Improving efficiency within feed-to-yield systems: understanding drivers of milk quality and fertility

End of Project Report for AgriSearch in Relation to
Research Challenge Fund Project RCF 03/2017

Research team

Aimee Craig, Gregory Hamill, Alan Gordon, Leiza Montgomery, Elizabeth Earle, 31 farmer co-researchers and Conrad Ferris

Report prepared by

Aimee Craig and Conrad Ferris

July 2021

This research programme was co-funded by the Department of Agriculture, Environment and Rural Affairs for Northern Ireland and by AgriSearch under the Research Challenge Fund

STRUCTURE OF REPORT

This report begins with an Executive Summary which briefly highlights the background to the overall project and provides a brief description of the work undertaken within the project.

The main body of the report comprises a background section, detailed description of the work undertaken, including methodology, results, economic analysis and discussion.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

- The efficiency with which concentrates are used on farms is extremely variable, and given that concentrates generally comprise 60-70% of the variable costs of milk production, low concentrate use efficiency reduces margins. In addition, inefficient use of concentrates can have a negative environmental impact.
- Previous studies at AFBI compared a group feeding approach (complete diet feeding) with a feed-to-yield approach. In general, the results of these studies demonstrated that concentrate allocation strategy had little impact on herd performance when total concentrate inputs over the winter were equal. Nevertheless, the use of feed-to-yield systems is now widespread on local dairy farms. These systems seek to improve precision of concentrate feeding by targeting concentrates to higher yielding cows, where an economic response is expected.
- Earlier studies with feed-to-yield systems have demonstrated a reduction in milk fat content (and milk protein content to a lesser extent) at high concentrate levels in the feed-to-yield system, and this reduced the value of each kg of milk produced. However, it was unclear if the fall in milk composition at higher concentrate levels was due to cow genetics, or due to the effect of diet on rumen function. In addition, it is unknown if a similar reduction in milk composition is observed on commercial farms.
- To address these issues, DAERA and AgriSearch co-funded this project which focused on providing a better understanding of feed-to-yield systems within a commercial setting.
- This study was conducted on 31 Northern Ireland dairy farms between August 2018 and August 2019. All farms offered concentrates on a feed-to-yield basis. Each farm was visited 4-6 times during the course of the study, and feed samples collected and detailed information on feeding practices were recorded. Milk production information was obtained from milk recording organisations. Concentrate and forage intakes were subsequently predicted for each individual cow.
- Data from the study were divided into two time periods: 1) Housed period for months 2 to 5 of lactation when data was available for all farms (a total of 3,471

cows), and 2) Grazing period (May, June and July) during which only 19 of the farms on the study had cows grazing full-time (a total of 1,556 cows).

- As expected, the approach to concentrate feeding differed across the farms. On 19 of the farms cows were offered a basal ration containing both forage and concentrate ingredients, prepared using a mixer wagon, with additional concentrates offered using in-parlour / out-of-parlour feeding systems. On the remaining farms cows were offered a forage only basal ration, with concentrates offered using in-parlour / out-of-parlour feeding systems.
- All farms adopted a concentrate ‘build-up’ period following calving, before a feed-to-yield approach was adopted. However, most farms had started offering concentrates on a feed-to-yield basis by day-30 post-calving, although on three farms this did not happen until at least day-60 post-calving.
- The ‘feed-rate’ settings for the in-parlour or out-of-parlour feeders varied between farms. While the majority of farms used a feed-rate of 0.45 kg concentrate/kg milk, 5 farms used a feed rate lower than 0.45, while 2 farms used a higher feed rate.
- As concentrate intakes increased, total dry matter intake also increased, as was expected. However, forage intakes showed only a slight decrease with increasing concentrate levels. This is explained by the fact that higher yielding cows have a greater overall intake potential, and consequently offering extra concentrates to these higher yielding cows does not dramatically reduce silage intakes.
- From a practical point of view, the fact that silage intakes decreased only slightly across the range of concentrate levels examined provides support for a key assumption which is made when cows are managed using a feed-to-yield approach, namely that the ‘basal diet’ is able to maintain the ‘same’ level of performance across a wide range of milk yields.
- However, caution is required at higher concentrate levels as the concentrate proportion of the total diet increased. For example, for cows with a concentrate intake of 8 kg per day, the diet contained 37% concentrate, while at a concentrate intake of 18 kg/day, the diet contained 58% concentrate (on a dry matter basis). Diet starch content also increased, meaning that without careful diet formulation higher yielding cows offered high concentrate levels are more likely to experience rumen upset if the ration is not formulated properly.

- Milk yields showed a ‘linear’ increase with increasing concentrate levels in both cows and heifers. This is as expected as the amount of concentrates offered ‘follow’ the milk yields of the cows. Part of this increase in milk yield can be explained by cow genetics. For example, the mean PTA (Predicted Transmitting Ability) for milk increased across the range of concentrate levels offered. However, this genetic difference does not explain all of the differences in yield observed, and it is likely that other factors such as general management, concentrate levels offered during the build-up period, and differences in forage quality also contribute to these differences.
- As concentrate levels increased, the fat % of the milk decreased. Between 20 – 50% of the reduction in milk fat % could be explained by cow genetics. This suggests that farmers with higher yielding herds have placed a greater focus on milk yield, than on milk composition, when selecting sires. The remainder of the reduction in milk fat % is likely due to diet.
- A few farms did not experience as large a decrease in milk fat % at higher concentrate levels as others did. The reasons for this were unclear, and it is likely that no single factor was responsible. Nevertheless, contributing factors appear to have included: similar PTA for milk fat % across the concentrate intake levels, the inclusion of alternative forages in the diet, lower than average concentrate intakes, and diets with slightly lower starch contents.
- In contrast, milk protein % remained relatively unchanged across the range of concentrate levels in the study. This can be explained in part by the fact that cow genetics for milk protein (PTA protein) changed very little across the range of concentrate levels. It might have been expected that milk protein would improve at higher concentrate levels (reflecting an improved energy balance of the cows), but this was not observed.
- Two ‘efficiency measures’ were examined in this study. The first of these examined how much milk is produced per kg of intake (i.e. kg milk per kg dry matter intake). In both heifers and cows this figure increased from approximately 1.35 – 1.70 kg milk per kg DM intake, across the range of concentrate levels offered, indicating an overall ‘improvement’ in efficiency at higher concentrate levels. This is because the energy required to ‘maintain’ the cows body remains fairly constant across a

wide range of concentrate levels, and this energy requirement is then ‘diluted’ as more milk is produced.

- The second ‘efficiency measure’ was ‘kg concentrates required to produce each kg milk’. This value also increased as concentrate level increased. However, this suggests that concentrate use efficiency has decreased (i.e. cows in the higher concentrate intake bands consumed more concentrate per kg of milk produced, which is undesirable as concentrates are more ‘expensive’).
- In general there was no clear impact of concentrate level on any of the fertility measures calculated. Thus, based on the outcomes of this experiment, higher yielding cows (which were offered higher levels of concentrates) did not have poorer fertility than lower yielding cows, when concentrates were offered on a feed-to-yield basis.
- On 19 of the farms some cows grazed full-time during May, June and July, and continued to be offered concentrates on a feed-to-yield basis. Although the project was primarily focused on the winter period, this provided an opportunity to examine trends in milk yields, and in milk fat and protein content for grazing cows offered concentrates on a feed-to-yield basis.
- Both milk yields and concentrate intakes were lower during the grazing period than during the winter period as cows were in later lactation. The trends in milk yield, and milk fat % were similar to those found during the winter period. For example, milk yield showed a linear increase with increasing concentrate levels, while milk fat % decreased as concentrate levels increased. The size of the decrease (from 4.5% fat to less than 4.0% fat for the cows) was almost double that observed during the winter. While part of this reduction is again due to genetics (decreasing PTA for milk fat %), it is likely that diet is a significant factor. Grazed grass is lower in fibre than grass silage, so if grazing cows are offered a starchy concentrate while grazing, milk fat % will often fall off quite considerably.
- In contrast to the housed period, the milk protein % of grazing cows decreased with increasing concentrate intake. While this was partly due to cow genetics, the size of this reduction was surprising. This reduction may reflect the fact that this part of the study took place in early summer when grass quality was high.
- A key objective of this experiment was to examine the impact of increasing concentrate feed levels within a feed-to-yield system on economic performance.

This is important as an earlier AFBI study demonstrated that due to the poorer milk composition, the economic performance of some cows offered higher concentrate levels was no better than that of cows offered much lower concentrate levels, especially when milk prices were low.

- Margin-over-feed costs for each individual cow was determined based on performance data for each cow over the winter feeding period. Feed costs were determined using feed intakes calculated for the housed period, with costs for grass silage, maize silage and whole crop silage assumed as £123, £189, £225/tonne DM, respectively. The cost of concentrates was assumed to be £260/tonne fresh. Margins were modelled at three different milk prices, namely 18, 26 or 34 pence per kg milk. The economic analysis also took into consideration the composition of milk produced.
- The value of each kg of milk produced decreased with increasing concentrate intake level. For example with heifers, at a concentrate intake of 4 – 6 kg/day, there was a bonus of 2 pence per kilogramme of milk produced, while at a concentrate intake of 12 – 14 kg/day, the bonus was reduced to 0.2 pence per kg milk. Similarly for cows, at a concentrate intake of 6 – 8 kg/day, there was a bonus of 2.3 pence per kilogramme of milk produced, while at a concentrate intake of 16 - 18 kg/day, there was a deduction of -0.1 pence per kg milk.
- At all milk prices margin-over-feed costs (£ per cow per day) continued to increase as concentrate intake levels increased, despite the reduction in milk bonus. However the size of this economic response decreased at higher concentrate levels. With cows offered higher levels of concentrates (higher yielding cows), feeding an extra 1 kg of concentrate resulted in a much smaller increase in margin-over-feed costs, with this increase being almost non-existent at a milk price of 18 pence per kg milk. The decreasing economic benefits observed at the higher concentrate levels are primarily due to: 1) decreasing value of each kg of milk produced, and, 2) the increasing cost of each kg of the diet consumed.
- These outcomes have important practical implications. Firstly, farmers offering high levels of concentrates on a feed-to-yield basis often suggest that ‘as the cow is producing an extra 1 kg milk for each 0.45 kg concentrate fed, then it make economic sense to keep feeding’. However, the results of this study demonstrate that the economic benefits decrease rapidly at higher concentrate levels. Secondly,

farmers should carefully consider the 'benefits' of 'chasing extra litres' when milk price is poor, as has been common in the past, as for many cows there will be little, if any, financial benefit from doing this.

- As we try to improve individual cow management on farms, one issue that is often overlooked is the accuracy with which concentrate feeding systems (in-parlour and out-of-parlour feeders) actually weigh out concentrates. As part of this project a total of 490 individual feeders were tested across 16 of the participating farms.
- On average, across all feeders on any farm, the error was approximately plus/minus 5%. However, on two farms the feeders dropped approximately 13 – 14% less concentrates than planned, while on one farm the feeders dropped 15% more concentrate than planned. However, even on the 'better' farms the averages did hide problems with individual feeder variations. For example, on one farm a feeder was overfeeding by 100% (i.e. dropping 2 kg instead of 1 kg), while on another farm a feeder was underfeeding by 70% (i.e. dropping 0.3 kg instead of 1 kg). The impact that these inaccuracies can have on the amount of concentrates offered on a farm can be considerably.
- While many farmers already check the accuracy of their feeders regularly (some on a weekly basis), given the cost of concentrate feeds, regular checking is a practice that all farmers should adopt. In addition, different types of concentrates have different densities, and feeders should be recalibrated for each new type of concentrate being fed. Feeder suppliers should be able to advise on how to calibrate feeding system, but in general, a simple weight scale, plastic bucket and time is all that is required.

SECTION 1

BACKGROUND

The adoption of breeding programmes with a significant focus on milk yield has contributed to increased levels of performance within the Holstein dairy cow in many countries (Oltenacu and Broom, 2010; Ingvartsen and Moyes, 2013). However, in early lactation voluntary dry matter intake (DMI) does not increase at the same rate as milk production (Ingvartsen and Andersen, 2000), and cows frequently enter a period of negative energy balance in early lactation, with associated mobilisation of body tissue reserves. To support higher milk yields, and in an attempt to reduce the extent of negative energy balance experienced by higher-yielding cows, the quantity of concentrates offered to dairy cows has increased in many countries. For example, within Northern Ireland (NI) concentrate inputs per litre of milk produced increased from 1.84 to 2.6 t/cow/year between 2004 and 2019 (DAERA statistics).

Due to the increase in concentrate supplementation, approaches taken to allocate and present concentrates to cows have also changed. While twice daily feeding of concentrates through in-parlour feeders may be appropriate for lower yielding cows, the adoption of out-of-parlour (OPF) feeding systems and/or mixer wagons facilitate higher concentrate feed levels with reduced risk of rumen upset. In practice, concentrates are presented to cows using a variety of methods: mixed with the forage component of the diet as part of a mixed ration, presented separately from forage via in-parlour or OPF concentrate feeding systems, or presented through a combination of these approaches. Presenting concentrates as part of a total mixed ration (TMR), compared to presenting concentrates separately from forage, has not been shown to improve milk yield (Agnew et al. 1996; Gordon et al., 1995; Yan et al., 1998; Purcell et al., 2016). In view of the difficulty in managing separate groups of cows on smaller farms found within the UK and Ireland, and in an effort to improve efficiency, many farms are now offering concentrates on an individual cow basis according to milk yield, namely feeding-to-yield (FTY). This approach has been facilitated by developments in concentrate feeding technology over the last few decades, with feeding systems now often directly linked to milking parlour software.

A number of studies involving both low (Gordon 1982; Taylor and Leaver, 1984a and b; Lawrence et al., 2015 and 2016) and high yielding cows (Little et al., 2016; Purcell et al., 2016) have compared flat rate concentrate feeding strategies to FTY approaches, with little differences in cow performance. Nevertheless, the adoption of FTY based systems during the winter period has become common place on NI farms, although approaches vary considerably from farm to farm. For example, on some farms the entire concentrate component of the diet is offered through OPF and/or in-parlour feeding systems. However, more commonly, all cows are offered a 'basal diet' consisting of a forage-plus-concentrate mix (partial mixed ration) designed to meet the cow's maintenance energy requirement plus the energy required for the production of a specific milk yield (often referred to as the M+ value). Additional concentrates are then offered to each individual cow, either through in-parlour and/or OPF feeders, with levels designed to support milk yields in excess of those sustained by the basal diet.

While the principle behind FTY systems is to bring increased levels of 'precision' to dairy cow feeding, the approach involves many assumptions. For example, the basal ration is assumed to support a common level of performance for all cows (excepting a distinction between primiparous and multiparous cows), but in reality individual animal intakes vary considerably. In a FTY system differences in basal ration /forage intakes are exacerbated by the variation in concentrate intakes, as in general forage intakes decrease as concentrate levels increase. In addition, assumptions relating to concentrate feeding normally assume a standard milk composition for all cows (based on the herd average), while in reality milk composition of individual cows within the herd can be very different. Furthermore, a FTY approach inevitably results in high levels of concentrates being offered to the highest yielding cows, which reduces the proportion of forage consumed, which may have a negative effect on milk composition. Reductions in milk fat concentration with increasing milk yields (Huhtanen and Rinne, 2007) and increasing concentrate intakes (Alatas et al., 2015; Purcell et al., 2015; Dewanckele et al., 2020) are well documented. Indeed, data from research undertaken at the Agri-Food and Bioscience Institute (AFBI; C.P. Ferris, Unpublished data) demonstrated that the reduction in milk composition can be so extreme that the financial value of milk produced by individual high yielding cows can be less than the value of milk produced by lower yielding cows offered much lower levels of concentrates. In addition, the impact of concentrate levels within FTY systems on cow health and fertility does not appear to have been examined previously.

While performance associated with FTY approaches have been periodically examined within a research setting (Taylor and Leaver, 1984a,b; Kellaway and Harrington, 2004; and Little et al., 2016) we are unaware of research specifically examining performance within FTY systems on commercial farms

This study was conducted to investigate how FTY systems are operated in practice on commercial farms in NI, and to examine the relationship between concentrate intakes, milk production and composition, concentrate use efficiency and cow health and fertility. The project also examined the impact of concentrate feed level on economic performance of dairy cows managed on a FTY system.

SECTION 2

PERFORMANCE OF DAIRY COW OFFERED CONCENTRATES ON A FEED-TO-YIELD BASIS DURING THE WINTER MONTHS

Introduction

This section examines the effect of offering concentrates on a FTY basis when cows were housed. This aspect of the study focused on months 2 – 5 of lactation. This section provides a detailed methodology of how the study was conducted, and the genetics of the cows on the study, details of intakes, milk production and milk composition, and fertility outcomes.

Methodology

Farm and animal selection: This experiment was conducted on 26 NI dairy farms during the ‘winter’ housed period (September 2018 to May 2019). The study and its objectives were advertised through the local press, and farmers interested in participating were invited to apply. Participating farms were selected on the basis of meeting the following criteria: predominantly Holstein-Friesian herds (18 herds were pedigree registered), at least 50 Holstein-Friesian cows due to calve between August 2018 and February 2019, an annual milk yield/cow in excess of 6500 litres, participating in an official milk recording scheme, offering concentrates on a FTY basis, established health and fertility recording system in place, and willingness to record additional information and provide AFBI scientists with the required information. During the year prior to this study the 26 farms had an average herd size, concentrate feed level (t/cow/year) and 305-day milk yield of: 195 cows (range: 80 - 500), 2.9 (range: 1.6 - 4.0) and 8,816 litres (range: 6,900 - 11,643), respectively.

The study involved 3,471 cows (average lactation 2.7 (range: 1 - 15; s.d. 1.8)) which calved between 1 August 2018 and 28 February 2019. Cows that were pedigree registered had an average PLI of £173 (range: -£229 to +£625, s.d. £150.7). On 19 of the farms cows were offered a basal ration, comprising a mixture of forage and concentrate ingredients, prepared using a mixer wagon. On these farms, additional concentrates were offered using either an in-parlour feeding system (n = 14), or an OPF system (n = 1), or both in-parlour and OPF feeding systems (n = 4). On the remaining seven farms, cows were offered silage either through a mixer wagon (n = 1), via blocks of silage placed along a feed barrier (n = 5), or cows had access to silage directly at the silo face (n = 1). On these seven farms concentrates were offered using either an in-parlour feeding system (n = 1) or both in-parlour and OPF feeding systems (n = 5). On all farms the FTY component of the concentrate was offered using either in-parlour or OPF feeding systems. Three of the farms used milking robots, while on all other farms a conventional ‘manual’ milking parlour was used.

Data collection: Participating farmers attended a briefing session at AFBI, Hillsborough, prior to the start of the experiment. Each farm was then visited approximately once every 6 -7 weeks (average of 5 visits/farm) between September 2018 and May 2019. During each visit information on cow health and fertility and detailed information on feeding practices were collected. Information on feeding practices included: information on all forages offered (type and quantity in the basal ration, or ratios of different forages if not offered via a mixer wagon), details and quantities of other diet ingredients, and information on each type of concentrate offered both as part of a basal ration or via in-parlour feeders and/or OPF, feeding management practices, dates of diet changes, and details of turnout (herd/group basis or individual cow basis). In addition, a sample of each forage and each concentrate type being offered was taken during each visit. Concentrate samples were dried at 60°C for 48 h, milled through a 0.85 mm sieve, and subsequently analysed for nitrogen (N) and starch concentration. Metabolisable energy (ME), N and starch concentration of straights/by-products which were offered on a small number of farms (n = 3) were obtained from FeedByte. The composition of grass silage (intake potential, pH, dry matter (DM), crude protein (CP), ammonia nitrogen, lactic acid, neutral detergent fibre (NDF), D-value and predicated acid load) were predicted from NIRS as described by Park et al. (1998). Similarly, DM, ME and N of maize silage and whole crop silage were predicted by NIRS. Starch concentration was determined using a Megazyme kit (Megazyme International, Bray, Ireland) and N concentrations were determined using the Kjeldahl method (Tecator Kjeltec Auto 2400/2460 Analyzer/Sampler System, Foss, Warrington, UK).

Milk yield and composition: All farms participated in a formal milk recording scheme through a Milk Recording Organisation (both technician led and ‘do-it-yourself’ systems), with the majority of farms (n = 21) recorded on a monthly basis, while the remaining five farms were recorded every 6 - 8 weeks. Data provided by the Milk Recording Organisation included: individual cow test-day milk yields, milk fat concentration and milk protein concentration. During the study period milk recording was undertaken on an average of 7.7 occasions per farm (range 6 - 8).

***Dry matter intake**:* On every occasion when milk recording was undertaken, the total daily dry matter intake (DMI) of each individual cow was estimated using the following equation which had been developed specifically for cows offered concentrates on a FTY basis (Shrilai et al., 2020):

$$\text{DMI} = 11.032 + (0.554 \times \text{lactation number}) + (0.343 \times \text{ECM kg}) + (-3.194 \times \text{Fat:Protein}) + (0.107 \times \text{week in milk})$$

The DMI of each component of the diet was subsequently estimated for each individual cow. On 11 farms concentrate intakes of each individual cow were available from milking parlour and/or OPF software, and the average concentrate intake for the seven-day period prior to milk recording was determined. Intakes of concentrates via in-parlour and/or OPF feeding systems on the remaining 16 farms were determined for each individual cow using milk yields obtained through milk recording, the feeding assumptions in place on the farm at time of milk recording (yield of milk that the basal ration or forage offered was assumed to support, termed the M+ value), and the concentrate feed rate (kg concentrate offered/litre of milk produced in excess of the M+ value)), as follows:

$$\text{Concentrate intake} = (\text{milk yield} - \text{M+}) \times \text{concentrate feed rate}$$

Fresh concentrate intakes were converted to a DM basis by assuming a DM of 88% for all concentrates. Concentrates offered through either the in-parlour and/or OPF feeding systems (either recorded or calculated) were then deducted from the estimated total daily DMI for each individual cow, and the remainder of the daily DMI was assumed to be either straight forage, or a mixture of forage and concentrates if a partial mixed ration was offered. In the case of the latter, the recorded fresh weight ratios, and subsequently DM ratios (based on measured forage DM concentration) were determined. The DM ratios of individual ration ingredients were used to apportion the remainder of the daily DMI to individual ingredients. Daily intakes of N, starch and ME from each individual component of the diet were subsequently calculated.

Fertility and health data: Reproductive data was recorded by farmers including: calving dates, dates of services, if a cow was bred using a stock bull or by AI, pregnancy diagnosis and subsequent calving date. The culling or death date and primary reason for culling or death was recorded by the farmers for all cows culled before the end of lactation. On 16 farms data was downloaded from herd management software and on 10 records where collected on paper or excel. Unfortunately incomplete data, and an inability to visit farms to source missing data meant that only data from 11 farms was sufficiently robust to be used in the final analysis (numbers of cows within each lactation and concentrate DMI band presented in Supplementary Table 2.1).

Statistical analysis: For all analyses the data was analysed separately in each case for the different lactation groups: lactation 1, lactation 2, lactation 3 and lactation 4+. To investigate the effect of total concentrate DMI on cow performance, total concentrate DMI was categorised by splitting it into 6 groups based on percentiles within each lactation group (number of cows within each category for each month within each lactation are detailed in Supplementary Table 2.1). Variables that varied over month of lactation were analysed as a linear mixed model (REML estimation method) with farm and animal within farm fitted as random effects, and month of lactation and total concentrate DMI and their interaction fitted as fixed effects. Variables that were constant over month of lactation (genetic and fertility data) were analysed as a linear mixed model (REML estimation method) with farm fitted as a random effect and total concentrate DMI as a fixed effect. If any of the fixed effects were significant ($P<0.05$) then pairwise differences between the levels of the individual effects were assessed using Fisher's least significant difference test. In all cases the adequacy of the models was assessed by visual inspection of the appropriate residual plots.

Within each lactation group a stepwise regression analysis was carried out using forward selection with backward elimination according to a criterion based on variance ratios. For each response variable in question a list of suitable explanatory variables was selected. The models were then refitted with the chosen explanatory variables using linear mixed model methodology (REML estimation method) with farm, and animal within farm, fitted as random effects. Any variables that weren't significant ($P<0.05$) were removed from the final models using a backward elimination procedure. In all cases the adequacy of the final models was assessed by visual inspection of the appropriate residual plots.

All analyses were carried out using the statistical software package GenStat 20th edition (VSN International Limited, Oxford, UK).

Results

Results presented in this section are confined to data collected for fully housed animals during months 2 – 5 of lactation. Data from month 1 of lactation was excluded as most cows were not managed on true FTY until month 2 of lactation.

Approaches to FTY in practice: Average M+ on the 26 farms surveyed was 20 (range: 8 – 30) and 17 (range: 6 – 28) kg of milk/day for cows and heifers respectively. Values for M+ remained stable during the first 5 months of lactation. The concentrate build-up period ranged from 10 - 100 days before FTY commenced, with most farms offering concentrates on a FTY basis by day 30 of lactation (Figure 2.1). Concentrate levels were built up to an average of 9.7 kg/d (range: 5 – 16 kg) for multiparous animals while primiparous animals were built up to an average of 7.8 kg/d (range: 3.5 – 14kg). When FTY commenced most farms (n = 19) used a feed rate of 0.45kg/l milk, three farms used a value of 0.40kg/l milk and the remaining four farms used values of 0.42, 0.43, 0.50 and 0.52kg/l milk.

Grass silage was offered on all farms and was the predominant forage offered. Quality of grass silage offered varied between farms (Table 2.1). Seventeen farms offered 'alternative forage' alongside grass silage, namely fermented whole crop silage (n = 10), maize silage (n = 3) or both maize and whole crop (n = 4). There was great variation in concentrate N and starch concentration, particularly within the concentrate offered as part of a mixed ration (Table 2.1).

Average farm milk yield per cow/d was in excess of 30kg throughout the study (Table 2.2). Milk fat and protein composition was 4.17 and 3.26%, respectively, when averaged over month 2 – 5 of lactation. Average concentrate intake decreased and forage intake increased as lactation progressed. Starch intake decreased as lactation progressed, but N and ME intake remained relatively stable (Table 2.2).

***Effect of concentrate level on performance**:* As concentrate DMI band increased, so the concentrate and total DMI increased ($P < 0.001$) and forage DMI decreased ($P < 0.001$) for all lactations (Tables 2.3 – 2.6). Both forage and total DMI showed a linear response for all lactations excepting lactation 1 for which there was a quadratic response (Supplementary Table 2.6).The effect of month of lactation was also significant ($P < 0.001$; Supplementary Tables 2.2-2.5), with concentrate levels declining and forage and total DMI intake increasing between months 2 - 5 of lactation. There was a significant interaction between month of lactation and concentrate DMI band for total forage and total DMI within lactation 1 and 2 ($P < 0.001$), and for total forage DMI within lactation 3 ($P < 0.042$), and for total concentrate, total forage and total DMI within lactation 4+ ($P < 0.001$).

