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Milk yield and feeding behaviour responses to two flat-rate levels of concentrate supplementation fed over a period of 8 months to cohorts of grazing dairy cows, differing in genotype, bodyweight, or milk yield

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ABSTRACT

Context. In most pasture-based herds in Australia, supplementation with concentrates is normally a flat rate, with quantities determined by average cow requirements, rather than individual-cow requirements. Comparisons between flat rate and individual feeding rarely show advantages such as milk yield benefits for either. However, in pasture-based systems little is understood regarding milk production responses or levels of pasture substitution, when different groups of cows within the herd are fed concentrates at higher supplementation levels. **Aims.** To investigate the effect on milk yield, feeding time, and ruminating time, of two flat-rate supplementation levels of concentrate, fed over 8 months to 180 cows selected for one of three different parameters. **Methods.** Cohorts of cows were selected on contrasting differences for either milk production at the start of lactation, bodyweight, or genotype. Each cohort was divided into two balanced groups receiving either 2 or 6 kg DM/cow.day of concentrate, from approximately 12 days in milk onward. All cows remained part of the main milking herd (total herd size 320 spring-calving cows), with a similar opportunity for all cows to graze pasture or feed on supplemented grass silage during periods of pasture shortage. Milk yield was recorded at each milking and feeding behaviour continuously recorded by MooMonitor+ collars. Results were analysed for three seasonal periods of 10, 12 and 10 weeks (P1, P2 and P3 respectively) commencing in spring. **Key results.** Mean marginal milk response (L milk per 1 kg DM extra of concentrate) over the trial period was 0.88 L, increasing from 0.71 L in P1, to 0.92 L in P2 and 1.03 L in P3. The high-concentrate cohorts recorded reduced feeding time per day of 37 min overall (46, 35 and 29 min for P1, P2 and P3 respectively). Significant differences were found for milk yield and feeding time between several contrasting cohorts. The lowest marginal milk response was for cross-breed cows in P1 with 0.18 L and feeding reduced by 65 min/cow.day, with the contrasting cohort of Friesian cows at a larger marginal response of 0.94 L and smaller feeding time reduction of 32 min/cow.day. **Conclusions.** The differences among cohorts demonstrated potential for targeted concentrate feeding to specific groups of cows that respond differently in marginal milk yield and grazing behaviour. **Implications.** When a significant change is made in strategic amounts of concentrate feeding, the impact not only on marginal milk response should be considered, but also on pasture intake.

Keywords: feeding time, flat-rate concentrate, lactating dairy cows, milk yield, pasture based, pasture substitution, resting time, rumination time.

Introduction

The Australian dairy farming systems are mostly pasture based, especially in Tasmania. Although grazing pasture is a cost-effective way of feeding dairy cows, pasture alone is often insufficient to feed high-producing dairy cows to requirement (Orr *et al.* 2001). In addition, seasonal variation in pasture production and pasture quality affects the amount of nutrients cows can graze (Hills *et al.* 2015). Supplementing pasture intake with

Collection: ADSS 2022: A Changing Climate for Dairy Science concentrates is a management tool that is increasingly used strategically by dairy producers, including for the aim to increase milk production, and responding to seasonal variation in quality of forage offered (Hills *et al.* 2015). Feed is the largest on-farm cost for pasture-based systems, with the cost of milk production declining as increasing utilisation of grazed pasture occurs (Dillon *et al.* 2008). However, in pasture-based systems, little is understood regarding production responses or levels of pasture substitution, when different cohorts of cows are fed higher amounts of concentrates (Hills *et al.* 2015).

Making informed concentrate supplementation decisions is essential. Although systems and technology exist to feed cows individually, as stated by Hills *et al.* (2015), 'the value proposition from individualised feeding of cows in grazing systems remains unclear' (p. 1364). Hence, most pasture-based herds receive concentrate supplementation at a flat rate for the herd. Research comparing flat-rate feeding with individualised feeding has not found one system more advantageous than the other (Bines 1985; Leaver 1988; Gill and Kaushal 2000), neither has a review of these systems (Hills *et al.* 2015). Dairy farms that have integrated cow ID, milk recording and concentrate feeding systems are able to adjust concentrate supplementation levels according to parameters measured, with the aim to improve productivity (Hills *et al.* 2015). However, little is understood of both cow responses with milk and levels of pasture substitution, when cohorts of lactating dairy cows that differ in parameters such as genotype or bodyweight (BW), are fed different amounts of concentrates over a whole grazing season.

Most feeding trials measure responses to different diets only over a short period of time. Consequently, they often cannot sufficiently account for changes in body condition, nor for different seasons with differing amounts and quality of available grass to graze (Thompson and Holmes 1995). Substitution, the decrease in pasture intake when dairy cows are fed more supplements, is greatest when the supplement is least additive to pasture (Stockdale 2000; Roche *et al.* 2017). In Australia, short-term experiments measuring immediate responses to feeding extra concentrate supplements have demonstrated average marginal response values of 0.5 kg milk/kg supplement, whereas long-term experiments, including both immediate and residual responses, have returned average values of 1 kg milk/kg supplemented concentrate (Kellaway and Porta 1993). Thompson and Holmes (1995) suggested that, in the whole-farm system, the responses to supplementary feeding in summer and autumn may be greater than assumed from results of short-term trials. Hills *et al.* (2015) reported that individual cows within a herd may have a milk response to extra concentrate supplementation different from that of the overall herd. However, determining which cows should receive different amounts of concentrate requires understanding which cow parameter(s) to use to achieve the best individual-cow response to the extra concentrate fed. This trial tested three of these parameters under the same grazing conditions, and was unique in its duration (8 months) from early lactation onward.

This investigation examined the responses of different cohorts of cows for production and feeding behaviour (as proxy for change in pasture intake) when fed concentrates at two different supplementation levels, where the different cohorts were selected on either BW (as proxy for cow size; a flat rate results in more concentrate per kilogram BW for a low-BW cow), milk production at the start of the lactation (high or low; cows starting off the lactation with a lower milk yield might benefit differently from concentrate), or the genotype of cows (Friesian or cross-breed; because genotype can affect responses to concentrate).

