A comparison of three contrasting systems of milk production for spring calving dairy cows

Final Report for AgriSearch in respect of the systems comparison component of Project D-29-06

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STRUCTURE OF REPORT

AgriSearch project D-29-06, ‘A comparison of three contrasting systems of milk production for spring calving dairy cows’ comprised two separate components: 1) a comparison of cow performance associated with three contrasting milk production systems, and 2) an evaluation of the performance of Holstein-Friesian and Jersey x Holstein-Friesian cows when managed on these three milk production systems. A report on the comparison of the two cow genotypes within this project has already been presented to AgriSearch. The current report presents the final outcomes of the systems comparison component of the study (Experiment 1), together with the outcomes of a small scale subsidiary study that was undertaken as part of this project (Experiment 2).

This report begins with an ‘Executive summary’ which highlights key findings of the research, and this is followed by a full description of the work undertaken and full details of the results.

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Executive summary

Reducing the costs of milk production is essential to ensure the long term survival of our dairy industry. While grazed grass represents the cheapest feedstuff available on most farms, on many farms the reliance on grazed grass is decreasing. The reasons for this are several, and include increasing herd sizes making the accessibility of an adequate grazing platform impossible, lack of confidence in the potential of grazed grass to make a substantial contribution to the diet of higher yielding cows, and the vagaries of our weather.

Spring calving systems that ‘maximise’ the use of grazed grass are widely adopted throughout the Republic of Ireland, and to a more limited extent in Northern Ireland (NI). While these ‘spring calving’ milk production systems are normally regarded as being ‘low cost’, on some farms even these spring calving systems increasingly rely on purchased concentrates, with this introducing additional costs into these systems. However, the use of additional concentrates may actually be justified provided an economic response to concentrate feeding can be obtained.

Experiment 1

The primary objective of Experiment 1 was to examine the milk production performance of dairy cows when managed on three grassland-based milk production systems differing in concentrate inputs. In addition, this project also provided an opportunity to examine the carbon footprint of these systems.

A study was established to compare the performance of dairy cows when managed on three contrasting grassland-based systems of milk production. In view of year to year variations which exist in climatic conditions, and the significant impact that this can have on cow performance within spring milk production systems with a high reliance on grazed grass, this study was conducted during three successive years. The experiment involved 78 cows each year.

The three grassland-based systems were defined as low concentrate (LC), medium concentrate (MC) or high concentrate (HC). Post calving, cows were housed and offered grass silage, supplemented with 6.0, 8.0 and 10.0 kg concentrate/cow/day (until turnout) in systems LC, MC and HC, respectively. Across the three years of the study cows on LC had a mean turnout date of 14 February, while cows on systems MC and HC had a mean turnout date of 30 March. Throughout the summer grazing period concentrate feed levels were 0, 2.5 and 5.0 kg/cow/day. Full time re-housing occurred on 12, 6 and 6 November across three years in each of systems LC, MC and HC, respectively. From re-housing until drying off, cows on systems LC, MC and HC were offered 1.0, 2.0 and 3.0 kg concentrate/cow/day, respectively.

While the systems examined differed in a number of ways (forage quality, grazing management, concentrate feeding system and turnout dates), the predominant difference between systems was in concentrate level. Consequently, this is likely to be the overriding driver of performance differences observed. Total concentrate intakes with LC, MC and HC were 560, 1138 and 1858 kg/cow/lactation, respectively, with concentrates comprised proportionally 0.11, 0.21 and 0.33 of total DM consumed, respectively.

Total silage intakes were unaffected by system (946, 1061 and 1035 kg DM with LC, MC and HC, respectively). The lower intake with LC reflected the shorter confinement period with this treatment. Similarly, the decrease in herbage intake from LC to HC (3128, 2752 and 2326 kg DM, respectively) reflects both the longer grazing period with the former treatment and the substitution of forage by concentrate during the grazing period.

Across the three years of the experiment, mean grazing stocking rates were 3.56, 4.34 and 5.39 cows/ha for LC, MC and HC, respectively. Mean annual stocking rates (taking account of grazing and silage) were 2.3, 2.6 and 2.9 cows/ha with LC, MC and HC, respectively.

Milk quality was excellent, a reflection in part of the presence of the Jersey crossbred cows within all systems. However, milk composition was unaffected by system.

Solids corrected milk yields were 5890, 6653 and 6875 kg with LC, MC and HC, respectively. The response to each kg of additional concentrate offered between system LC and MC was 1.52 kg milk/kg concentrate DM, compared to 0.35 kg milk/kg concentrate DM between systems MC and HC.

Blood non-esterified fatty acid concentrations in early lactation suggest that cows on LC experienced an increased level of body tissue mobilisation compared to cows on LC. However, this was not apparent from either the live weight or condition score curves. Thus the higher milk yields associated with systems MC and HC appear to be a direct consequence of higher total intakes and the increased energy density of the diet, rather than differences in body tissue mobilisation.

From approximately week-24 of lactation onwards, cows on HC experienced increased levels of liveweight gain compared to those on LC or MC. This increased partitioning of energy towards body tissue in late lactation will have contributed to the smaller marginal milk yield response observed between MC and HC, than between LC and MC.

Although concentrate inputs increased from 488 kg DM/cow with LC to 1616 kg DM/cow with HC, there was no evidence that fertility performance was influenced by level of concentrate input. In the absence of a system effect on BCS change in early lactation it is perhaps unsurprising that fertility performance was unaffected by concentrate supplementation.

There was no evidence that incidence of mastitis was affected by system. However, the proportion of cows with at least one case of lameness increased with increasing concentrate levels.

The carbon footprint of each of the systems was determined using the GHG calculator developed by the Agri-Food and Biosciences Institute. This calculator determines total GHG emissions in CO_2 equivalent (CO_2e) units using global warming potential conversions of 25 kg of CO_2e/kg of CH_4 and 298 kg of CO_2e/kg of N_2O.

When calculating the carbon footprint of the three dairy systems examined within the present study, all information was 'scaled up' to simulate a farming system comprising a herd of 100 dairy cows. Actual performance data from the study were adopted as the primary source of information, while assumed information on heifer management was used in order to simulate a whole farm system.

Total emissions from the whole farm systems derived from LC, MC and HC were 669, 724 and 760 t CO_2e, respectively, with the increase in emissions reflecting the increase in total DM intake and total milk output observed. 'On-farm' emissions accounted for 81%, 78% and 75% of total emissions for LC, MC and HC, respectively.

Total emissions per litre of milk were 1.09, 1.03 and 1.05 kg CO_2e with systems LC, MC and HC, respectively. While these differences cannot be compared statistically, emissions were 5.5% and 3.7% lower with MC and HC than with LC. Emissions from fertiliser application decreased with increasing concentrate use while emissions associated with concentrate production and transport increased with increasing concentrate inputs. The higher emissions with HC compared to MC is likely due to increased partitioning of food nutrients to body tissue with the former.

When carbon sequestration was taken into account, total GHG emissions were reduced by 15% on average (17%, 14% and 13% for the LC, MC and HC respectively). The difference in magnitude of these reductions reflect the different land areas associated with each system, systems involving more land providing increased potential for sequestration to take place.

Gross margins were examined for a number of milk price (16 - 32 pence per litre) concentrate cost (£200 - £300/t) scenarios. As expected, across all systems gross margins increased with increasing milk prices and decreased with increasing concentrate costs. In general, gross margin (per litre and per cow) was highest with MC across the range of milk price and concentrate cost scenarios examined. The exception to this was when margin per litre was examined at a concentrate cost of £300/t, in which case margins were higher with LC than with MC.

Within a low milk price scenario gross margin per cow tended to be higher with LC than with HC, while this trend was reversed within a high milk price scenario, especially at low concentrate costs. When examined on a gross margin per litre basis, margins with system LC were higher than those with system HC across all milk price-concentrate cost scenarios.

Within spring calving milk production systems, moving from a low to a medium concentrate input system is likely to improve profitability (per cow basis) within the range of milk price concentrate input scenarios examined. Provided cows have reasonable genetic potential, they will be able to produce an economic response to the inclusion of a small amount of additional concentrates in the diet. Moving from a medium to a higher concentrate input system is unlikely to result in any additional improvement in margin unless the cows have a high genetic potential for milk production.

Experiment 2

The concept of 'golf ball' grazing was introduced to Ireland from New Zealand approximately six years ago. This small scale study was conducted to examine the impact of a 'tighter' grazing regime on the performance of spring calving dairy cows.

Forty-six spring calving dairy cows were managed on either a 'Tight' or 'Normal' grazing system for a single season. This was achieved by managing cows on the Tight grazing system on paddocks that were 10% smaller than those used by cows in the Normal grazing system.

Stocking rates within the Normal and Tight grazing systems were 5.4 and 6.1 cows/ha, respectively. Pre and post grazing sward heights were 10.1 and 5.7 cm with the Normal treatment, and 9.4 and 5.0 cm with the Tight treatment.

Neither total milk yield nor total fat + protein yield over the course of the grazing season was affected by treatment. However, when expressed on an output per ha basis, the Tight and Normal grazing treatments had milk solids outputs of 1513 and 1405 kg/ha, respectively.

This study suggests that there is scope to improve grassland utilisation with lower yielding cows through the adoption of tighter grazing strategies. However, the real benefits of ‘golf ball grazing are claimed to arise during subsequent years due to overall improvement in sward quality associated with tighter grazing regimes.

EXPERIMENT 1

Cow performance, greenhouse gas emissions and economic performance of three contrasting grassland-based systems of milk production involving spring calving dairy cows

INTRODUCTION

The Northern Ireland (NI) dairy industry continues to face increasing pressures and challenges. These include volatile milk prices, increasing costs of inputs, ever increasing environmental pressures, labour shortages and increasing lifestyle expectations. However, within this scenario milk production systems on many farms have continued to become increasingly complex and both capital and labour intensive. Reducing the costs of milk production is essential to ensure the long term survival of our industry.

While most farmers realise that grazed grass usually represents the cheapest feedstuff available, the reliance on grazed grass is decreasing on many farms. The reasons for this are several, and include increasing herd sizes making the accessibility of an adequate grazing platform impossible, lack of confidence in the potential of grazed grass to make a substantial contribution to the diet of higher yielding cows, and the vagaries of our weather. However, systems that maximise the use of grazed grass are widely adopted throughout the Republic of Ireland, and in both favourable and non-favourable parts of NI. The ‘extreme’ example of these grass-based systems are traditional ‘spring calving’ milk production systems, with these normally regarded as being ‘low cost’, having lower labour inputs, reduced capital investment and fewer animal health challenges. Indeed it may be argued that producing each litre of milk at lowest cost may make real sense within the restrictions of a ‘milk quota’ situation. However, the United Kingdom (UK) has largely operated without the constraints of milk quotas for a number of years, while the European milk quota system will disappear completely within the next few years.

Nevertheless, on some farms even these spring calving systems increasingly rely on purchased concentrates, with this introducing higher costs into these systems. However, the use of additional concentrates may be justified provided an economic response to concentrate feeding can be obtained. While the response of ‘winter calving’ cows to concentrate supplementation has been examined within a previous AgriSearch co-funded project, no similar evaluation of contrasting ‘Spring calving’ systems has been made.

Thus the primary objective of the current experiment was to examine the milk production performance of dairy cows when managed on three contrasting grassland-based milk production systems, with the primary difference between these systems being in concentrate feed level. In addition, this project also provides the opportunity to examine the effect of ‘intensification’ within spring calving milk production systems, on the carbon footprint of these systems. In view of year to year variations which exists in climatic conditions, and the significant impact that this can have on cow performance within spring milk production systems which have a high reliance on grazed grass, this study was conducted during three successive years.

METHODOLOGY

This three-year experiment was conducted at the Agri-Food and Biosciences Institute, Hillsborough (latitude 54˚27'N; longitude 06˚04'W) between January 2006 and December 2008. Cows were managed on one of three grassland-based milk production systems over three successive years.

Animals

The experiment involved a total of 78 dairy cattle each year, 26 animals on each of the three systems. Cows involved in the experiment were a mixture of Holstein-Friesian and Jersey crossbreds, with cows of both genotypes allocated to both systems. The J x HF cows were the offspring of a breeding programme involving randomly selected Holstein-Friesian cows from the AFBI Hillsborough herd and Jersey sires of both Danish (n = 5) and New Zealand (n = 4) origin. The breed comparison component of this experiment has already been described in full in a report prepared for AgriSearch. As the effect of genotype has been removed within the REML analysis of the data within this study, this report will make no further mention of breed comparisons. During each of Years 1, 2 and 3, cows on the study had mean lactation numbers of 2.1, 2.2 and 2.5, respectively. Cows had a mean calving date of 5 February (s.d. 23.6 days), 12 February (s.d. 25.0 days) and 3 February (s.d. 24.4 days) in each of Years 1 – 3, respectively.

