Recognising and working within landscape limitations for increased productivity

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Introduction – Skills and aptitude

Would Phar Lap have made a good milk delivery horse? Would you use Labradors to round up sheep? The answer to these questions is 'maybe'. Phar Lap's ancestors had of course been selected over generations with the ability to run fast over a long distance, therefore this was his propensity. Labradors appear to be good at a couple of things – either clearing a coffee table with one wag of their tail while appearing oblivious to the commotion caused, or at the other end of the spectrum, capable of being the ultimate assistance dog. Again, selection and breeding has determined their propensity to perform either task. Really we can boil this down to saying that skills and aptitude to certain tasks are to some extent pre-determined, in these cases by breeding. So sure, Phar Lap may have made an okay milk delivery horse (depending on how quickly the milk delivery was required and how frothy you liked the milk), but would this have been the best use of his talents?

What then, does this have to do with landscapes and their management? Does the fact you have a property or paddock within your property automatically mean you have the ability to grow the pasture or crop of your choice there? Really what we want you to think about throughout this conference is what attributes does your farm have at the landscape or paddock level, what do its strengths and weaknesses pre-dispose it to in terms of productive capacity? In other words, what are the skills and aptitude of your farm? Knowing this, how can you manage the landscape more appropriately in terms of input allocation (fertiliser, fencing etc.), choosing the animal production systems you impose on it and is there a need to look at changing management?

What is the landscape?

The definition of landscape means different things to different audiences. Clements *et al.* (2010) challenges anybody 'to stand in the middle of any property, whether a 1000 ha commercial holding or a 16 ha hobby block, and look around. The chances are that both will have one thing in common – a great diversity in landscape!'

Agriculturally, we can think about landscapes as being composed of a number of building blocks. These include:

1. Descriptive features – topography (e.g. hilly, rolling, flat), aspect (e.g. north-facing, south-facing) and slope (e.g. steep, gentle).
2. Soil physical features – these include soil depth, soil texture, water holding capacity, propensity to drain well or be prone to waterlogging.
3. Soil chemical features – these include soil pH, available phosphorus (P), available sulphur (S), exchangeable cations.
4. Botanical composition features – this can include trees and pasture composition.
5. Microclimate conditions – factors such as aspect and slope affect microclimate conditions. These factors can influence soil physical and soil chemical conditions through weathering processes and subsequently the composition of the plant community growing there.

It is impossible to say comprehensively which of the landscape building blocks ultimately determine the productive capacity of the landscape. The factor most limiting production can vary within and between landscapes. From the list above though, it is easy to see that some factors we are able to influence through management, and others that we cannot. Recognition of what is limiting landscape productivity and our ability to influence it with management inputs will allow us to better match inputs with landscape productivity potential and therefore head towards maximising landscape potential in the long term.

What limitations do landscapes impose on us agriculturally?

The gross appearance of the landscape (aspect, topography) has major impacts on the usefulness of land for specific agricultural purposes. Other landscape components such as soil type, soil depth and botanical composition influence the productive capacity of the landscape and our ability through the application of inputs to alter pasture and therefore animal production. If we think broadly though, the structure of the landscape imposes certain limitations on us which include:

1. What we can use the landscape for – for example, steeper slopes generally preclude cropping due to inherent problems with trafficability and susceptibility to erosion. Similarly, landscape areas or paddocks in the path of cold winds make poor paddocks for lambing and calving.
2. How intensively we can use the land – for example, steeper sloping areas are more prone to erosion than more gently sloping areas so degradation through inappropriate grazing management can occur more quickly on steeper areas.
3. What the absolute productive capability of the land is – factors such as aspect, slope and soil depth will combine to determine the absolute productive capability of the land.
4. What our capacity is to alter production – for sure we can alter production on all land classes to some degree; however, the absolute extent to which we can alter production through addition of inputs will be determined by landscape characteristics such as slope, aspect, soil depth, soil chemistry and botanical composition and how we manage livestock consuming the pasture.

It is critical we understand what the capability of the landscape we are managing is, whether on a whole farm or paddock level. If we understand the limitations of the landscape we can more appropriately devise management strategies and prioritise inputs in a way that play to the strengths of the landscape and ultimately result in a better match of enterprise to landscape capability.

Recognising what you can and cannot change

Within landscapes there are things that you can and cannot change through general management and allocation of inputs. It is critical that land managers appreciate this as it will assist greatly in prioritising where inputs are allocated for greater production benefits.

Let's look firstly at what you cannot change and the impact these factors have on pasture production:

1. Gross landscape features – including topography, aspect and slope. We really have little capacity to change these features and they in turn affect the microclimate conditions in the landscape.
2. Soil physical factors – the type of soil we have to work with in a landscape has been pre-determined in the landscape formation process. Similarly, the depth of soil has largely been determined in the soil formation process, though it may have altered over time due to weathering and erosion. Hackney (2009) reported soil depth varied by up to 52% across one paddock in the Central Tablelands area of NSW. In this paddock, on average, soil depth of the north slope was only 67% of that on the south slope.

   Drainage issues within landscapes are also not something easily altered by management. The subsoils of many soils in the variable landscape of the permanent pasture zone are prone to dispersion on wetting. This means that drainage can be periodically affected.
3. Soil chemical factors – some soil chemical factors cannot be readily influenced through allocation of management input. A good example of this is subsurface soil acidity, a common problem throughout the higher rainfall permanent pasture zone (Scott *et al.*

2000). Lime can be effective in ameliorating acidity in the topsoil, but it is not a practical or economic option where acidity extends deep into the soil profile.

4. Microclimate – Hackney (2009) studied the effect of landscape features, specifically aspect, on microclimate. Results of these studies showed incoming solar radiation was higher throughout the period of the study on north facing compared to south facing slopes. The difference in solar radiation received was equivalent to 4 to 6 degrees of latitude depending on site. The sites used by Hackney (2009) were not extreme in terms of slope (8–16 degrees).

   Differences in solar radiation resulted in differences in soil temperature with north facing slope warmer than south facing slope which then influenced evaporation rates and the ability of different areas of the landscape to support sustained periods of plant growth. Indeed, Hackney (2009) found that north facing slopes generally dried out more rapidly in spring and/or had more erratic wetting and drying cycles.

   North and south slopes in the sites studied by Hackney (2009) had distinctly different pasture composition. Probably the best example of this is from a site at Jimenbuen in the Monaro region of NSW. This site was sown to a mixture of cocksfoot and subterranean clover in the 1970's and since then, the paddock had been managed uniformly with regard to input allocation and grazing management. When Hackney's study began in 2001, cocksfoot was absent from the north facing slope and subterranean clover content far less common on the north compared to the south facing slope.

   So we could say from this, that we really have no control over the climate at different points in the landscape and this is going to be a major factor influencing production through its effect on soil moisture and therefore capability to support different species and/or densities of pasture.