We investigated the effect on milk yield, and feeding, ruminating and resting time, of two flat-rate levels of either 2 or 6 kg DM concentrate supplementation, fed to six cohorts of spring-calving multiparous cows contrasting for three parameters, over a period of 8 months from the start of the lactation season.

Methods

Site details

All data were collected from the Tasmanian Institute of Agriculture Dairy Research Facility (TDRF) at Elliott (41′08″S, 145′77″E), Tasmania, during the lactation season of 2017–2018. The climate at this site is characterised as cool-temperate with high annual rainfall (long-term mean 1180 mm), with the majority of rain falling between April and October (winter and early spring). The site has well established predominantly perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pasture. Approximately 40% of the paddocks available for grazing by the milking herd were irrigated. Pasture management was based on rotational grazing, with a new pasture allocation after every milking, a target pasture biomass at the start of grazing of ~3000 kg DM/ha and a residual biomass of 1500 kg DM/ha. The site was undulating, with a clay loam red Ferrosol (Humic Etrodox) soil (Soil Survey Staff 1990; Isbell 1996).

Animals

The milking herd at TDRF consisted of 320 spring-calving cows rotationally grazing approximately 120 ha of pasture (48 ha under irrigation). The milking herd consisted of approximately 30% Holstein-Friesian animals, with the remainder primarily being cross-bred Friesian × Jersey, with fewer numbers of Friesian × Aussie Red and Friesian × Montbeliarde × Aussie Red. The cows were milked twice daily for the duration of the lactation. One hundred and eighty early lactation multiparous (parity range 2–7) dairy cows were selected from the TDRF milking herd as they started their lactation, and allocated to different cohorts on the basis of three cow parameters tested (60 cows per parameter). Cows were between 9 and 15 days in milk (DIM) when allocated to a cohort.

Experimental design and treatments

In early lactation, in a spring-calving herd, six cohorts of 30 cows each were selected on contrasting differences for either their genotype (Friesian (GF) or cross-breed (GC)), production at start of lactation (either high (PH) or low (PL) milk yield), or BW (high (WH) or low (WL) weight) as proxy for cow size (Table 1). Each cohort was divided into two balanced groups of 15 cows each, receiving concentrate at either 2 or 6 kg DM per cow per day (Table 1). Treatments for each cow started at recruitment into a cohort, and trial data collection after an adaptation period of one fortnight. The trial period was divided into three seasonal periods of 10, 12 and 10 weeks (P1, spring; P2, late spring–summer; P3, late summer–autumn), with the trial cows a mean of 28, 98 and 182 days in milk at the start of P1, P2 and P3 respectively. All trial cows remained part of the milking herd at TDRF, with similar opportunity for all cows to graze pasture or feed on supplemented grass silage during periods of pasture shortage (typically ~20% of the diet over summer and autumn). Milk yield was recorded at each milking, and feeding behaviour (as proxy for pasture intake) was continuously measured with MooMonitor+ collars.

Data collection

Cows were milked twice per day in a 20-unit aside swing-over dairy with automatic cup removers. All concentrate supplementation was provided individually in the dairy by an automated feeding system, checked weekly to ensure that concentrate delivery amounts from each individual feeder were accurate. Each cow had their own individual numbered ear tag as well as a National Livestock Identification System (NLIS) ear tag, which contained an electronic radio-frequency identification device (RFID). The tag had a unique ID number that could be read by sensors in the dairy. This system is used to ID individual cows as they enter the dairy for milking, or when they pass over the walk-over scales to measure BW. The dairy at TDRF uses DeLaval equipment (DeLaval International AB, Tumba, Sweden), including DeLaval's DELPRO® system, which uses the cow's RFID device to control and collect data for each individual cow and during each milking, using walk-over scales (DeLaval AWS100 automatic weighing system) for BW, the concentrate feeding system in the dairy (DeLaval individual bail concentrate feeding system), and the DeLaval milking-point controller MPCII with DeLaval milk meter MM27BC, which is an ICAR (International Committee for Animal Recording)-accredited milk-monitoring system. Each cow was fitted with a neck collar-mounted activity and behaviour monitoring system, MooMonitor+ (Dairymaster Inc., Kerney, Ireland). The commercially available MooMonitor+ uses a three-dimensional accelerometer to determine cow movement and head direction, and, on the basis of proprietary algorithms, distinguishes among feeding, ruminating and resting behaviours. Using the MooMonitor+, cows were continuously monitored, and the time each cow spent feeding, ruminating and resting reported as minutes per 15-min time block.

Feed analysis

Concentrate samples were collected each time the silo was filled. Samples were analysed by wet chemistry at Cumberland Valley Analytical Services, Waynesboro, PA, USA. Pre-grazing pasture samples (taken above residual height) were collected approximately once a week for a consecutive AM and PM pasture allocation throughout the 2017–2018 milking

Table 1. Experimental design, using 180 cows selected at the start of the 8-month experiment, with mean parameters at the start of the trial.

