Grazing management options to boost productivity and secure healthy landscapes

W Badgery[A], G Millar[A], K Broadfoot[A], J Martin[A], D Pottie[A], A Simmons[A] and P Cranney[B]

[A] NSW Department of Primary Industries, Orange Agricultural Institute, Orange NSW: warwick.badgery@dpi.nsw.gov.au

[B] Central Tablelands Local Land Services, Orange Agricultural Institute, Orange NSW

Abstract: *Grazing management systems help maintain pastures and can enhance other environmental outcomes but there is little information about the appropriate management of these systems. A grazing experiment was conducted on an introduced pasture at Orange, NSW to determine the impact of a range of grazing systems on pasture composition, quantity and quality. Data from pasture characteristics, faecal analysis and GrazFeed modelling were used to determine metabolisable energy intake (MEI) by animals. These data were then used to predict animal production of a spring lambing terminal sire system using GrazPlan equations and determine gross margins. High stocking rate (HSR) continuous grazing (CG) had the lowest pasture herbage mass, groundcover and cocksfoot density compared to all intensive rotational grazing treatments and low stocking rate (LSR) CG. The level to which pasture was grazed directly influenced animal performance. Budgeting green herbage allowance in rotational grazing to be >1.5 kg DM/DSE/day in spring and >3.5 kg DM/DSE/day at other times of the year would ensure higher levels of animal performance. The HSR, fast rotations (FR; 56 day rest) had the highest gross margin and high groundcover levels indicating they were the most profitable and sustainable systems, but LSR CG was nearly as profitable and had similar groundcover. These results occurred in two years of poor spring rainfall, which contributed to the relative success of the more conservative stocking rates.*

Key words: species composition, leaf development, GHA, modelling

Introduction

Producers have adopted a broad range of grazing practices, including the increased use of intensive rotational grazing with multiple paddocks (McCosker 2000), to manage native and introduced pasture in the high rainfall zone (HRZ) of south eastern Australia (Allan *et al.* 2003; Kaine *et al.* 2013). Producers' reasons for adopting intensive rotational grazing are varied, with surveys indicating that profit, environment and lifestyle are important considerations (Badgery *et al.* 2012). However, the shift to an intensive rotational grazing system in line with holistic principles (Savory 1988) has often been associated with changes to livestock enterprises and reduced application of phosphorus (P) fertiliser, which can have a larger influence on productivity and profitability of livestock systems (Sheath and Clarke 1996). This makes it difficult to determine the impact of specific grazing management *per se* when comparing the merits of different grazing systems.

It is generally acknowledged that some form of grazing management will help maintain pastures in a desirable and productive state (Kemp and Dowling 2000), but the appropriate intensity and management is debated. For intensive rotational grazing systems, the influence of rotation speed and paddock number has not been addressed. Flexible grazing, based on the leaf stage of development (e.g. 3–4 full developed leaves per tiller; Rawnsley *et al.* 2002; Turner *et al.* 2006) has been shown to maintain adequate plant carbohydrate levels and balance feed quality and quantity. However, this paddock scale management often cannot be implemented in every paddock on a farm, due to differences in the rate of development of pastures throughout the year. Furthermore, stocking rates interact with grazing management to determine the amount of pasture utilised at each grazing. Higher stocking rates have been supported in intensive rotational grazing systems due to higher levels of available forage (Badgery *et al.* 2012; Warn *et al.* 2002). Flexible stocking rates are also important to adapt to seasonal conditions, but in previous research variations in stocking rate have often been part of treatments and the influence of annual grazing pressure and the timing of grazing need further consideration.

To address these issues, an experiment was established to determine how grazing management and stocking rate influenced predicted gross margins and the sustainability of an introduced pasture, measured using groundcover, which is a common indicator of sustainability. The treatments examined combinations of stocking rate, number of paddocks in a grazing system and rotation speed (utilisation), plus a flexible treatment based on the stage of plant development. It was hypothesized that the treatments that had a lower stocking rate and slow rotations would have the greatest environmental benefits, while continuous grazing and fast rotations would have greater financial benefits.