If we now look at factors we can change. These include:

1. Soil chemical conditions – there is the capacity to alter some soil chemical conditions such as nutrient availability. Fertiliser can be used to increase availability of plant nutrients such as phosphorus and sulphur – nutrients which are almost universally lacking in Australian soils (Wild 1958). Application of these nutrients can have a significant impact on pasture production. Indeed, many historical studies such as Donald and Williams (1954) were able to show drastic increases in pasture production with application of phosphorus and sulphur where soil nutrient deficiencies existed. It is also possible to alter problems such as soil acidity and associated aluminium and manganese toxicities which do not extend into subsurface layers through application of lime (Scott *et al.* 2000).
2. Botanical composition – This can be altered through full pasture establishment, introduction of particular species into existing pastures through sowing or broadcasting (e.g. pasture legumes) or via grazing management. We can also manipulate pasture composition through use of herbicides, either alone or in combination with grazing management.
3. Paddock design – where significant differences exist in a landscape, there may be merit in dividing paddocks up based on these varying characteristics. For example, Hackney (2009) found significant differences between north and south aspects of paddocks in soil chemical, soil physical and botanical composition features. Inherently, these aspects showed significant differences in pasture production and therefore carrying capacity. Grazing behaviour is affected by factors such as temperature, wind direction and topography (Blackshaw 2003) – all microclimate factors which Hackney (2009) measured as varying across topographically diverse landscapes. Therefore to attain better control of grazing behaviour, it may be necessary to subdivide paddocks.

Prioritising landscape limitations as they relate to production – fundamentals before the fancy stuff – getting your ducks in a row

Really, what we need to know is what is it that is most limiting pasture production at various points in the landscape. At a practical level, the smallest unit of management we usually deal with is a paddock, so the question becomes 'What is most limiting productive potential within this paddock?' The answer is most likely going to differ paddock by paddock, but it is important that this is well understood. We would suggest a checklist for the paddock, similar to ones we use when going onto a farm for the first time which asks questions along the lines of:

1. How variable is the paddock topographically and does it contain a mixture of aspects and slopes? The more diverse the paddock is topographically, the greater the differences you will have in microclimate conditions and therefore potential pasture production. It could also be more difficult to manage grazing pressure in these paddocks as variation in microclimate conditions will have a greater influence on grazing behaviour.
2. What are the soil physical conditions like? Is the soil deep or shallow? Is the texture of the soil fine or coarse? This will affect the capacity of the soil to hold moisture. The shallower and coarser the soil, the lower the productive capacity. If the paddock is composed primarily of shallow, coarse textured soils, is it really worth pouring significant inputs into?
3. What is growing in the paddock now? Are there favourable nutrient responsive species? What is your capacity to change composition if it is currently not favourable? Is it feasible to attempt to change the composition?
4. What are the current soil chemical conditions like? What are the main chemical factors limiting production and do you have the capacity to change them?

Now that you have thought about all of these things individually, start to put them together so that you can assess what most limits pasture production. Are the soils in one paddock deep and covered with favourable nutrient responsive species, but your soil phosphorus level is low? If so, fertility is the most likely constraint on production.

Are the soils in another paddock shallower, but still contain nutrient responsive species and lack phosphorus? Is a third paddock similar in soil type to the second, but has a degraded pasture with a lot of non-nutrient responsive species? Start to think about prioritising these paddocks in terms of their *absolute* production potential. Where can you make the most profitable difference in applying your management inputs? Really, this is a case of understanding your fundamental production base. If you understand the fundamentals of each paddock and what is most limiting production, then you can more appropriately manage paddocks to their potential. At the end of the day, this will result in you developing realistic expectations for what each paddock can deliver rather than setting goals that are unachievable.

A quick look back at farm management – has our past management accounted for landscape differences?

In the past in variable landscapes has there been account taken of differences in production potential? Generally, it would have to be said that this has not occurred. Just how much does production differ within a variable landscape paddock? Hackney and Virgona (2001) measured pasture production at 100 points in a topographically variable paddock near Adelong in NSW. Here, pasture production across the site varied from 300–9000 kg DM/ha over the nine month measurement period with 30% of locations producing less than 1500 kg DM/ha. Similarly, Hackney (2009) measured pasture production in eight regions of a variable landscape paddock over a two year period and found a 2.7 fold difference in pasture production across these regions. With this in mind, could you see reason to alter the rates of fertiliser used within and/or between paddocks to account for differences in soil depth and species composition based on the capacity of the landscape to respond to the nutrients?

With respect to fertilisers and Australian pastures, we could classify their use as planned, reactionary, or a combination of the two. Where fertiliser application has been planned, decisions of where and how much fertiliser to apply have been largely based on the results of soil test analyses with suggestions made of critical soil available phosphorus levels required for non-limiting pasture production (McLachlan 1965, Rudd 1972, Blair *et al.* 1976, Brown and Smith 1998, Clements *et al.* 2000). The critical soil P levels considered non-limiting for pasture production have varied over time. McLachlan (1965), Rudd (1972), Blair *et al.* (1976) considered available Colwell P levels of 35 mg/kg as necessary for non-limiting pasture production while Clements *et al.* (2000) suggested 30 mg/kg. More recently Gourley *et al.* (2007) has refined critical P levels by incorporating PBI into calculations and this now gives estimation of critical P levels for a range of soil types. Simspon *et al.* (2009) has built upon the Gourley *et al.* (2007) model by enabling calculation of the P required to reach critical soil P levels. Simpson *et al.*'s (2009) calculations incorporate the P necessary to replace P removed in animal products and soil losses of P. This represents some refinement of the previous recommendations of application of 10 kg P/ha/yr for general pasture situations (Clements *et al.* 2000). Interestingly, Clements *et al.* (2000) states fertiliser use was considerably lower than the suggested level at 10 kg P/ha every third year. Clements *et al.*'s (2000) recommendations for fertiliser use do not take into consideration potential variation in pasture response across variable landscapes. While Gourley *et al.* (2007) and Simpson *et al.* (2009) have refined calculation of critical P and P fertiliser requirements to attain critical P respectively, the applicability of these calculations have not been tested in variable landscapes in Australia (with the exception of the work of Hackney and Virgona 2001 and Hackney 2009) where a multitude of factors other than soil nutrient levels have the potential to impact on pasture productivity.

Reactionary fertiliser use has occurred periodically throughout the variable landscape permanent pasture zone in periods of high financial returns for the purpose of reducing taxable income (Clements *et al.* 2000). Such application may or may not occur in conjunction with the use of soil test analyses.

What then is the result of uniform fertiliser application in variable landscapes? Hackney and Virgona (2001) reported the results of an application of 125 kg/ha single superphosphate (8.8% P, 11% S) on a north facing, south facing and flat area of a paddock. Herbage production without addition of fertiliser was 6.5, 4.5 and 10 t DM/ha/yr respectively at each location. Application of 125 kg/ha of single superphosphate increased production by 1.5, 2 and 1 t DM/ha at the north, south and flat location respectively. So the most productive location produced about double the amount of herbage compared to the least productive with or without fertiliser application. Interestingly, the north and south locations in this study had identical available phosphorus levels and soil pH.

