Optimal Sheep Stocking Rates for Broad Acre Farm Businesses in Western Australia: A Review

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Abstract

Sheep stocking rate influences farm profit significantly, however determining the optimal stocking rate is a difficult task. In this paper, we address this challenge through three main steps. First, we review the definition of stocking rate; second, we examine prior research relevant to the review topic and highlight the factors that need to be considered when determining the optimal stocking rate; and third, we make recommendations for improvements in research on establishing the optimal sheep stocking rate. Inconsistency in the definition of stocking rate can lead to miscommunication between researchers, advisers and farmers. If 10 DSE/ha is optimal for one flock it may not be optimal for another flock as the DSE measure does not fully capture the nuances of different patterns of nutritional requirements among sheep classes and feed availabilities and their respective prices and costs. The optimal stocking rate occurs when the marginal economic benefit of an additional animal equals its marginal cost. Determining this point requires an understanding of the quantity and quality of feed available throughout the year, the optimal live weight profile throughout the year, the impact of seasonal variation, the impact of labour availability, the cost of alternative feeds, prices of livestock and livestock products, the risk preferences of the farmer, and any emission policies relating to greenhouse gases. Farmers tend to use their own judgement to set their stocking rates with the aim of maximising utility. However, the complexities listed make it a challenging task. Thus, researchers have used various simulation and programming models to aid decision-making over optimal stocking rates, but most farmers continue to rely on their own personal judgement. Often farmers are unaware of the profits they are foregoing when choosing either an overly conservative or excessive stocking rate. Our research has shown that foregone income of up to $50 per hectare can occur when a stocking rate 30% below or above the optimum is selected. Thus, despite the complexities that underpin the stocking rate decision we believe there are potential rewards from further research on the optimisation of stocking rates.

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Introduction

Choice of sheep stocking rate affects the profitability and sustainability of mixed enterprise farms (White and Morley 1977; Warn *et al.* 2006a). Sheep stocking rates that are lower than the optimum underutilise available pasture or crop residues, foregoing potential profitability. Similarly, a stocking rate above the optimum can incur excessive costs due to an increased requirement for supplementary feed (Hinton 2007) and can leave paddocks at risk of wind and water erosion when left bare from overgrazing (Saul and Kearney 2002). Determining the optimal stocking rate is clearly beneficial to farm businesses, (Chisholm 1965; Lloyd 1966; Young *et al.* 2020) but it can be particularly challenging to determine because it is intertwined with many aspects of the farming system, such as; length and nature of the growing season and its associated pasture production, the myriad of options regarding flock structure and sheep management, the farm manager's skill and risk attitude, season and price variation and the availability of labour (Dillon and Burley 1961; Lloyd 1966; McArthur and Dillon 1971; Dunlop *et al.* 1984; Warn *et al.* 2006a).

The key issues linked to stocking rate decisions that are a focus of this review are:

- Definition of stocking rate.
- Determining the optimal stocking rate.
    - Season and price variation and their interaction with different levels of risk aversion.
    - The nature of feed supply, including supplementary feeds.
    - The biology of sheep production and the role of flock structure.
    - Greenhouse gas emission policy impacts on sheep economics.
- Future improvements for determining optimal stocking rate.

Defining stocking rate

Stocking rate is a metric of the grazing pressure applied on a farm (Scarnecchia 1990; Meat and Livestock Australia 2020b). A common approach is to use a component that represents the carrying capacity associated with the feed supply and a second component is grazing requirement of the different livestock classes, such that the resulting stocking rate is a number of grazing units per unit area. Optimum stocking rate is the stocking density that maximises long-term, expected whole farm profit.

The standard livestock unit adopted in Australia is known as a dry sheep equivalent (DSE) (Saul and Kearney 2002; Warn *et al.* 2006b; Young *et al.* 2011; Young *et al.* 2020), which was defined as the maintenance energy requirement of an adult wether (McDonald and Orchard 2015). The DSE measure allows different categories of sheep to be compared based on their relative energy requirement (Robertson *et al.* 2020).

