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Defoliation dynamics, pasture intake and milk production of dairy cows grazing lucerne pastures in a partial mixed-ration system

K. A. D. Ison[A,B,C], *D. G. Barber*[A], *M. A. Benvenutti*[A], *N. Kleinitz*[B], *D. Mayer*[A] *and D. P. Poppi*[B]

[A]Queensland Department of Agriculture and Fisheries, Agri-Science Queensland (Dairy), University of Queensland, Gatton Campus, John Mahon Building 8105, Lawes, Qld 4343, Australia.
[B]School of Agriculture and Food Sciences, Animal Science Group, University of Queensland, Gatton Campus, Natural and Rural Systems Management Building 8117A, Lawes, Qld 4343, Australia.
[C]Corresponding author. Email: Kieran.Ison@daf.qld.gov.au

Abstract. The effect of lucerne pasture allocation on defoliation dynamics, pasture intake and animal production was investigated in a subtropical partial mixed-ration dairy system. The study took place at the Gatton Research Dairy, south-eastern Queensland, with a 28-day adaptation period followed by an 8-day treatment period during November and December 2016. Twenty-four multiparous Holstein Friesian dairy cows were offered 11 kg of dry matter (DM)/cow.day as partial mixed-ration dairy system, and four levels of daily pasture allocation measured to 5-cm residual pasture height (averaging 30.6, 20.5, 15.1 and 10.9 kg DM/cow.day). Cows with lower allocations were forced to graze further down the vertical plane and pasture intake and milk yield significantly ($P < 0.001$) declined. Cows grazed the top grazing stratum (TGS) across 80% of the pasture area before re-grazing another area of the paddock, regardless of the allocation level. Pasture intake (kg DM/ha) of the TGS was at least 2.9 times higher than that of the lower strata, regardless of allocation level. Therefore, the decline in pasture intake is explained by the transition from grazing the TGS to grazing lower strata. When the horizontal utilisation of the TGS approached 100%, the proportion of ungrazed, uncontaminated pasture approached 0% of the area, and intake and milk production declined. Grazing management strategies for lucerne should allocate pasture to lactating dairy cows to achieve horizontal utilisations approaching 0% for proportion of ungrazed, uncontaminated pasture to maximise intake and production. Secondary grazing herds or mechanical methods should be used to remove residual pasture to the ideal height for pasture regrowth.

Additional keywords: alfalfa, grazing dynamics, grazing management, *Medicago sativa*.

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Introduction

Current industry practices within high-intensity dairy grazing systems in northern Australia aim to achieve vertical pasture-utilisation levels of at least 75%, with ~5-cm residual height to ensure optimum pasture productivity (McDonald *et al*. 2003). However, various grazing studies on multiple pasture species have found that lower pasture allocations increased grazing pressure and decreased pasture intake and animal productivity in ruminants (Gibb and Treacher 1978; Peyraud *et al*. 1996; Chilibroste *et al*. 2012). Beef cattle have been found to achieve high levels of pasture intake only when grazing the top leafy stratum (TLS) of grass pastures (Benvenutti *et al*. 2016). In pasture-based systems, reducing pasture allocation forces cows to graze down into the bottom stemmy stratum of the swards, and, consequently, decreases diet quality and pasture intake (Hendricksen and Minson 1980).

Within high-intensity grazing systems where the height of the bottom stemmy stratum varies within a pasture sward (McDonald *et al*. 2003; Benvenutti *et al*. 2016), allocating pasture based on a fixed post-grazing pasture height (vertical utilisation) cannot be recommended to consistently achieve high levels of pasture intake.

Grazing management based on the horizontal utilisation of the TLS consistently maximised pasture intake of beef cattle, irrespective of the height of the bottom stemmy stratum (BSS; Benvenutti *et al*. 2016). These findings led to the development of a new grazing management target to maximise pasture intake in all pasture conditions. The target is to achieve 100% horizontal utilisation of the uncontaminated pasture area. Cattle refuse to graze around areas within the pasture sward that have been contaminated with faeces. Consequently, pasture intake declines when the uncontaminated areas of the TLS are heavily depleted across the entire area (horizontal utilisation) of the pasture, and animals are forced to graze the bottom stemmy stratum.

The aim of the current study was to investigate if targeting 100% horizontal pasture utilisation, or 0% proportion of ungrazed, uncontaminated pasture (PUP) is also applicable to lucerne in dairy systems, and to quantify the defoliation dynamics, pasture intake and milk response at increasing levels of grazing pressure. Increasing grazing pressure was achieved by reducing pasture allocation, which forced cows to fully deplete the TLS across the horizontal plane, and graze further down into the bottom stemmy stratum of the sward.