Overview of feed systems

Throughout the experiment cows were managed on one of three grassland-based systems of milk production, namely 'low concentrate' (LC), 'medium concentrate' (MC) and 'high concentrate' (HC). The guiding principles behind these systems were as follows: LC, to maximise milk production from grazed grass: MC, to maximise milk production from forage (grazed grass and conserved forage) and; HC, high reliance on concentrates. Key aspects of each of these systems are summarised in Table 1, with full details presented later.

Table 1 Overview of the three experimental systems examined

	Low Concentrate (LC)	Medium Concentrate (MC)	High Concentrate (HC)
Winter feeding period	Grass silage supplemented with 6.0 kg concentrate/cow/day (via in-parlour feeders)	Grass silage supplemented with 8.0 kg concentrate/cow/day (via out-of-parlour feeders)	Grass silage supplemented with 10.0 kg concentrate/cow/day (mixed with silage in a complete diet)
Grazing period	Early turnout in spring. Flexible grazing system (daily herbage allocation of 16-18 kg dry matter/cow/day). Minimum concentrate supplementation	Later turnout in spring. Rotational paddock grazing system. Concentrate feed level approximately 2.5 kg/cow/day	Later turnout in spring. Rotational paddock grazing system. Concentrate feed level approximately 5.0 kg/cow/day
Late lactation period	Grass silage and 1.0 kg concentrate/cow/day	Grass silage and 2.0 kg concentrate/cow/day	Grass silage and 3.0 kg concentrate/cow/day

Cows were allocated to one of the three management systems within 36 hours of calving in Year 1, with cows on each system within any one year balanced according to calving date, genotype, parity, pre-calving live weight and body condition score, sire, and in the case of the HF cows, PTA_{2005} for fat plus protein yield. Cows remained on the same management system for the duration of the experiment, or until removed from the experiment. Cows that were removed during or at the end of Years 1 and 2 were replaced at the start of Years 2 and 3, respectively. Replacement animals were largely primiparous (with these also balanced across systems according to the traits described above), although on occasions multiparous cows were used as replacements.

Winter periods

Cows were transferred to cubicle accommodation within 36 hours of calving, and housed as a single group until the start of turnout. During the 'winter period', from calving until the start of turnout, all cows were offered diets comprising grass silage and concentrates. Throughout the experiment a common concentrate was offered to cows on all three systems, with the ingredient composition of this concentrate presented in Table 2. Changes in the availability and cost of some ingredients meant that the ingredient composition of the winter concentrate varied from year to year. Target concentrate intakes during the winter periods were 6.0, 8.0 and 10.0 kg/cow/day with systems LC, MC and HC, respectively. With system LC, the daily concentrate allowance was divided into two equal feeds each day, and offered via in-parlour feeders at each milking. Multiparous cows were offered their 6.0 kg daily concentrate allowance from calving onwards, while primiparous cows were offered 4.0 kg/cow/day during the first 10 days post calving, with this increasing to 6.0 kg/cow/day thereafter. With system MC, 1.0 kg of the daily concentrate allowance was offered during milking (0.5 kg at each milking), with the remaining 7.0 kg being offered through two out-of-parlour feed stations located within the cubicle house. The out-of-parlour component of the diet was 5.0 kg/cow/day for the first 10 days post calving, increasing to the full allowance of 7.0 kg/cow/day thereafter for both primiparous and multiparous cows. With system HC, 1.0 kg of the daily concentrate allowance was offered during milking (0.5 kg at each milking), while the remaining concentrate allocation was mixed with the silage part of the diet and offered in the form of a complete diet. Concentrates were incorporated into the mix at 9.5

kg/cow/day for each cow on this treatment, with the aim of achieving a total concentrate intake of approximately 10.0 kg/cow/day (including the in-parlour component).

Table 2 Ingredient composition of concentrate feedstuffs offered during the indoor winter period and summer grazing periods

	Winter period concentrate		Summer period concentrates	
	Years 1 and 2	Year 3	Year 1	Years 2 and 3
Barley	140	140	100	190
Wheat	140	140	0	0
Maize meal	0	0	280	190
Unmolassed sugar beet pulp	100	100	310	310
Citrus pulp	100	100	0	0
Maize gluten feed	120	190	0	0
Distillers grain (maize)	120	0	0	0
Soya bean (Hi protein)	100	110	200	200
Rape meal	120	160	40	40
Megalac	14	14	0	0
Low phosphorus mineral/vitamin mix	22	22	30	30
Calcined Magnesite	4	4	10	10
Molaferm	20	20	30	30

A common silage was offered to cows on all systems during the first winter period of the study. However, during the second and third winter periods silage offered to cows on system LC differed from that offered to cows on systems MC and HC, with cows on the latter two systems being offered a common silage. These differences arose as part of the systems comparison component of the experiment, whereby grazing and silage areas were integrated with system LC, but not with systems MC and HC, as described later.

Cows accessed the forage component of their diets (complete diet in the case of HC) via a Calan gate feeding system (American Calan, Northwood, NH, USA). Each Calan gate was linked to an automatic cow identification system, which allowed cows to gain access to a feed box mounted on a weigh scale (Griffith Elder, Bury St Edmunds, UK), thus allowing individual food intakes to be measured. Cows on each of systems LC, MC and HC accessed their food via separate boxes, with an average of three cows sharing each box. With all systems, the forage component of the diet (complete diet in the case of HC) was offered at proportionately 1.05 of the previous day's intake. Uneaten food was removed from the feed boxes daily at approximately 08:30 hours and fresh food offered between 09:00 and 10:30 hours.

Transitional grazing period

Across the three years of the experiment an early spring turnout date was adopted with system LC to maximise the length of the grazing season (Table 3). The duration of the daily grazing period increased from approximately two hours/day at the time of turnout, to approximately 12 hours/day by 30 March. During this period cows were allocated sufficient herbage to allow them to graze to a residual sward height of approximately 40 mm. In addition, during the non-grazing part of the day cows continued to be offered grass silage *ad libitum*, together with their full daily winter concentrate allocation (6.0 kg/cow/day).

With systems MC and HC the mean turnout date across the three years of the experiment was 7 April. Cows on these systems initially grazed for approximately eight hours/day (milking to milking) with this increasing to 12 hours/day by 14 April (mean date). When grazing commenced approximately half of the daily concentrate allocation was transferred from the out-of-parlour feeders (MC) and the complete diet mix (HC) to in-parlour feeders, and the overall daily concentrate feed levels reduced to 6.0 and 8.0 kg/cow/day (systems MC and HC, respectively). Concentrates remained at these levels until full turnout was achieved.

Table 3 Summary of key dates within the study

	System		
	LC	MC	HC
Year 1			
Part turnout	01-Feb-06	07-Apr-06	07-Apr-06
Full turnout	14-Apr-06	25-Apr-06	25-Apr-06
Housed at night	11-Oct-06	28-Sep-06	28-Sep-06
Full time housing	05-Nov-06	05-Nov-06	05-Nov-06
Dry cows housed	10-Nov-06	05-Nov-06	05-Nov-06
Year 2			
Part turnout	05-Feb-07	22-Mar-07	22-Mar-07
Full turnout	05-Apr-07	13-Apr-07	13-Apr-07
Housed at night	01-Nov-07	06-Oct-07	08-Oct-07
Full time housing	13-Nov-07	08-Nov-07	08-Nov-07
Dry cows housed	08-Nov-07	08-Nov-07	08-Nov-07
Year 3			
Part turnout	25-Feb-08	02-Apr-08	02-Apr-08
Full turnout	10-Apr-08	15-Apr-08	15-Apr-08
Housed at night	30-Sep-08	30-Sep-08	30-Sep-08
Full time housing	19-Nov-08	06-Nov-08	03-Nov-08
Dry cows housed	17-Oct-08	17-Oct-08	17-Oct-08

Approximately one week before full-time grazing commenced with all three systems, the ingredient composition of the concentrate offered was changed to a summer grazing concentrate (Table 2) which was offered throughout the entire grazing season in each of the three years of the experiment.

Main grazing season

Full-time turnout occurred on 10, 18 and 18 April (mean of the three years of the experiment) within systems LC, MC and HC, respectively. Once full-time turnout occurred, concentrate feed levels were reduced over a 10-15 day period to the target levels of 0.0, 2.5 and 5.0 kg/cow/day with systems LC, MC and HC, respectively. These concentrate feed levels were maintained throughout the main grazing periods, with the exception of system LC, where 1.0-2.0 kg/cow/day of the grazing concentrate was introduced into the diet during occasional periods of unfavourable weather conditions and grass shortages, and during the autumn grazing periods (from 26 September, 11 October, 4 September in years 1, 2 and 3, respectively). With systems LC, MC and HC, full-time grazing continued until 23, 19 and 19 October, respectively (mean across the three years of the experiment). Thereafter, cows grazed during the day, and were housed at night and offered grass silage as previously discussed.

Target pre-grazing herbage mass within each system was 3200–3400 kg DM/ha (above ground level), while the target post grazing herbage mass was 1800–2000 kg DM/ha (above ground level). Additional grazing areas (LC) or paddocks (MC and HC) were included or removed from grazing cycles to prevent excess herbage being available, or grass shortages occurring, according to a ‘grass wedge’ grassland management tool.

Cows on system LC were managed within a flexible grazing system with fresh herbage (approximately 16-18 kg herbage DM/cow/day) being allocated to cows each day after evening milking. These cows grazed a series of core grazing blocks, each measuring approximately 1.1 ha, with fence lines moved daily within these blocks to achieve the required daily herbage allowance. The actual length of the first eight grazing cycles (mean across the three years of the study) were 59, 29, 20, 21, 28, 24, 34 and 44 days, respectively. Cows on systems MC and HC were managed on a rotational paddock grazing system involving one-day paddocks (0.23 ha and 0.184 ha, respectively), with cows getting access to a new paddock after evening milking. The ‘target’ rotation lengths during grazing cycles 1–8 were 21 days (cycles 1–3), 24 days (cycles 4–6) and 27 days (cycles 7 and 8), while the actual number of paddocks grazed (mean across the three years of the study) were 24, 22, 21, 25, 24, 22, 26 and 31, respectively.

Late lactation period

Full-time housing commenced on 12, 6 and 6 November (average across the three years) in each of systems LC, MC and HC, respectively. Post re-housing cows were again managed within a single group in cubicle accommodation. Grass silage (as described earlier) was offered to all cows, with cows on systems LC, MC and HC being offered 1.0, 2.0 and 3.0 kg concentrate/cow/day (winter period concentrates: Table 2) until drying-off.

Dry period

Cows with a body condition score of ≥2.50 were dried off either eight weeks pre-calving, or if average weekly milk yield fell below 5.0 kg/day. Cows with a body condition score of 2.25 or ≤2.00 were dried-off either 10 or 12 weeks pre-calving, respectively. During the dry period cows on all three systems were offered grass silage, with cows on systems MC and HC not receiving any concentrate supplementation. During Years 2 and 3 of the experiment, dry cows on system LC were offered 2.0 kg/cow/day of dry cow concentrate due to their low condition score. Throughout the dry period cows were supplemented with 100 g/cow/day of a dry cow mineral and vitamin mix. Cows that were non-pregnant remained on their experimental treatment for the same mean number of days as the pregnant cows within their experimental groups, after which they were removed from the experiment.

Culling

Cows that were removed from the experiment during the grazing season (as a result of health issues) were replaced with 'spare cows' until the end of that grazing season, in order to maintain a constant grazing group size (26 cows/group). Cows removed either during or at the end of Years 1 and 2 were replaced by new experimental cows at the start of the subsequent lactation.

Breeding programme

A 12-week breeding season was adopted within all three systems, commencing on 29 March (mean across three years) within systems MC and HC and approximately three weeks later with LC. The latter was adopted so that cows within system LC would begin to calve at the start of the grass growing season, thus allowing milk output from grazed grass to be maximised. A voluntary waiting period of a minimum of 42 days prior to the start of breeding was adopted with all cows. Throughout the experiment cows were bred via artificial insemination approximately 12 hours after visual observation of oestrus. Holstein-Friesian cows were bred to Holstein sires while J x HF cows were bred to Swedish-Red and White sires. Pregnancy was confirmed via rectal scanning at day 60 post insemination. Cows were not treated with any fertility drugs until they were a minimum of 52 days post calving. The exceptions to this were cows that displayed symptoms of uterine infections, in which case treatment was given as soon as the problem was identified. Cows which had not been observed on heat prior to day-52 post calving were inspected by a veterinary surgeon, and treated as appropriate.