Hackney (2009) undertook fertiliser experiments at four locations (north upper, north lower, south upper and south lower) slope locations at two sites on the Central Tablelands and one site on the Monaro. Of the twelve locations where fertiliser was applied, only six were responsive to fertiliser application despite soil tests, taken prior to commencement of the experiment, indicating all locations were below the range considered for optimum pasture production based on soil available phosphorus. This indicated factors other than soil nutrient availability limited pasture production at these locations. Indeed, Hackney (2009) was able to show that significant differences in botanical composition were potentially limiting pasture production more than nutrient availability.

While few in number, the results of recent research on fertiliser response in variable landscapes of southern NSW indicate that fertiliser response is not uniform in variable landscape paddocks and greater understanding of other factors affecting pasture production are required so that more effective allocations can be made of inputs. Here you need to ask yourself – What is the most valuable part of the paddock or landscape? How well am I currently using the feed produced in the paddock? Do grazing animals utilise the paddock well or are there areas under or over grazed? Is it wise to allocate the same level of inputs to all these locations or am I better spending money on other things so that I can better target fertiliser inputs?

Tools available to you for increasing productivity in the landscape

There are many tools available for use in improving management of variable landscapes. Below the use of these tools are discussed and where information exists specifically relating to landscape management.

Fertiliser – uniform versus differential

As mentioned before a trial looking at responses achieved when fertiliser was applied to a variable landscape at uniform rates, although application was uniform, response was anything, but! So what are the alternatives?

Hackney (2009) examined the use of differential compared to uniform application rates of fertiliser. Basically, this involved removing fertiliser from areas which were non-responsive and applying it only to areas where a response was measured. At all three sites used by Hackney (2009) differential application resulted in increased economic return compared to uniform application with the effect magnified as fertiliser price increased. Hackney (2009) based results on calculated carrying capacity (using Prograze) of different locations in the landscape rather than on actual on-ground measurement. The results also included calculation of cost of subdivisional fencing to better target grazing pressure and fertiliser application.

Grazing management and fencing

The behaviour of grazing animals is affected by many factors including topography, wind direction and temperature (Blackshaw 2003), all factors which vary in the landscapes we deal with. Under set stocking systems animals have ultimate power of diet selectivity (Chapman 2000). At the other end of the spectrum, with smaller paddocks and very high stocking rates, selectivity of diet is reduced. Both systems have their positives and negatives. For example, in large paddocks under set stocking for long periods, significant nutrient transfer to camps can occur resulting in considerable differences in botanical composition across paddocks with over and under utilisation of different areas of the paddock (Hilder 1964, Hackney 1997). In systems where there are large numbers of small paddocks with long periods between grazing, pastures can become rank between grazing periods resulting in lower individual animal production and loss of legumes from the pasture (Waugh 1997, Chapman 2000).

Certainly past New Zealand research (Radcliffe 1982) and Australian research (Hackney and Virgona 2001, Hackney 2009) have shown significant difference in productive capacity between and within aspects. This, in combination with known effects of topography on grazing behaviour (Blackshaw 2003) would suggest that sub-division of larger highly topographically variable paddocks would improve management of grazing pressure and allow for more targeted use of fertiliser. The economic advantage of strategic fencing on an aspect and position on slope basis combined with a differential fertiliser application strategy has been shown in a desktop study by Hackney (2009). The economic benefit of this type of tactical management increases as fertiliser price rises. Badgery *et al.* (2012) is now evaluating this type of tactical fencing-fertiliser management in on-ground research.

Weed Control

Weeds may or may not have detrimental effects on productive capacity of the landscape. The extent of their influence will depend on the weed species present and where it is growing in the landscape and the stage of its growth. Barley grass (*Hordeum vulgare*), for example, in its vegetative state is a highly palatable, high quality feed (up to 77% dry matter digestibility, 33% crude protein and 11.5 MJ/kg Metabolisable Energy (NSW DPI Nutritive Value of Feeds Database). However, once it enters the reproductive phase of growth it can potentially cause injury to the eyes, gums and hides of animals (Kidston 2007). In a landscape sense, areas dominated by barley grass, or other short lived cool season annuals, can become bared out over summer and autumn resulting in higher erosion risk. So while beneficial to the animal production system at certain times, weeds such as barley grass can be detrimental to the animal production system and the landscape at other times.

Other weeds are more obviously detrimental to landscape productivity. An example of this is serrated tussock (*Nassella trichotoma*). Serrated tussock is unpalatable to livestock and if they are forced to eat it exclusively, animals will lose weight and can die through either weight loss and/or impaction (Ayres and Leech 2010). Unchecked, serrated tussock will dominate pasture and carrying capacity will be significantly reduced (Ayres and Leech 2010).

So thinking about the weeds you have; can you utilise them through grazing in a way that is beneficial to animal and landscape productivity? Can you control weeds using grazing or do you need to incorporate some herbicide use? Could you better target weed control and grazing pressure and therefore weed control through more strategic grazing and/or herbicide application if large topographically variable paddocks were subdivided? Are there some weeds that you absolutely have to control to maintain landscape productivity? Are there some you can live with and can actually be beneficial at certain times if they are growing at the right time and in the right place in the landscape?

Pasture renovation

Changing the pasture growing in the landscape can certainly have a dramatic effect on landscape production potential if combined with appropriate fertiliser and grazing management. Full pasture renovation is expensive as demonstrated by Scott and Keys (2007) who calculated the cost of sowing new perennial grass-based pasture at $230/ha with 12 years required to recoup sowing costs. If liming was required, then an additional $180/ha could be added requiring another five to seven years pay back time. So certainly you can change composition through full pasture renovation, but you need to ask yourself, should you be undertaking full renovation given the cost? Are there other things you can do to change the composition and therefore the productivity of your existing pastures?

If you do decide that full pasture renovation is necessary, then you need to give careful consideration to the effect differences in microclimate, soil physical and soil chemical factors and their impact on the production and persistence of the pasture you wish to sow. Hackney *et al.* (2008) evaluated the persistence of a range of perennial grass species on east and west aspects of a site on the Central Tablelands of NSW. Chemically, the soils at the sites used in this experiment were identical in pH, available phosphorus and exchangeable aluminium. The sites, however, differed considerably in texture with the west facing site having higher coarse particle content (percentage of soil particles greater than 2 mm) and therefore a lower water holding capacity. Temperature on the west facing slope was also consistently higher than on the east facing slope. Plant numbers were assessed two and a half years after sowing with results showing density was significantly higher on the east compared to the west facing slope. There were also important differences within species. For example, within the cocksfoots sown, varieties with higher levels of summer dormancy were more persistent on the west facing slope than summer active varieties. This shows that there is scope in selection of species and/or variety to attain better pasture persistence. Again, this demonstrates that uniformity, in this case, in selection of variety of species to sow could give significantly different results in persistence in topographically variable landscapes.

