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Winter rotation length effect on pasture production and animal performance

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Abstract
Data comparing pasture production in winter pastures subject to 16, 48 or 72-day rotation lengths were recovered from experiments at Massey University to support teaching of grazing management. 'Farmlets' with 16 breeding ewes on 0.8 ha were run from 2011-2016, and herbage production estimated from metabolic energy budgeting (MEB). The data illustrate: the roles of pasture cover and animal body weight as buffers to neutralise the impact of weather variability, the use of controlled cover release via the grazing rotation to partially meet winter feed deficit, and the potential value of MEB in systems research. Grass grown from May to September (early pregnancy to mid-lactation) was 3850, 4220 and 4840 kg DM/ha for 16, 48 and 72-day rotations, respectively. As a result of a reduction in herbage accumulation and the premature release of autumn-saved pasture to animals, the 16-day rotation failed to overwinter the animals in five of the 6 years, the exception being a winter with high pasture growth.

Keywords: winter rotation length, pasture growth rate, teaching pedagogy

Introduction
The majority of sheep and beef farms in New Zealand manipulate the grazing rotation length to store autumn-grown feed as increased cover for release back to stock during periods of lower growth rates in winter. This winter management practice is often referred to as a 'controlled grazing system' (CGS) (Milligan 1981; Sheath *et al.* 1987). A key component of a CGS is the rationing of herbage intake of stock to levels that provide for body maintenance and pregnancy requirements, while retaining any pasture growth which is surplus to those requirements as standing herbage mass or 'cover'. Longer rotation lengths are achieved by keeping animals longer on a paddock during a grazing event and result in lower residual herbage mass after grazing. Paradoxically, even though herbage removal (kg DM/ha) is increased when the rotation is lengthened, individual animals consume less feed/head/day. This is because intake per animal is progressively reduced during successive days of a paddock grazing event as herbage height is lowered. Daily herbage intake of animals in a rotational grazing event can be monitored by calculating the herbage removed during grazing and dividing by the grazing intensity (animal. days/ha) (Matthews *et al.* 1999). Herbage consumption at a whole farm level (kg DM/ha/day) is thus determined by the stocking rate and rotation length.

The optimal rotation length depends on a range of site factors and so can vary greatly between farms. The key factor to plan rotation length is expected winter pasture growth rate; for a higher growth rate, increased stocking rate and decreased rotation length would be indicated and vice versa. Compared to set-stocked (continuously grazed) systems typically practiced in the middle of last century, a CGS allows more animals to be overwintered, enhancing farm carrying capacity and profitability. Little definitive research exists on the question of whether the higher stocking rate possible in a CGS than in a set-stocked wintering system arises simply from the reconciliation of mismatches in time between when the feed grows and when animals need it, or whether the longer grazing rotations in a CGS actually increase pasture growth rates.

To assist teaching of grazing management theory and practice at Massey University, a series of 'farmlets' have been maintained for about 25 years, where final year students working in a group create a small scale CGS on a block of 8 x 0.1 ha paddocks with electric fences for subdivision, running from early-May to late-September. Calculations on a per hectare basis are similar to those for a commercial farm. Typically, there are 5 or 8 student groups, each with their own farmlet. For 13 years (2004-2016), 2nd year veterinary students have also been provided with farmlets for the teaching of grazing management theory and metabolic energy based feed budgeting. Farmlet teaching for veterinary students has involved a comparison of outcomes for farmlets commencing with a common herbage mass on 1 May, stocked at 20 ewes/ha, and running 16, 48 or 72-day grazing rotation lengths until lambing in mid-August. Near the start of lambing, sheep are set-stocked until late September when they are weighed and the

