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The Impact on Cow Performance and Feed Efficiency When Individual Cow Milk Composition and Energy Intake Are Accounted for When Allocating Concentrates

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Abstract: The objective of this three-treatment, 12-week study (involving 69 dairy cows) was to test three methods of concentrate allocation on milk production efficiency. All treatments were offered a basal mixed ration of grass silage and concentrates, with additional concentrates offered to individual cows based on either milk yield alone (Control), milk energy output (Precision 1) or energy intake and milk energy output (Precision 2). Concentrate requirements were calculated and adjusted weekly. Control cows had lower concentrate dry matter intake (DMI; $p = 0.040$) and milk protein content ($p = 0.003$) but yield of milk and energy-corrected milk (ECM), energy balance, bodyweight and condition score were unaffected by treatment. Efficiency measures such as ECM/DMI and ECM/metabolizable energy intake were also unaffected by treatment. Less concentrates were used per kg ECM yield in the Control compared to the Precision treatments ($p < 0.001$). In conclusion, accounting for individual cow milk composition or milk composition combined with individual cow energy intake did not improve production efficiency compared to an approach based on individual cow milk yield only.

Keywords: dairy cow; milk production efficiency; concentrate allocation; feed-to-yield

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1. Introduction

While individual cow concentrate inputs have increased in many countries in recent years, the higher cost of concentrates relative to forage [1] dictates that concentrates must be used efficiently if their inclusion in dairy cow diets is to improve overall farm profitability. Improved efficiency might be achieved through 'precision feeding' approaches. For example, on larger farms, the establishment of multiple nutritional groups allows increased precision to be introduced at a group level, with groups normally reflecting stage of lactation. However, precision feeding can be taken a stage further by exploiting within-herd variation. This normally involves increasing the quantity of concentrates that are offered to cows with greater milk yields and reducing the quantity of concentrates offered to lower yielding cows. Offering concentrates on an individual cow basis may improve productivity, efficiency, and lead to savings in feed costs [2].

Within the United Kingdom (UK), many farms adopt a feed-to-yield (FTY) approach to concentrate feeding, especially when cows are housed. While specifics vary between farms, commonly, a forage or forage-concentrate mix (basal ration) is offered and this is assumed to supply sufficient nutrients to meet the cow's maintenance energy requirements plus a given quantity of milk. Additional concentrates are then offered to individual cows on a FTY basis to support milk production above the yield that the forage/basal ration is assumed to support. However, while FTY systems are widely adopted, the literature provides little evidence that either performance or efficiency is improved when FTY systems are compared to 'flat-rate' feeding systems [3–6]. However, the majority of these studies targeted equal concentrate inputs within both feeding approaches, and this may have constrained the ability of cows to respond. Furthermore, despite targeting 'precision', FTY approaches involve multiple assumptions. For example, the calculated energy requirement for milk production is normally based either on standard values, or the average milk composition of the herd, and does not take account of the wide range of between-cow milk compositions that exist in practice. This is of particular importance as milk fat content has been observed to be reduced at higher concentrate levels within FTY systems [7,8]. Furthermore, FTY systems normally assume that the forage/basal ration offered supports a fixed level of milk production for all cows in the herd (although primiparous and multiparous cows are normally treated separately); but in practice intakes of individual cows vary greatly.

Recognising some of these limitations, a number of studies have investigated the use of parameters other than milk production as a basis for concentrate allocation. These have included using body weight (BW) as an indicator of dry matter intake (DMI) [9–11], or BW, DMI and milk energy output to account for herd energy balance (EB) [12]. Other studies have adopted a modelling approach to demonstrate that accounting for milk composition [13], energy intake [14] and body condition score (BCS) [15] may also allow improved precision to be achieved. The current study hypothesized that increasing the precision of concentrate allocation would improve cow performance and/or feeding efficiency. Within this paper, feeding efficiency has been defined as milk output per unit of nutrient intake, or milk output per unit of concentrate DMI.

2. Materials and Methods

This study was conducted at the Agri-Food and Biosciences Institute (AFBI), Hillsborough, Northern Ireland. All experimental procedures were conducted under an experimental license granted by the Department of Health, Social Services and Public Safety for Northern Ireland in accordance with the Animals (Scientific Procedures) Act 1986.