Materials and methods

The present study was undertaken at the University of Queensland, Gatton Research Dairy, Queensland, in November and December 2016; the study was conducted in agreement with the guidelines of the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (National Health and Medical Research Council 2004) and was approved by the Department of Agriculture and Fisheries Animal Ethics Committee (reference number SA 2016/10/578). Twenty-four multiparous Holstein Friesian (*Bos taurus*) lactating dairy cows were randomly allocated to four pure lucerne pasture allocation treatments based on days in milk (166 ± 50), milk yield (27.9 L/cow.day ± 3.6), milk fat concentration (3.68% ± 0.30), milk protein concentration (3.10% ± 0.18), somatic cell count (80 000 ± 35 000 cells/mL), liveweight (610 kg ± 49), body condition score (4.7 ± 0.3; 1–8 scale) and parity (2.5 ± 0.9). The experiment was conducted over a 36-day period, with a 28-day adaptation period and an 8-day measurement period where grazing dynamics, dry matter (DM) intake and milk production were recorded. Six cows were randomly allocated to each of the four pasture allocation treatments, with two replicates of three cows per treatment group. The four actual pasture allocation treatments averaged 30.6, 20.5, 15.1 and 10.9 kg DM/cow.day to 5 cm residual pasture height. All cows grazed from 0500 hours to 1230 hours and were then moved to a shaded area without access to feed until milking time at 1500 hours. All cows returned to the feedpad after milking at 1600 hours, were separated into their treatment groups and offered 11 kg DM/cow.day of a partial mixed ration (PMR) until the next milking at 0400 hours. Milk yield was measured at each milking period for individual cows by using automatic flow meters (Westfalia, 'Dairy Plan' Software, Düsseldorf, Germany), and samples were analysed for fat and protein (Siliker Australia, Eagle Farm, Brisbane, Qld, Australia). All cows were offered the same PMR, formulated using the Nittany Cow ration formulation program (NittanyCow Dairy Ration Evaluator software, MO, USA). Diets were balanced to meet the metabolic requirements of cows producing an average of 25 L/cow.day when combined with a nutrient intake from consuming 10 kg of DM of the lucerne pasture. Note that actual pasture intake could not have been predicted before the experiment as it was not known; therefore, formulating a diet for each treatment was not possible. Daily PMR refusals were removed and weighed to calculate individual daily PMR intake as an average for each group of three cows.

Defoliation dynamics

Defoliation dynamics were defined by calculating the vertical and horizontal utilisation of the pasture, using height measurements taken at fixed assessment points (2 × 2 m grid pattern) within each paddock. Grazing strata were defined as the vertical section of pasture removed during the biting process. The TLS was the vertical section of the pasture that was grazed for the first time. A new grazing stratum was formed every time the animals re-grazed the same area of pasture, leading to multiple superimposed grazing strata. Therefore, each grazing stratum had a vertical dimension, which was its depth, but also a horizontal dimension, which was its progressive utilisation across the total area of the paddock. Grazing strata should not be confounded with the four vertical section cuts used to establish the vertical distribution of the pasture mass (see next section). The depth of each grazing stratum was calculated as the average of the difference in pasture height before and after the stratum was grazed in each measuring point. The horizontal dimensions of each grazing stratum were calculated as a proportion of the number of grazed assessment points over the total points. Trampled and contaminated points were recorded within each paddock and recorded as 'ungrazable' areas. These values were subtracted from the total area allocated to determine the maximum grazable area within each paddock. Time-lapse cameras (GoPro Hero4 Silver®, GoPro, San Mateo, CA, USA) recorded cattle grazing pastures throughout the entire grazing period at 10 s intervals, and each image was analysed to determine the number of cattle grazing at that instant. Daily average grazing time (min/cow.day) was calculated by dividing the total grazing time from each paddock by the number of cows grazing.