Methods

Site

The experiment was conducted at Orange Agricultural Institute (33°19’24” S, 149°5’4” E), with an average annual rainfall of 922 mm, Red Dermosol soils (Isbell 2002) and a cocksfoot (*Dactylis glomerata*) dominant pasture that was 3 years old at the start of the experiment. The site had 125 kg/ha of superphosphate (14.2 kg P/ha) applied each year and neither P (56.8 mg/kg, Colwell) nor pH (6.4, $CaCl_2$) were limiting production, although there were obvious signs of N deficiency at times throughout the experiment. The experiment commenced in January 2012.

Treatments and layout

There were 11 treatments (Table 1) that integrated combinations of the number of paddocks in the grazing system, rest duration and stocking rates that were replicated in three blocks. There were 3 paddock levels: continuous grazing (CG) or 1-paddock, 15-paddock (15P) and 30-paddock (30P) systems. The rest durations were: no rest for the CG, an average rest of 56 days for fast rotations (FR) and an average rest of 112 days for slow rotations (SR). There were 2 stocking rates (dry sheep equivalent, DSE): a low stocking rate (LSR; annual average 7 DSE/ha) and a high stocking rate (HSR; annual average of 13 DSE/ha). There was also a flexible (FLEX) grazing treatment based on the stage of leaf development (3–4 fully extended leaves per tiller of cocksfoot).

The CG plots were 0.5 ha in size and grazed for the full term of the experiment. Intensive rotational grazing systems were partially implemented in that plots were 0.067 ha and represented 1paddock (i.e. 15P) or were subdivided into 2 paddocks that were grazed consecutively (i.e. 30P). Livestock grazed the

Table 1. Details of treatments including number of paddocks in each system, average annual stocking rate, average rest period, plot size and number of internal paddocks.

Treatment	System Paddock no.	Ave Stocking rate (DSE/ha)	Ave Rest (days)	Plot size (ha)	Sub paddocks
FLEX		Variable	Variable	0.067	1
HSG CG	1	13	0	0.5	1
HSR FR 15P	15	13	56	0.067	1
HSR FR 30P	30	13	56	0.067	2
HSR SR 15P	15	13	112	0.067	1
HSR SR 30P	30	13	112	0.067	2
LSR CG	1	7	0	0.5	1
LSR FR 15P	15	7	56	0.067	1
LSR FR 30P	30	7	56	0.067	2
LSR SR 15P	15	7	112	0.067	1
LSR SR 30P	30	7	112	0.067	2

plots 6 times per year for the FR and 3 times per year for the SR. The rest periods were adjusted (± 10%) based on the average annual pasture growth and were generally shorter in spring when pasture growth was highest and were longer in summer and winter when growth rates were lowest. The 3 replicates were grazed consecutively, because there were not enough sheep available to graze all replications at the same time.

The plots were grazed with Merino wethers that were approximately 12 months old (32 kg, condition score (CS) = 2.7) when the experiment began and their weight increased until May 2013 and then ranged between 50 and 60 kg. For each replication all animals entered the plot or first paddock of a plot (i.e. 30P) on the same day. The wethers grazed FR plots for 4 days (or 2 days for separate paddocks in the 30P) and 8 days in the SR (or 4 days for separate paddocks in the 30P) and the FR spent 4 days off plots before entering the next replication. The FLEX treatment was assessed prior to grazing and animal numbers were adjusted to leave approximately 0.6 t/ha of green herbage mass after a 3 day grazing period and spent 5 days off plots between replications. In the CG treatments animals were provided supplementary feed on plots as wheat, oats or lupins when there was insufficient feed to maintain an average CS >2.5, but animals were not fed in the rotational treatments due to the short time on plots.

Measurements

The climatic conditions were monitored at a BOM weather station located ~1 km from the trial site, with rainfall measured using an automated weather station.

Pastures were visually assessed using BOTANAL procedures (Tothill *et al.* 1992) at 30 permanent locations within each plot using a 30 × 30 cm quadrat, to determine species composition, green, dead, litter and standing biomass, and groundcover, with calibrations occurring at each assessment. Measurements were taken pre- and post-grazing for the rotational grazing treatments while the CG treatments were measured at the same time as the pre-grazing rotational treatments. Data are shown for times when all treatments were monitored (i.e. the FLEX was not always grazed with the other treatments).

Wethers were weighed and condition scored monthly in the CG treatments and pre- and post-grazing in the intensive rotations.