For all lactations, milk yield, fat plus protein yield and ECM yield increased ($P < 0.001$) as concentrate DMI band increased (Tables 2.3 – 2.6). The effect of month of lactation was also significant ($P < 0.001$; Supplementary Tables 2.2 – 2.5), with yields declining from month 2 - 5 of lactation for multiparous cows, and yields being significantly greater in month 3 and 4 of lactation compared to month 2 and 5 for primiparous cows. There were interactions between month of lactation and concentrate DMI band for milk yield for lactation 1 and lactation 4+ cows ($P < 0.001$). Milk fat % declined as concentrate DMI band increased ($P < 0.001$) in all lactations excepting lactation 3. There was a significant effect of month, with milk fat increasing from month 2 – 5 of lactation within all lactations ($P < 0.001$). There was also an interaction between month and concentrate DMI band for milk fat % in lactation 1 ($P = 0.024$) and 4+ ($P = 0.029$). Milk protein % was not significantly affected by concentrate DMI level for any of the lactations; however, milk protein % was effected by month of lactation and decreased as lactation progressed ($P < 0.001$). There was an interaction between month and concentrate DMI for milk protein % for lactation 1 cows ($P = 0.005$). Milk yield increased in a linear fashion for all lactations excepting lactation 1, when the response was quadratic (Supplementary Table 2.6). Milk fat % showed a linear increase in all lactations, while milk protein %showed a linear response in lactations 2 and 4+. Fat plus protein yield demonstrated a quadratic response to concentrate intake band, excepting lactation 2 which demonstrated a linear response. Similarly, ECM yield increased in a quadratic fashion for lactation 1 and 4+, and in a linear fashion for lactation 2 and 3.

Total starch, N and ME intake increased as concentrate DMI band increased for all lactations ($P < 0.001$; Tables 2.3 – 2.6). Month of lactation also had a significant effect on starch intake ($P < 0.001$; Supplementary Tables 2.2 – 2.5); within lactation 1 – 3 starch intake increased as lactation progressed, but within lactation 4+ starch intake decreased as lactation progressed. There where interactions between month and concentrate DMI band for lactation 1 ($P < 0.001$), 2 ($P < 0.001$) and 4+ ($P = 0.034$). Month of lactation had a significant effect on N intake for lactation 1 ($P < 0.001$), 3 ($P = 0.001$) and 4+ ($P < 0.001$), with N intake increasing as lactation progressed. There was an interaction between month of lactation and concentrate DMI band for N intake within lactation 1 ($P < 0.001$) and 2 ($P = 0.048$). Month of lactation had a significant effect on ME intake in lactation 1 ($P <0.001$) and 4+ ($P = 0.011$), with ME intake increasing as lactation progressed. There was an interaction between month of lactation and concentrate DMI band within lactation 1 ($P < 0.001$).

Effect of concentrate level on production efficiency*:* Nitrogen use efficiency (milk N/N intake) increased in a quadratic fashion as concentrate DMI increased ($P < 0.001$; Tables 3 – 6; Supplementary Table 2.6) for all lactations. Month of lactation also significantly affected N use efficiency ($P < 0.001$; Supplementary Tables 2.2 – 2.5) with N use efficiency decreasing as lactation progressed for all lactations. There was an interaction between month and concentrate DMI band for all lactations ($P < 0.001$) except lactation 3. Energy efficiency, measured as either milk energy/ME intake or ECM/DMI, increased in a quadric fashion as concentrate intake levels increased ($P < 0.001$) for all lactations (Supplementary Table 2.6). Month of lactation also had a significant effect ($P < 0.001$) with energy efficiency decreasing as lactation progressed. There was an interaction between month and concentrate DMI band for milk energy/ME intake within lactations 1 ($P < 0.001$) and 2 ($P = 0.013$). There was also an interaction between month and concentrate band for ECM/DMI within lactation 1 ($P < 0.001$) and 4+ ($P = 0.012$). Concentrate efficiency, measured as concentrate DMI/milk yield or concentrate DMI/ ECM yield, was poorer as concentrate intake bands increased ($P < 0.001$); this was a quadratic response for lactations 2 – 4+ and linear for lactation 1 (Supplementary Table 2.6). Month of lactation had a significant effect on concentrate DMI/milk yield in lactation 1 and 2 ($P < 0.001$; Supplementary Tables 2.2 – 2.3), with efficiency being significantly better in month 3 and 4 of lactation. There was also an interaction between month and concentrate DMI band for concentrate DMI/milk yield within lactation 1 ($P < 0.001$), 2 ($P = 0.046$) and 4+ ($P = 0.005$). Month of lactation had a significant effect on concentrate DMI/ECM yield ($P < 0.001$). In lactation 1 and 2 concentrate DMI/ECM was reduced in month 2, but in lactations 3 and 4+ it was reduced in month 5 (Supplementary Tables 2.2 – 2.5). There was an interaction between month and concentrate DMI band for concentrate DMI/ECM yield for lactations 1 ($P < 0.001$) and 4+ ($P = 0.040$).

Relationship between concentrate DMI and genetic merit: As lactation number decreased, PLI increased (Table 2.7). In lactation 2 and 4+, cows with greater PLI also had greater concentrate DMI. As concentrate DMI band increased so did the PTA for milk yield in all lactations. However, PTA for milk fat % decreased significantly in lactation 2 – 4+ as concentrate DMI band increased. In lactation 2 PTA for milk protein % was significantly reduced as concentrate DMI band increased. Fertility index was significantly lower as concentrate DMI band increased in lactation 2 and 3. Cows in lactation 4+ also differed in fertility index between concentrate DMI bands, but this trend was not linear. Predicted transmitting ability for somatic cell count (SCC) was not significantly different between concentrate DMI bands.

Relationship between concentrate DMI and fertility: There was no effect of concentrate DMI band on any fertility measures in lactations 1 and 4+ (Table 2.8). In lactation 2, cows in the lowest concentrate DMI band had significantly greater days to first service ($P = 0.004$). In lactation 3, there was a significant effect on days to first service ($P = 0.033$), days to pregnant ($P = 0.013$), pregnant at 100 days ($P = 0.018$), and calving interval (P = 0.019) with the middle two concentrate DMI bands showing the best performance (Table 2.8).

***Drivers of milk composition and efficiency**:* In all lactations milk yield had a negative effect on milk fat %, while DMI had a positive effect on milk fat % (Table 2.9). In lactation 1 total concentrate DMI had a positive effect on milk fat %, and in lactation 2 concentrate proportion of the diet had a positive effect. Also, in lactation 2 starch % of the diet had a negative effect on milk fat %.

Within the subset of cows with genetic data, milk yield and total DMI were negative and positive drivers of milk fat %, respectively, while PTA for milk fat % was also a positive driver (Table 2.10). Genetic potential for milk protein % was a negative driver of milk fat % in all lactations. In lactations 1 and 4+, PTA for milk yield was a positive driver of milk fat %.

Milk yield was a negative driver of milk protein %, while total DMI was a positive driver of milk protein % in all lactations (Table 2.9). In lactation 1, starch % of diet and concentrate proportion of the diet were also identified as negative and positive drivers of milk protein %, respectively. Within the subset of data containing cows with genetic data, milk yield and total DMI were negative and positive drivers of milk protein %, respectively, while PTA for milk protein % was also a positive driver in all lactations (Table 2.10). In lactations 2 – 4+, PTA for milk yield was identified as a positive driver for milk protein %.

Total DMI was a positive driver for ECM yield in all lactations (Table 2.9), and concentrate proportion was also a positive driver in lactations 2 – 4+, while forage DMI was a negative driver in lactation 1. Within the subset of data containing cows with genetic data, PTA for milk fat % was identified as a positive driver for ECM (Table 2.10). Genetic potential for milk yield was a positive driver for ECM in both lactations 1 and 4, while PTA for milk protein % was a negative driver of ECM in all lactations.

Both concentrate and forage DMI were positive drivers for ECM/DMI efficiency in all lactations (Table 2.9). Within the subset of data containing cows with genetic data, as well as forage and concentrate DMI being positive drivers, PTA for milk fat % was identified as a positive driver (Table 2.10). Genetic potential for milk yield was a positive driver for ECM/DMI in both lactations 1 and 4, while PTA for milk protein % was a negative driver of ECM/DMI in lactations 1-3.

Increased total DMI reduced concentrate efficiency (concentrate/ECM) in all lactations excepting lactation 1 (Table 2.9). Increased forage DMI improved concentrate efficiency in lactation 1 while concentrate proportion had a negative impact on efficiency within lactations 2 - 4+. Within the subset of data containing cows with genetic data, as total DMI increased efficiency improved; however, when concentrate proportion increased efficiency decreased (Table 2.10). Genetic potential for milk fat % improved concentrate efficiency in all lactations, as did PTA for milk yield in all lactations excepting lactation 3. Genetic potential for milk protein % was a negative driver of concentrate efficiency in lactation 1 and 2 (Table 2.10).

Table 2.1. Composition of forages and concentrates (mean, minimum and maximum) offered to cows throughout the study period (based on samples collected durin farm visits).

	Mean	Range	
		Min	Max
Conserved forages			
Grass silage			
Oven dry matter (g/kg)	318	211	393
Crude protein (g/kg DM)	139	122	155
Neutral detergent fibre (g/kg DM)	425	395	480
Metabolisable energy (MJ/kg DM)	11.2	10.0	12.1
pH	3.96	3.70	4.66
Ammonia nitrogen (g/kg total N)	81	60	190
Predicted acid load (meq/kg DM)	718	700	834
Predicted intake (g/kg $BW^{0.75}$)	107	90	115
Maize silage			
Oven dry matter (g/kg)	334	267	439
Crude protein (g/kg DM)	86	81	97
Metabolisable energy (MJ/kg DM)	11.4	10.5	11.9
Starch (g/kg DM)	293	211	387
Whole crop silage			
Oven dry matter (g/kg)	399	252	584
Crude protein (g/kg DM)	84	64	107
Metabolisable energy (MJ/kg DM)	10.0	9.2	11.1
Starch (g/kg DM)	244	46	344
Concentrates			
Feed-to-yield concentrate			
Crude protein (g/kg DM)	193	155	250
Starch (g/kg DM)	229	135	313
Basal ration concentrate			
Crude protein (g/kg DM)	219	100	345
Starch (g/kg DM)	247	129	418

Table 2.2. Summary of average farm performance and intake by month of lactation on 27 dairy farms offering concentrates on a FTY basis.

Month of lactation	2			3			4			5		
		Range			Range			Range			Range	
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Total Concentrate DMI (kg/d)	11.5	8.8	17.4	10.8	7.6	16.8	10.4	7.4	15.1	9.9	7.18	14.2
Total Forage DMI (kg/d)	10.3	5.4	12.7	11.3	5.9	13.5	11.7	7.3	14.3	12.2	7.9	14.7
Total DMI (kg/d)	21.8	18.6	23.7	22.1	20.2	24.5	22.1	20.2	24.1	22.0	20.0	24.3
Grass silage as proportion of total DMI	0.39	0.24	0.60	0.42	0.24	0.59	0.44	0.22	0.61	0.46	0.23	0.64
Alternative forage as proportion of DMI	0.07	0.00	0.29	0.08	0.00	0.33	0.09	0.00	0.38	0.08	0.00	0.38
Concentrate as proportion of DMI	0.52	0.40	0.76	0.48	0.36	0.74	0.46	0.34	0.67	0.44	0.33	0.64
Total starch intake (g/d)	3244	1700	5402	3125	1589	5496	3001	1533	5638	2859	1610	5547
Total nitrogen intake (g/d)	582	512	682	585	504	675	582	491	666	576	471	670
Total ME intake (MJ/d)	269	231	380	270	237	349	267	237	295	267	231	323
Milk yield (kg/d)	36.8	29.8	43.4	35.6	29.3	44.0	33.9	27.5	39.9	32.0	26.5	38.3
Fat (%)	4.09	3.44	5.16	4.13	3.61	5.11	4.20	3.62	5.21	4.26	3.61	5.24
Protein (%)	3.14	3.01	3.35	3.22	3.04	3.47	3.30	3.11	3.56	3.36	3.16	3.66
Fat plus protein yield (kg/d)	2.64	2.15	3.12	2.59	2.18	3.01	2.52	2.13	2.99	2.41	2.06	2.78

Table 2.3. Dry matter intakes, milk production, and nutrient intake and efficiency values within each concentrate intake band for first lactation cows.

	Concentrate intake band (kg DM/cow/day)							P values		
	1.6 - 6.0	6.0 - 7.2	7.2 - 8.2	8.2 - 9.4	9.4 - 11.0	11.0 - 20.2	SED	Month	Bands	Interaction
Dry matter intake										
Total concentrate DMI (kg/day)	5.1[a]	6.6[b]	7.7[c]	8.9[d]	10.2[e]	12.8[f]	0.05	<0.001	<0.001	0.988
DMI of concentrate offered on a FTY basis (kg)	1.8[a]	3.2[b]	4.1[c]	5.3[d]	6.6[e]	9.1[f]	0.07	<0.001	<0.001	<0.001
Total forage DMI (kg/day)	10.9[f]	10.7[e]	10.4[d]	10.2[c]	9.8[b]	8.8[a]	0.08	<0.001	<0.001	<0.001
Total DMI (kg/day)	16.1[a]	17.4[b]	18.1[c]	19.0[d]	20.0[e]	21.4[f]	0.09	<0.001	<0.001	<0.001
Diet composition and nutrient intakes										
Concentrate as % total DMI	0.32[a]	0.39[b]	0.43[c]	0.47[d]	0.51[e]	0.59[f]	0.003	<0.001	<0.001	<0.001
Alternative forages as % total DMI	0.11[d]	0.09[c]	0.08[bc]	0.08[b]	0.08[b]	0.07[a]	0.003	<0.001	<0.001	<0.001
Starch intake from concentrates (g/d)	1219[a]	1580[b]	1854[c]	2128[d]	2426[e]	2984[f]	14.9	<0.001	<0.001	0.694
Total starch intake (g/d)	1681[a]	1999[b]	2268[c]	2589[d]	2898[e]	3435[f]	21.6	<0.001	<0.001	<0.001
Starch % of total diet	10.7[a]	11.7[b]	12.6[c]	13.4[d]	14.2[e]	15.8[f]	0.11	<0.001	<0.001	<0.001
N intake from concentrates (g/d)	172[a]	219[b]	253[c]	288[d]	331[e]	410[f]	1.9	<0.001	<0.001	0.893
Total N intake (g/kg)	399[a]	441[b]	470[c]	497[d]	531[e]	589[f]	2.6	<0.001	<0.001	<0.001
Crude protein % of total diet	15.6[a]	15.9[b]	16.2[c]	16.4[d]	16.6[e]	17.1[f]	0.05	<0.001	<0.001	<0.001
ME intake from concentrate (g/d)	67[a]	90[b]	103[c]	117[d]	133[e]	163[f]	0.9	<0.001	<0.001	0.119
Total ME intake (g/kg)	189[a]	211[b]	221[c]	232[d]	243[e]	262[f]	2.0	<0.001	<0.001	<0.001
ME concentration of total diet (MJ/kg DM)	12.0[ab]	12.3[c]	12.3[c]	12.2[bc]	12.1[ab]	12.0[a]	0.10	<0.001	<0.001	<0.001
Milk production and efficiency values										
Milk yield (kg/day)	21.1[a]	24.4[b]	26.3[c]	28.7[d]	31.1[e]	35.1[f]	0.23	<0.001	<0.001	<0.001
Milk fat (%)	4.26[d]	4.16[c]	4.11[bc]	4.07[b]	4.05[ab]	3.97[a]	0.041	<0.001	<0.001	0.024
Milk protein (%)	3.26	3.26	3.27	3.25	3.26	3.27	0.012	<0.001	0.120	0.005
Fat + protein yield (kg/day)	1.56[a]	1.79[b]	1.94[c]	2.12[d]	2.28[e]	2.56[f]	0.020	0.002	<0.001	<0.001
Energy corrected milk yield (kg/day)	21.6[a]	24.9[b]	26.9[c]	29.4[d]	31.8[e]	35.7[f]	0.26	<0.001	<0.001	<0.001
Milk N/N intake	0.26[a]	0.28[b]	0.28[c]	0.30[d]	0.30[e]	0.31[f]	0.002	<0.001	<0.001	<0.001
Milk energy/ME intake	0.34[a]	0.36[b]	0.38[c]	0.40[d]	0.41[e]	0.43[f]	0.003	<0.001	<0.001	<0.001
ECM/DMI (kg/kg)	1.32[a]	1.43[b]	1.48[c]	1.55[d]	1.60[e]	1.67[f]	0.009	<0.001	<0.001	<0.001
Concentrate DMI/milk yield (kg/kg)	0.24[a]	0.27[b]	0.29[c]	0.31[d]	0.33[e]	0.36[f]	0.003	<0.001	<0.001	<0.001
Concentrate DMI/ECM yield (kg/kg)	0.25[a]	0.28[b]	0.30[c]	0.31[d]	0.33[e]	0.36[f]	0.003	<0.001	<0.001	<0.001

Table 2.4. Dry matter intakes, milk production, and nutrient intake and efficiency values within each concentrate intake band for second lactation cows.

	Concentrate intake band (kg DM/cow/day)							P values		
	1.8 - 7.7	7.7 - 9.1	9.1 - 10.3	10.3 - 11.6	11.6 - 13.4	13.4 - 23.3	SED	Month	Bands	Interaction
Dry matter intake										
Total concentrate DMI (kg/day)	6.7^{a}	8.4^{b}	9.7^{c}	11.0^{d}	12.4^{e}	14.9^{f}	0.06	<0.001	<0.001	0.062
DMI of concentrate offered on a FTY basis (kg)	3.1^{a}	4.6^{b}	5.8^{c}	7.0^{d}	8.4^{e}	10.8^{f}	0.08	<0.001	<0.001	<0.001
Total forage DMI (kg/day)	12.1^{f}	11.6^{e}	11.4^{d}	11.2^{c}	10.8^{b}	10.6^{a}	0.10	<0.001	<0.001	<0.001
Total DMI (kg/day)	18.8^{a}	20.1^{b}	21.1^{c}	22.2^{d}	23.2^{e}	25.4^{f}	0.11	<0.001	<0.001	<0.001
Diet composition and nutrient intakes										
Concentrate as % total DMI	0.36^{a}	0.42^{b}	0.46^{c}	0.50^{d}	0.54^{e}	0.59^{f}	0.003	<0.001	<0.001	<0.001
Alternative forages as % total DMI	0.09^{e}	0.09^{d}	0.08^{c}	0.08^{c}	0.07^{b}	0.06^{a}	0.003	<0.001	<0.001	<0.001
Starch intake from concentrates (g/d)	1638^{a}	2055^{b}	2336^{c}	2602^{d}	2948^{e}	3521^{f}	19.0	<0.001	<0.001	0.235
Total starch intake (g/d)	2142^{a}	2555^{b}	2820^{c}	3123^{d}	3450^{e}	4048^{f}	28.1	<0.001	<0.001	<0.001
Starch % of total diet	11.5^{a}	12.8^{b}	13.3^{c}	13.9^{d}	14.7^{e}	15.6^{f}	0.11	<0.001	<0.001	<0.001
N intake from concentrates (g/d)	225^{a}	277^{b}	317^{c}	357^{d}	401^{e}	478^{f}	2.3	<0.001	<0.001	0.011
Total N intake (g/kg)	476^{a}	518^{b}	556^{c}	586^{d}	622^{e}	691^{f}	3.3	0.472	<0.001	0.048
Crude protein % of total diet	15.8^{a}	16.1^{b}	16.4^{c}	16.5^{d}	16.8^{f}	17.1^{e}	0.05	<0.001	<0.001	<0.001
ME intake from concentrate (g/d)	90^{a}	112^{b}	128^{c}	145^{d}	163^{e}	195^{f}	0.9	<0.001	<0.001	0.039
Total ME intake (g/kg)	226^{a}	244^{b}	260^{c}	272^{d}	285^{e}	317^{f}	2.6	0.993	<0.001	0.068
ME concentration of total diet (MJ/kg DM)	12.1	12.2	12.3	12.3	12.3	12.4	1.0	0.053	0.141	0.029
Milk production and efficiency values										
Milk yield (kg/day)	26.9^{a}	30.5^{b}	33.2^{c}	36.0^{d}	38.9^{e}	44.4^{f}	0.30	<0.001	<0.001	0.755
Milk fat (%)	4.17^{c}	4.08^{bc}	4.06^{ab}	4.07^{b}	3.98^{ab}	3.96^{a}	0.050	<0.001	0.003	0.695
Milk protein (%)	3.32	3.31	3.29	3.30	3.29	3.27	0.014	<0.001	0.110	0.221
Fat + protein yield (kg/day)	2.00^{a}	2.25^{b}	2.44^{c}	2.65^{d}	2.83^{e}	3.23^{f}	0.027	<0.001	<0.001	0.071
Energy corrected milk yield (kg/day)	27.5^{a}	31.1^{b}	33.9^{c}	36.9^{d}	39.5^{e}	45.2^{f}	0.24	<0.001	<0.001	0.102
Milk N/N intake	0.29^{a}	0.30^{b}	0.31^{c}	0.31^{d}	0.32^{e}	0.33^{f}	0.002	<0.001	<0.001	<0.001
Milk energy/ME intake	0.37^{a}	0.40^{b}	0.41^{c}	0.43^{d}	0.44^{e}	0.46^{f}	0.005	<0.001	<0.001	0.013
ECM/DMI (kg/kg)	1.45^{a}	1.54^{b}	1.60^{c}	1.66^{d}	1.70^{e}	1.78^{f}	0.011	<0.001	<0.001	0.051
Concentrate DMI/milk yield (kg/kg)	0.26^{a}	0.28^{b}	0.30^{c}	0.31^{d}	0.32^{e}	0.33^{f}	0.003	<0.001	<0.001	0.046
Concentrate DMI/ECM yield (kg/kg)	0.25^{a}	0.28^{b}	0.29^{c}	0.30^{d}	0.32^{e}	0.33^{f}	0.003	<0.001	<0.001	0.058

Table 2.5: Dry matter intakes, milk production, and nutrient intake and efficiency values within each concentrate intake band for third lactation cows.

	Concentrate intake band (kg DM/cow/day)							P values		
	2.1 - 8.7	8.7 - 10.3	10.3 - 11.4	11.4 - 12.6	12.6 - 14.6	14.6 - 23.8	SED	Month	Bands	Interaction
Dry matter intake										
Total concentrate DMI (kg/day)	7.5^{a}	9.6^{b}	10.8^{c}	12.0^{d}	13.5^{e}	16.1^{f}	0.08	<0.001	<0.001	0.852
DMI of concentrate offered on a FTY basis (kg)	3.7^{a}	5.6^{b}	6.7^{c}	7.7^{d}	9.2^{e}	11.6^{f}	0.1	<0.001	<0.001	<0.001
Total forage DMI (kg/day)	12.2^{d}	11.9^{c}	11.8^{c}	11.7^{c}	11.4^{b}	11.1^{a}	0.12	<0.001	<0.001	0.042
Total DMI (kg/day)	19.7^{a}	21.5^{b}	22.6^{c}	23.7^{d}	24.8^{e}	27.1^{f}	0.14	0.089	<0.001	0.338
Diet composition and nutrient intakes										
Concentrate as % total DMI	0.38^{a}	0.45^{b}	0.48^{c}	0.51^{d}	0.54^{e}	0.59^{f}	0.003	<0.001	<0.001	0.082
Alternative forages as % total DMI	0.11^{d}	0.08^{c}	0.08^{bc}	0.08^{b}	0.07^{a}	0.06^{a}	0.004	<0.001	<0.001	0.008
Starch intake from concentrates (g/d)	1785^{a}	2300^{b}	2563^{c}	2838^{d}	3183^{e}	3766^{f}	22.7	<0.001	<0.001	0.853
Total starch intake (g/d)	2357^{a}	2815^{b}	3069^{c}	3345^{d}	3673^{e}	4327^{f}	33.9	<0.001	<0.001	0.069
Starch % of total diet	12.1^{a}	13.2^{b}	13.5^{c}	14.1^{d}	14.5^{e}	15.7^{f}	0.13	<0.001	<0.001	0.03
N intake from concentrates (g/d)	247^{a}	311^{b}	352^{c}	389^{d}	439^{e}	516^{f}	2.9	<0.001	<0.001	0.683
Total N intake (g/kg)	502^{a}	564^{b}	595^{c}	630^{d}	673^{e}	742^{f}	4.1	0.001	<0.001	0.248
Milk N/N intake	0.28^{a}	0.30^{b}	0.31^{c}	0.31^{c}	0.32^{d}	0.33^{e}	0.002	<0.001	<0.001	0.508
Crude protein % of total diet	15.9^{a}	16.4^{b}	16.4^{b}	16.7^{c}	17.0^{d}	17.2^{e}	0.07	<0.001	<0.001	0.614
ME intake from concentrate (g/d)	98^{a}	125^{b}	141^{c}	156^{d}	175^{e}	209^{f}	1.1	<0.001	<0.001	0.702
Total ME intake (g/kg)	232^{a}	261^{b}	275^{c}	288^{d}	300^{e}	335^{f}	2.8	0.087	<0.001	0.076
ME concentration of total diet (MJ/kg DM)	11.9^{a}	12.0^{ab}	12.1^{bc}	12.2^{bc}	12.2^{bc}	12.3^{c}	0.10	0.022	<0.001	0.018
Milk production and efficiency values										
Milk yield (kg/day)	28.5^{a}	33.1^{b}	36.1^{c}	38.8^{d}	42.1^{e}	47.8^{f}	0.34	<0.001	<0.001	0.712
Milk fat (%)	4.14	4.07	4.09	4.04	4.05	3.96	0.06	<0.001	0.066	0.684
Milk protein (%)	3.25	3.26	3.26	3.26	3.24	3.24	0.017	<0.001	0.823	0.384
Fat + protein yield (kg/day)	2.08^{a}	2.41^{b}	2.65^{c}	2.83^{d}	3.07^{e}	3.46^{f}	0.033	<0.001	<0.001	0.431
Energy corrected milk yield (kg/day)	28.7^{a}	33.5^{b}	36.8^{c}	39.5^{d}	42.9^{e}	48.4^{f}	0.42	<0.001	<0.001	0.394
Milk N/N intake	0.28^{a}	0.30^{b}	0.31^{c}	0.31^{c}	0.32^{d}	0.33^{e}	0.002	<0.001	<0.001	0.508
Milk energy/ME intake	0.37^{a}	0.40^{b}	0.42^{c}	0.43^{d}	0.45^{e}	0.46^{e}	0.006	<0.001	<0.001	0.149
ECM/DMI (kg/kg)	1.44^{a}	1.55^{b}	1.62^{c}	1.66^{d}	1.73^{e}	1.79^{f}	0.012	<0.001	<0.001	0.338
Concentrate DMI/milk yield (kg/kg)	0.27^{a}	0.29^{b}	0.30^{c}	0.31^{d}	0.32^{e}	0.33^{f}	0.003	0.052	<0.001	0.658
Concentrate DMI/ECM yield (kg/kg)	0.27^{a}	0.29^{b}	0.30^{c}	0.31^{d}	0.32^{e}	0.33^{f}	0.003	<0.001	<0.001	0.251

Table 2.6: Dry matter intakes, milk production, and nutrient intake and efficiency values within each concentrate intake band for fourth and higher lactation cows.