Parameter tested	Balanced for	Parameter difference	Number of cows	Concentrate kg DM	Cohort	Number of cows	Mean production (L/day) (s.d.)	Mean bodyweight (kg) (s.d.)
Genotype	Bodyweight, production	Friesian genotype (GF)	30	2	GF2	15	22.5 (3.94)	473 (53.0)
				6	GF6	15	24.4 (2.86)	489 (32.3)
		Cross-breed genotype (GC)	30	2	GC2	15	22.8 (1.95)	470 (35.3)
				6	GC6	15	21.5 (1.74)	454 (53.6)
Production at start of lactation	Bodyweight, genotype	High current production (PH)	30	2	PH2	15	26.1 (3.00)	497 (30.1)
				6	PH6	15	26.2 (2.12)	493 (32.3)
		Low current production (PL)	30	2	PL2	15	19.8 (2.49)	455 (45.5)
				6	PL6	15	19.7 (2.72)	466 (45.1)
Bodyweight as proxy for size	Production, genotype	Bodyweight high (WH)	30	2	WH2	15	24.3 (3.48)	580 (42.8)
				6	WH6	15	24.5 (3.86)	591 (57.8)
		Bodyweight low (WL)	30	2	WL2	15	21.4 (2.53)	424 (16.5)
				6	WL6	15	21.9 (2.06)	426 (26.3)

season. Samples were dried at 60°C and ground through a 0.1 mm sieve. Ground dried samples were analysed (Table 2) using near-infrared (NIR) analysis at Cumberland Valley Analytical Services (Waynesboro, PA, USA).

Milk yields

At each of the two daily milking events, each cow's milk yield (L) was recorded using the DeLaval milk metering system. Milk-composition samples were collected during alternate morning or afternoon milkings on 1 day in each month of the trial. Milk samples were assayed for fat and protein concentrations (% as w/v), and for somatic cell count (SCC) by using a Bentley B2000 Infrared Milk Analyser (Bentley Instruments Inc., Chaska, MN, USA) by TasHerd Pty Ltd (Hadspen, Tas., Australia).

Milk yields from once monthly alternating AM or PM herd tests were converted to fat and protein-corrected milk (FPCM) production for each month and cohort. FPCM was calculated using the following equation derived from Tyrrell and Reid (1965):

$$\text{FPCM (L)} = \text{milk yield (L)} \times ((0.383 \times \%\text{fat} + 0.242 \times \%\text{protein} + 0.7832)/3.140).$$

Bodyweight

Cow BW was measured twice daily with automatic in-race walk-over scales (DeLaval AWS100 automatic weighing system) as animals exited the dairy. The AWS100 utilises an algorithm that discounts recorded weights that differ greatly from the 7-day mean weights for individual animals (e.g. instances when more than one cow is on the scales at any one time). We used the 7-day average weight data as reported by the AWS100.

Table 2. Mean results per period for pasture quality (NIR analysis) obtained from pasture samples taken pre-grazing either before the AM or PM grazing throughout the trial, and mean wet-chemistry analysis results per period for pelleted concentrate.

Feed	Period	ME (MJ)	CP (%)	NDF (%)	ESC (%)	Fat EE (%)	TDN (%)	Starch (%)
Pasture	P1	11.4	18.0	43.8	8.7	3.6	72.3	
	P2	10.3	16.5	53.4	5.6	3.7	66.4	
	P3	11.0	23.2	47.2	5.8	4.1	70.1	
Concentrate	P1	11.8	11.3	24.1	3.3	2.2	74.6	48.2
	P2	11.8	14.4	24.5	4.8	3.1	74.4	38.9
	P3	11.3	14.7	25.0	5.6	3.5	71.7	34.9

Results are for DM. The cows in this trial were spring-calving, and P1 is spring, P2 late spring–summer, and P3 late summer–autumn.

Data analyses

Results were analysed separately for each of the three parameters (genotype, production and BW) and periods. Data for milk yield, time feeding, rumination and resting, and BW were averaged across fortnights, with P1 consisting of five fortnights from early September until mid-November, P2 of six fortnights from mid-November until early February, and P3 of five fortnights from early February until mid-April. Outcomes were analysed statistically within a linear mixed-modelling framework in which the experimental units are given by Cow ID, for which a random-effects model was applied, with cow ID as the random effect and treatment (parameter × feeding level) as the fixed effect. Calculations were performed using Proc mixed and Proc PLM in SAS ver. 9.4. For all terms in the resulting model, the predicted means with standard errors and 95% confidence intervals were reported. Contrasts of pairs of specific treatments were calculated. These were shown as the mean differences with standard errors of the differences. Contrasts were tested for equality; significance is reported under adjusted *P*-values. Significances of contrasts were adjusted for multiplicity using Scheffe's method. Confidence intervals for the contrasting parameter difference are shown, including after adjustment for multiplicity. Diagnostic plots were examined to assess conformance to modelling assumptions. The statistical analysis results report per cohort the fortnightly predicted means with standard errors, and the levels of adjusted *P*-values between the contrasting 6 kg and 2 kg DM treatments for each of the correlated cohorts as an indicator of the size of responses (Tables 3, 4 and 5 for the genotype, production and weight cohorts respectively).

Ethics

Animal ethics approval was granted prior to all animal procedures (University of Tasmania Animal Ethics Committee, A0016635) according to guidelines set out in the *Tasmanian Animal Welfare Act 1993*, and the 'Australian code of practice for the care and use of animals for scientific purposes, 8th edition' (National Health & Medical Research Council Australia 2013).

Results

Feed quality

Cows grazed ryegrass (*Lolium perenne*)- and white clover (*Trifolium repens*)-dominated pastures for the duration of the trial. Pasture quality ranged for metabolisable energy (ME) from 9.3 to 12.1 MJ (mean 10.9 MJ), crude protein (CP) from 12.6% to 25.5% (mean 18.5%) and neutral detergent fibre (NDF) from 39% to 63% (mean 48.1%). In total, 50 pasture samples were analysed, with the mean per period showing the lowest ME and CP and highest NDF in P2 (late spring–summer) (Table 2). In P2 and P3 (late summer–autumn),

Table 3. Results as adjusted mean and s.e. per cow per day for all genotype cohorts and each period, for milk, feeding (Feed), rumination (Rumin) and resting minutes (Rest), and 7-day average bodyweight (kg BW) at the end of each period.

