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Effect of herbage allowance and concentrate supplementation on dry matter intake, milk production and energy balance of early lactating dairy cows

E. Kennedy [a,b,*], M. O'Donovan [a], L. Delaby [d], F.P. O'Mara [b,c]

[a] *Dairy Production Research Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland*
[b] *School of Agriculture, Food Science and Veterinary Medicine, NUI Dublin, Belfield, Dublin 4, Ireland*
[c] *Teagasc HQ, Oakpark, Co. Carlow, Ireland*
[d] *INRA, UMR Production du Lait 35590 St. Gilles, France*

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Abstract

The objective of this study was to investigate the effect of daily herbage allowance and concentrate supplementation level offered at approximately 40 and 80 days in milk (DIM) and the carryover effects at 120 DIM on the production performance of spring calving dairy cows. Sixty-six (30 primiparous and 36 multiparous) Holstein–Friesian dairy cows (mean calving date — 7 Feb ± 9.9 days) were randomly assigned to a 6 treatment (n = 11) grazing study. The experiment was a randomised block design with a 3 × 2 factorial arrangement of treatments (3 daily herbage allowances (DHA's; approximately 13, 16 and 19 kg DM/cow/day; > 4 cm) and 2 concentrate allowances (0 and 4 kg DM/day). Treatments were imposed from 21 February to 8 May. Following this period (subsequent 4-weeks) animals were offered a daily herbage allowance of 20 kg DM/cow/day and no concentrate. Milk production, total dry matter intake (TDMI), energy balance (EB) and blood metabolites were measured on three occasions — at approximately 40, 80 and 120 days in milk, R1, R2 and the carryover period, respectively. Cows offered a low DHA had a lower post-grazing sward height but increased sward utilisation (>4 cm) during R1 and R2, there was no difference during the carryover period. Concentrate supplementation increased post-grazing sward height by 11% during R2 but had no effect during R1 and the carryover period. Daily herbage allowance had no effect on milk yield or composition during R1 however a low DHA tended to reduce milk yield in R2. Concentrate supplementation increased milk and solids corrected milk (SCM) yield by 4.1 and 2.8 kg/cow/day, respectively during R1 and also increased R2 milk production performance, this effect extended into the carryover period. Offering a low DHA restricted grass dry matter intake (DMI) during R1 and R2 yet concentrate supplementation significantly increased total DMI (2.3 (R1) and 3.0 (R2) kg DM/cow). Animals offered a low DHA had a significantly lower bodyweight (BW) than those offered a medium or high DHA during P1 and P2. Concentrate supplementation increased BW during P1 and P2 (+9 and +14 kg/cow, respectively). There was no effect of treatment on BW during P3. There was no effect of DHA on EB in R1; during R2 animals offered a low DHA had the lowest EB. Concentrate significantly increased EB in R1 and R2 and increased plasma glucose concentration while it decreased plasma NEFA and BHB concentrations. The results of this study indicate that animals should be offered a low DHA up to 80 DIM after which DHA should be increased however animals should also be supplemented with concentrate during the early post-partum period.

Keywords: Early lactation; Milk production; Grass allowance; Dry matter intake

* Corresponding author. Dairy Production Research Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland. Tel.: +353 25 42222; fax: +353 25 42340.
E-mail address: Emer.Kennedy@teagasc.ie (E. Kennedy).

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1. Introduction

Dry matter intake (DMI) of dairy cows is at its lowest following parturition and does not peak until 8–22 weeks (~155 days) post-partum (Ingvartsen and Andersen, 2000; Kertz et al., 1991). This indicates that dairy cows do not consume enough feed to meet the energetic requirements of lactation and is substantiated when the studies of Roche et al. (2006) and McCarthy et al. (2007) are examined. From these studies it is evident that bodyweight (BW) and body condition score (BCS) loss are greatest directly post-calving. Bauman and Currie (1980) stated that cows in early lactation generally undergo a process of adipose tissue mobilisation as the energy demand for milk production is greater than the energy supplied by the diet.

Cow size, as described by BW, has been shown to have a major influence on DMI (Stockdale, 2000a). It is reported that under grazing conditions daily intakes of herbage can be as high as 3.6% in early lactation dairy cows (Kolver et al., 2002). Daily herbage allowance (DHA), offered in early lactation, has previously been shown to influence total DMI and milk production (Kennedy et al., 2007; McEvoy et al., in press) with higher allowances resulting in higher levels of production. However, maximising dairy cow performance while maintaining sward nutritive value are dual objectives of efficient grassland management in any pasture-based system (Kennedy et al., 2006). Therefore, as intake is at its lowest directly post-partum a low DHA may be sufficient during the first grazing rotation, to attain a high level of milk production while simultaneously maintaining sward quality in subsequent rotations.

The inclusion of concentrate in the diet has previously been shown to increase total dry matter intake (TDMI) relative to that achieved with pasture only diets (Delaby et al., 2001; Stockdale, 2000b) while additionally increasing energy intake and improving energy balance (Coffey et al., 2004) i.e. reducing the mobilisation of body reserves. One of the main advantages of concentrate supplementation, when offered in conjunction with grazed pasture, is higher production per cow and per unit area. However, Delaby et al. (2001) found that post-grazing sward height was higher when animals were offered a high DHA and supplemented with concentrate. Such a feeding strategy may impact on sward utilisation and subsequent sward quality thereby undoing any potential benefit from the increased milk production from concentrate supplementation.