The unit of land area that underpins stocking rate has also varied between country and era. Historically the land area was measured in acres, though in Australia this has been replaced by the metric equivalent of hectares. In southern Australia, with its winter dominant pattern of rainfall, winter and spring pastures are the principal sources of cost-effective feed. The feed supplied by these pastures most affects the size of a farm's sheep carrying capacity (Moore *et al.* 2009). In southern Australia pasture growth during winter is much less than during spring (Cullen *et al.* 2008) and hence the winter feed period is most likely to constrain the number of sheep carried on farms. Therefore, the abbreviated measure often reported is DSE per WG hectare (Kingwell *et al.* 1992; Kenny *et al.* 2019).

The current definition of stocking rate represents the grazing pressure applied per hectare in the feed-limiting period. The definition is consistent across different flocks and properties. However, as shown by Young *et al.* (2020), if 10 DSE/ha is the most profitable stocking rate for a wether dominant flock, it does not mean 10 DSE/ha is the most profitable stocking rate for a ewe dominant flock. This is because in an environment where supplementary feeding can occur or grazing management can be altered to adjust grazing intensity during the year, optimal carrying capacity is affected by factors additional to energy requirements, such as timing of energy requirements throughout the year and livestock income. Additionally, Robertson and Friend (2020) used whole farm simulation modelling to evaluate the profitability of farm systems that varied by time of lambing and stocking rate. Their results indicated that April joining resulted in an optimal stocking rate of approximately 2 sheep/ha greater than February joining because the better match of pasture demand and supply reduced feed costs. Indicating that relative stocking density changes with time of lambing and the distribution of the energy requirement of the flock during the year. Thus, the DSE metric only represents the relative energy requirement at a given point in the year. Yet in practice the energy requirements of different classes of sheep can change greatly across a production year. Hence, the DSE metric only partially captures important differences in the patterns of energy requirements of different classes of sheep. As a consequence, using the DSE metric in reporting a stocking rate, although useful, has important limitations that are not always widely recognised.

The stocking rate challenge in Australia: early research

In previous decades a variety of economic evaluation approaches have been applied to determine the optimal sheep stocking rate. Dillon and Burley (1961); Chisholm (1965); Lloyd (1966); McArthur and Dillon (1971) all showed the importance of making sound decisions about stocking rate and provided a useful economic basis for determining stocking rate.

The results from this early work provided insights into important factors to consider such as:

(i) Seasonal variation and risk – seasonal and price variation coupled with the farmer's risk attitude and the farmer's drought management tactics could simultaneously impact the optimal stocking rate and hence must be considered jointly. McArthur and Dillon (1971) proposed that risk aversion lowers the stocking rate.

(ii) Feed availability – feed availability was a key driver of stocking rate, therefore optimising stocking rate required a full understanding of the nutrition available to sheep and its cost. More feed meant higher stocking rates. However, feed reserves had to be kept to handle poor seasons, which could reduce stocking rate by 15-20% (Lloyd 1966).

(iii) Sheep production – determining the optimal stocking rate required understanding the trade-off between stocking rate and sheep production. Early work showed negative relationships between stocking rate and wool production and positive relationships between stocking rate and wool value (Chisholm 1965; White and Morley 1977).

Seasonal variation and risk

Year-to-year seasonal and price variation causes large variance of farm profit (Kingwell 1994; Darbyshire *et al.* 2020) resulting in more complicated decision making (Kingwell *et al.* 1992). In addition, in Australia, empirical studies of farmer behaviour indicate the majority of farmers are slightly risk averse, meaning they would sacrifice some expected profit to reduce yearly profit variation (Bond and Wonder 1980; Bardsley and Harris 1991; Ghadim *et al.* 2005). Thus, there are two issues; (i) year to year variation; and (ii) farmer risk attitude that warrant consideration when determining an optimal stocking rate strategy.