Pasture structure, intake and quality

The physical structure, chemical composition and intake of the lucerne pasture were determined using a random, stratified double-sampling method adapted from Benvenutti *et al.* (2016) to estimate and explain nutrient intake from pasture. Twenty-two pasture samples (ranging in height from 25 to 75 cm) were cut 5 cm above the ground level and then further cut into four equal vertical strata. Within each stratum, dry matter (g) was determined by drying samples in an oven at 60°C, and grazing resistance (kg/cm^2) was calculated as the breakpoint force of stems multiplied by stem density (Jacobs *et al.* 2013). Subsamples from within each stratum were analysed at Dairy One Forage Laboratory (Ithaca, NY, USA) to estimate metabolisable energy (MJ/kg DM; National Research Council 2001), crude protein (% DM; Hames *et al.* 2008) and neutral detergent fibre (% DM; Van Soest *et al.* 1991). Pasture intake rate (kg DM intake/h) was determined as the daily pasture intake (kg DM/cow.day) divided by the daily grazing time. The stage of development of the lucerne pasture was determined using the methodology defined by Kalu and Fick (1981). Additionally, the stage of development was also calculated as the proportion of stems that were at the flowering stage or greater.

Statistical analyses

Multiple linear regressions were used to develop equations for pasture mass and quality parameters. The backward (step-down) selection method was used, and explanatory variables were removed if $P > 0.05$. Statistics were analysed using the GENSTAT® (18th edition, VSN International Ltd, Hemel Hempstead, England, UK) software package. Residual pasture height, quality and structure were analysed using one-way ANOVA, with treatments as fixed effects. Linear and non-linear regressions were used to assess the relationships between the explanatory (*x*) variable, i.e. residual pasture height, and the following response (*y*) variables: consumed pasture mass, pasture intake, milk yield and area grazed. Linear regressions were used to assess the relationships between the explanatory (*x*) variable, i.e. pasture allocation, and the response (*y*) variables milk fat yield and milk protein yield.

Results and discussion

Pasture quality and structure

The lucerne pasture had a typical pasture structure with a TLS and a BSS. Table 1 outlines that as grazing pressure increased due to lower pasture allocations, animals were forced to graze further down into the sward. As grazing depth increased, the consumed pasture declined in quality and the grazing resistance increased. This is consistent with the results found by Terry and Tilley (1964) and Martiniello *et al*. (1997) where stem density and grazing resistance increased with depth in lucerne pastures. Following the method defined by Kalu and Fick (1981), the average stage of development was 4 (late bud) and 3 (early bud) as measured by weight and count respectively. The average proportion of stems that were at the flowering stage or greater was 25%, which was slightly above the ideal 10% recommended for grazing or cutting (McDonald *et al*. 2003).

Defoliation dynamics

Cows grazed up to four grazing strata (Fig. 1*a*, Table 2). Lower pasture allocations increased grazing pressure, and, therefore, the number of defined grazing strata increased from three to four. With increasing grazing pressure, the area of pasture grazed for the first time, i.e. the top grazing stratum (TGS), increased and approached a high proportion (>80%) of the uncontaminated area before animals re-grazed an area of the paddock (Fig. 1*a*).

This pattern of initiating a new grazing stratum once the horizontal utilisation of the subsequent upper stratum approached a high proportion of the uncontaminated pasture area was consistent for all treatment groups, and similar among all grazing strata. These results are consistent with those of a study by (Benvenutti *et al*. 2016), who found that beef cattle grazing tropical grass pastures exhibited similar grazing patterns. Fig. 1*b* and Table 2 illustrate that the average pasture mass removed in the TGS was 2.9 times greater than all subsequent strata. Previous studies on vegetative pastures have found that bite depth was ~50% of sward height (Laca *et al*. 1992; Flores *et al*. 1993; Cangiano *et al*. 2002). However, this fraction was measured to be as deep as 65–86% of the pasture height (Benvenutti *et al*. 2009, 2016). These large differences in TGS depth among studies could be explained by the vertical structure of the plant. For example, cattle grazing pastures with deep TLS, such as C*ynodon* spp. or *Axonopus catharinensis*, result in deeper bites (Benvenutti *et al*. 2009) or a deep TGS (Benvenutti *et al*. 2016). In contrast, the presence of tough stems at the bottom of *Panicum maximum* swards have been shown to act as a vertical barrier to defoliation and result in shallower bites (Benvenutti *et al*. 2006). Stems may have acted as a vertical barrier to defoliation in the current study with lucerne, as the grazing resistance of the stems greatly increased from the top to the bottom of the swards (Table 1).

