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# Livestock weights in response to three whole-farmlet management systems

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**Abstract.** This paper reports changes in livestock weights recorded in a whole-farmlet experiment, which aimed to examine the profitability and sustainability of three different pasture and grazing management strategies. The assessment of liveweights was considered a key component of measuring the integrated effects of the farmlet-scale treatments. The three farmlets comprised a typical management regime, which employed flexible rotational grazing over eight paddocks with moderate soil fertility (farmlet B), a system based on the same grazing management and paddock number but with higher levels of sown pasture and soil fertility (farmlet A) and a farmlet with moderate soil fertility and intensive rotational grazing over 37 paddocks (farmlet C).

Early in the experimental period, there were no significant differences between farmlets in the liveweight of any class of livestock. However, from the second year onwards, as the pasture renovation, soil fertility and grazing management treatments took effect, differences in liveweight between farmlets became more apparent and significant. The stocking rate, which was treated as an emergent property of each farmlet, reached a maximum annual average value after 5 years of 12.6, 8.5 and 7.7 dry sheep equivalents (dse)/ha on farmlets A, B and C representing 84, 113 and 51% of their respective target stocking rates which were 15, 7.5 and 15 dse/ha.

The liveweights of ewes, both before joining and during pregnancy, varied with year and farmlet with those on farmlets A and B tending to be significantly heavier than those on farmlet C. From 2003 to 2006, liveweights were significantly ($P < 0.001$) affected by a wide array of factors and their interactions including: date, ewe age, green digestible herbage, legume herbage mass, proportion of farmlet grazed, stocking rate and level of supplementary feeding.

The weights of lambs/weaners/hoggets, both pre- and post-weaning, were at times also higher on farmlets A and B compared with those on farmlet C and were affected by a similar range of factors to those which affected ewe weights. Similar relative differences also applied to the liveweights of the other livestock run on the farmlets, namely wethers and non-reproductive cattle.

The results suggest that stocking rate was able to be increased towards the higher target of farmlet A due to the higher level of pasture renovation and soil fertility on that farmlet, which led to high liveweights per head as well as the higher stocking rate. However, as the stocking rate increased on farmlet A, the differences between farmlets in liveweight per head diminished and the need for supplementary feeding increased. In contrast, the intensive rotational grazing practised on farmlet C did not allow the farmlet to increase its stocking rate towards its higher target. It appears that the higher proportion of each of farmlets A and B grazed at any one time allowed all classes of livestock to reach higher liveweights per head than on farmlet C, due presumably to the greater proportion of those two farmlets grazed at any one time.

**Additional keywords:** dietary choice, farming systems, grazing management, grazing rest, green digestible herbage, stocking rate.

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## Introduction

Livestock production from grazing enterprises depends largely on the interaction between the feed supply, the animal species and their physiology as well as stocking rate and grazing management. On the Northern Tablelands of New South Wales (NSW), Australia, the annual feed supply from rain-fed, pasture-based systems is commonly constrained by the highly variable, summer-dominant rainfall combined with severe limitations to pasture growth in winter, due primarily to low temperatures.

Early studies on the Northern Tablelands of NSW, with native pastures, demonstrated that while grazing management of Merino sheep (continuous vs weekly rotational over four paddocks) had little effect on wool production per head, increasing the stocking rate by 67% resulted in a 56% increase in wool production per ha. Liveweights generally increased in spring and summer and declined in winter and were closely related to the amount of green herbage available (Roe *et al*. 1959). The crucial role of green pasture in winter in this region for supporting increased sheep liveweight and wool production was also identified by Willoughby (1959), suggesting that, in order to be valid, experimental studies of grazed pastures needed to consider both the effects of animals on pastures and of pastures on animals and of the balance between supply and demand.

As pointed out by Maxwell (1990), fixing the stocking rate in grazing experiments denies the effects of variability in growth over time and space, and therefore, he argued that stocking rate should not be used as a determining variable. Morley and Spedding (1968) pointed out that if stocking rate is allowed to vary within a grazing experiment, then it is necessary to adopt a 'whole-farm' approach. They also stated that the design of systems needs to be practically relevant to producers if the results are to be of use. The Cicerone farmlet experiment adopted such an approach, conducting the studies at what was judged by producer members of the project to be a 'credible' scale.

The Cicerone Project was set up in 1998 as a producer-led research and extension project to investigate issues of relevance to grazing enterprises on the Northern Tablelands of NSW (Sutherland *et al*. 2013). A survey of some 350 livestock producers across the Northern Tablelands region (Kaine *et al*. 2013) revealed that the greatest challenges facing grazing enterprises at the time were feed supply issues. Many questioned the long-term value of investments in pasture renovation and fertiliser and wondered if grazing management options, such as intensive rotational grazing, might be a solution to help maintain a reliable feed supply, which would adequately support profitable livestock production.

There are limited data published on long-term differences in sheep productivity under different grazing management regimes. In a comprehensive review, Norton (1998) pointed out that many graziers in several countries have claimed that rotational grazing is one of the keys to successful, profitable livestock production and better planning and business management. However, generally small scale grazing trials suggest that continuous grazing is actually no worse than rotational grazing and may even be preferable from a livestock production point of view. The literature seems equivocal on this subject with reports showing rotational grazing being more productive than continuous grazing systems under some conditions (Booysen and Tainton 1978; Chapman *et al*. 2003) while others in southern Australia have shown animal performance to be higher under continuous stocking compared with rotational grazing due to the increased legume content of the continuously grazed pasture (Graham *et al*. 2003). Morley (1995) suggested that the benefits of either rotational or continuous grazing depend on seasonal conditions, with rotationally grazed sheep performing better than continuous stocked sheep in poorer years.

The decision by the Cicerone Project to explore livestock production from three different management approaches applied as whole systems to different farmlets reflected the fact that the technologies investigated (pasture species, soil fertility and grazing management) were likely to be affected by climate and were likely to interact over time and space. A wide array of livestock performance measurements was recorded over the duration of the experiment (July 2000–December 2006). This paper reports on the liveweight changes that were observed for all classes of sheep and cattle run on the farmlets over the duration of the experiment, with a special focus on reproductive ewes and weaners/hoggets.

The two primary research hypotheses in this paper, related to livestock performance, were that either or both higher pasture inputs (farmlet A) and/or intensive rotational grazing (farmlet C) would lead to improved animal productivity compared with a typical management system with moderate inputs (farmlet B).

## Methods

The Cicerone Project farmlets were located ~17 km south of Armidale, NSW, Australia, and were planned such that each 53-ha farmlet commenced with equivalent areas of land having the same initial potential for supporting pastures and livestock (Scott *et al*. 2013*d*). Being adjacent to each other, all farmlets experienced the same climatic conditions. Fine wool, self-replacing Merino sheep was the dominant enterprise on the farmlets while, as is common in the region, cattle were purchased and sold as a means of utilising surplus seasonal feed.

The design and management guidelines developed by the Cicerone Project for the farmlets have been described in detail by Scott *et al*. (2013*c*). As explained, pastures were renovated and fertilised according to the target levels chosen for each farmlet. Animal management decisions were implemented by the farm manager who, in conjunction with the Cicerone Board, took into account the changes of seasonal conditions, pasture states and animal measurements over time.