2.1. Animals, Pre-Experimental Diets and Housing

This 12-week study involved 69 Holstein dairy cows (mean of 120 days calved ± 13.9), 45 multiparous (mean lactation number 3.1 ± 0.96) and 24 primiparous. Cows had a mean pre-experimental milk yield of 33.6 ± 7.36 kg/d. For three weeks prior to the study commencing, cows were offered a partial mixed ration (grass silage and concentrates mixed in a 70:30 ratio on a dry matter (DM) basis), which was calculated to support daily milk yields of 13.5 and 19.6 kg (primiparous and multiparous cows, respectively). Additional concentrates were offered through an out-of-parlour (OPF) concentrate feeding system according to individual cow milk yields (0.43 kg additional concentrate for each kg of milk in excess of yields assumed to be supported by the basal ration). Cows were housed in a free-stall house with a concrete floor and had access to individual cubicles which were fitted with rubber mats and bedded with sawdust.

2.2. Treatments

Three treatments were examined. Within each treatment multiparous and primiparous cows were balanced separately with an equal number (n = 15) of primiparous cows within each treatment. Animals were balanced for lactation number, days-in-milk, and mean milk yield, milk composition, DMI, and BW during the 7-day period prior to the start of the experiment. Throughout the experiment cows on all treatments were offered a basal ration comprising grass silage (produced from a perennial ryegrass (*Lolium perenne*) based sward: DM, 292 g/kg; crude protein (CP), 130 g/kg DM; metabolisable energy (ME), 11.1 MJ/kg DM: Table 1), mixed with a concentrate (in the form of a coarsely ground meal: ingredient composition, Table 2). Rations were prepared using a diet-feeder (Vari-Cut 12, Redrock, Armagh, Northern Ireland). Concentrates were included in the mix at a rate of 4.3 and 5.3 kg/d (fresh weight) for primiparous and multiparous cows, respectively, to achieve nominal target concentrate intakes of 4.0 and 5.0 kg/d, respectively.

Table 1. Chemical composition of grass silage offered as part of the basal ration during the study.

	Mean	**SD**
Oven dry matter (g/kg)	292	29.2
VCODM (g/kg)	303	28.7
Crude protein (g/kg DM)	130	8.4
Ash (g/kg DM)	95	3.4
Acid detergent fibre (g/kg DM)	286	4.5
Neutral detergent fibre (g/kg DM)	482	9.0
Gross energy (MJ/kg DM)	18.5	1.57
Metabolisable energy (MJ/kg DM)	11.1	0.26
pH	4.01	0.103
Lactic acid (g/kg DM)	97	23.0
Acetic acid (g/kg DM)	19.2	4.15
Ethanol (g/kg DM)	13.1	3.37
Ammonia (g/kg total N)	75	0.81

VCODM—volatile corrected oven dry matter.

Table 2. Ingredient list (g/100 g fresh) and chemical composition (SD in parenthesis) of the concentrates offered to all cows through the out-of-parlour feeding system (OPF), and of concentrates mixed with grass silage as part of the basal ration.

	Concentrate Offered via OPF	**Concentrate Offered in Basal Ration**
Ingredients		
Wheat	17.4	
Maize meal	17.5	28.0
Extruded rapeseed meal		19.0
Distillers dried grains	8.5	
Maize gluten	11.0	
Sugar beet pulp	6.1	
Soyabean meal (high protein)	8.6	19.1
Soya hulls	17.5	25.4
Molaferm	8.0	2.5
Palm fatty acid distillate	1.0	
Protected fat (Megalac) [1]	1.5	3.0
Limestone ($CaCO_3$)	0.9	0.6
Calcined magnesite	0.2	0.2
Salt	0.6	0.9
RumiTech [2]	0.7	0.7
Mineral/vitamin mix	0.7	0.7
Chemical Composition		
Oven dry matter (g/kg)	888 (4.6)	894 (4.5)
Starch (g/kg DM)	262 (8.0)	193 (34.0)
Crude protein (g/kg DM)	169 (2.5)	239 (16.8)
ADF (g/kg DM)	152 (5.8)	191 (47.7)
NDF (g/kg DM)	295 (24.0)	342 (80.0)
Ash (g/kg DM)	77 (2.0)	79 (8.0)
Metabolisable energy (MJ/kg DM) [3]	13.5	13.3

[1] Volac Wilmar Feed Ingredients Ltd., Hertfordshire, UK. [2] John Thompsons and Sons, Belfast, UK. [3] using ME values in FeedByte, SRUC (Edinburgh, UK) ADF, acid detergent fibre; NDF, neutral detergent fibre.