The objective of this study was to investigate the effect of daily herbage allowance and concentrate supplementation level at approximately 40 and 80 days in milk (DIM) and the subsequent carryover effects at 120 DIM. This was achieved by evaluating the consequences of treatment on TDMI, milk production performance, blood metabolites, energy balance (EB), BW and BCS of spring calving dairy cows.

2. Materials and methods

The experiment was conducted at Moorepark Research Centre, Fermoy, Co. Cork, Ireland (52°09′N; 8°16′W). The soil type was a free draining, acid brown earth with a sandy loam-to-loam texture. A detailed description of experimental design, herbage measurements, total lactation animal performance and dietary composition offered over the entire lactation has previously been reported (Kennedy et al., 2007).

This paper focuses on milk production, TDMI, blood metabolites, EB, BW and BCS at 40 (R1) and 80 (R2) days into lactation, when the treatments outlined below were imposed, and also the carryover effects of each treatment at 120 DIM (the carryover period).

2.1. Animals and experimental design

The experiment was a randomised block design with a 3×2 factorial arrangement of treatments. Sixty-six Holstein–Friesian dairy cows were selected from the Moorepark spring calving herd. Thirty cows were primiparous while the remaining thirty-six were pluriparous (16 cows in their second lactation and 20 cows in their third or greater lactation). All animals ($n=66$) were balanced on the basis of calving date (7 February; S.D. 9.9 days), parity (2.2 S.D. 1.66), milk yield during the first ten days of the present lactation (22.3; S.D. 4.40 kg), bodyweight (525; S.D. 60.3 kg) and body condition score (3.2; S.D. 0.32). Previous lactation milk yield (5123; S.D. 1002.0 kg) [dam's first lactation milk yield (first 36 wk) in the case of the primiparous animals] was also used as a balancing factor. All animals were calved approximately 14 (S.D. 9.9) days before the trial commenced.

The cows were blocked into groups of six and randomly assigned to one of six grazing treatments ($n=11$). The treatments ($n=6$) consisted of three DHA's and two concentrate levels. Animals were offered a low (L; 13 kg DM/cow/day), medium (M; 16 kg DM/cow/day) or high (H; 19 kg DM/cow/day) DHA and either 0 or 4 kg DM/cow/day of concentrate from 21 February to 8 May (11 weeks; 2 grazing rotations), which coincided with 40 and 80 DIM. Concentrate composition, on a fresh weight basis was: molassed beet pulp, 48%; soybean meal, 25%; barley, 20%; vegetable fat, 3%; dicalcium phosphate (DCP), 1.6%; calcined magnesite, 1.3%; ground limestone, 0.6%; salt, 0.5%; and trace elements. Following this period, during which animals reached 120 DIM, all animals remained in their individual groups and were offered a DHA of 20 kg DM/cow/day and no concentrate for a further 4-week period to monitor carryover effects.

2.2. Grazing management

A permanent grassland site consisting of a predominantly perennial ryegrass sward (*Lolium perenne* L.) was used; the swards were on average three years old. The cultivars initially sown were cv. Twystar (late diploid), cv. Cornwall (late diploid) and cv. Gilford (late diploid). A total area of 24.1 ha (12 paddocks) was available for grazing.

Within each paddock, the six grazing treatments (3 DHA × 2 concentrate levels) grazed adjacent to one another in their separate areas, defined using temporary electric fences. The position of each herd in relation to the other herds was retained throughout the experiment. Herds did not however re-graze the same area in the second grazing rotation as was grazed during the first grazing rotation.

2.3. Sward measurements

Herbage mass (>4 cm) was determined twice weekly on the low, medium and high herbage allowance areas by defoliating two strips (1.2 m × 10 m) per allowance with an Agria machine (Etesia UK Ltd., Warwick, UK.). Ten grass height measurements were recorded before and after harvesting on each cut strip using an electronic plate meter (Urban and Caudal, 1990) with a plastic plate (30 cm × 30 cm and 4.5 kg/m; Agrosystèmes, Choiselle, France). This allowed the calculation of mass of herbage per cm [herbage mass [dry matter (DM)/ha] / (pre-cutting height − post-cutting height); kg DM/cm/ha]. All mown herbage from each strip was collected. It was weighed and sampled (0.3 kg). A sub-sample of approximately 0.1 kg of the herbage sample was dried for 24 h at 90 °C in a drying oven for determination of DM content.

Pre-grazing sward height was measured by recording 40 measurements across the two diagonals of each grazing area for the L, M and H treatments, using the electronic plate meter described above. The measured pre-grazing sward height, multiplied by the mean mass of herbage per cm, was used to calculate the DHA required for the L, M and H allowances. Post-grazing sward height was measured for each of the six individual treatments.

Herbage mass utilisation was calculated using the method of Delaby and Peyraud (1998). It is the proportion of herbage removed ((pre-grazing height − post-grazing height) × mass of herbage per cm × area ÷ (number of cows × 10,000)) relative to the DHA offered. Herbage, representative of that selected by the low, medium and high allowance groups, was sampled weekly with a Gardena hand shears (Accu 60, Gardena International GmbH, Ulm, Germany). A sub-sample was stored at −20 °C before being freeze-dried and milled prior to chemical analysis.