It is noteworthy that, as much as was feasible, farmlet operations mimicked those of commercial farms. For example, all pasture renovation took place within each farmlet with livestock having to be grazed on paddocks within that farmlet that were not being renovated at the time, thus imposing greater strain on the non-renovated paddocks, just as is practised on commercial grazing enterprises. Some details of the specific methods relevant to this paper are provided below.

The farmlets (A, B and C), each of 53 ha, were subdivided into 8, 8 and 37 paddocks, respectively. The management regime on farmlet B (control treatment) was chosen to represent a 'typical' production system of many Northern Tablelands properties, with a target stocking rate of 7.5 dry sheep equivalents (dse)/ha. On this farmlet, the target soil phosphorus (P) level was chosen to be 20 mg/kg (bicarbonate extract) and 6.5 mg/kg sulfur (S) (KCl-40 extract) (Guppy *et al*. 2013). Farmlet B employed a flexible grazing management system based on Prograze principles (Bell and Allan 2000), which used regular pasture and animal assessments to assist decisions concerning stocking rate, stock movement and supplementary feeding decisions.

Farmlet A was set a target of 100% sown pastures and higher soil fertility levels of 60 mg/kg P and 10 mg/kg S but with the same grazing management regime as farmlet B. Because of its higher level of inputs, a target stocking rate of 15 dse/ha was selected for this system.

Although farmlet C had the same target soil nutrient levels as farmlet B, it employed an intensive rotational grazing management system involving short graze and long rest periods. Due to claims made by some proponents of such systems, that stocking rates can be doubled (McCosker 2000), the target stocking rate was initially set at 15 dse/ha.

In spite of specifying stocking rate targets within the farmlet guidelines, consistent with other studies (Morley and Spedding 1968; Maxwell 1990; Chapman *et al*. 2003), it was acknowledged at the outset that stocking rate would be an emergent property of the experiment, rather than one or more fixed treatment levels. In summary, farmlets A and B differed principally in the levels of inputs whereas farmlets B and C differed in grazing management while farmlets A and C differed in both factors.

On all farmlets, regular assessments of liveweight and fat score of animals were complemented by regular visual assessments of the pastures in each of the paddocks with notes being taken by the farm manager on both the livestock and pasture attributes at each stock move. More details of the fat score changes between farmlets and links to reproduction have been provided by Hinch *et al*. (2013).

In the case of farmlets A and B, animals tended to be grazed as separate mobs of ewes, hoggets, wethers and cattle. However, on farmlet C, in order to increase stock density and allow long rest periods between grazing events, livestock classes were commonly grazed together. In general, farmlet C adopted a less flexible regime of stock movements between paddocks with regular short graze and long rest periods. The decisions on stock movements were modified when necessary, such as during dry times and when approaching periods which demanded either the accumulation of sufficient green feed for lambing, and/or the creation of ‘clean’ pasture, through resting, for weaners.

Stocking rate decisions were taken by the management team in response to seasonal conditions, feed supply and animal performance measurements. As stocking rate was considered an emergent property of each system, rates were not fixed for long periods of time. In April of each year, before joining, a decision was taken on the number of ewes to join on each farmlet. Also, decisions on culling wethers and/or reducing numbers of hoggets and/or the numbers of cattle to be purchased for the summer–autumn period were taken in relation to the anticipated feed supply appropriate to each farmlet. These decisions meant that, at times, such as the serious drought conditions of 2002, substantial numbers of stock were sold earlier than would have been the case under more favourable conditions. While this contributed to the variability of the numbers of animals over time and between farmlets, it was considered to be the most realistic response as it was consistent with livestock producers’ actions when faced with similar circumstances.

The self-replacing, fine wool, Merino flocks that were run on the farmlets were based on the same strain ensuring that the sheep run on each farmlet were of equal genetic merit. The same proportion of rams to ewes, from the same fine wool stud source, was used for joining on each of the farmlets in the first 2 years. Subsequently, to further ensure genetic equality of animals on each of the farmlets, these same rams were used with all ewes from each farmlet being run together on the same periphery paddocks surrounding the farmlet areas for the joining period (usually for 6 weeks during April–May).

Crutching of adult sheep normally occurred between February and April, before joining in April–May. Shearing usually took place in late July and lambing occurred from mid September and weaning from mid December to early January.

Liveweights of all classes of livestock were recorded regularly, immediately off pasture, primarily at key management events throughout the experiment. Ewes were generally weighed at weaning (December), joining (April) and pregnancy scanning (~D90–100 of pregnancy), before the pre-lambing shearing. More frequent measurements of weight were carried out for weaners and hoggets, while the weights of wethers and cattle were recorded at less frequent intervals.

Samples of faeces were taken and analysed at regular intervals from representative sheep in all mobs in order to monitor faecal egg counts, which influenced the strategic drenching decisions taken for different flocks on the different farmlets. More details of the faecal egg counts, the drenches used and their frequency of use on different mobs and farmlets have been provided in a related paper by Walkden-Brown *et al*. (2013).

Although the primary focus of the farmlet experiment was sheep production, some cattle were included on each farm, as it is a common practice to incorporate cattle on typical grazing properties in the region (Alford *et al*. 2003). Thus, during periods when excess feed was available, such as early summer in some years, weaner cattle were purchased and the weight gain recorded up to the point of sale, which was generally from late summer to autumn. Upon purchase, cattle were allocated randomly among the farmlets to avoid bias. Where possible, the ratio of sheep to cattle stock units was maintained at similar levels between farmlets.

From 2001 onwards, liveweights were recorded for all animals in all mobs of ewes, hoggets, wethers and cattle, thus providing measures of each population directly and thereby overcoming the constraints imposed in many experiments where small subsamples of animals have been used to estimate trends. For example, in the case of the immature hoggets, the dataset of weights comprised some 20 500 records derived by regular weighing of some 2422 individual animals.

Supplementary feeding strategies evolved over the duration of the experiment. Over the first 2 years, a wide range of feeds (e.g. hay, protein blocks, lupins and on farmlet C, a ‘loose mix’ ration reportedly suited to intensive rotational grazing) was fed at generally low levels, in an attempt to maintain ewe fat scores during pregnancy and weaner growth rates following weaning. Once pregnancy scanning of ewes commenced in 2003, ewes were separated into single- and twin-bearing ewe mobs on farmlets A and B allowing the twin-bearing ewes to be fed at a higher rate. As different classes of livestock were run mostly as a single mob on farmlet C, separation of the ewes was not feasible.

Later, the number of supplementary feeds was reduced to mainly protein sources such as lupins and cotton seed meal and, when there was insufficient total herbage available, to the energy rich supplement, maize. In the last year (2006), a supply of low quality silage harvested from farmlet A in late 2005 was used as the sole supplement fed on that farmlet.