Pasture Management

Cows on system LC were managed on a flexible grazing system with fresh herbage (approximately 16-18 kg herbage DM/cow/day) being allocated to cows each day after evening milking, while cows on systems MC and HC were managed on a rotational paddock grazing system. With systems MC and HC, 21 x 0.23 ha and 21 x 0.184 ha paddocks, respectively, were initially established in a set paddock grazing system. For these systems the grazing season commenced with a 21-day grazing rotation, with additional paddocks being incorporated into the cycle as the season progressed.

Total N fertiliser application rates within the core grazing areas (across all systems) were 292 kg N/ha in Years 1 and 2, and 264 kg N/ha in Year 3. In order to maintain pasture quality, grass trimming (topping) was undertaken to a height of approximately 6.0 cm within all systems mid way through the grazing season.

Measurements

Cows were milked twice daily between 06:00 and 08:00 hours and between 15:00 and 17:00 hours, with milk yields recorded automatically at each milking. Milk fat, protein and lactose concentrations were determined weekly on two consecutive (morning and evening) milk samples (Milkoscan, Model FT 120, Foss UK Ltd., Warrington, UK) while milk somatic cell count (SCC) was determined monthly using a Fossomatic 360 (Foss Electric, Hillerød, Denmark). On four occasions (18 March, 20 May, 12 August and 29 September) during the final year of the experiment, while cows on all three systems were grazing full-time, milk was sampled during two consecutive milkings, bulked in proportion to yield, and subsequently analysed for milk fatty acid concentrations as described by Keady *et al.* (2000). In addition, milk progesterone concentrations were determined twice weekly (Monday and Friday; am samples) between calving and day-52 post calving for all cows during each of Years 1-3. Milk samples were preserved (Lactab Mark III, Thompson and Cooper Ltd., Lydney, UK) and stored at 4°C until analysed (within four weeks). Milk progesterone concentrations were determined using an enzyme-linked immuno-sorbent assay (ELISA) kit (Ridgeway Science Ltd., Gloucestershire, UK), based on the method of Sauer *et al.* (1986), as described in detail by McCoy *et al.* (2006). Interval to the commencement of luteal activity (LA) was defined as the interval from calving to the first of at least two consecutive increases in milk progesterone concentration above 3.0 ng/ml (Darwash *et al.*, 1997).

Cow live weight was recorded automatically after each milking and an average weekly live weight subsequently calculated. Body condition score of lactating cows was assessed weekly by two trained operators, on alternate weeks, using a five point scale (Edmonson *et al.*, 1989), where 1 = emaciated and 5 = extremely fat. Locomotion score was recorded fortnightly by a single trained operator using a five point scale (Manson and Leaver, 1988), where 1 = no unevenness in gait or tenderness, and 5 = difficulty in walking and adverse effects on behaviour pattern. Blood samples were taken from the coccygeal vein of each cow between 06:30 and 08:30 hours at weeks 2, 4, 6, 8, 10 (± 3 days), 20, 30 and 40 (± 7 days) post calving. Blood plasma was recovered via centrifugation and stored at -20°C until analysed for β-hydroxybutyrate (BHB) and non-esterified fatty acids (NEFA) content (using a Wako kit, Wako Chemicals GMBH, Germany). Calving difficulty score was on a scale of 1–5, where 1 = unassisted calving and 5 = caesarean section (McEvoy *et al.,* 1995).

During periods when cows on each of the three systems were housed, individual food intakes were measured daily using the Calan gate feeding system, as described previously. Mean daily herbage DM intakes during the grazing season were calculated weekly for each cow from animal performance data, and the mean daily intake over the grazing season subsequently calculated. Within this calculation, milk energy content was determined from fortnightly milk samples using the equations of Tyrrell and Reid (1965), while mean daily liveweight change over the grazing period was determined by linear regression of weekly liveweight data. Total energy required for maintenance, production, tissue change, pregnancy (where appropriate) and walking (assumed as 2.0 km/day) was determined using the equations contained within 'Feed into Milk (FIM)', the UK dairy cow feed rationing system (Agnew *et al.*, 2004). The metabolisable energy content of herbage (and silage during period of part turnout) were determined by NIRS, while the ME content of the concentrates offered was assumed as 12.65 MJ/kg DM (based on published values for individual ingredients: AFRC, 1993). Throughout the grazing season, pre- and post-grazing sward heights were measured daily within each milk production system using a rising plate meter (Jenquip, New Zealand).

Throughout the study cows with health problems were treated by either a veterinary surgeon or by a member of Institute staff, as appropriate. All incidences of mastitis and lameness were recorded throughout the experiment with an incidence defined as one where antibiotic treatment was used.

Feed chemical analysis

Throughout the indoor periods of the experiment grass silages offered were sampled daily and analysed for DM content. In addition, on one occasion each week a fresh grass silage sample was analysed for concentrations of N and metabolisable energy (ME) using Near Infrared Reflectance Spectroscopy (NIRS), as described by Park *et al.* (1998). On one occasion each week a fresh sample of herbage was collected pre-grazing from the grazing areas associated with each of the systems and analysed for DM, N and ME content using NIRS as described by Park *et al.* (1998) for grass silage, but using calibration equations developed for fresh grass. Each one tonne batch of concentrates made during the study was sampled and the samples bulked for each 4-week period. Concentrate samples were analysed for DM and N concentrations as described by Ferris *et al.* (1999).

Statistical Analysis

Data were analysed using GenStat Version 11.1 (Payne *et al.*, 2008). Ten cows were removed from the study 'within' years, with their data excluded from the statistical analysis. Reasons for their removal included mastitis/udder problems (n = 5), lameness (n = 2), injury (n = 2) and photosensitivity (n = 1). Food intake, milk production data, parameters describing live weight and body condition score data at fixed time points, and continuous fertility data were analysed using Residual Maximum Likelihood (REML) analysis using a repeated measures mixed model. The model included the following terms as fixed effects: genotype (HF or J × HF), lactation number (1, 2, 3+), year (1, 2 or 3), milk production system (LC, MC or HC), while cow + cow within lactation were included as random effects. Lactation length was not included within the model as differences in lactation length between systems were due in part to differences in dry period length associated with differing body condition scores. Fortnightly live weight and condition score data (mean of each two week period) were analysed using REML analysis using a repeated measures mixed model, with the model containing the following terms as fixed effects: genotype (HF or J × HF), lactation number (1, 2, 3+), year (1, 2 or 3), week of lactation (2-44), system (LC, MC or HC) and system x week of lactation, while cow and cow within week of lactation were included as random effects. Blood metabolite data were analysed using a similar model, with week of lactation defined as 2, 4, 6, 10, 20, 30 and 40 post calving. Binomial fertility and health data were analysed using logistic regression analysis using a model with the following terms fitted: genotype (HF or J × HF), lactation number (1, 2, 3+), year (1, 2 or 3), milk production system (LC, MC or HC), with Generalised Estimating Equations (GEE) used to account for the repeated measured nature within the data set.

RESULTS

Concentrates offered across the three years of the experiment had mean crude protein concentrations of 192 (winter) and 189 (grazing) g/kg DM (Table 4), while across the three years the silages offered with system LC and with systems MC and HC had a similar composition (Table 4). Across the three years of the experiment, herbage offered within systems LC, MC and HC had a mean DM concentration of 177, 170 and 163 g/kg, a mean CP concentration of 164, 170 and 182 g/kg, and a mean ME concentration of 10.9, 10.7 and 10.9 MJ/kg DM, respectively (Table 5). Mean pre- and post-grazing sward heights (across Years 1–3) were 10.0 and 5.9 cm for LC, 9.6 and 6.0 cm for MC and 9.4 and 5.7 cm for HC. In addition, actual pre and post grazing sward heights are presented in Figures 1–3 (fortnightly basis) for years 1–3, respectively. These again highlight that apart from brief periods in early season, sward heights tended to be remarkably consistent with each of the three systems.

In view of year to year variations in climatic conditions, and the significant impact that this can have on cow performance within spring milk production systems which have a high reliance on grazed grass, this study was conducted during three successive years. Unsurprisingly there was a significant effect of 'year' on a number of the main milk production parameters examined, including milk yield (P=0.001), milk fat, protein and lactose content (P<0.001), solids corrected milk yield (P=0.077) and somatic cell score (P=0.024). However, as the primary objective of undertaking this study over three successive years was to obtain a longer term view of performance, individual year effects have not been presented. There were no significant (P>0.05) year x systems interactions for any of the main performance parameters examined.

While lactation length was unaffected by system, dry period length decreased from system LC to HC (P<0.003) (Table 6). Intake data presented in Table 6 describe total DM intakes during the lactation and subsequent dry period. Total concentrate intakes were 488, 990 and 1616 kg DM per cow (P<0.001) with systems LC, MC and HC, respectively. There were no differences between systems in total silage DM intake (P>0.05), while total grass intake decreased from system LC to HC (P<0.05). Total lactation DM intakes increased from LC to HC (P=0.025). Total silage intakes and total DM intakes during the dry period were highest with LC and lowest with HC (P=0.014 and P<0.001, respectively).

Full lactation milk yields and solids corrected milk yields were significantly lower with system LC and HC (P<0.001), while there were no differences in yield between systems MC and HC (Table 7). Neither milk fat, protein nor energy content were affected by system (P>0.05). Fat yield, protein yield, fat + protein yield and milk energy yield all followed similar trends, with yields with system LC being lower than for either of MC or HC, while there were no differences in yield between systems MC and HC. Somatic cell score was unaffected by system.

System had no significant effect on mean live weight during the first 44 weeks of lactation (Figure 4), while live weight changed with week of lactation ($P<0.001$), and there was a significant system x week of lactation interaction ($P=0.002$). The latter was reflected in the cows on system HC having a significantly higher live weight at dry off than those on system LC ($P = 0.006$).

Over the course of the lactation body condition score was unaffected by system ($P=0.345$), while systems differed over time ($P<0.001$) and there was a significant interaction between system and week of lactation ($P=0.034$) (Figure 5). Cows on system LC completed the lactation with a BCS which was 0.2 units lower than those on system HC ($P=0.078$).

Changes in plasma NEFA, BHB, glucose and urea concentrations during the first 40 weeks of lactation are presented in Figures 6–9, respectively. With regards NEFA, concentrations were affected by system ($P=0.007$), and time ($P<0.001$), while there was a significant system x time interaction ($P=0.004$). Similarly, while plasma BHB concentrations were unaffected by system ($P=0.081$), there was a significant effect of time and a significant system x time interaction ($P<0.001$). While plasma glucose concentrations were unaffected by system ($P=0.223$), concentrations changed with time ($P<0.001$).

None of the fertility parameters presented in Table 8 were affected by system. Similarly, system had no effect on the proportion of cows with one or more cases of mastitis or on mean locomotion score, while the proportion of cows with one or more cases of lameness increased from LC to HC.

Table 4 Mean chemical composition of silages and concentrates offered across the three years of the experiment

	Silage				Concentrate			
	LC	s.d.	MC and HC	s.d.	Winter	s.d.	Summer	s.d.
Dry matter (g/kg)	299	52.5	281	58.2				
pH	3.98	0.285	3.84	0.249				
Ammonia N (g/kg total N)	73	21.7	69	18.5				
Crude protein (g/kg DM)	137	18.1	133	16.6	192	(21.1)	189	(16.9)
Lactic acid (g/kg DM)	77	33.8	94	35.1				
Gross energy (MJ/kg DM)					17.8	(0.36)	17.5	(0.32
Acid detergent fibre (g/kg DM)					116	(14.3)	113	(11.9)
Neutral detergent fibre (g/kg DM)	571	40.6	575	44.4	249	(39.3)	220	(25.5)
Metabolisable energy (MJ/kg DM)	10.9	0.69	11.1	0.63				

Table 5 Mean pre- and post-grazing sward heights, and the chemical composition of herbage offered across the three years of the experiment