	Concentrate intake band (kg DM/cow/day)							P values		
	2.1 - 9.1	9.1 - 10.7	10.7 - 11.8	11.8 - 13.0	13.0 - 14.9	14.9 - 24.3	SED	Month	Bands	Interaction
Dry matter intake										
Total concentrate DMI (kg/day)	7.7[a]	10.1[b]	11.3[c]	12.5[d]	14.0[e]	16.3[f]	0.06	<0.001	<0.001	<0.001
DMI of concentrate offered on a FTY basis (kg)	3.6[a]	5.9[b]	7.2[c]	8.2[d]	9.6[e]	11.7[f]	0.08	<0.001	<0.001	<0.001
Total forage DMI (kg/day)	13.5[e]	12.9[d]	12.7[c]	12.6[c]	12.2[b]	11.6[a]	0.10	<0.001	<0.001	<0.001
Total DMI (kg/day)	21.2[a]	23.0[b]	24.0[c]	25.1[d]	26.2[e]	27.9[f]	0.11	<0.001	<0.001	<0.001
Nutrient intakes										
Concentrate as % total DMI	0.36[a]	0.44[b]	0.47[c]	0.50[d]	0.54[e]	0.58[f]	0.003	<0.001	<0.001	<0.001
Alternative forages as % total DMI	0.09[e]	0.09[d]	0.08[c]	0.08[c]	0.07[b]	0.06[a]	0.003	<0.001	<0.001	0.078
Starch intake from concentrates (g/d)	1849[a]	2418[b]	2715[c]	2979[d]	3331[e]	3866[f]	19.9	<0.001	<0.001	<0.001
Total starch intake (g/d)	2403[a]	2979[b]	3244[c]	3529[d]	3878[e]	4391[f]	26.8	<0.001	<0.001	0.034
Starch % of total diet	11.3[a]	13.0[b]	13.5[c]	14.0[d]	14.7[e]	15.5[f]	0.10	<0.001	<0.001	0.007
N intake from concentrates (g/d)	255[a]	329[b]	368[c]	404[d]	454[e]	524[f]	2.5	<0.001	<0.001	<0.001
Total N intake (g/kg)	540[a]	601[b]	630[c]	666[d]	706[e]	758[f]	3.46	<0.001	<0.001	0.090
Crude protein % of total diet	15.9[a]	16.3[b]	16.4[c]	16.6[d]	16.8[e]	17.0[f]	0.06	<0.001	<0.001	0.154
ME intake from concentrate (g/d)	103[a]	133[b]	149[c]	164[d]	184[e]	212[f]	1.1	<0.001	<0.001	<0.001
Total ME intake (g/kg)	254[a]	279[b]	293[c]	309[d]	324[e]	343[f]	3.0	0.011	<0.001	0.053
ME concentration of total diet (MJ/kg DM)	12.1	12.2	12.2	12.3	12.3	12.2	1.0	0.684	0.285	0.121
Milk production and efficiency values										
Milk yield (kg/day)	28.7[a]	34.0[b]	37.0[c]	40.0[d]	43.2[e]	48.2[f]	0.30	<0.001	<0.001	<0.001
Milk fat (%)	4.16[d]	4.10[cd]	4.04[bc]	4.03[bc]	3.98[b]	3.87[a]	0.049	0.001	<0.001	0.029
Milk protein (%)	3.22	3.21	3.20	3.19	3.20	3.18	0.013	<0.001	0.166	0.199
Fat + protein yield (kg/day)	2.12[a]	2.50[b]	2.68[c]	2.92[d]	3.12[e]	3.41[f]	0.028	<0.001	<0.001	0.232
Energy corrected milk yield (kg/day)	29.3[a]	34.8[b]	37.5[c]	40.8[d]	43.7[e]	48.1[f]	0.36	<0.001	<0.001	0.158
Milk N/N intake	0.26[a]	0.28[b]	0.29[c]	0.30[d]	0.31[e]	0.32[f]	0.002	<0.001	<0.001	<0.001
Milk energy/ME intake	0.35[a]	0.39[b]	0.40[c]	0.41[d]	0.42[e]	0.45[f]	0.005	<0.001	<0.001	0.051
ECM/DMI (kg/kg)	1.37[a]	1.51[b]	1.55[c]	1.62[d]	1.66[e]	1.71[f]	0.010	<0.001	<0.001	0.012
Concentrate DMI/milk yield (kg/kg)	0.27[a]	0.30[b]	0.31[c]	0.32[c]	0.33[d]	0.34[e]	0.002	0.101	<0.001	0.005
Concentrate DMI/ECM yield (kg/kg)	0.27[a]	0.30[b]	0.31[c]	0.31[c]	0.33[d]	0.34[e]	0.003	<0.001	<0.001	0.040

Table 2.7. Predicted Transmitting Ability (PTA) $_{2019}$ of experimental cows within each lactation and concentrate intake band.

	Concentrate intake band (kg DM/cow/day)						SED	P values
Lactation 1	1.6 - 6.0	6.0 - 7.2	7.2 - 8.2	8.2 - 9.4	9.4 -11.0	11.0 - 20.2		
PLI £	191	230	221	235	258	273	25.0	0.121
Milk yield (kg)	87^{a}	127^{a}	133^{a}	202^{b}	266^{c}	261b^{c}	30.2	<0.001
Fat (%)	0.06	0.06	0.06	0.04	0.04	0.04	0.011	0.060
Protein (%)	0.04	0.04	0.04	0.03	0.03	0.03	0.006	0.081
SCC	-2.9	-3.1	-3.5	-3.5	-4.4	-4.2	0.89	0.605
Fertility Index	3.8	4.3	3.4	3.5	2.9	3.7	0.57	0.119
Lactation 2	1.8 - 7.7	7.7 - 9.1	9.1 - 10.3	10.3 - 11.6	11.6 - 13.4	13.4 - 23.3		
PLI (£)	140^{a}	142^{a}	170^{ab}	190^{b}	194^{b}	236^{c}	18.4	<0.001
Milk yield (kg)	-12^{a}	30^{a}	89^{b}	144^{c}	202^{d}	335^{e}	27.7	<0.001
Fat (%)	0.08^{c}	0.08^{c}	0.07^{c}	0.06^{bc}	0.05^{b}	0.02^{a}	0.011	<0.001
Protein (%)	0.04^{b}	0.04^{b}	0.04^{b}	0.03^{b}	0.03^{b}	0.01^{a}	0.005	<0.001
SCC	-3.7	-4.1	-3	-3.3	-3.9	-5.5	0.93	0.096
Fertility Index	4.3^{d}	3.4^{cd}	2.9^{bc}	2.5^{b}	2.1^{b}	0.8^{a}	0.58	<0.001
Lactation 3	2.1 - 8.7	8.7 - 10.3	10.3 - 11.4	11.4 - 12.6	12.6 - 14.6	14.6 - 23.8		
PLI (£)	131	143	148	164	186	206	22.3	0.058
Milk yield (kg)	-34^{a}	22^{a}	81^{b}	88^{b}	169^{c}	242^{d}	31.2	<0.001
Fat (%)	0.07^{b}	0.06^{b}	0.06^{b}	0.06^{b}	0.03^{a}	0.01^{a}	0.012	<0.001
Protein (%)	0.04	0.04	0.04	0.03	0.02	0.03	0.006	0.128
SCC	-4.4	-3.7	-3.7	-2.7	-3.8	-3.5	1.02	0.690
Fertility Index	4.6^{c}	3.8^{bc}	3.4^{bc}	3.0^{b}	3.5^{bc}	1.5^{a}	0.67	0.002
Lactation 4	2.1 - 9.1	9.1 - 10.7	10.7 - 11.8	11.8 - 13.0	13.0 - 14.9	14.9 - 24.3		
PLI (£)	59^{a}	109^{b}	116^{b}	121^{bc}	131^{bc}	153^{c}	16.8	<0.001
Milk yield (kg)	-122^{a}	-74^{a}	-9^{b}	27^{b}	82^{c}	121^{c}	29.0	<0.001
Fat (%)	0.09^{e}	0.08^{de}	0.07^{cd}	0.05^{bc}	0.04^{ab}	0.03^{a}	0.011	<0.001
Protein (%)	0.04	0.04	0.04	0.03	0.03	0.03	0.006	0.327
SCC	-3.5	-4	-4.6	-4.7	-3.4	-4.9	0.98	0.460
Fertility Index	2.7^{ab}	3.3^{b}	2.3^{ab}	2.2^{a}	1.5^{a}	2.5^{ab}	0.60	0.040

Table 2.8. Fertility parameters measured in a subset of experimental cows within each lactation and concentrate intake band (LCI – UCI in parenthesis).

	Concentrate intake band (kg DM/cow/day)						SED	P values
Lactation 1	1.6 - 6.0	6.0 - 7.2	7.2 - 8.2	8.2 - 9.4	9.4 -11.0	11.0 - 20.2		
Days to first service	78	69	68	66	68	75	5.0	0.283
Days to pregnant	116	96	99	97	102	106	9.9	0.494
Calving interval	400	378	379	381	380	378	10.5	0.637
Number of services	2.2	2.1	2.1	2.1	2.3	2.3		0.947
	(1.7 - 2.9)	(1.7 - 2.5)	(1.8 - 2.5)	(1.8 - 2.5)	(1.9 - 2.7)	(1.9 - 3.0)		
Pregnant to 1st service	0.33	0.49	0.36	0.39	0.3	0.38		0.398
	(0.17 - 0.56)	(0.34 - 0.64)	(0.24 - 0.50)	(0.26 - 0.53)	(0.18 - 0.46)	(0.20 - 0.60)		
Pregnant at 100 d	0.32	0.59	0.49	0.56	0.64	0.45		0.052
	(0.17 - 0.54)	(0.44 - 0.73)	(0.36 - 0.62)	(0.43 - 0.68)	(0.50 - 0.76)	(0.27 - 0.64)		
Pregnant at 200 d	0.87	0.92	0.88	0.91	0.94	0.91		0.598
	(0.64 - 0.96)	(0.81 - 0.97)	(0.79 - 0.93)	(0.83 - 0.95)	(0.86 - 0.97)	(0.79 - 0.97)		
Conception rate	0.92	0.93	0.93	0.94	0.95	0.96		0.672
	(0.77 - 0.98)	(0.84 - 0.97)	(0.85 - 0.97)	(0.87 - 0.98)	(0.89 - 0.98)	(0.88 - 0.99)		
Lactation 2	1.8 - 7.7	7.7 - 9.1	9.1 - 10.3	10.3 - 11.6	11.6 - 13.4	13.4 - 23.3		
Days to first service	93b	70a	73a	71a	70a	66a	5.8	0.004
Days to pregnant	118	107	102	104	93	109	11.1	0.494
Calving interval	397	386	383	389	375	392	10.8	0.409
Number of services	2.2	2.2	2.2	2.2	2	2.2		0.965
	(1.6 - 2.9)	(1.8 - 2.6)	(1.8 - 2.7)	(1.9 - 2.7)	(1.6 - 2.5)	(1.8 - 2.8)		
Pregnant to 1st service	0.51	0.38	0.42	0.42	0.54	0.31		0.320
	(0.301 - 0.71)	(0.25 - 0.52)	(0.28 - 0.57)	(0.28 - 0.57)	(0.38 - 0.70)	(0.17 - 0.52)		
Pregnant at 100 d	0.31	0.49	0.49	0.42	0.56	0.5		0.300
	(0.15 - 0.52)	(0.33 - 0.64)	(0.34 - 0.65)	(0.28 - 0.58)	(0.39 - 0.71)	(0.32 - 0.68)		
Pregnant at 200 d	0.87	0.86	0.89	0.9	0.91	0.86		0.857
	(0.67 - 0.96)	(0.74 - 0.93)	(0.78 - 0.95)	(0.80 - 0.95)	(0.81 - 0.96)	(0.72 - 0.93)		

Conception rate	0.89	0.91	0.91	0.94	0.92	0.88		0.748
	(0.68 - 0.97)	(0.81 - 0.96)	(0.81 - 0.96)	(0.86 - 0.98)	(0.82 - 0.96)	(0.75 - 0.95)		
Lactation 3	2.1 - 8.7	8.7 - 10.3	10.3 - 11.4	11.4 - 12.6	12.6 - 14.6	14.6 - 23.8		
Days to first service	78b	70ab	72ab	64a	80b	72ab	6.1	0.033
Days to pregnant	131bc	112ab	106ab	98a	140c	102ab	14.2	0.013
Calving interval	408bc	392abc	389abc	375a	409c	378ab	12.8	0.019
Number of services	2.7	2.4	2.2	2.2	2.6	1.9		0.243
	(2.0 - 3.6)	(2.0 - 3.0)	(1.8 - 2.7)	(1.9 - 2.7)	(2.1 - 3.2)	(1.5 - 2.5)		
Pregnant to 1st service	0.14	0.43	0.33	0.37	0.22	0.51		0.059
	(0.04 - 0.39)	(0.27 - 0.60)	(0.20 - 0.49)	(0.25 - 0.52)	(0.11 - 0.39)	(0.31 - 0.70)		
Pregnant at 100 d	0.31	0.54	0.49	0.58	0.28	0.56		0.018
	(0.13 - 0.58)	(0.35 - 0.71)	(0.32 - 0.66)	(0.42 - 0.72)	(0.15 - 0.46)	(0.35 - 0.75)		
Pregnant at 200 d	0.84	0.91	0.88	0.84	0.78	0.92		0.286
	(0.61 - 0.95)	(0.77 - 0.97)	(0.75 - 0.95)	(0.71 - 0.92)	(0.61 - 0.89)	(0.78 - 0.97)		
Conception rate	0.9	0.93	0.91	0.85	0.83	0.93		0.484
	(0.70 - 0.97)	(0.81 - 0.97)	(0.79 - 0.96)	(0.72 - 0.92)	(0.67 - 0.92)	(0.77 - 0.98)		
Lactation 4	2.1 - 9.1	9.1 - 10.7	10.7 - 11.8	11.8 - 13.0	13.0 - 14.9	14.9 - 24.3		
Days to first service	75	77	73	72	73	77	5	0.786
Days to pregnant	113	116	112	111	112	129	10.9	0.638
Calving interval	390	393	397	390	398	403	11.3	0.843
Number of services	2.5	2.3	2.3	2.4	2.2	2		0.817
	(1.9 - 3.3)	(1.9 - 2.8)	(1.9 - 2.8)	(2.0 - 2.8)	(1.8 - 2.7)	(1.5 - 2.6)		
Pregnant to 1st service	0.35	0.31	0.34	0.41	0.28	0.34		0.637
	(0.20 - 0.55)	(0.21 - 0.43)	(0.24 - 0.45)	(0.31 - 0.52)	(0.19 - 0.41)	(0.21 - 0.50)		
Pregnant at 100 d	0.45	0.46	0.46	0.45	0.4	0.33		0.662
	(0.26 - 0.66)	(0.33 - 0.60)	(0.33 - 0.59)	(0.33 - 0.57)	(0.24 - 0.50)	(0.19 - 0.51)		
Pregnant at 200 d	0.88	0.77	0.82	0.87	0.79	0.85		0.585
	(0.67 - 0.96)	(0.63 - 0.87)	(0.72 - 0.89)	(0.77 - 0.93)	(0.67 - 0.87)	(0.69 - 0.93)		
Conception rate	0.92	0.8	0.86	0.89	0.83	0.87		0.286
	(0.73 - 0.98)	(0.69 - 0.88)	(0.75 - 0.92)	(0.80 - 0.93)	(0.71 - 0.90)	(0.74 - 0.94)		

Table 2.9. Equation of best fit for milk yield and composition values and energy and concentrate efficiency (standard error in parenthesis).

Response variable	Constant	Explanatory variables								r2
		Total concentrate DMI (kg/day)	Total forage DMI (kg/day)	Total DMI (kg/day)	Concentrate % of total DMI	Milk yield (kg/day)	Starch % of diet	CP% of diet	ME content of diet (MJ/kg DM)	
Lactation 1										
Fat %	2.77 (0.142)	0.04 (0.007)	-	0.208 (0.0102)	-	-0.10 (0.004)	-	-	-	54.5
Protein %	2.02 (0.041)	-	-	0.145 (0.0027)	0.32 (0.044)	-0.06 (0.001)	-	-	-	84.2
ECM yield	-14.75 (0.520)	-	-0.630 (0.0272)	2.656 (0.0220)	-		-	-	-	87.0
ECM/DMI	0.75 (0.029)	0.06 (0.001)	0.026 (0.002)		-		-	-	-	59.0
Concentrate DMI/ECM	0.47 (0.006)		-0.029 (0.0003)	0.007 (0.0003)	-		-	-	-	83.5
Lactation 2										
Fat %	1.86 (0.171)	-	-	0.253 (0.0010)	1.19 (0.241)	-0.10 (0.004)	-	-	-	60.7
Protein %	2.68 (0.042)	-	-	0.090 (0.0025)	-	-0.04 (0.001)	-	-	-	84.2
ECM yield	-24.15 (0.691)	-	-	2.407 (0.0278)	15.65 (0.840)		-	-	-	86.6
ECM/DMI	0.87 (0.033)	0.05 (0.001)	0.018 (0.0018)		-		-	-	-	59.4
Concentrate DMI/ECM	0.21 (0.006)		-	-0.007 (0.0003)	0.50 (0.008)		-	-	-	83.2
Lactation 3										
Fat %	1.88 (0.157)	-	-	0.242 (0.0101)	-	-0.09 (0.003)	-	-	-	61.7

Protein %	2.70 (0.051)	-	-	0.077 (0.0029)	-	-0.03 (0.001)	-	-	-	80.6
ECM yield	-26.81 (0.804)	-	-	2.475 (0.0333)	15.78 (1.166)		-	-	-	86.4
ECM/DMI	-0.32 (0.056)	-	0.070 (0.0027)		2.32 (0.057)		-	-	-	58.6
Concentrate DMI/ECM	0.21 (0.007)		-	-0.007 (0.0003)	0.50 (0.009)		-	-	-	81.8
Lactation 4+										
Fat %	1.81 (0.161)	-	-	0.211 (0.0090)	-	-0.08 (0.003)	-	-	-	62.3
Protein %	2.49 (0.044)	-	-	0.079 (0.0024)	-	-0.03 (0.001)	-	-	-	84.0
ECM yield	-28.83 (0.846)	-	-	2.429 (0.0322)	17.16 (1.021)		-	-	-	88.9
ECM/DMI	-0.43 (0.055)	-	0.068 (0.0024)		2.38 (0.053)		-	-	-	72.1
Concentrate DMI/ECM	0.25 (0.007)		-	-0.007 (0.0003)	0.51 (0.009)		-	-	-	80.5

* an '-' indicates that the model was able to select the variable, but the variable did not improve the fit of the equation

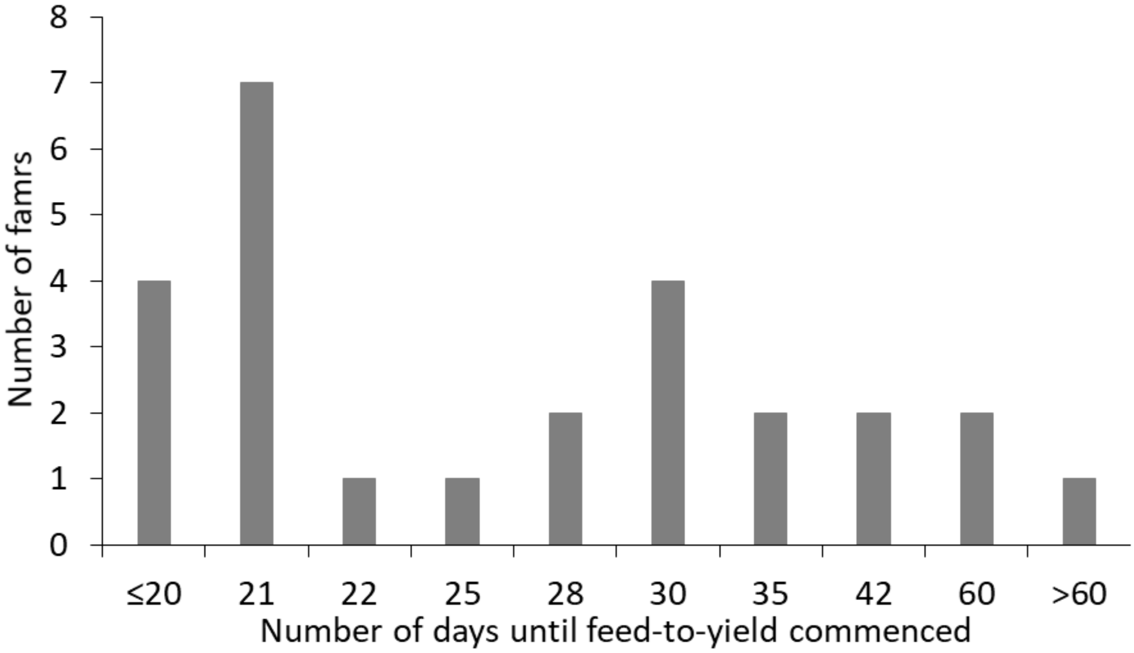
Table 2.10. Equation of best fit for milk yield and composition values and energy and concentrate efficiency using a subset of cows with data for predicted transmitting ability (PTA) (standard error in parenthesis).

Response variable	Constant	Explanatory variables											r2
		Total concen-trate DMI (kg/d)	Total forage DMI (kg/d)	Total DMI (kg/d)	Concen-trate % of total DMI	Milk yield (kg/d)	Starch % of diet	CP % of diet	ME content of diet (MJ/kg DM)	PTA milk yield (kg)	PTA fat (%)	PTA protein (%)	
Lactation 1													
Fat %	0.55 (0.294)	-	-	0.44 (0.289)	-	-0.17 (0.010)	-	-	-	0.0003 (0.00009)	3.33 (0.285)	-2.71 (0.573)	65.6
Protein %	0.66 (0.097)	-	-	0.30 (0.009)	-	-0.11 (0.003)	-	-	-	-	-	0.45 (0.129)	82.2
ECM	-23.24 (0.615)	-	-	2.76 (0.031)	-		-	-	-	0.0009 (0.00036)	10.81 (1.099)	-10.28 (2.17)	87.5
ECM/DMI	-0.63 (0.055)	-	0.11 (0.004)		2.21 (0.058)		-	-	-	0.0001 (0.00002)	0.57 (0.056)	-0.49 (0.112)	83.1
Concentrate DMI/ECM	0.23 (0.007)		0.66 (0.016)	-0.01 (0.001)	-		-	-	-	-0.00001 (0.000004)	-0.10 (0.013)	0.08 (0.058)	91.0
Lactation 2													
Fat %	0.45 (0.269)	0.37 (0.026)	0.38 (0.023)	-	-	-0.13 (0.008)	-	-	-	-	2.73 (0.289)	-3.16 (0.591)	62.8
Protein %	1.72 (0.109)	-	-	0.17 (0.008)	-	-0.07 (0.003)	-	-	-	0.0002 (0.00004)	-	2.19 (0.200)	73.5
ECM	-27.41 (0.872)	-	-	2.77 (0.044)	-		-	-	-	-	11.78 (1.335)	-14.43 (2.72)	93.8
ECM/DMI	-0.71 (0.071)	-	0.10 (0.004)		2.45 (0.073)		-	-	-	-	0.55 (0.062)	-0.67 (0.127)	76.1
Concentrate DMI/ECM	0.21 (0.010)		-	-0.01 (0.001)	-		-	-	-	-0.00001 (0.000006)	-0.12 (0.016)	0.12 (0.031)	88.0
Lactation 3													
Fat %	-0.17 (0.311)	-	-	0.41 (0.025)	-	-0.14 (0.008)	-	-	-	-	2.62 (0.359)	-2.65 (0.707)	64.3

Protein%	2.08	-	-	0.13	-	-0.06	1.17	-	-	0.0002	-	2.81	73.8
	(0.120)			(0.009)		(0.003)	(0.440)			(0.00004)		(0.238)	
ECM	-37.09	-	-	2.90	-		-	-	-	-	10.84	-11.23	94.3
	(2.321)			(0.044)							(1.625)	(3.224)	
ECM/DMI	-1.09	-	0.10		2.61		-0.59	-	0.03	-	0.48	-0.38	80.6
	(0.112)		(0.004)		(0.091)		(0.289)		(0.008)		(0.067)	(0.131)	
Concentrate	0.30		-	-0.01	0.59		0.13	-	-0.01	-	-0.08	-	88.9
DMI/ECM	(0.021)			(0.001)	(0.021)		(0.056)		(0.002)		(0.013)		
Lactation 4+													
Fat %	2.00	-	-	0.21	-	-0.08	-	-	-	0.0005	2.92	-1.63	57.9
	(0.272)			(0.018)		(0.006)				(0.00108)	(0.316)	(0.563)	
Prot %	2.77	-	-	0.06	-	-0.03	1.10	-	-	0.0003	-	2.91	58.6
	(0.110)			(0.007)		(0.002)	(0.434)			(0.00004)		(0.191)	
ECM	-26.68	-	-	2.67	-		-	-	-	0.0047	12.21	-9.3	86.9
	(1.364)			(0.053)						(0.00069)	(2.064)	(3.652)	
ECM/DMI	-0.30	-	0.06		2.20		-	-	-	0.0002	0.467	-	66.1
	(0.093)		(0.004)		(0.091)					(0.00003)	(0.068)		
Concentrate	0.21		-	-0.01	0.54		-	-	-	-0.00003	-0.08	-	81.6
DMI/ECM	(0.011)			(0.001)	(0.019)					(0.000006)	(0.015)		

* an '-' indicates that the model was able to select the variable, but the variable did not improve the fit of the equation

Figure 2.1. Spread of concentrate 'build-up' periods adopted on farms before cows were moved to a FTY concentrate feeding approach.