Given the very high cost of full pasture renovation, it is prudent to consider manipulation of existing pastures through other means. Numerous studies have shown that strategic grazing can result in increases in density of favourable species over time. Kemp *et al.* (2000) reported tactical grazing was an effective means to manipulate the density of a range of perennial grass species provided the species of interest contributed to 10–70% of the overall pasture sward. Depending on species, resting either at a time when the pasture was likely to experience extreme environmental stress or when the species of interest was actively growing generally resulted in an increase in density. Paddock size and variation in the landscape will affect your ability to successfully implement this strategy.

Loss or decline in legume populations can also result in reduction in pasture production. Dear *et al.* (2007) found an inverse relationship between perennial grass density and subterranean clover seed set and regeneration. Tactical grazing can again be used to manipulate the balance between grasses and legumes in the pasture. Ensuring sufficient light and bare ground for regeneration of annual legumes in autumn may be achieved through use of tactical grazing. Again paddock size and variation in the landscape will affect your ability to successfully implement this strategy.

Adequate nutrition to support the pasture you are trying to achieve also needs to be considered. There is little point in employing good grazing techniques to encourage desirable pasture species if there is insufficient nutrition to support these species.

Again you need to ask yourself some questions. What is my current pasture composition? Is there sufficient population of desirable species in the existing pasture to allow me to manipulate composition through altering grazing management? Does the current location of fences allow me to manage grazing pressure in a way that will allow me to manipulate pasture composition? Should I be applying fertiliser in combination with grazing management changes – if so, where and how much?

Livestock enterprise

Production potential varies across landscapes and therefore the number of livestock that can be supported at specific points in the landscape also differs. However, it is not only the number of livestock given areas or paddocks within your farm can support that needs consideration, but about the type of livestock system you are running in these areas? For example, if you have two paddocks capable of running 10 DSE/ha, one is relatively flat and well sheltered and the other has more variable topography what options do you have for these areas? Given the first site is flat and well sheltered, animals need not expend too much energy either keeping warm or walking to forage. The second site has good pasture, but the topography and microclimate conditions mean more energy might be expended in keeping warm or walking to source feed. So as a paddock for finishing animals the first paddock is most favourable. For animals being kept as replacements, either paddock would likely be suitable. Given what has been discussed throughout this paper, are all paddocks created equal in terms of their capacity to support different livestock production enterprises? Should you assess which paddocks are suitable for specific purposes? Are there things you can do to change the purpose a paddock is used for?

Livestock genetics

So you've decided on what the strengths and weaknesses of different areas of your farm are. You have decided which animal enterprise best suits different areas of the farm. What else can you do to fine tune management? Various animal performance trials are conducted in many locations throughout NSW and Australia to evaluate the performance of different bloodlines of sheep and cattle under the same controlled grazing conditions. Martin (2009) reported results from a NSW wether trial a net profit difference of $297/ha between top and bottom performing teams. Thus there is considerable potential to change return generated from livestock enterprises by choosing animals with higher genetic merit. It should not be forgotten though, that livestock can only express their true genetic merit if their nutrition is adequate. Therefore, it is critical that you understand your pasture production base and what may be limiting it as a primary function.

Prioritising management tools for increased whole farm production – Level 1 to Level 3 tier importance

There are many tools available to you to increase whole farm production. How then do you prioritise which ones to use, how to use them and how much of each to use? Really there is not a simple, uniform answer. Firstly and most critically, you must understand the production base you are working with. Then you need to really understand the tools you have available to you, what they are capable of achieving and what their limitations are. One of the first things you should ask yourself is 'How easy is my farm (or specific paddocks) to manage?' Then secondly, 'Can I apply the management options available to me to these areas of the farm and reap the rewards?' The third tier question to ask yourself is; 'Now that I have assessed the ease of management of different areas of the farm (or paddocks) what else is available to me to increase productivity?'

An example of this is use of fertiliser. Ask yourself some questions; If I am applying fertiliser to this paddock, will it increase pasture production? If so, where? At what time will the production increases occur? Can I get the animals to utilise the extra production I achieve in those areas? If you can increase production, but you can not effectively control grazing, then an important first step may be considering subdividing the paddock in some way so that you can better target the grazing pressure. Once you have done this, then you might assess whether you can fine tune production potential through other means such as investigating whether some change in genetic merit of the livestock is required.

Putting it all together – isolate it, understand it, put it back together

Throughout this paper we have pulled apart different components that make up a landscape and investigated what influences production in the landscape and the tools we have available to manipulate production. Really what this is all about is getting you to understand what drives pasture production in the landscape, what is likely to be limiting and what capacity you have to change it. This paper should also highlight to you that in determining what affects production and the capacity you have to manipulate it, you should not focus too heavily on any one facet.

Another thing to keep in mind is if you know what you want the end product to look like, it's easier to implement the processes required to get there. This means you need to understand the limitations of each component of the production system, which can be manipulated, which can not and the value of such manipulations. Does your expectation of the end goal match up with reality? Is your goal achievable? Do you need to alter your goals to better fit landscape potential?

Conclusions

Managing variable landscapes should be simple – but that does not necessarily mean it is easy. Many factors combine to affect pasture production in the landscape and these can change within and between seasons. Can we give you a recipe to manage variable landscapes – the answer is no. What we can give you though are some general principles to consider. These are:

1. Identify factors that are likely to limit production.
2. Determine whether they are changeable or unchangeable factors.
3. Determine the economic feasibility of changing what is limiting production.
4. Rank different areas in terms of productive capacity.
5. Look at the paddock with the greatest absolute potential – what is holding it back?
6. In general, apply resources to the paddock with the greatest absolute potential and work back from there.
7. Make sure your expectations for productive potential match up with reality.

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Table 3. Plant density (plants/m^2) and total dry matter (DM, kg/ha) for the year following pasture establishment.