2.4. Herbage chemical analyses

The herbage samples for each treatment were freeze-dried and milled through a 1 mm sieve. Samples were analyzed for dry matter (DM), ash, acid detergent fibre (ADF), neutral detergent fibre (NDF; Van Soest, 1963), crude protein content (CP; Leco FP-428; Leco Australia Pty Ltd.) and organic matter digestibility (OMD; Morgan et al., 1989). The concentrate offered was analyzed for DM content, nitrogen, crude fibre, ether extract and ash concentrations.

2.5. Animal measurements

2.5.1. Milk yield and bodyweight

Milking took place at 07:30 h and 16:30 h daily. Individual milk yields (kg) were recorded at each milking (Dairymaster, Causeway, Co. Kerry, Ireland). Milk fat, protein and lactose concentrations were determined from one successive morning and evening milking sample taken weekly. The concentrations of these constituents were determined using Milkoscan 203 (Foss Electric DK-3400, Hillerød, Denmark). Solids-corrected milk (SCM) yield was calculated using the equation of Tyrell and Reid (1965). All cows were weighed weekly. Bodyweight was recorded electronically using a portable weighing scale and Winweigh software package (Tru-test Limited, Auckland, New Zealand). Body condition score was recorded weekly during the lactation on a 0 to 5 scale (0 = emaciated, 5 = extremely fat) with 0.25 increments (Lowman et al., 1976).

2.5.2. Intake estimation

Individual dry matter intake (DMI) was estimated during R1, R2 and the carryover period (approximately 40, 80 and 120 DIM, respectively) using the *n*-alkane technique (Mayes et al., 1986) as modified by Dillon and Stakelum (1989). All cows were dosed twice daily, before milking, for twelve consecutive days with a paper filter or bung (Carl Roth, GmbH and Co. KG, Karlesruhe, Germany) containing 500 mg of dotriacontane (C32). From the seventh day of dosing, faecal grab samples were collected from each cow twice daily for the remaining six days. The faecal grab samples were then bulked by cow (10 g of each collected sample) dried for 48 h in a 40 °C oven and chemically analyzed.

In conjunction with the faecal collection, the diet of the animals was also sampled. Herbage representative of that grazed (following close observation of the grazing animals' previous defoliation) was manually collected from each treatments respective paddock prior to morning grazing on days 6 to 11 (inclusive) of the intake measurement period. Two samples of approximately twenty-five individual grass snips were taken from each paddock with a Gardena hand shears. The ratio of herbage C33 (tritriacontane) to dosed C32 was used to estimate intake. The *n*-alkane concentrate was determined as described by Dillon (1993).

2.5.3. Energy balance

Energy balance was estimated as the difference between energy intake and the sum of energy for maintenance, milk production, growth and a pasture correction factor (INRA, 2007). The net energy (NE) of the herbage and concentrate offered was determined using the NE values of the ingredients where 1 unité fourragère lait (UFL) is the net energy for lactation equivalent of 1 kg of standard air-dry barley (Jarrige, 1989). The following equations were used to determine the energy required for maintenance plus a pasture correction factor, milk production and growth (applicable to animals less than 40 months old):

Energy requirement for maintenance: UFL/day

$$= 1.4 + (0.6 \times \mathrm{BW}/100)$$

Energy requirement for maintenance at pasture (i.e. pasture correction factor included): UFL/day

$$= (\text{Energy requirement for maintenance(UFL)} \times 120))/100$$

Energy output in milk: UFL/day

$$= \text{Milk yield(kg)} \times (0.44 + 0.0055 \times (\text{milk fat(g/kg)} - 40)$$

$$+0.0033 \times (\text{milk protein(g/kg)} - 31))$$

Energy output in growth if <40 months old: UFL/day

$$= 3.25 - 0.08 \times \text{age(months)}.$$

2.5.4. Blood sampling

One blood sample was taken from each animal ten days post-calving following morning milking this sample was used as the pre-experimental value in the analysis. During each measurement period (R) every animal was blood sampled once. Sampling took place directly after morning milking during R1, R2 and the carryover period. Blood samples were taken from the coccygeal vessel into one 10 ml vacutainer which contained lithium heparin as an anticoagulant. Samples were centrifuged within 15 min at 3000 ×*g* for 10 min at 5 °C. The plasma was decanted into borosilicate glass scintillation vials and stored at −20 °C prior to analysis.

The blood plasma was analyzed for plasma glucose, NEFA (non-esterified fatty acids), BHB (ß-hydroxybutyrate) and urea using appropriate kits and an ABX Mira auto analyzer (ABX Mira, Cedex 4, France).

2.6. Statistical analysis

All statistical analyses was carried out using SAS (SAS Institute, 2002).

All herbage data were analyzed using the following model:

$$Y_{ijk} = \mu + A_i + C_j + A_i \times C_j + T_k + e_{ijkl}$$

where; μ=mean, A_i=daily herbage allowance (i=1 to 3); C_j= concentrate level (j=1 to 2); $A_i \times C_j$=the interaction between daily herbage allowance and concentrate level; T_k=period (k=1 to 3) and e_{ijkl}=residual error term.