Seasonal variation is concerned with the probability of each season type and price scenario, the production associated with each season type, and the seasonal tactics that can be implemented to boost expected utility by lessening downside risk in less productive years and increasing the upside in productive years. To attempt to capture the impact of seasonal variation on stocking rate Trompf *et al.* (2014) ran MIDAS (whole farm optimisation model, described in detail below) multiple times with different production inputs to represent a poor, average and good season in a low rainfall and medium rainfall zone in Western Australia, and a higher rainfall zone in south west Victoria. They used a weighted average of the season types to determine the overall optimal stocking rate. Their results showed that across the rainfall zones the optimal stocking rate in the poor years was between 57% and 87% lower than the optimum long term average stocking rate, and the optimum stocking rate in the good years was 31% to 35% above the long term average. They then discussed strategies and tactics that farmers could use to flexibly alter the stocking rate on farm.

Commodity price variation adds further risk to farm businesses. The relative profitability of sheep production is linked closely to the prices of key farm products and their inputs (Warn *et al.* 2006a; Kopke *et al.* 2008). The key commodities' prices that impact the livestock enterprise are grain, meat, and wool. Changes in meat and wool prices directly affect the profitability of the sheep enterprise. Changes in grain prices also impact sheep enterprises in two main ways. First, they affect the price of grain feeding. Second, they impact the profitability of cropping enterprises, which may alter the optimal area of cropping, the type of crop, and consequently, the area of pasture available and the quantity and quality of stubble. Kopke *et al.* (2008) found that as grain prices increased, the optimal area of land allocated to pasture decreased and the number of sheep declined. Further, as wool and meat prices increased so did the optimal number of sheep. There was evidence that as the profitability of the sheep enterprise increased, both the area of pasture and the stocking rate increased (Kingwell *et al.* 1992), however there has been little subsequent research to quantify such changes.

Future seasonal conditions and commodity prices are not firmly known. Therefore, farmers must decide on a base stocking rate and use management tactics to handle variations as a season unfolds. There are various management tactics able to be implemented by farmers as a season unfolds. Trompf *et al.* (2014), for example noted the tactic of selling wethers as lambs rather than retaining them in the advent of a poor season could increase optimal stocking rate by one or two DSE/ha. Using MUDAS, Kingwell *et al.* (1992) found that altering the area of crop and pasture as a season unfolded, where possible, and agisting livestock in poor years were also viable seasonal tactics. In higher production seasons it was optimal to have up to 35% more crop and hence a higher stocking rate than in a poor production season. Furthermore, Moore *et al.* (2009) suggests that management tactics such as fertilising pasture and grazing crops rather than adopting a long term strategic response could be especially worthwhile in environments where a feed gap was unpredictable in terms of its timing and magnitude. Thus, successful implementation of seasonal tactics by farmers can help reduce the impacts of poor seasons and maximise the benefits of good seasons and thereby affect the optimum stocking rate.

Farmer risk attitude is the behaviour of farmers in response to year-to-year variation. Price and climate variation result in a high variability of yearly profit for farmers. Risk averse farmers opt for a farm management strategy that attempts to lower the profit variability albeit at some cost to expected profit. Kingwell (1994) used MUDAS to examine farm management decisions of moderate and highly risk averse farmers. His results showed that risk aversion only reduced the expected profit by 2-6%, yet the key management changes involved shifting resources away from cropping towards livestock enterprise due to the greater variability of profits associated with crop production. Pasture area, stock numbers and stocking rate were all increased for the risk averse strategies, with the increase in optimal stocking rate being due to an increased area of pasture on the most productive land management units because that generated lower variation in farm profit. Kingwell's findings showed the important interplay between soil types, enterprise selection on those soils and seasonal tactics applicable to enterprises on some of those soil types. However, the switch to younger flock structures (Young *et al.* 2020) and the knowledge of the importance of good ewe condition on farm profit (Young *et al.* 2011) may mean that switching resources towards the sheep enterprise to minimise profit variation is less effective now.

