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The effect of grazing state on pasture quality and implications for the New Zealand Greenhouse gas inventory

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by V Burggraaf, D Stevens, R Vibart (Agresearch)

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Ministry for Primary Industries
PO Box 2526
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Client Report Number: RE450/2018/023

agresearch

āta mātai, mātai whetū

Contents

1. Executive Summary

The New Zealand national greenhouse gas (GHG) inventory uses values for predicted metabolisable energy (ME) and nitrogen (N) concentrations in pasture to calculate methane and nitrous oxide emissions by grazing livestock. The accuracy of emission estimates will be improved if the data used in the inventory reflect the quality of pasture grazed. Previous work has shown the effects of farm type and region and season on pasture quality, but little consideration has been made of the effect of grazing management. A literature review was undertaken to understand the impact of grazing management, in particular, grazing interval, on pasture quality and the interactions with pasture species, season, land slope and other drivers of pasture quality in a New Zealand context.

The key drivers of pasture quality are botanical composition, with legumes and herbs generally being higher quality than grasses, and morphological composition, with green leaf being higher quality than fibrous stem and dead material. Although ryegrass is the dominant pasture species, steep slopes can be dominated by grasses tolerant of lower fertility, such as browntop, and these tend to have lower N concentrations. Regional variation also exists, with lower quality subtropical grasses being an important component of pastures from Northland to Waikato and Bay of Plenty. The proportion of each of these pasture components varies across seasons, with the largest impact being an increase in stem material in late spring and over summer as most pasture species enter their reproductive phase of growth. The amount of dead material is influenced by leaf development rate and aging, and pasture utilisation. Temperature and soil fertility play a further influence on pasture ME and N contents.

The rate of decline in green leaf quality between grazings is affected by the time of year and climate. The rate of decline in quality is largely related to the rate of pasture growth. Once ryegrass tilllers have three live leaves the amount of dead matter increases and pasture quality declines. The time to reach this stage is approximately 3 to 4 weeks after grazing, but this varies across regions and seasons and with previous grazing intensity.

Grazing management alters pasture quality primarily through the severity (how much forage remains; residuals) and the frequency of grazing relative to the rate of pasture growth. Grazing to low residuals removes the poor quality dead material and stem and allows more light to the base of the pasture to encourage clover growth, whilst short intervals between grazings reduces the opportunity for dead material and reproductive stem to form before the next grazing. The impact of continuous versus rotational grazing on pasture quality is likely to have less impact than variability caused by grazing residuals and grazing intervals under rotational grazing.

The quality of the diet eaten by grazing animals depends on the quality of the pasture on offer, and selection of sward components that differ in quality. Cattle have less ability to be selective than sheep as cattle use their tongue to assist prehension, while sheep use their teeth. Both sheep and cattle will actively avoid dead material in the pasture, whilst clover and herbs are often selected in favour of grasses. Also, as grazing pressure increases (less feed availability), livestock graze further towards the base of the pasture, increasing the proportion of stem and dead matter consumed.

It is recommended that pasture analyses used for the GHG inventory should take into account regional and monthly variation, and be representative within farms within a region and amongst years. Currently, N% data are the same for every month of the year, whereas concentrations can drop by more than a quarter between early spring and late summer. Farms and paddocks sampled must reflect typical contours, botanical composition, grazing interval and severity, as all of these factors impact on predicted ME and N concentration. Under a rotational grazing management system pasture sample collection should be immediately before grazing, particularly in late spring and summer, when pasture quality declines rapidly.

Samples must also be collected to the height that the pasture will be grazed, to accurately represent the proportions of leaf, stem and dead matter consumed. Pastures sampled from sheep and beef farms need to take into account the variable nature of the topography, the type of livestock grazing and the target of the grazier at different times of the year. This will best be done using different sampling heights for different livestock classes at different times of the year, as detailed in Table 14.

2. Introduction

Ruminant livestock are a major source of the greenhouse gases (GHG) methane and nitrous oxide in New Zealand pastoral farming systems. Nitrous oxide is predominantly formed from nitrogen (N) in livestock urine (Jarvis 1997) and methane is produced as a by-product of fermentation of feed in the rumen. Urinary nitrogen excretion increases with increasing nitrogen concentration in the diet and increasing intake (Holmes *et al*. 2002), and methane production is positively correlated with intake. It would therefore appear that as N concentration in pasture increases and metabolisable energy (ME), decreases, GHG emissions from New Zealand livestock would increase.

New Zealand's GHG inventory uses monthly average values of pasture ME and N to calculate emissions from livestock (Bown *et al.* 2013). Separate values have been derived from published data for dairy and sheep and beef farms, due to dairy farms typically being on flatter contours with higher fertility soils than sheep and beef farms, resulting in different species composition, management, and nutritive value of the pastures. However, within each of these farming systems there are large variations in pasture quality within and across farms and regions, due to differences in climate, pasture species composition, contour and pasture management. In order to get accurate estimates of monthly average pasture ME and N, contributing data must take into account this variability within each farming region.

Further pasture samples are to be collected for some regions (Joel Gibbs, personal communication) to improve the accuracy of predicted ME and N data used in the GHG inventory. This review quantifies the impact of some of the key drivers of pasture quality so as to guide methodology for deriving accurate ME and N data to best represent material eaten. In particular, it assesses the magnitude of the impact of grazing interval (time since last grazing) on pasture quality for New Zealand dairy and sheep and beef pastures. It considers both continuous and rotational grazing systems and the interactions with forage species, land slope, and climate.

When collecting samples for assessing pasture quality, it is not only important to consider the variability in the pasture available, but also what components of the pasture grazing animals will preferentially select, so as to accurately represent the animals diet. Selective grazing is discussed, with its implications for how pasture samples collected reflect the intake of ME and N by grazing sheep and cattle. The implications of these factors on the collection and use of pasture quality data in the national GHG inventory are then considered.

3. Methods

The project team discussed the context of the literature review and how the information generated will be used with Ministry for Primary Industries (MPI) representatives (Joel Gibbs, George Strachan) on 1 March 2018. The authors then scoped out the review with a knowledge advisor and prepared a methodology and draft contents, approved by MPI on 7 March 2018.

AgResearch scientists in forage science, farm systems and environmental research were consulted to access relevant past reviews and unpublished reports related to pasture quality and the greenhouse gas inventory. Ian Brookes (Massey University) was contacted regarding ME values used for dairy pastures in the GHG inventory.

The scholarly journal databases BIOSIS, CAB Abstracts and SCOPUS were searched using a variety of related keywords by an experienced knowledge advisor. Further searches were conducted through the New Zealand Grassland Association and New Zealand Society of Animal Production publications and the DairyNZ website.

Relevant information was compiled in a partial draft report. Following this, industry expertise at Massey University (Prof. Peter Kemp, Head of School of Agriculture) was contacted for further relevant information to fill information gaps.

A draft full report was prepared and subjected to AgResearch's internal review process, with revisions incorporated. The report was then circulated to MPI and Garry Waghorn (independent external expert reviewer) in May 2018. The report was edited to incorporate suggestions from this review before this final report was submitted to MPI.

4. Findings

4.1 Pasture ME and N data in the national greenhouse gas inventory

4.1.1 Calculation of methane and nitrous oxide emissions

The New Zealand government is required to report on its GHG emissions on an annual basis to comply with international agreements. Livestock-driven methane emissions from enteric fermentation and soil-mediated nitrous oxide emissions from animal excreta, fertiliser and effluents make up the vast majority of New Zealand's agricultural GHG emissions.

Emissions of methane and nitrous oxide are calculated from estimates of livestock dry matter intake (DMI), assuming pasture is the sole component of the diet (Ministry for Primary Industries 2016). Livestock voluntary intake is determined by physiological demand for energy, feed supply, and ease of harvest, and is influenced by feed composition and quality. Estimated ME values and N concentrations of pasture change throughout the year, as described in later sections of this review.

The agricultural GHG inventory model uses estimated ME and N concentration of pasture to predict animal DM and N intake for dairy cattle, beef cattle, sheep and deer. In the model, ME is used as the sole indicator of forage quality, and intake is back-calculated from estimates of animal energy requirements and pasture ME values according to the following equation:

$$\text{DMI (kg/d)} = \text{ME required (MJ ME/d)} / \text{ME value of pasture (MJ ME/kg DM)}$$

Nitrogen intake is then calculated as:

$$\text{N intake (kg/d)} = [\text{pasture DMI (kg/d)} \times \text{N concentration in pasture (\%)}] / 100$$

Monthly DMI is calculated from the monthly mean ME value of pasture. This value is then multiplied by the monthly population of a particular livestock subcategory. This provides the basis for estimating enteric methane emissions and N excretion (in turn, allowing for nitrous oxide emission calculations, as explained below) by each livestock category, first by month and then by year. As a final step, by aggregating all livestock categories, the annual inventories of methane and nitrous oxide emissions are estimated (Ministry for Primary Industries 2016).

Following tier 2 methodology, most calculations of energy requirements are based on ME equations in the Australian feeding standards for livestock (CSIRO 1990), and pasture ME values used differ between months. Ian Brookes (personal communication) and Litherland *et al*. (2002), provided the ME values for pasture grazed by dairy, and sheep and beef animals, respectively (Appendices 3 and 9; Ministry for Primary Industries 2016). Consequently, national estimates of pasture quality, specifically ME and N concentration, underpin methane and nitrous oxide emission estimates.

Once DMI and population data are calculated, the amount of methane emitted per animal is based on methane emissions per unit of feed intake (g CH_4/kg DMI; emission factor, EF). Beef cattle use the same EF as dairy cattle (21.6 g CH_4/kg DMI) and deer use a value of 20.25 g CH_4/kg DMI (Ministry for the Environment 2018). For sheep, two separate non-linear equations are used, depending on their age (Ministry for the Environment 2018). The amount of nitrous oxide generated from livestock manure requires N excreta calculations for each livestock subcategory (Ministry for Primary Industries 2016).

4.1.2 Values of ME and N in the GHG inventory

There is no comprehensive and published dataset on ME values of pasture dating back to 1990 (Clark *et al.* 2003). ME values of sheep and beef pastures used in the GHG inventory originate from hand-plucked herbage samples that simulated diet selection on commercial sheep and beef farms in four regions across New Zealand (Litherland *et al.* 2002). Nineteen sheep and beef farmers in the Waikato, Tararua, Canterbury and Southland regions collected pre-grazing herbage samples from autumn 2000 to autumn 2001. Although herbage samples were collected once a month (Litherland *et al*. 2002), mean values for autumn, winter, spring and summer seasons are reported in the National Inventory. Low estimated ME values for sheep and beef pastures in summer and autumn pasture were attributed to a high proportion of dead tissue and reproductive stems in the swards (Litherland *et al*. 2002).

Ian Brookes (personal communication) provided pre-grazing ME values of dairy pastures. Monthly data were collected from 10 dairy farms in a 12-month study in 2001-2002 as part of a Massey University postgraduate study programme. Although not specified in the model, the assumption at the time of selecting these values was that samples were also collected in a way that simulated diet selection on commercial dairy farms (Clark *et al.* 2003).