	System					
	LC	s.d.	MC	s.d.	HC	s.d.
Year 1						
Mean pre-grazing sward height (cm)	10.3	2.26	10.3	2.15	10.1	2.21
Mean post grazing sward height (cm)	6.2	1.07	6.5	1.10	6.1	1.05
Dry matter (g/kg)	186	47.7	170	49.1	165	39.6
Crude protein (g/kg DM)	164	37.9	155	38.1	163	26.5
WSC (g/kg DM)	140	47.5	121	47.8	124	43.1
ADF (g/kg DM)	298	54.8	321	50.3	305	36.6
Metabolisable energy (MJ/kg DM)	10.8	0.9	10.4	0.88	10.5	0.56
Year 2						
Mean pre-grazing sward height (cm)	10.2	1.92	9.6	1.69	9.3	1.70
Mean post grazing sward height (cm)	6.3	1.07	6.3	1.01	6.1	1.01
Dry matter (g/kg)	170	26.5	171	25	161	21
Crude protein (g/kg DM)	158	26.1	165	30.7	181	32.4
WSC (g/kg DM)	138	36.7	131	41.8	124	34.9
ADF (g/kg DM)	304	52	315	32.6	306	28.9
Metabolisable energy (MJ/kg DM)	10.8	0.51	10.7	0.53	10.9	0.47
Year 3						
Mean pre-grazing sward height (cm)	9.6	2.18	8.9	1.75	8.7	1.96
Mean post grazing sward height (cm)	5.3	1.15	5.1	0.98	4.9	1.02
Dry matter (g/kg)	173	44.4	169	45.8	164	37.5
Crude protein (g/kg DM)	170	35.1	190	24.3	203	28.7
WSC (g/kg DM)	139	63	107	60.2	120	57.8
ADF (g/kg DM)	300	39.4	300	32.3	284	25.7
Metabolisable energy (MJ/kg DM)	11.1	0.7	11.1	0.58	11.3	0.43

WSC, water soluble carbohydrate; ADF, acid detergent fibre

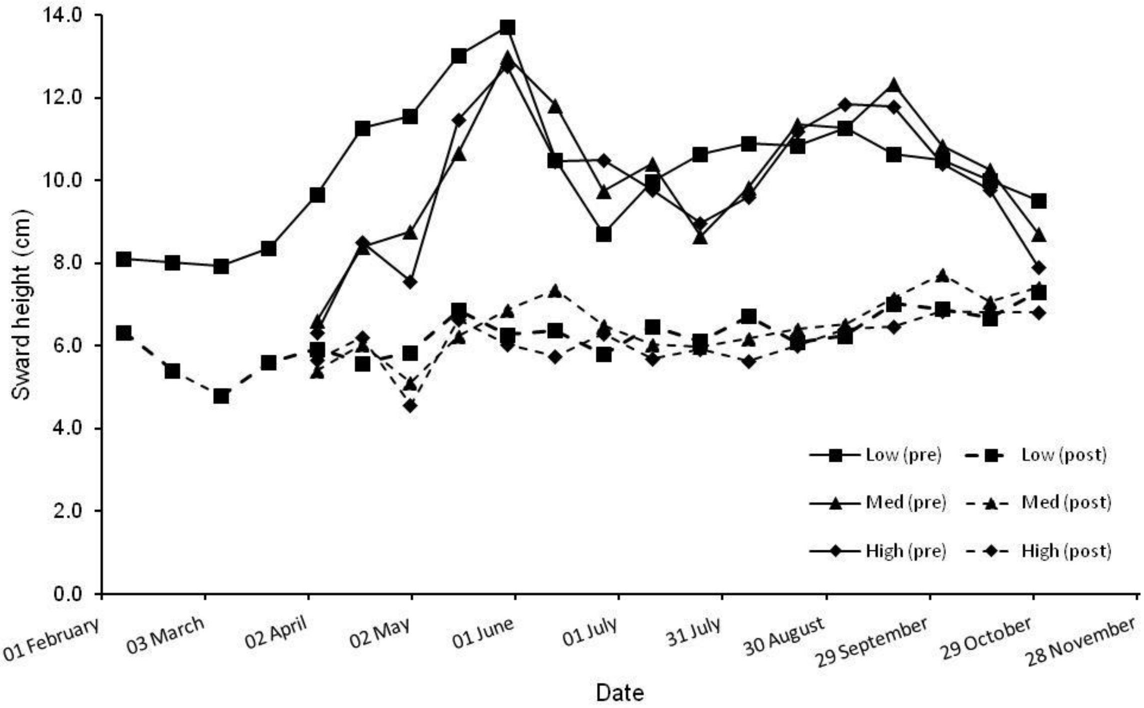

Figure 1 Pre and post grazing sward heights with each of the three systems during Year 1

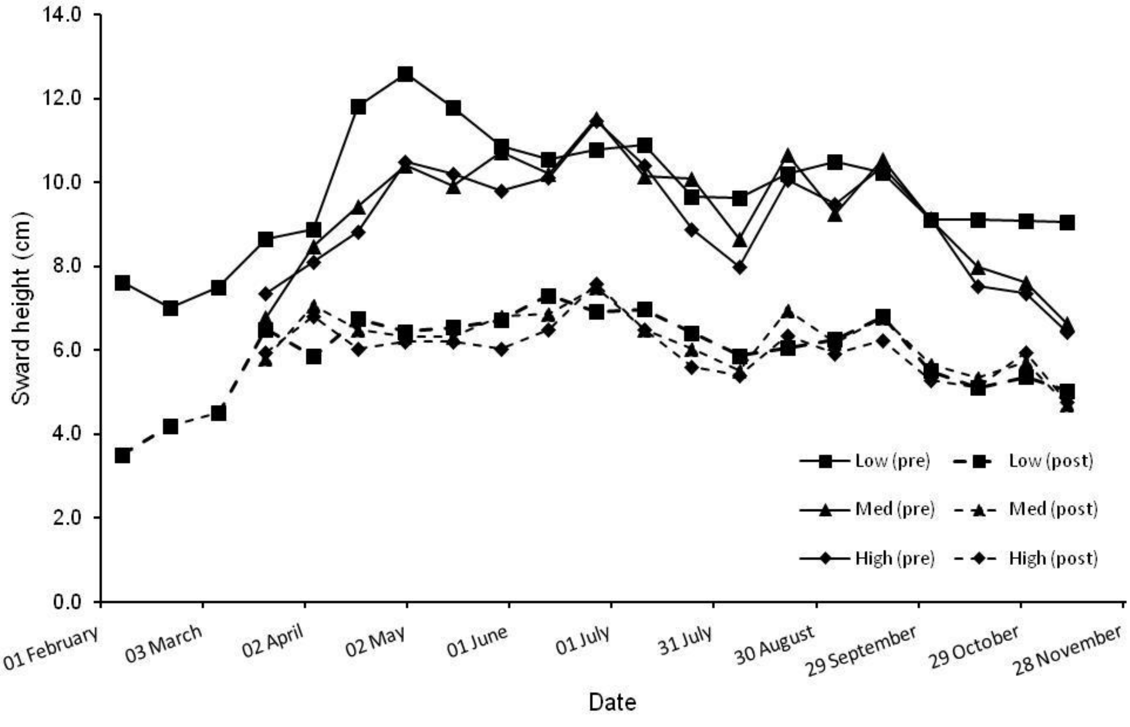

Figure 2 Pre and post grazing sward heights with each of the three systems during Year 2

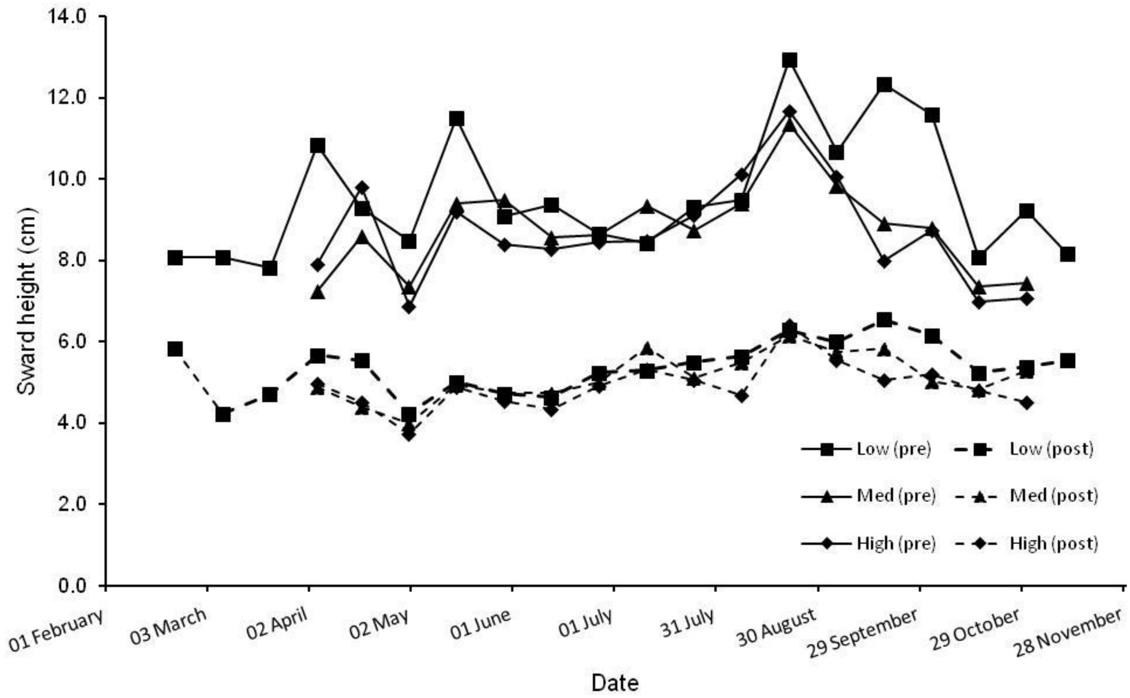

Figure 3 Pre and post grazing sward heights with each of the three systems during Year 3

Table 6 Effect of management system on the length of the lactation and dry period (days) and on total food intake during the lactation and the subsequent dry period (kg DM/cow)

	System				
	LC	MC	HC	SED	Sig.
Lactation length (days)	298	300	304	4.8	0.383
Dry period length (days)	88	80	77	3.4	0.003
Lactation intake (kg DM/cow)					
Concentrate	488	990	1616	29.8	<0.001
Silage	946	1061	1035	58.6	0.119
Grass	3128	2752	2326	65.2	<0.001
Total	4589	4813	4962	117.6	0.025
Dry period intake (kg DM/cow)					
Silage	900	826	804	44.2	0.014
Concentrate†	93	0	0		
Total	993	826	803	45.9	<0.001

† Concentrates offered during years 2 and 3 only

Table 7 Effect of system on full lactation milk production performance

	System				
	LC	MC	HC	SED	Sig.
Milk yield (kg)	5650	6289	6571	188.4	<0.001
Solids correct milk yield (kg)[1]	5890	6653	6875	189.7	<0.001
Milk composition (g/kg)					
Fat	44.7	45.8	44.8	0.82	0.419
Protein	34.2	34.6	34.7	0.39	0.383
Lactose	45.7	45.9	46.3	0.26	0.058
Milk solids yield (kg)					
Fat	252	286	292	8.8	<0.001
Protein	192	217	226	6.0	<0.001
Fat + protein	441	503	518	14.3	<0.001
Milk energy content (MJ)	3.28	3.33	3.31	0.038	0.308
Milk energy yield (GJ)[2]	18.48	20.88	21.58	0.595	<0.001
Somatic cell count (000/ml)	171	196	220		
Somatic cell score (000/ml, log 10)	2.15	2.20	2.17	0.059	0.694

LC. Low concentrate, MC, medium concentrate, HC, high concentrate

[1] Solids corrected milk yield (kg/day) = 0.0123 fat + 0.00656 solids not fat – 0.0752 x (milk yield) (Tyrrell and Reid, 1965). Where solids not fat = protein + lactose + ash; ash assumed as 7.1 g/kg

[2] Milk energy content = 0.0386 Fat + 0.0205 solids not fat – 0.236 (Tyrrell and Reid, 1965)

Table 8 Effect of milk production system on body tissue reserves

	System				
	LC	MC	HC	SED	Sig.
Live weight (kg)					
Mean	499	506	512	8.62	0.259
At calving	535	533	542	9.4	0.621
At day-100 post calving	486	484	492	8.8	0.579
At day-200 post calving	492	503	504	8.8	0.299
At drying off	524	545	558	10.5	0.006
Nadir	464	464	464	8.1	0.991
Loss to nadir	70	70	77	5.8	0.505
Days to nadir	17.1	16.1	17.1	1.21	0.658
Gain from nadir to drying off	63.7	82.3	97.6	5.1	<0.001
Condition score					
Mean	2.4	2.4	2.4	0.05	0.319
At calving	2.8	2.7	2.8	0.05	0.157
At day-100 post calving	2.4	2.4	2.5	0.06	0.716
At day-200 post calving	2.3	2.3	2.3	0.05	0.365
At drying off	2.2	2.3	2.4	0.07	0.078