In summary, farming is very uncertain with weather and price changes effecting choice of stocking rate (Kingwell *et al.* 1992; Pannell *et al.* 2000; Kopke *et al.* 2008; Trompf *et al.* 2014). Pannell *et al.* (2000) discussed the inclusion of risk attitudes and production and price risk in farm analyses and concluded that the most important aspect of risk to be modelled is not farmers' aversion to risk, but rather their short-term tactical responses to variation in weather and prices. For stocking rate decisions that are often impacted by tactical decisions as the season unfolds (Kingwell *et al.* 1992), we support the idea that year to year variation and associated management tactics need to be represented. However, the need to include risk aversion is less clear. As argued by Pannell *et al.* (2000), representation of aversion is often not a high priority. However, Kingwell (1994) did find that risk aversion affected decisions around choosing stocking rates. Therefore, regarding livestock enterprise management, inclusion of risk aversion may warrant some investigation.

Feed supply

The main feed sources for sheep in Australia are pastures and crop residues with supplements of grain, hay, and silage. The seasonality of supply in most regions means that there is often a mismatch between supply of newly grown forage and the daily demands of livestock (Bell *et al.* 2008). Imbalances between feed supply and demand suggest that there are inefficiencies in production in terms of excess feed wasted, or unmet animal demand. Farmers supplement sheep diets during periods when the marginal value of extra feed is high because pasture and crop residues are insufficient in quantity or quality to meet the production targets of the animals being run (Hinton 2007). Supplementary feeding also allows farmers to defer pastures at the break of season to increase leaf area and subsequent growth rate, which allows an increase in the number of sheep carried through the winter period (Brown 1976). However, supplementary feed is often expensive and is the main contributor to the increase in the marginal cost of increasing stock numbers on farms. This is an important contributor to the determination of the optimum stocking rate, because at the optimum stocking rate the marginal cost of the extra animal must equal the marginal benefit to the farm enterprise.

Crop residues (i.e. stubbles) are a summer feed source for sheep on mixed crop-livestock farms. Stubbles are a cheap source of feed for the livestock enterprise, resulting in a lower marginal value of feed over the summer period. Thus, as mentioned above, increasing the area of crop tends to support higher stocking rates. Cropping complicates the analysis of stocking rate decisions for these mixed enterprise farms, as feed availability is also linked to crop production and crop area. The introduction of dual purpose crops over the last decade on mixed farms also enhances the influence of cropping on the optimal sheep stocking rate, as does the introduction of summer active perennials (Kingwell and Squibb 2015). Hence, the relationship between the crop enterprise and feed availability must be included when determining the optimal stocking rate.

Understanding pasture production is also crucial to determining optimal stocking rate, however, the interaction between pasture production and grazing is complicated and multi-faceted. The quantity and quality of pasture available depends on a multitude of factors such as time of year, rainfall distribution, grazing intensity, soil fertility and pasture composition (Dunlop *et al.* 1984; Saul and Kearney 2002). The average digestibility of pasture is greater at low levels of feed on offer (FOO) because most of the pasture is new growth and its digestibility decreases as FOO and lignification increases, or when pasture senesces later in the growing season and over summer. Pasture growth increases as FOO increases, and decreases as grazing pressure increases, caused by defoliation (Dunlop *et al.* 1984). Animal production also varies with FOO and digestibility because voluntary feed intake increases with higher FOO and the capacity for selective grazing to achieve a higher quality diet than the sward average digestibility is increased with increasing FOO (Freer *et al.* 2007). Therefore, it is vital to consider biological relationships between pasture quality and quantity and, pasture growth rate and animal production when determining the optimal grazing strategy.

MIDAS was used to determine the whole-farm economic impact of pasture improvement in the central wheatbelt zone of Western Australia (Bathgate *et al.* 2009). Pasture improvement involves sowing of new pasture to increase growth and quality (Alcock and Hegarty 2006; Bathgate *et al.*

2009). In this agricultural zone, pasture improvement led to a 26% increase in farm profit, but had little impact on optimal stocking rate, which remained at 6 DSE/ha. Bathgate *et al.* (2009) concluded that this was due to the optimisation of rotation selection, with improved pasture causing more of the farm area to be optimal for grazing rather than cropping, and hence there was less crop residues available for grazing during the summer-autumn period.