Pasture N concentrations from published and unpublished research were included in a database that contained about 6000 pasture samples analysed by a commercial laboratory (2638 sheep and beef and 4198 dairy pasture samples) collected from 1992 to 1999. Data originate from farms in 16 regions of New Zealand (Ledgard *et al*. 2002).

Although the GHG inventory is based on annual average N concentrations of 3.7% of DM for dairy and 3.0% of DM for sheep and beef pastures, the original analysis identified pasture N concentrations by month, region and topography (slope).

Table 1. Monthly metabolisable energy (ME; MJ/kg DM) values and nitrogen (N; % of DM) concentration of dairy and sheep and beef pastures used for calcuations in the agricultural greenhouse gas inventory. From Ian Brookes, Personal Communication, Litherland *et al*. (2002) and Ledgard *et al*. (2002). Note, dairy ME values have been rounded.

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
DAIRY												
ME	12.6	11.5	11.7	12.0	11.6	10.8	11.1	10.6	10.7	11.3	11.9	11.7
N	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
SHEEP AND BEEF												
ME	10.8	10.8	11.4	11.4	11.4	9.9	9.9	9.9	9.6	9.6	9.6	10.8
N	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

4.2 Drivers of pasture quality

Metabolisable energy (ME) is the most commonly used indicator of feeding value in New Zealand farm systems, representing the energy derived from digestion and absorption of nutrients. It is calculated from the energy in feed eaten (gross energy), less the energy lost in faeces, urine and methane (Waghorn and Clark 2004). The major under-pinning driver of metabolisable energy is the ratio of the digestible cell contents and less digestible cell wall (fibre) of the herbage, and the chemistry of the cell wall itself. ME is not a measured value. It is calculated from chemical composition and digestibility data, often predicted using Near Infrared Spectroscopy (NIRS; Corson *et al*. 1999), and to a lesser extent by assuming 18% of digestible energy is lost to methane and urine during digestion (Waghorn 2007).

The protein content of forages is typically expressed as crude protein, and is derived by measuring the total nitrogen concentration and multiplying this value by 6.25. The values for crude protein may be as low as 10% of dry matter (DM) in senescent ryegrass to 30% of DM in fertilised pasture and legumes (Waghorn 2007).

ME values and N concentrations are influenced by a complex interaction of factors. The most important are the relative proportion of legumes, herbs and grasses and their relative proportions of leaf, stem and dead material. The age of the herbage and the temperature prevailing during the growth of the herbage affect the proportion of these factors as well as the quality of these components. Nitrogen fertiliser can also increase plant N concentrations (Shepherd and Lucci 2013) and affect species composition. Grazing management affects plant species composition and the proportion of leaf, stem and dead matter, through the effects of selective grazing and competition for light.

4.3 Pasture composition effects on feed quality

4.3.1 Drivers of pasture composition and its effect on pasture quality

The proportions of different pasture species (botanical composition) is affected by soil fertility, climate, and management. Different species have different abilities to compete for soil nutrients and grow under nutrient limitations, with legume content generally increasing with improved trace element status (Lambert and Litherland 2000) and nitrogen influencing the proportion of legumes and grasses (Scott *et al*. 1985). Pasture species also differ in their growth rate under different temperatures and levels of soil moisture. These differences in optimal conditions for growth result in changing proportions in pasture species across seasons and across and within farms (Figure 2).

Grasses typically make up 60-85% of DM intake for most ruminants (Waghorn and Barry 1987). Pastures, growing on hill and high country may contain a high proportion of poor quality pasture species such as browntop. Dairy pastures and more gently sloping sheep and beef pastures are dominated by perennial ryegrass, typically with varying proportions of white clover, but may include other grasses, legumes herbaceous species and weeds.

Most temperate grass species are of similar nutritive value if compared at the same stage of maturity. Cocksfoot is an exception, having a lower digestibility leaf than other species (Barker *et al*. 1993). Similarly, tetraploid ryegrasses are typically of better nutritive value than the more typical diploid ryegrasses (Lambert and Litherland 2000). Legumes and herbs typically have higher ME values and N concentrations than grasses (Table 2; Holmes *et al*. 2002).

Northland pastures are dominated by temperate grasses from winter into early summer and the subtropical grasses, kikuyu and paspalum, from mid-summer into autumn. Subtropical grasses are also a major component of pastures as far south as Waikato and the Bay of Plenty. Studies of nutritive value of subtropical grasses in New Zealand generally show higher levels of structural fibre and lower levels of protein, ME and digestibility than in companion temperate grasses (Crush and Rowarth 2007).

Table 2. Typical metabolisable energy (ME) values and crude protein (N x 6.25) concentration of commonly used pasture species. Adapted from Holmes *et al*. (2002) and DairyNZ (2017). Note these values are obtained from various locations and experiments and will vary across seasons, locations, cultivars and management.

Pasture species	ME (MJ/kg DM)	Crude protein (% of DM)
Grass/clover pasture		
Spring, immature	12.0	25
Late spring, leafy	11.0	20
Summer, leafy	10.0	18
Summer, dry and stalky	9.0	14
Autumn	11.8	30
Winter	11.0	24
'Tama' annual ryegrass	12.0	21
Kikuyu	9.8	16
Paspalum	9.8	14
Red clover	12.0	27
White clover	12.0	27
Chicory	11.7	23

4.3.2 Effect of plant maturity on plant morphology and feed quality

The development and life-cycle of leaves and stems determines the effect of grazing interval on pasture quality. Once leaves have reached their final size they remain on the plant for a period, then senesce, die and decay. The time span of this process depends on plant species, time of year and climate (Korte *et al*. 1987). In spring, the majority of pasture species enter their reproductive phase of growth. Vegetative growth consists mainly of leaf and sheath whereas with reproductive growth, stem elongation increases the proportion of stem to leaf (Wilman *et al*. 1976). Depending on the botanical composition and location, reproductive growth can occur from late October to late February in New Zealand.

The digestibility of stem and dead matter is lower than that of green leaf (Table 3) and is overall lower in older material. Most legumes maintain a high proportion of leaf to stem as they mature, and the digestibility of the leaf is also better maintained than for grasses. This is particularly so for the most dominant legume, white clover, which does not produce true stem, and less so for other more erect legumes such as lucerne and red clover which do produce true stem (Waghorn and Barry 1987). ME is typically calculated based on predicted digestibility (Waghorn and Clark 2004). High values for ME and N% are reported for herbage that is composed of predominantly young and growing tissue and where leaf and clover proportions are high and dead content low (Tables 4, 5, 6).

Table 3. Metabolisable energy (ME) of ryegrass plant components. From Kay *et al*. (2014). Note, source of data not described, use with caution.

	Green leaf	Soft stem	Hard mature stem	Dead material
ME (MJ/kg DM)	10.5-12.5	10.0-11.0	6.5	6.5

Table 4. Change in ME, protein and non-protein nitrogen of perennial ryegrass at different stages of maturity (Waghorn and Barry 1987).

	Young leafy	Old leafy	Seed head emergence	Seed set
ME (MJ/kg DM)	12	11	11	9
True protein (% of DM)	15	12	11	6
Non protein nitrogen (% of DM)	4	4	3	3

4.3.3 Effects of grazing management on pasture composition and quality

Frequently and/or intensely grazed pastures will have a greater proportion of young and actively growing plant tissue than pastures that are less frequently and more leniently grazed, and thus their ME content and N% would be expected to be higher. Conversely, prolonged grazing intervals and lax grazing increase the proportion of stem and dead material in the pasture (Table 4), with a concomitant decrease in ME values and N%. The increase in proportion of stem is most marked during reproductive growth (Korte *et al*. 1982; 1984, Butler 1986). The decline in pasture quality is most marked in grasses (Table 5), with legumes maintaining quality better as grazing intervals increase (Table 6).

Defoliation frequency and intensity also affects pasture botanical composition. Under infrequent defoliation, erect species such as grasses are able to grow taller and thus shade and suppress more prostrate species such as clovers, whereas under frequent defoliation the competitive advantage of the erect species is lessened and the more prostrate species such as white clover may dominate the sward (Brougham 1959, Brougham 1960, Vickery 1981). Creeping grasses, such as browntop, can also dominate swards when closely grazed on a regular basis (Hay and Baxter 1989), but may be suppressed by intensive cattle grazing due to treading. Conflicting reports on the effects of defoliation regime on the relative competitive abilities of pasture species (Baines *et al.* 1983, Grieshaber-Otto 1984) are attributed to interactions between soil type and fertility, pasture species present (Grieshaber-Otto 1984) and livestock species.

Grazing intensity can also influence the dominance of subtropical versus temperate grasses. Lax grazing in spring decreases paspalum relative to ryegrass, whereas hard grazing in spring has the opposite effect (Campbell *et al*. 1996). Hard grazing in summer with cattle may increase the proportion of paspalum as a result of ryegrass death through removal of plants by the roots by grazing (Baars *et al*. 1979). Intensive grazing of kikuyu during April-May is necessary to switch composition to temperate species dominance in June (Campbell *et al*. 1996).

Table 5. Changing proportion of ryegrass components and whole plant metabolisable energy (ME; MJ/kg DM) from spring to autumn with increasing harvest interval. From Waghorn and Barry (1987).

	Harvest interval (weeks)						
	2	4	6	8	10	12	14
DM distribution (%)							
Green leaf	82	63	37	25	15	8	4
Dead leaf	0	0	3	6	8	11	14
Stem	18	37	57	63	67	65	64
Flower	0	0	3	6	10	16	18
DM digestibility (%)							
Green leaf	64	66	65	61	65	61	58
Dead leaf	-	-	-	52	44	49	47
Stem	64	68	63	62	59	57	49
Flower	-	-	-	65	62	65	63
ME (Whole plant)	12.0	11.5	11.0	10.5	10.1	9.6	9.2

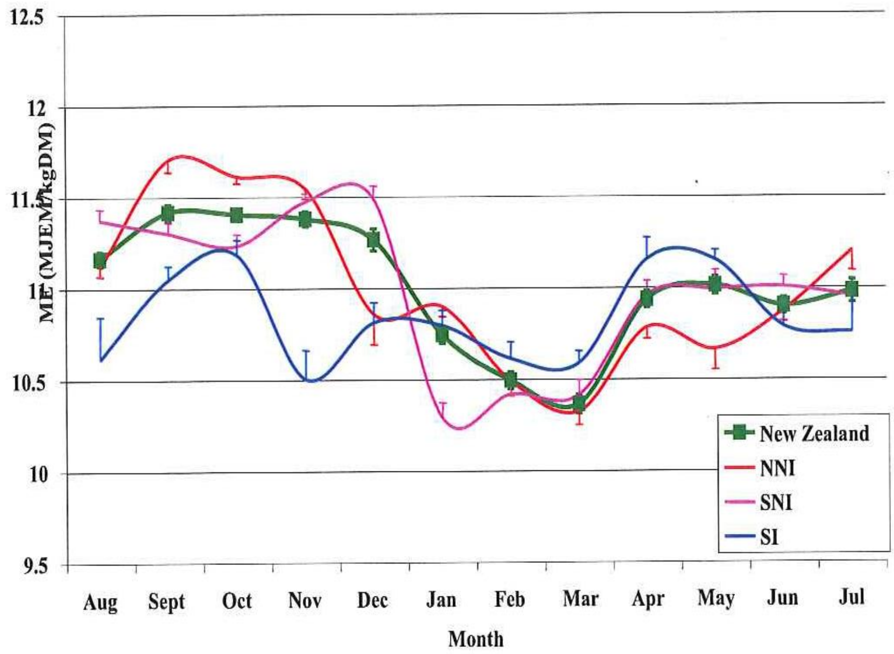
Table 6. Change in metabolisable energy (ME: MJ/kg DM) of white clover and Lucerne with different cutting intervals during flowering. From Waghorn and Barry (1987).