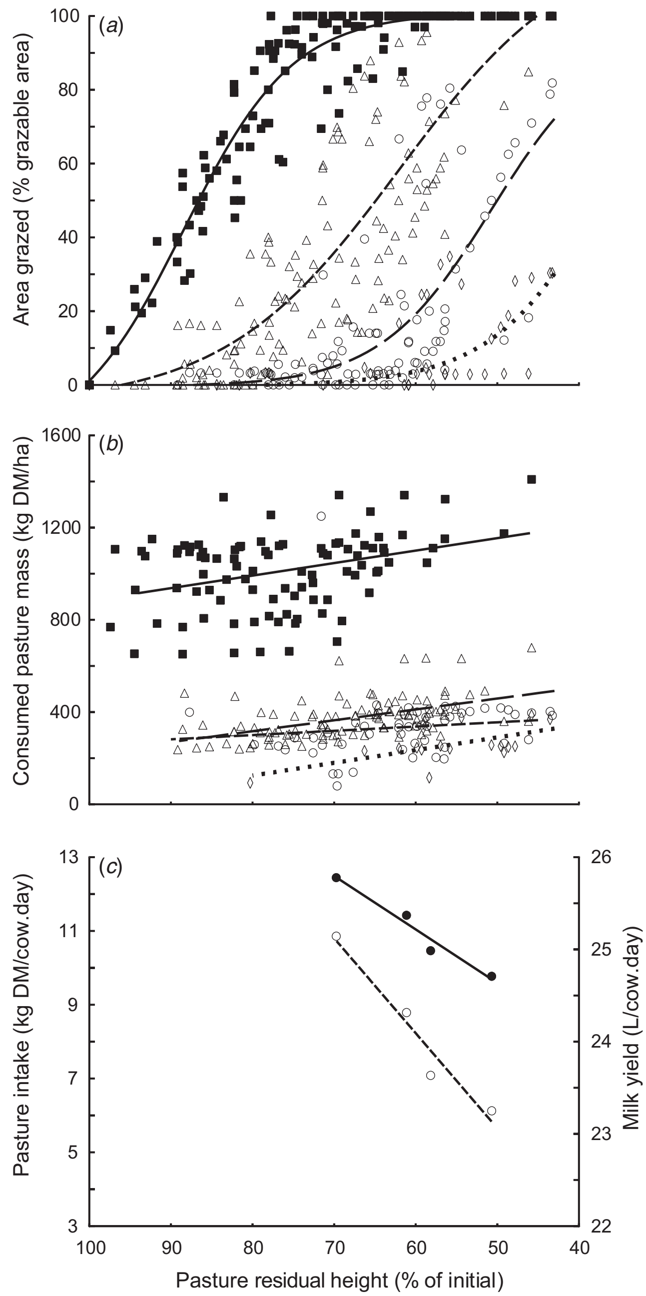

Fig. 1. (*a*, *b*) The relationship between grazing dynamics and residual pasture height (% of the initial). Symbols indicate individual grazing strata: Top stratum 1 (■), Stratum 2 (Δ), Stratum 3 (○) and Stratum 4 (◇). (*c*) The relationship between residual pasture height (% of the initial) and pasture intake (○) and milk yield (●).

Grazing time declined numerically from 216 to 170 min/cow.day ($P = 0.064$) for cows allocated 30.6 to 10.9 kg DM/cow.day respectively, which is similar to the results reported for sugarcane pastures (Benvenutti *et al*. 2017). This indicates that once cattle had removed the TGS and were forced to graze down into the BSS, they refused to continue grazing.

Table 1. Mean pasture allocation (kg dry matter (DM)/cow.day), residual pasture height (% of initial), nutritive (neutral detergent fibre (NDF), crude protein (CP) and metabolisable energy (ME)) and physical properties for Treatment groups T1, T2, T3 and T4

Means within a row followed by the same letter do not differ significantly (at $P = 0.05$). *Not significant ($P > 0.05$). s.e.m., estimated standard error of the mean

Parameter	T1	T2	T3	T4	s.e.m.	*P*-value
Pasture allocation (kg DM/cow.day)	30.6a	20.6b	14.8c	10.8d	0.86	<0.001
Residual pasture height (% of initial)	69.7a	61.1ab	58.2ab	50.7b	3.79	0.028
NDF (% DM)	22.2a	23.7a	24.9ab	27.5b	0.95	0.013
CP (% DM)	30.2	30.3	29.5	27.8	0.70	0.086*
ME (MJ/kg DM)	11.0a	10.9ab	10.7abc	10.4c	0.12	0.023
Grazing resistance (kg/100 cm^2)	43.8a	53.7ab	59.4abc	72.8c	5.33	0.016

Table 2. Linear and non-linear regressions among variables milk yield (L/cow.day), pasture intake (kg dry matter (DM)/cow.day), pasture mass removed (kg DM/ha), area grazed (% of grazable area) and pasture residual height (% of initial)