The amount fed to each mob was determined on a weekly basis by the farm manager, with guidance from the Cicerone Board, after regularly fat scoring and/or strategically weighing a subsample of animals in each mob. As noted in a related paper on the balance between feed supply and animal demand (Shakhane *et al*. 2013*c*), supplements were mostly fed to ewes during pregnancy when their fat score declined below 2.5 and also to maintain the growth rate of hoggets above 50 g/day. If weights continued to decline, rates were increased while occasionally, when weights increased above targets, rates of feeding were reduced. A summary of the amount of metabolisable energy fed to the main classes receiving feed is shown as a covariate below the ewe liveweight results in Fig. 4. Full details of the supplements fed over the duration of the experiment have been provided in a related paper on the general farmlet experimental methods and guidelines by Scott *et al*. (2013*c*).

### *Statistical methods*

Although the farmlets themselves were not replicated, great care was taken to allocate land to each farmlet so that differences in their productive capacity at the commencement of the trial were minimal. This was confirmed by comparing remotely sensed images, obtained in June 2000, before the commencement of the experiment, of the greenness (normalised difference vegetation index) over all paddocks of each farmlet (Scott *et al*. 2013*d*).

The differences in animal liveweights for the various classes of livestock were explored for a wide range of variables using pair plots (Zuur *et al*. 2007), which provided estimates of the Pearson correlation coefficients between the response and explanatory variables. In addition, generalised linear (GLM) and generalised additive modelling (GAM) (Zuur *et al*. 2007) were employed using the statistical program 'Brodgar' (version 2.7.2), which provides an interface to the statistical package R (R Development Core Team 2011). For each analysis, the output was examined for normality with Q-Q plots; no transformations of the liveweight data were required.

Both GLM and GAM models were fitted initially to the ewe liveweight data over the entire experimental period from July 2000 to December 2006. However, as detailed monthly data on the herbage mass and quality of pastures were only collected from April 2003 onwards, these factors were only included as covariates after that date. Analyses of the relationship between liveweight and a wide array of explanatory variables [date, age, green digestible herbage (green herbage DM × percent digestibility (Shakhane *et al*. 2013*a*))], legume herbage [DM (Shakhane *et al*. 2013*a*)], stocking rate, grazed proportion (proportion of each farmlet grazed at any one time, providing a single parameter to allow comparisons of each farmlet's grazing management) and amount of supplementary feeding) were carried out with both GLM and GAM models.

The figures depicting liveweight changes over time include confidence intervals of the liveweights of each farmlet animal cohort, fitted with local regression, likelihood and density using the locfit package of R (Loader 2010).

Statistical analyses of liveweight data for hoggets and wethers were also conducted using GLM and GAM models by testing of an array of explanatory variables similar to those for ewe weights.

## Results

### *Stocking rate*

The annual average stocking rate across all years and farmlets (Fig. 1), shows similar rates between farmlets in the first 2 years with the average rate on farmlet A increasing above those of farmlets B and C from 2002 onwards, reaching a maximum annual value (12.6 dse/ha) in 2004.

The monthly average changes in (*a*) stocking rate, (*b*) stock density and (*c*) the proportion of each farmlet grazed simultaneously, together with notations showing the dates of joining, lambing and weaning are shown in Fig. 2. Stocking rates were initially relatively high, due to the large body of feed present on all farmlets at the start of the trial on 1 July 2000, a consequence of little prior grazing. The stocking rates also fluctuated considerably, especially on farmlet A, due to the impact of the high level of pasture renovation on that farmlet over the years up to 2004. In 2001, the stocking rates on farmlets A and C increased briefly towards their higher target of 15 dse/ha. Thereafter, during the drought conditions of 2002, stocking rates had to be reduced on all three farmlets. Later, when feasible, stocking rates were increased slowly as seasonal conditions permitted and the impacts of pasture renovation and higher soil fertility on farmlet A were realised.

The large reductions in stocking rate shown at each joining date from 2003 onwards reflects the fact that from that date, the ewes from all three farmlets were joined to common rams

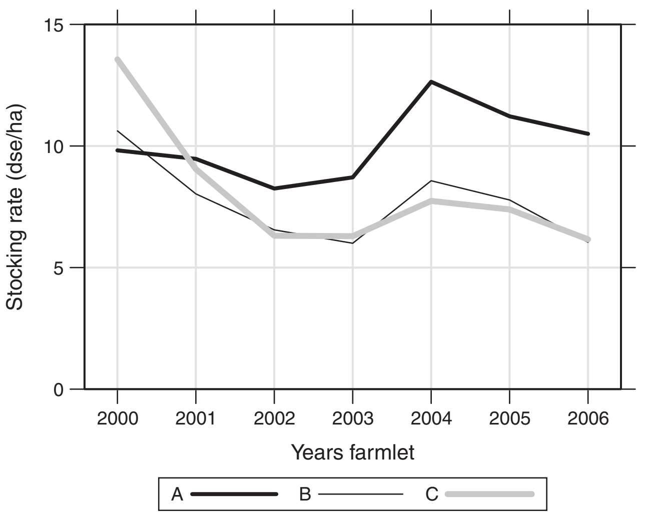


**Fig. 1.** Annual mean stocking rate (dse/ha) on farmlets A, B and C from 2000 to 2006 inclusive. The target stocking rates for farmlets A, B and C were 15, 7.5 and 15, respectively.