Rations were prepared as follows: each day the total quantity of grass silage required for all three treatment groups (based on diets being offered at 107% of the previous day's intake) was mixed for approximately five minutes in the diet-feeder (Vari-Cut 12, Redrock, Armagh, UK) and then deposited in a pile on a clean silo floor. The quantity of grass silage required for each individual treatment was then removed from this pile, placed back in the diet-feeder, and the appropriate quantity of concentrate added to the mix, and mixing continued for further five minutes. Following mixing the rations were then transferred from the diet-feeder to a series of feed-boxes mounted on weigh-scales, with cows accessing food in these boxes via an electronic identification system, thus enabling individual cow intakes to be recorded daily (Controlling and Recording Feed Intake, Bio-Control, Rakkestad, Norway). The rations were prepared daily and offered between 09.00 and 10.00 h, while uneaten food was removed the following day at approximately 08.00 h. Cows had access to fresh water at all times.

Cows were offered additional concentrates on a FTY basis (ingredient composition in Table 2), with 1.0 kg/d of this offered via an in-parlour feeding system (fixed throughout the duration of the study; 0.5 kg at each milking) and the remainder offered via an OPF system. Concentrate levels were reviewed and adjusted weekly according to treatment as follows:

(1) Control: this treatment involved a 'conventional' FTY approach in which the concentrate allocation for each cow was adjusted weekly according to each cow's milk yield. First, average daily grass silage and concentrate DMI of the basal diet during the previous week was determined for multiparous cows on this treatment using information from the automatic feed intake recording system (heifer intake was assumed as 77% that of multiparous cows [16]). Total ME intake was determined by multiplying the average grass silage and concentrate DMI by the ME content of the silage (predicted weekly using NIRS) and the estimated ME content of the concentrate (13.3 MJ/kg DM: determined using the ME content of each individual ingredient: FeedByte, SRUC). This ME intake was assumed to support the cow's energy requirement for maintenance, plus the production of a certain amount of milk. Daily energy requirements for maintenance were calculated to be 73 and 84 MJ ME (primiparous and multiparous cows, respectively) based on mean pre-experimental BW, and using equations detailed in 'Feed into Milk' [17]. ME from the basal ration available for milk production was determined as total ME intake less ME required for maintenance. ME available for milk production was divided by 5.11 (MJ) to determine the quantity of milk (kg/day) supported by the basal ration. The value of 5.11 MJ/kg was determined as follows: the gross energy (GE) content of milk (3.17 MJ/kg) was determined from the average pre-experimental milk composition (41.5, 32.5 and 48.4 g/kg for fat, protein and lactose, respectively [18]) and an assumed lactation efficiency (k_l) of 0.62 [19]. On average, over the course of the experiment, the basal ration was calculated to provide sufficient ME to meet energy requirements for maintenance and to support the production of 20.8 and 14.4 kg milk/day for multiparous and primiparous cows, respectively. The value of milk supported by the basal ration is commonly referred to as the M+ value. The milk yield not supported by the basal ration was determined as the difference between average milk yield for each individual cow over the previous week, and the weekly group M+ value. Additional concentrates were then offered via an OPF (at a rate of 0.43 kg fresh concentrate/kg milk) to support milk yields in excess of that which was supported by the basal ration. The latter feed rate was determined by dividing the calculated ME requirement for milk production (5.11 MJ/kg milk), by the ME content of the concentrate offered (12.0 MJ/kg fresh). This calculation is similar to that undertaken automatically on many farms within FTY concentrate allocation programmes. In practice, the M+ value will be based on an estimate of DMI, usually determined based on the quantity of basal ration offered via the diet feeder, less an estimate of uneaten ration, while cow BW will also be estimated.

(2) Precision 1: Calculation of concentrate levels in this treatment took account of the energy content of the milk produced by each cow. Total ME intake from the basal ration, and the mean ME required for maintenance was calculated as per the Control treatment. The ME required for milk production was calculated using each individual cow's average milk yield over the previous week and each individual cow's average milk composition over the previous two weeks. The GE content of milk produced for each cow was calculated as per Tyrrell and Reid [18] and ME required for milk production calculated assuming a k_l of 0.62 [19], as for the Control treatment. Finally, the mean ME supplied by the basal ration was subtracted from the total ME required for maintenance (as per Control treatment) and milk energy production for each individual cow. The difference between the ME supplied by the basal ration and the ME requirements for each cow was divided by the ME content of the concentrate offered through the OPF (MJ/kg), to determine the quantity of concentrates required to meet individual cow ME requirements.