Cohort	Period	Milk (L)	s.e.	P	Feed (min)	s.e.	P	Rumin (min)	s.e.	P	Rest (min)	s.e.	P	BW (kg)	s.e.	P
GF2	P1	21.6	0.78		499	10.3		499	9.6		341	13.0		480	11.3	
GF2	P2	16.5	0.64		467	10.3		547	8.7		302	10.0		507	11.8	
GF2	P3	12.8	0.48		476	9.5		443	9.0		403	13.4		495	11.3	
GF6	P1	25.4	0.78	0.013	459	9.5	0.196	500	9.6	1.000	364	13.0	0.682	481	11.3	1.000
GF6	P2	20.6	0.64	<0.001	475	15.9	0.658	538	8.7	0.922	320	10.0	0.674	509	11.8	0.999
GF6	P3	16.6	0.46	<0.001	443	15.2	0.573	436	8.7	0.965	426	12.9	0.691	512	10.9	0.829
GC2	P1	22.6	0.77		502	10.0		477	9.6		356	12.8		456	11.3	
GC2	P2	17.2	0.64		438	10.3		529	8.7		301	10.0		483	11.8	
GC2	P3	12.8	0.44		493	9.5		430	8.4		398	12.4		478	10.5	
GC6	P1	23.4	0.78	0.915	442	9.5	<0.001	485	9.6	0.959	394	13.0	0.233	450	11.3	0.987
GC6	P2	19.7	0.64	0.062	489	14.7	0.005	532	8.7	0.998	337	10.0	0.113	485	11.8	1.000
GC6	P3	16.2	0.44	<0.001	428	14.7	0.046	420	8.4	0.851	450	12.4	0.045	492	10.5	0.829

The adjusted *P*-value (*P*), adjusted for multiplicity using Scheffe's method, is reported for the 6 kg DM cohorts, analysed for the difference from the corresponding 2 kg DM cohort. GF and GC are the genotype, Friesian and cross-breed cohorts respectively, with 2 or 6 indicating the kg DM concentrate supplemented to each cohort. The cows were spring-calving, and P1 is spring, P2 late spring–summer, and P3 late summer–autumn.

Table 4. Results as adjusted mean and s.e. per cow per day for all production cohorts and each period, for milk, feeding (Feed), rumination (Rumin) and resting minutes (Rest), and 7-day average bodyweight (kg BW) at the end of each period.

Cohort	Period	Milk (L)	s.e.	P	Feed (min)	s.e.	P	Rumin (min)	s.e.	P	Rest (min)	s.e.	P	BW (kg)	s.e.	P
PH2	P1	24.0	0.72		503	9.2		504	8.2		332	10.3		477	11.2	
PH2	P2	17.8	0.57		481	9.8		555	7.5		290	10.1		505	11.8	
PH2	P3	13.7	0.50		462	15.4		460	8.0		394	13.4		499	12.5	
PH6	P1	26.5	0.72	0.121	451	9.2	0.003	509	8.2	0.974	366	10.3	0.148	481	11.2	0.996
PH6	P2	21.5	0.57	<0.001	453	9.8	0.247	542	7.5	0.648	326	10.1	0.098	514	11.8	0.965
PH6	P3	18.2	0.50	<0.001	458	15.4	0.999	437	8.0	0.258	428	13.4	0.369	517	12.5	0.796
PL2	P1	19.6	0.72		510	9.2		488	8.2		339	10.3		438	11.2	
PL2	P2	14.8	0.57		501	9.8		548	7.5		287	10.1		461	11.8	
PL2	P3	11.7	0.48		494	14.8		439	7.7		391	12.9		459	12.1	
PL6	P1	23.0	0.72	0.017	461	9.2	0.005	498	8.2	0.877	366	10.3	0.350	468	11.2	0.323
PL6	P2	19.2	0.57	<0.001	454	9.8	0.017	542	7.5	0.953	319	10.1	0.187	507	11.8	0.070
PL6	P3	16.4	0.48	<0.001	449	14.8	0.211	426	7.7	0.688	432	12.9	0.177	516	12.1	0.017

The adjusted *P*-value (*P*), adjusted for multiplicity using Scheffe's method, is reported for the 6 kg DM cohorts, analysed for the difference from the corresponding 2 kg DM cohort. PH and PL are the production at start of lactation, high and low cohorts respectively, with 2 or 6 indicating the kg DM concentrate supplemented to each cohort. The cows were spring-calving, and P1 is spring, P2 late spring–summer, and P3 late summer–autumn.

grass silage was supplemented to fill the feed gap when pasture growth was insufficient. During these occasions, the amount of silage fed was usually ~20% of the diet, with the long-term average silage quality at TDRF typically ~9.7 MJ ME, 13.6% CP and 53.5% NDF. The calculated energy content in the pelleted concentrate ranged from 10.9 to 11.9 MJ ME, and CP from 11.2% to 17.6%. The means per period for the nutrients analysed are shown in Table 2. The higher CP in the concentrate in P2 and P3 is due to an increased protein concentration from the start of P2 onward, to account for the decline in %CP in the pasture that time of the year, and the silage fed in P2 and P3 with a lower %CP than for pasture.

Cohort responses

The fortnightly predicted means with standard errors and adjusted *P*-values between concentrate supplementation at the 6 kg DM (6 kg) and their contrasting treatments at 2 kg DM (2 kg) for genotype, production and BW are

Table 5. Results as adjusted mean and s.e. per cow per day for all bodyweight (as proxy for cow size) cohorts and each period, for milk, feeding (Feed), rumination (Rumin) and resting minutes (Rest), and 7-day average bodyweight (kg BW) at the end of each period.