	Harvest interval (weeks)					
	3	5	7	9	11	13
White clover	12.6	12.2	12.0	11.5	11.2	10.6
Lucerne	12.0	11.5	11.0	10.7	10.5	10.3

4.4 Climatic, seasonal and regional effects on pasture quality

There is variation amongst regions (Figure 1) in pasture quality, primarily due to variation in rainfall and temperature. Variation is also influenced by the dominance of different pasture species. For example, in dry, warm climates, subtropical grass species (e.g. kikuyu, paspalum) can form a large proportion of the pasture in summer. Also, in cooler, drier regions and in hill country, alternatives to ryegrass may be used, such as cocksfoot and tall fescue (Bown *et al*. 2013). Upsdell *et al*. (2017) reviewed New Zealand data on ME values and N concentrations in pastures and showed the variation between regions was less than the variation across land grazed by different stock classes (dairy, sheep, beef, deer) and across sites within regions. Some of the variation reported across regions is therefore likely an interaction between climate, soils, land contour and the stock classes and management used.

Metabolisable energy



Crude protein

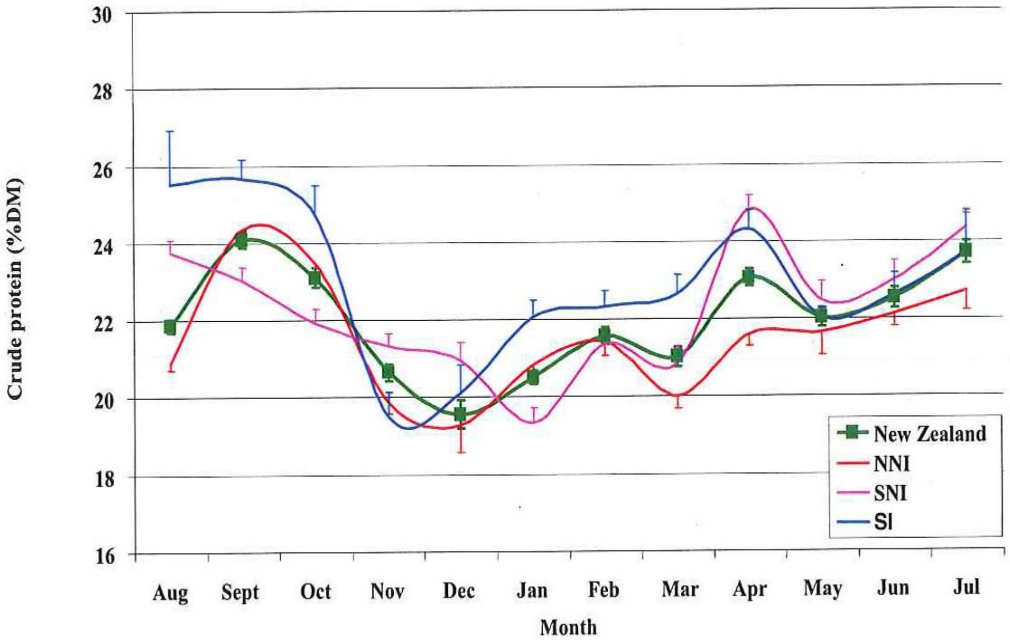


Figure 1. Monthly predicted metabolisable energy values and crude protein (B) concentrations of pasture tested north of Taupo (NNI), southern North Island (SNI) and the South Island (SI). Data include approximately 1500 to 2600 samples per region. From Litherland and Lambert (2007).

Within a given location, the quality of a pasture also varies over the year due to plant maturity and changes in pasture botanical composition (Figure 2). ME values and N concentrations typically start to rise in autumn, after sufficient rain to reduce the proportion of dead matter, peaking in spring, then begin to decline from November, as the dominant species begin their reproductive phase of growth. Lowest values occur in February/March. When comparing regions, there is an earlier decline in pasture quality in warmer, than cooler regions, with lower minimum values for ME and N in hot, dry summer (Figures 1 and 2).

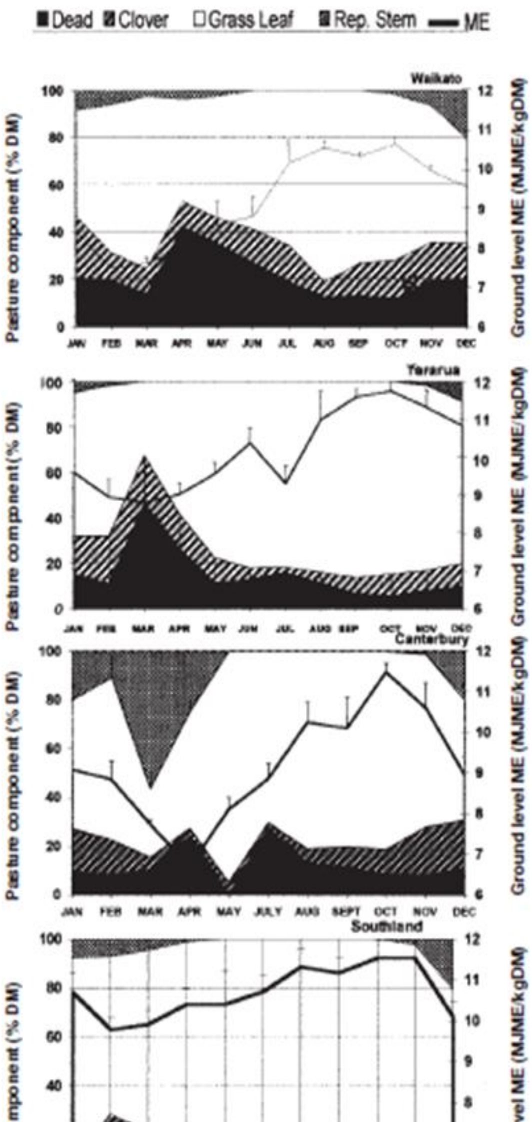


Figure 2. Seasonal variation in predicted ME values and percentage of dead, clover, grass leaf and grass reproductive stem (Rep. Stem) on commercial sheep and beef farms in four regions of New Zealand from autumn 2000 to autumn 2001. From Litherland *et al*. (2002).

Pasture nutritive value drops as temperatures increase, caused by increased lignification of cell walls, an increased proportion of cell wall to cell contents and an increase in stem relative to leaf. Hence in warm conditions, even leafy pastures that have not been grazed for long periods are of lower nutritive value than those grazed more frequently (Buxton and Mertens 1995). The decline in ME is 0.03 MJ/kg DM/day for grass leaf and 0.06 MJ/kg DM/day for grass stem at a daily maximum of 18°C. The rate of decline is negligible when temperatures are less than 12°C, which is the case for much of New Zealand in winter (Lambert and Litherland 2000).

Drought will reduce ME values and N concentrations, but dry (brown) pasture is of higher quality than dead matter caused by aging (Lambert and Litherland 2000). Hence variability in pasture quality across a given year is more pronounced in regions where temperatures are high and summer soil moisture deficits occur.

4.5 Effect of hill slope and aspect on pasture quality

Pastoral farming in New Zealand covers a range of landscapes, with the flattest land dominated by dairy farming and hill country dominated by sheep and beef farming. Hill and high country may contain a high proportion of grasses tolerant of low fertility, such as browntop, which is of low nutritive value relative to improved species such as ryegrass. Flat land tends to be dominated by ryegrass, typically in association with white clover (Waghorn and Clark 2004).

Hill country contains a mosaic of slopes in any one paddock. These may include the benched stock tracks seen in very steep paddocks, or a general mix of slopes within a single paddock. As animals graze a heterogeneous landscape with different slopes there is a general transfer of soil nutrients from steeper slopes to flatter slopes (Stevens and Turner 1990) and from exposed to sheltered aspects (King *et al*. 2011), associated with the proportion of time spent grazing or resting on different parts of the landscape. Also, fertiliser application is easier on flatter land, hence soil fertility is generally lower on hill country.

The soil moisture content is also often higher on the flatter areas of a given paddock. This, along with the transfer of nutrients by grazing animals, leads to declining pasture growth rates as slope increases. Botanical composition will vary across different degrees of slope but will also depend on grazing intensity, soil moisture deficit and soil fertility. The impacts of aspect on pasture growth are less pronounced and vary across climates and locations, with more dead matter possible on northerly aspects in dry summers.

ME and N can be assumed to decline with increasing slope because of reported increases in the ratio of poor fertility tolerant grasses (e.g.browntop) to ryegrass, with increasing degree of slope (Figure 3; Lambert *et al*. 1986). The effects of increasing slope are also greater than the effect of changing aspect on pasture composition (Figure 3).

Pasture sampled from sheep and beef farms in autumn has shown decreasing N concentrations with increasing slope, as demonstrated by the mean in Table 7. However, there were some exceptions to this within farms, and this was explained by the effect of pasture species present at the sampling sites (Ledgard *et al*. 2002). For example, Low N concentrations on some flat sites in Taumaranui coincided with a higher browntop content in those pastures, whilst ryegrass was more dominant on the rolling and easy sloping sites of those farms.