All animal variables were analyzed as 66 individual variables; to improve the accuracy of the model pre-experimental milk yield, milk composition, BW and BCS were used as covariates specific to the traits being analyzed. Daily milk yield, milk constituent yield, milk composition, BW and BCS (n=66) were analyzed with the following model:

$$Y_{ijk} = \mu + P_i + A_j + C_k + A_j \times C_k + T_l + b_1 X_{ijk} + b_2 \mathrm{DIM} i_{jk} + ei_{jk}$$

where: Y_{ijk} represents the response of the animal in parity i offered DHA j and concentrate level k; μ=mean; P_i=parity (i=1 to 2); A_j=daily herbage allowance (j=1 to 3); C_k= concentrate level (k=1 to 2); $A_j \times C_k$=interaction of daily herbage allowance and concentrate level; T_l=period (l=1 to 3); $b_1 X_{ijk}$=the respective pre-experimental milk output or BW/BCS variable, $b_2 \mathrm{DIM}_{ijk}$=days in milk and e_{ijk}=residual error term. Dry matter intake, energy balance and blood metabolite data were analyzed using the same model as above, however values for pre-experimental milk yield and BW were also included as additional covariate values in the model.

Due to the differences in parity, in terms of pre-experimental values, these covariates were centred within parity before inclusion. That is, the deviations from the parity mean were used as covariates. The incorporation of individual animal covariates within the model reduced the residual error term, therefore explaining more variation within parity.

3. Results

3.1. Sward measurements

A detailed overview of the composition of the diet throughout the entire lactation study has previously been reported (Kennedy et al., 2007). Specifically during the first measurement period the composition was ash (74.1, S.D. 6.95 g/kg), CP (250.8; S.D. 9.25 g/kg), NDF (462.7; S.D. 18.76 g/kg), ADF (251.3; S.D. 10.74 g/kg) and OMD (860.5; S.D. 2.11 g/kg). During R2 the ash, CP, NDF, ADF and OMD were 71.7 (S.D. 5.01), 175.5 (S.D. 16.59), 356.2 (S.D. 8.29), 230.7 (S.D. 25.31), 861.3 (S.D. 5.29) g/kg, respectively while during the carryover period they were 99.3, 193.3, 428.1, 250.2 and 846.0 g/kg, respectively.

Throughout R1 and R2 there was no difference between the low, medium and high DHA treatments in DM yield >4 cm or pre-grazing sward height (Table 1). The mass of herbage per cm did not differ significantly between treatments during any of the measurement periods (R1, 253; R2, 233; the carryover period 239 kg DM/cm/ha).

Throughout R1, DHA had a significant effect (P<0.001) on post-grazing sward surface height (PGSSH) and herbage utilisation. Animals offered a low DHA had a lower PGSSH (3.3 cm) than both the medium and high DHA treatments (4.5 cm; Table 2). Herbage utilisation was greatest for the low DHA treatment (1.11) and least for the high DHA treatment (0.90); the medium DHA treatment was intermediate

Table 1
Effect of daily herbage allowance and concentrate level on sward measurements during the first, second and third measurement period

	Daily herbage allowance			Significance	
	Low	Medium	High	SED	Sig
Period 1					
DHA >4 cm (kg DM/cow/day)	12.8	14.7	17.5	0.86	0.001
DM yield >4 cm (kg/DM/ha)	1660	1508	1501	112.3	0.210
Pre-grazing height (cm)	10.6	10.0	9.9	0.47	0.250
Area (m^2/cow/day)	80	99	119	8.1	0.001
Period 2					
DHA >4 cm (kg DM/cow/day)	14.1	17.0	20.0	0.04	0.001
DM yield >4 cm (kg/DM/ha)	2809	2826	2776	142.3	0.922
Pre-grazing height (cm)	16.1	16.1	15.9	0.61	0.923
Area (m^2/cow/day)	51	62	72	3.0	0.001
Period 3					
DHA >4 cm (kg DM/cow/day)	20.1	20.2	20.1	0.15	0.689
DM yield >4 cm (kg/DM/ha)	2714	2754	2655	108.8	0.595
Pre-grazing height (cm)	15.3	15.5	15.1	0.44	0.571
Area (m^2/cow/day)	75	74	76	3.2	0.670

DHA = daily herbage allowance.

(0.97). During R2, both PGSSH and herbage utilisation differed significantly ($P<0.001$) between all three DHA treatments. Similar to R1 the low DHA treatment had the lowest PGSSH (3.8 cm) and highest herbage utilisation level (1.02) while the high DHA treatment had the highest PGSSH (5.6 cm) and lowest herbage utilisation level (0.87), the medium DHA treatment was intermediate (4.6 cm and 0.95, respectively). There was no effect of initial DHA offered on PGSSH during the carryover period, i.e. animals offered a low DHA during R1 and R2 did not graze more severely than animals offered a medium or high DHA during the carryover period.

Concentrate supplementation did not affect PGSSH and herbage utilisation level in the first and third measurement period. However, concentrate supplementation significantly increased ($P<0.001$) PGSSH (+0.5 cm) and decreased herbage utilisation (−0.04) when compared to animals that were unsupplemented (4.4 cm and 0.97, respectively) during R2.