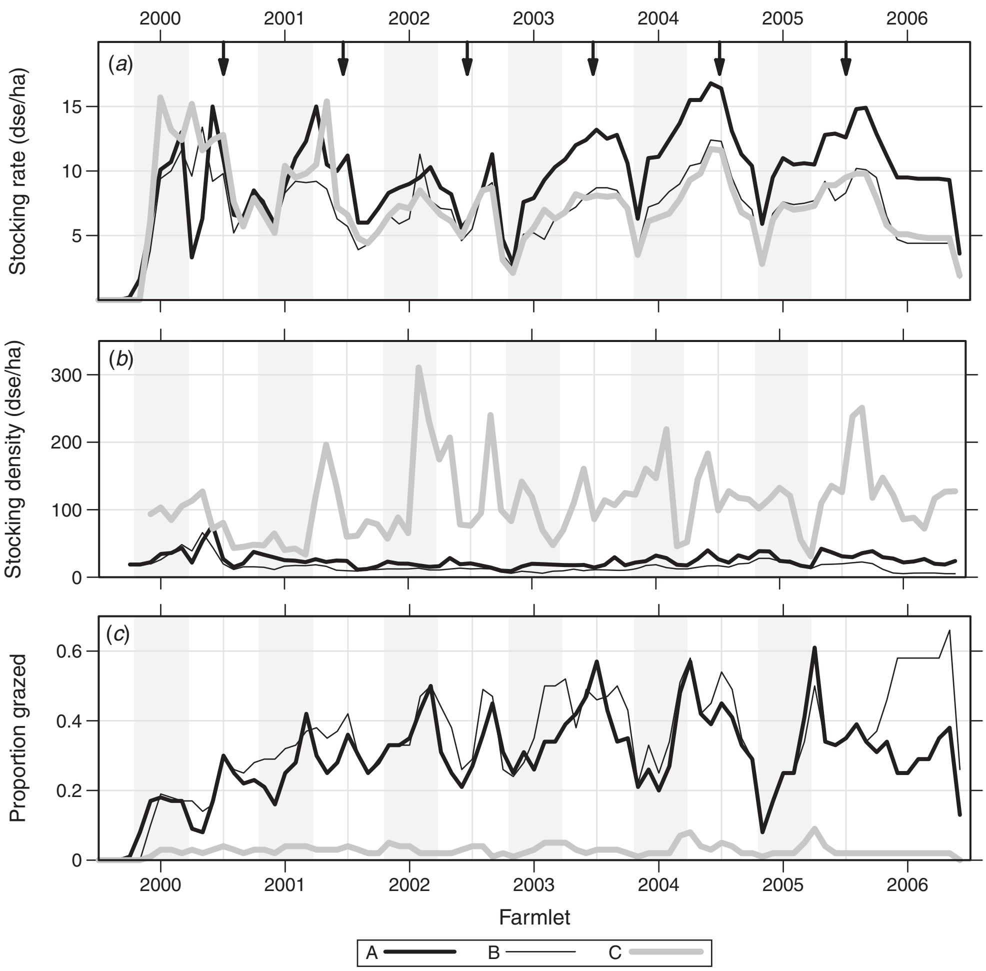


**Fig. 2.** Monthly mean (*a*) stocking rate (dse/ha), (*b*) stocking density and (*c*) proportion of farmlet grazed on farmlets A, B and C from 2000 to 2006 inclusive. Shaded bars indicate the period from joining to lambing while the black arrows indicate the weaning date.

off the farmlets on peripheral paddocks, in order to ensure equivalent genetic attributes of each farmlet flock.

On two occasions, seasonal stocking rates reached a maximum of more than 15 dse/ha on farmlet A (Fig. 2*a*) whereas the maximum annual average stocking rate (Fig. 1) was reached at 12.6 (48% higher than farmlet B) in 2004 and 11.2 (44% higher than farmlet B) in 2005. On farmlets B and C, the maximum seasonal stocking rates reached were 12 dse/ha in 2004 whereas the annual average stocking rates for both these farmlets was between 6.5 and 8 dse/ha. In no year did the annual average stocking rate on farmlet C approach its target of 15 dse/ha. The generally lower stocking rates shown for 2006 were due to the fact that the experiment was being wound up by the end of that year and hence no animals were joined and also no supplementary feed was purchased in that final year.

Stocking density (Fig. 2*b*) shows that, at any one time, the number of stock units grazing a particular paddock was much lower on farmlets A and B compared with farmlet C, which had densities ranging from 100 to 300 dse/ha. As the stocking rate on farmlet A increased relative to that of farmlet B, the stock density increased slightly, in proportion to that change in stocking rate.

The proportion of each farmlet grazed at any one time (Fig. 2*c*) was relatively similar for farmlets A and B, ranging from ~0.2 to 0.6, whereas on farmlet C, the proportion grazed was much lower, ranging from 0.03 to 0.08.

### Graze and rest periods

In general, farmlet A experienced graze periods of 20–80 days with rest periods of similar length whereas farmlet B tended to have longer graze periods (40–100 days) than rest periods (Fig. 3). In contrast, farmlet C had short graze periods, commonly less than 5–10 days, but with much longer rest periods ranging from 50 to 180 days, the latter length of rest occurring during parts of the drought year 2002 when rest periods were extended in an attempt to ‘ration’ the low levels of herbage mass available.

### Liveweights

#### Adult ewes

Changes in the liveweight of mature ewes (2+ years old) over the duration of the farmlet trial show the changes over time

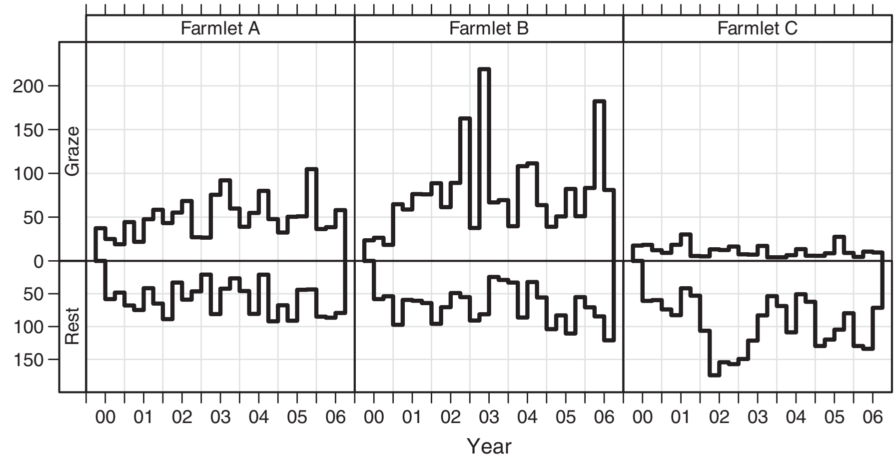


**Fig. 3.** Mean quarterly graze and rest periods (days) per grazed paddock on farmlets A (8 paddocks), B (8 paddocks) and C (37 paddock cells).

including all key events such as joining, pregnancy, lambing and weaning (Fig. 4). As expected, there was no significant difference between ewe weights on any of the farmlets up to the end of 2001. However, differences appeared thereafter, especially between ewes on farmlet C and the other two farmlets (A and B). The extent of weight loss/gain varied between years/seasons and farmlet management systems. For all three farmlet systems, the lowest bodyweight tended to be around the weaning date (mid December or early January).

At joining, ewes on farmlet A had heavier weights in most years than ewes on farmlets B and C. In general, the combination of pre-lambing shearing and the demands of late pregnancy and lactation resulted in significant weight loss of ewes in all systems during the early lactation period. Again in 2001, there was no difference in the liveweights of mature ewes during pregnancy but thereafter, farmlet A and/or B ewes tended to be significantly heavier than farmlet C ewes.

Fig. 4 shows no difference between farmlets in the liveweight of adult ewes before joining in 2001 but some significant differences ($P < 0.05$) between the farmlets can be observed at later times, especially between the farmlets which practised flexible rotational grazing (farmlets A and B) and farmlet C, which employed intensive rotational grazing.

Attempts were made to fit both GLM and GAM models to the liveweight data for mature ewes from each farmlet over time. After inspection of the Q-Q plots, the Akaike information criterion values and finding that the residual plots were without trends, it was determined that the best fit for a model of mature ewe liveweights (4912 records) with explanatory variables was a GAM using the Gaussian distribution with an identity link function, which explained 42.5% of the overall deviance.

The significant main effects identified by a GAM analysis were date, ewe age, green digestible herbage (green DDM), legume herbage (legume DM), grazed proportion, stocking rate and level of supplement fed ($P < 0.001$). Significant two-way interactions were found for date by green DDM, date by legume DM, date by grazed proportion, date by stocking rate and date by level of supplement fed ($P < 0.001$). Higher level interactions were not explored.

Because it is clear that there was a highly significant and complex interaction of at least five factors, Fig. 4 shows not only the liveweights of mature ewes for each farmlet over time, but also trends between farmlets of green DDM, legume DM, stocking rate, grazed proportion and level of supplement fed. While it is difficult to visualise the interactions, there are some clear indications of the factors which were likely to have affected the liveweights most strongly. Thus, the tendency for farmlet A ewes (higher pasture renovation and soil fertility) to be heavier than farmlet B ewes (typical management), seems to be linked to the trend towards higher green DDM and higher legume DM on farmlet A, in spite of the fact that the whole-farmlet stocking rate on farmlet A was substantially higher than that on farmlet B, whereas the grazed proportion was similar between both.