The quality of herbage mass consumed by animals during the grazing of the intensive rotational treatments was assessed. Six exclusion cages were randomly placed in the plot; quadrats were paired inside and outside the exclusion cage so that green and total herbage mass and species composition were similar. After grazing, the plants in the quadrats within the exclusion cages were plucked by hand until they compared with the quadrat outside the cage that had been grazed. Forage samples were pooled for each plot and immediately dried at 60°C for 48 hours. Samples were tested for neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (N% × 6.25), dry matter digestibility (DMD) and digestible organic matter in dry matter (DOMD) by wet chemistry and the organic matter (OM) content determined from ash. Metabolisable energy (ME) of the pasture sample was then calculated from DOMD (Freer *et al.* 2007).

The quality of the diet consumed by wethers over a grazing period was determined for the SR and CG treatments. The FR treatments were not included because the sequence of grazing was interrupted between replications. There was a factorial combination of paddock number (CG, 15P and 30P) and stocking rate (HSR and LSR) examined. The diet quality was assessed based on organic matter digestibility (OMD) consumed, which was predicted from analysis of the faeces (Wang *et al.* 2009). Faecal samples were collected on days 3, 5 and 7 of grazing within the plots representing days 1, 3 and 5 of grazing. The 30P animals were moved to a new paddock in the plot on day 4. At each sampling time 5 freshly excreted faecal samples were collected from each plot and pooled. The samples were dried immediately at 60°C for 48 hours. The samples were analysed for OM and N%, using the techniques outlined to determine pasture quality. The OMD consumed by each animal was determined by:

$OMD_w = 0.899 - 0.644 \times EXP(-0.5775 * CP_f) * (OM_f * 0.1)/100)$

Where, OMD_w is the OMD consumed, CP_f is the crude protein (%) of the faeces and OM_f is the OM (%) of the faeces. The pasture quality and faecal analysis data were used in modelling animal production but are not presented.

Modelling and gross margins

The treatments were designed so that the number of wethers varied throughout the year to simulate the grazing pressure and estimated metabolisable energy intake (MEI) of a spring lambing, terminal sire system with lambs sold at weaning. That is, wethers were added from July through to peak numbers in October before the additional animals were removed in December. All intensive rotational grazing treatments could be examined in this framework, except for the FLEX, that had varying wether numbers and grazing intervals. A daily time step model was therefore developed that used estimates of pasture and diet quality (Pasture MD (ME density, MJ of ME/kg of feed) and MEI of animals) to estimate ewe weight and condition gains or losses, wool quantity and quality, and lamb weights. The model was developed using the equations from Freer *et al.* (2007) and the SheepExplorer spread sheet tool (www.pi.csiro.au/grazplan), except the level of microbial crude protein, which was estimated from the method described by Behrendt (2008) so that protein intake and microbial protein synthesis did not have to be predicted. The equations are the fundamental functions used in the sheep biology model of the GrazPlan suite of decision support tools (Donnelly *et al.* 1997; Freer *et al.* 1997).

For the CG and SR treatments, the GrazFeed model (Freer *et al.* 2003) was used to determine the MD and MEI, using the weight gain/loss of the wethers and the availability of green and dead herbage mass, and the proportion of clover. The DMD was adjusted until the predicted animal production matched the actual animal production (Zhang *et al.* 2014). This approach assumed there were no production losses due to animal health issues and over the life of the experiment there were no obvious animal health issues, other than isolated animals, which were excluded from the average weights when this occurred.

For the FRs, MEI could not be estimated using the same method and was instead estimated using predicted equations (described in the results) and pasture MD was estimated from plucked samples. For both the continuous and rotational grazing treatments, predicted means were determined daily using the spline smoothing function in Genstat 16 (Payne *et al.*, 2013).

The animal production output generated by the spread sheet model was used to determine gross margins calculated using average prices from 2007–2012. The wool price varied based on the average fibre diameter and the strength was subjectively assessed by examining the rate of change in fibre diameter along the profile generated from the model.

ANOVA was used to determine the differences between treatments over time. Regression analysis was also performed to determine the relationship between variables. All analysis was conducted using Genstat 16 (Payne *et al.*, 2013).

Results

Rainfall

Average monthly rainfall was below average throughout the experiment except in February and March each year and in June 2013 (Fig. 1). The rainfall was extremely poor in October and November in both 2012 and 2013 and resulted in lower than expected pasture growth.