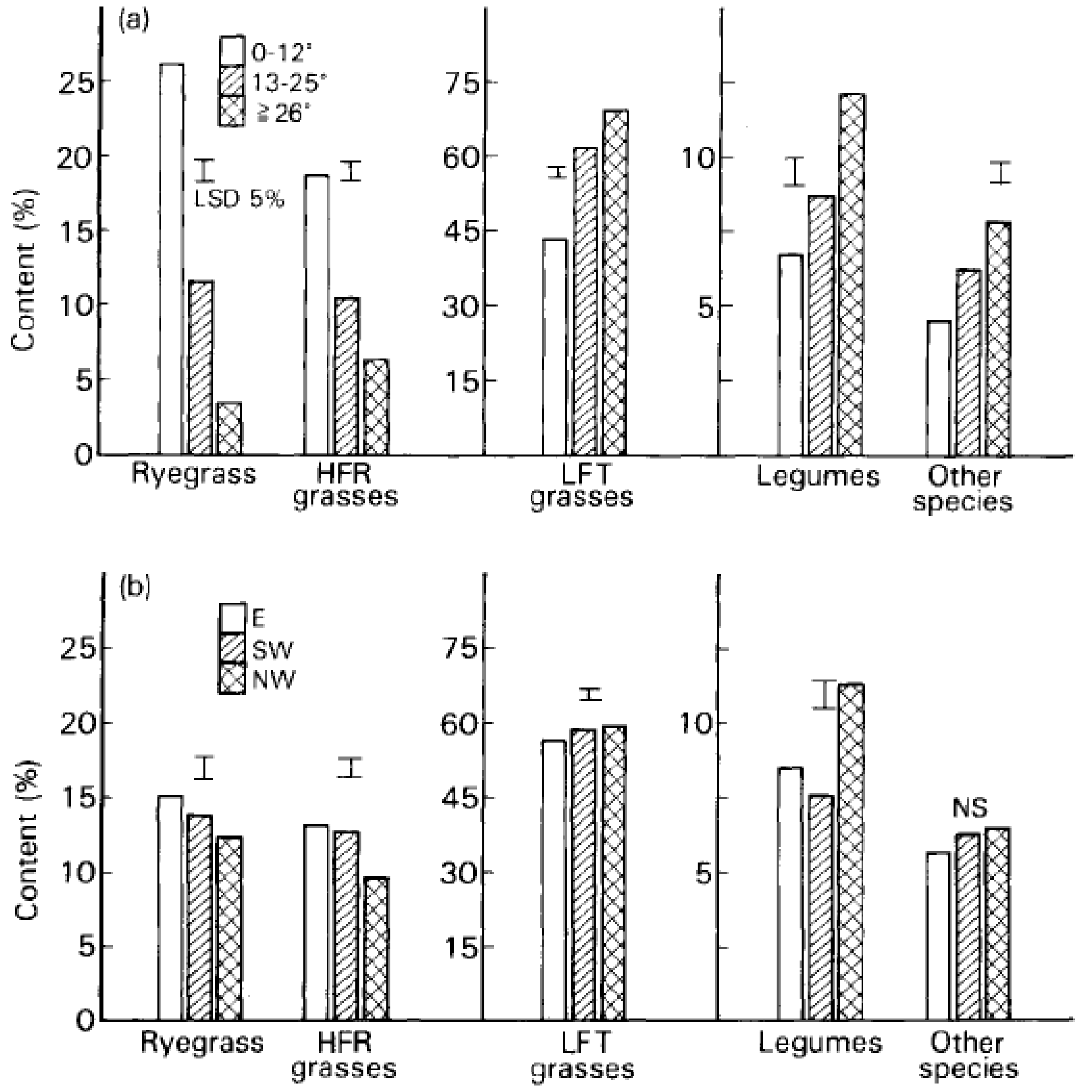


Figure 3. Effect of degree of slope (a) and aspect (b) on the content (% of DM) of ryegrass, HFR (grasses other than ryegrass that dominate high fertiity pasture), LFR (grasses tolerant of low fertility and typically of low feed quality), legumes (clover species and lotus) and other species (weeds) at Ballantrae, near Palmerston North. From Lambert *et al*. (1986).

Table 7. Nitrogen concentration (% of DM) in pasture samples collected in autumn 2002 from "average" sheep and beef farms throughout New Zealand. From Ledgard *et al*. (2002). Sampling height not reported.

		Slope			
Region	**Location**	**Flat (0-5º)**	**Rolling (5-10º)**	**Easy (11-20º)**	**Steep (>20º)**
King Country	Taumarunui	3.34	3.74	3.88	3.09
		3.4	3.53	3.36	3.49
		3.66	3.67	3.75	2.71
		4.1	3.99	3.66	2.63
		3.56	3.38	3.15	3.05
		3.27	3.15	2.37	1.81
	Mean	**3.56**	**3.58**	**3.36**	**2.80**
Gisborne	E. Coast		4.54	3.24	2.86
			3.89	3.50	1.39
Canterbury	Tara Hills	0.93			0.45
high country					0.67
Canterbury	Methven	4.29	3.49	3.13	2.69
foothills		3.21	3.21	3.34	4.45
		3.44	2.72	2.58	2.66
			2.63	2.83	
			3.47	2.94	
North Otago	Ranfurly	3.41	2.11		1.63
Central Otago	Alexandra		2.44		2.02
			3.6		
East Otago	Milton	3.97	2.91		
		2.31	2.78		1.95
Central Southland	Dipton	2.83			
		3.72			
East Southland	Woodlands	4.14			
West Southland	Tuatapere	4.47			
		4.02			
Table mean		**3.45**	**3.29**	**3.21**	**2.35**

4.6 Effect of grazing management on pasture quality

4.6.1 Principles of grazing management

Optimal grazing management is a balance between the changing rate of pasture growth throughout the year and changing animal demands, depending on their age and physiological state. This variation in supply and demand of pasture during the year results in changes in grazing frequency and severity throughout the year. The complexities around managing changing feed supply and demand means that pastures are often not grazed in an optimal manner (Lambert *et al*. 2004).

Livestock mainly graze leaves, which have a life span in the order of weeks. The life span depends on plant species, season and climate (Korte *et al*. 1987). Unless leaves are harvested within this lifespan, they die and decay after reaching their final size. Grazing management seeks to create a balance between maintaining enough leaf area to allow photosynthesis to drive further pasture growth whilst minimising loss to death, so as to optimise intake of quality herbage by livestock (Parsons and Chapman 2000).

The two main types of grazing management are continuous grazing (or set-stocking) and rotational grazing. Continuous grazing is used at certain times on sheep, deer and beef farms, and is described further in section 4.7.5. Mobs of livestock are spread across the farm and remain in a given paddock for months at a time, with the number of animals intended to balance the supply and demand of pasture. With rotational grazing, any one paddock is part of the larger system the animals are grazing, with paddocks ranging from just grazed, to being grazed weeks or several months previously, depending on the rate of pasture growth. Dairy pastures are rotationally grazed, with a recommended pre-grazing herbage mass of 2.6 to 3.2 t DM/ha (Chapman 2014), down to a post-grazing pasture height of 3.5 to 4 cm in spring, 4.0 cm in summer and 3.5 cm again in late autumn/winter (McCarthy 2014).

Dairy farmers may enable pasture mass to exceed optimal levels in autumn/early winter to carry feed forward to late winter/early spring when calving begins and pasture growth rates are low. This may result in an accumulation of dead matter (Lambert *et al*. 2004), and hence a decline in pasture quality. Similarly, in spring, when pasture growth exceeds demand by animals, deferred grazing (missing one or more grazing rotations) can be used by sheep and beef farmers on a portion of the farm to enable shorter grazing intervals on the remainder of the farm, so as to maintain pasture quality. In practice this control is often not achieved (Devantier *et al*. 2017).

4.6.2 Impact of the three-leaf rotational grazing principle on pasture quality

The interaction between grazing interval and pasture quality will depend on the rate of pasture growth. Using the 3 leaf principle to manage grazing interval overcomes the variability in pasture growth rate within and between years and locations when setting grazing intervals and is widely recommended.

After grazing, ryegrass plants develop new leaves, and once there are 3 fully formed leaves, the oldest leaf begins to die. The optimal time to graze ryegrass to maximise growth and minimise senescence is between the 2 and 3 leaf stage. Increasing grazing intervals to graze ryegrass pastures after the three leaf stage reduces pasture quality, as older leaves begin to die (https://www.dairynz.co.nz/feed/pasture-management/assessing-and-allocating-pasture/leaf-stage/). Based on average temperatures, leaf appearance rates for each season for different regions are reported in Table 8. This demonstrates variability amongst regions and seasons exists in optimum grazing intervals and hence there will be differences in their rate of decline in quality after grazing. Minimum grazing intervals should allow for the full development of two new leaves. In winter, for example, this would average 26 days in Northland, but 90 days in the sourthern South Island.

Table 8. Time (days) for the development of one new perennial ryegrass leaf in regions across New Zealand (https://www.dairynz.co.nz/feed/pasture-management/assessing-and-allocating-pasture/leaf-stage/).

Region	Spring	Summer	Autumn	Winter
Northland	9 - 11	8 - 10	8 - 12	11 - 15
North Waikato	9 - 13	8 - 11	8 - 14	12 - 16
South Waikato	9 - 16	9 - 11	10 - 17	15 - 21
Bay of Plenty	9 - 15	8 - 11	8 - 16	12 - 21
Taranaki	9 - 15	10 - 12	10 - 17	15 - 18
Lower North Island	9 - 15	8 - 12	10 - 17	15 - 18
Upper South Island/Westland	9 - 15	10 - 12	10 - 17	16 - 21
Canterbury/North Otago	10 - 21	10 - 13	11 - 28	18 - 72
Southland/South Otago	11 - 21	10 - 13	12 - 28	18 - 72

Although perennial ryegrass is the dominant pasture species, tall fescue is used on some farms for improved summer/autumn growth. Perennial ryegrass and tall fescue were compared for feed quality at different leaf stages in dairy pastures in the Manawatu (Kaufononga *et al*. 2017). The ME content generally declined between the shortest defoliation interval (one-leaf stage) and the longest defoliation interval (three- or four-leaf stage) for both species across all seasons, except during flowering in the second year for ryegrass. Crude protein content declined with increasing leaf stage for both species in all seasons (Table 9). These changes demonstrate the universal application of the first principles that govern changes in feed quality across grass species.

Table 9. Herbage quality values (metabolisable energy, ME; crude protein, CP% of DM) of tall fescue (TF) and perennial ryegrass (PR) subjected to different defoliation timing (one-leaf stage, -1; two-leaf stage, -2; three-leaf stage, -3; four-leaf stage, -4). From Kaufononga *et al*. (2017). Samples were hand-plucked to heights of 5 or 8 cm above ground level (averages presented) from field plots.

Nutritive values	TF-1	TF-2	TF-4	PR-1	PR-2	PR-3	*P*-value
Flowering period[1]							
4 October–31 December 2013							
ME (MJ/kg DM)	10.7^{ab}	9.7^{bc}	9.6^{c}	11.2^{a}	11.2^{a}	9.3^{c}	$P < 0.001$
CP%	20.7^{a}	12.9^{b}	13.3^{b}	19.7^{a}	19.3^{a}	11.5^{b}	$P < 0.001$
Winter/spring							
1 May–30 September 2014							
ME (MJ/kg DM)	11.1^{b}	10.4^{c}	9.5^{d}	11.4^{a}	10.3^{c}	10.3^{c}	$P < 0.001$
CP (%)	32.2^{a}	28.8^{b}	24.5^{c}	27.6^{b}	23.6^{c}	22.9^{c}	$P < 0.001$
Flowering period[2]							
1 October–7 November 2014							
ME (MJ/kg DM)	11.7^{a}	11.5^{b}	9.6^{d}	11.7^{a}	11.3^{c}	11.7^{a}	$P < 0.001$
CP (%)	26.2^{a}	23.8^{b}	14.6^{d}	23.3^{b}	21.2^{c}	14.1^{d}	$P < 0.001$

Note: Means within columns/seasons having different superscripts are significantly different at $P < 0.05$.

4.6.3 Continuous versus rotational grazing

With set-stocking or continuous grazing, good pasture quality is maintained by high stocking rates and a high grazing pressure with frequent defoliation of individual plants. With low stocking rates, defoliation is reduced and as herbage mass increases, pasture quality declines (Figure 4) as a greater proportion of the pasture becomes mature or dead. Stem material builds up and the higher quality plant components are selectively grazed. Orr *et al*. (1998) showed that increasing the grazing pressure under continuous grazing by sheep, from average pasture heights of 7 cm down to 5 cm or 3 cm maintained pasture quality over summer, with respective organic matter digestibilities of 73, 78 and 82% of DM. Note that these were irrigated experimental ryegrass pastures, with quality higher than that on most commercial farms in summer.