Determining the optimal feed management strategy and stocking rate is a complex process, requiring the biological characteristics of each feed option and their interactions with other aspects of the farming system to be represented and examined. For example, pasture production depends on stocking rate and grazing management yet stocking rate itself depends on pasture production. These mutual relationships and interactions need to be accurately described and evaluated simultaneously. This is a complex modelling challenge but is made possible by modern computational power.

Sheep Production

A sheep's energy intake profile throughout the year, which reflects in the animal's liveweight profile, has significant impacts on sheep productivity because it can influence key traits such as lambing percentage, lamb survival and wool quality and quantity (Thompson and Young 2002). It is important therefore to consider the trade-offs between nutrition profile and production when determining the optimal stocking rate, particularly for ewes where their liveweight profile can impact the productivity of both the ewe and her progeny.

Ferguson *et al.* (2011) and Oldham *et al.* (2011) found that production of ewes and their progeny could be predicted by the ewe's liveweight profile throughout the year. Using these relationships Young *et al.* (2011) modelled a range of liveweight patterns for properties in Victoria, Western Australia and southern New South Wales, and found that the optimum liveweight profiles for ewes lambing in spring were similar in all three regions, and were insensitive to changing commodity prices, pasture productivity and management. For ewes, the optimum profile was to join at approximately 90% of their standard reference weight (i.e. the weight of a sheep when mature, not pregnant, bare shorn and in medium condition), allow them to then lose a small amount of weight after joining and regain that weight in late pregnancy to return to their joining weight by lambing. In the Western Australian region, their results showed that whole farm profit increased with stocking rate increases up to an optimum of 14.3 DSE/ha. Additionally, optimal ewe liveweight management increased farm profit at all levels of stocking rate. These results implied that the economic priority for allocating available feed to different animal classes varied during the year. This is consistent with the findings of Young *et al.* (2016) who examined the profitability of using ultra-sound pregnancy scanning to identify the pregnancy status and litter size of ewes. They showed that the optimum nutrition profile changes and that profit could be increased if extra feed was allocated to the ewes carrying 2 foetuses. These results suggested that when calculating optimum stocking rate, feed should be allocated throughout the year to ensure sheep met their optimal liveweight profile. This is in accord with economic theory whereby the optimum stocking rate, and hence optimum liveweight profile, occurs at the point where the marginal cost of providing extra feed equals the marginal revenue, and that the marginal revenue is equal for each class of stock. This is a theoretically simple concept but computationally difficult to identify.

Environmental factors

Most decision-making models used in farm planning reflect the basic economic criterion of profit maximization with little concern for environmental factors such as greenhouse gas (GHG) emissions (Sintori 2014). However, both farmers and the general public are becoming more aware of the adverse effects of GHG on the environment and agriculture's contribution to GHG emissions (Kopke *et al.* 2008; Sintori 2014). In response the Australian government, like many governments, is adopting policies and initiatives to reduce emissions of GHGs (Thamo *et al.* 2013).

Petersen *et al.* (2003) considered GHGs emitted from four sources in the farm system: nitrogen fertiliser, fuel use, stubble burning and sheep. Their results indicated that, on a livestock dominated farm (85% pasture), 97% of total farm emissions were from sheep in the form of methane. They found that the relatively high GHG emissions from the sheep enterprise meant that the inclusion of emission abatement policies resulted in a shift towards cropping. Although prospective environmental changes are likely to restrict sheep production and limit stocking rates, it is not yet clear what future emission policies might be and therefore their additional impact on sheep production and stocking rates is unclear. A likely scenario is that the joint influence of environmental change and emissions policy will lower optimal stocking rates. For example, if there is a tax on emissions then the marginal cost of each sheep increases, reducing the incentive to feed supplements, resulting in a lower stocking rate. However, if the policy is simply an emission restriction then another plausible scenario is that the optimal stocking rate could remain similar, although it may also be necessary to shift toward cropping or allocate some land to plant trees, thereby reducing the total DSE count.