By contrast, the trend towards lower liveweights of farmlet C ewes compared with those of farmlet B seems not to be related to green DDM, legume DM, stocking rate, or supplementary feeding, all of which were similar for both farmlets, but rather to the much lower grazed proportion on farmlet C (intensive rotational grazing) compared with farmlet B (typical management).

Although the data are not presented here, it was evident that the liveweights of maiden ewes, while generally lower than adults, followed similar trends to adult ewes with few differences evident before joining in 2001 but thereafter differences became more apparent with maiden ewes on farmlets A and B being heavier than maiden ewes on farmlet C, especially in 2003 and 2004.

### *Lambs*

Lambs born in years 2000–05 were weighed either once or twice between lambing and weaning. The number of lambs born in 2000 was similar among farmlets (210, 211 and 183 on farmlets A, B and C, respectively), but by 2004, there were large differences due largely to differences in stocking rate, with farmlets A, B and C recording 282, 189 and 158 lambs, respectively. More details of sheep reproduction in the farmlet experiment are given in a related paper by Hinch *et al*. (2013).

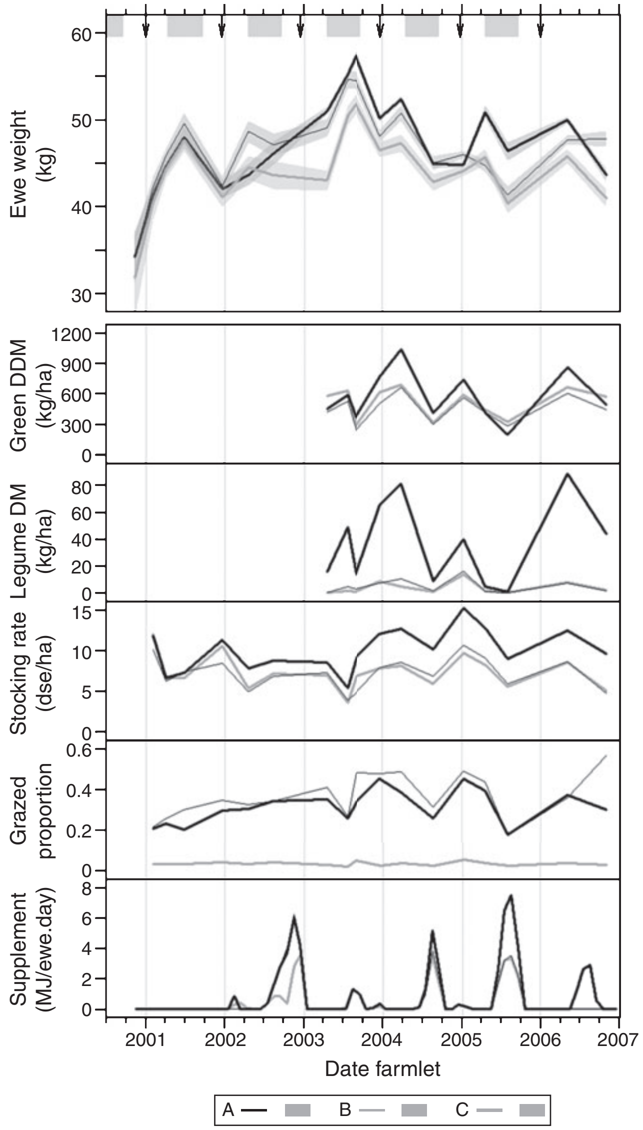


**Fig. 4.** Mean mature ewe (>2 years) weight (kg) from all ewes from November 2000 to November 2006 on each farmlet. 95% confidence intervals for mature ewe weights are shown as shaded. Significant covariates were: green digestible herbage, legume herbage, stocking rate, grazed proportion and weighted average of supplement fed for all farmlets between weighing dates. The grey bars at top of figure indicate the period of pregnancy for each year from joining to lambing; arrows indicate the weaning date in each year.

As with the ewes, the average weight of lambs up to weaning tended to be somewhat higher on farmlets A and B compared with farmlet C. A linear regression analysis of lamb weights from birth to weaning, (which were normally distributed) found that weight was significantly ($P < 0.001$) related to lamb age, born year and farmlet with a significant interaction ($P < 0.001$) between farmlet and born year.

### *Hoggets*

The liveweight of hoggets (Fig. 5) increased approximately linearly from birth to 18 months of age, apart from periods of weight loss in the winter of 2002 and slower growth in the winter of 2004; both of these winters were colder and drier than normal (Behrendt *et al*. 2013). The hoggets born in 2000 showed similar weight gains between farmlets whereas those born in 2001 and 2003 on farmlets A and B grew at a similar but somewhat higher rate compared with farmlet C hoggets. For the 2002-born hoggets, again farmlets A and B growth rates were similar but those for farmlet C hoggets were markedly lower, being some 6 kg lighter at 18 months of age.

A GAM fitted using the Gaussian distribution with an identity link function showed that the weights of hoggets were at times significantly higher on farmlets A and B compared with those on farmlet C and were affected significantly ($P < 0.001$) by the main effects of born year, date, legume DM mass, stocking rate and proportion of farmlet grazed with significant two-way interactions ($P < 0.001$) between born year and green DDM, legume DM, proportion of farmlet grazed and level of supplement fed. This fitted model explained 78.6% of the deviance.

The overall weight of lambs weaned per farmlet and per ha (Table 1) reflect both the numbers of lambs and their liveweight per head at weaning. Early in the experimental period, the number of weaners per farmlet was similar but, over time, the numbers on each of the farmlets diverged considerably. In all years except one, the sum of the weaner weights per farmlet and per ha were higher on farmlet A than on farmlet B which in turn was higher than farmlet C. The exception was in 2003 when, due to a considerable number of lamb losses soon after birth (Hinch *et al*. 2013), farmlet A had lower numbers and thus lower weight weaned per ha than farmlet B.

### *Wethers*

As most of the wethers retained on the farmlets were born in 2001, they were only classified as mature wethers from September 2003. From that date to late in 2005, a total of 50, 43 and 36 mature wethers were run on farmlets A, B and C, respectively. Part of the reason for the overall rise in weights over the period measured was that the age of this same cohort of wethers increased from ~745 to ~1300 days over the period shown. Fig. 6 shows the mean liveweights of this cohort of mature wethers together with 95% confidence intervals determined by local regression, likelihood and density (locfit). Clearly, the wethers on farmlets A and B were not significantly different from each other but both these farmlets supported significantly heavier wethers than farmlet C in spite of the latter farmlet running the least number of wethers and having the lowest overall average farmlet stocking rate. This cohort of wethers received no supplementary feed during the experiment and hence this factor was not explored in statistical analyses. As for the ewes and hoggets, both GAM and GLM models were tested along with explanatory factors. The GAM explained 59.2% of the deviance. As the GLM had a slightly lower Akaike information criterion value, this model with a Gaussian distribution and an identity link function, was accepted as having a better fit. After forwards and backwards selection, the most parsimonious model fitted included the main effects of date, proportion of farmlet grazed, stocking rate, green DDM and an interaction between date and proportion of farmlet grazed.