At similar stocking rates, grazing rotations greater than three weeks resulted in less frequent defoliation than continuous grazing regimes (Chapman and Clark 1984), and hence a decline in quality of the sward on offer. The impact of continuous versus. rotational grazing will also depend on the pasture species. For example the higher ME of feed on offer under rotational than continuous grazing by sheep in Figure 4 over winter (average of 2 years) likely reflects the reduction of low-fertility grasses (e.g. browntop) in the second year of the experiment for rotationally grazed pastures (Clark *et al*. 1982).

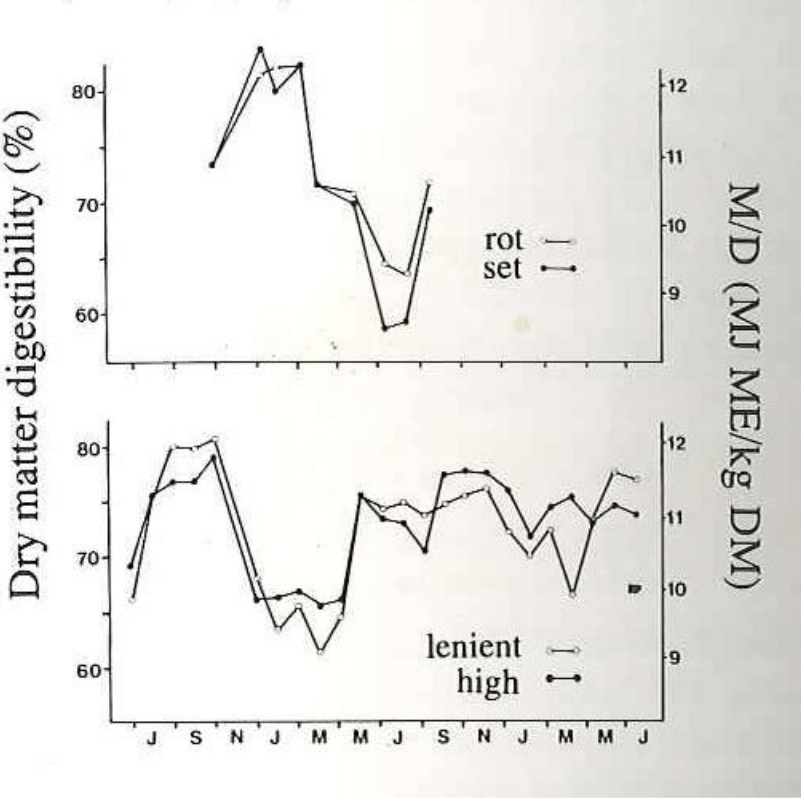


Figure 4. Annual variation in *in vitro* organic matter digestibility and predicted metabolisable energy values of pasture grazed by ewes under rotational grazing (rot) or continuous stocking (set) on hill country, and of calves under lenient or high grazing pressure in Palmerston North. From Waghorn and Barry (1987).

4.6.4 Effect of grazing interval

Grazing intervals typically reflect the rate of pasture growth, with long intervals in winter, when growth is slow and shorter periods between grazings during rapid growth in spring. Generally, as grazing intervals increase, plant tissue ages, with increasing proportions of dead matter (and stem material) and increasing proportions of cell wall to cell contents, resulting in reduced ME values and N concentrations.

Effect of grazing interval on dairy pastures in spring/summer

There is a rapid decline in dairy pasture quality in Waikato as the time after grazing increases in spring (Table 10; McGrath *et al*. 1998) and pasture mass increases. Pastures are typically grazed when mass reaches 2.5 to 3.5 t DM/ha, so data reported for samples collected after 5 weeks (for silage; Table 10) do not represent typical grazed pastures.

Table 10. Decline in crude protein (N x 6.25) concentration and metabolisable energy (ME) values and increase in dry matter yield during regrowth after grazing on a Waikato dairy farm in September and October (McGrath *et al*. 1998).

Pasture parameter	Time since grazed				
	3 weeks	5 weeks	7 weeks	9 weeks	SED
ME (MJ/kg DM)	12.0	11.3	10.8	10.3	0.06
Crude protein (% of DM)	20.9	15.1	12.6	10.4	0.48
Pasture mass (kg DM/ha)	2065	3315	4950	5930	0.06

Effect of grazing interval on sheep pastures in spring/summer

The effects of sheep grazing frequency and intensity on the mass of sward components was studied on ryegrass-based pastures in the Manawatu (Figure 5; Butler and Chu 1988). Grazing intensity (hard, medium and lax) at 14 day intervals, and frequency (regrowth intervals of 7, 14, 21 and 26 days at medium intensity (400 kg DM/ha post-grazing herbage mass) treatments were imposed over spring. Lax grazing and long grazing intervals increased the amount of reproductive stem during the treatment period and hard grazing reduced the amount of dead matter. During summer, after the treatment period, swards that had received lax grazing with long grazing intervals previously contained greater amounts of dead herbage. Although the actual quality was not measured, this can be estimated from the quality of ryegrass components reported in Table 3.

Autumn grazing intervals and nitrogen fertiliser

Manipulation of defoliation frequency and severity in late spring can affect summer and autumn pasture quality through minimising seedhead development. Most studies on grazing interval have been undertaken in spring. Effects of autumn grazing intervals are less pronounced. Martin *et al*. (2017) compared the N% and predicted digestible organic matter in dry matter (DOMD) of six forage species at four regrowth intervals and three nitrogen fertiliser regimes on a Canterbury dairy farm in autumn. N% in the DM increased with increasing nitrogen fertiliser application rates for grasses and herbs, but not legumes and predicted DOMD also increased under high N fertiliser rates. With increasing grazing intervals, predicted DOMD (Figure 6) increased throughout the 4 weeks and N% (Figure 7) increased for the first 2 weeks then dropped by week 4. At week 4 the grasses were at the third leaf stage, so leaf senescence did not occur, hence the herbage would have been green and leafy, maintaining good digestibility.

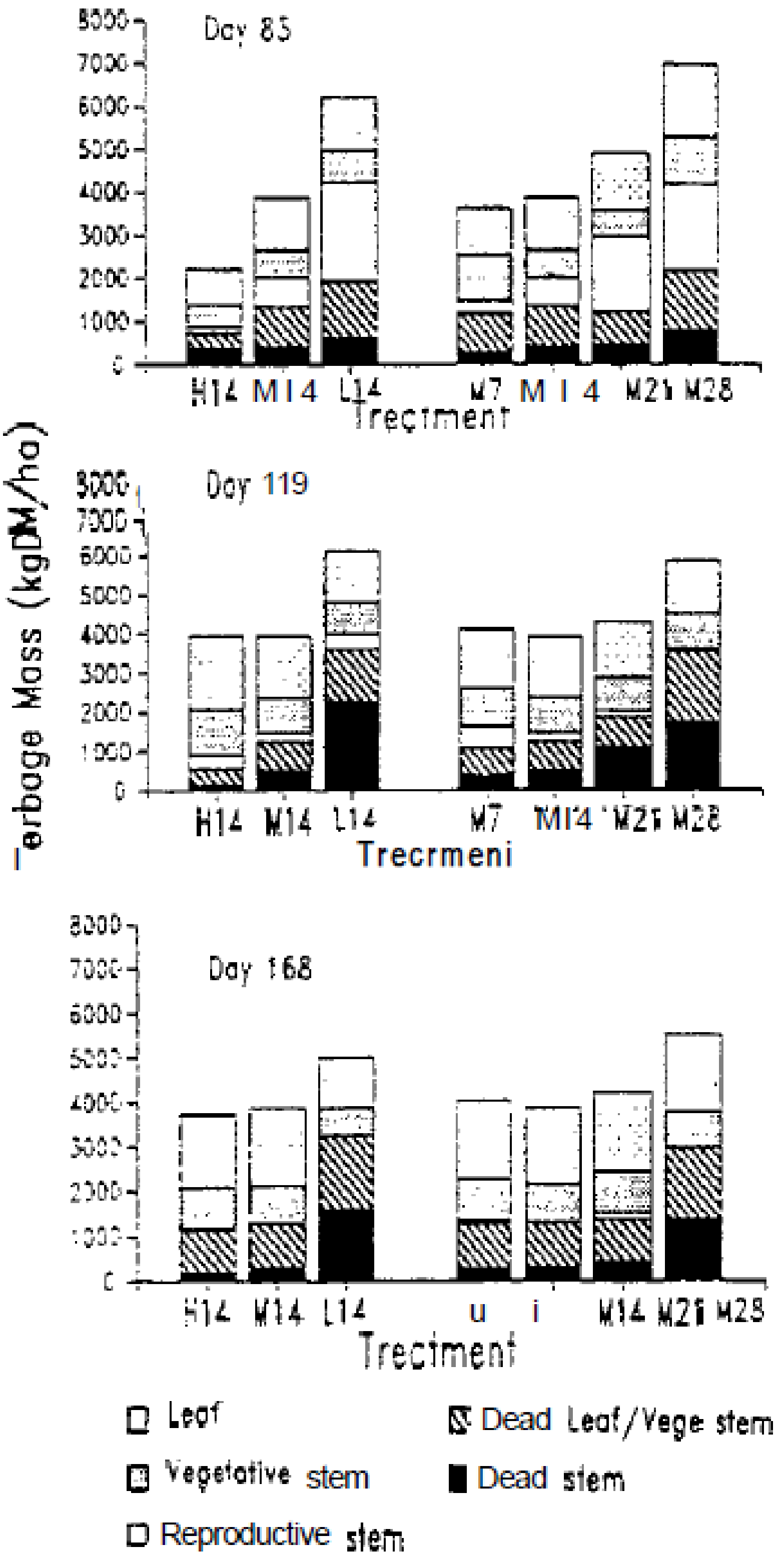


Figure 5. Effect of hard (H), medium (M) or lax (L) sheep grazing (residuals of 150, 400 and 750 kg DM, respectively) at a grazing interval of 14 days (left 3 bars) and grazing intervals of 7,14, 21 or 28 days for medium intensity; on the yield of grass components over 85 days whilst the treatments were imposed (day 85), and subsequently (119 and 168 days). See Butler and Chu (1988) for details.