Modelling approaches to determine optimum stocking rate

There are many approaches to evaluate farm management ranging from simple field experiments, benchmarking (Kahan 2013) and gross margins (DPI 2020) to more complex system modelling (Kingwell and Pannell 1987; Moore *et al.* 1997). Benchmarking can provide general insights about farm management by comparing productivity of different businesses. However a key limitation is quoted by Malcolm (2000) "there are no benchmarks for yet to be introduced change". Gross margins, although a simple framework, can be challenging to correctly apply as obtaining relevant and accurate information to underpin the analyses is not always a simple task. For example, if gross margins were used to examine stocking rate, inputs would need to capture the relationship between grazing pressure and wool per head. The choice of approach depends on the problem at hand. For each problem there is an optimum degree of generality (Malcolm 2000).

As discussed in previous sections, the stocking rate problem is highly complex, which makes it difficult to evaluate using field experiments and other simple appraisal tools. Thus, most recent work has been conducted using various farm or partial farm models. There are four models used widely in Australia and that have been applied to evaluate sheep stocking rate:

(i) Model of an Integrated Dryland Agricultural System (MIDAS) (Kingwell and Pannell 1987) – MIDAS is a steady state whole farm linear programming model with a joint emphasis on biology and economics, it represents multiple land management units and a self-replacing flock with all classes of stock. However, MIDAS assumes an average season so there is no inclusion of year to year variation (Young *et al.* 2020)
(ii) Model of an Uncertain Dryland Agricultural System (MUDAS) (Kingwell *et al.* 1991) – MUDAS is a whole farm discrete stochastic programming model that explicitly accounts for climatic risk and dryland farm management responses to such risk.
(iii) GrassGro (Moore *et al.* 1997) – GrassGro is a partial farm simulation model that couples the GRAZFEED feed intake and ruminant nutrition models (Freer *et al.* 1997) for a single class of animal with a daily simulation model of pasture growth and dynamics.
(iv) AusFarm (Moore *et al.* 2007) – AusFarm is a whole farm simulation model, representing the detail of GrassGro with multiple sheep classes along with the crop enterprise.

Each of the modelling approaches has its pros and cons. MIDAS has been used frequently to evaluate the impact of various factors on whole farm profit in southern Australian farming systems, particularly those in Western Australia (Young *et al.* 2004a; Kopke *et al.* 2008; Kingwell and Fuchsbichler 2011; Trompf *et al.* 2014; Thamo *et al.* 2017; Young *et al.* 2020). MIDAS captures the complex biology of pasture and livestock production and allocates the farm resources in such a way that optimises whole farm steady state profit. However, as mentioned previously, a key weakness of MIDAS is its steady-state framework that assumes an average season and expected price scenario (Kingwell *et al.* 1992). MIDAS also does not represent a farmer's risk attitude nor their seasonal tactics.

MUDAS was developed in the early 1990's to analyse the impact of seasonal variation and price risk in Western Australian farming systems (Kingwell *et al.* 1991). However, the complexity and lack of ease in updating MUDAS meant it quickly fell into disuse. Moreover, the model was built when computational power was limited, resulting in long solution times and an arduous error-checking and calibration process. Due to these limitations MUDAS has not been updated since the late 1990's.Therefore, it is likely that many of the findings from the early analyses based on MUDAS are no longer relevant or accurate and therefore require reassessment.