(3) Precision 2: This treatment took account of individual cow milk yield, milk composition and ME intake from the basal ration. First, total ME intake from the basal ration was calculated as per the other two treatments, but at an individual cow level instead of at group level. Next, the ME required for maintenance and milk was calculated as per Precision 1. Finally, the difference between the ME provided to each individual cow by the basal ration and the ME requirements for each cow was divided by the ME content of the concentrate offered through the OPF (MJ/kg), to determine the quantity of concentrates required to meet individual cows ME requirements.

Across all treatments maximum and minimum concentrate levels offered through the OPF were set at 16 kg/d and 0.5 kg/day, while the maximum increase in concentrate intakes between successive weeks was restricted to 4 kg/week for cows or 3 kg/week for heifers.

2.3. Cow Measurements

All cows were milked twice daily (between 06.00 and 08.00 h and between 15.00 and 17.00 h) throughout the experiment using a 50-point rotary milking parlour (Boumatic, Madison, WI, USA). Milk yields were automatically recorded at each milking, and a total daily milk yield for each cow for each 24 h period calculated. Milk samples were taken during two consecutive milkings each week throughout the study, treated with a preservative tablet (Broad Spectrum MicroTabs II, Advanced Instruments, Norwood, MA, USA), and stored at 4 °C until analysed (normally within 48 h). Milk samples were analysed for fat, protein and lactose concentrations using an infrared milk analyser (Milkoscan CombifossTM7; Foss Electric, Hillerød, Denmark), and a weighted concentration of each constituent determined for the 24 h sampling period. Energy corrected milk (ECM) yield (kg/d) was calculated as described by Muñoz et al. [20].

Body weight was recorded twice daily (immediately after each milking) using an automated weighbridge, and a mean weekly BW for each cow was determined. The BCS of each cow was estimated by a trained technician at the beginning, mid-point and end of the experiment, according to Edmonson et al. [21] according to a 5-point (including quarter points) scale. The daily EB of each individual cow was calculated using equations contained within 'Feed into Milk', the current UK dairy cow rationing system, as the difference between each cow's total ME intake and her total ME requirements (maintenance, milk production, and activity [17]).

2.4. Feed Analysis

A sample of the grass silage offered was taken daily throughout the experiment and dried at 60 °C for 48 h to determine oven DM content. Twice weekly a sample of the dry silage was collected, bulked for each 14 d period, with the bulked sample milled and analysed for neutral detergent fibre (NDF), acid detergent fibre (ADF) and ash concentrations. Each week a fresh grass silage sample was analysed for GE, nitrogen (N), pH, ammonia-N and volatile components, and the ME concentration of the sample predicted using near infrared reflectance spectroscopy (NIRS) according to Park et al. [22]. A sample of each concentrate offered was taken weekly, dried at 60 °C for 48 h to determine ODM content, the weekly dried sample bulked over each 14 d period, milled and subsequently analysed for N, NDF, ADF, ash and starch concentrations. All chemical analysis of the feedstuffs offered were undertaken as described by Purcell et al. [6].

2.5. Statistical Analysis

One cow was removed from Precision 2 due to mastitis and excluded from the analysis. Data for intake, milk yield, milk composition, BW and efficiency parameters were analysed using REML repeated measure analysis, with week (start, mid-point and end in the case of BCS) as the time point and an autoregressive model of order 1 was set as the correlation structure. Pre-experimental variables (total DMI, milk yield, milk fat content, milk protein content) were included as covariates when analysing corresponding dependent variables. For variables where significant treatment effects were identified ($p < 0.05$), differences were tested using Fisher's protected-adjusted multiple comparisons. A tendency was assumed with $p > 0.05$ and <0.1. All data were analysed using GenStat (18.1; VSN International Limited, Oxford, UK).

3. Results

Grass silage DMI did not differ between treatments ($p > 0.05$). Control cows had a significantly lower concentrate DMI ($p = 0.040$; Table 3; Figure 1) compared to cows on Precision 1 and 2; however, total DMI was unaffected by treatment. Intakes of all diet components decreased over the course of the study ($p < 0.001$) and there were significant treatment × week interactions for grass silage DMI, concentrate DMI and total DMI ($p < 0.001$).

Table 3. Effect of a three feed-to-yield concentrate allocation strategies, each differing in 'precision', on feed intake, milk production, body tissue reserves and efficiency measures.