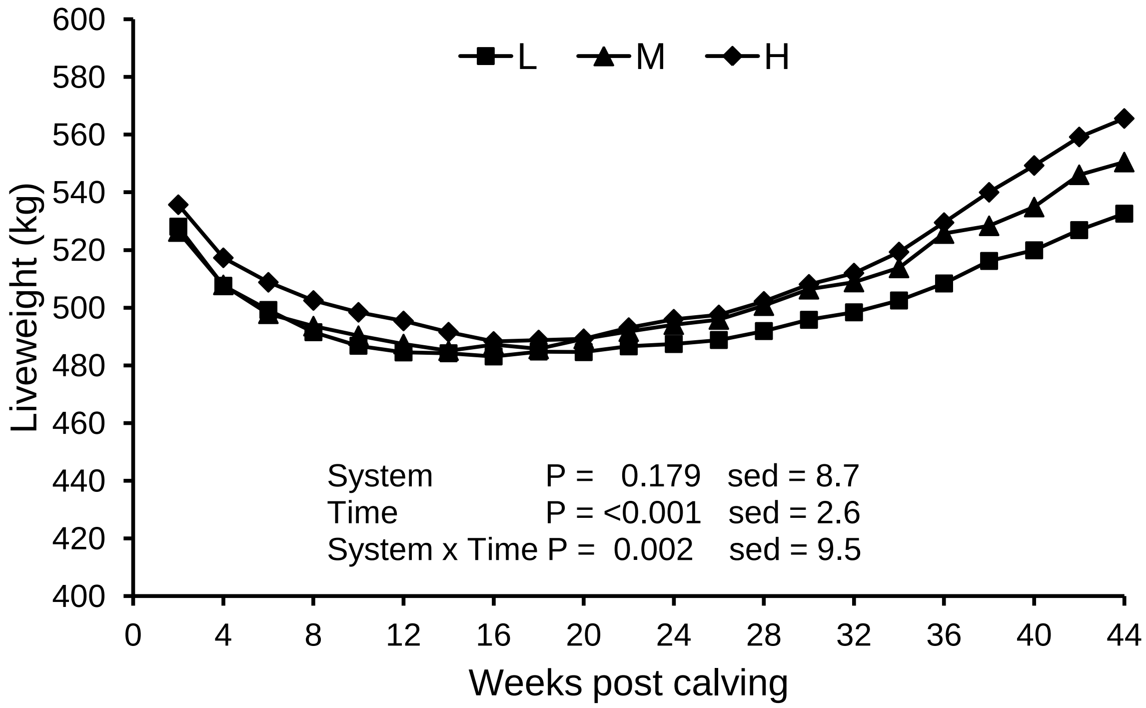

Figure 4 Effect of system on live weight change during the first 44 weeks of lactation

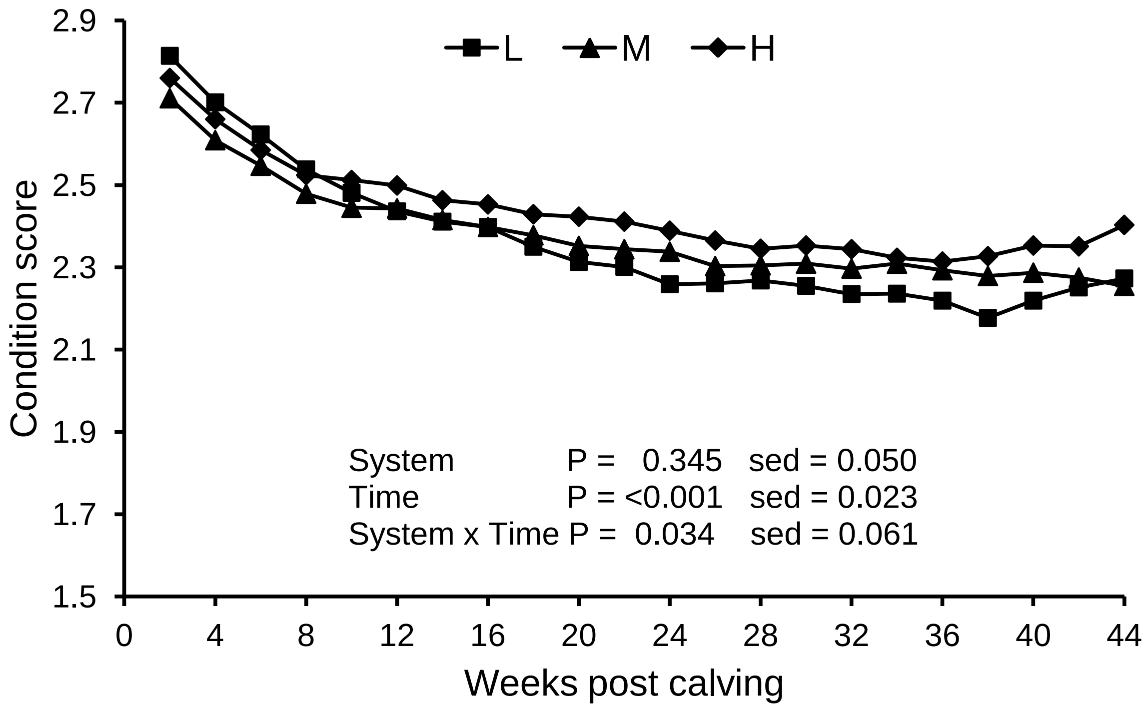

Figure 5 Effect of system on body condition score change during the first 44 weeks of lactation

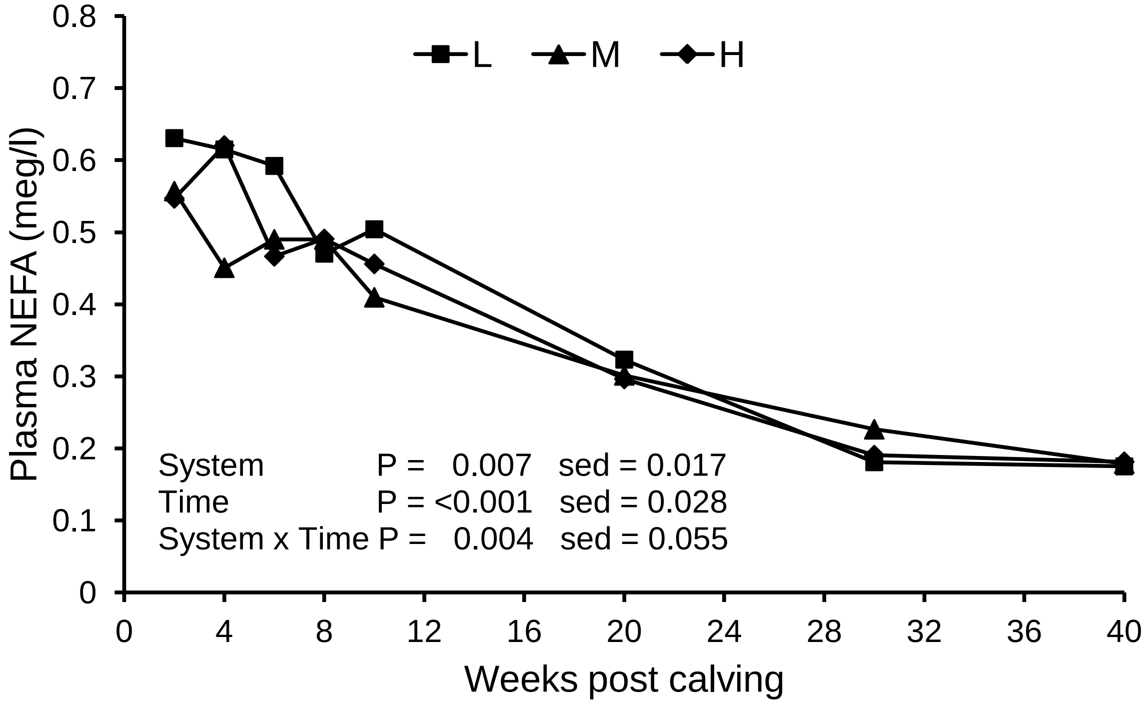

Figure 6 Effect of system on plasma NEFA concentrations during the first 40 weeks post calving

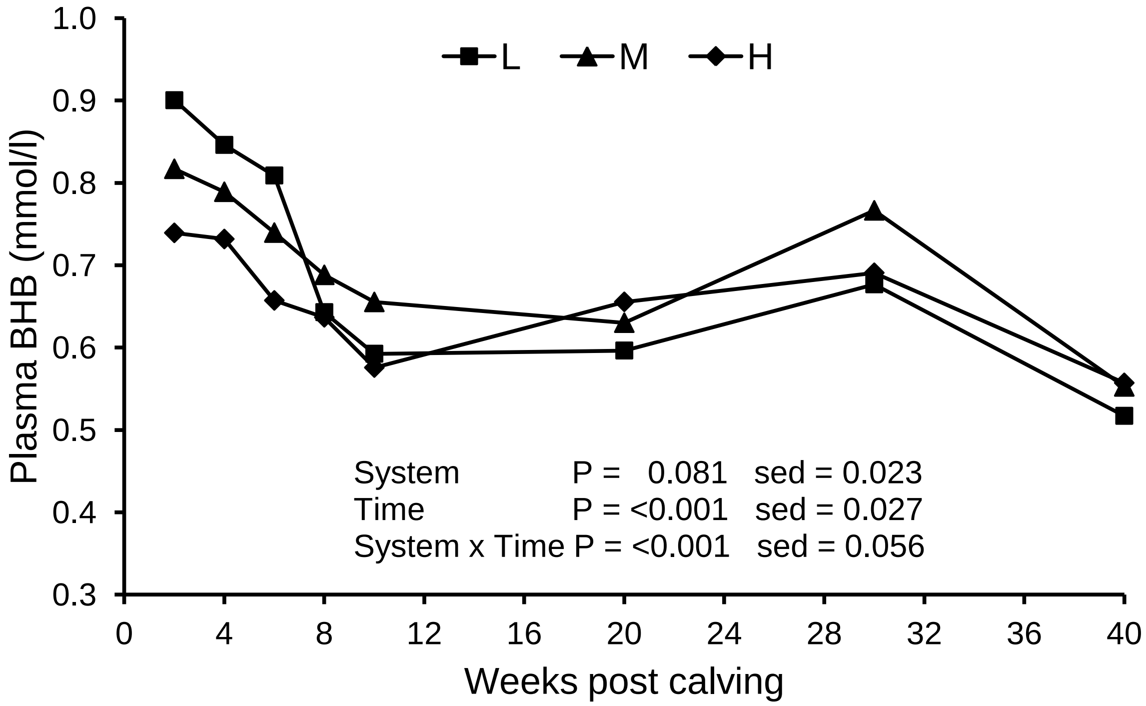

Figure 7 Effect of system on plasma BHB concentrations during the first 40 weeks post calving

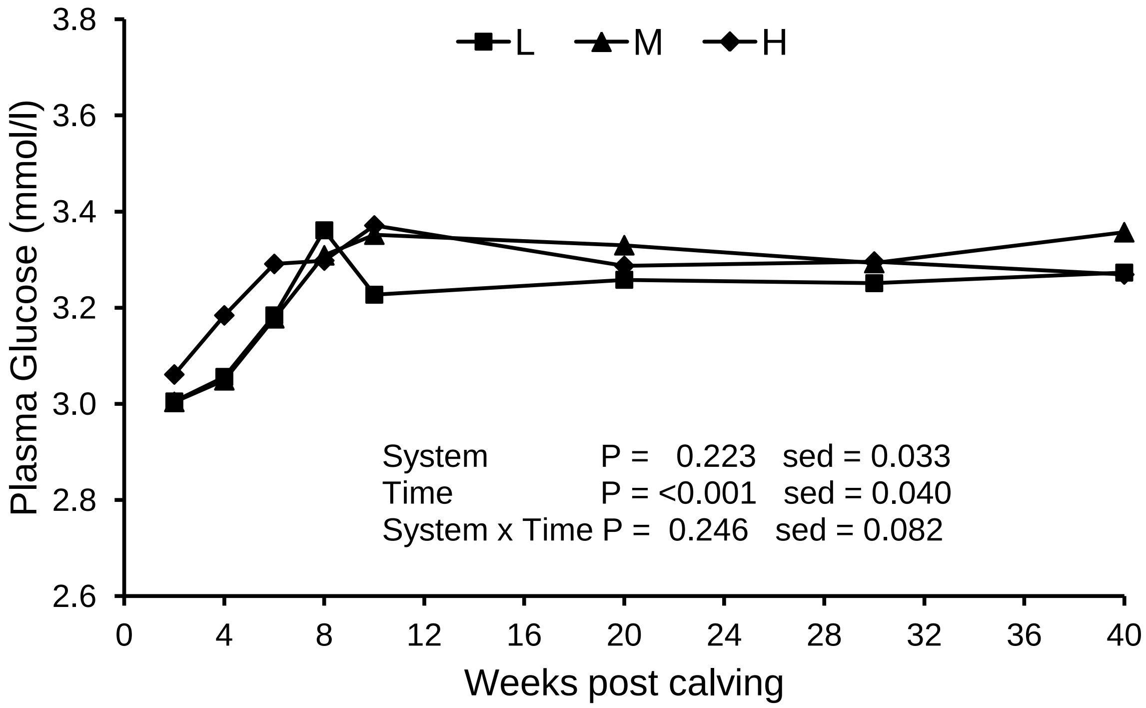

Figure 8 Effect of system on plasma glucose concentrations during the first 40 weeks post calving