Ariah Park 2009		**Cover crop rate**		**Significance**
	0 kg/ha	**10kg/ha**	**20kg/ha**	
Plants/m^2 (May 2010)				
Lucerne	15a	11a	3b	
Phalaris	5a	1b	0b	
Dry matter kg/ha in 2010				
Lucerne	4090a	4120a	1760b	$P < 0.05$
Phalaris	4460a	1770b	500c	$P < 0.05$
Ariah Park 2010		Cover crop rate		
	0 kg/ha	10kg/ha	20kg/ha	
Plants/m^2 (March 2011)				
Lucerne 2 kg/ha	20a	18a	20a	$P < 0.05$
Lucerne 4 kg/ha	33b	31b	31b	
Phalaris 0.5 kg/ha	19b	20b	7d	$P < 0.05$
Phalaris 1 kg/ha	32a	20b	15c	
Dry matter (kg/ha) in 2011				
Lucerne	2907	2943	2909	ns
Phalaris	2137a	1082b	812b	$P < 0.05$
Total DM	5734	5129	4896	ns
Brocklesby 2009		Cover crop rate		
	0 kg/ha	60 kg/ha		
Plants/m^2				
Lucerne	27	21		ns
Dry matter (kg/ha) in 2010				
Lucerne	20195a	15066b		$P < 0.05$
Total DM	23529a	18034b		$P < 0.05$
Brocklesby 2010		Cover crop rate		
	0 kg/ha	22.5 kg/ha	45 kg/ha	
Plants/m^2 (Dec 2010)				
Lucerne	34	31	32	ns
Chicory	7	9	7	ns
Dry matter (kg/ha) in 2011				
Lucerne	4647a	2252b	3053a,b	$P < 0.05$
Chicory	3965a	4256a	3354b	$P < 0.05$
Total DM	10266a	9250b	8885b	$P < 0.05$

Table 4. Decision support tool (DST) analysis of the field experiments at Ariah Park and Brocklesby in 2009 and 2010.

Site	Year	Grain yield (t/ha)	CC relative effect	Total gross margin
Ariah Park	2009	0.8	0.69	-$134
	2010	3.3	0.80	$303
Brocklesby	2009	4.0	0.77	$313
	2010	3.8	0.90	$400

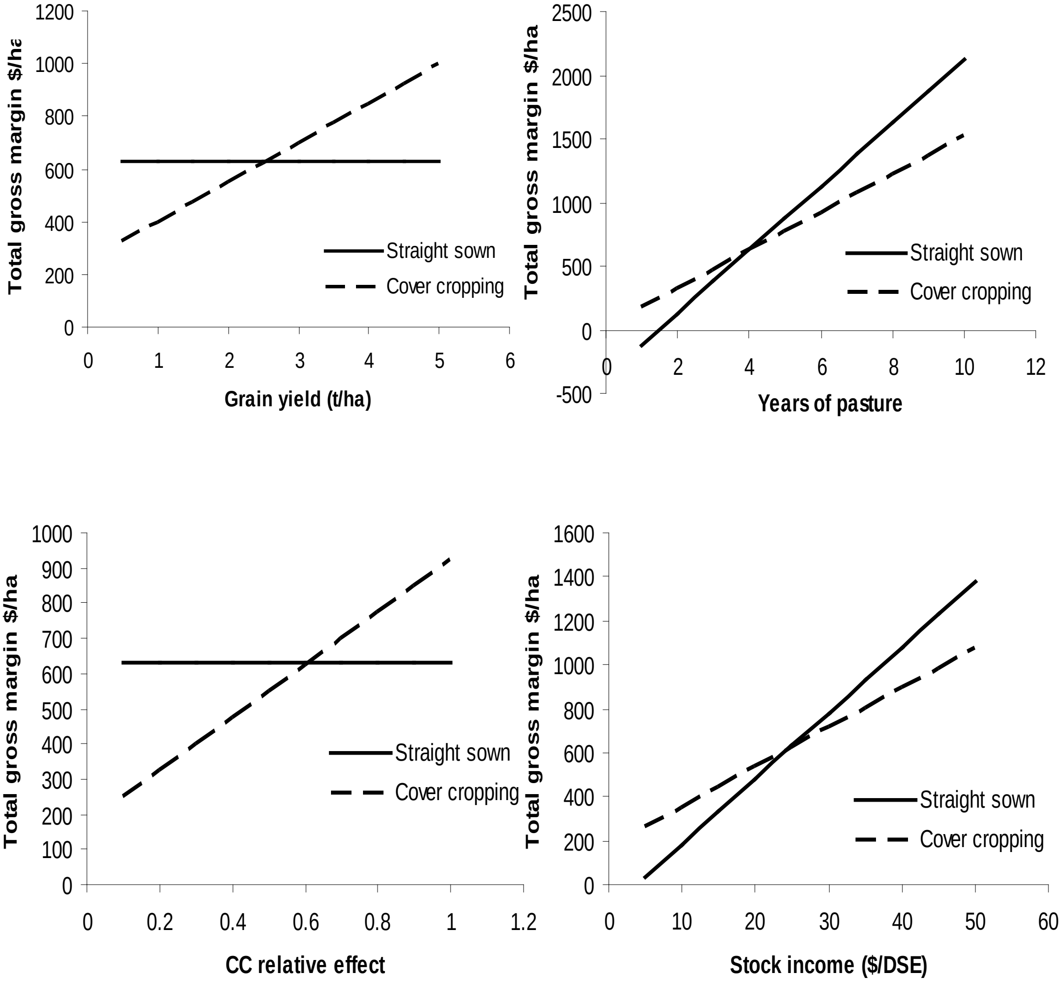

Figure 1. Sensitivity graphs for the DST simulation study for the effect on (a) grain yield, (b) length of pasture phase, (c) cover-cropping relative effect and (d) stock income.

to similar dry matter production. Plants species also differ in their ability to establish under cover-cropping with lucerne more robust than phalaris.

The primary purpose of pastures on farms is to increase long term profitability of the farming system. Although the field experiments demonstrated a loss of pasture production in more favorable seasonal conditions, the DST indicated that it was difficult for animal production systems to utilise the extra pasture to cover the cost of not producing grain in the establishment year.

One of the difficulties of the current version of the DST is that it does not predict pasture production for a certain set of parameters as it is not a biological model. This is particularly important for determining the CC relative value. Farmers will tend to believe that cover cropping does not reduce pasture growth, while agronomists believe reductions in pasture production are large. This data tends to indicate that commonly the relative difference between pasture establishment methods is 0.6–0.8. Only at Ariah Park in 2009 at the 20 kg/ha cover rate was this value reduced markedly. This can have a large influence on the DST (Figure 1c). Another difficulty regarding the model is in relation to pasture establishment failure. The model does not determine whether there has been a pasture failure. Currently there is no published data to define pasture failure quantitatively.

The DST is currently being showcased to producers to determine their interest in the model and whether it corresponds to what they observe. It will be important to simplify some inputs such as $/DSE as these are difficult for the individual farmer to quantify. Incorporating climate data into the model will enable specific sites to determine over a large number of seasonal years whether cover cropping is more profitable or not.

Conclusions

The establishment of pastures by cover cropping resulted in reduced plant density in drier seasons. Pasture production in the following year depended on species. Lucerne could compensate at lower rainfall levels, but phalaris could not. Under higher rainfall conditions, lucerne established under cover cropping had reduced dry matter production. Utilising the DST demonstrated that cover crop yields above 2.5 t/ha led to higher profitability from the cover crop. Higher stock income and longer pasture phases resulted in directly established pasture being more profitable.