	Treatment				*p* Values		
	Control [1]	**Precision 1 [2]**	**Precision 2 [3]**	**SED [4]**	**Treatment**	**Week**	**Week × Treatment**
Grass silage DMI (kg/d)	12.4	11.6	11.5	0.36	0.242	<0.001	<0.001
Concentrate DMI (kg/d)	9.4 [a]	10.5 [b]	10.3 [b]	0.43	0.044	<0.001	<0.001
Total DMI (kg/d)	21.2	21.8	21.5	0.24	0.113	<0.001	<0.001
Milk yield (kg/d)	32.9	34.5	34.3	0.68	0.181	<0.001	0.002
Fat (g/kg)	45.1	44.9	43.1	0.81	0.055	<0.001	0.767
Protein (g/kg)	32.7 [a]	33.5 [b]	33.1 [b]	0.24	0.003	0.059	0.910
Lactose (g/kg)	48.0	48.1	48.1	0.20	0.940	0.192	0.972
Fat yield (kg/d)	1.47	1.54	1.46	0.035	0.064	<0.001	0.726
Protein yield (kg/d)	1.07 [a]	1.15 [b]	1.13 [b]	0.022	0.001	<0.001	0.461
Fat plus protein yield (kg/d)	2.54 [a]	2.69 [b]	2.58 [a]	0.052	0.017	<0.001	0.607
Energy corrected milk (kg/d)	34.6	37.0	36.3	1.93	0.563	<0.001	0.578
ECM/DMI (kg/kg)	1.63	1.65	1.64	0.031	0.783	<0.001	0.092
ECM/ME intake (kg/MJ)	0.14	0.14	0.13	0.002	0.984	<0.001	0.187
Concentrate DMI/milk yield (kg/kg)	0.27 [a]	0.31 [b]	0.30 [b]	0.007	<0.001	<0.001	<0.001
Concentrate DMI/ECM (kg/kg)	0.25 [a]	0.29 [b]	0.29 [b]	0.007	<0.001	<0.001	<0.001
Energy balance (MJ/d)	8.7	10.9	11.1	2.51	0.592	<0.001	0.021
Body weight (kg)	626	644	645	19.8	0.416	<0.001	0.181
Body condition score	2.1	2.3	2.4	0.20	0.694	<0.001	0.798
Locomotion score	2.3	2.4	2.5	0.07	0.958	<0.001	0.397

[1] Control; concentrates offered on a FTY basis, adjusted on the basis of individual cow milk yields, [2] Precision 1; concentrates offered on a FTY basis, adjusted on the basis of individual cow milk yields and milk composition. [3] Precision 2; concentrates offered on a FTY basis, adjusted on the basis of individual cow milk yields, milk composition, and dry matter intake. [4] Standard error of the differences of the mean. [ab] Within a row, means without a common superscript are significantly different ($p < 0.05$)

There were no significant differences between treatments for milk yield (Figure 2) or ECM yield ($p > 0.05$; Table 3). There was a tendency for milk fat content ($p = 0.055$) and milk fat yield ($p = 0.064$) to be lower in Precision 2 compared to Precision 1. Control cows had a lower milk protein content ($p = 0.003$) and milk protein yield ($p = 0.001$) than those on Precision 1 and Precision 2. Fat plus protein yield was significantly greater in Precision 1 compared to the other two treatments ($p = 0.017$). Milk yield, ECM, fat yield, protein yield and fat plus protein yield all changed over time ($p < 0.001$), declining over the course of the study. There was a significant treatment × week interaction for milk yield ($p = 0.002$: Figure 2), but no interaction for any of the other milk production parameters.

While ECM/DMI and ECM/ME intake were unaffected by treatment, these two parameters decreased as the study progressed ($p < 0.001$). Both concentrate DMI/milk yield and concentrate DMI/ECM yield were lower with Control than with either of the other two treatments ($p < 0.001$). The concentrate efficiency parameters changed over time following a similar pattern to milk yield and there were significant week × treatment interactions.

Energy balance, BW and BCS were not affected by treatment, but changed over time ($p < 0.001$; Table 3), increasing as the study progressed. There was a treatment × week interaction for EB, but not for BW or BCS.