Discussion

The overall objective of this study was to increase the understanding of cow intake, milk composition and efficiency responses to FTY concentrate allocation strategies. The farms involved in this study had an average herd size of 190 cows and annual milk sales of 8,780 litres/cow which was greater than the average values for the NI dairy herd during the year the study was conducted, namely 100 cows and 7,252 litres of milk/annum (DAERA, 2019). This is unsurprising, as a FTY approach to concentrate feeding is more likely to be adopted within higher yielding herds where concentrate feed levels are higher.

Effect of concentrate levels on intake parameters*:* The farms involved in this study were typical of those in NI, with grass silage the predominant forage in the diet over the winter months (40 - 46% of total DMI). 'Alternative forages' (maize silage and cereal silage) were offered on 17 of the 27 farms, comprising approximately 20% of total forge DMI on those farms during the study period. While the proportion of the alternative forages in the diet decreased across the concentrate bands in each lactations, this reflects the increase in total DMI, as actual intakes of alternative forage remained relatively constant. Forages offered within the study generally had a good nutritive value, although there was considerable variability, as demonstrated by the data range. The on-farm approach adopted meant that intakes (except intakes of the recorded concentrate component of the diet) were predicted. However, predicted total DMI within this study (22.0 kg DM per cow/day: mean for all lactations) was similar to that measured in early lactation dairy cows offered similar grass silage based diets, namely 22.3 and 22.4 kg DM per cow/day (Little et al., 2016; Purcell et al., 2016, respectively). The pattern of DMI over the study period (months 2 – 5 of lactation) was also in agreement with these studies with total DMI and forage DMI increasing and total concentrate DMI decreasing. Furthermore, the 17%, 24% and 32% increase in total DMI between lactation 1, and each of lactations 2, 3 and 4+ was similar to the increases observed between lactations in a meta-analysis of 27 feeding studies involving grass silage based diets (22%, 31% and 34%, respectively: E. Cabezas-Garcia, Unpublished data).

As concentrate feed level increases, total DMI normally shows a quadratic increase (Huhtanen et al., 2008). While total DMI of primiparous cows did show a quadratic increase within the current study, the increase for multiparous cows across the six concentrate levels was linear, the latter highlighting a key difference between traditional studies examining performance responses to concentrate feeding, and studies examining a FTY approach. In the former, 'balanced' groups of cows of mixed yield potential are allocated to a number of different concentrate 'level' treatments. The curvilinear responses at higher concentrate levels are a consequence of the inability of cows with a lower yield potential to fully respond to higher concentrate levels (Ferris et al., 1999). In contrast, within a FTY approach higher levels of concentrates are offered only to higher-yielding cows, which have greater intake potential/drive; therefore, the absence of a curvilinear intake response is observed. The results from the current study support the findings of Purcell et al. (2016) and Little et al. (2016) who noted that the increase in DMI with increasing milk yield was greater for cows offered concentrates on a FTY basis compared to 'flat rate' feeding strategies.

Similarly, forage DMI normally shows a quadratic decrease (Huhtanen et al., 2008a) with increasing concentrate levels. Within the current study the decrease was linear with primiparous cows, although quadratic with multiparous cows. Mean forage substitution rates (SR) between the six concentrate levels were: 0.13, 0.27, 0.17, 0.31 and 0.38 kg forage DM/kg concentrate DM (primiparous), and 0.23, 0.13, 0.11, 0.25 and 0.15 kg forage DM/kg concentrate DM (multiparous). In contrast, in a meta-analysis by Huhtanen et al. (2008a), mean SR were 0.35, 0.54 and 0.73 kg forage DM/kg concentrate DM at daily concentrate DMI of 5, 10 and 15 kg, respectively, these values being substantially higher and increasing to a greater extent, than in the current study. Purcell et al. (2016) concluded that SR within FTY systems are low due to the overall higher intake potential of cows offered the higher concentrate levels within a FTY system. The low SR within these FTY studies lends support to the assumption commonly used when rationing cows on a FTY basis, namely that the basal diet is likely to sustain a relatively constant level of performance for cows across a range of milk yield potentials.

In contrast to TMR feeding systems, which maintain a constant forage : concentrate ratio for each group of cows, the forage : concentrate ratio of individual cows offered concentrates on a FTY basis varies according to milk yield. For example, mean concentrate proportion in the diet increased across the concentrate bands (from between 0.32 and 0.38 at the lowest concentrate band, to 0.58 - 0.59 at the highest concentrate band, across all lactations). However, individual cows within the highest and lowest concentrate bands will have been offered diets with more extreme forage : concentrate ratios than the band average. Increasing concentrate proportions were associated with a (mostly) quadratic increase in both starch (from 11.4 to 15.7% DM) and CP % (from 15.8 to 17.1% DM) content of the diet (mean concentrations within lowest and highest concentrate bands across all lactations). Given that the quantity of alternative forage in the diets remained relatively constant across bands, the increasing starch content of the diet was largely driven by increasing concentrate proportion in the diet. However, this effect was mitigated to some extent by the concentrate component of the diet offered on a FTY basis having a lower starch content (and lower CP content) than the concentrate component of the basal rations.

Effect of concentrate intake on milk production: On the majority of farms a feed rate of 0.45 kg concentrate (fresh) per kg milk was adopted, with few farms adopting either a lower (n = 5) or higher (n = 2) feed rate. While a feed rate of 0.45 kg assumes that 1 kg of concentrate contains approximately 11.5 MJ of ME (fresh), and that the production of 1 kg of milk requires approximately 5.2 MJ of ME, the actual ME content of concentrates offered and herd milk composition will vary greatly between farms, so alternative feed rates may be appropriate. Alternatively, higher feed rates may simply reflect a desire to increase milk production, while lower feed rates may reflect a desire to produce more milk from forage.

The linear increase in milk yields with increasing concentrate levels were as expected, given that additional concentrates were offered in response to milk actually produced. However, these linear milk yield responses to additional concentrates contrast with the curvilinear milk responses recorded within ‘traditional’ concentrate feeding studies (Ferris et al., 1999; Ferris et al., 2001), a reflection of the experimental design adopted in these studies, as already discussed. Within these ‘traditional’ studies it would be expected that when cows with a lower yield potential were offered the high concentrate treatment/level they would respond by laying down a greater proportion of nutrients as body tissue (Yan et al., 2006).

The increase in milk yield between the lowest and highest concentrate groups is partly reflected by the increase in PTA for milk between these extreme groups, namely 174, 347, 276 and 243 kg (lactations 1 – 4+, respectively). These genetic differences would account for an additional 348, 694, 552 and 486 kg milk/lactation between the extreme concentrate treatments, or 1.1, 2.3, 1.8 or 1.6 kg additional milk/day in a 305 day lactation. Nevertheless, actual differences in milk yield between the extreme concentrate groups were 14.0, 17.5, 19.3 and 19.5 kg/day for lactations 1 – 4, respectively, considerably greater than the values expected based on differences in PTA. While these differences could be partly explained by the increase in total DMI, concentrate proportion in the diet, and diet starch and CP content with increasing concentrate DMI band, this alone will not explain how such differences arose. The most likely explanation is the effect of differing management systems in early lactation prior to start of FTY. During this 'build up period' concentrate inputs will reflect the overall management system operating on the farm (e.g. 'low', 'moderate' or 'high' concentrate input) more than the herd genetic potential. This is supported by the fact that an examination of data from individual farms demonstrates that while cows on most farms straddled a wide range of concentrate intake bands, a greater proportion of cows from higher yielding herds were within higher concentrate intake bands, and vice versa for cows from lower yielding herds. Differences in forage quality, concentrate type, and overall management will also have impacted on performance at this time. Thus, differences in performance which arose in early lactation as a result of farm-specific management decisions will have placed cows on a milk yield trajectory, and with the introduction of FTY higher yielding cows will move to higher concentrate levels, which will drive higher yields and concentrate intakes within a repeated feedback loop.

Mean milk fat and protein contents in the study (4.12% and 3.26%, respectively) were similar to the NI average (4.07% and 3.31%, respectively), and both fat and protein followed the normal lactation increase from months 2 – 5 of lactation (Garcia and Holmes, 2001). In an earlier study undertaken at AFBI, milk fat content declined from 40.9 to 38.1 g/kg as feed rate increased from 0.45 to 0.55 kg concentrate/kg milk (Purcell et al., 2015), while an analysis of individual cows within the dataset indicated that both milk fat and milk protein content decreased with increasing concentrate level within each of the two feed rates (C. Ferris, unpublished data). Therefore, one of the key objectives of the current study was to examine the impact of FTY concentrate feeding approaches on milk composition on commercial farms. This is especially important for farmers supplying milk for processing as milk pricing mechanisms normally include either bonuses or deductions according to milk composition.

In agreement with the findings of Purcell et al. (2016), milk fat showed a significant (P < 0.01) decease between the lowest and highest concentrate levels (by 0.29, 0.21 and 0.29 of a percentage unit in lactations 1, 2 and 4+, respectively), while in lactation 3 the reduction was 0.18 of a percentage unit (P = 0.066). Most of this reduction, especially in multiparous cows, is a direct genetic effect as PTA for milk fat % was observed to be a positive driver for milk fat % within the multivariate analysis. The 0.06 of a percentage unit decrease in PTA for milk fat % observed between the lowest and highest concentrate levels in each of lactations 2, 3 and 4, could account for a reduction in milk fat of up to 0.12 of a percentage unit across concentrate levels. Thus, differences in cow genotype between the extreme concentrate treatments would account for up to 57, 67 and 41% of the reduction in milk fat % in each of lactations 2, 3 and 4, respectively. While the difference in PTA for milk fat % between concentrate groups was not significant in primiparous cows, the actual difference would still account for 0.04 of a percentage unit of the observed reduction in milk fat %. The reduction in PTA for milk fat % across lactations with increasing concentrate level likely reflects sires used in higher yielding herds being selected with an increased focus on milk volume, and with less attention paid to milk fat content.

The remaining variation in milk fat % not explained by genetic merit is likely to be explained by diet. Increasing concentrate levels have been associated with a reduction in milk fat content in many studies (Ferris et al., 1999 and 2001; Dewanckele 2020), with this primarily driven by the increasing starch content of the diet (Keady et al., 1998; 1999). Rapid rumen fermentation of the starch in some concentrate diets results in a fall in rumen pH (Agle et al., 2010), which reduces microbial biohydrogenation of dietary unsaturated fatty acids and a greater ruminal production of trans-fatty acids (for example: *trans*-10, *cis*-12 CLA; Bauman and Griinari, 2001, 2003). These trans-fatty acids inhibit milk fat synthesis in the mammary gland, resulting in milk fat depression. A significant reduction in milk fat content was not observed in some studies until the concentrate proportion of the diet reached 0.56 (Purcell et al., 2016) or even 0.70 (Ferris et al., 2001). However, significant reductions in milk fat content in the current study were observed at concentrate proportions in the diet of less than 0.50. It is also worth noting that milk yield *per se* can be a negative driver of milk fat % due to a dilution effect (Garcia and Holmes, 2001; Huhtanen and Rinne et al., 2007) and this was demonstrated in the multivariate analysis.

Despite the milk fat depression observed as concentrate DMI band increased, when a multivariate analysis was conducted, concentrate was found to be a positive driver on milk fat % in lactation 1 and lactation 2. However, fit of both equations was low (r^2 54.5 – 60.7) and it is likely that concentrate DMI sustains milk fat % up until a certain point before a negative effect is observed, but it was beyond the scope of this study to find the point at which concentrate DMI becomes a negative influence on milk fat %.

Milk protein % did not differ across any concentrate DMI band within the current study, although there was a linear decline in lactation 2. This reflects in part the absence of differences in PTA for milk protein % between concentrate bands in all lactations, with the exception of the highest concentrate intake band in lactation 2. Milk protein content is generally influenced by energy intake, particularly the breakdown of starch to glucose which increases microbial protein synthesis (Osorio et al., 2016). Therefore, an increase in the diet's starch content (in this study supplied mainly through concentrates) would be expected to increase milk protein. Indeed, most studies have recorded increased milk protein content with increasing concentrate level (Keady et al., 1998; Beever et al., 2001), and concentrate intake was identified as a driver for milk protein within the multivariate analysis. Therefore, it is an anomaly that as the concentrate DMI bands and starch content of the diet increased that there was no improvement in protein %, which indicates that other factors were at play. The likely explanation for the lack of effect on milk protein % is a combination of the dilution effect as milk yield increased (Garcia and Holmes, 2001), and that cows demonstrating high milk yields may have had poorer energy balance.

Effect of concentrate levels on production efficiency*:* Feed efficiency, normally defined as the ratio of 'output to input', is of increasing importance due to increasing environmental pressures, and the need to improve resource use efficiency. Furthermore, any improvement in feed use efficiency can have a direct positive effect on the profitability of dairy farms. Both ECM/DMI and milk energy/energy intake increased with increasing concentrate levels across all lactations. This was accompanied by an improvement in PTA for milk, with increasing genetic merit for milk yield normally associated with improvements in gross feed use efficiency (Veerkamp and Emmans et al. 1995). However, there is little evidence that cows with greater milk yields have improved metabolic efficiency for milk production (k_l) than lower yielding cows (Agnew et al., 1998). The increasing efficiency with increasing concentrate levels in the current study can be largely attributed to 'dilution of maintenance energy requirements' with increasing milk yields, although these higher yielding cows may also have had a greater negative energy balance, as discussed previously, and this will contribute to a greater apparent efficiency.

Improving N use efficiency (milk N/N intake) can reduce N excretion from dairy systems, and which in turn contributes to reductions in N losses to the atmosphere as ammonia (causing terrestrial eutrophication; Sajeev et al., 2018) or nitrous oxide (a potent green-house gas; Eggleston et al., 2006), and to waterways (causing eutrophication; Stark and Richards, 2008). Across all lactations milk N/N intake increased with increasing concentrate DMI, despite an increase in total diet CP levels. While milk N/N intake normally improves with decreasing diet protein levels (Brodrick et al., 2009; Huhtanen et al., 2008b), the opposite effect in the current study can be attributed to a dilution of protein requirements for maintenance with increasing milk yields. Mean efficiency of conversion of dietary N into milk N in this study (0.30, across all lactations) is similar that recorded by Huhtanen et al. (2008b), namely 0.28. However, N use efficiency within dairy production can vary from 0.15 – 0.40 (Calsamiglia et al. 2010).

Concentrate DMI/milk yield is a 'crude' efficiency factor often used by farmers and nutritionists to provide an indication of efficiency of concentrate use on farms. In general, a higher value indicates a reduced reliance on forage in the diet. Within the current study each 0.30 kg of concentrate DM consumed was associated with the production of one kg milk (mean across all lactations). While this value is substantially higher than the mean efficiency for the UK dairy sector (0.27 kg fresh concentrate/kg milk: approximately equivalent to 0.24 kg concentrate DM/kg milk) published almost a decade ago by Wilkinson (2011), it is similar to the value of 0.32 (concentrate DM basis) available from CAFRE benchmarking data for higher yielding cows in

2018/2019. However, across all lactations concentrate DMI per kg milk yield produced increased with increasing concentrate input, reflecting the reduction in total forage DMI and the forage proportion in the diet. This is the inevitable consequence of increasing concentrate inclusion levels in the diet.

Effect of concentrate levels on fertility: Due to the normal negative correlation between genetic merit for milk production and fertility parameters (Pryce and Veerkamp, 2001), the fertility of high yielding cows within a FTY system might be expected to decrease. In the current study, PTA for fertility did decline between the lowest and highest concentrate groups with second and third lactation cows, although the difference was relatively small. However, within this study there was no consistent relationship between concentrate DMI and fertility outcomes. While recent AFBI research has shown a clear link between the extent of negative energy balance in early lactation, and commencement of luteal activity (Civerio, M., Unpublished), this study did not establish a relationship between early lactation energy balance and fertility outcomes.

Conclusion

Increasing concentrate intake was associated with an increased total DM intake. However, due to the feed-to-yield approach adopted, there was little substitution of forage as a result of concentrate feeding. Milk yield showed a linear response to concentrate feeding, although in reality concentrates ‘followed’ milk yields. Milk fat % decreased with increasing concentrate intake, and this reduction was partly explained by cow genotype (i.e. decreasing PTA for milk fat %). However, diet also contributed to the reduction in milk fat %. Milk protein % and fertility measures were not affected by concentrate level. Energy efficiency, measured as ECM/DMI, milk energy/energy intake, and nitrogen use efficiency, improved at higher concentrate intakes, likely a direct result of ‘dilution of maintenance’. However, more concentrates were offered per kg of milk produced at higher concentrate intakes. This study has provided an insight into the effect of feed-to-yield systems on cow performance and efficiency within a commercial setting, with evidence that milk composition can be reduced at high concentrate feeding levels, and this has the potential to reduce milk value.

Supplementary Table 2.1. Number of cows within each month of lactation and concentrate intake band for each lactation.

Month	Concentrate intake band (kg DM/cow/day)					
Lactation 1	1.6 - 6.0	6.0 - 7.2	7.2 - 8.2	8.2 - 9.4	9.4 -11.0	11.0 - 20.2
2	56	104	151	158	198	194
3	151	172	140	153	125	128
4	175	146	142	138	135	128
5	181	141	129	115	104	112
Cows with genetic data	51	138	162	107	103	48
Cows with fertility data	32	70	122	120	98	37
Lactation 2	1.8 - 7.7	7.7 - 9.1	9.1 - 10.3	10.3 - 11.6	11.6 - 13.4	13.4 - 23.3
2	48	67	126	144	147	173
3	114	123	119	113	110	118
4	136	132	108	97	98	91
5	148	124	92	92	91	63
Cows with genetic data	38	161	109	121	114	106
Cows with fertility data	27	91	68	87	65	46
Lactation 3	2.1 - 8.7	8.7 - 10.3	10.3 - 11.4	11.4 - 12.6	12.6 - 14.6	14.6 - 23.8
2	28	68	107	99	99	117
3	72	79	74	93	96	88
4	106	85	80	77	78	73
5	122	96	67	59	55	50
Cows with genetic data	46	84	88	108	77	76
Cows with fertility data	20	54	54	66	47	37
Lactation 4	2.1 - 9.1	9.1 - 10.7	10.7 - 11.8	11.8 - 13.0	13.0 - 14.9	14.9 - 24.3
2	58	88	169	130	134	175
3	118	120	114	164	143	159
4	141	139	122	112	131	103
5	184	155	98	94	93	64
Cows with genetic data	57	121	138	128	114	100
Cows with fertility data	27	74	88	99	71	43

Supplementary Table 2.2. Effect of month of lactation on intake, performance and production efficiency of lactation 1 cows managed on a FTY basis.

	Month of lactation					
	2	3	4	5	SED	P values
Dry matter intake						
Total concentrate DMI (kg/day)	8.6b	8.5a	8.5a	8.5a	0.04	<0.001
DMI of concentrate offered on a FTY basis (kg)	5.7d	5.0c	4.8b	4.6a	0.05	<0.001
Total forage DMI (kg/day)	8.9a	10.1b	10.5c	11.0d	0.06	<0.001
Total DMI (kg/day)	17.5a	18.6b	19.1c	19.5d	0.06	<0.001
Nutrient intakes and efficiency values						
Concentrate as % total DMI	0.48d	0.45c	0.44b	0.43a	0.002	<0.001
Alternative forages as % total DMI	0.07a	0.09b	0.10c	0.10c	0.002	<0.001
Starch intake from concentrates (g/d)	2048b	2044b	2030b	2005a	10.7	<0.001
Total starch intake (g/d)	2405a	2494b	2523c	2491b	15.5	<0.001
Starch % of total diet	0.14d	0.13c	0.13b	0.13a	0.001	<0.001
Nitrogen intake from concentrates (g/d)	275a	278a	281b	282b	1.4	<0.001
Total nitrogen intake (g/kg)	462a	488b	498c	505d	1.8	<0.001
Milk nitrogen/N intake	0.29b	0.29d	0.29c	0.29a	0.001	<0.001
Crude protein % of total diet	0.16c	0.16b	0.16b	0.16a	0.004	<0.001
ME intake from concentrate (g/d)	114b	112a	111a	111a	0.7	<0.001
Total ME intake (g/kg)	215a	225b	229c	237d	1.5	<0.001
ME content of total diet (MJ/kg DM)	12.3c	12.1ab	12.0a	12.2b	0.07	<0.001
Milk production and efficiency values						
Milk yield (kg/day)	27.1a	28.6c	28.1b	27.2a	0.15	<0.001
Milk fat (%)	4.04a	4.02a	4.12b	4.23c	0.028	<0.001
Milk protein (%)	3.16a	3.23b	3.30c	3.37d	0.008	<0.001
Fat + protein yield (kg/day)	1.95a	2.08b	2.08b	2.07b	0.013	0.002
Energy corrected milk yield (kg/day)	27.3a	29.0c	28.9c	28.5b	0.18	<0.001
Milk energy/MEI	0.39bc	0.40c	0.39b	0.38a	0.002	<0.001
ECM/DMI (kg/kg)	1.54c	1.54c	1.50b	1.45a	0.006	<0.001
Concentrate DMI/milk yield (kg/kg)	0.32d	0.30a	0.30b	0.31c	0.002	<0.001
Concentrate DMI/ECM yield (kg/kg)	0.31c	0.29a	0.30ab	0.30b	0.002	<0.001

Supplementary Table 2.3. Effect of month of lactation on intake, performance and production efficiency of lactation 2 cows managed on a FTY basis.

	Month of lactation					
	2	3	4	5	SED	P values
Dry matter intake						
Total concentrate DMI (kg/day)	10.6b	10.6b	10.5a	10.4a	0.04	<0.001
DMI of concentrate offered on a FTY basis (kg)	7.3d	6.7c	6.5b	6.1a	0.06	<0.001
Total forage DMI (kg/day)	10.3a	11.2b	11.6c	12.1d	0.07	<0.001
Total DMI (kg/day)	20.9a	21.7b	22.1c	22.5d	0.08	<0.001
Nutrient intakes						
Concentrate as % total DMI	0.50d	0.48c	0.47b	0.46a	0.002	<0.001
Alternative forages as % total DMI	0.06a	0.08b	0.09bc	0.09c	0.003	<0.001
Starch intake from concentrates (g/d)	2538b	2540b	2506a	2482a	13.5	<0.001
Total starch intake (g/d)	2971a	3059b	3039b	3022b	20.8	<0.001
Starch % of total diet	0.14d	0.14c	0.13b	0.13a	0.001	<0.001
Nitrogen intake from concentrates (g/d)	339a	343b	343b	344b	1.6	<0.001
Total nitrogen intake (g/kg)	553	575	581	590	2.3	0.472
Milk nitrogen/N intake	0.31c	0.31bc	0.31b	0.31a	0.001	<0.001
Crude protein % of total diet	0.17b	0.17b	0.16a	0.16a	0.0003	<0.001
ME intake from concentrate (g/d)	140c	139bc	138ab	137a	0.7	<0.001
Total ME intake (g/kg)	258	267	271	273	2.0	0.993
ME content of total diet (MJ/kg DM)	12.3	12.3	12.3	12.2	0.08	0.053
Milk production and efficiency values						
Milk yield (kg/day)	35.2b	35.6c	35.1b	34.2a	0.19	<0.001
Milk fat (%)	3.97a	4.05b	4.06b	4.14c	0.034	<0.001
Milk protein (%)	3.19a	3.26b	3.33c	3.40d	0.009	<0.001
Fat + protein yield (kg/day)	2.53a	2.59b	2.59b	2.56ab	0.019	<0.001
Energy corrected milk yield (kg/day)	35.4a	36.1b	35.9b	35.3a	0.24	<0.001
Milk energy/MEI	0.42c	0.42bc	0.41ab	0.41a	0.004	<0.001
ECM/DMI (kg/kg)	1.67d	1.64c	1.61b	1.56a	0.007	<0.001
Concentrate DMI/milk yield (kg/kg)	0.30b	0.30a	0.30a	0.30b	0.002	<0.001
Concentrate DMI/ECM yield (kg/kg)	0.30b	0.30a	0.30a	0.30a	0.002	<0.001

Supplementary Table 2.4. Effect of month of lactation on intake, performance and production efficiency of lactation 3 cows managed on a FTY basis.

	Month of lactation					
	2	3	4	5	SED	P values
Dry matter intake						
Total concentrate DMI (kg/day)	11.6b	11.6b	11.6b	11.4a	0.05	<0.001
DMI of concentrate offered on a FTY basis (kg)	7.9d	7.6c	7.3b	6.9a	0.07	<0.001
Total forage DMI (kg/day)	11.0a	11.5b	11.9c	12.4d	0.08	<0.001
Total DMI (kg/day)	22.5	23.1	23.5	23.8	0.10	0.089
Nutrient intakes						
Concentrate as % total DMI	0.51d	0.49c	0.49b	0.47a	0.002	<0.001
Alternative forages as % total DMI	0.07a	0.08b	0.08b	0.08b	0.003	<0.001
Starch intake from concentrates (g/d)	2770c	2751bc	2738b	2698a	16	<0.001
Total starch intake (g/d)	3248a	3281b	3281b	3248a	24.7	<0.001
Starch % of total diet	0.14d	0.14c	0.14b	0.13a	0.001	<0.001
Nitrogen intake from concentrates (g/d)	370a	375b	380c	378bc	2.0	<0.001
Total nitrogen intake (g/kg)	597a	615b	626c	633d	2.9	0.001
Milk nitrogen/N intake	0.31c	0.31b	0.31a	0.31a	0.002	<0.001
Crude protein % of total diet	0.17a	0.17bc	0.17c	0.17ab	0.001	<0.001
ME intake from concentrate (g/d)	151ab	151b	151ab	149a	0.8	<0.001
Total ME intake (g/kg)	273	282	282	290	2.2	0.087
ME content of total diet (MJ/kg DM)	12.1ab	12.2b	12.0a	12.2b	0.08	0.022
Milk production and efficiency values						
Milk yield (kg/day)	38.6c	38.5c	37.5b	36.4a	0.23	<0.001
Milk fat (%)	3.98a	4.02a	4.11b	4.12b	0.041	<0.001
Milk protein (%)	3.15a	3.22b	3.30c	3.35d	0.011	<0.001
Fat + protein yield (kg/day)	2.75ab	2.78b	2.77b	2.70a	0.022	<0.001
Energy corrected milk yield (kg/day)	38.6b	38.8b	38.4b	37.4a	0.29	<0.001
Milk energy/MEI	0.44c	0.43b	0.43b	0.40a	0.004	<0.001
ECM/DMI (kg/kg)	1.69d	1.66c	1.62b	1.56a	0.008	<0.001
Concentrate DMI/milk yield (kg/kg)	0.3	0.3	0.31	0.31	0.002	0.052
Concentrate DMI/ECM yield (kg/kg)	0.30ab	0.30a	0.30a	0.31b	0.002	<0.001

Supplementary Table 2.5. Effect of month of lactation on intake, performance and production efficiency of lactation 4+ cows managed on a FTY basis.

