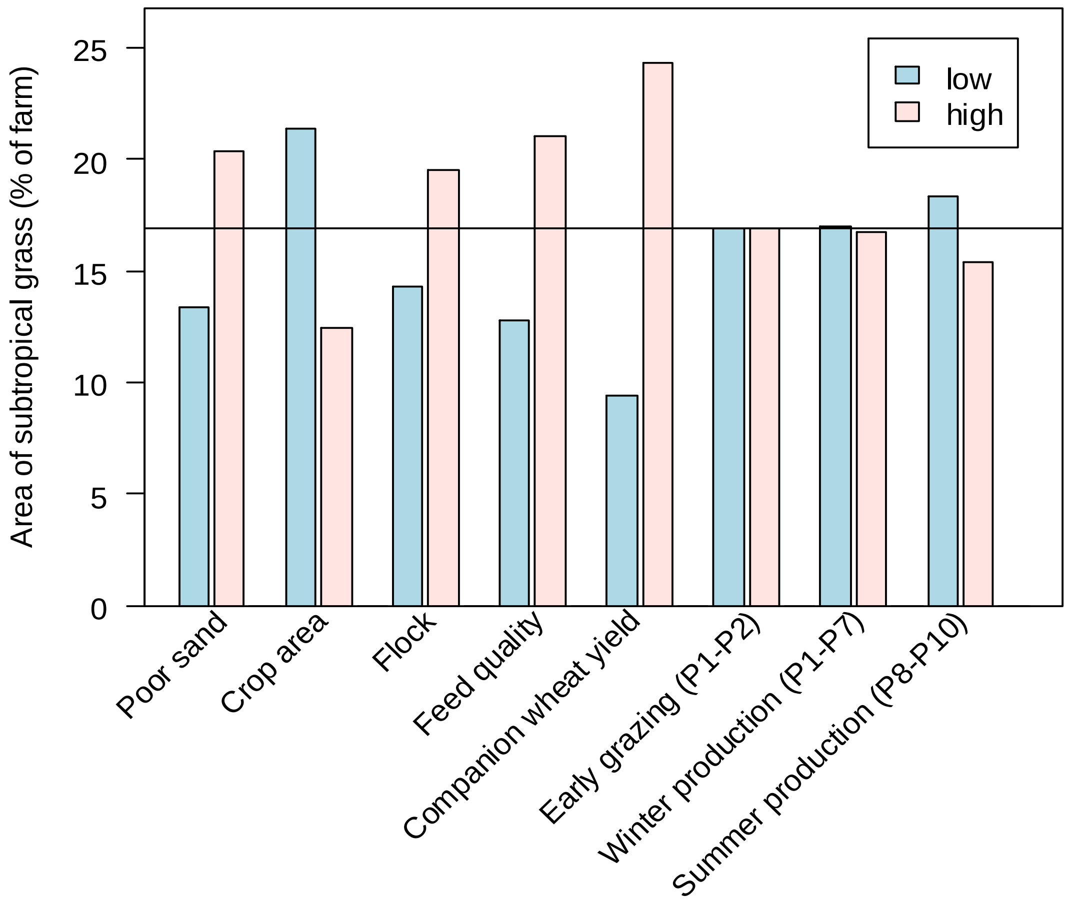

Figure 7. Results of sensitivity analysis: area of pasture-cropping (percent of farm) associated with different factor levels[7].

Table 1. Animal and forage related time periods in MIDAS.

Period	From	Until
1	10-May	23-May
2	24-May	13-Jun
3	14-Jun	18-Jul
4	19-Jul	12-Sep
5	13-Sep	10-Oct
6	11-Oct	31-Oct
7	1-Nov	5-Dec
8	6-Dec	28-Feb
9	1-Mar	25-Apr
10	26-Apr	9-May

Table 2. Land management units (LMU) or soil types in the Western Australia central wheatbelt version of the MIDAS model.

LMU	Name	Dominant soil type	Standard area (ha)
1	Poor sands	Deep pale sand	140
2	Average sand-plain	Deep yellow sand	210
3	Good sand-plain	Yellow gradational loamy sand	350
4	Shallow duplex soil	Sandy loam over clay	210
5	Medium heavy soil	Rocky red/brown loamy sand/sandy loam; Brownish grey granitic loamy sand	200
6	Heavy valley floors	Red/brown sandy loam over clay; Red and grey clay valley floor	200
7	Sandy surfaced valley	Deep sandy surfaced valley; shallow sandy-surfaced valley floor	300
8	Deep duplex soils	Loamy sand over clay	390

Table 3. Relative yield of annual pasture, lucerne, subtropical grass and wheat on different land management units.