Cohort	Period	Milk (L)	s.e.	*P*	Feed (min)	s.e.	*P*	Rumin (min)	s.e.	*P*	Rest (min)	s.e.	*P*	BW (kg)	s.e.	*P*
WH2	P1	24.3	0.71		494	10.1		505	9.1		342	11.5		547	9.3	
WH2	P2	18.3	0.58		471	10.4		557	7.9		305	9.4		576	8.7	
WH2	P3	13.8	0.48		455	13.3		467	8.8		399	12.3		563	8.6	
WH6	P1	27.9	0.74	0.012	455	10.4	0.074	488	9.4	0.638	385	11.9	0.096	561	9.6	0.810
WH6	P2	21.6	0.60	0.003	447	10.8	0.483	535	8.2	0.282	338	9.7	0.120	595	9.0	0.523
WH6	P3	17.6	0.50	<0.001	452	13.9	1.000	438	9.1	0.172	434	12.8	0.298	594	8.9	0.118
WL2	P1	19.6	0.71		519	10.1		479	9.1		340	11.5		413	9.3	
WL2	P2	14.6	0.58		509	10.4		538	7.9		288	9.4		437	8.7	
WL2	P3	11.1	0.52		491	14.4		431	9.5		400	13.3		436	9.3	
WL6	P1	23.0	0.71	0.018	476	10.1	0.042	504	9.1	0.301	346	11.5	0.991	420	9.3	0.964
WL6	P2	18.8	0.58	<0.001	464	10.4	0.037	542	7.9	0.988	301	9.4	0.791	454	8.7	0.577
WL6	P3	16.0	0.52	<0.001	464	14.4	0.622	436	9.5	0.985	401	13.3	1.000	458	9.3	0.428

The adjusted *P*-value (*P*), adjusted for multiplicity using Scheffe's method, is reported for the 6 kg DM cohorts, analysed for the difference from the corresponding 2 kg DM cohort. WH and WL are the bodyweight, high (as proxy for large cows) and low (as proxy for small cows) cohorts respectively, with 2 or 6 indicating the kg DM concentrate supplemented to each cohort. The cows were spring-calving, and P1 is spring, P2 late spring–summer, and P3 late summer–autumn.

presented in Tables 3, 4, 5. The 6 kg cohorts that achieved a significant ($P < 0.05$) difference in milk yield compared with the 2 kg cohort were for GF6 in all periods and GC6 in P3; PH6 in P2 and P3 and PL6 in all periods; and both WH6 and WL6 in all three periods. There was a significant difference for feeding time for GC6 in all three periods; PH6 in P1 and PL6 in P1 and P2; and WL6 in P1 and P2. A significant difference was found for resting time only for GC6 in P3, and for BW only for PL6 in P3. No significant difference was found for rumination time.

The mean for all cohorts and all periods for milk yield, and feeding, rumination and resting time (minutes per cow) per day was 18.85 L, and 472, 492 and 360 min respectively. The mean results for cohorts in each of the three parameters tested were very similar and the difference to the mean for each of the three parameters ranged from −0.05 to 0.08 L, −2.95 to 4.16 min, −3.85 to 5.42 min, and −6.46 to 6.59 min for milk yield and feeding, rumination and resting respectively. The differences between the 6 kg and their contrasting 2 kg cohorts are reported in Tables 6 and 7 and are calculated from the statistically analysed results presented in Tables 3, 4, 5. The calculated results include marginal milk responses, and are reporting the difference between cohorts, and provide comparison for the results that differ significantly. Mean marginal milk response (L milk per 1 kg DM extra of concentrate) for all 6 kg cohorts over the trial period was 0.88 L, increasing from 0.71 L in P1, to 0.92 L in P2 and 1.03 L in P3 (Table 6). GF, PL and WL achieved the highest marginal response, whereas GC achieved the lowest.

The higher level of concentrate supplementation resulted in a mean reduction in feeding time (a proxy for pasture substitution) of 37 min per cow per day between all 6 kg and 2 kg cohorts, and the difference reduced from 46 to 29 min from P1 to P3, with GC6 showing the greatest overall reduction (58 min, Table 6). The higher amount of concentrate supplementation resulted in a mean reduction in rumination time of 5 min per cow per day (1% of total rumination time) between all 6 kg and 2 kg cohorts, with P1 reporting an increase of 5 min rumination time, reducing to −13 min in P3 (Table 6). Resting time increased for all 6 kg cohorts by 29 min, with not much difference among periods (Table 6), and the overall average was 360 min (6 h) per day resting.

The ratio between the difference in feeding minutes per cow per day and litres milk yield between 6 kg and 2 kg cohorts was used, to infer a magnitude of substitution of pasture by concentrate (i.e. more substitution, as indicated by a greater reduction in feeding time, will result in a lower ratio value). The 6 kg supplementation resulted in a mean ratio of difference in feeding minutes to difference in litres of milk of −10.5 between all 6 kg and 2 kg cohorts, with that ratio increasing (less pasture substitution) from −16.3 in P1 to −7.0 in P3. The lowest overall mean ratio for GC at −26.5 (Table 6), with a nadir for GC in P1 of −89.8 (Table 7), indicated the largest pasture substitution.

The mean differences between each 6 kg and 2 kg cohorts and each period are reported in Table 7. The smallest marginal milk response (0.18 L/kg DM) was for GC in P1, and the highest (1.22 L/kg DM) for WL in P3. The GC6 cohort showed the largest reduction in feeding time (i.e. largest pasture substitution) for all three periods, compared with all other cohorts. This was reflected in the feeding to milk ratio, especially in P1 (−89.8, Table 7).

Results from once monthly alternating AM or PM herd tests were investigated to calculate the mean litre FPCM production for each month and cohort. The results of these

Table 6. Calculated difference from the mean results per cow per day between 6 kg and corresponding 2 kg cohorts (i.e. GF6 vs GF2), for milk, feeding, rumination and resting, and the marginal response per 1 kg DM of concentrate fed extra to the 6 kg cohorts and the ratio between milk and feeding, for the whole period (All), and periods P1, P2 and P3.