	Month of lactation					
	2	3	4	5	SED	P values
Dry matter intake						
Total concentrate DMI (kg/day)	12.0b	12.1c	11.9b	11.9a	0.04	<0.001
DMI of concentrate offered on a FTY basis (kg)	8.1d	7.9c	7.6b	7.3a	0.06	<0.001
Total forage DMI (kg/day)	11.9a	12.5b	12.8c	13.1d	0.07	<0.001
Total DMI (kg/day)	23.9a	24.6b	24.8c	25.0d	0.08	<0.001
Nutrient intakes						
Concentrate as % total DMI	0.49d	0.49c	0.48b	0.47a	0.002	<0.001
Alternative forages as % total DMI	0.07a	0.08ab	0.08ab	0.08b	0.002	<0.001
Starch intake from concentrates (g/d)	2888c	2905c	2839b	2807a	14.1	<0.001
Total starch intake (g/d)	3425bc	3452c	3397b	3343a	19.6	<0.001
Starch % of total diet	0.14d	0.14c	0.13b	0.13a	0.001	<0.001
Nitrogen intake from concentrates (g/d)	384a	391b	391b	390b	1.8	<0.001
Total nitrogen intake (g/kg)	633a	652b	654b	661c	2.5	<0.001
Milk nitrogen/N intake	0.30b	0.30b	0.30b	0.29a	0.001	<0.001
Crude protein % of total diet	0.17ab	0.17b	0.16a	0.16ab	0.0004	<0.001
ME intake from concentrate (g/d)	159b	160b	156a	155a	0.8	<0.001
Total ME intake (g/kg)	293a	301b	302b	307c	2.4	0.011
ME content of total diet (MJ/kg DM)	12.2	12.2	12.2	12.3	0.09	0.684
Milk production and efficiency values						
Milk yield (kg/day)	39.4c	39.4c	38.3b	37.0a	0.20	<0.001
Milk fat (%)	3.99a	4.02ab	4.02ab	4.09b	0.034	0.001
Milk protein (%)	3.09a	3.17b	3.25c	3.30d	0.008	<0.001
Fat + protein yield (kg/day)	2.81bc	2.83c	2.79b	2.74a	0.02	<0.001
Energy corrected milk yield (kg/day)	39.6c	39.7c	38.8b	38.0a	0.26	<0.001
ECM/DMI (kg/kg)	1.63d	1.60c	1.55b	1.50a	0.007	<0.001
Milk energy/MEI	0.42d	0.41c	0.40b	0.39a	0.004	<0.001
Concentrate DMI/milk yield (kg/kg)	0.31	0.31	0.31	0.32	0.002	0.101
Concentrate DMI/ECM yield (kg/kg)	0.31a	0.31a	0.31a	0.32b	0.002	<0.001

Supplementary Table 2.6: Linear and quadratic responses of production parameters for all lactations.

	Lactation 1		Lactation 2		Lactation 3		Lactation 4+	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Dry matter intake								
Total concentrate DMI (kg/day)	<0.001	0.488	<0.001	0.548	<0.001	0.714	<0.001	0.497
DMI of concentrate offered on a FTY basis (kg)	<0.001	<0.001	<0.001	0.069	<0.001	0.212	<0.001	0.130
Total forage DMI (kg/day)	<0.001	<0.001	<0.001	0.950	<0.001	0.110	<0.001	0.163
Total DMI (kg/day)	<0.001	<0.001	<0.001	0.799	<0.001	0.153	<0.001	0.090
Nutrient intakes								
Concentrate as % total DMI	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Alternative forages as % total DMI	<0.001	0.813	<0.001	0.686	<0.001	0.011	<0.001	0.489
Starch intake from concentrates (g/d)	<0.001	<0.001	<0.001	0.544	<0.001	0.183	<0.001	0.267
Total starch intake (g/d)	<0.001	<0.001	<0.001	0.209	<0.001	0.420	<0.001	0.105
Starch % of total diet	<0.001	0.002	<0.001	<0.001	<0.001	0.151	<0.001	<0.001
Nitrogen intake from concentrates (g/d)	<0.001	0.082	<0.001	0.376	<0.001	0.076	<0.001	0.439
Total nitrogen intake (g/kg)	<0.001	<0.001	<0.001	0.510	<0.001	0.084	<0.001	0.043
Milk nitrogen/N intake	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Crude protein % of total diet	<0.001	0.777	<0.001	0.006	<0.001	0.009	<0.001	0.022
ME intake from concentrate (g/d)	<0.001	0.002	<0.001	0.486	<0.001	0.858	<0.001	0.381
Total ME intake (g/kg)	<0.001	<0.001	<0.001	0.824	<0.001	0.083	<0.001	0.018
ME content of total diet (MJ/kg DM)	0.056	0.036	0.012	0.984	<0.001	0.250	0.084	0.098
Milk production and efficiency values								
Milk yield (kg/day)	<0.001	<0.001	<0.001	0.511	<0.001	0.361	<0.001	0.150
Milk fat (%)	<0.001	0.051	<0.001	0.308	0.005	0.919	<0.001	0.600
Milk protein (%)	0.093	0.062	0.021	0.480	0.194	0.583	0.029	0.253
Fat + protein yield (kg/day)	<0.001	<0.001	<0.001	0.380	<0.001	0.042	<0.001	<0.001
Energy corrected milk yield (kg/day)	<0.001	<0.001	<0.001	0.372	<0.001	0.057	<0.001	<0.001
Milk energy/MEI	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
ECM/DMI (kg/kg)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Concentrate DMI/milk yield (kg/kg)	<0.001	0.188	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Concentrate DMI/ECM yield (kg/kg)	<0.001	0.100	<0.001	<0.001	<0.001	0.002	<0.001	0.004

SECTION 3

PERFORMANCE OF DAIRY COW OFFERED CONCENTRATES ON A FEED-TO-YIELD BASIS WHILE GRAZING

Introduction

Giving cows access to grazing can have many advantages, including improved cow health and welfare (Arnott et al., 2017), and the production of milk with both a lower environmental footprint and also enhanced health characteristics (Vance et al., 2012). In addition, production costs decrease as the proportion of grazed grass in dairy cow diets increase. Furthermore, there is also evidence of consumer preference for livestock products derived from pasture based systems (Stampa et al., 2020).

Milk yields that can be sustained from grazed grass alone will vary during the grazing season, from 28 kg in late May to 14 kg per cow by mid-September (Ferris, 2007). Dry matter intake of grazing cows is considered the primary factor limiting milk yield (Bargo et al., 2002), and grazing cows are often offered concentrates to sustain higher milk yields than would be possible from grazed grass alone. Grazing cows are normally offered concentrates through in-parlour feeders, either on a flat rate basis (a set amount of concentrates per cow per day) or on a feed-to-yield (FTY) basis, to support individual cow performance. Both approaches are common within Northern Ireland (NI), although with modern milking facilities most farmers have the potential adopt a FTY approach. Within a FTY approach the level of milk production that is assumed to be sustained from grazed grass, after accounting for maintenance energy requirements, is estimated, and concentrates are offered at a set rate per kg of milk in excess of the yield assumed to be sustained from grazed grass. A FTY approach allows concentrates to be targeted to higher-yielding cows to meet their higher energy requirement, while avoiding concentrates being ‘overfed’ to lower yielding cows.

One of the main challenges when offering concentrates to grazing cows is the variability in milk yield response observed (Bargo et al., 2003; Baudracco et al., 2010), and this is due in part to variation in substitution of grazed grass with concentrates (Stockdale, 2000). A number of studies have examined the response of grazing cows when concentrates are offered either on a FTY or flat rate basis, with positive effects in some studies (Garcia et al., 2007) but no effect in others (Delaby and Peyraud, 1997; Patton and Lawless, 2013; Dale et al., 2016). The current study did not seek to compare FTY with flat rate feeding systems, but instead was primarily designed to compare the effect of increasing level of concentrates within a FTY system on milk composition.

Methodology

Farm and animal selection: This study involved a subset of 19 of the farms (1,556 cows; average lactation 2.8 (range: 1 - 15; s.d. 1.9)) participating in the larger on-farm FTY project (Section 2). These farms were selected on the basis that either all or part of the herd grazed 'full-time' during the months of May to July 2019. During the grazing period these farms offered concentrates on a FTY basis through in-parlour feeders. All 19 farms used a conventional manually operated milking parlour.

Data collection: Over the grazing period details of feeding practices and samples of concentrates offered were recorded as described in Section 2. Test day milk yield and milk composition data were obtained from milk recording organisations. At the time of each milk recording individual cow DMI was estimated using the same calculations detailed in Section 2. Individual cow concentrate intake data was either obtained from the milking parlour software, and the average concentrate intake for the seven-day period prior to milk recording determined, or calculated based on cow milk yields and the feeding assumptions in place on the farm at time of milk recording (yield of milk that grazed grass was assumed to support (M+ value), and the concentrate feed rate (kg concentrate offered/litre of milk produced in excess of the M+ value)), as per Section 2. Concentrates offered were deducted from the estimated total daily DMI for each individual cow and the remainder of the daily DMI was assumed to be forage in the form of grazed grass. Grass composition (metabolisable energy (ME) and nitrogen (N) content) was obtained from the average NI grass quality data as recorded by GrassCheck, with data obtained from the nearest week to the time of milk recording (GrassCheck, 2019). Daily intakes of N, starch and ME from grass and concentrates was subsequently calculated.

Pedigree information was available for 13 out of the 19 herds that had cows grazing full time, with the genetic information (£PLI, PTA Milk (kg), PTA Fat (%), PTA Protein (%), PTA Somatic Cell Count (SCC), and Fertility Index) for each cow obtained from AHBD. The number of cows for which pedigree information was available within each lactation, together with the details of the concentrate DMI bands, is presented in Table 3.1.

Statistical analysis: In all analyses data for primiparous and multiparous cows was analysed separately. Total concentrate DMI was categorised by splitting it into 6 groups based on percentiles within each lactation group (number of cows within each category for each month within each lactation are detailed in Table 3.1). Variables that varied over month of lactation were analysed as a linear mixed model (REML estimation method) with farm, and animal within farm, fitted as random effects and total concentrate DMI fitted as fixed effects. Variables that were constant over month of lactation (genetic data) were analysed as a linear mixed model (REML estimation method) with farm fitted as a random effect and total concentrate DMI as a fixed effect. If any of the fixed effects were significant ($P<0.05$) then pairwise differences between the levels of the individual effects were assessed using Fisher's least significant difference test. In all cases the adequacy of the models was assessed by visual inspection of the appropriate residual plots. All analyses were carried out using the statistical software package GenStat 20th edition (VSN International Limited, Oxford, UK).

Results

Approaches to FTY while grazing: The average M+ value adopted during the grazing period across the participating farms was 16 (range: 6 – 28) and 15 (range: 6 – 26) kg of milk/day for cows and heifers, respectively. While most farms (n = 13) used a concentrate feed rate of 0.45 kg concentrate/litre milk, three farms used a value of 0.40 kg/litre milk, while the remaining three farms used values of 0.43, 0.44, and 0.50 kg/litre milk, respectively. The mean assumed oven DM, CP and ME content of grass offered during the experimental period, based on Grass Check samples, was 172 g/kg, 178 g/kg DM and 11.2 MJ/kg DM, respectively. Similarly, the mean CP and starch content of the grazing concentrates offered during the experimental period, based on the analysis of concentrate samples collected on the farms, were 194 and 221 g/kg DM, respectively. The average daily milk yield during the grazing period was 22.2 kg, while average milk fat and milk protein content was 4.33 and 3.54%, respectively (Table 3.2).

Effect of concentrate level on performance and efficiency: Within both primiparous and multiparous cows, as concentrate DMI increased, total DMI also increased (P < 0.001), while forage DMI decreased (P < 0.001; Tables 3.3 – 3.4). Forage DMI was lowest within the highest concentrate DMI group, although this was not a linear trend (Tables 3.3 – 3.4). The total starch, N and ME content of the diet, and total intakes of each of these parameters increased as concentrate DMI increased for both primiparous and multiparous cows (P < 0.001; Tables 3.3 – 3.4). For both primiparous and multiparous cows, milk yield, fat plus protein yield and ECM yield increased (P < 0.001) as concentrate DMI increased (Tables 3 - 4). However, milk fat % and protein % declined as concentrate DMI increased for both primiparous and multiparous cows (P < 0.001). Nitrogen use efficiency (milk N/N intake) and energy efficiency (measured as either milk energy/ME intake or ECM/DMI) increased as concentrate DMI increased for both primiparous and multiparous cows (P < 0.001; Tables 3.3 – 3.4), while concentrate use efficiency (measured as concentrate DMI/milk yield or concentrate DMI/ ECM yield) decreased with increasing concentrate DMI (P < 0.001).

Relationship between concentrate DMI and genetic merit: Across the 6 concentrate DMI bands, PLI of primiparious cows did not differ, while in the multiparous cows there was a trend (P = 0.068; Table 3.5) for PLI to increase with increasing concentrate DMI. As concentrate DMI increased, PTA for milk yield increased in both primiparous and multiparous cows (P < 0.001; Table 3.5), while PTA for milk fat % decreased for both primiparous (P = 0.002) and multiparous (P < 0.001) cows. The PTA for milk protein % also decreased for both primiparous (P = 0.005) and multiparous (P < 0.001) cows as concentrate DMI band increased.

Table 3.1. Number of primiparous and multiparous cows within each concentrate intake band.

	Concentrate intake band (kg DM/cow/day)					
Primiparous	0.0–0.3	0.3 – 0.9	0.9 – 1.8	1.8 – 3.0	3.0 – 4.8	4.8 – 12.0
Cows with production data	164	164	164	164	164	164
Cows with genetic data	32	41	54	35	36	40
Multiparous	0.0–0.3	0.3 – 1.5	1.5 – 2.9	2.9 – 4.3	4.3 – 5.8	5.8 – 15.4
Cows with production data	395	395	395	395	395	395
Cows with genetic data	142	113	110	152	128	113

Table 3.2. Average performance of cows across the 19 dairy farms during the months of May – July when grazing, and when offered concentrates on a FTY basis.

		Range	
	Mean	Min	Max
Total Concentrate DMI (kg/d)	3.4	0.5	8.3
Total Forage DMI (kg/d)	16.6	13.1	19.1
Total DMI (kg/d)	20.0	17.6	21.6
Concentrate as proportion of total DMI	0.16	0.02	0.39
Total starch intake (g/d)	754	110	2146
Total nitrogen intake (g/d)	590	523	648
Total ME intake (MJ/d)	229	202	253
Milk yield (kg/d)	22.6	18.9	28.0
Fat (%)	4.32	3.82	4.84
Protein (%)	3.51	3.33	3.80
Fat plus protein yield (kg/d)	1.74	1.46	2.18

Table 3.3. Dry matter intakes, milk production, and nutrient intake and efficiency values within each concentrate intake band for primiparious cows.

	Concentrate intake band (kg DM/cow/day)							
	0.0 - 0.3	0.3 - 0.9	0.9 - 1.8	1.8 - 3.0	3.0 - 4.8	4.8 - 12.0	SED	P-value
Dry matter intake								
Total concentrate DMI (kg/day)	0.3^{a}	0.9^{b}	1.6^{c}	2.6^{d}	3.9^{e}	6.0^{f}	0.09	<0.001
Total forage DMI (kg/day)	15.7^{abc}	15.8^{bcde}	15.8^{bcd}	16.1^{ce}	15.5^{ab}	15.3^{a}	0.19	<0.001
Total DMI (kg/day)	16.1^{a}	16.7^{b}	17.3^{c}	18.6^{d}	19.4^{e}	21.2^{f}	0.20	<0.001
Diet composition and nutrient intakes								
Concentrate as a proportion of total DMI	0.02^{a}	0.05^{b}	0.09^{c}	0.14^{d}	0.20^{e}	0.29^{f}	0.004	<0.001
Starch intake from concentrates (g/d)	125^{a}	229^{b}	378^{c}	584^{d}	850^{e}	1253^{f}	20.8	<0.001
Starch % of total diet	0.7^{a}	1.3^{b}	2.1^{c}	3.1^{d}	4.4^{e}	6.0^{f}	0.09	<0.001
Nitrogen intake from concentrates (g/d)	10^{a}	27^{b}	50^{c}	80^{d}	123^{e}	193^{f}	2.8	<0.001
Total nitrogen intake (g/kg)	471^{a}	478^{a}	511^{b}	547^{c}	571^{d}	630^{e}	7.8	<0.001
Crude protein % of total diet	18.4^{b}	17.9^{a}	18.5^{b}	18.4^{b}	18.4^{b}	18.5^{b}	0.16	0.002
ME intake from concentrate (g/d)	4^{a}	12^{b}	21^{c}	33^{d}	51^{e}	78^{f}	1.1	<0.001
Total ME intake (g/kg)	176^{a}	187^{b}	195^{c}	214^{d}	225^{e}	251^{f}	2.3	<0.001
ME content of total diet (MJ/kg DM)	11.1^{a}	11.2^{b}	11.3^{c}	11.5^{d}	11.6^{e}	11.8^{f}	0.03	<0.001
Milk production and efficiency values								
Milk yield (kg/day)	12.1^{a}	14.5^{b}	16.3^{c}	19.8^{d}	23.5^{e}	28.8^{f}	0.45	<0.001
Milk fat (%)	4.51^{c}	4.71^{d}	4.45^{bc}	4.32^{b}	4.13^{a}	4.16^{a}	0.083	<0.001
Milk protein (%)	3.61^{cd}	3.64^{d}	3.54^{c}	3.46^{b}	3.40^{a}	3.43^{ab}	0.036	<0.001
Fat + protein yield (kg/day)	1.01^{a}	1.24^{b}	1.32^{c}	1.56^{d}	1.78^{e}	2.14^{f}	0.036	<0.001
Energy corrected milk yield (kg/day)	13.5^{a}	16.6^{b}	17.8^{c}	21.3^{d}	24.5^{e}	29.6^{f}	0.48	<0.001
Milk nitrogen/N intake	0.15^{a}	0.17^{b}	0.18^{b}	0.20^{c}	0.22^{d}	0.25^{e}	0.004	<0.001
Milk energy/MEI	0.24^{a}	0.27^{b}	0.28^{c}	0.31^{d}	0.34^{e}	0.37^{f}	0.005	<0.001
ECM/DMI (kg/kg)	0.85^{a}	0.99^{b}	1.03^{c}	1.14^{d}	1.26^{e}	1.40^{f}	0.019	<0.001
Concentrate DMI/milk yield (kg/kg)	0.03^{a}	0.06^{b}	0.10^{c}	0.13^{d}	0.17^{e}	0.21^{f}	0.003	<0.001
Concentrate DMI/ECM yield (kg/kg)	0.02^{a}	0.05^{b}	0.09^{c}	0.12^{d}	0.16^{e}	0.21^{f}	0.003	<0.001

Table 3.4. Dry matter intakes, milk production, and nutrient intake and efficiency values within each concentrate intake band for multiparous cows.

	Concentrate intake band (kg DM/cow/day)							
	0.0 -0.3	0.3 - 1.5	1.5 - 2.9	2.9 - 4.3	4.3 - 5.8	5.8 - 15.4	SED	P-value
Dry matter intake								
Total concentrate DMI (kg/day)	0.2^{a}	1.1^{b}	2.4^{c}	3.7^{d}	5.1^{e}	7.2^{f}	0.05	<0.001
Total forage DMI (kg/day)	17.2^{b}	17.8^{c}	17.6^{c}	17.0^{b}	16.8^{ab}	16.7^{a}	0.16	<0.001
Total DMI (kg/day)	17.4^{a}	18.9^{b}	19.9^{c}	20.8^{d}	21.9^{e}	23.8^{f}	0.17	<0.001
Diet composition and nutrient intakes								
Concentrate as a proportion of total DMI	0.01^{a}	0.06^{b}	0.12^{c}	0.18^{d}	0.24^{e}	0.31^{f}	0.002	<0.001
Starch intake from concentrates (g/d)	104^{a}	285^{b}	539^{c}	819^{d}	1119^{e}	1504^{f}	10.9	<0.001
Starch % of total diet	0.5^{a}	1.4^{b}	2.7^{c}	4.0^{d}	5.2^{e}	6.5^{f}	0.05	<0.001
Nitrogen intake from concentrates (g/d)	5^{a}	33^{b}	73^{c}	117^{d}	161^{e}	227^{f}	1.6	<0.001
Total nitrogen intake (g/kg)	500^{a}	544^{b}	585^{c}	615^{d}	654^{e}	710^{f}	5.9	<0.001
Crude protein % of total diet	18.2^{ab}	18.1^{a}	18.4^{bc}	18.4^{bc}	18.5^{c}	18.4^{bc}	0.10	0.002
ME intake from concentrate (g/d)	3^{a}	15^{b}	31^{c}	48^{d}	67^{e}	93^{f}	0.63	<0.001
Total ME intake (g/kg)	192^{a}	210^{b}	226^{c}	239^{d}	256^{e}	282^{f}	1.9	<0.001
ME content of total diet (MJ/kg DM)	11.1^{a}	11.2^{b}	11.4^{c}	11.5^{d}	11.6^{e}	11.8^{f}	0.02	<0.001
Milk production and efficiency values								
Milk yield (kg/day)	13.5^{a}	17.3^{b}	20.7^{c}	24.1^{d}	28.0^{e}	33.9^{f}	0.32	<0.001
Milk fat (%)	4.50^{d}	4.47^{d}	4.29^{c}	4.24^{c}	4.12^{b}	3.96^{a}	0.052	<0.001
Milk protein (%)	3.82^{f}	3.68^{e}	3.56^{d}	3.49^{c}	3.43^{b}	3.35^{a}	0.021	<0.001
Fat + protein yield (kg/day)	1.13^{a}	1.41^{b}	1.64^{c}	1.87^{d}	2.13^{e}	2.48^{f}	0.027	<0.001
Energy corrected milk yield (kg/day)	15.0^{a}	19.0^{b}	22.2^{c}	25.5^{d}	29.2^{e}	34.4^{f}	0.357	<0.001
Milk nitrogen/N intake	0.16^{a}	0.18^{b}	0.20^{c}	0.22^{d}	0.23^{e}	0.25^{f}	0.003	<0.001
Milk energy/MEI	0.24^{a}	0.28^{b}	0.30^{c}	0.33^{d}	0.36^{e}	0.38^{f}	0.003	<0.001
ECM/DMI (kg/kg)	0.87^{a}	1.01^{b}	1.11^{c}	1.24^{d}	1.33^{e}	1.45^{f}	0.012	<0.001
Concentrate DMI/milk yield (kg/kg)	0.02^{a}	0.07^{b}	0.12^{c}	0.16^{d}	0.17^{e}	0.22^{f}	0.002	<0.001
Concentrate DMI/ECM yield (kg/kg)	0.01^{a}	0.06^{b}	0.11^{c}	0.15^{d}	0.18^{e}	0.22^{f}	0.002	<0.001

Table 3.5. Predicted Transmitting Ability (PTA) $_{2019}$ of primiparous and multiparous cows within each concentrate intake band.

	Concentrate intake band (kg DM/cow/day)						SED	P values
Primiparous	0.0 – 0.3	0.3 – 0.9	0.9 – 1.8	1.8 – 3.0	3.0 – 4.8	4.8 – 12.0		
PLI £	211	205	204	165	218	269	34.3	0.207
Milk yield (kg)	26^{ab}	-1^{a}	53^{ab}	92^{bc}	142^{c}	305^{d}	48.4	<0.001
Fat (kg)	8.8	8.6	9.3	9.3	11.1	13.9	1.82	0.239
Protein (kg)	5.4	4.6	5.9	6.1	7.6	11.4	1.34	0.004
Fat (%)	0.10^{bc}	0.11^{c}	0.09^{bc}	0.07^{b}	0.07^{b}	0.02^{a}	0.018	0.002
Protein (%)	0.06^{c}	0.06^{c}	0.05^{bc}	0.04^{ab}	0.03^{a}	0.02^{a}	0.009	0.005
Multiparous	0.0 – 0.3	0.3 – 1.5	1.5 – 2.9	2.9 – 4.3	4.3 – 5.8	5.8 – 15.4		
PLI (£)	127	124	136	143	132	165	13.8	0.068
Milk yield (kg)	-99^{a}	-47^{b}	-32^{b}	11^{c}	45^{c}	105^{d}	24.8	<0.001
Fat (kg)	4.3^{a}	4.6^{a}	5.8^{ab}	6.1^{ab}	6.9^{bc}	8.3^{c}	0.89	0.001
Protein (kg)	1.8^{a}	2.4^{a}	2.8^{a}	4.2^{b}	4.4^{b}	6.7^{c}	0.69	<0.001
Fat (%)	0.10^{d}	0.09^{cd}	0.08^{bc}	0.07^{b}	0.06^{ab}	0.05^{a}	0.010	<0.001
Protein (%)	0.06^{c}	0.05^{b}	0.05^{b}	0.05^{b}	0.04^{a}	0.04^{ab}	0.005	<0.001

Discussion

While the M+ value for grazing cows was lower than that for housed cows, concentrate feed rate per kg of milk was similar. As many housed cows were offered concentrates as part of the basal ration, it is unsurprising that the milk production assumed to be sustained from grazed grass was lower than that of housed cows. Nevertheless, milk assumed to be sustained from grazed grass was 'relatively high', reflecting the fact that this study involved the early season grazing period only. Due to the on-farm approach adopted in this study, intakes were predicted using equations. Nevertheless, total DMI predicted within this study (19.3 kg DM per cow/day: mean for both lactation groups) was similar to that measured in grazing dairy cows by Kolver and Muller (1998), namely 19.0 kg DM per cow/day.

Due to the lower milk yields of cows within the grazing study, and the fact that concentrate feed level was restricted by the use of in-parlour concentrate feeding, concentrate DMI was lower compared to that during the housed part of the study. While increasing concentrate DMI also resulted in an increase in total DMI during the grazing period, there was no effect on forage DMI, likely reflecting the relatively small amounts of concentrate offered. While forage DMI was lowest for cows in the highest concentrate DMI band, this was not significantly different from that within the lowest concentrate DMI band in primiparous cows. In both lactation groups, the highest forage DMI was observed in the middle concentrate DMI bands. As the starch intake of grazing cows was solely from concentrates, the starch % of the diet and the ME content of the diet increased with concentrate DMI band. As the nitrogen content of the grazed grass and concentrates offered were relatively similar, the CP content of the total diet changed little across the concentrate DMI bands.