Pastures

Overall, the HSR CG had the lowest standing herbage mass at 2.87 t DM/ha and the LSR SR treatments had the highest standing herbage mass with an average of 4.42 t DM/ha ($P < 0.01$) with no significant difference between the remaining treatments. For all treatments, the standing herbage mass decreased over time ($P < 0.001$), from February 2012 (5.43 t DM/ha) to October 2013 (2.77 t DM/ha). Standing herbage mass showed significant interaction between grazing treatment and time (P <0.05; Table 2). For the first two grazing periods there was no significant difference in standing herbage mass between grazing treatments. Generally CG treatments had the highest herbage mass during the first grazing, but had the lowest herbage mass by October 2013. The intensive rotational grazing treatments, particularly at HSR, were able to maintain higher levels of standing herbage mass than CG treatments at the same stocking rate.

Overall, the highest bare ground was found in the HSR CG treatment, which averaged 11.5% (P <0.001). The lowest bare ground levels were found in the LSR 30P treatments with 1.7% and 2.1% for the SR and FR, respectively. Bare ground levels were similar for HSR, FLEX, LSR 15P and LSR CG treatments, averaging 5.1%. Bare ground significantly increased over time (P <0.001) with more bare ground in October 2013 (7.1%) than at other times (average value 4.0%). There was also a change between treatments over time (P <0.05). There was no significant difference between grazing treatments in February 2012 (average value 3.6%), but by October 2013, the HSR CG had the highest levels of bare ground (18.3%) and they were significantly higher than the LSR 30P treatments (ave 2.6%). At this time the HSR SR 30P (7.2%) was also significantly higher than the LSR SR 30P (2.2%).

Cocksfoot was the dominant species of the pasture composition and increased over time from 83% at the beginning of the experiment to 90% by October 2013 (P<0.001). However, the proportion of cocksfoot in the HSR CG treatment decreased over time and by October 2013 was significantly lower than LSR FR 30P

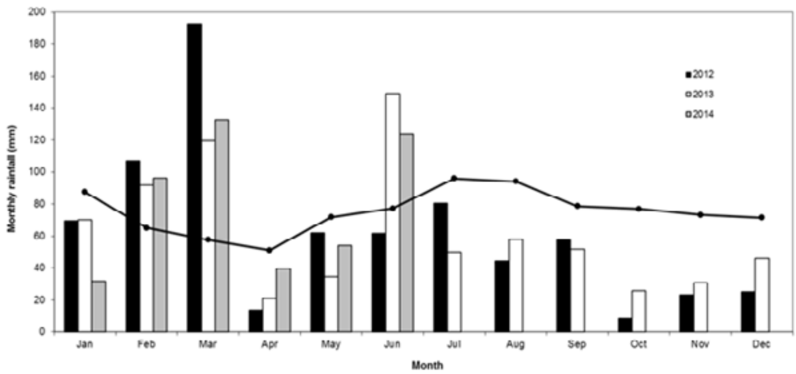

Figure 1. Monthly rainfall (bars) and average monthly rainfall (line) at Orange Agricultural Institute.

Table 2. Standing herbage mass in each treatment when grazed. The least significant difference (P<0.05) among treatments and sample dates is presented.

Treatment	10/02/2012	19/10/2012	6/06/2013	3/10/2013	lsd
FLEX	5.26	3.48	2.31	3.37	1.62
HSR CG	6.84	2.54	1.56	0.55	
HSR FR 15P	4.88	3.00	3.19	2.50	
HSR FR 30P	5.06	3.42	3.75	3.08	
HSR SR 15P	5.20	3.02	3.90	2.55	
HSR SR 30P	4.69	3.11	4.01	2.65	
LSR CG	6.47	4.11	2.68	1.76	
LSR FR 15P	5.18	3.68	3.83	3.25	
LSR FR 30P	5.00	4.15	4.21	3.65	
LSR SR 15P	6.25	3.94	4.40	3.31	
LSR SR 30P	4.91	3.94	4.86	3.79	

(P <0.05; Table 3). Fescue was a relatively minor perennial grass species but it changed the most in response to the grazing treatments. The proportion of fescue increased steadily in the HSR CG treatment replacing cocksfoot, and by October 2013 it was higher than all other treatments except the FLEX (P <0.01; Table 3).