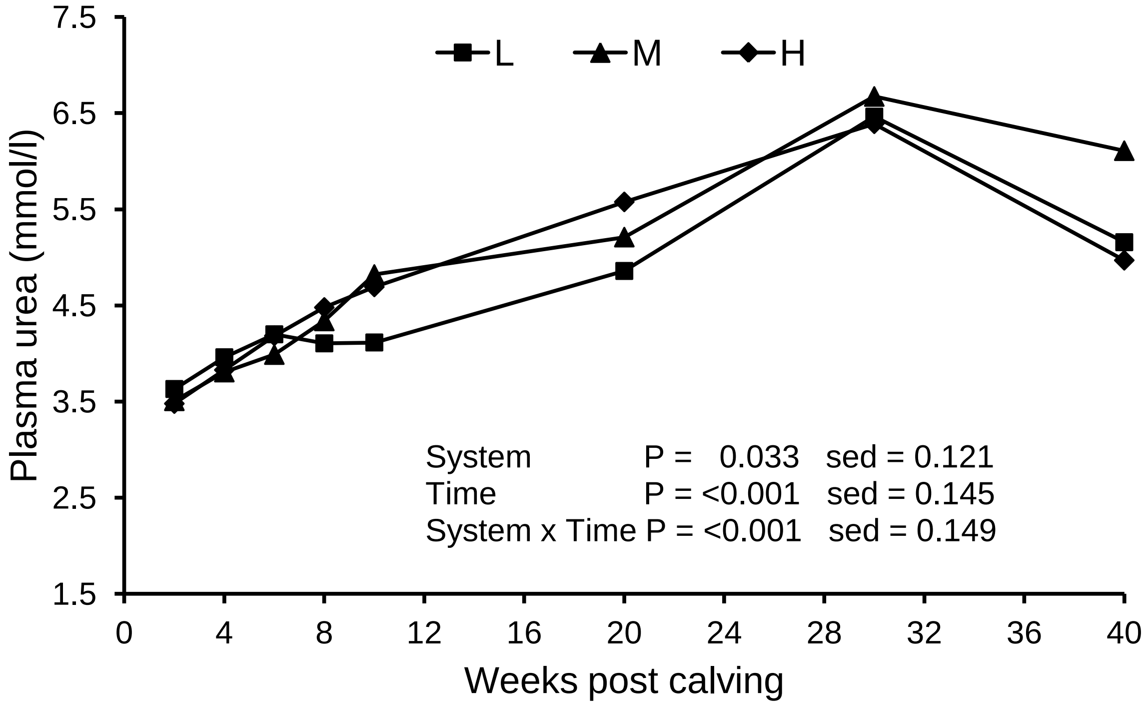

Figure 9 Effect of system on plasma urea concentrations during the first 40 weeks post calving

Table 9 Effect of milk production system on fertility performance and cow health

	System			SED	Sig.
	LC	MC	HC		
Fertility performance (proportional basis unless stated otherwise)					
Days to first observed heat	41.8	46.8	49.0	4.05	0.181
Conception to first service (proportion)	0.44	0.41	0.36		0.698
Conception to first and second service (proportion)	0.72	0.61	0.64		0.427
Interval from calving to conception (days)	96.1	88.1	93.4	5.1	0.309
Pregnancy rate at end of breeding season (proportion)	0.80	0.79	0.83		0.829
Calving interval (days)	397	390	382	10.0	0.147
Health parameters					
Proportion of cows with one or more cases of mastitis	0.24	0.20	0.25		0.933
Proportion of cows with one or more cases of lameness	0.01	0.13	0.22		0.012
Mean locomotion score	2.7	2.8	2.8	0.05	0.316

DISCUSSION

This experiment was undertaken to examine animal performance associated with three spring calving milk production systems. The 'systems approach' adopted within this experiment meant that the systems examined differed in a number of ways, including concentrate feeding system in early lactation, silage quality, turnout date and grazing management practices. While these different practices were adopted because they were believed to be most 'appropriate' for the systems being examined, most are unlikely to have had a major effect on cow performance. For example, across a number of studies it has been shown that at concentrate inclusion levels of less than proportionally 0.70 total DM (considerably less than in the current study), concentrate feeding system (in-parlour vs complete diet) is unlikely to have an impact on cow performance (Ferris *et al*., 1998). Similarly, although the silage offered with LC differed from that offered with systems MC and HC (due to the integration of silage and grazing areas with the former), the silages offered across the two systems had similar DM, crude protein, fibre and ME concentrations (all key drivers of intake: Steen *et al*. (1995)), with the small differences which existed unlikely to have significantly impacted on milk production during the relatively short confinement periods adopted. While the use of 'extended grazing' (early turnout) has been shown to result in positive performance benefits (normally 1–2 kg milk/cow/day), especially in situations involving silage of poor quality (Ferris *et al*., 2001a: Mayne and Laidlaw, 1995), silage quality in the current study was moderate, while any positive performance benefits for LC are likely to have been small within this full lactation milk production study. In addition, the similar pre and post grazing sward heights and similar herbage composition between systems suggests that the effects of differences in grazing management between systems (daily allocation (LC) vs rigid paddock systems (MC and HC)) on cow performance is unlikely to have been large. Thus the predominant difference which existed between systems was in concentrate feeding level, and this is likely to be the overriding driver of the performance differences observed.

Food intake and milk production

While the small differences in lactation length between systems will have contributed to the difference in food intake and milk production performance between systems, it was deemed inappropriate to 'remove' these 'lactation length' effects through the statistical model. This was justified as these differences were partly a consequence of the 'dry-off' criteria adopted, which required cows with a lower body condition score in late lactation (ie those offered less concentrates) to have a longer dry period. This was reflected in the significant increase in dry period length between HC and LC. Thus the differences in lactation length and dry period length are a direct consequence of the systems examined.

The total lactation diets offered with systems LC, MC and HC comprised proportionally 0.11, 0.21 and 0.33 concentrates on a DM basis, representing full lactation concentrate intakes of 488, 990 and 1616 kg DM/cow. While total silage intakes were unaffected by system, these tended to be lower with LC reflecting the shorter confinement period with this treatment. Similarly, the decrease in herbage intake from LC to HC reflects both the longer grazing period with the former treatment and the substitution of forage by concentrate during the grazing period. For example, Bargo *et al.* (2003) reported a mean substitution rate (across 10 studies) of 0.39 kg herbage DM/kg concentrate DM (range, 0.02–0.71). The relatively low residual sward heights in this study (6.0, 6.0 and 5.7 cm for LC, MC and HC, respectively) suggests that cows were grazing relatively tightly, and that substitution effects are likely to have been moderate low. These 'decreasing' herbage intakes during the grazing period were reflected in increasing stocking rates, with mean stocking rates during the grazing season, across the three years, being 3.56, 4.34 and 5.39 cows/ha for LC, MC and HC, respectively. The overall effect of concentrate supplementation within this study was for total food intake to increase between system LC and HC, but for total forage intakes to decrease. This was reflected in the overall annual stocking rates calculated, namely, 2.3, 2.6 and 2.9 cows/ha with LC, MC and HC, respectively. The 'silage stocking rates' which contributed to these annual stocking rates were determined using actual silage intake data and assumed data for silage yields and silage utilisation, as described later.

Milk quality within this experiment was excellent, with this a reflection in part of the Jersey crossbred cows groups producing milk with a high fat and protein content (Vance *et al*., 2013). Nevertheless, milk composition did not differ between systems, perhaps reflecting the ‘relatively’ small differences in daily concentrate inputs between systems during the early winter confinement period (4.0 kg/cow/day) and during the grazing period (5.0 kg/cow/day). In addition, the maximum concentrate feed level during the winter period was 10.0 kg/cow/day, while earlier research by Ferris *et al*. (2001b) indicated that milk fat levels did not begin to fall dramatically until concentrate feed levels were in excess of 12–14 kg/cow/day.

As a result of the excellent fat and protein content of the milk produced, solids corrected milk yields were considerably higher than unadjusted milk yields. When the response to concentrate supplementation between systems is examined on a solids corrected milk yield basis, the response to each kg of additional concentrate offered between systems LC and MC was 1.52 kg milk/kg concentrate DM, compared to 0.35 kg milk/kg concentrate DM between systems MC and HC. As already discussed, while this response may not have been entirely due to differences in concentrate feed levels, differences in feed levels are likely to have been the key drivers of the responses observed. Milk yield responses to concentrate supplementation within the literature are variable, with Bargo *et al.* (2003) reporting a mean response of 0.75 kg milk/kg concentrate DM intake (range, 0.06 to 1.56). The response of grazing dairy cows to concentrate supplementation is known to be influenced by many factors, including herbage allowance and composition, stage of lactation, and level and type of concentrate offered (Bargo *et al.*, 2003). However, as all cows were offered the same concentrate type and grazed to similar residual sward heights, differences in concentrate levels are likely to have been the primary drivers of the different responses observed.

Body tissue change and blood metabolites

While blood metabolite data (NEFA’s and BHB) suggest a trend towards an increased level of body tissue mobilisation with cows on LC compared to HC in early lactation, blood glucose levels provided no indication that cows on different systems differed in terms of energy status. In support of the latter, neither the live weight nor condition score curves were affected by system in early and mid lactation. Thus the higher milk yields associated with systems MC and HC appear to be a direct consequence of higher total intakes and increased energy density of the diet, both direct effects of concentrate inclusion in the diet. Nevertheless, there was some evidence of a divergence in live weights from approximately week-24 of lactation onwards, with live weights at drying off and liveweight gain from nadir to drying off increasing with increasing concentrate levels. Similarly, Walsh *et al.* (2008) reported higher liveweight gains (between weeks 13 to 44 of lactation) in a range of dairy cow genotypes managed on a high concentrate feeding system compared with those managed on a low concentrate feeding system. Furthermore, while none of Kennedy *et al.* (2002), Roche *et al.* (2006) or McCarthy *et al.* (2007) observed a significant difference for live weight and condition score loss in early lactation between feeding systems which differed in concentrate inputs, both live weight and condition score gain (post nadir) was highest in cows managed on high concentrate feeding systems, in line with the current study. This tendency to an increased partitioning of energy towards body tissue in late lactation will have contributed to the smaller marginal milk yield response observed between MC and HC. While at first sight this appears to have introduced an 'inefficiency' into the higher concentrate systems, it is unclear if this would have resulted in a long term beneficial effect in subsequent lactations. For example, although there does not appear to be scientific evidence to substantiate it, there is anecdotal evidence that cows being managed on low concentrate input systems should have a higher body condition score at calving than those managed on a higher concentrate input system. Nevertheless, system HC involved 1616 kg concentrate DM, and as such not be considered 'low concentrate'.

Cow fertility and health

Although concentrate inputs increased from 488 kg DM/cow with LC to 1616 kg DM/cow with HC, there was no evidence that fertility performance was influenced by level of concentrate input. Previous studies have highlighted the association between negative energy balance, excessive tissue mobilisation during early lactation and reduced fertility performance (Veerkamp *et al.*, 2003). However, in view of the absence of a system effect on BCS change in early lactation, and on concentrations of plasma NEFA and BHB, it is perhaps unsurprising that fertility performance was unaffected by concentrate supplementation. Similar effects have been observed in previous studies (Buckley *et al.*, 2000; Snijders *et al.*, 2001; Horan *et al.*, 2004). For example, within the latter study Horan *et al.* (2004) observed no difference in conception rates to first service, conception to first and second service and overall pregnancy rates, when concentrate feed levels increased from 366 kg/cow to 1452 kg/cow.

There was no evidence that incidence of mastitis, or SCS, was affected by concentrate feed levels. However, the proportion of cows with at least one case of lameness increased dramatically with increasing concentrate levels. While excessive concentrate feeding is known to contribute to laminitis, the magnitude of the difference observed within the current study is difficult to explain.

Carbon footprint of the three systems

The GHG calculator used to determine emissions within the present study was developed by the Agri-Food and Biosciences Institute (AFBI). This calculator uses a life cycle assessment approach to quantify GHG emissions arising from all sources within the 'farm gate' related to the 'dairy system', as well as quantifying emissions from number of significant sources outside of the farm gate. Primary data requirements and calculation approaches for each emission source have been described in detail by Aubry *et al*. (2013). The calculator determines total GHG emissions in CO_2 equivalent (CO_2e) units using global warming potential conversions of 25 kg of CO_2e/kg of CH_4 and 298 kg of CO_2e/kg of N_2O.