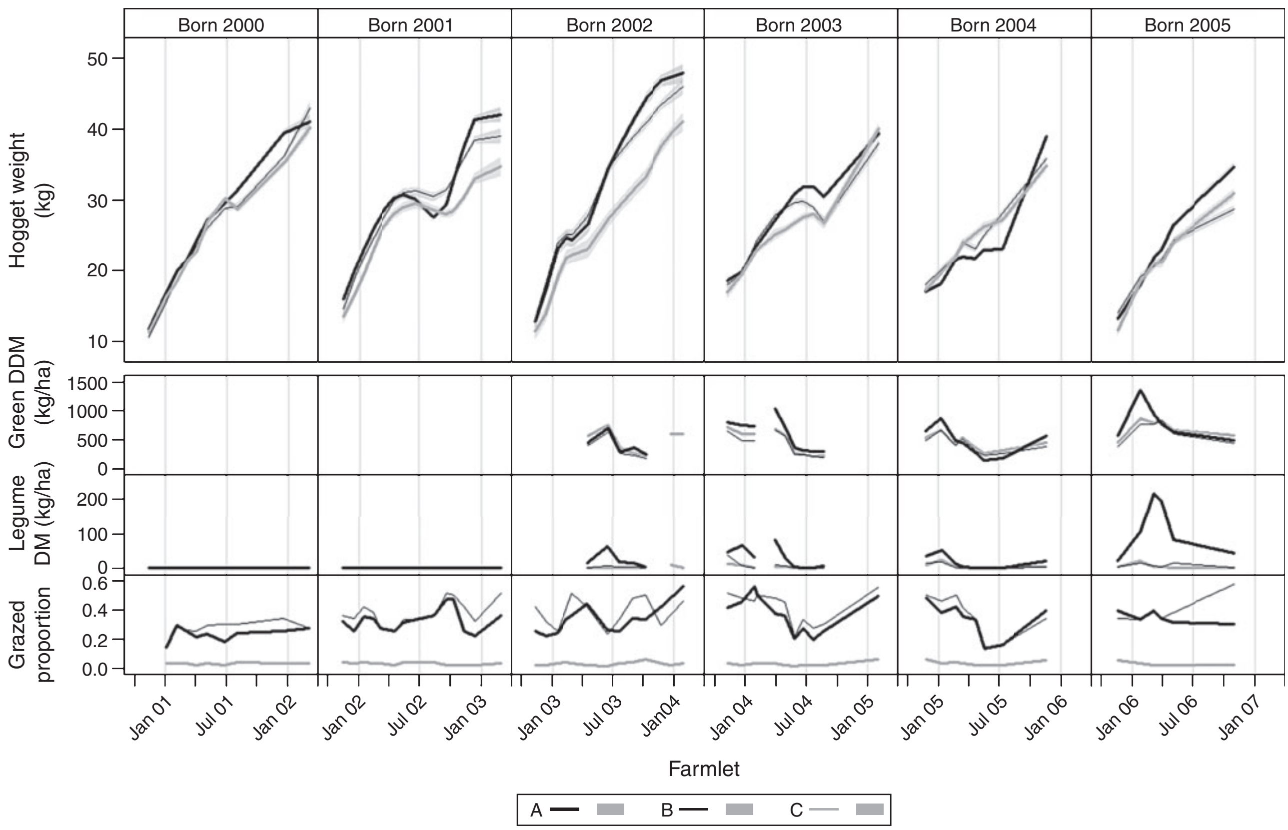


**Fig. 5.** Mean hogget weight (kg) from pre-weaning to 18 months of age for each cohort on each farmlet by year born. 95% confidence intervals are shown as shaded. Significant covariates were: green digestible herbage, legume herbage and grazed proportion.

**Table 1. Number of weaner sheep and total liveweights (at weaning) per farmlet and per ha during the farmlet trial**

| Year weaned | No. of sheep/ farmlet | | | Total liveweight (kg)/ farmlet | | | Total liveweight (kg)/ha | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C |
| 2001 | 199 | 197 | 175 | 3981.1 | 3697.8 | 3240.2 | 75.0 | 69.6 | 61.7 |
| 2002 | 98 | 87 | 80 | 2343.8 | 1988.6 | 1569.0 | 44.1 | 37.5 | 29.9 |
| 2003 | 68 | 88 | 58 | 1558.2 | 2097.8 | 1084.0 | 29.3 | 39.5 | 20.6 |
| 2004 | 194 | 118 | 100 | 4327.2 | 2778.4 | 2236.8 | 81.5 | 52.3 | 42.6 |
| 2005 | 264 | 170 | 146 | 4760.6 | 3405.0 | 2868.8 | 89.7 | 64.1 | 54.6 |

### *Cattle*

The numbers of cattle run on each of the farmlets over the duration of the trial, together with their liveweight gains per head and per ha, are shown in Table 2. Due to the generally low numbers of cattle and the infrequent recording of weights, the data were not subjected to statistical analyses. It is clear that in 2002, due to severe drought, the average daily gain for cattle was low. In all years, cattle on farmlet A had higher liveweight gains per ha than either farmlets B or C, which were similar to each other; farmlet A recorded average daily gains equal to or greater than 1 kg/head.day in 3 out of the 6 years while cattle on farmlets B and C reached this level in only 1 year.

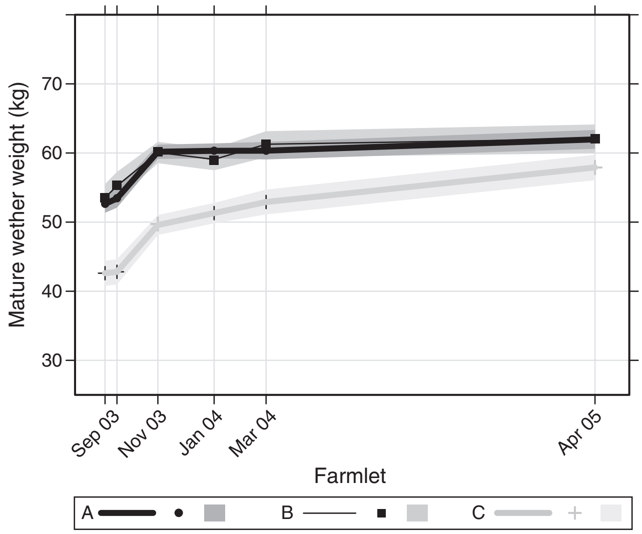


**Fig. 6.** Fitted liveweights (kg) of same cohort of mature wethers (born in September 2001) for farmlets A, B and C from September 2003 to April 2005. 95% confidence intervals are shown as shaded.