Li, linear: $y = A + B \times PRH$; Lo, logistic: $y = A + C/(1 + \exp{-B} \times (PRH - D))$. *Not significant ($P > 0.05$)

y	Model	Coefficient				R^2	*P*-value
		A	B	C	D		
Milk yield (L/cow.day)	Li	21.7	0.06			0.94	0.019
Pasture intake (kg DM/cow.day)	Li	–7.22	0.26			0.93	0.025
Pasture mass removed (kg DM/ha)							
Stratum 1	Li	1426	–5.42			0.12	<0.001
Stratum 2	Li	694.3	–4.72			0.27	<0.001
Stratum 3	Li	448	–1.85				0.402*
Stratum 4	Li	565.0	–5.51			0.32	0.011
Area grazed (% grazable area)							
Stratum 1	Lo	–16.6	–0.15	117.5	88.4	0.97	<0.001
Stratum 2	Lo	–5.17	–0.09	127.1	62.0	0.78	<0.001
Stratum 3	Lo	–0.46	–0.15	96.3	50.7	0.61	<0.001
Stratum 4	Lo	–0.29	–0.13	130	34.2	0.51	<0.001

Pasture intake and milk yield

All treatment groups were allocated at least 10 kg DM pasture/cow.day; however, only cows offered at least 28.5 kg DM/ha.day achieved a pasture intake of 10 kg DM/cow.day. Pasture intake declined when grazing pressure increased and the residual pasture height was less than 70% of the initial pasture height (Fig. 1*c*, Table 2). This decline in pasture intake is explained by the transition from grazing the TGS to grazing subsequent strata, or once 0% PUP had been achieved. Consistently, Benvenutti *et al*. (2016) found that pasture intake significantly declined at high levels of horizontal utilisation of the TGS. Our results are in agreement with Hendricksen and Minson (1980), who found that increasing stem proportions and grazing resistance resulted in reduced grazing depth, bite size and pasture intake when cows were forced to graze beyond the TGS, as shown in Fig. 1*b*, *c*.

Pasture intake rate also declined significantly ($r = 0.98$, $P = 0.047$) by 0.5 kg DM/cow.h for every 10 kg DM/cow.day decline in pasture allocation. The changes in the vertical structure of lucerne can increase the difficulty to prehend the tougher lower sections of the pasture, reducing bite mass and intake rate. The more resistant portions of pasture decrease the amount of plant material that can be consumed per hour of grazing time (Stobbs 1973; Pérez-Ramírez *et al*. 2009) and impose an ingestive constraint to intake rate (Boval *et al*. 2007). Therefore, pasture intake declined at lower pasture allocations due to reduced bite mass and lower intake rates, but also declining grazing time. Milk yield had a significant positive linear relationship with residual pasture height (Fig. 1*c*, Table 2). Milk fat and milk protein yield increased significantly by 0.041 kg/cow.day ($P = 0.006$) and 0.024 kg/cow.day ($P = 0.015$) respectively, for every 10 kg DM/cow.day increase in pasture offered. The intake of PMR was not statistically different among treatments (averaging 10.9 kg DM/cow.day); however, total DM (kg) and nutrient intake declined due to the declining pasture intake, and, consequently, milk yield declined (Schingoethe 1996; Moran 2005; Fariña *et al*. 2011). The decline in pasture intake was much greater than in milk yield, and it is possible that the mobilisation of body reserves could have ameliorated the negative impact of energy intake on milk yield.

Conclusions

The amount of pasture removed from the TGS was almost three times more than that from all subsequent strata. Pasture intake and milk production began to decline rapidly as the horizontal utilisation of the TGS approached 100% of the uncontaminated area of the paddock. The decline in intake occurred as cows transitioned from grazing the TLS, to grazing subsequent stemmy strata, where pasture removal declined significantly. This point of transition can be visually observed as the PUP approaching zero. Increasing the horizontal area of the paddock (higher allocation) increased the volume of the TGS on offer and, consequently, increased pasture intake. Allocating pastures on the basis of the TGS on offer rather than on the basis of total pasture on offer, to achieve 0% PUP could be used as a target to maximise pasture intake and milk yield in high-producing dairy herds. Post-grazing visual observations of the pasture can then indicate whether the target of 0% PUP has been achieved. The target has been achieved if ungrazed pasture is observed only around the faecal patches. If the target has not been achieved, further adjustments of the pasture or PMR allocations would be necessary. Secondary grazing herds or mechanical methods should be used to remove residual pasture to the ideal height for pasture regrowth.

Conflicts of interest

The authors declare no conflicts of interest.

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