3.2. Dry matter intake

There was no significant interaction between DHA and concentrate supplementation in terms of GDMI and TDMI nor was there a quadratic response to the extra DHA allocated (Table 6). There was a linear response to the extra herbage offered at both R1 ($P<0.05$) and R2 ($P<0.001$). Animals offered a low DHA had a GDMI and a TDMI 8% and 7% lower, respectively ($P<0.05$) than that of the animals offered a medium and high DHA (13.2 and 15.2 kg DM/cow, respectively) during R1 (40 DIM). This equated to 2.9% of their BW, 0.1% lower than the intake of the medium and high DHA animals. During R1 increases of 0.53, 0.23 and 0.04 kg GDMI/kg DM increase in DHA were observed when allowances were increased from low to medium, low to high and medium to high, respectively. The same trend was observed during R2 (80 DIM), however the differential was higher between the low DHA treatment (−1.8 kg DM/cow; $P<0.001$) and the medium and high DHA treatments (16.1 and 18.1 kg DM/cow; GDMI and TDMI, respectively). The increases in GDMI/kg DHA offered in R2 were 0.62 and 0.31 kg GDMI/kg DM increase in DHA when allowance was increased from a low to medium and low to high level, respectively. Similar to R1 animals offered a low DHA consumed a lower proportion of their BW (2.9%) during R2 than animals offered a medium and high DHA (3%). There was no effect of initial DHA offered on DMI during the carryover period (120 DIM).

Supplementing animals with concentrate significantly decreased GDMI (−1.8 kg DM/cow; $P<0.001$) but increased TDMI (+2.2 kg DM/cow; $P<0.001$) during R1. Similarly, during R2 supplemented animals had a lower GDMI (−1.1 kg DM/cow; $P<0.01$) but had a greater TDMI (+2.9 kg DM/cow; $P<0.001$). There was no effect of initial concentrate supplementation level on DMI during the carryover period. On average supplemented animals consumed 0.4% more of their BW during R1 and 0.5% during R2 than their unsupplemented counterparts (2.7 and 3.2% of BW, respectively). There was no difference in the carryover period.

The substitution rate during R1 at a low, medium and high DHA were 0.40, 0.63 and 0.35 kg DM herbage/kg DM concentrate, respectively. During R2, the substitution rates were 0.48, 0.20 and 0.13 kg DM herbage/kg DM concentrate for the low, medium and high DHA treatments, respectively.

3.3. Milk production

There was no significant interaction between DHA and concentrate supplementation level for any of the variables analyzed. Daily herbage allowance did not significantly impact on any of the milk production

Table 2
Effect of daily herbage allowance and concentrate level on post-grazing height and sward utilisation during the first and second grazing rotation

	Treatment						Significance		
	L0	L4	M0	M4	H0	H4	SED	DHA	Conc
Period 1									
Post-grazing height (cm)	3.2	3.4	4.0	4.5	4.5	4.8	0.29	0.001	0.117
Utilisation	1.12	1.09	1.01	0.93	0.92	0.87	0.045	0.001	0.100
Period 2									
Post-grazing height (cm)	3.6	4.0	4.3	4.8	5.3	6.0	0.13	0.001	0.001
Utilisation	1.03	1.00	0.97	0.93	0.89	0.84	0.010	0.001	0.001
Period 3									
Post-grazing height (cm)	5.4	5.7	5.8	5.5	5.7	5.7	0.29	0.881	0.813
Utilisation	0.87	0.85	0.84	0.87	0.85	0.85	0.028	0.899	0.864

L = low herbage allowance; M = medium herbage allowance; H = high herbage allowance; 0 = no concentrate; 4 = 4 kg DM/cow/day concentrate; DHA = daily herbage allowance; Conc = concentrate.

variables during the three measurement periods (Tables 3–5) with the exception of milk lactose concentration which was significantly higher ($P<0.05$) for animals offered a high DHA (+1.0 g/kg) compared to those offered a low DHA (47.4 g/kg), during the carryover period. Consequently milk lactose yield was higher for animals offered a high DHA.

At 40 and 80 DIM when animals were supplemented with 4 kg DM/cow/day concentrate there was a significant increase ($P<0.001$) in milk (+4.1 and 5.9 kg/cow, respectively) and SCM yield (2.7 and 5.0 kg/cow, respectively). Although animals were not offered concentrate during the carryover period (Table 5) milk and SCM yield were still significantly higher ($P<0.05$) for animals originally supplemented (+1.2 and 1.1 kg/cow, respectively) compared to their unsupplemented counterparts (18.9 and 17.6 kg/cow, respectively). There was no effect of concentrate supplementation on milk fat and protein concentration yet milk lactose concentration was significantly higher for supplemented animals during each of the three measurement periods (+1.1, 0.9 and 0.6 g/kg, respectively). Both milk protein and lactose yield were greater ($P<0.001$) for supplemented animals during the first (+124.6 and +191.1 g/kg, respectively) and second measurement period (+229.7 and +309.3 g/day, respectively) when compared to animals that did not receive concentrate supplementation. Additionally, during R2 (Table 4) when animals, at 80 DIM, were offered 4 kg DM/cow/day concentrate milk fat yield was significantly higher ($P<0.001$; +185.1 g/day) than that of unsupplemented animals (830.5 g/day). However, during the carryover period only milk fat ($P<0.05$; +61.9 g/day) and lactose ($P<0.01$; +309.4 g/day) yield were higher for animals that received concentrate supplementation during R1 and R2 when compared to