White clover was only a small proportion of the composition but it is important due to the positive influence it has on animal production. It changed over time (P <0.001; data not shown) with the highest levels found in October 2012 (3.3%) and lowest levels in June 2013 (0.2%). Grazing treatment also influenced the proportion of white clover (P <0.01), with lower levels in the LSR CG (0.5%) and highest levels in the HSR SR 15P (2.6%).

Diet quality

Residual herbage mass of pasture after animals have been removed from an intensively grazed paddock is an indicator of whether the quantity or quality of pasture was restrictive towards the end of the grazing. DM intake of sheep can decrease dramatically below 0.5 t DM/ha (Freer *et al.* 2007), but in this experiment post grazing herbage mass was never below 1 t DM/ha. However, sheep generally selectively graze the green proportion of the pasture and at times the residual green herbage mass was < 50 kg DM/ha (e.g. HSR in January 2013).

Green herbage allowance per head per day (GHA; kg DM/hd/day), defined as the amount of green herbage mass (kg DM/ha) available pre-grazing, divided by the number of animals per ha and the number of days of grazing, was found to be an important factor. There was a consistent positive linear relationship between MEI and

Table 3. The proportion of cocksfoot and fescue in each treatment when grazed. The least significant difference (P<0.05) among treatments and sample dates is presented.

Species	Treatment	10/02/2012	19/10/2012	6/06/2013	3/10/2013	lsd
Cocksfoot	FLEX	84.1%	82.7%	90.5%	81.0%	10.5%
	HSR CG	86.5%	89.9%	80.0%	75.2%	
	HSR FR 15P	83.0%	87.6%	87.2%	86.9%	
	HSR FR 30P	83.8%	90.4%	86.5%	87.7%	
	HSR SR 15P	82.6%	85.6%	90.0%	87.9%	
	HSR SR 30P	84.4%	85.4%	88.9%	88.0%	
	LSR CG	77.6%	91.3%	88.3%	90.9%	
	LSR FR 15P	83.3%	87.8%	93.2%	90.2%	
	LSR FR 30P	83.4%	88.8%	94.1%	92.2%	
	LSR SR 15P	85.6%	86.7%	93.2%	89.1%	
	LSR SR 30P	80.1%	86.0%	94.0%	90.0%	
Fescue	FLEX	1.7%	5.2%	2.7%	6.3%	3.8%
	HSR CG	2.1%	4.5%	8.8%	10.8%	
	HSR FR 15P	2.1%	3.8%	1.7%	4.0%	
	HSR FR 30P	0.5%	2.4%	1.0%	2.0%	
	HSR SR 15P	1.0%	2.5%	0.3%	1.3%	
	HSR SR 30P	2.3%	2.6%	0.8%	1.6%	
	LSR CG	0.5%	3.5%	3.0%	2.9%	
	LSR FR 15P	1.8%	3.5%	1.1%	1.7%	
	LSR FR 30P	0.8%	3.1%	0.7%	2.3%	
	LSR SR 15P	3.9%	5.8%	0.9%	2.7%	
	LSR SR 30P	3.3%	5.2%	1.8%	3.6%	

GHA throughout the year, except during spring (MEI = 1.853 * GHA + 4.567, P <0.001, R^2 = 0.72; Figure 2). In spring the relationship was much steeper and more variable between years. At this time a relationship between the green herbage mass pre-grazing (GDM_{pre}) and the green disappearance (GDM_{dis}; the reduction in green herbage mass per head per day; kg DM/head/day) showed a more consistent relationship with MEI (MEI = –4.9 * GDM_{pre} + 14.86 * GDM_{dis} + 10.64, P <0.001, R^2 = 0.71). These equations were used to predict the MEI for the FR rotations.

Gross margins

The main factors were combined between treatments to compare the relative influence of each. There was little difference between HSR and LSR, on average the gross margin for the HSR treatment was \$199 ± 21/ha (mean ± 1 standard error) and the LSR was \$177 ± 14/ha. Considering the stocking rate was nearly doubled in the HSR it did not perform well on a per ewe basis (HSR = \$28 ± 3/ewe, LSR = \$46 ± 4/ewe), and this was particularly due to lower simulated lamb weights predicted at sale (HSR = 21.8 ± 1.0 kg, LSR = 28.3 ± 1.3 kg). The speed of the rotation influenced gross margins, with a lower gross margin in the SR (\$162 ± 6/ha) than FR (\$211 ± 26/ha) and CG (\$195 ± 29/ha) treatments. The poor performance of the SR was due to lower MEI compared with the FR and CG. Extra subdivision from 15P (\$184 ± 21/ha) to 30P (\$189 ± 21/ha) also did not influence gross margin.