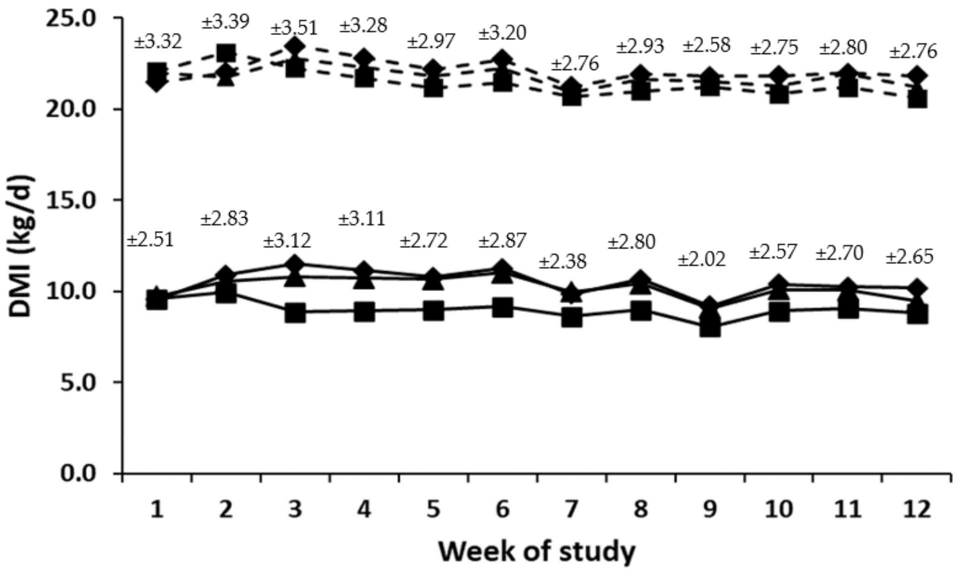

Figure 1. Concentrate DMI (solid line) and total DMI (broken line) of cows offered concentrates according to a conventional FTY system (Control; ■), or corrected for milk composition (Precision 1; ♦), or corrected for milk composition and individual intake (Precision 2; ▲) over a 12 week period.

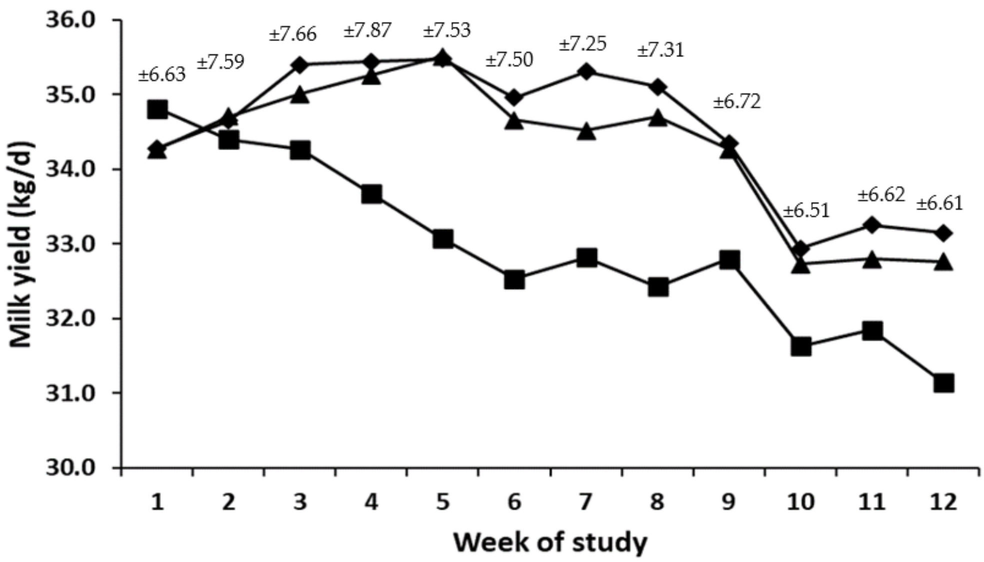

Figure 2. Mean milk yield (kg/d) of cows offered concentrates according to a conventional FTY system (Control; ■), or corrected for milk composition (Precision 1; ♦), or corrected for milk composition and individual intake (Precision 2; ▲) over a 12 week period.

4. Discussion

Early attempts to match individual cow concentrate inputs with energy needs were based on milk yield as the sole variable as this was the only performance measurement readily available on farms at that time. While the need to consider parameters in addition to milk yield if individual cow feeding strategies were to be successful was recognised over thirty years ago [23], on the majority of farms milk yield remains the only variable used [24]. The precision feeding treatments within the current study were designed to investigate the impact of allocating concentrates according to either individual cow milk yield, milk energy output, or milk energy output in combination with actual energy intakes. The benefits, or otherwise, of any precision concentrate feeding strategy should be evident in improved feed use efficiency.