Table 3
Effect of daily herbage allowance and concentrate level on milk yield, bodyweight and body condition score at 40 days in milk (R1)

	Treatment						Significance			
	L0	L4	M0	M4	H0	H4	SED	DHA	Conc	Lin
Milk yield (kg)	25.3	29.9	26.8	30.0	26.4	30.9	0.98	0.295	0.001	0.132
Milk fat content (g/kg)	38.1	38.1	41.5	37.9	38.1	34.7	2.18	0.125	0.08	0.297
Milk protein content (g/kg)	32.1	33.3	33.3	32.7	32.7	32.9	0.77	0.868	0.605	0.820
Milk lactose content (g/kg)	48.9	49.8	48.7	49.5	48.3	49.7	0.56	0.705	0.05	0.432
Milk fat yield (kg)	962.5	1126.8	1133.8	1101.8	1016.6	1087.1	78.94	0.388	0.167	0.897
Milk protein yield (kg)	817.2	989.7	880.9	966.1	892.7	1010.6	36.78	0.203	0.001	0.07
Milk lactose yield (kg)	1230.6	1484.5	1295.7	1478.6	1285.5	1537.7	57.19	0.437	0.001	0.195
SCM yield (kg)	23.3	27.5	26.6	27.7	24.7	27.5	1.15	0.124	0.001	0.435
Bodyweight (kg)	489	494	502	507	500	515	6.61	0.01	0.03	0.01
Body condition score	2.93	3.05	2.96	3.02	2.96	2.99	0.73	0.943	0.118	0.756

L = low herbage allowance; M = medium herbage allowance; H = high herbage allowance; 0 = no concentrate; 4 = 4 kg DM/cow/day concentrate; DHA = daily herbage allowance; Conc = concentrate; Lin = linear; SCM = solids corrected milk yield; BCS = body condition score.

Table 4
Effect of daily herbage allowance and concentrate level on milk yield, bodyweight and body condition score at 80 days in milk (R2)

	Treatment						Significance			
	L0	L4	M0	M4	H0	H4	SED	DHA	Conc	Lin
Milk yield (kg)	21.4	28.5	23.6	27.7	23.4	30.0	1.12	0.117	0.001	0.03
Milk fat content (g/kg)	37.8	35.4	38.3	36.2	33.5	35.1	1.77	0.068	0.408	0.078
Milk protein content (g/kg)	33.1	33.5	34.1	33.7	33.1	33.6	0.77	0.482	0.710	0.886
Milk lactose content (g/kg)	47.8	48.3	47.3	48.4	47.7	48.9	0.60	0.581	0.01	0.568
Milk fat yield (kg)	805.5	1006.6	897.1	981.7	788.8	1058.4	59.31	0.741	0.001	0.688
Milk protein yield (kg)	714.2	955.3	795.1	924.8	799.2	1001.7	43.66	0.121	0.001	0.04
Milk lactose yield (kg)	1021.4	1376.2	1110.9	1339.7	1122.6	1467.3	60.25	0.086	0.001	0.03
SCM yield (kg)	19.7	25.3	22.1	25.1	20.5	26.8	1.063	0.244	0.001	0.142
Bodyweight (kg)	490	500	504	518	511	531	8.53	0.001	0.01	0.001
Body condition score	2.69	2.79	2.81	2.85	2.79	2.87	0.97	0.303	0.212	0.195

L = low herbage allowance; M = medium herbage allowance; H = high herbage allowance; 0 = no concentrate; 4 = 4 kg DM/cow/day concentrate; DHA = daily herbage allowance; Conc = concentrate; Lin = linear; SCM = solids corrected milk yield; BCS = body condition score.

unsupplemented animals (729.2 and 1085.0 g/day, respectively).

3.3.1. Bodyweight and body condition score

There was no significant interaction between DHA and concentrate supplementation level for BW or BCS. Yet, there was a linear response to the quantity of DHA offered in terms of BW. Offering a low DHA during R1 (Table 3) significantly reduced BW (−15 kg; $P<0.01$) when compared to animals offered a medium and high DHA, which did not differ significantly (507 kg). Similarly, BW during R2 (Table 4) was not significantly different between the medium and high DHA treatment animals (516 kg), however animals offered a low DHA were significantly lighter ($P<0.01$; −21 kg). Daily herbage allowance had no effect on BW during the carryover period (512 kg; Table 5).

Animals supplemented with concentrate had a higher BW during R1 ($P<0.01$; +9 kg) and R2 ($P<0.001$; +14 kg) when compared to unsupplemented animals (497 and 502 kg, respectively). Offering concentrate during R1 and R2 tended ($P<0.06$) to result in increased BW during the carryover period.

Neither DHA nor concentrate level had any effect on BCS during the three measurement periods.