When calculating the carbon footprint of the three dairy systems examined within the present study, all information was 'scaled up' to simulate a farming system comprising a herd of 100 dairy cows. Data presented within this report were adopted as the primary source of information when determining the carbon footprint of these systems. Nevertheless, a number of assumptions were required to allow the calculation to be completed.

Firstly, while the study examined the performance of the 'milking herd' over three full lactations, in order to simulate a whole farm system it was necessary to include information on emissions associated with dairy herd replacements. As described by Aubry *et al.* (2013), emissions arising from enteric methane fermentation and manure management are calculated based on the age structure and physiological state of the dairy herd, with heifers defined as either >2 years, 1 to 2 years and less than 1 year. Key to determining the number of replacement heifers required within each system was the annual culling rate of mature cows. Culling rates were assumed not to differ between the three systems, with a common annual culling rate of 30% adopted. This assumption was based on the absence of any effect of management system on fertility performance (the primary reason for culling on most dairy farms) within this study (although the number of animals involved was insufficient to assess this robustly). All heifers were assumed to calve at 24 months of age, and mortality rates were assumed to be 3.5% for heifers aged between 12 and 24 months and 10% for heifers less than 12 months old. These mortality rates were based on recent data obtained from UK dairy herds (Wathes *et al*., 2008), with mortality rates assumed to be unaffected by management system. Based on these cow culling rates and heifer mortality rates, the number of heifers required to maintain herd size at 100 dairy cows within each system was determined. One hundred calves were assumed to be born alive each year (from cows and replacement heifers), with bull calves (50% of calves born) and heifers not required as replacements assumed to be exported within the first week of life.

The quantity of concentrates and forage consumed by heifers during the rearing period, until the time of entering the dairy herd at first calving, were derived from average farm business data for Northern Ireland based on a 24-month old calving system (DARD, 2012). A common management strategy was assumed for heifers entering all systems, with a total of 680 kilograms of concentrates (7–9 months, 90 kg: 10–15 months, 405 kg: 16–21 months, 50 kg: 22–24 months, 135 kg) and 6.25 tonnes of grass silage (fresh basis: 10–15 months, 3.75 tonnes; 22–24 months, 2.5 tonnes) consumed by each heifer during the period from 7 to 24 months of age (DARD 2012). The concentrate offered was assumed to have an average crude protein content of 170 g/kg DM, while the silage offered was assumed to have a dry matter content of 250 g/kg, while the crude protein content of the silages offered was assumed to be the same as that offered to the dairy cows. In addition, heifers were assumed to stay indoors during the ‘winter’ periods and to graze during the ‘summer’ periods (7–9 months, 0.075 ha/heifer; 16-21 months, 0.22 ha/heifer)). Fertiliser nitrogen application rates were assumed to be the same as those used within the main dairy cow grazing study.

The total area (ha) of land required to meet the herd's requirements (cows plus heifers) within each system was calculated as the area of grassland needed for grazing plus the area of grassland needed for silage production. The land required for dairy cow grazing was derived from the actual stocking rates during the grazing season, while land required for heifer grazing was as described above. Silage requirements for dairy cows were as measured within the study (lactation and dry period combined), while silage requirements for heifers were as described above.

The area of grassland required for silage production was calculated using an assumed annual harvested yield of 12.3 t DM/ha. This value was derived from a field scale study conducted over four seasons at Hillsborough, and was the mean of the annual yield of herbage measured within a two-harvest system and within a four-harvest system (Ferris, 2002). Total annual inorganic fertiliser N application rates within this latter study averaged 266 kg/ha across the four seasons and over the two different harvesting regimes, with a value of 272 kg N/ha/year assumed within this calculation. This is the current maximum permitted fertiliser application rate within NI. In-silo/feed-out losses were assumed as 15% of DM ensiled, giving a value of 10.5 t silage DM consumed/ha of grassland. Information on total silage DM intakes (cows and heifers combined) was then used to determine the area of land necessary to meet the silage requirements of each system.

Total emissions from LC, MC and HC (whole farm system basis) were 669, 724 and 760 t CO_2e, respectively (Table 10), with these reflecting the increase in total DM intakes and total milk outputs associated with increasing concentrate feed levels. 'On-farm' emissions accounted for 81%, 78% and 75% of total emissions for LC, MC and HC, respectively (Figure 10). This decrease in on-farm emissions moving from system LC to HC reflects the increasing proportion of concentrate in the diet, and the increase in 'off-farm' emissions associated with the production and manufacture of these concentrates. In addition, the increase in emissions on a per ha basis when moving from LC to HC, primarily reflects the increase in stocking rates, as well as the increase in food intakes. With regards the former, total emissions are simply divided over a smaller land area.

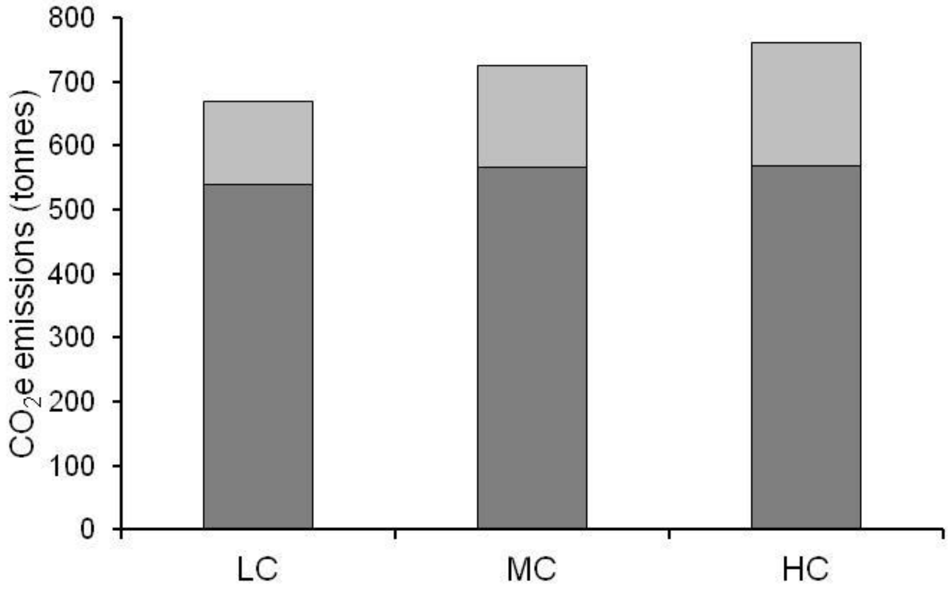

Figure 10 Total GHG emissions associated with each of systems LC, MC and HC (for a 100 cow herd plus young stock): the bottom part of each bar represents emissions on the farm, while the top part of the bar represents off farm emissions.

Total emissions per litre of milk were 1.09, 1.03 and 1.05 kg CO_2e with systems LC, MC and HC, respectively. While these differences cannot be compared statistically, emissions were 5.5% and 3.7 % lower with MC and HC than with LC. When the sources of these emissions were broken down further, a number of distinct trends were identified. For example, emissions from fertiliser application decreased with increasing concentrate use (reflecting the higher stocking rates, and corresponding lower land requirements), while emissions associated with concentrate production and transport increased with increasing concentrate inputs. There was little evidence of emissions associated with enteric fermentation, manure, land use, and fuel and electricity being affected by system.

In a similar modelling exercise, Lovett *et al*. (2006) modelled emissions from three pastoral dairy systems in Ireland involving concentrate inputs of 376, 810 and 1540 kg/cow/year, with the primary data for this exercise obtained from a study undertaken at Moorepark. While these concentrate feed levels were similar to those adopted within the current study, there were differences between the methodologies used to define the systems. For example, Lovett *et al*. (2006) adjusted cow numbers and land areas to achieve a given milk output/farm, while the boundaries of the system also differed from those adopted within the current study. Nevertheless, calculated emissions (1.149, 1.103 and 1.040 kg CO_2e/kg milk for the low, medium and high concentrate system, respectively) were in close alignment with those within the current experiment. However, these values demonstrate a clear trend for emissions to decrease with increasing concentrate levels, something that was not numerically evident within the current study.

Table 10 Annual GHG emissions (CO_2e) allocated to milk production with each of systems LC, MC and HC

	Farming system		
	LC	MC	HC
Excluding sequestration			
Total emissions for milk production (t)	669	724	760
Allocation factor for milk production (% of tot.)*	81	83	83
Emissions per cow (t/cow)	6.7	7.2	7.6
Emissions per ha (t/ha)	12.1	14.7	17.1
Emissions per kg of milk produced (kg/kg milk†)	1.09	1.03	1.05
Source of emissions (%)			
Enteric fermentation	45	45	43
Manure	19	19	19
Fertiliser	22	18	16
Concentrate	6	10	15
Land use	3	3	3
Fuel, electricity	2	2	2
Other sources	3	3	3
Including sequestration			
Total emissions (t)	555	620	664
Emissions per cow (t/cow)	5.6	6.2	6.6
Emissions per ha (t/ha)	10.0	12.6	14.9
Emissions per kg of milk produced (kg/kg milk†)	0.90	0.88	0.92

*Percentage of total CO_2e emissions from the dairy enterprise allocated to milk production, with the remaining percentage of total emissions allocated to meat production from the dairy enterprise.
†Energy corrected milk production.

Within the current study emissions might have been expected to decrease with increasing concentrate levels, a reflection of the improved quality of the diet being offered and the higher milk yields diluting emissions associated with the cow's maintenance requirements. While a reduction in methane emissions with increasing concentrate feed levels has been clearly demonstrated when examined across a wide range of concentrate feed levels (Yan *et al*., 2010), this effect has not always been evident when emissions associated with relatively similar concentrate feed levels were examined. For example, methane production (per kg intake) from grazing cows was unaffected when concentrate feed levels increased from 0.87 to 5.24 kg DM/day (Lovett, 2005). While milk production was higher with HC than with LC, the trend for the GHG footprint/litre of milk produced to be higher with HC than with MC may reflect the fact that the additional concentrates offered were not used efficiently for milk production. The lower marginal milk yield response per kg concentrate offered when moving from MC to HC, in comparison to that observed when moving from LC to MC, has already been highlighted, and reflects in part a tendency for the HC cows to lay down body tissue reserves in late lactation. Thus while extra concentrates and DM (full lactation basis) was consumed, this was not fully reflected in the additional milk produced. This further highlights the need to achieve high levels of efficiency in all aspects of milk production systems so as to reduce GHG emissions.

When taking carbon sequestration into account, total GHG emissions were reduced by 15% on average (17%, 14% and 13% for the LC, MC and HC respectively) (Table 10). The magnitude of these reductions reflect the greater land areas associated with LC, which in turn provides an increased potential for sequestration to take place. These values highlight the potential importance of carbon sequestration within NI's grassland-based dairy systems, and the need to have robust local information available so that this sequestered carbon can be accounted for when examining emissions from the local industry.

Economics of production systems

The gross margin per ha and per litre of milk was calculated for each of the three systems across a range of milk price-concentrate cost scenarios. These calculations involved a number of common assumptions across all systems, as follows: a culling rate of 30%, milk composition bonuses as currently adopted within the NI dairy sector; 15% heifer mortality before entering the herd; 95% of calves born alive; £100 and £150 per bull and heifer calf sold, respectively; cull cow value of £500/cow, with 80% of ‘cull cows’ having a market value; forage costs of £105.6 (3-cut grass silage) and £59.7 (grazed grass) per tonne of forage consumed (based on CAFRE 2013 Forage costs, but excluding land charges and infrastructure depreciation); sundry costs (vet/medicine, AI/semen, miscellaneous livestock costs) of £165/cow/year. For each of the three systems annual milk sales, actual milk composition and quantities of forages and concentrate consumed per year were included within the gross margin calculations. Margins were examined at five milk prices (16, 20, 24, 28 and 32 pence per litre) and at three concentrate prices (£200, £250 and £300/t).

Gross margins per cow and per litre of milk produced are presented in Tables 11 and 12 respectively, with values presented graphically for milk prices of 16, 24 and 32 pence per litre in Figures 11 and 12, respectively. As expected, across all systems gross margins increased with increasing milk price and decreased with increasing concentrate cost. With regards the effect of system, in general gross margin (per litre and per cow) was highest with MC across the range of milk price and concentrate cost scenarios examined. The exception to this was when margin per litre was examined at a concentrate cost of £300/t, in which case margins were higher with LC than with MC.

In addition, irrespective of concentrate cost, within a low milk price scenario gross margin per cow tended to be higher with the LC compared to HC, while this trend was reversed within a high milk price scenario, especially at low concentrate costs. When examined on a gross margin per litre basis, margins with system LC were higher than those with system HC across all milk price concentrate cost scenarios.