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Increasing the proportion of female lambs by supplementary feeding oats high in omega-6 fatty acids at joining

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Abstract: *At the time of joining, sheep commonly graze pasture which is high in omega-3 fatty acids. If pasture supply is limited, supplements such as grain that are high in omega-6 fatty acids may be fed. Therefore, the aim of the current paper was to review dietary sources of fatty acids in the diet of sheep in south-east Australia and the contribution of these fatty acids to reproduction and, specifically, the sex of lambs. In a series of studies, Merino x Border Leicester or Merino ewes were allocated to one of two dietary treatments, 100% silage (low in omega-6 and high in omega-3) or 70% oat grain and 8% cottonseed meal (CSM, high in omega-6). In study 1, ewes consumed the diets for 44 days prior to the assessment of the prostaglandin (PGF2α) response to an oxytocin challenge. In studies 2–4, ewes consumed the diets for approximately six weeks prior to and 17 days following joining to assess the effect of diet on the sex ratio of lambs. Plasma omega-6 was higher (P <0.001), PGF2α response to oxytocin was greater (P <0.05), the time to behavioural oestrus was shorter (P =0.006) and the proportion of female lambs was increased (58.2 versus 43.5%, P = 0.010) when ewes were fed the oat grain/CSM compared with the silage diet. Targeted feeding of oats at joining may provide a practical way for producers to manipulate the sex ratio of their flock in favour of females.*

Key words: omega-3, oestrus, sex ratio

Introduction

Omega-3 fatty acids have a number of positive effects on human and animal health. In particular, the ratio of omega-6 to omega-3 may play an important role in several aspects of animal production and reproduction (Abayasekara and Wathes 1999). A number of studies have examined the effects of fatty acids on peripheral markers of reproductive success in sheep and cattle such as hormones, oocyte quality or inflammatory markers (Gulliver *et al.* 2012), however, few studies have examined measurable outcomes of reproductive success. The aim of the current paper was to review the sources of omega-3 and omega-6 fatty acids in sheep and cattle diets in Australia and examine their metabolism and effects on reproduction, specifically effects on inflammation and sex ratio of lambs.

Omega-3 and omega-6 fatty acids

The primary fatty acids of interest in studies examining reproduction in animals are the long-chain omega-3 fatty acids including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) and the long-chain omega-6 fatty acid arachidonic acid (AA). The first double bond in omega-3 fatty acids occurs three bonds from the methyl end of the fatty acid chain, whereas, the first double bond in omega-6 fatty acids occurs six bonds from the methyl end (Figure 1). These long-chain fatty acids are synthesised in the body from the short-chain omega-3 α-linolenic acid (ALA) and omega-6 linoleic acid (LA, Figure 2). The

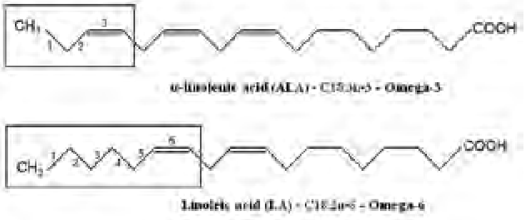

Figure 1. Short-chain omega-3 (α-linolenic acid, ALA) and omega-6 (linoleic acid, LA) fatty acids important in reproduction in sheep and cattle showing the position of the first double bond.

short-chain fatty acids ALA and LA cannot be synthesised by animals (Lands 1992) and, therefore, must be consumed in the diet.

Sheep commonly graze pasture at the time of joining in south-eastern Australia (King *et al.* 2010) and pasture is high in omega-3 fatty acids (Clayton *et al.* 2010). If pasture supply is limited, however, sheep producers may feed supplements, such as grain, that are low in omega-3 and high in omega-6 fatty acids. While the effects of feeding diets high in fatty acids to sheep and cattle on improved reproduction are well established (Gulliver *et al.* 2012), the specific effects of omega-3 and omega-6 fatty acids on reproduction and, specifically, altered sex ratios in sheep, have not previously been reported.

Prostaglandins (PG), in particular $PGF_{2\alpha}$ and $PGF_{3\alpha}$, play an important role in several aspects of reproduction, including ovulation, oestrus, embryo survival and parturition (for review, see Gulliver *et al.* 2012). The series-3 PG are less inflammatory, while the series-2 PG are more inflammatory (Lands 1992). The long-chain omega-3 and omega-6 fatty acids EPA and AA are the precursors for these PGs. In the metabolism of these fatty acids to PG, the removal of two double bonds from AA leaves two double bonds and leads to the formation of series-2 PG ($PGF_{2\alpha}$). Conversely, the removal of two double bonds from EPA leads to the formation of series-3 PG ($PGF_{3\alpha}$, Figure 2b). Therefore, the ratio of omega-6 to omega-3 in ruminant diets is particularly important in determining the relative availability of the precursors for PG formation.

Omega-6 fatty acids and prostaglandins

Diets high in omega-6 are associated with increased $PGF_{2\alpha}$ synthesis, however, few studies have reported the specific effects of omega-6 on the potential PG response to an oxytocin challenge in sheep. The aim of study 1 was to determine whether oxytocin stimulated $PGF_{2\alpha}$ was significantly increased when ewes were fed a diet high in omega-6 compared with a diet low in omega-6 fatty acids.

Merino x Border Leicester ewes (n = 30) were allocated to one of two dietary treatments, either low in omega-6 (100% cereal/legume silage) or high in omega-6 (70% oat grain, 22% silage and 8% cottonseed meal, CSM). Ewes consumed the diets for 44 days prior to two consecutive oxytocin challenges to stimulate PG release.

Plasma omega-6 and $PGF_{2\alpha}$ metabolite (PGFM) concentrations following oxytocin challenge were greater ($P < 0.05$) when ewes were fed the oat grain/CSM diet high in omega-6 (Figure 3). The time to the onset of behavioural oestrus was also numerically, but not significantly ($P = 0.06$), shorter when ewes were fed the oats/CSM diet. A shorter time to oestrus in ewes fed the high omega-6 may be related to increased *in vivo* synthesis of $PGF_{2\alpha}$, resulting in a faster initiation of the hormonal sequences leading to oestrus and

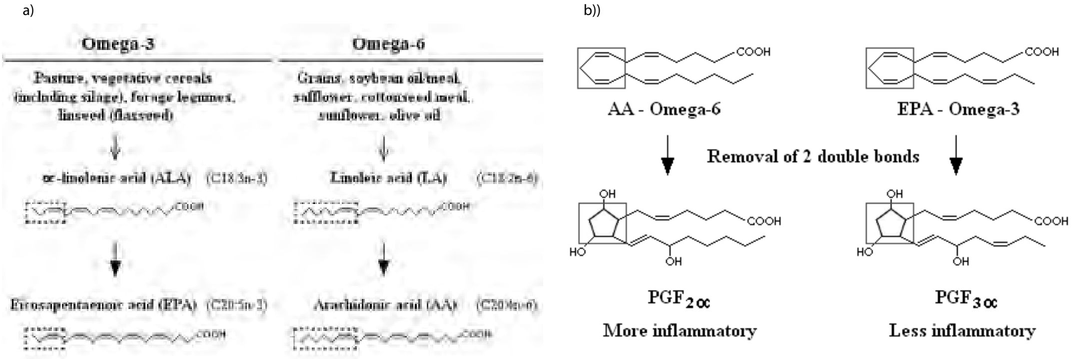

Figure 2. (a) Sources and metabolism of short-chain omega-3 or omega-6 fatty acids from plant material or oilseeds to long-chain fatty acids including arachidonic acid (AA) and eicosapentaenoic acid (EPA) and (b) metabolism to prostaglandin. Sources: (for review, see Gulliver *et al.* 2012).