3.3.2. Energy balance

There was no significant effect of DHA on UFL requirements during R1 (18.3 UFL/cow/day; Fig. 1), R2 (17.0 UFL/cow/day) or the carryover period (14.6 UFL/cow/day). Nor was there an effect of DHA on UFL intake in R1 (15.6 UFL/cow/day). However, in R2 animals offered a low DHA had a lower UFL intake (−1.6 UFL/cow/day; Fig. 2) than those offered a medium and high DHA (19.2 UFL/cow/day). There was no effect of initial DHA offered on UFL intake during the carryover period (15.4 UFL/cow/day). Daily herbage allowance did not significantly effect EB in R1 (−2.73 UFL/cow/day), however during R2 animals offered a medium and a high DHA were in greater ($P<0.01$) positive EB (+0.99 UFL/

Table 5
Effect of daily herbage allowance and concentrate level on milk yield, bodyweight and body condition score at 120 days in milk (the carryover period)

	Treatment						Significance			
	L0	L4	M0	M4	H0	H4	SED	DHA	Conc	Lin
Milk yield (kg)	18.4	19.1	19.2	20.4	19.2	20.9	0.94	0.137	0.04	0.061
Milk fat content (g/kg)	41.3	38.6	37.3	40.5	37.3	39.3	2.10	0.551	0.507	0.281
Milk protein content (g/kg)	33.7	33.6	34.1	33.1	32.8	33.1	0.74	0.343	0.567	0.193
Milk lactose content (g/kg)	46.6	46.2	46.4	47.4	46.8	48.0	0.52	0.04	0.05	0.01
Milk fat yield (kg)	756.2	729.2	701.4	812.7	730.0	831.3	51.98	0.608	0.05	0.320
Milk protein yield (kg)	625.2	637.5	652.5	665.6	649.9	680.6	32.83	0.318	0.373	0.157
Milk lactose yield (kg)	854.2	877.4	881.2	967.5	900.1	1000.7	47.19	0.04	0.01	0.01
SCM yield (kg)	17.6	17.3	17.4	19.4	17.6	19.6	0.91	0.181	0.03	0.086
Bodyweight (kg)	503	505	509	520	507	527	9.81	0.136	0.06	0.06
Body condition score	2.63	2.73	2.77	2.76	2.60	2.75	0.104	0.412	0.207	0.949

L = low herbage allowance; M = medium herbage allowance; H = high herbage allowance; 0 = no concentrate; 4 = 4 kg DM/cow/day concentrate; DHA = daily herbage allowance; Conc = concentrate; Lin = linear; SCM = solids corrected milk yield; BCS = body condition score.

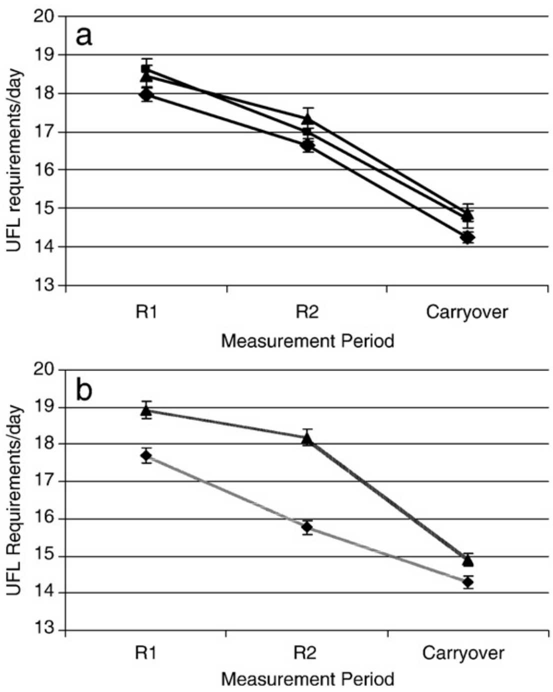

Fig. 1. Effect of daily herbage allowance (a) and concentrate level (b) on UFL requirements during R1, R2 and the carryover period. A) ▲ = high DHA; ■ = medium DHA; ♦ = low DHA; b) ♦ = 0 kg concentrate ▲ = 4 kg concentrate. The error bars correspond to the S.E. for the treatment.

cow/day) than those offered a low DHA (0.98 UFL/cow/day). During the carryover period animals initially offered a low and medium DHA had a higher ($P<0.01$; +1.15 UFL/cow/day) EB than those initially offered a high DHA (0.06 UFL/cow/day).

Offering concentrate significantly increased UFL intake in R1 (+2.4 UFL/cow/day; $P<0.001$) and R2 (+3.0 UFL/cow/day; $P<0.001$) compared to unsupplemented animals (14.4 and 17.1 UFL/cow/day, respectively). During the carryover period when all animals were offered a similar diet there was no effect of initial concentrate supplementation on UFL intake. During R1 unsupplemented animals (−3.3 UFL/cow/day) were in greater ($P<0.01$) negative EB than their supplemented counterparts (−2.1 UFL/cow/day). Supplemented animals were in more positive EB in R2 (+0.61 UFL/cow/day) compared to the unsupplemented animals (1.33 UFL/cow/day) however there was no effect of concentrate on EB during the carryover period.