Simulation models have also been widely used to evaluate stocking rate. They represent the bio-physical aspects of the farm in more detail than the bio-economic models such as MIDAS. They also represent the year-to-year variation in climate by using historical weather data. These features mean that different management can be evaluated in detail. Some simulation models, for example AusFarm, includes the capacity to develop flexible management rules and hence can represent tactical management adjustments in response to varying seasons. However, bio-physical models are often developed without a strong economic focus and rely on the skill of the user to incorporate the economics (e.g. Thomas *et al.* 2010). Furthermore, optimisation of simulation models is inefficient (Doole and Pannell 2008). Without optimisation, the results are highly dependent on the skill of the user and the management rules implemented. For example, the level of supplementary feeding is often determined by a minimum condition score for the sheep rather than the marginal cost relative to the marginal revenue of the feeding decision. Similarly, the allocation of paddock feed is often not related to the marginal benefit of feed for the different livestock classes but rather to a fixed grazing rule (e.g. McGrath *et al. 2016)* . As discussed in the previous sections, stocking rate is highly complex with a large number of contributing factors. Therefore, without an optimising mechanism, evaluating an optimal stocking rate is extremely challenging.

There have be numerous farm modelling frameworks developed ranging in complexity and scope (Janssen *et al.* 2016). We argue that although each model has served a purpose, none fully captures the intricacies of the stocking rate problem. Simulation models such as GrasGro and AusFarm capture the biology of the farm system in detail yet lack the capacity for optimisation (Doole and Pannell 2008; Thomas *et al.* 2010; Thomas *et al.* 2018). Conversely, mathematical programming models like MIDAS provide a framework for efficient optimisation but are resource constrained and lack detailed representations of aspects of biology and uncertainty (Kingwell *et al.* 1991; Trompf *et al.* 2014; Young *et al.* 2020). To accurately determine optimal stocking rate requires an optimisation framework or model that includes the important bio-physical details of the farm but also represents seasonal variation and can optimise strategic and tactical management.

Stocking rate: Generalisations from studies

Most research on the optimal stocking rate for sheep production has been conducted in eastern Australia (White and Morley 1977; Young *et al.* 2004b; Warn *et al.* 2006b; Gicheha *et al.* 2014). Unfortunately, the results from these studies are not easily generalized to all other regions of Australia. For example, Western Australia, unlike many parts of New South Wales and Queensland, has a different climate and seasonal conditions. Hence there is a gap in the research about stocking rates especially for Western Australia. This gap in the literature has only been partially addressed by Trompf *et al.* (2014) and Young *et al.* (2020). Both used MIDAS, yet as outlined above, MIDAS has limitations when applied to certain aspects of determining the optimal stocking rate.

The case for many years is that most farmers consistently run relatively conservative stocking rates compared to calculated optimums (Lloyd 1966; Young *et al.* 2020). For example, zonal benchmarking shows that the average stocking rate in the south-west of the Western Australian Wheatbelt was 8.5 DSE/ha with the top 25% running 11.8 DSE/ha and the bottom 25% running 6.2 DSE/ha (Planfarm/BankWest 2016). By contrast, Young *et al*. (2020) indicated an optimal stocking rate in the region was between 10 and 13.7 DSE/ha. Farmers' rationale for selecting lower stocking rates may be explained by a host of factors not captured by MIDAS as used by Young *et al.* (2020).

Conclusion

Optimising stocking rate requires an understanding of the quantity and quality of feed available throughout a year, the optimal live weight profile throughout a year, the impact of seasonal variation, the impact of labour availability, the risk preference of the farmer, the array of crop and pasture options available to the farmer, the tactical management options farmers can embrace, the accuracy of seasonal forecasts they can draw upon to facilitate their decision-making, relative prices of inputs and outputs and GHG abatement policy settings that might alter the costs of running livestock. To account for this diverse array of factors researchers have relied on the use of computer models.

The models, MIDAS, AusFarm and GrassGro, which have been used widely to estimate the optimal stocking rate, have key limitations. Another model, MUDAS, has fewer limitations but is no longer operational and does not accurately reflect modern farm practices and seasonal and commodity price conditions. Hence, stocking rate recommendations based on applications of these models lack credibility because some key factors likely to affect a farmer's stocking rate choices are not captured by these models.