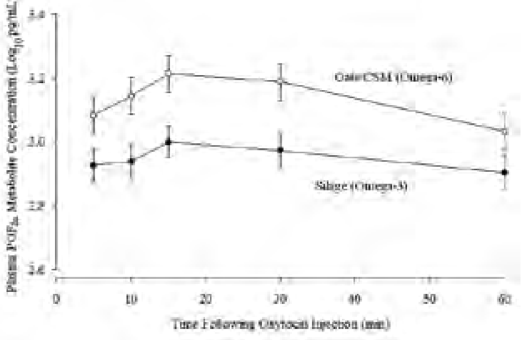

Figure 3. Change in plasma $PGF_{2\alpha}$ metabolite (PGFM) concentration over time following an oxtyocin challenge in ewes fed silage high in omega-3 (●) or oats/cottonseed meal high in omega-6 (○). Baseline PGFM concentrations for the high omega-3 and high omega-6 diets were 637.1 and 550.2 pg/mL, respectively (re-transformed means) and were included in the statistical analysis as a co-variate. Significant difference between treatment diets, $P = 0.002$.

ovulation, however, further research is required to determine the exact mechanisms involved

Omega-6 fatty acids and sex ratio

Sheep operations would benefit from the ability to skew the sex ratio of offspring towards their preferred gender. For example, male prime lambs grow approximately 20% faster than females and have increased muscle accumulation, thereby reaching a higher market weight over a set time period. First cross enterprises, however, prefer breeding females, which may achieve a higher sale price at weaning.

Maternal nutrition may significantly affect the sex ratio of offspring (for reviews, see Cameron 2004). Maternal body condition, reflecting a high plane of nutrition (Cameron and Linklater 2007; Mathews *et al.* 2008), as well as a number of specific nutritional factors, such as glucose (Kimura *et al.* 2005), total fat (Rosenfeld *et al.* 2003) and polyunsaturated fatty acid (PUFA, Green *et al.* 2008) content of the diet, have been implicated in altering sex ratios. Feeding a diet specifically high in omega-6 fatty acids was also associated with a higher proportion of female offspring in mice (Fountain *et al.* 2008), however, no previous studies have examined the effects of diets high in omega-6 or omega-3 fatty acids on the sex ratio of lambs.

Methods

Animals and dietary treatments

A series of three studies (2–4) with Merino x Border Leicester and Merino ewes were conducted in 2010 and 2011. In study 2 (2010), 296 Merino x Border Leicester (X-Bred) ewes (12 months of age) were allocated to one of two treatment groups. Treatments consisted of pea silage (n = 148) high in omega-3 fatty acids or oat grain/cottonseed meal high in omega-6 fatty acids (n = 148). Details of animals and feeding have been presented previously (Gulliver *et al.* 2010). In study 3 (2011), 304 X-Bred ewes (12 and 24 months of age) were fed either barley silage or oats/CSM. In study 4 (2011), 320 Merino ewes were fed either ryegrass silage or oats/CSM (Table 1).

In all three studies, animals were fed the treatment diets for approximately six weeks prior to and 17 days following joining. Liveweight and fat score of all ewes was recorded prior to feeding and during pen feeding. Feed samples were collected daily during pen feeding and bulked across weeks of feeding for proximate analysis as described previously (Packer *et al.* 2011). Blood samples were collected from a randomly selected sub-set of ewes prior to the introduction of experimental rations and again following the consumption of treatment diets. Total plasma fatty acids were analysed as described previously (Clayton *et al.* 2012).

Oestrous synchronisation, mating and detection of oestrus

The oestrous cycles of all ewes were synchronised using a controlled internal release device (CIDR, Eazibreed®, Pfizer, Australia) inserted intra-vaginally for 14 days (King *et al.* 2010). Dorset rams (for X-Bred ewes) or Border Leicester rams (for Merino ewes) were randomly allocated to pen within age (two rams per pen) with a total ram proportion of approximately one ram to 25 ewes as used previously (Robertson *et al.* 2011). Rams were introduced to pens at the estimated time of the first natural oestrus and ram pairs were rotated daily through each pen. Each ram was fitted with a crayon harness and ewes were inspected daily for crayon marks to estimate the time of commencement of behavioural oestrus from time of ram introduction. Ewes were mated over two consecutive oestrous cycles and were fed for a further 17 days after oestrus detection.

Statistical analyses

Differences in measures between treatment groups were examined using the Mixed Model procedure in SAS with treatment as a fixed effect and individual animal, litter size and pen as random effects (SAS Institute Inc. 1997). Statistical analyses have not been completed for studies 3 and 4. An alpha of 0.05 was used for all statistical tests.

Results

Plasma omega-6 was higher and omega-3 was lower when ewes were fed the oats/CSM diet high in omega-6 compared with silage diet high in omega-3 (Figure 4). The time to showing behavioural oestrus from ram introduction was shorter (Figure 5) and the proportion of female

Table 1. Components and proximate analysis of diets fed to X-Bred or Merino ewes for approximately six weeks prior to and 17 days following joining in three studies examining the sex ratio of lambs.

	Study 2 (X-Bred)		Study 3 (X-Bred)		Study 4 (Merino)	
Ingredients[a]	**Silage**	**Oats**	**Silage**	**Oats**	**Silage**	**Oats**
Inclusion (% DM)						
Silage	88.3	19.5	88.7	21.8	98.2	21.7
Oat grain	0.0	69.9	0.0	70.1	0.0	68.3
Cottonseed meal	0.0	7.8	0.0	5.5	0.0	7.6
Molasses	9.8	0.0	9.9	0.0	0.0	0.0
Urea	0.0	0.48	0.0	0.44	0.0	0.0
Mineral Premixb	1.84	2.40	1.42	2.22	1.78	2.38
Proximate analysis (% DM)						
Neutral detergent fibre	35.4	37.4	41.8	33.4	50.6	28.3
Acid detergent fibre	26.1	17.9	23.4	19.0	29.1	18.9
Crude protein	12.8	14.8	10.6	16.8	11.2	16.4
ME (MJ/kg DM)	9.6	11.2	9.7	11.2	10.7	11.6
Total lipid	1.15	3.78	2.15	6.83	2.69	4.7
Omega-6:Omega-3 ratio	0.93	13.03	0.41	32.17	0.32	30.00

[a] DM = dry matter; ME = Metabolisable energy.