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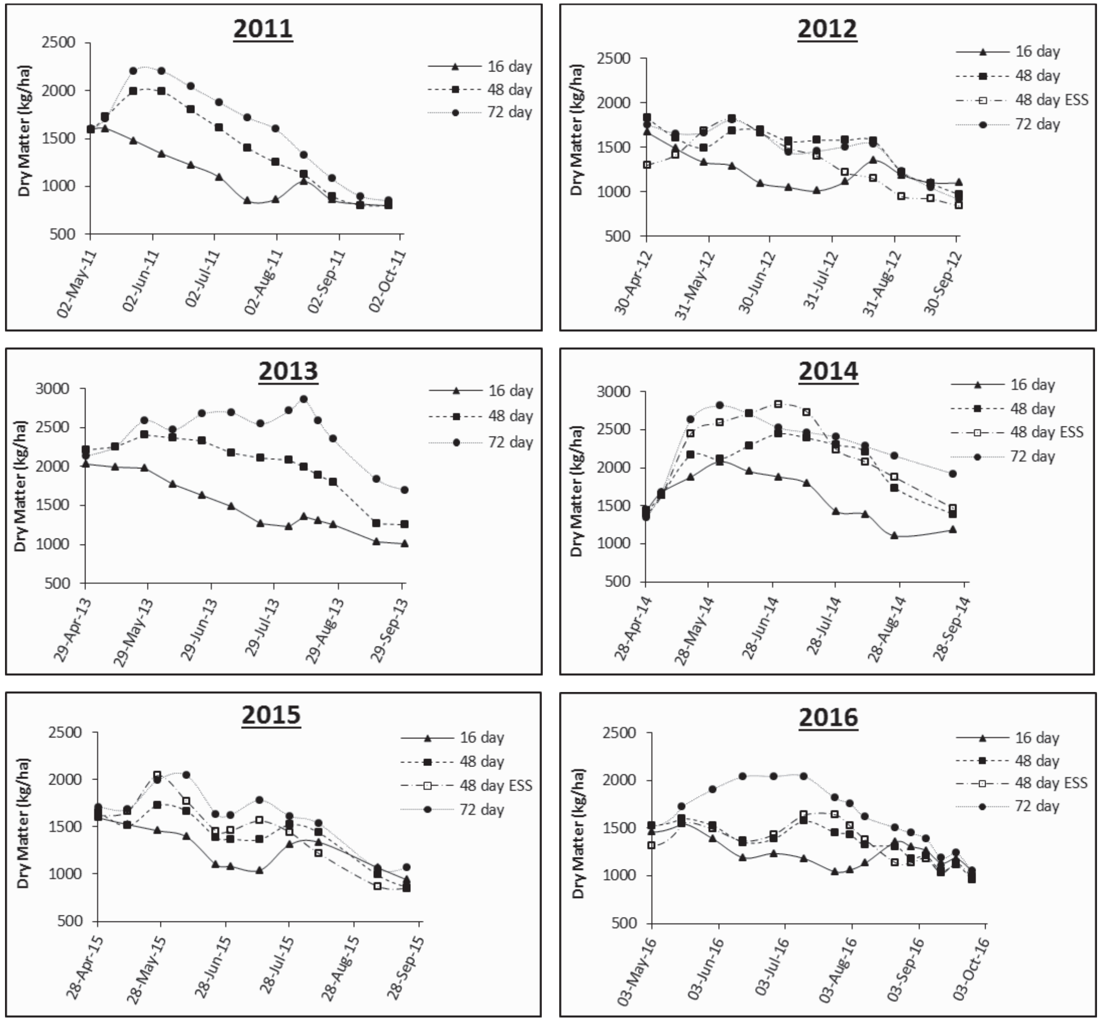

Figure 1 Pasture cover trajectories for farmlets with 16, 48 and 72-day rotations in 6 successive years. Different shapes in different years indicate system resilience to compensate for year to year weather variation. Falling cover from a peak in May or June indicates tactical release of stored feed to animals during winter feed deficit.

experiment terminated. Normally, two identical 48-day rotation farmlets are set up so one can be set-stocked early for lambing.

The primary objective of this paper was to present a time series of 6 years data from the veterinary teaching programme farmlets investigating the effect of rotation length on winter pasture growth rate. As animal weights and pasture herbage mass were monitored during the experiments, herbage harvested can be calculated by metabolic energy-based feed budgeting (Nicol & Brooks 2007). A secondary objective was to record anecdotal pedagogical data to facilitate the possible use of a farmlet methodology for teaching grazing management in other institutions.

Methods

Farmlet setup

The farmlets were located at the Massey University Pasture and Crop Research Unit (Lat. 40.38°S, Long. 175.62°E), on a flat to gently undulating terrace with a Tokomaru silt loam (Typic Fragiaqualf) soil type, Olsen P=44 mg/kg, and ryegrass-dominant (*Lolium perenne*) pastures with white clover (*Trifolium repens*), and a minor presence of some Poa species and herbs such as penny royal (*Mentha pulegium*). The 8-paddock farmlets were placed on the terrace to make them as similar as possible for factors expected to affect system performance, such as differing pasture botanical composition linked to microenvironment factors where topography or soil factors vary.