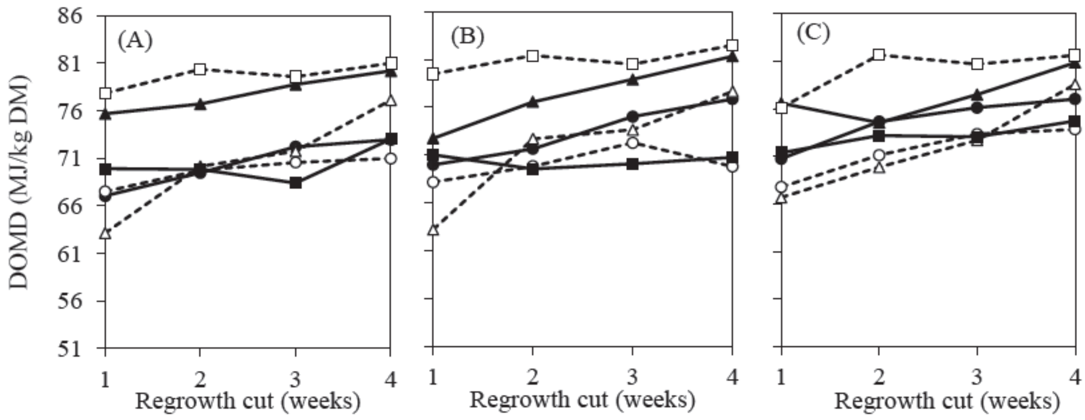


Figure 6. Effect of regrowth interval on predicted digestibility of organic matter (% of DM, note incorrect units on figure) under nil (A), medium (B) and high (C) nitrogen fertilisers rates for perennial ryegrass (●), cocksfoot (○), chicory (▲), plantain (∆), red clover (■) and white clover (□) grown in plots in autumn in Canterbury. From Martin *et al*. (2017).

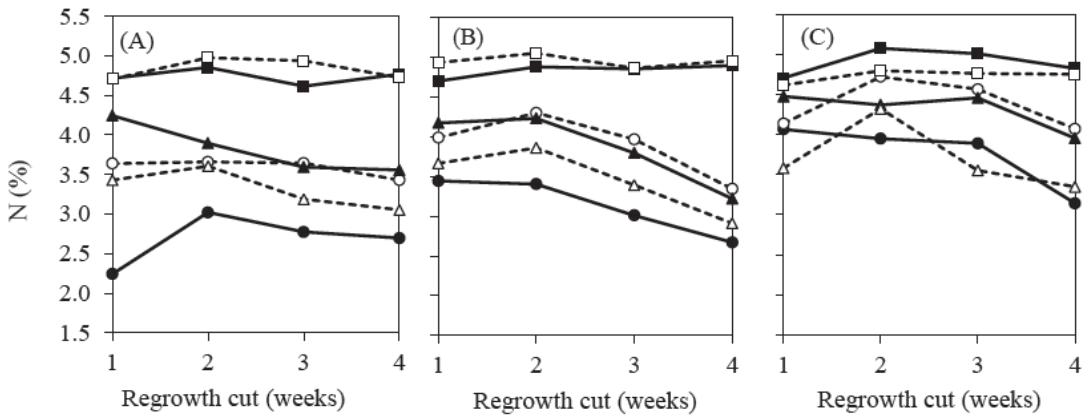


Figure 7. Effect of regrowth interval on plant N% under nil (A), medium (B) and high (C) nitrogen fertilisers rates for perennial ryegrass (●), cocksfoot (○), chicory (▲), plantain (∆), red clover (■) and white clover (□) grown in plots in autumn in Canterbury. From Martin *et al*. (2017).

4.6.5 Interaction with post-grazing herbage mass and date of last grazing

The amount of pasture left after grazing affects the quality of pasture available for subsequent grazings. When pasture growth rates are low, such as in winter, or when stocking rates are high, little pasture is left behind after grazing. However, in spring and early summer, after high growth rates, more pasture is typically left after grazing. This is also at a time pasture quality is rapidly declining (Waghorn and Barry 1987). With higher residuals, dead matter also accumulates at the base of the pasture, and hence the ME content and CP concentrations at subsequent grazings is reduced (Waghorn and Barry 1987).

When pastures are grazed below the recommended residual the plants take much longer to recover, and overall pasture growth will be less, but the decline in pasture quality will be slower. If high residuals are left, feed that was high quality will deteriorate and much of it will die before the next grazing. This deterioration will be more pronounced over spring and summer, when pastures are in the reproductive phase of growth.

Dairy pastures

McGrath *et al*. (1998) showed decreasing crude protein concentrations with increasing time since last grazing in Taranaki high fertility perennial ryegrass and white clover based dairy pastures in spring. With grazing to residuals of 1.2 to 1.4 t DM/ha, this decline was less pronounced than for residuals of 1.9 t DM/ha or greater (Figure 8). They concluded that the low post-grazing pasture residual likely killed developing reproductive tillers. The resulting pasture had a higher proportion of vegetative tillers, and less seedhead and stem and hence better overall quality. At six weeks post-grazing, the predicted ME values were 10.1, 10.0, 9.5 and 9.6 MJ/kg DM for hard, moderate, lax and very lax grazing, respectively.

Based on trials on Waikato dairy pastures that tracked changes in pasture quality over a seven week period in spring, McGrath *et al.* (1998) concluded that the decline in pasture quality in spring is determined more by date (and its effect on reproductive development) than time since last grazing. Woodward (1998) also suggested that the transition of ryegrass from vegetative to reproductive tillers occurred in the late winter and stem elongation started 6 weeks later, followed by ryegrass flower emergence after a further 6 weeks.

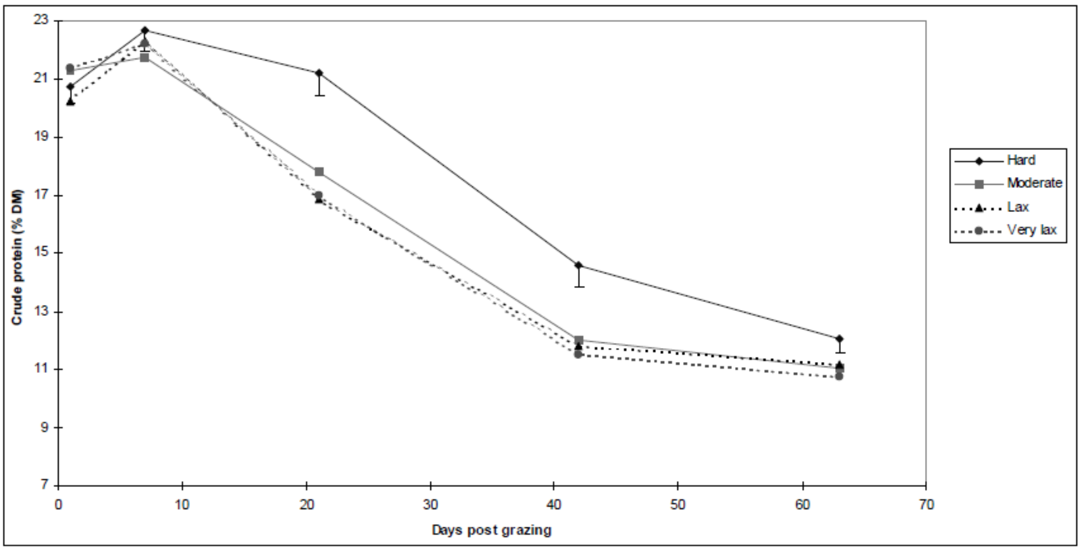


Figure 8. Change in crude protein percentage in pasture DM after grazing Taranaki dairy pastures in mid-spring to hard (1.3 t DM/ha), moderate (1.9 t DM/ha), lax (2.3 t DM/ha) or very lax (2.7 t DM/ha) post-grazing residuals. Error bars are standard errors of the difference. From McGrath *et al*. (1998).

In a perennial ryegrass based Waikato dairy pasture, winter grazing to low residuals of 1260 vs 1868 t DM/ha did not affect crude protein concentrations at the following grazing at the third leaf stage, but increased ME by 0.3 MJ/kg DM (Lee *et al*. 2007). This was because of the increased proportion of ryegrass leaf and decreased dead matter.

Research by DairyNZ in the Waikato, compared target (1.5 to 1.6 t DM/ha) versus high grazing residuals (1.8 to 2.0 t DM/ha) in spring and showed similar pasture quality in spring, but predicted ME values and crude protein concentrations were reduced at subsequent grazings in summer and autumn (Table 11). The reduction was attributed to an increase in dead matter and reduced proportion of ryegrass leaf in the regrowth from farmets with high residuals after spring grazing (https://www.dairynz.co.nz/news/latest-news/dairynz-s-post-grazing-residual-project-what-it-tells-us-about-pasture-management/).

Table 11. Effect of target (1.5 to 1.6 t DM/ha) or high (1.8 to 2.0 t DM/ha) spring grazing residuals on the quality of pasture at subsequent grazings. DairyNZ unpublished data.

Parameter	Target residual	High residual	Significance
Spring			
ME (MJ/kg DM)	12.6	12.5	ns
Crude protein (% of DM)	19.2	18.5	ns
Summer/Autumn			
ME (MJ/kg DM)	10.8	10.0	***
Crude protein (% of DM)	18.3	14.8	***

Sheep and beef pastures

A trial on southern Hawke's Bay hill country compared deferred grazing at three closing times from mid-spring to early summer (Devantier *et al*. 2017) with grazing every 3 to 4 weeks. They found pasture ME was reduced by 0.6 MJ ME/kg DM and crude protein reduced by 2% as grazing interval was extended compared to the control. The closing date did not affect quality across the deferred grazing treatments, but in all cases resulted in lower ME (10.2 to 10.3 vs 10.7 MJ/kg DM, respectively) and crude protein (17.9 to 18.0 vs 19.3% of DM, respectively) than the non-deferred treatment.

4.7 Effect of selective grazing on diet quality

The intake of ME and N by livestock is affected by the composition of the feed on offer, the availability of the feed on offer and the intake requirements of the animal for its given stock class and physiological state. The grazing animal tends to select a diet of higher quality than the average of the pasture offered, selecting clover over grass and leaves over stem and dead material (Litherland and Lambert 2007). The foraging behaviour of the grazing animal is a complex result of the interactions among multiple food sources and the animal itself (Villalba et al 2015), with grazing selection affected by topography, shade and shelter and spatial distribution of sward components.

4.7.1 Spatial distribution of sward components

Within New Zealand pastures are a range of botanical and structural components which influence the animals' dietary choice. These components may also be present in different parts of the sward, both horizontally and vertically. New leaves tend to migrate to the top of the sward as they seek light for photosynthesis, while senescing and dead components migrate to the bottom of the sward. This distribution provides a segregation of sward components with high quality components occurring in the upper horizons and low quality components in the lower horizons (Table 12). This provides the opportunity to ingest a diet of higher quality than the average of the sward. Horizontal variations in quality also occur in response to changes in soil properties and to differential grazing pressure.

Table 12. Percentage of total sward dry matter (DM) and plant components within each stratum of a ryegrass/white clover sward under lax or intensive dairy grazing. Data are pre-grazing swards with 4.2 and 3.7 t DM/ha for lax and 1.85 and 2.05 t DM/ha for intensive systems, for October/November and December, respectively. From Hoogendorn (1986).

		October/November					December				
	Stratum			Grass					Grass		
Grazing	(cm)	DM%	Senes	Stem	Leaf	Clover	DM%	Senes	Stem	Leaf	Clover
Lax	25+	7	6	17	76	0	1	12	81	4	3
	20-28	7	9	24	62	5	2	15	70	12	3
	12-20	15	8	38	45	9	7	24	44	20	12
	4-12	31	18	45	28	9	37	40	26	17	17
	0-4	40	37	53	6	4	53	44	33	7	16
Intensive	12-20	2	4	11	85	0	2	2	46	52	0
	4-12	16	4	22	64	10	18	4	11	67	18
	0-4	82	17	36	34	13	80	22	23	35	20

Senes = senescent.