[b] Mineral premix (AusFarm Nutrition Products) containing (DM basis) 36.5% NaCl, 21.9% Ca, 2.1% P, 0.10% K, 2.1% S, 3.1% Mg, 52.1 mg/kg Co and 1.04 mg/kg Cu fed at recommended rate of 20 g/hd per day.

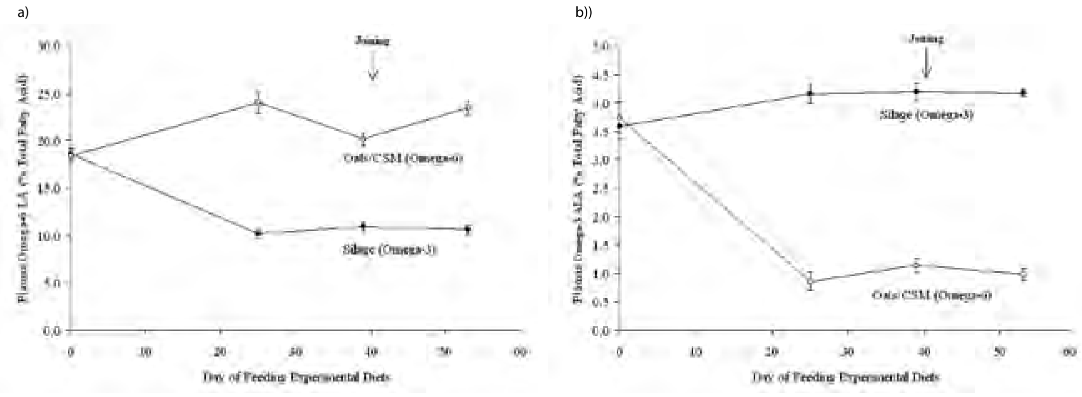

Figure 4. Change in plasma (a) omega-6 and (b) omega-3 in ewes fed silage high in omega-3 (●) or oats/cottonseed meal high in omega-6 (○) for approximately six weeks prior to joining and 17 days following joining.

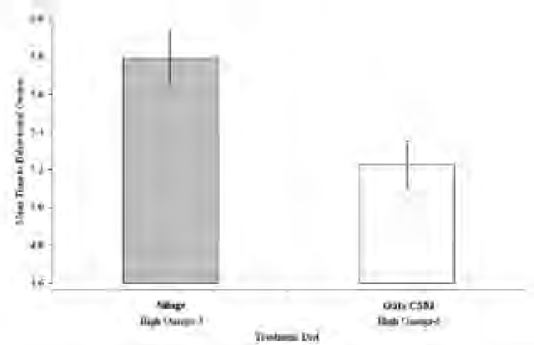

Figure 5. Mean time to behavioural oestrus following synchronisation in first cross ewes fed silage high in omega-3 or oats/cottonseed meal high in omega-6 for approximately six weeks prior to joining.

offspring was higher (58.2 versus 43.5%, P = 0.010, Figure 6) when ewes were fed the oats/CSM diet high in omega-6. Although results of studies 3 and 4 have not been statistically analysed, the proportion of female lambs appeared to be consistently higher when ewes were fed the oats/CSM diet in all three studies (Figure 6).

Discussion

The current studies are the first to show an increased $PGF_{2\alpha}$ response to oxytocin and a consistently higher proportion of female lambs when ewes are fed oats/CSM diets high in omega-6 compared with silage diets low in omega-6 at joining. The exact mechanisms linking the diets with the observed effects are currently not known, however, an increased $PGF_{2\alpha}$ response and shorter time to oestrus when ewes consumed the oats/CSM diets may affect the timing of conception. The fertilisation of younger ova compared with more mature ova *in vitro*, was associated with a higher proportion of females (Gutierrez-Adan *et al.* 2001; Gutierrez-Adan *et al.* 1999) and the proportion of females was higher in dairy cattle (Pursley *et al.* 1998) and sheep (Gutierrez-Adan *et al.* 1999) when the timing of artificial insemination was closer to ovulation

Selective loss of male embryos post-conception due to increased $PGF_{2\alpha}$ and increased *in utero* inflammation would also skew the sex ratio in favour of females (Rosenfeld and Roberts 2004). The higher proportion of female offspring in mice observed previously (Fountain *et al.* 2008) appeared to be due to loss of male embryos (Rosenfeld 2012). In the current studies, however, the total numbers of lambs born were not significantly different when ewes were fed the high omega-6 diets compared with the low omega-6 diets (data not shown), suggesting post-conception loss of male embryos did not occur.

The major limitation of the current studies was that the oats/CSM diets were higher in saturated fatty acids and total fat than the silage-based diets, thereby representing substantial differences apart from omega-3 and omega-6 content. Despite the limitation of differences in diets, the significantly higher proportion of female lambs observed when ewes were fed the high omega-6 diet based on oats/CSM compared with the low omega-6 diet is of considerable practical significance. These changes certainly warrant further investigation in order to determine the mechanisms leading to the observed effects, regardless of whether the effects were related to altered fatty acid status. Feeding a targeted diet for approximately six weeks prior to joining in synchronised ewes may provide a practical mechanism by which to increase the proportion of female lambs.

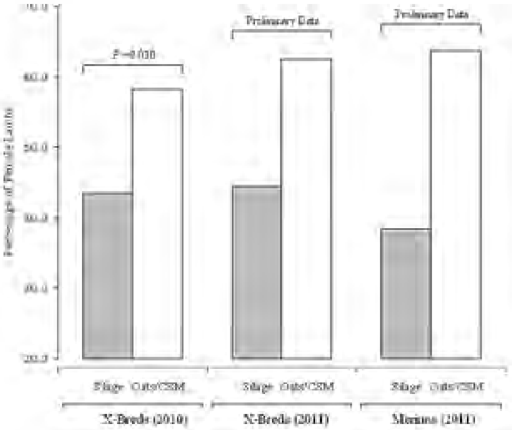

Figure 6. Proportion of female lambs in X-Bred or Merino ewes fed silage high in omega-3 (shaded bars) or oats/cottonseed meal high in omega-6 (unshaded bars) for approximately six weeks prior to joining and 17 days following joining.

A number of on-farm studies are also currently in progress examining whether the feeding regimes can be practically implemented and whether the effects are consistent in un-synchronised ewes.

Conclusions

Feeding diets based on oats/CSM high in omega-6 fatty acids for six weeks prior to joining and 17 days post-joining were associated with an increased $PGF_{2\alpha}$ response to oxytocin, a shorter time to oestrus and a higher proportion of female lambs. Further research is required to determine the mechanisms linking the effects observed in the current study, in particular, whether the effects of omega-6 act pre- or post-conception. If these mechanisms can be identified and there are no detrimental effects to overall lamb survival and subsequent production, practical guidelines may be developed to allow producers to alter female proportions in order to specifically target individual production systems.

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