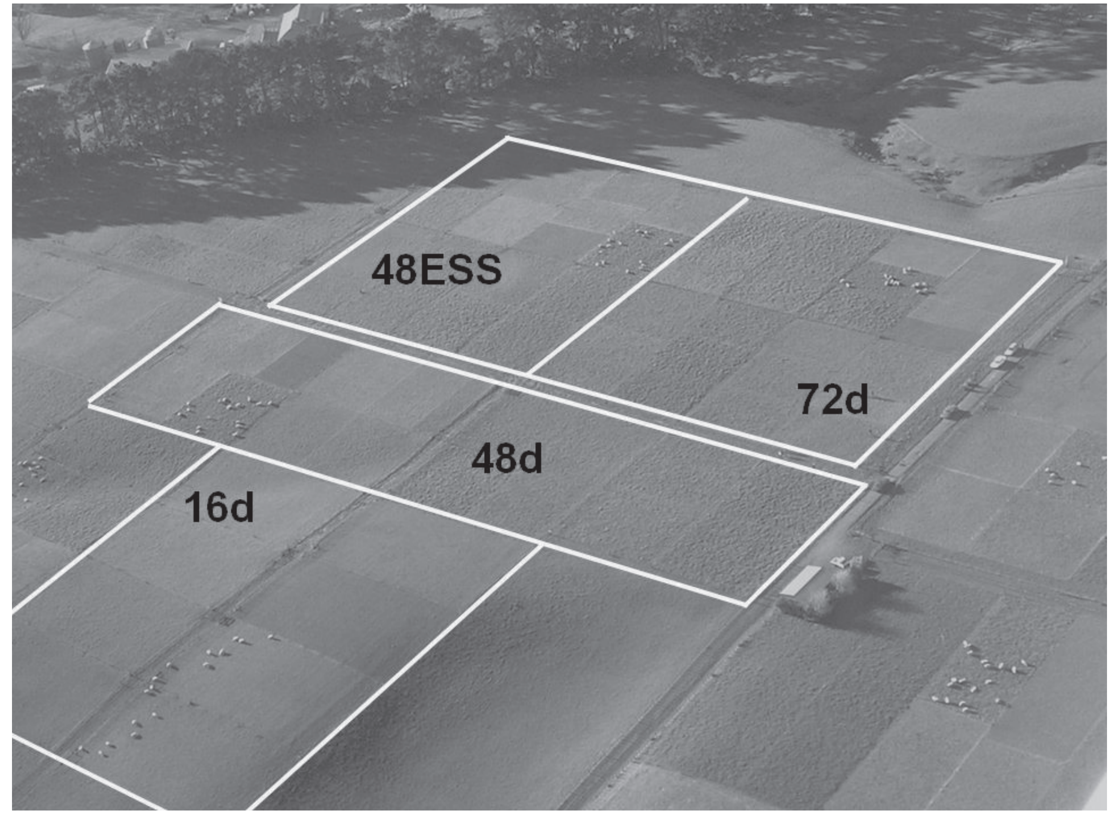

Figure 2 Aerial view of farmlets in early July 2004. The 16-day rotation was achieved with a 2 day grazing duration in each of the 8 paddocks. Sheep were temporarily spread over two paddocks to avoid treading after rain. The 48-day rotation was achieved with a 3 day grazing duration in each half paddock. The 72-day rotation was achieved with a 3 day grazing duration in each third of a paddock. Grazing intensities were 320, 960, and 1440 sheep.day/ha for 16, 48 and 72-day rotations, respectively. 48ESS was implemented in 2012 and 2014-2016.