There was considerable variation between individual treatments, with the interaction between stocking rate and rotation speed providing the most profitable combination of factors. There was little difference in gross margin for the SR treatments at different stocking rates (HSR SR = \$167 ± 9/ha, LSR SR = \$158 ± 6/ha), while the FR had higher gross margins at HSR (\$243 ± 37/ha) than at LSR (\$178 ± 33/ha). However, the CG had the opposite trend with lower gross margins at HSR (\$177 ± 63.3/ha) and higher gross margins at LSR (\$206 ± 25/ha), but there was very high variability between years for the HSR.

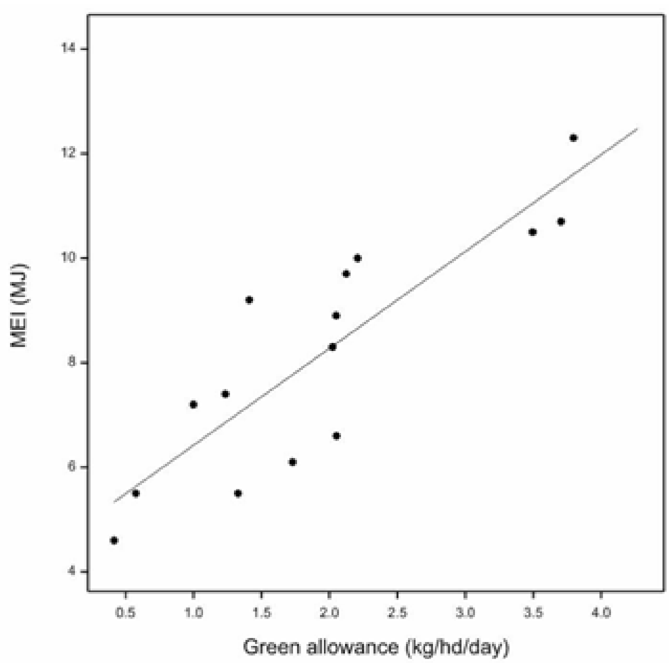

Figure 2. The relationship between green herbage allowance (kg DM/head/day) and MEI (MJ/hd/day) estimated by animal weight changes using GrazFeed for the SR treatments at all times except spring. Values in spring were excluded because of steeper and inconsistent relationship between years.

Discussion

This experiment addressed the profitability and sustainability of grazing management and stocking rate options for a typical introduced pasture. The profitability of the treatments were assessed using gross margins that were produced from a model that converted the feed quality and quantity consumed by wethers into animal production for a spring lambing terminal sire system. While there are many measures that can be used to assess sustainability, the two year life of the experiment meant there was limited time for differences to develop between systems. This was shown by only small differences in pasture composition throughout the experiment, while differences in bare ground were more prominent.

To determine the most desirable systems the average gross margin and average bare ground, as an indicator of sustainability for each system, were plotted (Fig. 3) – with the most desirable systems located in the top left hand corner. The HSR FR treatments performed best as these systems were able to maintain a higher diet quality and feed availability than the other treatments with acceptable bare ground levels. Generally, the bare ground levels of all the rotations and LSR CG were acceptable (<10%). The LSR CG also performed nearly as well financially as the HSR FR treatments. The worst performing treatment was the HSR CG, which had significant feeding costs and lower feed-on-offer that limited animal performance. The two years of failed spring rainfall reduced the performance of the HSR treatments, particularly as grazing pressure was weighted towards spring. Further, the distribution of rainfall was particularly abnormal with monthly totals above average in February and March, but below average at nearly all other times. However, there was high variability in the gross margin for the HSR CG between years, indicating that this system was likely to have higher gross margins in better years. There was also little difference between the 15P and 30P treatments, indicating that there was limited advantage increasing subdivision to 30 paddocks per mob. Increasing paddock subdivision achieved small gains in additional groundcover, but with the additional capital outlay required to increase subdivision then this is not likely to be viable. Focusing on getting the stocking rate right is a better strategy. However, the advantages from using subdivision to utilise