4.1. Cow Intake and Performance

Most studies examining the milk yield response of dairy cows to concentrate feeding have involved fixed, predetermined concentrate levels, thus making interpretation of outcomes straight-forward. Similarly, earlier studies comparing individual cow concentrate allocation strategies with group feeding approaches were designed to ensure total concentrate inputs over the feeding period were similar with each strategy [4–6]. In contrast, within the current study achieving equal concentrate inputs across the three treatments was not a pre-requisite. Rather, concentrate inputs were adjusted on a weekly basis throughout the study according to the specific requirements of each treatment (milk yield, milk composition, DM intakes). As a result, concentrate levels differed between treatments with cows on the Precision treatments consuming significantly more concentrates than those on the Control treatment. This difference, while making interpretation of outcomes more challenging, is an inevitable outcome of the treatment regimens imposed. Maltz et al. [12] encountered a similar issue when precision feeding was implemented on a group basis, with concentrate intakes being 0.9 kg/day higher with precision fed cows. Nevertheless, while concentrate intake was greater with the Precision treatments, total DMI did not differ, reflecting the numerically lower forage intakes with the precision treatments due to substitution. Thus, the absence of a treatment effect on milk yield likely reflects the similar total DMI across treatments.

With all treatments, milk fat content and milk protein content increased during the course of the experiment, reflecting normal lactational changes over time. The greater milk protein content with the Precision treatments is likely due, in part, to the greater concentrate intake within these treatments [14] with milk protein content being generally driven by energy intake, particularly the breakdown of starch to glucose [25]. Indeed, previous studies comparing individual cow vs. group concentrate feeding strategies where concentrate levels were equal reported that milk protein content was unaffected [5,6]. In contrast, compared to Control, milk fat tended to be reduced in Precision 2 (but not Precision 1). Purcell et al. [6] also observed a reduction in milk fat content with a precision feeding approach which they attributed to the greater proportion of concentrate in the diet. Concentrate proportion with Precision 1 and 2 (0.48 and 0.47 of total DMI, respectively) were both higher than with Control (0.44 of total DMI). It is therefore unclear why milk fat tended to decrease with one precision treatment but not the other. However, an examination of individual cow data highlighted two cows from Precision 2 with unusually low milk fat contents. Due to the reduction in milk fat content, fat plus protein yield with Precision 2 did not differ from that of Control.

The occurrence of low milk fat contents with cows offered high levels of concentrates within FTY systems has been examined on commercial farms [8], with the authors attributing this in part to higher yielding cows having a lower genetic potential for milk fat content, but also due to the effect of diet. Typically, the highest yielding cows are offered the highest concentrate levels irrespective of the impact of additional concentrate feeding on milk composition. Taking account of individual cow milk composition, as in Precision 1 and 2, means that it is each individual cow's milk energy output that determines concentrate feed levels, rather than simply milk volume.

With the Control treatment, mean milk composition at the start of the experiment was used to determine the concentrate feed-rate (0.43 kg fresh concentrate/kg milk) throughout the 12-week study period, with this derived from the mean GE content of the milk and an assumed efficiency of lactation. This value could have been revised over time in view of the increase in milk composition over the study period due to increasing stage of lactation, and this would likely have resulted in an increase in concentrate intake with this treatment. However, this is not normal practice within FTY systems given the spread of calving dates typically found on most farms. Rather, if concentrate feed rates are changed from the default setting within the parlour software (typically 0.45 kg fresh concentrate/kg milk)—something that is rarely done on farms—this will be on the basis of average milk composition for the herd over the course of a year. Nevertheless, accounting more frequently for changes in herd milk composition in total mixed ration fed cows has been shown to improve both the fat and protein content of milk [26].

The adoption of a FTY approach has been shown to reduce the range of EB experienced by individual cows within a treatment group, compared to a group feeding approach, while having no effect on mean EB [6]. However, within that study treatments were designed to have similar concentrate inputs across all treatments. In the current study the precision feeding approaches had no significant impact on cow EB, which was positive for all treatments (average, 10.2 MJ/d) reflecting the mid-lactation status of the cows. There was also no difference in mean BW or BCS between treatments, supporting the absence of an effect on EB. By taking account of differences in milk composition and energy intakes between cows it might have been expected that cows on these precision treatments would have moved closer to zero EB; however, this was not the case. Similarly, Maltz et al. [12] found no difference in EB, BW or BCS when feeding cows on the basis of EB. In the current study it is possible that mean EB values may have been closer to zero if the calculations had taken account of changes in body tissue deposition, and differences in individual cow BW (with correspondingly higher or lower maintenance energy requirements compared to the fixed BW adopted within this study). However, although daily BW measurements were available on the AFBI farm it was decided not to include individual cow BW within the calculation of energy requirements for maintenance. While individual cow 'walk-over' weighing systems already exist and are in place on some commercial farms, their adoption within the UK is very limited, and this situation looks unlikely to change for the foreseeable future. Nevertheless, research has attempted to predict individual cow BW on the basis of days-in-milk, milk yield, parity and milk mid-infrared spectrum [27]. If this approach is successful then individual cow BW values could be predicted with sufficient accuracy to improve precision within individual cow feeding systems.