A total of 6 farmlets have been used in the experiment from 2011-2016, and the four rotation length treatments were rotated between the 6 farmlets in a semi-random manner, so that in the course of the 6 years of data collection, each rotation length has been trialled on at least 3 different farmlets. Each 0.8 ha farmlet was stocked in the first week of May each year with 16 Romney-cross breeding ewes (weight range 60-65 kg, but in 2014 and 2015, 57-58 kg, following summer drought) and a common target start cover of about 1600 kg DM/ha (ranging from 1450-2030 kg DM/ha) (Figure 1), depending on summer-autumn pasture growth conditions. Ewes were mated from mid-March to early April, using a tupping crayon to detect early and late submission. Farmlet groups of 16 ewes were balanced for bodyweight and mating date each year. Husbandry details such as anthelmintic dosing, crutching, and vaccination followed normal farm practices. Ultrasound scanning was carried out in June each year and dry ewes replaced with a pregnant one. In all 6 years, the experiment included a 48-day rotation length, considered optimal for this site, and 16 and 72-day rotation lengths considered to be 'deliberate mistakes' that would overfeed and underfeed ewes, respectively, in early winter. During periods of unusually high rainfall, if treading damage to pasture was about to occur, sheep were moved to the next paddock a day sooner than scheduled. By way of context for the rotation length determination, a pasture growth rate of 15-20 kg DM/ha/day is typical in June and July, at this site. The rotation was transitioned to set-stocking by spreading sheep between paddocks on about 10 August each year, about a week before the start of lambing. In 2012 and 2014-2016 a second farmlet with a 48-day rotation (designated 48ESS) was included and set-stocked early, in late July, 3 weeks before lambing, to allocate remaining stored cover to sheep in late pregnancy rather than early lactation, as a third 'deliberate mistake'. Implementation of the four grazing rotation treatments is shown in Figure 2. Lower than normal pasture growth rates in some winters were corrected by application of urea fertiliser (30 kg N/ha in

2012 on all farmlets; 23 kg N/ha in 2015 on all farmlets; 37.5 kg N/ha in 2013 on the 16-day farmlet only; and 45 kg N/ha in 2016 on 16, 48-day and 48ESS farmlets, but not the 72-day farmlet).

Data collection and metabolic energy budgeting

Sheep were typically weighed about seven times during the experiment, using a Prattley sheep weighing crate fitted with either a TruTest model 702 or model XR3000 indicator. There was no weighing from late-July to mid-September to avoid stress on heavily pregnant ewes or ewes with lambs at foot. Pasture cover was measured fortnightly with a standard rising plate meter by an experienced operator alert to potential issues such as the meter shaft sinking more deeply into wet soils in winter; the equation "x140 + 400" was used to convert meter reading to kg DM/ha. Net pasture growth was assumed to equal herbage harvested by animals, which was inferred from the energy requirements of the sheep, determined using metabolic energy budget (MEB) feed calculations (Nicol & Brooks 2007; Matthew *et al.* 2010). In all, there were 18 feed budget calculations for the three rotation length treatments over 6 years and a further four feed budget calculations for the additional farmlet treatment that was set-stocked early in four of the 6 years (spreadsheet available from the authors on request).

Herbage metabolisable energy (ME) was assumed to increase gradually from 11.8 MJ/kg DM in May to 12.5 MJ/kg DM in September (based on occasional near infrared spectroscopy testing and personal communication from M.G. Lambert); pasture consumption by animals was inferred as (energy requirement of sheep) divided by herbage ME. Body maintenance requirements were assumed to be 0.6 MJ/kg$^{0.75}$, K_g as 45 and 30 MJ/kg liveweight gain for ewes and lambs, respectively, and energy recovery on ewe weight loss assumed to be 30 MJ/kg. For the cases where farmlets differed in N fertiliser application rate, a response to N of 10 kg DM/kg N was assumed, resulting in 375 kg DM/ha being deducted from modelled grass growth on the 2013 16-day farmlet and 450 kg DM/ha added to modelled grass growth on the 2016 72-day farmlet. The N fertiliser response was assumed to convert to lamb bodyweight at 1.375 kg lamb bodyweight/ha/kg N/ha, a conversion deduced by a metabolic energy calculation assuming 33% of feed energy in the system allocated to lamb growth, and production data were adjusted accordingly for those two cases.

Summary data for the 22 data points from the four grazing management regimes tested over the 6 years of data collection were subjected to ANOVA using the GLM command of Minitab version 10.51, with factors of Farmlet block (A-F), year (2011-2016) and, grazing rotation treatment (16-day, 48-day, 48ESS, 72-day). When Farmlet block was found to be non-significant for all but one summary statistic analysed, this term was removed from the model and a two factor GLM, testing for effect of year and grazing rotation treatment used to assess the data. Given that years served as replicates for grazing rotation treatments, a year x grazing treatment interaction was not included in the model and was in fact the error term for the model.

Results and Discussion

Farm system implications of rotation length

A key point of interest in any discussion about grazing management is whether the available options change the outcome by (i) compensating for variability in pasture growth rate, (ii) changing the timing of consumption of feed by stock, (iii) changing the quantity of feed consumed by stock, or (iv) the quality of feed consumed.