Period	Cohort	Marginal response (L/kg DM)	Milk (L/day)	Feeding (min/day)	Rumination (min/day)	Resting (min/day)	Ratio feeding to milk
P1	ALL 6–2	0.71	2.85	−46.5	5.2	28.7	−16.3
P2	ALL 6–2	0.92	3.69	−35.0	−7.3	27.9	−9.5
P3	ALL 6–2	1.03	4.14	−28.9	−13.3	31.5	−7.0
All	ALL 6–2	0.88	3.53	−37.1	−5.1	29.4	−10.5
All	GF 6–2	0.95	3.81	−26.1	−6.3	22.0	−6.9
All	GC 6–2	0.55	2.20	−58.3	0.1	42.2	−26.5
All	PH 6–2	0.89	3.55	−29.5	−9.8	35.2	−8.3
All	PL 6–2	1.04	4.16	−46.9	−3.0	32.8	−11.3
All	WH 6–2	0.88	3.53	−22.3	−22.7	36.6	−6.3
All	WL 6–2	1.02	4.09	−39.1	11.3	7.5	−9.6

These results are reported for all 6 kg and 2 kg cohorts combined (ALL 6–2), as well as corresponding cohorts separately. GF, GC, PH, PL, WH and WL are the genotype Friesian, genotype cross-breed, production high, production low, weight high and weight low cohorts respectively, with 6–2 indicating the 6 minus 2 kg DM results for each contrasting cohort. The cows were spring-calving, and P1 is spring, P2 late spring–summer, and P3 late summer–autumn.

Table 7. Calculated difference from the mean results per cow per day reported in Tables 3, 4 and 5, between 6 kg and corresponding 2 kg cohorts (i.e. GF6 vs GF2), for milk, feeding, rumination and resting, and the marginal response per 1 kg DM of concentrate fed extra to the 6 kg cohorts and ratio between milk and feeding, for periods P1, P2 and P3. GF, GC, PH, PL, WH and WL are the genotype Friesian, genotype cross-breed, production high, production low, weight high and weight low cohorts respectively.

Period	Cohort	Marginal response (L/kg DM)	Milk (L/day)	Feeding (min/day)	Rumination (min/day)	Resting (min/day)	Ratio feeding to milk
P1	GF 6–2	0.94	3.77*	−32.1	0.6	22.6	−8.5
P2	GF 6–2	1.03	4.12*	−17.0	−8.6	17.6	−4.1
P3	GF 6–2	0.95	3.79*	−31.2	−6.5	22.6	−8.2
P1	GC 6–2	0.18	0.73	−65.4*	7.4	41.4	−89.8
P2	GC 6–2	0.63	2.50	−50.3*	2.4	35.5	−20.1
P3	GC 6–2	0.84	3.37*	−60.9*	−10.5	51.7*	−18.0
P1	PH 6–2	0.63	2.52	−51.2*	5.5	34.5	−20.3
P2	PH 6–2	0.94	3.76*	−28.7	−13.6	36.5	−7.6
P3	PH 6–2	1.13	4.52*	−3.5	−23.1	34.0	−0.8
P1	PL 6–2	0.85	3.40*	−49.0*	9.6	26.8	−14.4
P2	PL 6–2	1.10	4.39*	−46.3*	−6.1	31.7	−10.5
P3	PL 6–2	1.18	4.71*	−45.3	−13.2	41.3	−9.6
P1	WH 6–2	0.89	3.56*	−39.3	−17.1	42.8	−11.0
P2	WH 6–2	0.82	3.29*	−23.7	−22.5	33.3	−7.2
P3	WH 6–2	0.94	3.78*	−2.4	−29.0	34.5	−0.6
P1	WL 6–2	0.83	3.32*	−42.2*	25.0	5.4	−12.7
P2	WL 6–2	1.05	4.20*	−44.4*	4.1	13.5	−10.6
P3	WL 6–2	1.22	4.88*	−27.2	5.2	1.0	−5.6

Asterisk indicates that values are significantly ($P < 0.05$) different from their corresponding cohort in Tables 3, 4 or 5. The cows were spring-calving, and P1 is spring, P2 late spring–summer, and P3 late summer–autumn.

8 monthly herd tests (not reported) indicated that FPCM response generally was higher than the litre response. The only exception was for WL, for which the mean litre FPCM tended to be just below the litre response.

Bodyweight

The mean 7-day average BW per cow at the end of each period, as a mean for all cohorts and all periods, was 492 kg. The mean BW results for the cohorts in each of the three parameters tested were very similar and within ±10 kg of the mean of 492 kg. Similar change trends between cohorts were observed over the trial period for the 7-day mean BW at the end of each period, i.e. a drop from recruitment (9–15 DIM) to the end of the adaptation period (mean 27 DIM), a start of recovery in BW by the end of P1 (mean 97 DIM), an increase of BW by the end of P2 (mean 181 DIM), and another small increase by the end of P3 (mean 251 DIM). Overall, the 7-day mean BW gain for all cohorts was 23 kg from recruitment. The mean weight gain between the end of P1 and the end of P3 for all cohorts was 29 kg. All 2 kg cohorts gained 20 kg BW, and the 6 kg cohorts achieved a 38 kg BW gain. Only cohort PL6 reached significance (adj. $P < 0.05$) for BW at the end of P3 compared with PL2 (Table 4), gaining an extra 27 kg BW between the end of P1 and P3 compared with PL2. Cohort PH6 only gained 14 kg more compared with PH2. The 6 kg cohorts WH6 and WL6 had similar additional gains (18 and 15 kg respectively) compared with WH2 and WL2, which is similar to the mean 18 kg higher gain for all 6 kg cohorts.

Discussion

One of the motives for farmers to feed supplementary concentrate to their pasture-based dairy herds is to improve productivity of their cows. While cows respond to being fed extra concentrate with changes in milk volume and composition, they also can change their feeding behaviour in pasture. Hence, a significant difference in cow responses may not be achieved because of differing levels of individual pasture substitution and BW change resulting from the extra concentrate fed, as well as changes in NDF digestibility (Dixon and Stockdale 1999; Roche *et al.* 2017). For instance, Stockdale (1999) found over seven experiments, a substitution rate of 0.4 kg DM pasture per 1 kg DM concentrate (ranging between 0.3 and 0.5) in trials between unsupplemented cows, and cows supplemented with an average of 4.7 kg DM of concentrate. However, in this 8-month-long investigation involving cows selected for a specific parameter, we found over the whole period and all cohorts a marginal response of 0.88/L per kg DM of concentrate fed extra (Table 6), with some cohorts and periods achieving a marginal response >1.00 L (Tables 6, 7).