Table 11 Gross margin/cow (£) with each of systems LC, MC and HC across a range of milk-price concentrate-cost scenarios

Milk price (pence/litre)	Concentrate (£200/t)			Concentrate (£250/t)			Concentrate (£300/t)		
	LC	MC	HC	LC	MC	HC	LC	MC	HC
16	171	232	152	139	173	58	106	115	-37
20	400	490	420	368	431	326	336	373	231
24	630	748	688	597	689	594	565	631	499
28	859	1005	957	827	947	862	795	889	767
32	1088	1263	1225	1056	1205	1130	1024	1147	1035

Table 12 Gross margin/litre (pence) with each of systems LC, MC and HC across a range of milk-price concentrate-cost scenarios

Milk price (pence/litre)	Concentrate (£200/t)			Concentrate (£250/t)			Concentrate (£300/t)		
	LC	MC	HC	LC	MC	HC	LC	MC	HC
16	3.0	3.6	2.3	2.4	2.7	0.9	1.9	1.8	-0.6
20	7.0	7.6	6.3	6.4	6.7	4.9	5.9	5.8	3.4
24	11.0	11.6	10.3	10.4	10.7	8.9	9.9	9.8	7.4
28	15.0	15.6	14.3	14.4	14.7	12.9	13.9	13.8	11.4
32	19.0	19.6	18.3	18.4	18.7	16.9	17.9	17.8	15.4

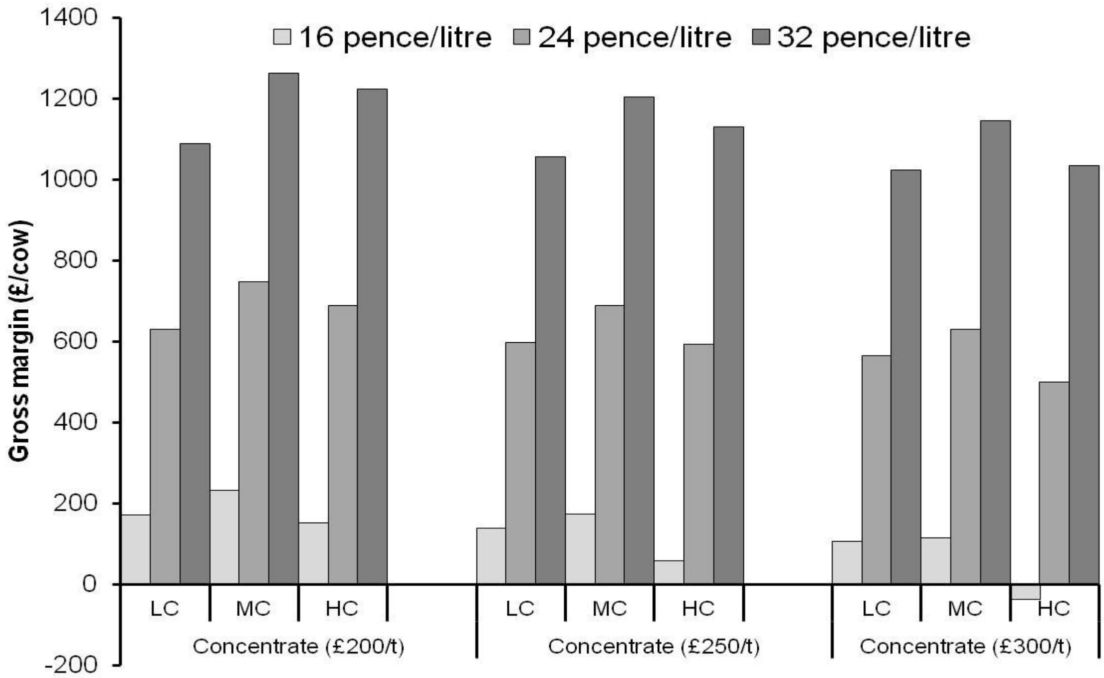

Figure 11 Gross margin per cow with each of systems LC, MC and HC across a range of milk price/concentrate cost scenarios

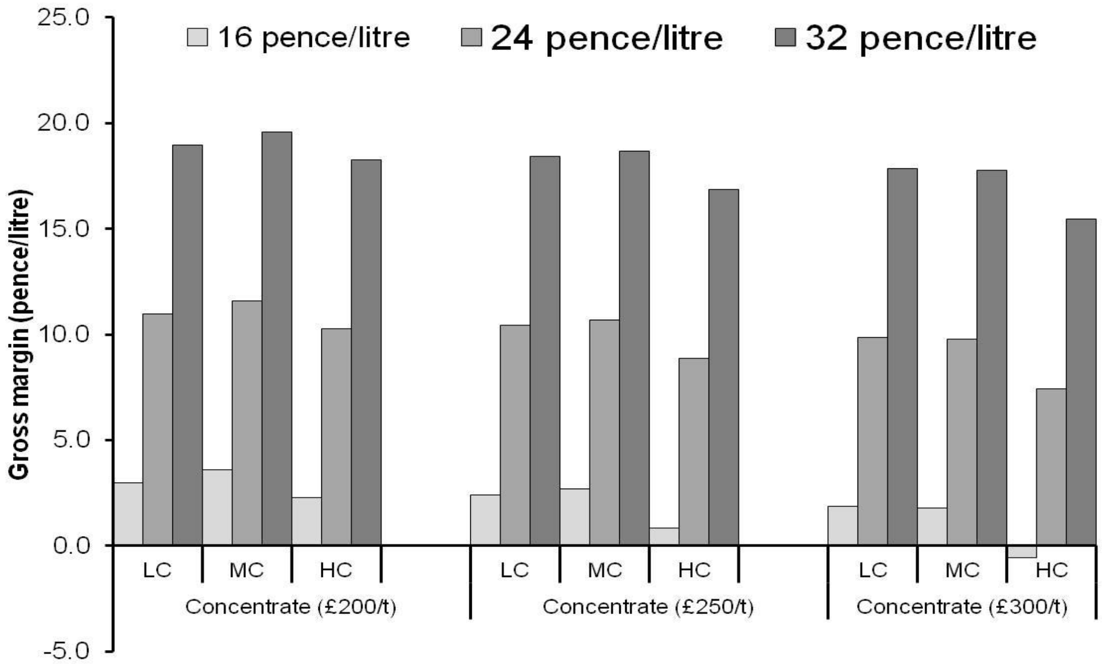

Figure 12 Gross margin per litre with each of systems LC, MC and HC across a range of milk price/concentrate cost scenarios

On the basis of this economic analysis it is concluded that within spring calving milk production systems, moving from a low to a medium concentrate input system is likely to improve profitability (per cow basis) within the range of milk price concentrate input scenarios examined. This reflects the fact that provided cows have reasonable genetic potential, they will be able to produce an economic response to the inclusion of a small amount of additional concentrates in the diet. However, the margins associated with these responses decrease as concentrate costs increase or as milk price decreases. Moving from a medium to a higher concentrate input system will not result in any additional improvement in margin unless the cows have the genetic potential to continue to produce an economic response to the additional concentrates offered. Within the current experiment, approximately half of the cows were Jersey x Holstein crossbreds, and their ability to respond to high levels of concentrate feeding has been shown to be less than for pure bred Holstein cows (Vance *et al*., 2012). Alternatively, if the objective is to maximise margin per litre, when concentrate cost is greater or equal to £250/t, moving from a low to a medium concentrate input system will have little effect on profitability, while profitability will fall considerably when moving to a higher concentrate input system.

While this study has presented economic performance on a gross margin basis, there are unlikely to be large differences in fixed costs between the systems examined, and as such the assumption of a common fixed cost with each system is likely to be valid. Thus, the relative differences between systems observed in terms of gross margin per cow is unlikely to change if data have been presented on a net margin basis.

CONCLUSIONS

Within the spring calving milk production systems examined, the marginal milk yield response to concentrate supplementation decreased with increasing concentrate level. However, concentrate feed level had no effect on fertility performance. Across a wide range of concentrate cost-milk price scenarios, margin per cow was highest with the medium concentrate input systems.

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EXPERIMENT 2

Effect of increasing grazing stocking rate on pre- and post-grazing sward parameters and on dairy cow performance

Copy of paper presented at the British Grassland Society Ninth Research Conference, 8th – 9th September 2009, Harper Adams University College, Shropshire

A.J.Dale, C.P.Ferris and C.S. Mayne

INTRODUCTION

Although grazed grass continues to represent the cheapest feedstuff available for milk production in Northern Ireland, many farmers are failing to achieve the full potential of grazed grass due to poor grass production and utilisation. The latter is due in part to a failure to match grazing stocking rates with grass production, resulting in an over supply of grass. The availability of land, especially land that can be easily accessed by grazing animals, is also a limitation to improving performance from grass. The objective of this study was to examine the influence of increasing grazing stocking rate on animal performance and sward parameters.

MATERIALS AND METHODS

This study was conducted in 2006, and involved sixty-four spring-calving multiparous dairy cows (mean calving date 5 February). The study commenced on 28 April, at which point the cows were divided into two grazing treatments. Both groups were managed under a fixed paddock system, with the cows moved to a fresh twenty-four hour allocation of grass following the evening milking. Treatments comprised a ‘HIGH’ and ‘NORMAL’ stocking rate, with the HIGH group grazing paddocks which were 10% smaller than the NORMAL group. With both treatments the lengths of the grazing cycles (1 to 7) were identical (19, 22, 24, 24, 24, 24 and 20 days, respectively). Fertiliser nitrogen (N) was applied after each paddock was grazed, with a total application of 300 kg N/ha over the season. Within each treatment an initial application of 28 kg N/ha was applied as urea pre-turnout, followed by applications of 60, 50, 40, 40, 30, 30 and 22 kg N/ha during each of the grazing cycles 1 to 7. Concentrate feed levels were the same for both treatments, with 4 kg/cow/day fed initially from 28 April to 23 May, 2 kg/cow/day to 5 July, and 4 kg/cow/day until the end of the study. Throughout the study pre- and post-grazing sward heights were measured daily using a rising plate meter. Milk yields were recorded daily, with milk composition, animal live weight and body condition score recorded weekly. Animal production data were analysed by ANOVA, with the appropriate pre-experimental values used as covariates where applicable.

RESULTS

Stocking rates with the NORMAL treatment were 6.5 cows/ha (cycle 1), 5.6 cows/ha (cycles 2), 5.1 cows/ha (cycles 3 to 6) and 6.2 cows/ha (cycle 7), while with the HIGH treatment these were 10% higher within each grazing cycle. Overall grazing stocking rate for the experimental period (28 April to 3 October) was 5.49 cows/ha for the NORMAL group and 6.10 cows/ha for the HIGH group. Treatment has no effect (P>0.05) on total milk yield produced over the study, average daily milk yield, average daily milk fat plus protein yield, average milk protein content, and either average live weight or body condition score (P>0.05) (Table 1). Average milk fat content was reduced by increasing grazing stocking rate (P>0.05). Overall, the season pre- and post-grazing swards heights were 10.1 and 5.7 cm within the NORMAL treatment and 9.4 and 5.0 cm within the HIGH treatment, respectively.

Table 1 Effect of stocking rate on cow performance

	Treatment			
	NORMAL	HIGH	SED	Sig
Total milk yield produced over study (kg/cow) (158 days)	3398	3351	65.9	NS
Average daily milk yield (kg/cow/day)	21.5	21.2	0.42	NS
Milk fat content (g/kg)	41.9	40.5	0.66	*
Milk protein content (g/kg)	33.8	33.64	0.32	NS
Fat + protein yield (kg/cow/day)	1.62	1.57	0.035	NS
Average live weight (kg)	525	532	11.3	NS
Average body condition score	2.5	2.5	0.05	NS

DISCUSSION

Increasing grazing stocking rate in this study has minimal effect on cow performance, with only milk fat content reduced at the higher stocking rate. On an output/ha basis, the HIGH and NORMAL stocking rate treatment produced 1,513 and 1,405 kg milk solids/ha grazed, respectively. Although pre- and post-grazing sward heights were numerically lower with the higher stocking rate treatment, the average quantity of herbage removed by the NORMAL (10.1 -5.7 = 4.4 cm) and HIGH (9.4 -5.5 = 4.4 cm) groups was similar, although the daily grazing area was reduced with the HIGH treatment. This would suggest a reduced intake with the HIGH treatment, however this was not apparent from the animal performance data achieved, and may be related to improved sward quality as a result of the lower pre- and post-grazing sward heights within the HIGH treatment.

CONCLUSIONS

The increase in grazing stocking rate in this study had minimal detrimental effects on animal performance, and resulted in improvements in output per hectare. If land base is the main limiting resource on farms, then maximising output per hectare will have a major influence on profitability at farm level.