With respect to compensating for variability, pasture growth rate is subject to random year to year weather variation outside of a farmer's control. In this study May - September herbage accumulation averaged across rotation lengths ranged from 3830 kg DM/ha in 2011 to 5060 kg DM/ha in 2014, with 'low-growth' episodes of 1-3 weeks occurring in any of the 5 months from May to September. Ironically, the high winter growth in 2014 followed a severe summer drought, leading to low animal liveweight and pasture cover (Figure 1) at the start of the farmlet experiment in that year. Farm systems must be resilient to absorb weather variation; the variability of feed reserve accumulation and allocation between years in Figure 1 represents resiliency of the system to absorb the year to year weather variation. For example, use of stored cover commenced in June in 2011, but occurred mainly in August in 2013. Another resiliency factor in the system is ewe body weight. Across the 22 farmlet examples assessed, May to September change in ewe bodyweight ranged from -9.4 to +14.7 kg, which with MEB calculations equated to 1430 kg DM/ha buffering of feed supply variability. Accordingly, across the 22 farmlet examples, ewe liveweight loss over winter was strongly correlated with total herbage accumulation (R^2=0.682; P<0.001).

With respect to timing of feed release, the fall in cover between start and end points represents a feed reserve available to partially cover winter feed deficits in periods of low pasture growth. This results in more 'herbage consumed' in winter than was grown (Table 1), and the timing of release of this feed reserve was under the farmer's control through manipulation of rotation length. Figure 1 shows the accumulation of reserve feed in May at this site, except for 2012, and the timing of release of the reserve feed over the following winter and early spring. Compared to the 48-day

rotation, the 72-day rotation consistently built a greater reserve (through restricting herbage intakes of animals) (Figure 1), and moves distribution of the reserve feed until later in winter, whereas the 16-day rotation consistently allocated the reserve to animals in June and July (through allowing higher intakes to occur at that time). The question of timing of feed release has to be placed in context with animal status, the ewes being in late-pregnancy in late-July and lactating from late-August with requirements of approximately 1.8 and 2.5 kg DM/head/day, respectively. Hence, later release of the feed was a better fit to animal requirements. In this series of experiments early winter reserve allocation to animals via a 16-day rotation resulted in a need to supply additional feed (grazing off-farm or N fertiliser) in every year except the high growth winter of 2014 when stocking rate was also reduced to 17.5 ewes/ha to facilitate recovery from summer drought. Meanwhile the 'deliberate mistake' of early set-stocking saw a non-significant trend of reduced herbage accumulation after set-stocking (2070 kg DM/ha versus 1940 kg DM/ha, Table 1) that may have been biologically real, and a significant (P=0.051) reduction in lamb weight/ha compared to 48 and 72-day rotations (Table 1), which can be attributed to partial shift in allocation of reserve feed from early lactation when ewe energy requirement is higher to late pregnancy when requirement is lower.

With respect to effect of rotation on quantity of feed grown, assessment by MEB methodology revealed that in addition to differences in timing of reserve accumulation and release evident in Figure 1 and discussed above, there were also differences between the rotation lengths in herbage accumulation with the 72-day rotation averaging 26% more feed grown than the 16-day feed rotation, and 11% more feed grown than the average of the two 48-day rotations (P<0.001, Table 1). Comparing 48 and 72-day rotations, these differences changed ewe weight profiles (P=0.077), but not lamb production (Table 1). Comparing 72, 48 and 16-day rotations the drop in lamb production with reduced feed grown in the 16-day rotation was not significant, but it has to be borne in mind that the 16-day rotation required grazing off-farm or additional N fertiliser in five of the 6 years (not included in 'Herbage consumed' in Table 1), so lamb production costs were higher under the 16-day system.

Feed quality was not directly measured in these experiments, but a likely scenario is loss of herbage ME with longer regrowth interval in the 72-day rotation treatment. However, given that herbage accumulation for the 72-day rotation was greater than for the 48-day rotation, assuming a common ME in all rotations and

Table 1 Grazing rotation length effect on herbage grown (kg DM/ha), lamb numbers and weights, and ewe body weight change from May to September in farmlet systems imitating commercial lamb production. Difference between May to September total growth and herbage consumption reflects average cover decline (kg DM/ha) during the experiment. Growth periods: 1st 5 weeks - period of herbage storage; June/July - period of low herbage mass on the 16-day rotation; late-July onwards represents the set-stocked period; difference between total growth and herbage consumption reflects difference between starting and closing farmlet herbage mass.