Milk

The treatment cows in this investigation received a flat rate of 6 kg DM of concentrate per day, 4 kg DM more per day than did the control cows. Although a positive response for milk yield is expected when feeding more supplementary concentrate, substitution effect diminishes its overall effect (Bargo *et al.* 2003; Wales and Kolver 2017). A kilogram DM of concentrate has an approximate ME content equal to the requirement of producing 2 L of milk. However, the mean marginal response during this trial was 0.88 L. Table 7 shows the highest marginal response at 1.22 L for the WL6 cohort in P3, and the lowest at 0.18 L for GC6 in P1. The lowest response for all 6 kg cohorts (Table 6) was in P1 (0.71), increasing towards the highest response in P3 (1.03). The pasture quality is lowest in late spring and summer (P2). And under dry conditions such as those that occur in P2 at the trial site, pasture growth can reduce, necessitating supplementing the diet with silage of quality below that of pasture. The highest response was in autumn (P3), when pasture growth reduces because of declining temperatures, with pasture growth dropping below herd requirement, necessitating supplementing the diet with silage. The 6 kg cohorts produced 2.9 L (13.2%) more milk in P1, and showed a more persistent milk production, declining less in milk in P2 with 4.6 L (18.6%) and 3.4 L (13.7%) in P3, totalling 8.0 L (32.3%), than the 2 kg cohorts which declined 5.4 L (24.7%, and 3.9 L (17.6%) respectively, totalling 9.3 L (42.3%). We postulate that if this trial had continued until the end of lactation, the marginal responses for the 6 kg cohorts would have increased, similar to findings by Kellaway and Porta (1993), Thompson and Holmes (1995) and Roche *et al.* (2013). In P1, the strongest response to the extra concentrate fed was for the GF6 cohort and the PL6 and WL6 cohorts (Table 7). Underlying causes could be that the Friesian genotype is genetically inclined to produce more milk, and the PL cows struggled in early lactation to reach a normal milk peak when they were recruited into the trial (at 9–15 DIM), with the extra concentrate from then onwards helping them reach a normal peak. Cabezas-Garcia *et al.* (2021) reported cows normally achieving 85–90% of their peak at ~2 weeks in milk (when we recruited cows into the trial), and their milk production peak approximately 5–7 weeks in milk (which was in P1 for cows in our trial). We postulate that the smaller cows in WL might suffer more competition from bigger cows in the herd, reducing opportunities to feed, and that impact might have been lessened with the additional concentrate fed. Cross-breed cows have a lower proportion of Friesian genotype than do GF, and the GC6 cohort had the lowest milk response, most pronounced in P1 (Table 7). The low response of the GC6 cows supports the general consensus that cross-breed cows are better suited for low supplemental concentrate-input grazing systems.

The results from the 8-monthly herd test FPCM response investigation, which indicated that the L FPCM response (adjusted to a standard concentration of 4.00% fat and 3.40% protein) by the 6 kg cohorts generally was higher than the litre response, was expected because this is a reflection of the mean fat and protein concentration in the milk from the whole herd, which was 4.67% fat and 3.45% protein for the 2017–2018 season. However, higher milk-yield responses to feeding extra concentrate can cause some reduction of fat and protein concentration owing to higher rumen fermentation rates compared with forages (Auldist *et al.* 2013, 2014). We indeed found that with higher milk-yield responses, the difference in FPCM responses tended to diminish somewhat compared with litre responses. For all 6 kg cohorts, overall response in FPCM was greater than was the response in litre. The only exception was for WL, for which the mean FPCM tended to be just below the litre response, mostly owing to low fat and protein concentrations in P1.

Feeding time

Soca *et al.* (2014) found in a trail similar to our investigation, lower grazing time and lower DM intake from pasture (measured using the chromic oxide method) for cows grazing unrestricted pasture and receiving 6 kg than for cows receiving 3 kg of concentrate. The overall reduction in feeding time in this investigation for the 6 kg compared with the 2 kg cohorts was 37 min per cow per day, with the largest reductions in feeding time for 6 kg cohorts being in P1 with 47 min (Table 6). This is when the herd had access to high-quality spring grass similar in quality to concentrate, and hence with a small difference in rumen fill between these two feeds. When the average diet quality reduced in P2 and P3 (the forage became more rumen filling than was concentrate), the difference in feeding time dropped to 35 min in P2 and 29 min in P3 (Table 6). Using change in feeding time (minutes per cow per day) as proxy for substitution of pasture intake, the feeding time dropped, on average, overall for the 6 kg cohorts with 9.3 min extra per kilogram DM concentrate. As reported in Bargo *et al.* 2003, this is in the range found by Arriaga-Jordan and Holmes (1986), Kibon and Holmes (1987) and Bargo *et al.* (2002), who reported a mean grazing-time reduction per extra kilogram DM concentrate supplemented of 9.9 min, ranging between 8.3 and 12.3 min. The largest reduction in feeding time overall was for the GC6 cohort (58 min, Table 6), and in P1 with a low milk response, the feeding time for GC6 declined 65 min (Table 7), resulting in the lowest feeding to milk ratio of −89.8 (Table 7). Generally, the reduction in feeding time and the ratio for feeding to milk diminish as lactation progresses (Table 6, All 6–2, P1, P2 and P3), partially also due to the mid- to late lactation cow directing some of the energy intake towards recovery of body reserves as evidenced in this study by the 6 kg cohorts gaining more weight than the 2 kg cohort.