LMU	Relative Yield			
	Annual pasture	Lucerne	Subtropical grass	Wheat
1	0.40	0.50	0.65	0.40
2	0.65	0.65	0.75	0.75
3	1.00	0.90	0.90	1.00
4	0.65	0.75	0.75	0.90
5	1.00	1.00	1.00	0.90
6	0.80	0.75	0.80	1.00
7	0.75	0.75	0.80	0.95
8	0.75	1.00	1.00	0.90

Table 4. Factors varied in sensitivity analysis.

	Factor	Description	Level: Default	low	high
1.	Poor sand	Triangular distribution of soils or land management units	Standard[8]	See Figure 4	See Figure 4
2.	Crop area	Percentage of farm planted in arable crops	50 to 60 percent[9]	25 percent	75 percent
3.	Flock	Livestock income predominantly from:	Meat	Wool	Meat
4.	Feed quality	Dry matter digestibility of subtropical grass	63 to 66 percent	47 to 49 percent	79 to 83 percent
5.	Companion wheat yield	Yield of companion wheat crop relative to a conventionally managed wheat crop	85 percent	75 percent	95 percent
6.	Early grazing (periods 1 to 2)	Animals permitted to graze during the early stages of the wheat phase of a pasture-cropping rotation.	No	No	Yes
7.	Winter production (periods 1 to 7)	Level of subtropical grass production in winter relative to standard assumptions	100 percent	75 percent	125 percent
8.	Summer production (periods 8 to 10)	Level of subtropical grass production in summer relative to standard assumptions	100 percent	75 percent	125 percent

[8] Standard refers to a distribution of soils that is typical for the region (see Table 2)
[9] The crop area is normally unconstrained but in most analyses between 50 and 60 percent of the farm is planted to crops.

Table 5. Standard runs: key model output for lucerne, subtropical grass, and pasture-cropping scenarios.

Flock type	Scenario	Crop area (ha)	Annual pasture area (ha)	Lucerne area (ha)	Subtropical grass area (ha)	Supp. feed (kg per DSE[10])	Stocking rate (DSE per WG ha[11])	Farm profit ($ per ha)
Wool flock	1) Baseline	1,614	386	-[12]	-	46	7.0	58
	2) + lucerne	1,489	318	193	-	34	7.5	62
	3) + subtropical grass	1,570	412	-	18	37	7.2	60
	4) + pasture-cropping	1,574	411	-	19	37	7.2	60
	5) + luc, stg and p.c.[13]	1,416	343	209	42	27	7.3	65
Meat flock	6) Baseline	1,502	498	-	-	45	6.7	67
	7) + lucerne	1,351	340	309	-	36	6.9	76
	8) + subtropical grass	1,287	639	-	74	38	6.5	73
	9) + pasture-cropping	1,309	634	-	76	38	6.5	73
	10) + luc, stg and p.c.	1,239	344	312	140	38	7.4	82

[10] DSE refers to dry stock equivalents.
[11] WG ha refers to winter grazed hectares or the sum of annual pasture, lucerne, and subtropical grass.
[12] A dash reflects this cell is not applicable for the particular scenario.
[13] luc refers to lucerne, stg to subtropical grass, and p.c. to pasture cropping.

Table 6. Land area for lucerne, subtropical grass, and pasture-cropping scenarios (meat dominant system).

Rotation	LMU	Standard (ha)	+lucerne (ha)	+subtropical grass (ha)	+pasture-cropping (ha)	+luc, stg and p.c. (ha)
Lucerne (4 years), wheat	8		386[14]			390
Subtropical grass	1			74		
Pasture-cropped subtropical grass, wheat every 2nd year	1				76	140
Annual pasture	1, 2, 5 8	498	340	639	634	344
Wheat, barley, lupins, field peas	2, 3, 4, 6 7, 8	1502	1274	1287	1290	1126

[14] Please note the land area associated with this rotation includes 309 ha of lucerne and 78 ha of wheat.