## Discussion

This study has provided valuable ‘whole-farmlet’ information on medium term liveweight changes of all animals supported by

**Table 2. Cattle numbers and liveweight gain (per head and per ha) on farmlets A, B and C at intervals during the farmlet experiment**

| End date | Period (days) | No. of cattle/ farmlet | | | Liveweight gain (kg/ head.day)/farmlet | | | Liveweight gain (kg/head.period)/ farmlet | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | A | B | C | A | B | C |
| Oct. 2002 | 182 | 7 | 5 | 4 | 0.6 | 0.3 | 0.3 | 13 | 5 | 4 |
| Dec. 2002 | 168 | 17 | 14 | 11 | 1.1 | 0.6 | 0.4 | 38 | 19 | 18 |
| Apr. 2003 | 70 | 26 | 26 | 26 | 1.2 | 0.9 | 0.8 | 41 | 30 | 28 |
| May 2004 | 306 | 21 | 19 | 21 | 0.8 | 0.8 | 0.8 | 101 | 84 | 93 |
| Feb. 2005 | 106 | 29 | 25 | 29 | 1.1 | 1.1 | 1.0 | 68 | 59 | 65 |
| May 2006 | 194 | 25 | 15 | 16 | 0.7 | 0.8 | 0.8 | 61 | 42 | 48 |

different management regimes. Liveweight records for all classes of livestock showed similar livestock performance between the farmlets early in the experimental period (2000–01) but differences between the farmlet management regimes became apparent later in the study (from 2002 onwards). As noted by Murison and Scott (2013), although the lack of replication of the farmlets means that traditional tests of significance could not be used, there is consistent evidence presented here for all classes of livestock that suggests the differences between similar animal cohorts on the three farmlets were more likely to have come about due to treatment effects than due to random variation or bias.

Because of their prime importance to the productivity of a self-replacing Merino enterprise, most attention has been given in this paper to the liveweight changes of reproductive ewes and hoggets. It can be argued that a way to quantifying management 'success' is in any liveweight advantage shown between farmlets at joining and late pregnancy as liveweight at these times reflects productivity in terms of lambs born and lamb growth to weaning and fleece growth (Oldham *et al*. 2011; Young *et al*. 2011).

The within-year pattern shown in liveweight change is typical of that previously reported for many regions of Australia (Ferguson *et al*. 2011). The value of the data presented here is that the changes are presented over longer time frames as a response to differences in whole-farmlet management. Reports of liveweight changes over a series of years has been previously reported by Dowling *et al*. (1987) who reported weight changes in ewes in the New England region of NSW of between 1 and 5 kg during any one year, depending on the pasture development strategy being used. However, over the 4 years of their study, variation in the weight of mature ewes was much less than that reported here (~12 kg) nor were there apparent differences in pasture management in that study. It is clear that, in this present study, pasture attributes such as legume content, digestibility of both green and dead herbage and levels of green DDM, which differed between farmlets (Shakhane *et al*. 2013*a*), were significant factors affecting ewe liveweight. These changes in green DDM were linked to differences in level of pasture renovation, botanical composition and soil fertility. In the case of botanical composition, Shakhane *et al*. (2013*b*) have reported that, whereas sown perennial grasses were highest on farmlet A, due largely to the high rate of pasture renovation on that farmlet, the levels of warm-season native grasses, which contribute little green herbage over the winter months, increased more over time on both farmlets B and C than on farmlet A. Over the duration of the experiment, 71% of the area of farmlet A was renovated with sown pastures whereas only 8% of each of farmlets B and C was renovated (Scott *et al*. 2013*c*). Regarding soil fertility changes, the target soil P and S levels were reached within the first 2 years of the experiment with farmlet A continuing to have higher levels of both nutrients than the other two farmlets over the latter 5 years of the experiment (Guppy *et al*. 2013). They reported that soil P and S levels were significantly positively correlated with changes in legume DM, green DDM and stocking rate.

In addition, the generally below-normal soil moisture conditions experienced during the trial (Behrendt *et al*. 2013) no doubt affected pastures and liveweights to varying degrees in different years. For example, relatively good seasons were experienced in the springs of 2001, 2003 and 2005 with much drier conditions experienced in the intervening years. The significant association between liveweights and pasture and grazing management covariates has helped to explain the reasons for the differences which arose. These insights point to the benefits of taking many parallel measurements during complex, agroecosystem experiments.

The within-year patterns of ewe liveweight were associated with changes in physiological status and are similar to those previously reported in different environments. For example others have reported maximum weights before lambing and gradual recovery post-weaning (Hinch *et al*. 1996; Ferguson *et al*. 2011). The likely impact of weights at the end of the recovery period on fertility and fecundity have been discussed by Ferguson *et al*. (2011). In general it would seem that, at joining, the differences between mean weights of the farmlets was up to 5 kg, which would be predicted to contribute to fecundity differences in the subsequent year of 10–15% in the number of twins. This issue is examined further in Hinch *et al*. (2013) but it is possible that an increased proportion of twins in farmlet A in some years may have contributed to the slightly higher mean liveweights on this farmlet in late pregnancy.

There is surprisingly little published evidence of patterns of weight change for various follower groups (weaners, wethers and ewe hoggets) of Merinos under various grazing management systems. Recent studies on weaners (Hocking Edwards *et al*. 2008; Hatcher *et al*. 2010) have examined in some detail the impact of managing liveweight to improve weaner survival but these studies did not address issues of grazing management. The data collected in this present study was not frequent enough to allow close examination of post-weaning growth rates, which have been linked to probability of weaner survival but weaner weight differences between the farmlets do not appear to have been great enough to have had implications for weaner survival, which was high across all farmlets and years.

In a study in South Australia, Brown (1976) reported consistent weight losses of wethers of ~2 kg at various stages of the year but little difference between set stocked and deferred (rotationally) managed flocks. In that winter rainfall environment, these losses usually occurred in the autumn. In contrast, in the present study, losses if they did occur (e.g. in 2003) occurred through late autumn and winter when quality and quantity of feed was reduced (Shakhane *et al*. 2013*a*).

In a Western Australian study, Marshall (1985) showed that Merino weaners and wether hoggets had a 'saw-tooth' growth pattern that was also observed in most years of the present study but with animals reaching 35–40 kg in the first year. In the present study, weights were a few kilograms lower than those reported by Marshall (1985) but this was possibly due to the fine wool background of the animals used; alternatively it may reflect poorer/more variable pasture conditions and this is supported by the large year-to-year variation in liveweights of the ewes.

The greater differential between hogget weights on the different farmlets may have been due to the much greater grazing rest period imposed on farmlet C stock, particularly in the drought year of 2002 when the grazing rest period was longest. Because of this difference in hogget weights in that year, grazing management on farmlet C was subsequently adjusted to restrict the length of the grazing rest period. Hoggets born in 2004 were similar in 18-month weight for all farmlets although farmlet A hoggets only caught up in the last 2 months of this phase, possibly reflecting the much higher number of 2004-born hoggets carried on farmlet A (260) compared with farmlets B (170) and C (150).

The Cicerone farmlet experiment has provided a unique overview, at a whole-farmlet scale, of the consequences on animal liveweights of either higher pasture inputs or of intensive rotational grazing compared with an otherwise typical management system. As shown by the detailed records of stocking rate, stocking density, grazed proportion and the duration of graze and rest periods, the three management systems resulted in significantly different animal liveweight profiles and consequently kilograms of liveweight per ha. While two of the farmlets (A and B) were quite similar in many respects, stocking rate increased markedly on farmlet A even though it reached its target of 15 dse/ha on only two brief occasions over the duration of the trial.