4.7.2 Effect of pasture toxins, faeces and urine patches on grazing

Associated with both botanical and structural components may be a range of toxic, or anti-nutritional compounds, produced by either the plant or plant/microbial interactions. Ryegrass endophyte is a well known plant/fungal interaction. Selecting endophytes that protect ryegrass from insect predation, without negative impacts on livestock health require pastures to be replaced with appropriate cultivars. The use of appropriate endophytes has had most effect in the dairy industry because pasture renewal on flat to rolling land is relatively reliable, cheap and can be associated with cropping, with subsequent pasture replacement. Many sheep and beef pastures, in hill country, continue to have ryegrass/endophyte combinations that produce aversion in the grazing animal. This aversion can reduce intake (Edwards *et al*. 1993).

Livestock also avoid grazing around faeces to avoid ingestion of parasites and other pathogens (Michel 1955, Cooper *et al*. 2000). As the herbage around faeces is avoided the higher pasture mass around faecal pats can lead to more stem and dead material in these patches. Weeda (1967) found the difference in pasture mass around areas affected versus not affected by faeces most prominent in spring and greater under lax than hard grazing. Similarly, urine patches are avoided and senescence of the un-grazed forage provides an ideal environment for fungi that can have negative impacts on animal health.

The presence of rust on leaves has been demonstrated to reduce intake (Cameron 1979). However, the presence of facial eczema spores do not appear to affect grazing behaviour (Keogh 1974). This suggests that taste, rather than toxic effect, has the greatest role in diet selection when pathogens are present.

4.7.3 Animal effects on grazing behaviour

The animal influences the selection of its diet in several ways. Firstly in the mechanism for harvesting food. Cattle mainly use their tongues to harvest forage, while sheep use their teeth. Cattle have a large mouth with a broad bite (incisor spread), while sheep have a small mouth with a narrow incisor spread. Sheep are therefore able to be more selective than cattle (Table 13) and are able to graze lower into the sward.

Previous experiences of the animal will also influence its choice of pasture components, in such a way that classical homeostatic mechanisms of food ingestion, based on the energy balance of the animal, can be overridden, if toxins are potentially present. The physiological status of the animal will also influence the drive for the animal to select. For example, when given free choice, lactating ruminants will actively choose a diet of approximately 75% clover, while non-lactating animals will select a diet of 65% clover (Hill *et al.* 2009).

Previous feeding regime can influence the selection of feed, as animals that are trained to the provision of daily allowances may reject the current food source in anticipation of a new source. Animals that are under a high competitive pressure may exhibit different ingestion behaviours to those with less competition. Finally, the digestive processes of the ruminant also influence the drive to select their diet. Cattle are defined as non-selective grazers, sheep as selective grazers, while both red deer and goats are defined as intermediate selectors, making them adaptable to pasture grazing (Hofmann 1985).

Table 13. Mean proportions of sward components selected by calves and sheep grazing similar ryegrass based swards and under similar grazing pressures. Diet composition was determined via sampling of feed from the oesophagus. From Hughes *et al*. (1984).

Pasture component	Ungrazed herbage (% of DM)	Lamb diet (% of DM)	Calf diet (% of diet)
Grass	41	56	76
Clover	26	42	19
Dead matter	33	2	5

4.7.4 Effect of pasture availability and composition on selective grazing

Poppi *et al*. (1987) described a general relationship between the state of the pasture and the drivers of intake. As the amount of pasture available increases, the animal shifts from a non-selective to a selective phase, initially using intake to meet the homeostatic requirements of maintenance, and then using selection to maximise the nutritional value of each mouthful, i.e. taking time to select a diet of higher quality.

Much of the literature regarding selective grazing focuses on relatively extreme cases where the animal has the opportunity to select between monocultures that are offered side by side at the same time. For example, a review by Hill *et al.* (2009), which summarised clover grazing selection in monoculture, showed that high clover intakes were achieved this way, but lower performance was exhibited in mixed pastures. So while selection can be achieved where a clover sward is offered alongside a ryegrass sward, selection was much reduced in typical mixed swards. This indicates that selectivity is often only seen when the opportunity for choice is large.

When considering the pastures of New Zealand, selectivity often becomes based on the horizontal and vertical position of pasture components relative to the animals grazing horizon. This is depicted by Clark *et al.* (1986) (Figure 10), where dead material is rejected, grass is the most regular component of the diet, and clover is represented in direct relationship to its occurrence in the pasture. With poor quality pastures (ME of 8-8.5 MJ/kg DM) selection can increase the quality of the diet by up to 1.8 MJ ME/kg DM (Webby and Bywater 2007). Intensive grazing forces livestock to graze closer to ground level as less herbage becomes available, increasing the proportion of stem and dead material in their diet. On average, however, diet composition tends to fairly closely reflect sward composition to the given grazing height, as livestock typically consume a high proportion of the available feed. However, certain weeds such as thistles and ragwort are avoided.

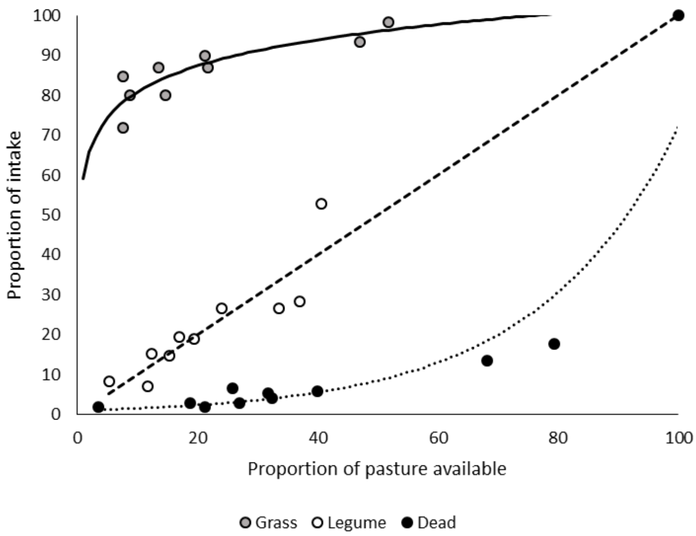


Figure 10. Diet choice exhibited by sheep grazing hill country pastures, demonstrating the rejection of dead material, regardless of its proportion in the pasture. From Clark *et al*. (1986).

4.7.5 Effect of grazing management on diet selection

The state of the grazed pasture has a significant influence on the ability for selection. Pastures grazed frequently, at high intensity, such as dairy pastures, have significant amounts of leaf and fresh stem that is removed at each grazing event. The height of the grazing residual is often kept constant and therefore aging and decaying pasture remains below the grazing height. This ensures that the diet at each grazing event is dominated by high quality freshly grown leaves. The variation in nutritive value of the pasture will therefore vary between regions and seasons (see Figures 12, 13) to a greater extent than effects associated with selective grazing.

Interventions by the pasture managers will also influence the opportunity for selection. Most dominant is the use of mowing (topping) to remove pasture left after grazing, particularly in late spring when seedhead is elongating. Again, this is most predominant in the dairy industry, and standard practice on some farms between October and December.

As a result of grazing and management practices, the opportunities for diet selection by dairy cows is limited. Generally, pastures sampled to grazing height will provide an accurate estimate of diet quality. Examples of the relatively consistent quality of dairy pastures are presented by Dalley and Geddes (2012) and Dalley and Gardner (2012) in Figure 11.

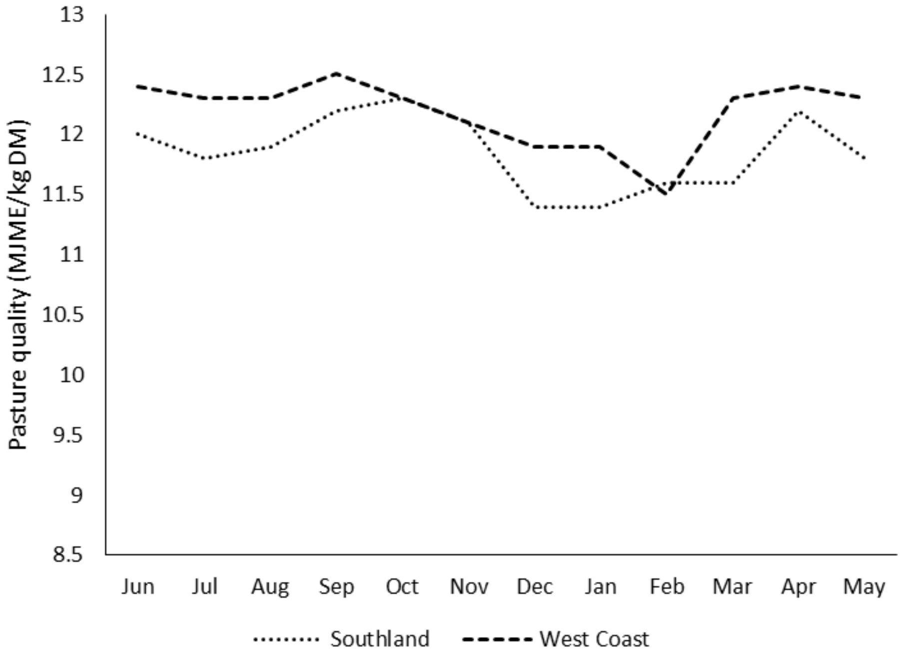


Figure 11. Dairy pasture quality throughout the year in Southland and the West Coast . Adapted from Dalley and Geddes (2012) and Dalley and Gardner (2012).

Compared to dairy pastures, hill country pastures exhibit more variability in botanical and structural composition, as well as grazing management. They often have a range of plant species (Cosgrove and Field 2016), that vary across the regions of New Zealand. Legume content is typically below 15-20%, and hence the predominant driving force of selection in these hill country pastures will be the amount of dead material and seedhead present.

From parturition in spring, then over the 3 to 4 months to weaning, hill country pastures are typically under continuous grazing regimens, especially for sheep. During summer, rotational grazing may be used, though usually with long (4-8 week) periods between grazings, followed by long (1-3 weeks) periods of grazing. During autumn, rotational grazing is used with shorter intervals. Finally, winter consists of long periods between grazings with short (1-4 day) intensive grazing periods. This winter management aims to remove poorer quality pasture that may have built up during other times of the year, to ensure green leafy pasture for continuous grazing in spring to support lactation and animal growth. Mechanical control of feed quality is unavailable due to contour constraints.

Pastures within a farm are managed differently throughout the year, depending on growth and livestock requirements. Data from Litherland *et al.* (2002) demonstrate the typical pasture on sheep and beef farms across the year from different regions (Figure 12), whilst Figure 4 indicates differences in diet quality across the year under contrasting management.