As cows which were used in this study, were either mid or late lactation, milk yields were also lower compared to the housed period when cows were in early lactation. In addition, this aspect of the study involved only 19 of the original 26 farms described in Section 2, and it is likely that the excluded herds will have been predominantly higher yielding, with this being a main reason for keeping cows indoors during the summer. The linear increase in milk yields, and therefore ECM and fat plus protein yield, with increasing concentrate levels were as expected, given that additional concentrates were offered in response to milk actually produced. The increase in milk yield between the lowest and highest concentrate groups is partly reflected by the increase in PTA for milk between these extreme groups, namely an increase of 279, and 204 kg (primiparous and multiparous cows, respectively). These genetic differences may account for an additional 558 and 408 kg milk/lactation between the extreme concentrate DMI bands, or 1.8 or 1.3 kg additional milk/day in a 305 day lactation. Nevertheless, actual differences in milk yield between the extreme concentrate groups was 16.7 and 20.4 kg/day for primiparous and multiparous cows, respectively, considerably greater than the values expected based on differences in PTA. While these differences could be partly explained by the increase in total DMI, concentrate proportion in the diet, and diet starch and ME content with increasing concentrate DMI band, it is likely that the overall management during the housed period and also the stage of lactation of individual cows had an effect as cows used in the grazing analysis where between 4 and 9 months calved.

Although the concentrate levels offered to cows were much lower during the grazing season compared to the housed period, in agreement with observations during the winter period, a reduction in milk fat % was observed as concentrate DMI band increased. The 0.08 (primiparous) and 0.05 (multiparous) of a percentage unit decrease in PTA for milk fat % observed between the lowest and highest concentrate levels in each lactation group could account for 0.16 and 0.10 of a percentage unit decrease across the concentrate levels. Thus, differences in cow genotype between the extreme concentrate treatments would account for up to 45 and 19% of the reduction in milk fat % in primiparous and multiparous cows, respectively. The remaining variation in milk fat % not explained by genetic merit is likely to be explained by diet, particularly the increase in concentrate intake. In contrast to the housed period, in which concentrate DMI band had no effect on milk protein %, during the grazed period milk protein percent also decreased as concentrate DMI band increased. Milk protein % decreased by 0.18 (primiparous) and 0.47 (multiparous) percentage units between the lowest and highest concentrate intake group. As PTA for protein % also decreased as concentrate DMI band increased, genetic merit could account for 44% and 9% of the total variation in milk protein % with primiparous and multiparous cows, respectively.

Nitrogen utilization efficiency increased with increasing concentrate DMI band across both lactation groups, reflecting the corresponding increase in milk yield. The efficiency of N utilization was lower during the grazing period compared to the housed period due to the higher CP content of grazed grass offered, resulting in higher total diet CP content. This indicates that improving N use efficiency with grazing cows can be a challenge. Research has demonstrated that a reduction in fertiliser N inputs can reduce the CP content of the herbage offered, and can improve nitrogen use efficiency, as well as having direct environmental benefit (Watson et al. 2000). However, if a reduction in fertiliser N inputs reduce herbage yield, a reduction in stocking rate will be necessary to maintain animal performance, with an associated lower performance per ha (Delaby and Peyraud,1998). Nevertheless, AFBI research has demonstrated that cow performance was not affected provided fertiliser levels did not drop below 250 kg of N/ha/year (Dale et al. 2005, 2006). Reducing the CP content of concentrate supplements is an alternative method by which the N content of the diet of grazing dairy cows can be reduced (Delaby et al., 1996; Ferris et al. 2002). These studies have demonstrated that the protein content of grazing concentrates can be reduced for lower yielding cows with no loss in performance, although this is an area that requires further research.

Both ECM/DMI and milk energy/energy intake increased with increasing concentrate levels across both lactation groups, with this accompanying the improvement in PTA for milk. The improvement in efficiency with increasing concentrate levels is likely due to ‘dilution of maintenance energy requirements’ with increasing milk yields as per the housed period. As expected, concentrate DMI/milk yield increased as concentrate DMI band increased in line with the housed period indicating the more concentrates were offered to produce a kg of milk at the high concentrate levels.

Conclusion

Supplementing cows with high levels of concentrates while grazing can increase milk yield, but may have a negative impact on milk fat and protein percentages. Some of the reduction in milk composition was found to be a genetic effect, but over 50% of the reduction in milk composition can be attributed to diet. Therefore, producers should give careful consideration to the level of concentrate supplementation given to cows at grass to improve efficiencies of concentrate use.

SECTION 4

ECONOMIC ANALYSIS OF THE EFFECT OF OFFERING CONCENTRATES ON A FEED-TO-YIELD BASIS DURING THE WINTER

Introduction

A key objective of this experiment was to examine the impact of increasing concentrate feed levels within a FTY system on economic performance across a range of milk prices. This was of interest as an earlier study conducted at AFBI demonstrated that due to the poorer milk composition observed at higher concentrate levels with some cows, the economic performance of these cows was no better than that of cows offered much lower concentrate levels, especially when milk prices were low. This study sought to examine if a similar trend was observed on commercial dairy farms. This analysis was restricted to the data from the winter feeding period.

Methodology

Margin-over-feed costs for each individual cow was determined based on performance data for each cow over the winter feeding period, as described in Section 2. Feed costs were determined using feed intakes calculated for the housed period, as described in Section 2. Costs for grass silage, maize silage and whole crop silage were assumed as £123, £189, £225/t DM, respectively, based on a recent update of forage costs in Northern Ireland (Craig et al., 2021), while the cost of concentrates was assumed to be £260/t fresh. Margins were modelled at three different milk prices, namely 18, 26 or 34 pence per kg (p/kg). The economic analysis also took into consideration the composition of milk produced using a bonus/deduction of 0.022 pence for every 0.1 g/kg above/below a base level of 38.5 g/kg fat, and a bonus/deduction 0.036 pence for every 0.1 g/kg above/below a base level of 31.8 g/kg protein (based on Dale Farm milk pricing structure, 2020). Margins were calculated on both a per cow basis, and a per kg basis.

Outcomes

The impact of concentrate intake band on the mean milk price bonus/deductions is presented in Figures 4.1 and 4.2 for primiparous and multiparous cows, respectively. These figures clearly demonstrate the impact of increasing concentrate DMI band on the value of milk produced. For example, within the first concentrate DMI band, the total milk price bonus associated with each kg of milk was 2.06 p/kg and 1.81 p/kg for primiparous and multiparous cows, respectively. However, within the highest concentrate intake band, the milk price bonus was only 0.61 p/kg for primiparous cows, while for multiparous cows there was a small deduction (0.04 pence/kg). These are of course only averages for each band, and individual cows have much lower and higher values.

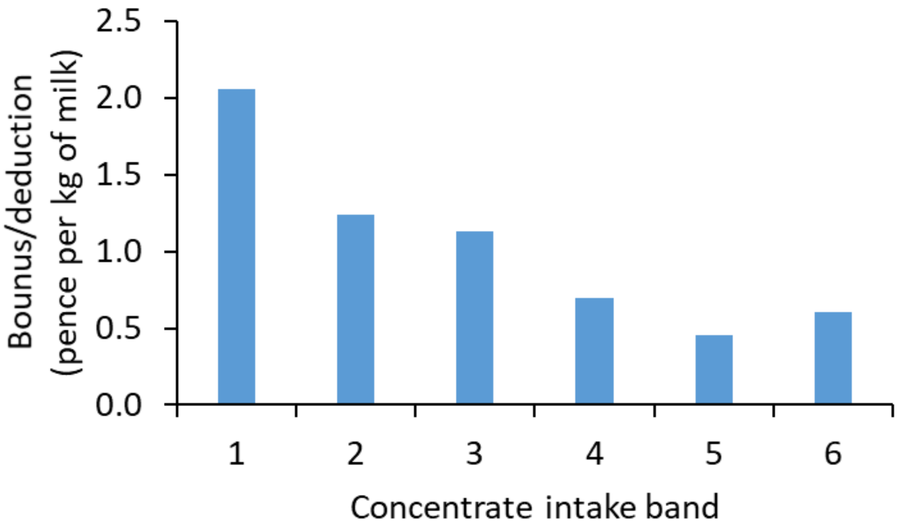


Figure 4.1. Mean bonus per kg of milk produced by primiparous cows within each concentrate DMI band.

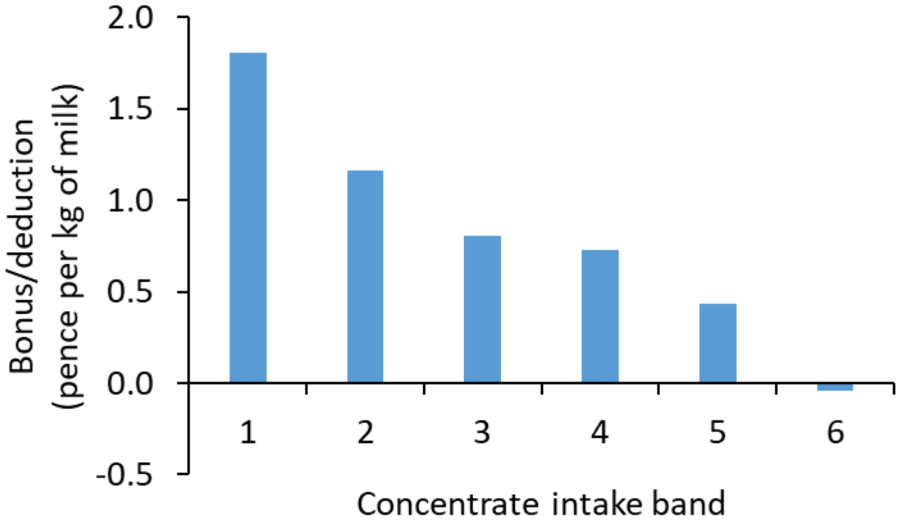


Figure 4.2. Mean bonus/deduction per kg of milk produced by multiparous cows within each concentrate DMI band.

The calculation of mean margin-over-feed cost within each concentrate DMI band is shown for primiparous (Table 4.1) and multiparous cows (Table 4.2). Total feed costs increased with increasing concentrate DMI band, largely reflecting the increase in concentrate intake (the most expensive feed ingredient) across bands, but also reflecting to a lesser extent small differences in forge costs between bands. The increase in the volume of milk produced with increasing concentrate DMI bands meant that the value of milk per cow/day increased at all milk prices, despite the poorer milk composition at higher concentrate levels. Across all milk prices, margin-over-feed costs (per cow/day) increased with increasing concentrate DMI band, although the increase was extremely small at a milk price of 18 p/kg (Figures 4.3 and 4.4). For example when milk prices were low, the benefits of feeding additional concentrates are marginal, and for some cows will be non-existent. This was further demonstrated when marginal economic responses were examined per kg additional concentrate offered (i.e. inter-band comparison: Table 4.3). This table highlights that marginal responses decreased with increasing concentrate levels, reflecting the reduction in milk fat content, and the associated reduced value of milk produced. This is important as when milk prices are low, some farmers seek to increase income by producing more milk. For many it is likely this this results in little overall benefit for herd profitability.

Margin-over-feed costs per kg milk was also examined in this analysis. Across all milk prices, the margin over-feed-costs per kg of milk decreased as concentrate DMI band increased. In primiparous cows this was a steady decrease; however, in multiparous cows there was little difference between margins per kg of milk between the first four concentrate DMI bands, although margins were greatly reduced in concentrate intake bands 5 and 6. In many earlier studies margin-over-feed-costs per litre of milk decreased sharply with increasing concentrate levels, however, this is much less of an issue in feed-to-yield systems. Nevertheless, in today’s quota free environment ‘milk volume’ is not the major limiting factor on dairy farms, and as such margin per kg milk is a less relevant metric than in the past.

Table 4.1. Calculation of mean of margin-over-feed costs (£ per cow/day and pence/kg) for primiparous cows within each concentrate intake band.

Concentrate DMI band	1	2	3	4	5	6
Feed costs (£/cow/day)						
Concentrate	1.46	1.94	2.24	2.57	2.96	3.76
Grass silage	1.07	1.02	0.93	0.90	0.92	0.80
Maize silage	0.18	0.26	0.37	0.38	0.26	0.20
Whole crop silage	0.28	0.23	0.21	0.19	0.15	0.14
Total	2.99	3.44	3.76	4.04	4.29	4.90
Value of milk produced (£/cow/day						
@ 18p/kg	4.21	4.78	5.20	5.55	5.86	6.55
@ 26p/kg	5.89	6.77	7.38	7.93	8.41	9.38
@ 34p/kg	7.57	8.76	9.56	10.32	10.97	12.22
Margin over feed costs (£/cow/day, at a range of milk prices)						
@ 18p/kg	1.21	1.34	1.44	1.51	1.57	1.65
@ 26p/kg	2.89	3.33	3.62	3.90	4.12	4.48
@ 34p/kg	4.57	5.32	5.80	6.28	6.68	7.31
Margin over feed costs (pence per kg, at a range of milk prices)						
@ 18p/kg	5.48	5.24	5.23	4.95	4.82	4.53
@ 26p/kg	13.48	13.24	13.23	12.95	12.82	12.53
@ 34p/kg	21.48	21.24	21.23	20.95	20.82	20.53

Table 4.2. Calculation of mean of margin-over-feed costs (£ per cow/day and pence/kg) for mulitparous cows within each concentrate intake band.

Concentrate DMI band	1	2	3	4	5	6
Feed costs (£/cow/day)						
Concentrate	2.06	2.73	3.09	3.43	3.88	4.73
Grass silage	1.26	1.18	1.17	1.16	1.09	0.99
Maize silage	0.25	0.33	0.29	0.30	0.28	0.21
Whole crop silage	0.24	0.25	0.22	0.18	0.21	0.26
Total	3.81	4.49	4.77	5.08	5.46	6.19
Value of milk produced (£/cow/day						
@ 18p/kg	5.41	6.41	6.84	7.36	7.75	8.51
@ 26p/kg	7.60	9.11	9.77	10.52	11.13	12.33
@ 34p/kg	9.79	11.81	12.69	13.67	14.50	16.14
Margin over feed costs (£/cow/day, at a range of milk prices)						
@ 18p/kg	1.60	1.92	2.07	2.28	2.29	2.32
@ 26p/kg	3.79	4.62	5.00	5.44	5.66	6.14
@ 34p/kg	5.98	7.31	7.92	8.60	9.04	9.95
Margin over feed costs (pence per kg, at a range of milk prices)						
@ 18p/kg	5.56	5.65	5.61	5.71	5.36	4.85
@ 26p/kg	13.56	13.65	13.61	13.71	13.36	12.85
@ 34p/kg	21.56	21.65	21.61	21.71	21.36	20.85

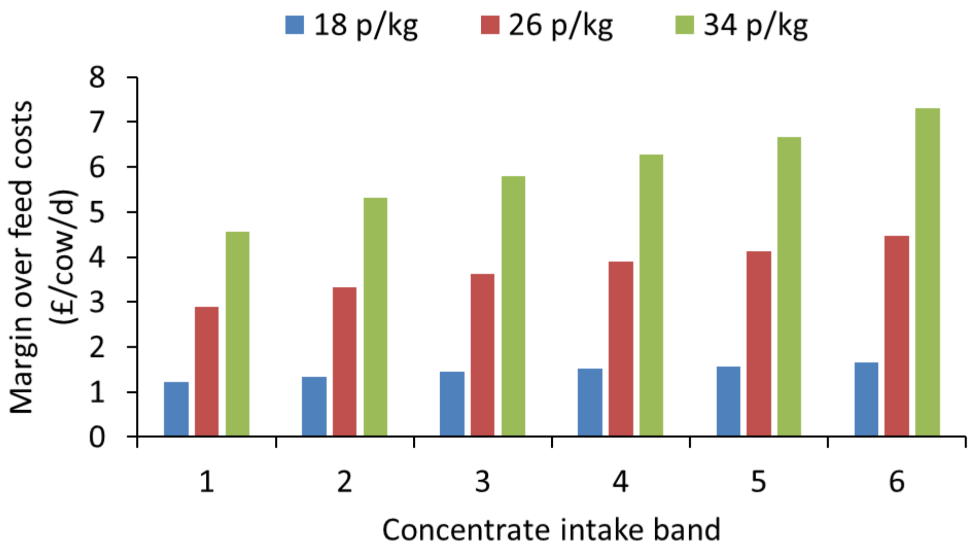


Figure 4.3 Effect of concentrate DMI band on margin over feed costs (£/cow/d) for primiparous cows at three milk prices.

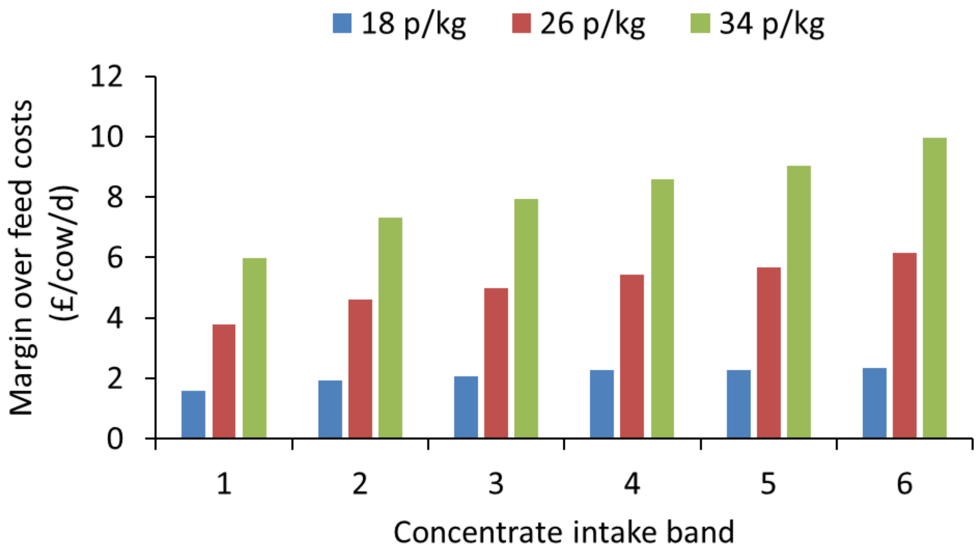


Figure 4.4. Effect of concentrate DMI band on margin over feed costs (£/cow/d) for multiparous cows at three milk prices.

Table 4.3. Calculation of marginal economic response (£ per cow/day) between each concentrate intake band for primiparous and mulitparous cows.

		Marginal economic response/kg concentrate DM intake (£/cow/day)		
		@18 p/kg	@26 p/kg	@34 p/kg
Primiparous	Between bands 1 - 2	0.08	0.29	0.50
	Between bands 2 - 3	0.09	0.26	0.44
	Between bands 3 - 4	0.06	0.23	0.39
	Between bands 4 - 5	0.04	0.17	0.31
	Between bands 5 - 6	0.03	0.14	0.25
Multiparous	Between bands 1 - 2	0.17	0.44	0.70
	Between bands 2 - 3	0.12	0.31	0.49
	Between bands 3 - 4	0.17	0.37	0.57
	Between bands 4 - 5	0.00	0.15	0.30
	Between bands 5 - 6	0.02	0.21	0.39

Figures 4.5 and 4.6 show calculated margin-over-feed costs for two individual farms on the study (Farm A and Farm B), with each dot representing an individual cow. Margins here are again presented at three milk prices, namely 18, 26 and 34 p/kg. Margins on most farms followed a similar pattern to that of Farm A, with margin-over-feed-costs tending to level-off at a concentrate intake of approximately 11 kg DM per day (Figure 4.5), especially at lower milk prices. However, on a small number of farms margin-over-feed-costs continued to increase even at higher concentrate levels (Figure 4.6). On closer examination, these farms did not experience as large a decrease in milk composition at higher concentrate levels. The reasons for this were unclear from the data, and it is likely that no single factor was responsible. Nevertheless, contributing factors appear to include no major reduction in PTA for milk fat at higher concentrate DMI bands, the inclusion of alternative forages in the diet, lower than average concentrate intakes, and diets with slightly lower starch contents. It is apparent that farms which can maintain milk composition at high concentrate feed levels will be able to maintain greater margin-over-feed costs.

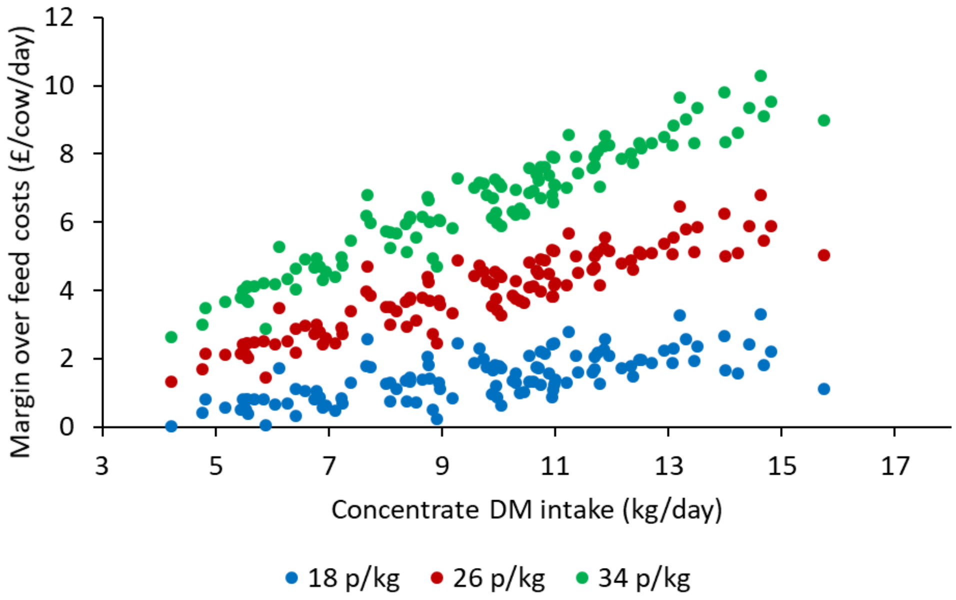


Figure 4.5. Effect of concentrate DMI band on margin over feed costs (£/cow/d) on Farm A at three milk prices.

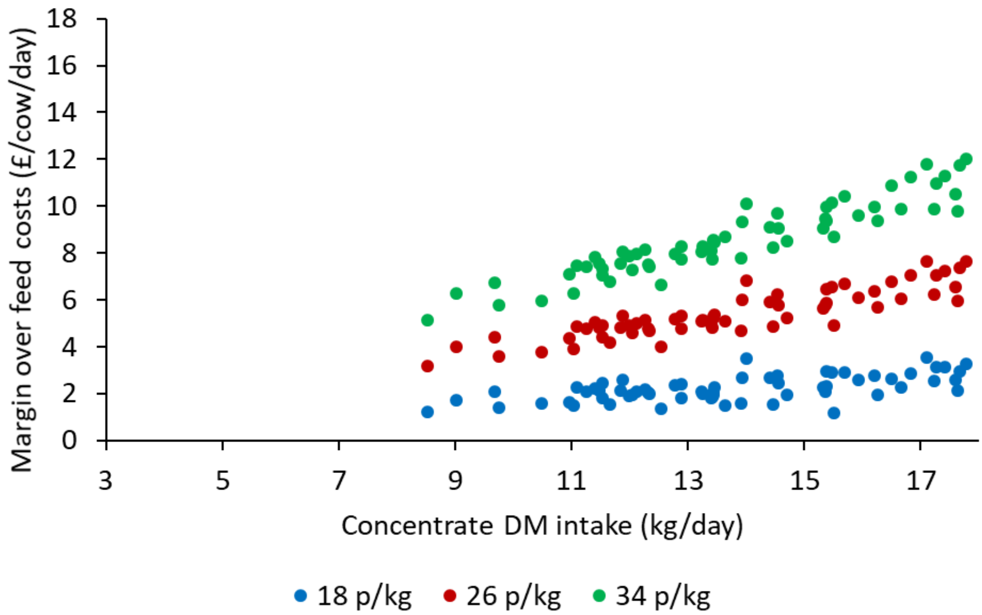


Figure 4.6. Effect of concentrate DMI band on margin over feed costs (£/cow/d) on Farm B at three milk prices

Conclusion

The economic responses to concentrate feeding within a feed-to-yield system are very different from the 'traditional' economic responses to concentrate feeding, where 'break-even' feed levels at a herd level typically occur at relatively modest concentrate levels. Within a feed-to-yield system, economic responses are examined at an individual cow level, as each cow is treated as an individual during feeding. Thus, individual cows can continue to exhibit economic responses to high levels of concentrate feeding as these individual cows have the genetic capacity to consume more food and produce more milk.

When milk prices are high it can make economic sense to continue to increase concentrate feed levels, to support the extra milk produced. There are of course associated animal health risks, and issues with excess phosphorus surplus on farms. However, while the milk yield 'response' to increasing concentrate levels may be linear, the increase in margin is curvilinear. This decreasing marginal response at higher concentrate levels is due to two effects, namely the increasing cost of each unit of food consumed, and the decreasing value of each litre of milk produced due to declining milk quality observed on most farms. The impact of these latter effects are particularly important at lower milk prices, where there may be little overall benefit in continuing to feed additional concentrates.

SECTION 5

CALIBRATION OF ON-FARM CONCENTRATE FEEDING SYSTEMS

Introduction

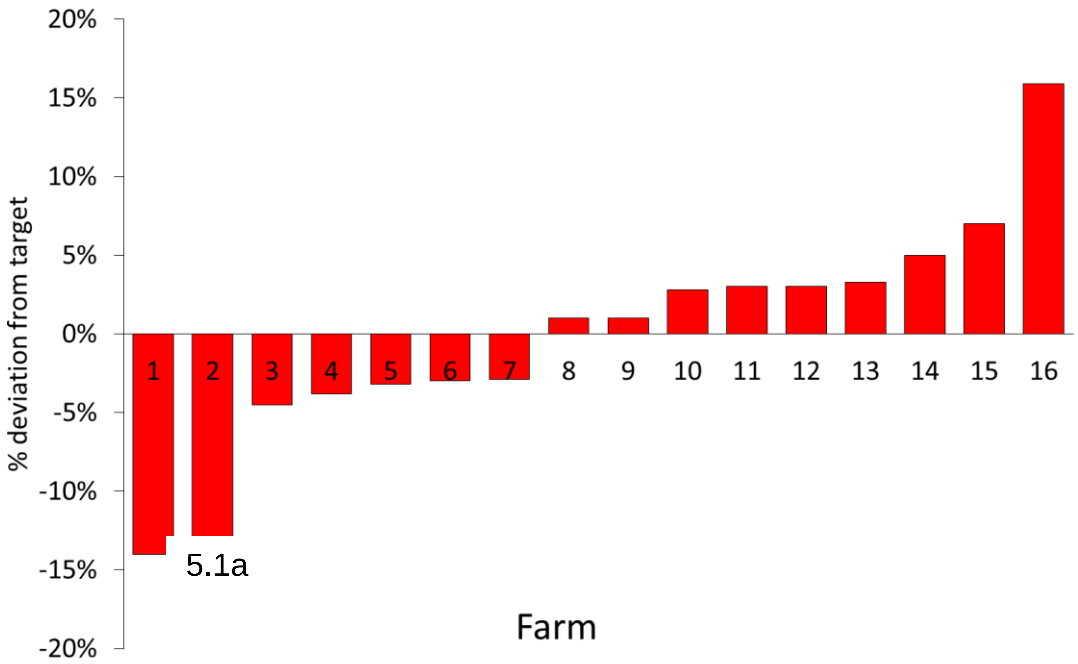
The concentrate component of dairy cow diets represents between 60 – 70% of the variable costs of milk production on many dairy farms. Given the significant cost of concentrates, it is important that concentrates are accurately allocated to cows. Indeed, many modern concentrate feeding systems, both in-parlour and out-of-parlour systems, allow concentrates to be allocated to individual cows based on their current milk yields. However, the accuracy with which cows are offered concentrates can be seriously impacted if concentrates are not dispensed accurately. This study was conducted on 16 of the farms participating within this project to examine the accuracy with which concentrate feeding systems on commercial farms dispensed concentrates.