Rumination and resting time

Differences in rumination time exist, but they are generally small. This is not unexpected, because even though concentrate triggers less rumination per kilogram DM than does forage, and some of that forage is substituted, a total increase in DM intake when feeding more concentrate moderates that impact (Mertens 1997; Bargo *et al.* 2002). None of the results for rumination time in the 6 kg cohorts was significantly different from the others (Tables 3, 4, 5). The longest rumination times were recorded for P2, the period with the highest NDF concentrations (i.e. the lowest diet quality), and as a reflection P2 also recorded the shortest resting time. The MooMonitor+ sensors report only feeding, rumination and resting time, which leaves unreported for the daily time budget of a cow (1440 min) the not classified time, which cows spend on behaviours such as walking (mostly between dairy and paddocks), socialising, and drinking water. The unclassified time was 117 min/cow.day over the trial period (not reported), with hardly any variation between cohorts. Hence, the increase in resting time for the 6 kg cohorts was due to an overall decrease in the combined time for feeding and ruminating. Resting time (i.e. no activity) as reported by MooMonitor+ is different from the resting time, i.e. referring to lying time, often reported for cows in housed systems. Resting time for the 6 kg cohorts was higher with a mean of 29 min per cow per day overall (Table 6). The mean resting time within the 6 kg as well as within the 2 kg cohorts varied little within each period. The overall resting time was 345 min (5.75 h) for 2 kg cohorts and 374 min (6.25 h) for 6 kg.

BW

Bodyweight changes were similar for both treatments, but all 6 kg cohorts gained more weight than did 2 kg cohorts. In an invited review, Roche *et al.* (2009) reported correlations between BW and body condition score (BCS). Enevoldsen and Kristensen (1997) investigated the correlation between BCS and BW and stated that a 50 kg increase in BW with each unit of increase on the 5-point BCS scale is a generally accepted rule of thumb in Denmark (p. 1995). Using BW as proxy for BCS in this trial with only multiparous cows, the difference in BW gain corroborated that feeding a higher amount of concentrate can also be used strategically to gain BCS in mid- to late lactation when need be. However, if cows have reached their BCS target, a reduction in the amount of supplemented concentrate could be warranted to avoid over-conditioning these cows; this could be investigated in future research. BCS recovery when not lactating is less efficient, with the same BCS gain requiring about 26% extra energy (Freer *et al.* 2007). And intending for a cow to gain a mean of 23 kg BW during the dry period would require an additional 3 kg DM intake per day over a period of 45 days, which is difficult to achieve under current dry period conditions and diets for spring-calving pasture systems in Oceania. However, body condition gain in late lactation should be monitored, and the concentrate supplementation reduced if BCS moves above target levels.

General

All 6 kg cohorts spent less combined time feeding and ruminating, resulting in an increase of resting time. Whereas understanding impacts of changes in resting time on production and feeding behaviour of dairy cows in pasture-based systems warrants further research, we postulate that with the average 360 min (6 h) resting time per cow per day, that resting time was not limiting production in this trial. We postulate that for cows with production levels and diets as in this trial, there is still some scope to adjust transition management of those cows in a direction that increases the peak milk production, and, consequently, the appetite of the cows, converting some of the resting time to grazing and rumination time.

Feeding a higher amount of concentrate to lactating dairy cows inherently comes with increased inefficiencies such as those associated with wastage of feed, partitioning of nutrients, and NDF digestibility (Roche *et al*. 2017). In this trial, we postulate that the following energy flows from DM intake may have occurred. The mean marginal response for all 6 kg cows was 0.88 L of milk (ME requirement 5.85 MJ/L) per 1 kg DM of extra concentrate fed, which, on the basis of its energy density, requires ~0.50 kg DM of that concentrate. Feeding-time reduction was 37 min, which infers a reduced pasture intake (substitution) of 0.28 kg DM assuming 1.8 kg DM pasture intake per hour feeding time (on the basis of the daily feeding time in this trial and findings by Bargo *et al*. (2002)). The additional weight gain for the 6 kg cohorts was 23 kg, which is approximately a BCS score of 0.5 in the 8-point Australian BCS scoring system, which requires over the duration of this trial about 0.10 kg DM per day to achieve. Combining the marginal response in milk, reduced pasture intake, and extra BW gain, this could account for a total of 0.88 kg DM for each kg DM concentrate fed, leaving 0.12 kg unaccounted for, which could be labelled 'loss owing to inefficiencies'.

Conclusions

Under the conditions of this trial, the difference in milk and feeding behaviour response among some cohorts of spring-calving dairy cows to supplementing extra 4 kg DM of concentrate demonstrated potential for targeted concentrate supplementation to these cohorts of cows. The GC cohort was least responsive with milk to the extra concentrate, while showing the largest feeding-time reduction (i.e. largest substitution) in spring (P1). Targeting the GF, PL and WL cohorts with extra concentrate resulted in a much higher milk response, indicating that cohorts of cows that genetically are inclined to higher milk yields (GF), and cows that are not achieving the herd average peak milk production in early lactation (PL and WL), could benefit more from extra concentrate supplementation. Extra concentrate intake can lead to a higher peak milk production, and a more persistent lactation performance for milk. Feeding-time reduction, as an indicator for substitution of grass intake with concentrate, was most prominent when milk response was low (such as in P1 for GC and PH), but all cohorts receiving the high amount of concentrate reduced their feeding time, i.e. substituted some pasture with concentrate. Findings of this investigation can also be used to inform individual-cow feeding strategies, which in the context of large pasture-based herds, calving seasonally, includes feeding different groups of cows within the herd differently. When strategically feeding high amounts of concentrate, transition management should support cows in achieving a high milk peak, and late lactation BCS should be monitored to avoid over-feeding cows that have reached their BCS target. When a strategic decision is made to change the amounts of supplemental concentrate significantly, the impact not only on marginal milk response should be considered, but also on pasture intake, and the response differed between cohorts of cows that differ for the parameters tested.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

Conflicts of interest. James Hills is a guest Associate Editor of *Animal Production Science*. To mitigate this potential conflict of interest they were blinded from the review process. All other authors declare no conflicts of interest.

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