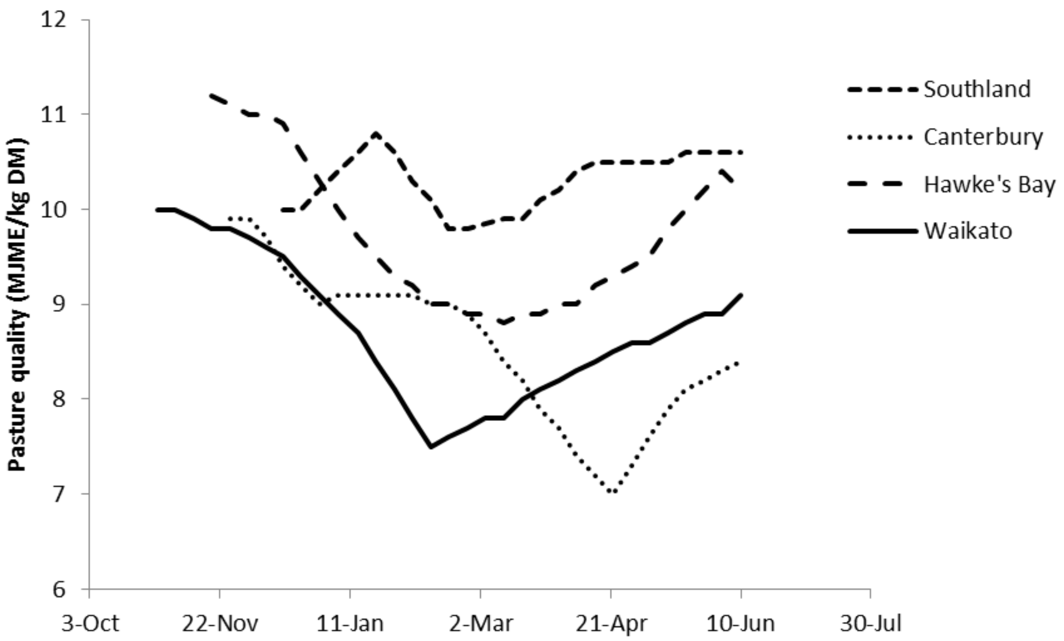


Figure 12. Metabollisable energy estimates of the highest quality pasture on offer to finishing animals on sheep and beef farms for four regions of New Zealand. From Litherland *et al.* (2002).

To adequately represent the diet chosen by sheep and cattle in hill country pastures, several factors must be taken into account, at different times of year. Understanding the actual diet ingested requires a harvest technique that mimics the prehension of the animals, and must also include a provision for differences in diet selection based on stock class.

4.7.6 Influence of slope on diet selection

Grazing animals ingest feed from from an entire paddock and excrete unutilised nutrients, such as nitrogen, in urine and dung patches. On intensively managed flat land, animals tend to graze in a spatially homogenous pattern as there is little scope for exercising preference for grazing and resting sites. Thus while nutrients are concentrated into urine and dung patch areas, the distribution of that excreta is relatively random at any grazing event, and so over time all areas in a paddock have an equal chance of receiving nutrients via excreta (King *et al*. 2011).

In hill country, where grazing systems are usually more extensive, animals have greater opportunity to show preference in choosing grazing and excreting sites. Animals tend to graze the easier slopes and warmer and more sheltered aspects before there is pressure for them to graze the steeper and/or more exposed country (as reviewed by King *et al*. 2011). In doing so, animals on hill country will tend to graze higher quality pasture first.

Although patterns of animal behaviour that determine where an animal eats and where it excretes are determined by interactions between slope, aspect, other topographic features and current weather there are additional farm management factors such as stocking rate, grazing regime and size and shape of a paddock which also influence animal behaviour (King *et al*. 2011).

5. Summary of findings

This review has collated information on the effects of grazing management on pasture quality and composition. Increased stem production due to reproductive growth and decay of leaves with aging are the largest causes of decline in pasture quality. Effects are most pronounced where grasses are dominant, with legumes and herbs having a higher average quality and lesser decline in ME values during the reproductive stage. This decline in quality can be manipulated by grazing management. Grazing to low residuals removes the low quality dead material and stem and allows more light to the base of the pasture to encourage clover growth, whilst short intervals between grazings reduces the opportunity for dead material and reproductive stem to form before the next grazing and reduces shading out of clover.

The time taken for this decline in quality between grazings and the degree of the decline is dependent on the time of year and climate. Reproductive growth results in rapid and large declines in pasture quality from late spring to late summer. For the remainder of the year, the rate of decline in quality is largely related to the rate of pasture growth and hence describing effects based on weeks between grazings alone is of limited use. For ryegrass dominant pastures, this is best described by the 3-leaf principle, where each tiller grows new leaves, and once the third leaf is fully grown, the oldest leaf begins to die. This increase in dead material results in a drop in both ME value and N% of pasture. The typical time to reach the 3 leaf stage is approximately 3 to 4 weeks, but this varies across regions and seasons.

With warm temperatures, the proportion of cell wall increases, decreasing pasture quality over time, even when green and leafy. The decline is roughly 0.05 MJ/kg DM/day for grass at a daily maximum of 18°C, with a negligible decline when temperatures are less than

12°C. Seasonal changes in soil moisture and temperature also alter pasture botanical composition, which can affect pasture quality.

Sheep and beef farms cover a range of contours, from flat to rolling to steep with a range of aspects for these slopes. Nutrients are typically transferred from steeper slopes to flatter areas from the deposition of dung and urine by grazing animals. The differences in soil fertility and moisture amongst slope classes results in differences in pasture botanical composition and pasture growth, with lower fertility grasses and lower growth rates on steeper slopes. The impact of soil fertility on pasture species also results in differences in pasture quality amongst slope classes, generally improving on flatter land. The aspect of slopes is of less importance than the degree of steepness for pasture quality, but north facing slopes may contain a higher proportion of dead matter in dry conditions.

Dairy pastures use rotational grazing management, whilst sheep and beef farms may use a combination of rotational and continuous grazing for raising livestock. The impact of different types of grazing management on feed quality is affected by stocking rate and pasture species, but these are likely to have less impact than grazing residuals and grazing intervals. Dairy pastures typically have high ME values and N concentrations due to greater proportions of improved species (ryegrass and clover), flatter contours, higher soil fertility and an ability to manage the sward effectively.

The quality of the diet of grazing animals depends on the quality of the pasture on offer, and animal selection of sward components that differ in quality. Cattle will be less selective than sheep as cattle use their tongue to assist prehension, while sheep use their teeth. Both sheep and cattle will actively avoid dead material in the pasture. Sampling of dairy pastures can be done by taking herbage to grazing height. This is relatively consistent across New Zealand with a residual of 3-4 cm being targeted. Pasture sampled for sheep and beef monitoring need to take account of the variable nature of the topography, the type of livestock grazing and the target of the grazier at different times of the year. This will best be done using a stratified process of different sampling techniques for different livestock classes at different times of the year.

Although some of the data referenced in this report date back more than 20 years, the typical pasture mixes used and overall management have changed little since then, with the methods of collecting pasture samples still the same, hence the data are still relevant. It must be noted, however, that the methods used for analysis of pasture quality have changed. Since the 1990s near infrared reflectance spectroscopy (NIRS; Corson *et al*. 1999) has become the main method of estimating ME values and N% of pasture, due to the speed and low cost of this method. The accuracy of estimation of feed composition by NIRS is dependent upon the data used to calibrate the instrument. Much of the data reported here were analysed at FeedTECH, AgResearch, with equations validated from New Zealand pasture samples. An increasing number of laboratories are now using NIRS for feed quality analysis, but may use calibrations from other countries, so results may differ slightly.

6. Implications for the GHG inventory

Data for pasture predicted ME and N concentrations used in the greenhouse gas inventory must reflect the average diet consumed by sheep and cattle. The largest drivers of pasture quality are botanical and morphological composition, affected by stock management and climate, and these must be accurately reflected for dairy and sheep and beef pasture sampling procedures. Considerations for pasture sampling are detailed below.

1. **Regional differences must be taken into account.** For example, the contribution of subtropical grass species in Northland pastures. Sampling must not be a national average, given the large variability in pasture quality, e.g. Northland versus Southland sheep and beef pastures may differ by 2 MJ ME/kg DM in February.

2. **Farms and paddocks sampled must be representative of their region.** It is important that sampling be undertaken on farms that undertake grazing management that is representative of the region, with typical pasture species and on land that has a typical contour for the region. Sampling of specific farms should include sampling a range of steepness of slopes that represent the proportion of such land. Sampling to a consistent sward height across all slopes is recommended. Note that N% of DM could drop by one third going from flat to very steep sites.

3. **Sampling should occur monthly.** Samples should be collected monthly to accurately reflect seasonal changes in pasture quality due to changes in plant maturity and pasture botanical composition and to provide more accurate seasonal averages. ME can vary by more than 2 MJ/kg DM across months in a given region. It is recommended that samples are collected over several years to account for variation in climate across years, particularly where there are high temperatures and summer soil moisture deficits. If only collecting in one year is feasible, years with extreme climatic events must be avoided.

4. **Sampling should occur within one week of the recommended grazing interval.** For all farm types, ME values can drop by approximately 0.35 MJ/kg DM every week however, in winter the decline is negligible when temperatures are below 12°C, so collection timing is less crucial. N% may drop by approximately 0.5% of DM every week over spring and summer. Grazing (and hence pasture sampling) at the ryegrass 2 to 3 leaf stage represents best practice, but it must be remembered that best-practice is not always achieved.

5. **When dairy cows are not lactating sampling may need to be done off the milking platform.** The majority of dairy farmers graze their cows off the main farm in winter when they are not lactating. Pasture quality samples for dairy cattle over this wintering period should be reflective of the land they are grazing on, rather than what is on the milking platform of dairy farms at that time.

6. **Sampling height must reflect grazing height.** This will ensure that the relative proportion of grass versus legume, stem versus leaf and live versus dead matter collected reflects what is grazed. Because different livestock classes are presented with pastures of different height and composition, separate samples

should be taken for sheep and cattle and for breeding and growing stock, reflecting management at the given time of the year. This can be achieved by sampling to estimated grazing height randomly across a paddock. Recommended grazing heights are detailed in Table 14, but note that actual grazing height will vary across farms.

7. **Sampling should avoid pasture components avoided by livestock.** For example, weeds such as thistles and ragwort and the long pasture around dung patches.

Table 14. Seasonal recommended grazing height of pasture (from ground level) for New Zealand dairy and sheep and beef farms for different classes of livestock.

	Season			
Livestock	Spring (set-stocking for sheep and beef farms)	Summer	Autumn	Winter
Dairy cows‡	3.5-4 cm	4 cm	3.5 cm‡	3.5 cm
Beef breeding cows	4-5 cm	4-5 cm	3-4 cm	1-2 cm†
Breeding ewes*	4-5 cm	1-2 cm	2-3 cm	1-2 cm†
Breeding hinds	2-3 cm	3-4 cm	2-4 cm	1-3 cm
Growing cattle	3-4 cm	3-4 cm	3-4 cm	3-4 cm
Weaned lambs*	3-4 cm	2-3 cm	2-3 cm	3 cm
Growing deer	3-4 cm	3-4 cm	3-4 cm	3 cm

‡ McCarthy (2014). For early autumn use summer recommendations.

* Beef + Lamb New Zealand (2012).

† Derived from post-grazing residuals reported in Morris (2007).

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