	Grazing Rotation				P		SEM
	16-day	48-day	48ESS	72-day	Rot.	Yr.	Rot.*
Herbage DM (kg/ha)							
Growth 1st 5 weeks (May)	1040	1200	1468	1550	0.010	0.001	100
Growth Jun/Jul (7 weeks)	710	940	990	860	0.186	0.018	84
Growth from late July	2090	2070	1940	2420	0.090	NS	122
Growth: total May–September	3850	4220	4470	4840	<0.001	0.001	110
Herbage consumption	4640	5090	5060	5563	0.005	NS	143
Animal performance							
Lamb no. (mean 6 years)	19.0	20.8	19.3	21.0	0.120	0.002	0.67
Lamb weight (kg/head)	15.1#	14.7	14.1	15.1	NS	<0.001	0.29
Lamb weight (kg/ha)+	345	384	329	390	0.051	0.018	13.7
Ewe weight change (kg)	1.8	–2.5	0.3	3.4	0.077	<0.001	1.50

Abbreviations: P, probability; SEM, standard error of mean; 16 day, 48-day, 72-day denote rotation lengths; 48ESS, 48 day rotation set-stocked early; NS not significant

*Multiply SEM by 1.3 for grazing rotation 48ESS because only four of 6 years data were available.
#Inclusive of effect of additional feed supplementation required in late winter for animal welfare reasons in five of 6 years for 16-day rotation farmlets.
+Lamb weight at close of experiment in late-September each year.

lamb production/ha of the latter equalled that of the former, the herbage accumulation advantage of the 72-day rotation was underestimated in proportion to any loss of herbage quality, and the overall impact on animal performance of this rotation looks more positive than negative (Table 1).

Scientific insights

This pattern of herbage accumulation difference 72>48>16-day, would have been hard to predict from available literature, as alternative logical expectations can be developed from different historical studies. After farmlet setup in May, high residuals after grazing in the 16-day rotation (compared to longer rotation lengths) might have been expected to increase herbage accumulation (Chapman 2016), though in contrast to that there is known to be a period of low accumulation following defoliation (Matthew *et al.* 1991) and in set-stocked swards at lower herbage mass (Bircham & Hodgson 1983), and there is an old New Zealand farm extension adage "grass grows grass". Hence the present results support those studies that indicate loss of growth potential in ryegrass after defoliation, so that the more frequent the defoliation, the greater the herbage production loss, even at residual herbage mass after grazing as high as 1500 kg DM/ha. At the high herbage mass end of the spectrum, it is perhaps surprising that there was no evidence of loss of growth to senescence in the 72-day rotation, other than a non-significant trend in June/July growth (860 versus 990 kg DM/ha, Table 1). The leaf appearance interval in Palmerston North in the coldest months of July and August was around 13 days for 1 year of weather data analysed (Matthew *et al.* 2016), so on this basis the 72-day paddocks should have been at leaf stage six and incurring senescence losses (Fulkerson & Donaghy 2001). Even so, any increased senescence that did occur was not detectable in the farm system level data, and therefore must have been comparatively small.

From a system perspective, correlations between variables in Table 1 across the 22 farmlets considered in this study, indicated lamb liveweight/ha was most strongly linked to herbage accumulation after set-stocking (R^2=0.569; P=0.006), and increased numbers of lambs on a farmlet resulted in lower lamb liveweight/head (R^2= -0.519; P=0.013 after extraction of the spring growth effect).

A point for wider consideration from this data analysis is the consistency with which rankings for effect of rotation length on total herbage grown were detected by the MEB methodology across 6 years of experimentation, using just animal liveweight and pasture cover data, and with a coefficient of variation of under 3% (Table 1). This suggests the potential of MEB analysis in farm systems research is currently underutilised by the New Zealand pastoral industries.

Pedagogical comments

Grazing systems comprise multiple interacting factors and exhibit complex behaviour, meaning that mastering key concepts is a significant challenge to students who come to this topic without a farming background. Hence it is not automatic, that setting up a farmlet experiment will secure student engagement and understanding of systems principles. However, this mode of teaching grazing management provides experiential insight into the time dimension of grazing systems where today's decisions have future impacts on system outcomes. The farmlets facilitate visualisation of important concepts including the concept of feed storage as cover in periods of surplus for release in later deficit, and the counter-intuitive reality where less herbage is removed in a paddock grazing event in order for the animals to eat more/head/day in a short than in a long rotation. It is not uncommon to receive feedback such as: "because of the farmlet practical I understood what the farmer was telling me during my summer vacation practical work."

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