Methodology

The study was conducted on 16 of the farms participating in the on-farm FTY study, and measurements were conducted over a six-week period during November and December 2018. The 16 farms had a mean herd size of 174 (s.d., 66.6) cows, and a mean annual milk yield of approximately 8,618 (s.d., 1235.2) kg. Each farm was visited by an AFBI staff member who tested all concentrate feeders for accuracy. A total of 490 concentrate feeders were tested, ranging from 16 - 48 feeders per farm. This test involved allowing a pre-programmed quantity of concentrates (normally between 500 – 2000 g, depending on the feeder calibration setting) to be dispensed from each feed hopper into a plastic bucket, and weighing this on a tared weigh-scale. This information was then used to determine the percentage deviation of the dropped weight of concentrate from the target weight. The information on the actual weight of concentrate dropped was then used to recalibrate the weigh cell in each feed hopper using the inbuilt computer software.

Outcomes

Across all feeders on each farm, the average deviation from target (zero) was 0.2% (s.d., 7.4%), while at the extremes, Farm 1 had a mean average deviation of -14% across all feeders, while Farm 16 had a mean average deviation of +16% (Figure 5.1a) across all feeders. However in general, the majority of farms (farms 3 – 14) had an overall inaccuracy of ± 5%. Nevertheless, these mean values across all feeders on each farm mask the individual feeder-feeder variations which exist on many farms. For example, when averaged across the 16 farms the maximum positive deviation (most extreme feeder on each farm) from target was +24% (s.d., 26.3%), while the mean maximum negative deviation from target was -32% (s.d., 19.3%) (Figure 5.1b). However, individual feeders on some farms had deviations of between 75 and 100%.



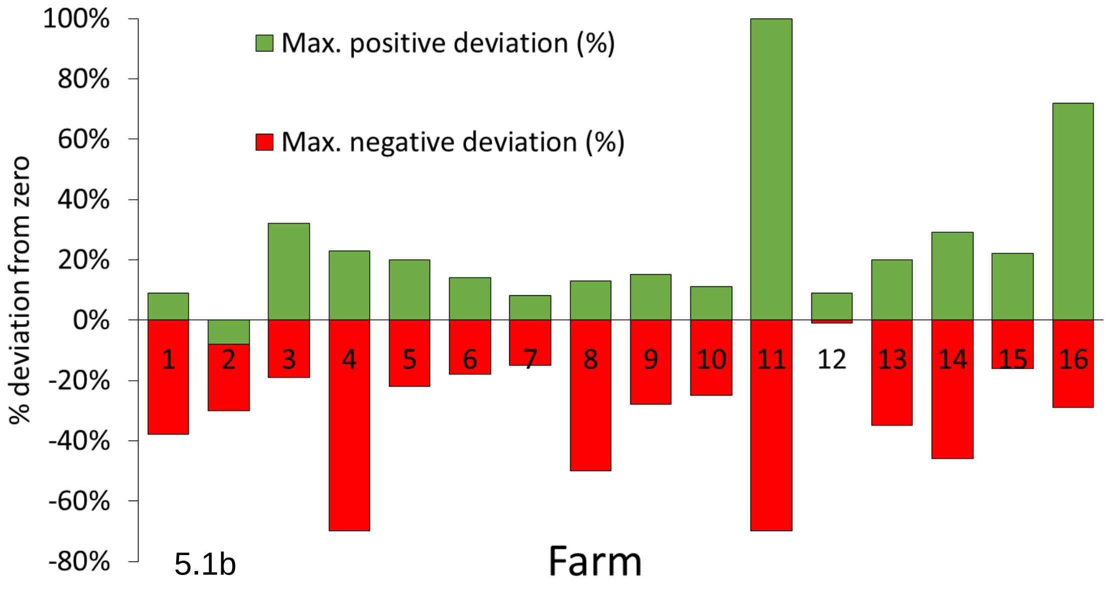


Figure 5.1. Average percentage deviation from target (zero) of all in-parlour feeders on each of the 16 farms (a) and percentage deviation from target (zero) of the in-parlour feeder on each farm with the largest positive and negative deviation from zero (b).

Leaving concentrate feeders uncalibrated can lead to high levels of under-feeding or over-feeding of concentrates The implications of the average deviation of all feeders on Farms 1 and 16 (Figure A) is examined for a 100 cow herd offering an average of 6.0 kg concentrate/cow/day through in-parlour feeders over a 180 day winter period. The target concentrate usage in this situation is 108 t concentrate over the winter. However based on the mean deviations observed, Farm 1 would actually have fed only 93 t concentrate, while Farm 16 would have actually fed 125 t concentrate, representing underfeeding and overfeeding of 15 t and 17 t respectively.

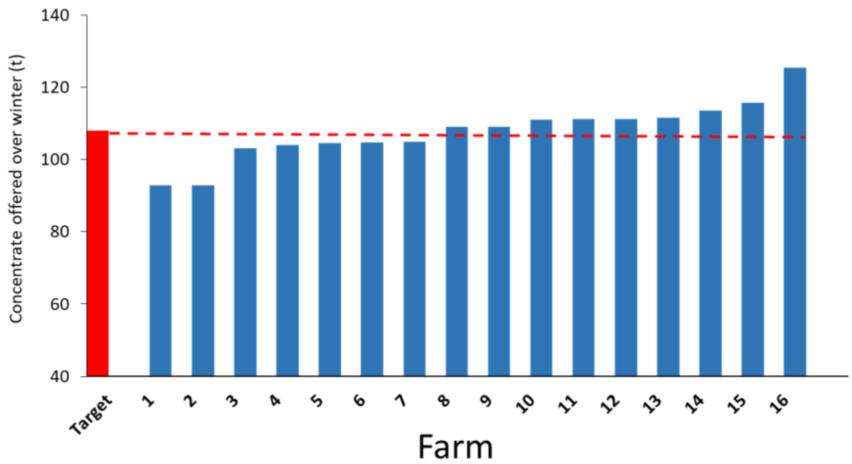


Figure 5.2. Impact of feeder inaccuracy on farms 1 – 16 on the quantity of concentrates that would be fed over a 180 day winter period (modelled for a 100 cow herd offered 6 kg/cow/day), compared to the target level of concentrates offered for feeders working at 100% accuracy (black bar).

Conclusions

Poorly calibrated concentrate feeders are common on many NI dairy farms, and this can result in substantial underfeeding or overfeeding of concentrates. Frequent checking of concentrate feeders is essential on all farms, and as a minimum this each feeder should be calibrated at least monthly using the built in feeder software. Details of how to do this can be obtained from the suppliers of the feeders. If FTY systems are to deliver precision to concentrate feeding, it is vital that concentrates are delivered accurately to individual cows to avoid overfeeding or underfeeding. On farms where the average feeder performance is close to target, individual feeders can still be inaccurate resulting in significantly overfeeding or underfeeding of individual cows on a daily basis.

SECTION 6

AN INDIVIDUAL ‘FARMERS REPORT’ PREPARED FOR ONE OF THE FARMS PARTICIPATING IN THE STUDY

The Research Challenge Fund

“Improving efficiency within feed-to-yield systems: understanding drivers of milk quality and fertility”

AgriSearch NI Driving Excellence & Innovation

DAERA Department of Agriculture, Environment and Rural Affairs www.daera-ni.gov.uk

afbi AGRI-FOOD & BIOSCIENCES INSTITUTE

Background to this report: This report summarises some of the data collected from your farm over the course of the experiment. Throughout the experiment your farm was visited a total of 4 times between September 2018 and June 2019. This report summarises the main data recorded on your farm during that time, and in places will compare your farm to others in terms of performance. However, these 'between-farm' comparisons need to be treated with caution, and higher or lower levels of performance do not necessarily mean that your farm is more/less efficient or more/less profitable than other farms on the study.

Forages offered: The forages offered on your farm were sampled during farm visits. Table 1 provides a comparison of the mean analysis of silages sampled on your farm, compared to the average of silages sampled across all farms on the study. As highlighted at the 'Start-up Meeting', we are unable to provide the analysis of concentrates offered on your farm.

Table 1. Chemical composition of forages offered on your farm, compared to those offered on other farms within the project.

	Grass silage		**Maize silage**		**Whole crop silage**	
	Your farm	Average of all farms	Your farm	Average of all farms	Your farm	Average of all farms
Dry matter (%)	36.9	31.4	36.7	31.9	47.1	38.6
pH	3.89	4.00			3.83	3.79
Crude protein (%)	13.5	13.9	7.8	8.5	7.8	9.0
Ammonia (as a % of total Nitrogen)	6.2	8.1			11.9	10.8
D value (%)	75.3	69.9	69.7	67.4		
ME (MJ/kg DM)	12.0	11.2	11.5	11.1	10.6	10.0
Starch (%)			30.4	25.6	39.3	25.6

Performance during the winter (months 2 – 5 post-calving): Mean cow performance on your farm over the winter (months 2 – 5 post-calving) is presented in Table 2, alongside the average values for all farms on the study. Intakes were calculated for each individual cow based on the information obtained during visits.

Table 2. Intakes, milk production, diet composition and some efficiency values for heifers and cows on your farm while housed (months 2 – 5 following calving), compared to the average values for the other farms on the project

	Heifers		Cows	
	Your farm	Average of all farms	Your farm	Average of all farms
Intakes (dry matter basis: DM)				
Concentrate DM Intake (kg/d)	7.3	8.5	12.0	11.5
Forage DM Intake (kg/d)	10.6	10.1	12.5	11.9
Total DM Intake (kg/d)	17.9	18.6	24.5	23.3
Composition of diets offered (DM basis)				
Concentrate % of total diet	40.8	45.1	48.7	48.5
Starch % of total diet	13.6	13.0	15.7	13.7
Crude protein % total diet	16.4	16.3	16.7	16.5
ME content of diet (MJ/kg DM)	12.4	11.9	12.4	12.0
Milk production				
Milk yield (kg/d)	25.6	27.6	40.7	37.3
Milk fat (%)	4.23	4.14	4.03	4.09
Milk protein (%)	3.29	3.26	3.27	3.24
Efficiency values				
Nitrogen use efficiency (% of the nitrogen eaten by the cow which ends up in milk)*	28	29	31	30
Concentrate use efficiency (kg of concentrate eaten, per kg of milk produced) **	0.33	0.34	0.33	0.34

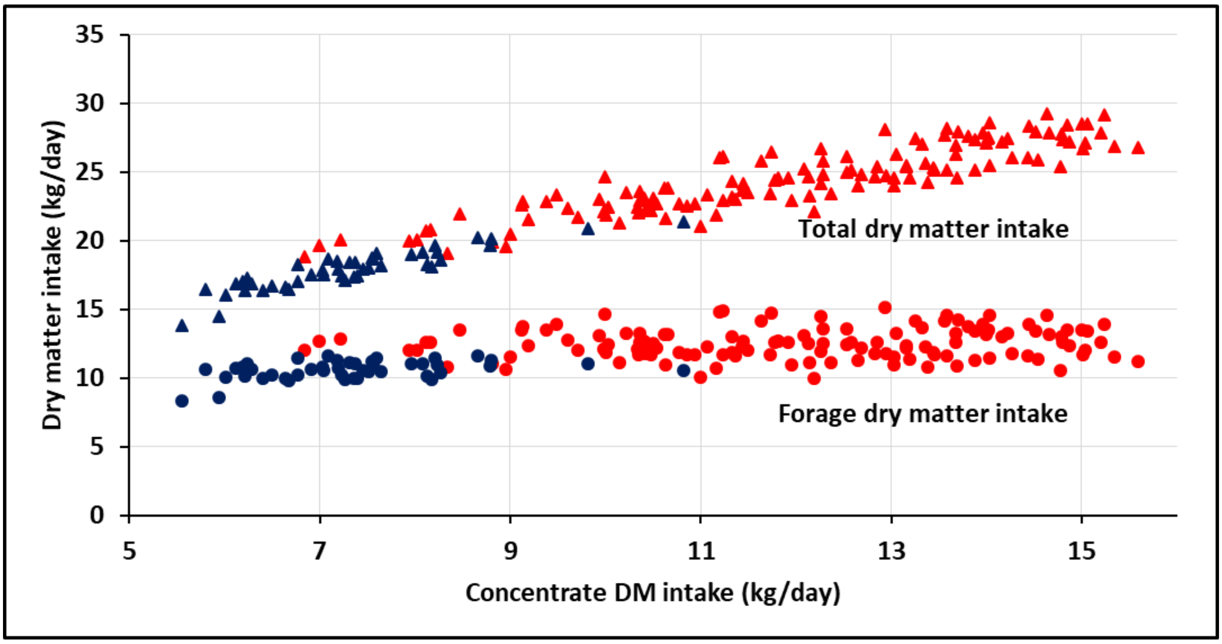
* Nitrogen use efficiency: this value provides an indication of how much of the nitrogen in the diet ends up in milk in the form of milk protein. In general, cows use nitrogen with a low efficiency, and normally only 25 – 35% of the nitrogen cows consume ends up in milk. Most of the remaining nitrogen is lost in manure, and this can then be lost to watercourses as nitrates, or to the atmosphere as nitrous oxide (a greenhouse gas) or as ammonia. However, some nitrogen is retained in the cow's body for muscle development or for the growing calf. Nitrogen use efficiency is normally lower when cows are grazing as grass contains higher levels of nitrogen.

**Concentrate use efficiency: this value provides an estimate of how much concentrate is offered (fresh) per kg of milk produced. In general, a low value indicates that less concentrates are being offered, and this is desirable if it is due to higher quality silage being available. However, a lower value can also arise when cows are mobilising excess body tissue ('milking off their backs'). Farms with lower milk yields also tend to have lower values, so the value cannot be used in 'isolation', and is best used to compare farms with similar milk yields.

Overview of data in Figures 1 - 10: In Figures 1 – 10 we have presented some diet, performance and efficiency traits for cows in your herd, relative to concentrate intake (on a DM basis). Each dot in the graphs below represents 1 animal (**heifers are blue dots** and **cows are red dots**). This is the mean data for the housed period (for 2 – 5 months after calving).

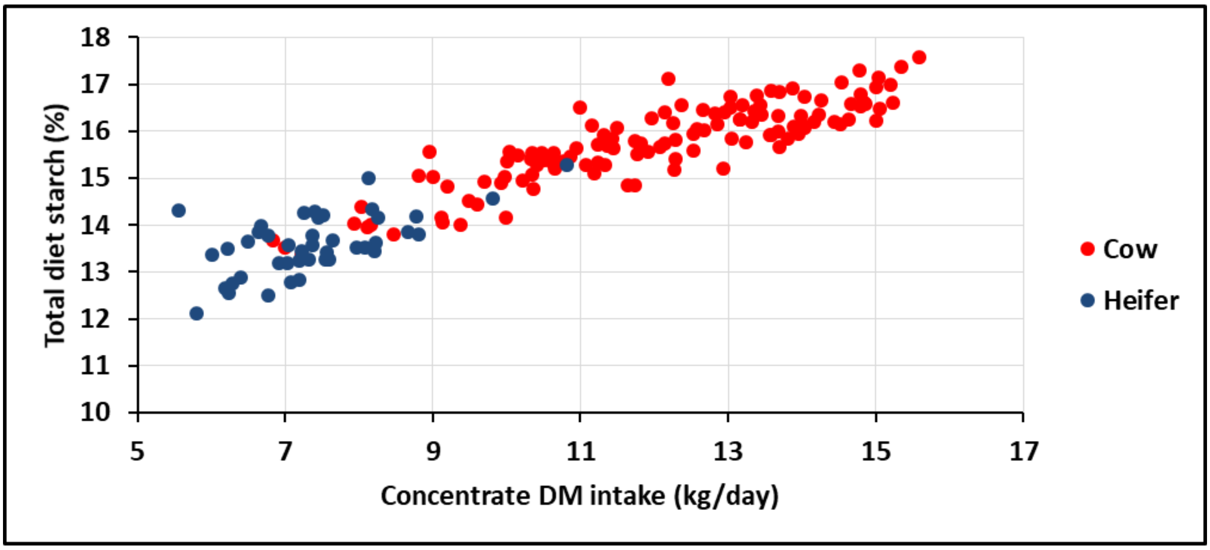
Dry matter Intakes: Figure 1 shows how forage DM intake and total DM intake changes with increasing concentrate DM intake. This figure highlights a number of trends. Firstly, as concentrate DM intake increases, total DM intake also increases. However, in general, forage DM intake remained stable across the range of concentrate levels offered, which is something we tend to find in feed-to-yield systems. This is important as it lends support to the assumption made within most feed-to-yield systems that the 'basal diet' supports a common milk yield (i.e. the maintenance plus value) for both higher and lower yielding cows.

Figure 1. Effect of concentrate DM intake on forage DM intake (●) and total DM intake (▲) of **heifers** and **cows** on your farm



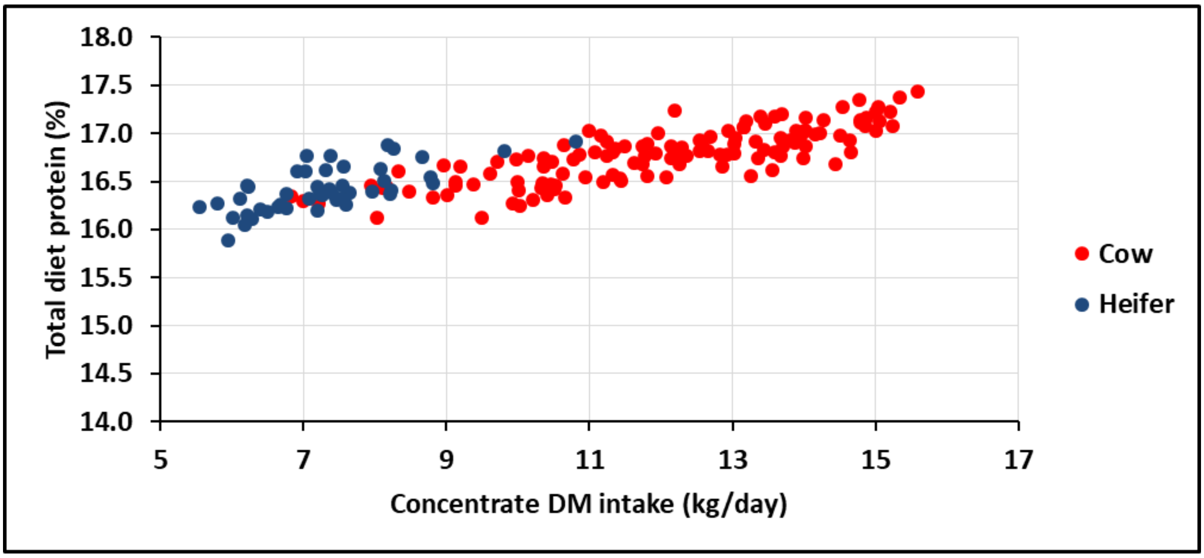
Starch content of the diets offered: Figure 3 shows the strong relationship between concentrate DM intake and the starch content of the total diet. This relationship is as expected as concentrates contain starch, so feeding more concentrates will increase starch intake, and this will drive milk production. However, at very high starch intakes there is a risk of rumen upset.

Figure 3. The effect of concentrate DM intake on the starch percentage of the total diet offered on your farm (for **heifers** and **cows**)



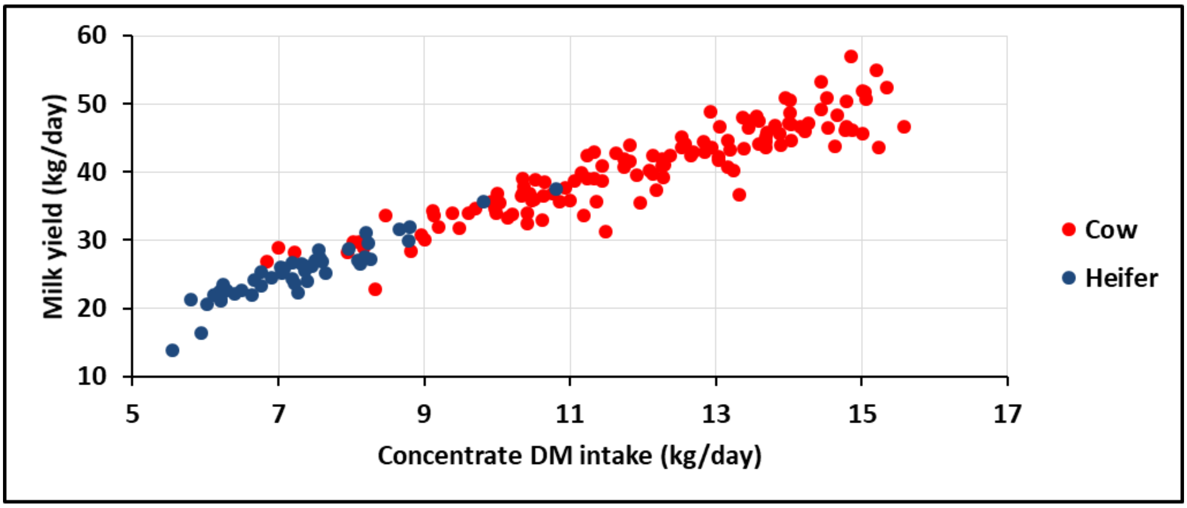
Crude protein content of the diets offered: Figure 4 shows the impact of increasing concentrate DM intakes on the crude protein content of the diet offered. It is generally accepted that diet crude protein levels in excess of 17% are more than adequate for dairy cows, although AFBI research is currently examining diets with lower protein levels. The increase in total diet crude protein with increasing concentrate level is due to intakes of the lower protein forage remaining constant, while intakes of the higher protein concentrates increased.

Figure 4. Effect of concentrate DM intake on the crude protein percentage of the total diet offered on your farm (for **heifers** and **cows**)



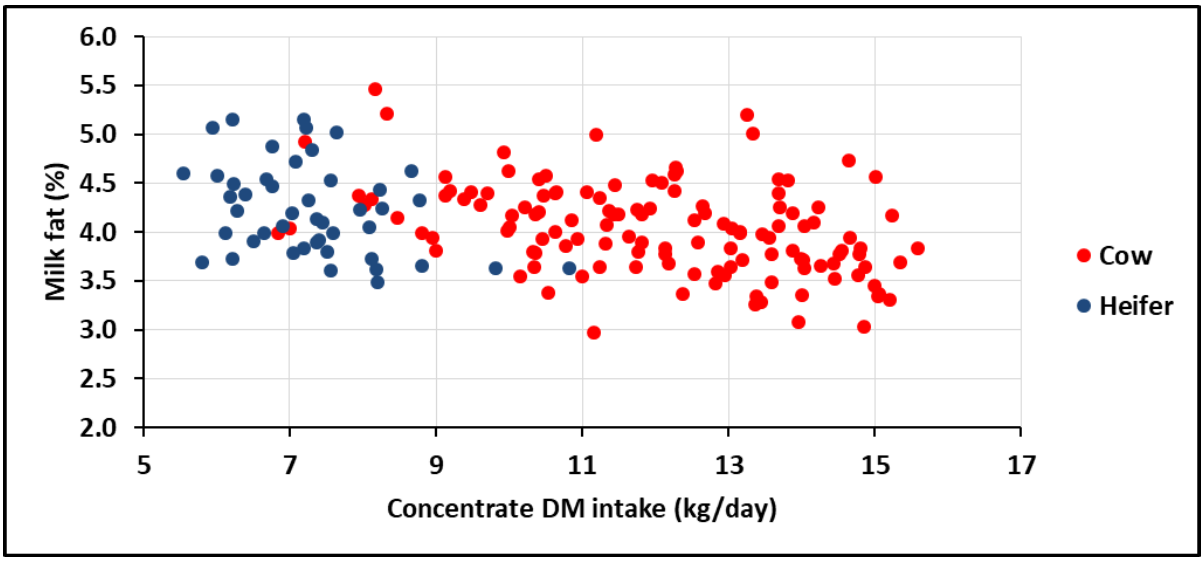
Milk production: Figure 5 shows the relationship between concentrate DM intake and milk yield. It is clear from this figure that there is a strong relationship between milk yield and concentrate DM intake. This is because in a feed-to-yield system, extra concentrates are offered according to the extra milk produced. The slope of this milk yield response line will be largely determined by the quality of the diet offered, especially silage quality.

Figure 5. Effect of concentrate DM intake on the milk yield of **heifers** and **cows** on your farm



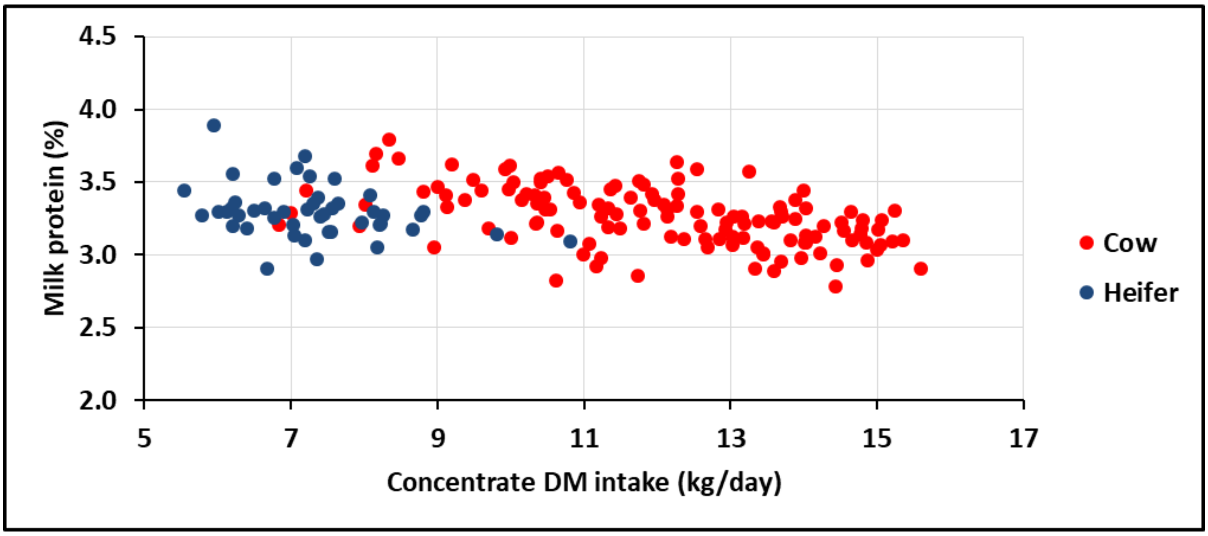
Milk fat %: Figure 6 shows the relationship between concentrate DM intake and milk fat %. At any concentrate level the dots are quite scattered, indicating that there is quite a lot of variability in milk fat content between individual cows in the herd. This variation at any given concentrate level is most likely due to genetic differences between cows. Across the range of concentrate levels there was a trend for milk fat content to decrease at higher concentrate levels. Again, this is likely to be partly due to cow genetics as within the project higher yielding cows had a lower PTA for milk fat content. However, diet will also have had an effect as at higher concentrate levels there is less fibre in the diet and more starch, and this will result in a lower milk fat content.