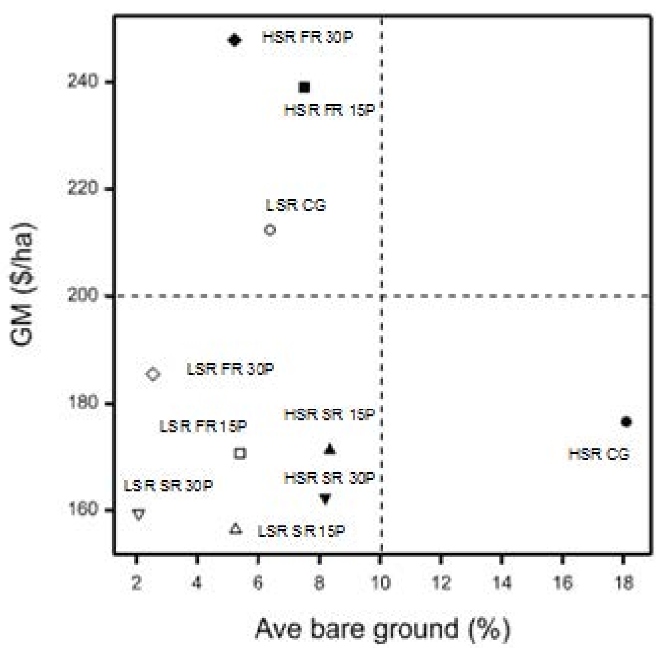

Figure 3. Average gross margin (GM, $/ha) and average bare ground (%) for each treatment (except FLEX).

different areas of the landscape more efficiently was not assessed and there may be additional benefits if this is considered.

The GHA (kg DM/hd/day) had a strong relationship with the MEI of wethers modelled using GrazFeed for the SR treatments (Fig. 2). As GHA increased from 0.5 kg/head/day to up to 4 kg/head/day the MEI improved linearly, with a greater improvement during spring when there were higher grazing intensities and higher pasture MD (data not shown). This may be used as a method to budget feed in intensive rotations to ensure animal performance is not inhibited. Budgeting feed using a GHA of >1.5 kg/DSE/day in spring and >3.5 kg/DSE/day at other times of the year may be used as a management strategy to maintain higher levels of animal performance. SR often had the highest pasture mass, but had to be grazed heavily at each grazing event, and had lower GHA than other treatments. This resulted in a poor quality diet that often did not meet the demand of dry sheep (9 MJ), particularly at high stocking rates. As a result, slow rotations should not be recommended in the HRZ.

The flexible management treatment (FLEX) was imposed to graze pastures at the optimum stage, based on previous research. The cocksfoot pasture was grazed when the cocksfoot plants had between 3 and 4 fully extended leaves per tiller (Rawnsley *et al.* 2002; Turner *et al.* 2006) and were stocked with enough sheep to graze the pasture down to 0.6 t/ha of green DM. The profitability of the systems could not be assessed using the spreadsheet model, because livestock numbers and the grazing times varied and did not fit the pattern of a spring lambing terminal sire system, as the other treatments did. Therefore the best way to judge the profitability is to assess the stocking rate and the quality of the pasture consumed. The FLEX resulted in an annual stocking rate 2 DSE lower than the HSR treatments and pastures were grazed more frequently in autumn and spring when they were actively growing, but rarely through winter. Designing a grazing system on a single pasture type with this pattern of utilisation would be difficult and it may not be possible to optimise pasture utilisation at the desired leaf-stage across an entire property.

Conclusions

The most profitable and sustainable systems were fast rotations with an average 54 day rest period. Stocking rate can substantially impact on what is the most profitable and sustainable system, and the optimum stocking rate is likely to be lower for continuous grazing than intensive rotations. This was demonstrated with both the HSR FR and the LSR CG having profitable and sustainable systems. While neither the high nor the low stocking rates were likely to be optimum for this site and the seasonal conditions experienced, which favoured more conservative stocking than might otherwise be expected, the general principle is important. Moreover, budgeting feed using a GHA of >1.5 kg DM/DSE/day in spring and >3.5 kg DM/DSE/day at other times of the year may be used as a management strategy in intensive rotational system to maintain higher levels of animal performance.