Farmlet C was dramatically different to the other two farmlets in terms of its grazing management, having much higher stocking densities on the much smaller proportion of the farmlet grazed at any one time and yet was not able to reach its target stocking rate of 15 dse/ha, ultimately settling down at a stocking rate which was no greater than that of farmlet B. This is consistent with the findings of Waller *et al*. (2001*a*) who found that stocking rate was much more affected by improvements to pastures and soil fertility than it was by grazing method. These authors explored tactical stocking compared with continuous grazing on two different pasture types in western Victoria: typical perennial pastures which received ~6 kg P/ha.year vs upgraded pastures which had been renovated and received 26 kg P/ha.year. The tactical stocking allowed a 9% increase in stocking rate whereas the upgraded pasture type supported a 51% increase in stocking rate. In the present study, the higher soil fertility treatment received an average of only 13.1 kg P/ha. year while farmlets B and C averaged 4.9 and 4.3 kg P/ha.year, respectively (Guppy *et al*. 2013).

Compared with continuous grazing, Waller *et al*. (2001*b*) found lower ewe liveweights under tactical stocking over spring and summer, which was linked to higher levels of pasture herbage mass but lower herbage quality in spring. The liveweights of the ewes were similar across all treatments during autumn and winter, but the tactically stocked ewes were 3–6 kg lighter than continuously stocked ewes during spring and summer. In terms of animal production, upgraded pastures resulted in a 56% increase in the total weight of lamb weaned per ha compared with an 11% increase due to tactical grazing management. They therefore recommended that grazing management be applied strategically rather than as an overall policy.

This is consistent with the findings of many other trials, which have demonstrated the positive effects of pasture and soil fertility on ewe and lamb liveweight (Robinson and Lazenby 1976; Curll 1977; Marshall 1985; Mears and Cullis 1993; Graham *et al*. 2003; Holst *et al*. 2006).

Waller *et al*. (2001*a*) found that lamb weaning weights were increased by increases in legume content. Also, as reported by Waller *et al*. (2001*b*), it is likely that differences in digestibility of the pastures, such as those measured on the three farmlets of the current experiment (Shakhane *et al*. 2013*a*), were potentially responsible for the differences in ewe and weaner liveweights. They found that green digestibility on farmlet A ranged from summer to early spring from ~60 to 75% whereas the range for both farmlets B and C was from ~50 to 65%.

As emphasised by Chapman *et al*. (2007), it is challenging to balance the quantity and quality of feed on offer to grazing animals. They pointed out that grazing animals and the management of grazing affect the pasture supply, including botanical composition; these pasture factors, in turn, affect dietary intake and animal performance.

Sheep liveweight gains and their wool production are known to be related to the amount of green herbage available and in particular to levels of green DM above 500 kg/ha (Hamilton 1975). It is well known that providing lactating ewes with sufficient quality feed is challenging. In an experiment in the UK, Penning *et al*. (1994) reported that lactating ewes with twin lambs under rotational grazing needed 1500 kg of green DM in order to maximise their intake; this level of green feed was only reached on the farmlets for just one brief period within one favourable season in spring–summer of 2005 (Shakhane *et al*. 2013*a*). Also, for pastures grazed at the same height of 60 mm, the continuously variable stocking treatment ewes maximised their intake while those on the rotational grazing treatments, with extended rest periods, were limited to about half that rate (Penning *et al*. 1994).

The low levels of legume measured in this farmlet experiment, which experienced generally drier than normal conditions (Behrendt *et al*. 2013), were lower than might be expected in higher rainfall years. The difficulty of measuring substantial amounts of legume were no doubt related to the observation made by McCaskill and Blair (1988) that, in dry seasons, legumes are consumed by the grazing animal before they are permitted to accumulate. Nevertheless, the consumption of small amounts of legume can contribute greatly to liveweight gain (McCaskill and Blair 1988).

In general, ruminant livestock exhibit a partial preference for clover compared with grass when grazing mixed pastures, while clover can result in an increased intake (Chapman *et al*. 2007). It is an aim of grassland management that the dietary preferences of grazing animals should be met in ways which result in high levels of animal production per ha (Chapman *et al*. 2007). Research conducted within the Sustainable Grazing Systems National Experiment found that the legume component of perennial pastures was increased by set stocking and soil P and that both these factors were significant contributors to higher stocking rates (Sanford *et al*. 2003).

As pointed out by Saul and Chapman (2002), there are 'trade-offs' between the proportion of legumes in a pasture and animal production, as legumes tend to be restricted under rotational grazing regimes. Nevertheless, they claimed that compared with continuous grazing, rotational grazing can improve per ha production, especially at high stocking rates. They also suggested that long-term comparisons should be undertaken, which would allow the systems under study to reach some sort of equilibrium. Unfortunately, due to funding constraints, the current experiment did not continue long enough to reach an equilibrium nor to experience one or more years of above-average rainfall. Under the conditions of the Cicerone farmlet experiment, intensive rotational grazing was not found to lift per ha production compared with flexible rotational grazing.

It has been found that cattle grazing rangelands in Oklahoma, USA, recorded lower weight gains under short-duration grazing than under continuous grazing, due primarily to the lower quality intake consumed by the steers under the short-duration grazing regime (McCollum and Gillen 1998). In a related publication, they reported that more frequent grazing periods were associated with higher and more stable levels of crude protein and digestibility than under systems with slower rotation intervals (McCollum *et al*. 1994).

These findings are consistent with those reported here; that is, that short grazing periods with a high stock density, resulted in lower liveweights, not only of sheep but also of cattle. This is presumably caused by the fact that, due to high stock densities, the animals on farmlet C were 'forced' to be less selective in their dietary intake and thereby consumed a diet of lower quality than animals which were given more opportunity for selectivity, such as on farmlets A and B. This suggests that, ideally, grazing animals need to be managed in such a way that they are able to choose an optimal diet, comprised of adequate quantity and quality.

The finding that the intensive rotation grazing system (farmlet C) did not lift stocking rates beyond those of farmlet B, is consistent with research published by Heitschmidt *et al*. (1987) who found that 'cell' grazing involving up to 42 paddocks, with short graze periods and long rests, neither resulted in higher herbage production nor higher stocking rates of cattle. They also found that aboveground net primary production was similar between different rotational grazing treatments.

In a study examining sustainable grazing systems on the Central Tablelands of NSW, Dowling *et al*. (2006) found that by applying P there was a corresponding increase in net growth rate, particularly when pastures were continuously grazed, with instances where net growth rate was significantly greater during the cooler months when available forage might be limiting (Curll 1977).

It is clear from the results reported here, that modifying the feed supply through pasture renovation and higher soil fertility (farmlet A) had a substantial positive effect on animal production compared with the typical management system of farmlet B. On the other hand, the hypothesis that intensive grazing management (farmlet C) would lead to increased animal productivity must be rejected both on per head and per ha performance. However, these conclusions need to be interpreted within the context of other related outcomes reported in complementary papers in this Special Issue including: internal parasites (Walkden-Brown *et al*. 2013), the balance between feed supply and animal demand (Shakhane *et al*. 2013*c*), fat scores and reproduction (Hinch *et al*. 2013), wool production and quality (Cottle *et al*. 2013), profitability (Scott *et al*. 2013*a*) and integrated outcomes (Scott *et al*. 2013*b*).

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