4.2. Feed Use Efficiency

Given that the Precision treatments took account of individual cow milk composition and milk composition combined with actual intakes, it was hypothesized that the nutrient requirements of cows within the Precision treatments would be met more accurately with a subsequent improvement in efficiency. However, feed use efficiency, when expressed as either ECM/DMI or ECM/ME intake, did not differ between treatments, with an average value of 1.64 for the former, and 0.14 for the latter. Similarly, Bossen and Weisbjerg [11] found no improvement in energy efficiency (ECM: MJ NE) when feeding cows according to BW changes. Maltz et al. [12] observed an increase in efficiency of conversion of DMI into ECM during early lactation in precision fed cows; however, when expressed on an energy basis, this difference was not significant.

Concentrate DMI/milk yield (and concentrate DMI/ECM) was reduced which indicated improved efficiency with the Control treatment (0.27 kg concentrate DMI/kg milk) compared to either of the Precision treatments (0.31 and 0.30 for Precision 1 and 2, respectively). Values for the latter are similar to the value of 0.31 (converted to a DM basis) reported as the mean efficiency for the UK dairy sector [28]. This reflects the fact that the proportional reduction in concentrate intake with the Control treatment was greater than the proportional reduction in milk yield, resulting in an apparent improvement in concentrate use efficiency in the Control group. However, this metric is considered a 'crude' efficiency factor, often used by farmers and nutritionists, to provide an indication of efficiency of concentrate use on farms and does not take account of the contribution of other components of the diet to milk production.

4.3. Practical Implications

On the majority of farms, precision feeding systems continue to use milk yield alone as the basis on which to adjust concentrate feed levels. Nevertheless, information already exists on many farms that would allow more precise concentrate allocation strategies to be adopted, and given the speed of agri-tech development, additional information will continue to become available. For example, while many farms now have access to individual cow test-day milk composition data on a monthly basis, robotic milking systems and developments within in-line sensors means that milk composition data will increasingly be available in real time on a day-to-day basis. Furthermore, while group intakes can be measured with a reasonable degree of accuracy by recording feed offered using a diet-feeder, a number of approaches are being developed that allow individual cow intakes to be either predicted or 'measured'. For example, equations exist which allow intake to be predicted using readily available farm data such as lactation number, ECM, fat:protein ratio and lactation stage [29]. Furthermore, the potential of MIR analysis of milk to predict intakes has been examined, although the majority of studies observed that combining MIR data with other animal-level variables, such as milk yield, BW and feeding behaviour resulted in improved accuracy compared to predictions based on MIR data alone [30]. There is also interest in the development of camera and positioning systems that could allow individual cow intakes to be predicted [31,32]. In addition, automatic BCS systems, and systems which record BW at each milking have already been commercialised, and these can provide information on the energy status of individual cows, with similar information available through MIR analysis of milk [33].

Nevertheless, despite the potential to greatly improve the precision with which concentrates are allocated to individual cows, there is still limited evidence that the adoption of improved precision at an individual cow level will improve overall feeding efficiency. Within the current study it was hypothesised that a precision concentrate allocation strategy would improve feeding efficiency due to the energy requirements of all cows being met more accurately. However, no such benefit was observed, in general agreement with previous studies [11,34,35]. Thus, further research is required to determine optimum and readily available traits that could be utilized to improve concentrate allocation accuracy, and to establish if feeding efficiency really can be improved by the adoption of these techniques.

5. Conclusions

Adjusting concentrate levels to account for either milk composition, or for milk composition and DMI, increased concentrate intakes and improved milk protein content, compared to adjusting according to milk yield only. However, accounting for milk composition and individual DMI did not improve feeding efficiency (ECM/ME intake). There is still limited evidence that feeding efficiency can be improved through the adoption of individual cow 'precision feeding' systems.

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