Figure 6. Effect of concentrate DM intake on the milk fat percentage of individual **heifers** and **cows** on your farm



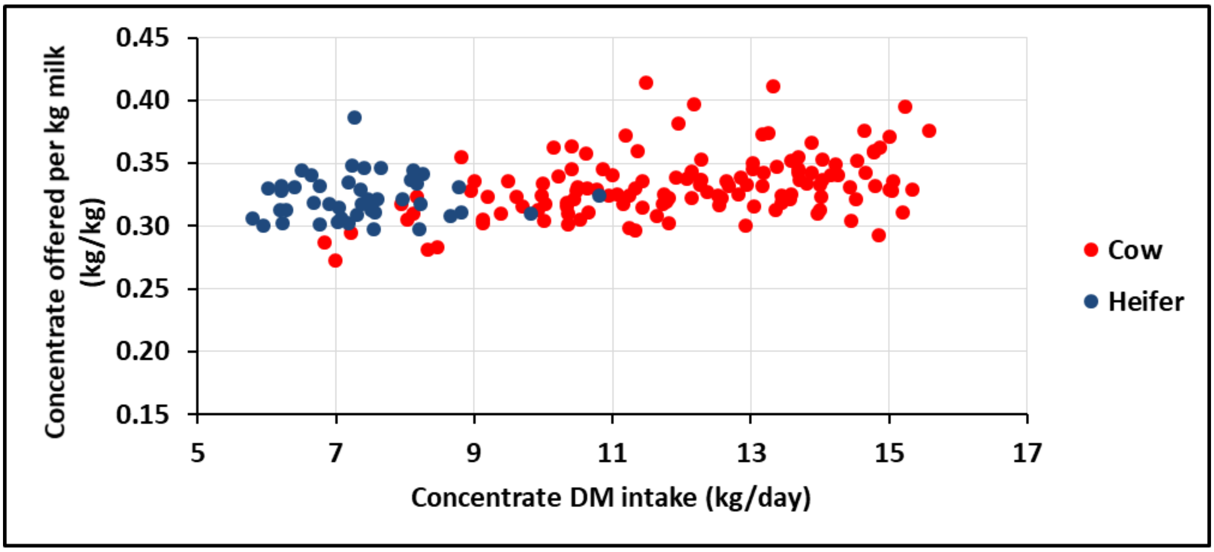
Milk protein %: Figure 7 shows the relationship between concentrate DM intake and milk protein %. At any given concentrate level, the dots are quite close together indicating that there is less variation between cows in milk protein content compared to milk fat content. Milk protein tended to be relatively unaffected by concentrate level, although there was a trend for reduced protein levels at higher concentrate levels.

Figure 7. Effect of concentrate DM intake on the milk protein percentage of individual **heifers** and **cows** on your farm



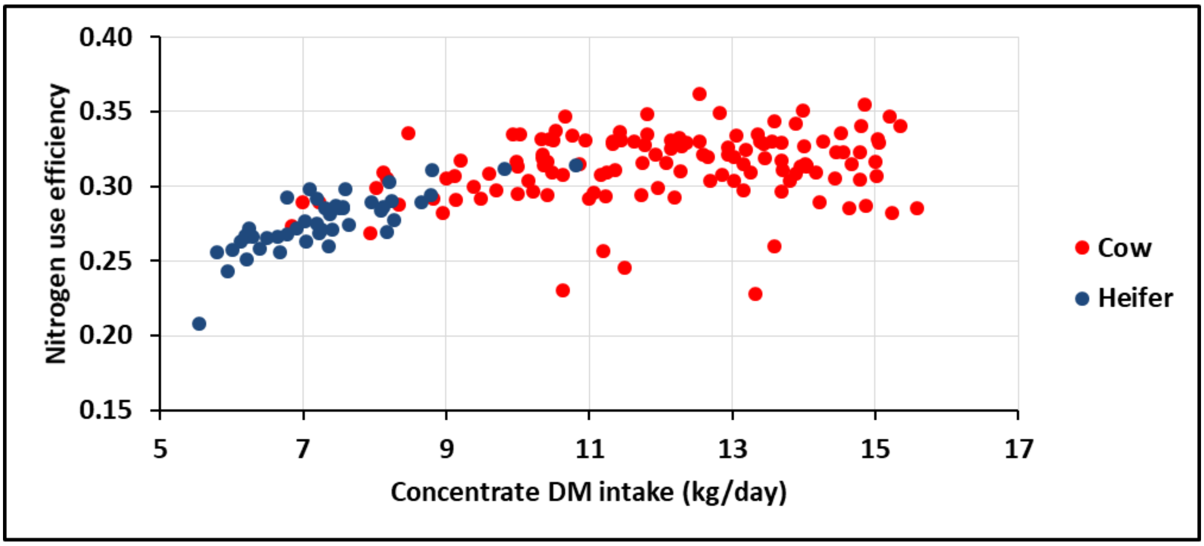
Concentrate use efficiency: Figure 8 highlights the concentrate use efficiency of each individual animal. The vertical axis indicates the amount of concentrate fed (fresh basis) per kg of milk produced. A high figure indicates a lower concentrate use efficiency. Concentrate use efficiency was relatively constant across the range of concentrate levels offered. However, it is important to recognise that this calculation is based on 'milk yield' and does not take account of the lower composition of milk produced by higher yielding cows.

Figure 8. Effect of concentrate DM intake on the 'concentrate use efficiency' of individual **heifers** and **cows** on your farm



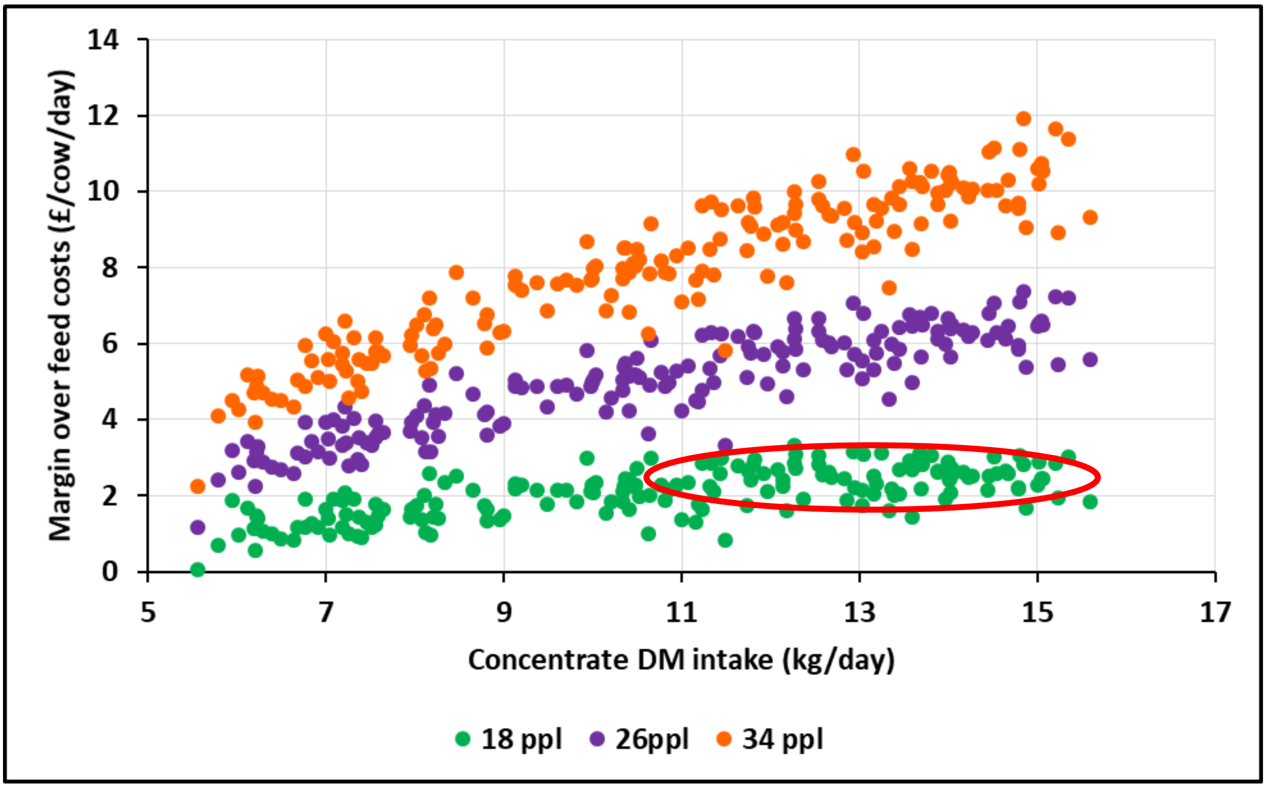
Nitrogen use efficiency: Figure 9 indicates the efficiency with which each animal converts nitrogen in the diet to nitrogen (protein) in the milk. A higher value indicates higher efficiency. Nitrogen use efficiency increased at higher concentrate levels due to the higher milk yields.

Figure 9. Effect of concentrate DM intake on the 'Nitrogen use efficiency' of individual **heifers** and **cows** on your farm



Margin-over-feed costs: Figure 10 examines the relationship between margin-over-feed cost (£ per cow/day) and concentrate intakes. These calculations take account of the calculated intakes of the forage(s) and concentrates offered (with standard costs applied), milk yield and milk composition (with bonuses/penalties applied). We examined this under three different milk prices scenarios, namely 18, 26 and 34 pence per litre (ppl). This clearly illustrates that when milk prices are very low (18 ppl), increasing concentrate level will only have a small effect on margin per cow. For example, at a milk price of 18 ppl the red 'circle' shows that the margin for many cows was similar irrespective of whether they were offered between 11 to 15 kg concentrate/day. This is because milk composition was reduced (thus reducing the value of the milk produced) at these higher concentrate levels. These effects are less dramatic at moderate and high concentrate levels, but still exist.

Figure 10. Effect of concentrate DM intake on the margin-over-feed costs (£/cow/day) of individual animals on your farm (examined at 3 different milk prices: 18 ppl, 26 ppl and 34 ppl)



Performance data during the grazing period: While the main focus of this study was on the housed period, a limited number of measurements were undertaken during the grazing period on farms where full time grazing took place (19 out of the 31 participating farms). In general the results during the grazing period aligned with those during the housing period, although concentrate levels were much lower. Full results for the grazing period will be available in the 'Final Report' on the AgriSearch website. However, Table 3 summarises the main performance values for your farm relative to the other farms where grazing took place.

Table 3. Intakes, milk production, diet composition and some efficiency values for heifers and cows on your farm while grazing (May-June), compared to the average values for the other grazing farms on the project

	Heifers		**Cows**	
	Your farm	Average of all farms	Your farm	Average of all farms
Intakes (Dry matter basis: DM)				
Concentrate DM Intake (kg/d)	1.4	2.6	4.0	3.5
Forage DM Intake (kg/d)	15.3	15.7	15.0	17.1
Total DM Intake (kg/d)	16.6	18.3	19.0	20.6
Composition of the diets offered				
Concentrate % of total diet	8.1	13.5	21.3	16.2
Starch % of total diet	1.9	3.0	5.0	3.5
Crude protein % total diet	22.0	18.4	21.0	18.4
ME content of diet (MJ/kg DM)	11.6	11.4	11.7	11.5
Milk production				
Milk yield (kg/d)	15.8	19.3	23.4	23.4
Milk fat (%)	4.33	4.42	4.07	4.29
Milk protein (%)	3.49	3.52	3.38	3.55
Efficiency values				
Nitrogen use efficiency (% of the nitrogen eaten by the cow which ends up in milk)	14	20	19	21
Concentrate use efficiency (kg of concentrate eaten per kg of milk produced)	0.07	0.11	0.14	0.12

SECTION 7

REFERENCES

Agle, M., Hristov, A.N., Zaman, S., Schneider, C., Ndegwa, P.M. and Vaddella, V.K. 2010. Effect of dietary concentrate on rumen fermentation, digestibility, and nitrogen losses in dairy cows. Journal of Dairy Science 93, 4211 - 4222.

Agnew, K. W., Mayne, C. S. and Doherty, J. G. 1996. An examination of the effects of method and level of concentrate feeding on milk production in dairy cows offered a grass silage-based diet. Animal Science 63, 21–31.

Agnew, R.E., Yan, T. and Gordon, F.J. 1998. Nutrition of the high genetic merit dairy cow - energy metabolism studies. In: Recent Advances in Animal Nutrition (Eds. P.C. Garnsworthy and J. Wiseman). Pp. 181 – 208. Nottingham University Press: Nottingham, UK.

Alatas, M. S. Citil, O. B. Kahraman, O. and Ozbilgin, A. 2015. Causes of milk fat depression in dairy cows. Scientific Papers-Series D-Animal Science 58, 80-85.

Arnott, G., Ferris, CP. And O'Connell, N.E. 2017. Review: welfare of dairy cows in continuously housed and pasture-based production systems. Animal 11, (2), 261-273.

Bargo, F., Muller, L. D., Delahoy, J. E. and Cassidy, T. W. 2002. Milk response to concentrate supplementation of high-producing dairy cows grazing at two pasture allowances. Journal of Dairy Science 85, 1777– 1792.

Bargo, F., Muller, L. D., Kolver, E. S. and Delahoy, J. E. 2003. Production and digestion of supplemented dairy cows on pasture. Journal of Dairy Science 86,1 – 42.

Baudracco, J., Lopez-Villalobos, N., Holmes, C. W. and Macdonald, K. A. 2010a. Effects of stocking rate, supplementation, genotype and their interactions on grazing dairy systems: A review. New Zealand Journal of Agricultural Research 53, 109 – 133.

Bauman D.E. and Griinari J.M. 2001. Regulation and nutritional manipulation of milk fat: low-fat milk syndrome. Livestock Production Science 70, 15-29.

Bauman D.E. and Griinari J.M. 2003. Nutritional Regulation of Milk Fat Synthesis. Annual Review of Nutrition 23, 203-227.

Beever, D. E., Sutton, J. D. and Reynolds, C. K. 2001. Increasing the protein content of cow's milk. Australian Journal of Dairy Technology 56, (2), 138-149.

Broderick, G. A. 2003. Effects of varying dietary protein and energy levels on the production of lactating dairy cows. Journal of Dairy Science 86, 1370–1381.

Calsamiglia, S., Ferret, A. Reynolds, C.K. Kristensen, N.B. and Van Vuuren, A.M. 2010. Strategies for optimizing nitrogen use by ruminants. Animal 4, 1184–1196.

Craig, A., Mullholland, M., McConnell, D. and Ferris, C. 2021. An examination of forage production costs on Northern Irish dairy farms. Proceedings of the British Society of Animal Science, Annual Conference, Online, Abs. 168.

Dale, A. J., Ferris, C. P. and Mayne, C. S. 2006. The effect of reducing fertiliser nitrogen inputs and crude protein content of grazing supplements on the performance of grazing dairy cows. Proceedings of the 8th British Grassland Society Research Meeting, Cirencester Agricultural College, pp 93–94.

Dale, A. J., Mayne, C. S., Ferris, C. P. and Laidlaw, A. S. 2005. Effect of three different early season management regimes on the performance of dairy cows under rotational grazing. Proceedings of the Agricultural Research Forum, Irish Grassland and Animal Production Association, Tullamore, Ireland, pp 38.

Dale, A. J., McGettrick, S., Gordon, A. W. and Ferris, C. P. 2016. The effect of two contrasting concentrate allocation strategies on the performance of grazing dairy cows. Grass and Forage Science 71, (3), 379-388.

Delaby l. and Peyraud J.l. 1997. Influence of concentrate supplementation strategy on grazing dairy cows performance. Proceedings of the 18th International Grassland Conference, Winnipeg, Manitoba, pp. 137–138.

Delaby, L. and Peyraud, J. L. 1998. Effet d'une réduction simultanée de la fertilisation azotée et du chargement sur les performances des vaches laitières et la valorisation du pasturage. Annales de Zootechnie 47, 17–39.

Delaby, L., Peyraud, J.L., Verite, R. and Marquis, B. 1996. Effect of protein content in the concentrate and level of nitrogen fertilisation on the performance of dairy cows in pasture. Annales de Zootechnie 45, 327–341.

Dewanckele, L., Toral, P. G., Vlaeminck, B. and Fievez, V. 2020. Invited review: Role of rumen biohydrogenation intermediates and rumen microbes in diet-induced milk fat depression: An update. Journal of Dairy Science 103, (9), 7655-7681.

Eggleston, S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K. 2006. IPCC Guidelines for National Greenhouse Gas Inventories; Institute for Global Environmental Strategies: Hayama, Japan, 2006; Volume 5.

Ferris C.P. 2007. Sustainable pasture-based dairy systems – meeting the challenges. Canadian Journal of Plant Science 87, 723–738.

Ferris, C.P., Patterson, D.C., Gordon, F.J. and Kilpatrick, D.J. 2002. Response of grazing dairy cows to level of concentrate supplementation and concentrate protein content. Proceedings of the British Society of Animal Science, Winter Meeting. Paper No. 112.

Ferris, C. P., Gordon, F. J., Patterson, D. C., Kilpatrick, D. J., Mayne, C.S. and M. A. McCoy, M. A. 2001. The response of dairy cows of high genetic merit to increasing proportion of concentrate in the diet with a high and medium feed value silage. Journal of Agricultural Science 136, 319–329.

Ferris, C. P., Gordon, F. J., Patterson, D. C., Mayne, C. S. and Kilpatrick, D. J. 1999. The influence of dairy cow genetic merit on the direct and residual response to level of concentrate supplementation. Journal of Agricultural Science 132, 467–481.

Garcia S.C., Pedernera M., Fulkerson W.J., Horadagoda A. and Nandra, K. 2007. Feeding concentrates based on individual cow requirements improves the yield of milk solids in dairy cows grazing restricted pasture. Australian Journal of Experimental Agriculture 47, 502–508.

Garcia, S. C. and Holmes, C. W. 2001. Lactation curves of autumn- and spring-calved cows in pasture-based dairy systems. Livestock Production Science 68, (2-3), 189-203.

Gordon, F. J. 1982. The effects of degree of chopping grass for silage and method of concentrate allocation on the performance of dairy cows. Grass Forage Science 37, 39–46.

Gordon, F.J., Patterson, D.C., Yan, T., Proter, M.G., Mayne, C.S., and Unsworth, E.F. 1995. The influence of genetic index for milk production on the response to complete diet feeding and the utilization of energy and protein. Animal Science 61, 199–210.

Huhtanen, P. and Rinne, M. 2007. Effects of increasing the milk yield of dairy cows on milk composition. Journal of Animal and Feed Sciences 16, 42-58.

Huhtanen, P. Rinne, M. and Nousiainen, J. 2008a. Evaluation of concentrate factors affecting silage intake of dairy cows: a development of the relative total diet intake index. Animal 2, (6), 942-953.

Huhtanen, P., Nousiainen, J. I., Rinne, M., Kytola, K., and Khalili, H. 2008b. Utilization and partition of dietary nitrogen in dairy cows fed grass silage-based diets. Journal of Dairy Science 91, (9), 3589-3599.

Ingvartsen, K. L. and Moyes, K. 2013. Nutrition, immune function and health of dairy cattle. Animal 7(Suppl. 1), 112–122.

Ingvartsen, K.L. and Andersen, J.B. 2000. Integration of metabolism and intake regulation: a review focusing on periparturient animals. Journal of Dairy Science 83, 1573–1597.

Keady, T.W.J., Mayne, C.S. and Marsden, M. 1998. The effects of concentrate energy source on silage intake and animal performance with lactating dairy cows offered a range of grass silages. Animal Science 66, 21-33.

Keady, T.W.J., Mayne, C.S., Fitzpatrick, D.A. and Marsden, M. 1999. The effects of energy source and level of digestible undegradable protein in concentrates on silage intake and performance of lactating dairy cows offered a range of grass silages. Animal Science 68, 763-777.

Kellaway, R. and Harrington, T. 2004. Feeding concentrates: supplements for dairy
Kolver, E. S. and Muller, L. D. 1998. Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. Journal of Dairy Science 81, 1403–1411.

Kolver, E.S. and Muller, L.D. 1998. Perfomance and Nutrient Intake of High Producing Holstein Cows Consuming Pasture or a Total Mixed Ration. Journal of Dairy Science 81 (5), 1403-1411.

Lawrence, D. C., M. O'Donovan, T. M. Boland, E. Lewis, and E. Kennedy. 2016. An examination of two concentrate allocation strategies which are based on the early lactation milk yield of autumn calving Holstein Friesian cows. Animal 10, (5), 796-804.

Lawrence, D.C., O'Donovan, M., Boland, T. M., Lewis, E. and Kennedy, E. 2015. The effect of concentrate feeding amount and feeding strategy on milk production, dry matter intake, and energy partitioning of autumn-calving Holstein-Friesian cows. Journal Dairy Science 98, 388–348.

Little, M.W., O'Connell, N.E. and Ferris, C.P. 2016. A comparison of individual cow versus group concentrate allocation strategies on dry matter intake, milk production, tissue changes, and fertility of Holstein-Friesian cows offered a grass silage diet. Journal of Dairy Science 99, (6), 4360-4373.

Oltenacu, P.A., and Broom, D.M. 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Animal Welfare 19(Suppl.), 39–49.

Osorio, J.S., Lohakare, J. and Bionaz, M. 2016. Biosynthesis of milk fat, protein, and lactose: roles of transcriptional and posttranscriptional regulation. Physiological Genomics 48, 4:231-256.

Park, R.S., Agnew, R.E., Gordon, F.J. and Steen R.W.J. 1998. The use of near infrared reflectance spectroscopy (NIRS) on undried samples of grass silage to predict chemical composition and digestibility parameters. Animal Feed Science Technology 72, 155–167.

Patton, J. and Lawless, A. 2013. Milk production and performance of autumn-calving Holstein-Friesian cows managed under flat-rate or feed-to-yield concentrate feeding systems. Proceedings of Agricultural Research Forum 2013, Tullamore, Carlow, Ireland, pp. 33.

Pryce, J.E. and Veerkamp, R.F. 2001. The incorporation of fertility indices in genetic improvement programmes. BSAS Occasional Publication Vol. 26, 237–250.

Purcell, P.J., Law, R.A. and Ferris, C.P. 2015. Effect of concentrate feed rate within a feed-to-yield system on the performance of dairy cows in early to mid-lactation. In: Advances in Animal Science – Science with Impact. Proceedings of the British Society of Animal Science, in association with AVTRW, CFER and EBLEX. April 2015, Vol 6 Part 2. Cambridge University Press. Pp 192.

Purcell, P.J., Law, R.A., Gordon, A.W., McGettrick, S.A. and. Ferris C.P. 2016. Effect of concentrate feeding method on the performance of dairy cows in early-to-mid lactation. Journal of Dairy Science 99, (4), 2811-2824.

Sajeev, E.P.M., Amon, B., Ammon, C., Zollitsch,W. and Winiwarter,W. 2018. Evaluating the potential of dietary crude protein manipulation in reducing ammonia emissions from cattle and pig manure: A meta-analysis. Nutrient Cycling in Agroecosystems 110, 161–175.

Shirali, M., Hynes, D. and Ferris, C. 2020. Using herd information and milk production data to predict dry matter intake within feed-to-yield concentrate allocation strategies. In Proceedings of the British Society of Animal Science annual conference, Nottingham, UK. Abs. 72.

Stampa, E, Shipmann-Schwarze, C. and Hamm, U. 2020. Consumer perceptions, preferences, and behavior regarding pasture-raised livestock products: A review. Food Quality and Preference 82.

Stark, C.H. and Richards, K.G. 2008. The continuing challenge of nitrogen loss to the environment: Environmental consequences and mitigation strategies. Dynamic Soil Dynamic Plant 2, 41–55.

Stockdale C.R. 2000. Levels of pasture substitution when concentrates are fed to grazing dairy cows in northern Victoria. Australian Journal of Experimental Agriculture 40, 913-921.

Taylor, W., and J.D. Leaver. 1984a. Systems of concentrate allocation for dairy cattle 1. A comparison of three patterns of allocation for autumn-calving cows and heifers offered grass silage ad libitum. Animal Science 39, 315–324.

Taylor, W., and J.D. Leaver. 1984b. Systems of concentrate allocation for dairy cattle 2. A comparison of two patterns of allocation for autumn-calving cows offered two qualities of grass silage ad libitum. Animal Science 39, 325–333.

Vance, E.R., Ferris, C.P., Elliott, C.T., McGettrick, S.A. and Kilpatrick, D.J. 2012. Food intake, milk production, and tissue changes of Holstein-Friesian and Jersey x Holstein-Friesian dairy cows within a medium-input grazing system and a high-input total confinement system. Journal of Dairy Science 95, 1527–1544.

Veerkamp, R.F. and Emmans, G.C. 1995. Sources of genetic variation in energetic efficiency of dairy cows. Livestock Production Science 44, 87-97.

Watson, C. J., Jordan, C., Lennox, S. D., Smith, R. V. and Steen, R. W. J. 2000. Inorganic nitrogen in drainage water from grazed grassland in Northern Ireland. Journal of Environmental Quality 29, 225–232.

Wilkinson, J.M. 2011. Re-defining efficiency of feed use by livestock. Animal 5, (&), 1014-1022.

Yan, T., Mayne, C.S., Keady, T.W.J., Agnew, R.E. 2006. Effects of dairy cow genotype with two planes of nutrition on energy partitioning between milk and body tissue. Journal of Dairy Science 89, (3), 1031-1042.

Yan, T., Patterson, D.C. and Gordon, F.J. 1998. The effect of two methods of feeding the concentrate supplement to dairy cows of high genetic merit. Animal Science 67, 395–403.