Acknowledgments

We would like to thank Australian Wool Innovations for funding this project. We would also like to thank the Orange EverGraze Regional Group for contributing to the development of this project.

References

Allan CJ, Mason WK, Reeve IJ, Hooper S (2003) Evaluation of the impact of SGS on livestock producers and their practices. *Australian Journal of Experimental Agriculture* **43**, 1031–1040.

Badgery WB, Cranney P, Millar GD, Mitchell D, Behrendt K (2012) Intensive rotational grazing can improve profitability and environmental outcomes. *In*: 'Proceedings of the 27th Annual Conference of the Grassland Society of NSW', Eds C Harris, G Lodge, C Waters (Grassland Society of NSW, Orange NSW), 85–91.

Behrendt K (2008) Bioeconomics of pasture resource development in sheep production systems. PhD thesis (University of New England: Armidale).

Donnelly JR, Moore AD, Freer M (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises .1. Overview of the GRAZPLAN project, and a description of the MetAccess and LambAlive DSS. *Agricultural Systems* **54**, 57–76.

Freer M, Dove H, Nolan JV (2007) Nutrient requirements of domesticated ruminants. (CSIRO Publishing: Melbourne).

Freer M, Moore AD, Donnelly JR (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises .2. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* **54**, 77–126.

Freer M, Moore AD, Donnelly JR (2003)The GRAZPLAN animal biology model for sheep and cattle and the GrazFeed decision support tool. CSIRO Plant Industry Technical Paper.

Isbell RF (2002) The Australian soil classification. (CSIRO Publishing: Collingwood).

Kaine G, Doyle B, Sutherland H, Scott JM (2013) Surveying the management practices and research needs of graziers in the New England region of New South Wales. *Animal Production Science* **53**, 602–609.

Kemp DR, Dowling PM (2000) Towards sustainable temperate perennial pastures. *Australian Journal of Experimental Agriculture* **40**, 125–132.

McCosker T (2000) Cell Grazing – the first 10 years in Australia. *Tropical Grasslands* **34**, 207–218.

Payne R, Murray D, Harding S, Baird D, Soutar D (2013) Introduction to GenStat® for Windows™ (16th Edition). (VSN International: Hemel Hempstead, Hertfordshire).

Rawnsley RP, Donaghy DJ, Fulkerson WJ, Lane PA (2002) Changes in the physiology and feed quality of cocksfoot (*Dactylis glomerata* L.) during regrowth. *Grass and Forage Science* **57**, 203–211.

Savory A (1988) Holistic resource management. (Island Press: Washington, D.C).

Sheath GW, Clark DA (1996) Management of grazing systems: temperate pastures. In 'The Ecology and Management of Grazing Systems'. (Eds J Hodgson, AW Illius). pp 301–325 (CAB International: Wallingford).

Tothill JC, Hargraves JNG, Jones RM (1992) BOTANAL – a comprehensive sampling and computing procedure for estimating pasture yield and composition. I. Field sampling. CSIRO Australian Division of Tropical Crops and Pastures, Tropical Agronomy Technical Memorandum No. 78.

Turner LR, Donaghy DJ, Lane PA, Rawnsley RP (2006) Effect of defoliation management, based on leaf stage, on perennial ryegrass (*Lolium perenne* L.), prairie grass (*Bromus willdenowii* Kunth.) and cocksfoot (*Dactylis glomerata* L.) under dryland conditions. 1. Regrowth, tillering and water-soluble carbohydrate concentration. *Grass and Forage Science* **61**, 164–174.

Wang CJ, Tas BM, Glindemann T, Rave G, Schmidt L, Weißbach F, Susenbeth A (2009) Fecal crude protein content as an estimate for the digestibility of forage in grazing sheep. *Animal Feed Science and Technology* **149**, 199–208.

Warn LK, Frame HR, McLarty GR (2002) Effects of grazing method and soil fertility on stocking rate and wool production. *Wool technology and Sheep Breeding* **50**, 510–517.

Zhang XQ, Luo HL, Hou XY, Badgery WB, Zhang YJ, Jiang C (2014) Effect of restricted time at pasture and indoor supplementation on ingestive behaviour, dry matter intake and weight gain of growing lambs. *Livestock Science* **167**, 137–143.