3.3.3. Blood metabolites

There was no significant interaction between DHA and concentrate supplementation for any of the blood metabolite parameters (Table 7). At 40 DIM (R1) there was a linear response to the extra DHA allocated in plasma NEFA and BHB concentrations. There was no effect of DHA on plasma glucose during the three measurement periods. Plasma NEFA ($P<0.001$) and BHB ($P<0.05$) concentrations were significantly higher (+0.17 mmol/l and +0.46 mmol/l, respectively) for animals offered a low DHA compared to those offered a medium or high DHA (0.41 mmol/l and 0.71 mmol/l, respectively) during R1. There was no effect of DHA on plasma NEFA concentrations at 80 DIM (R2). However, the BHB concentrations of animals offered a medium DHA were lower ($P<0.05$; 0.11 mmol/l) than that of animals offered a low and high DHA (0.52 mmol/l). Similar to R1, plasma NEFA concentrations were lower ($P<0.01$) during the carryover period, for animals initially offered a low DHA (−0.06 mmol/l) compared to animals offered a medium and high DHA (0.14 mmol/l). There was no effect of initial DHA allocation on BHB concentrations during the carryover period. Offering a low DHA during R1 significantly increased ($P<0.05$) plasma urea concentration (+0.68 mmol/l) compared to animals offered a medium and high DHA (5.54 mmol/l). There was no difference between treatments in urea concentrations during R2 and the carryover period.

Concentrate supplementation significantly increased plasma glucose concentration (+0.32 mmol/l; $P<0.01$)

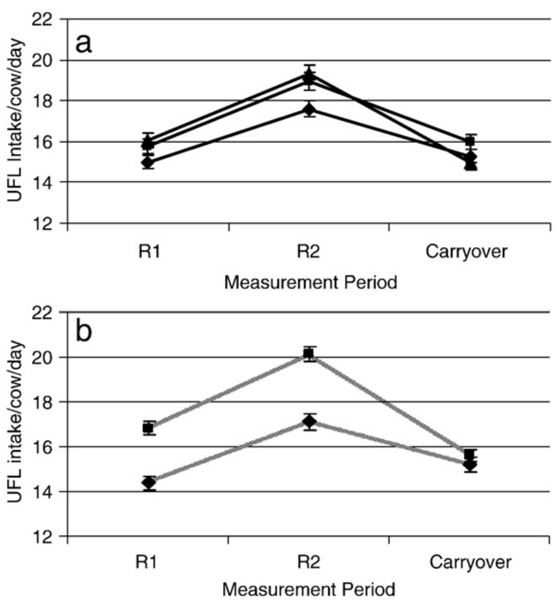

Fig. 2. Effect of daily herbage allowance (a) and concentrate level (b) on UFL intake during R1, R2 and the carryover period. A) ▲ = high DHA; ■ = medium DHA; ♦ = low DHA; b) ♦ = 0 kg concentrate ▲ = 4 kg concentrate. The error bars correspond to the S.E. for the treatment.

Table 6
Effect of daily herbage allowance and concentrate level on herbage and total dry matter intake at 40, 80 and 120 days in milk

	Treatment						Significance			
	L0	L4	M0	M4	H0	H4	SED	DHA	Conc	Lin
R1 (Herbage DMI)	12.9	11.3	14.3	11.8	13.9	12.5	0.67	0.04	0.001	0.03
(Total DMI)	12.9	15.3	14.3	15.8	13.9	16.5	0.67	0.04	0.001	0.03
R2 (Herbage DMI)	15.2	13.3	16.5	15.7	16.3	15.8	0.69	0.001	0.01	0.001
(Total DMI)	15.2	17.3	16.5	19.7	16.3	19.8	0.69	0.001	0.01	0.001
Carryover period (Herbage DMI)	16.2	15.7	16.7	16.9	15.0	16.3	0.67	0.07	0.454	0.564

L = low herbage allowance; M = medium herbage allowance; H = high herbage allowance; 0 = no concentrate; 4 = 4 kg DM/cow/day concentrate; DHA = daily herbage allowance; Conc = concentrate; Lin = linear; DMI = dry matter intake; Total = herbage + concentrate.

while it decreased plasma NEFA and BHB concentrations (−0.14 and −0.22 mmol/l) during R1 when compared to unsupplemented animals (3.04, 0.53 and 1.07 mmol/l). Similarly during R2 supplemented animals had greater plasma glucose ($P<0.01$) and lower ($P<0.001$) plasma NEFA (+0.24 and −0.22 mmol/l, respectively) concentrations than animals that remained unsupplemented (3.33 and 0.44 mmol/l, respectively). However, there was no difference between treatments in terms of plasma BHB concentration during R2. There was no effect of initial concentrate supplementation level on any blood metabolite parameters during the carryover period.

4. Discussion

Stage of lactation influences the DMI of dairy cows and hence the resulting milk production. Therefore the quantity of herbage and concentrate allocated in early lactation has repercussions on both sward quality and animal performance throughout lactation. The objective of the present study was to investigate the effect of daily herbage allowance and concentrate supplementation level on sward and milk production, TDMI and blood metabolites of spring calving dairy cows at approximately 40, 80 and 120 DIM.

4.1. Sward measurements

Due to poor growth rates in the spring of 2005, DHA was restricted to ensure that there was sufficient herbage to finish the first grazing rotation (O'Donovan, 2000). As growth rate improved DHA was increased thus all animals were offered on average 2 kg/cow/day more during R2 than during R1. Characteristic of swards grazed early in spring with a greater stocking density,

Table 7
Effect of daily herbage allowance and concentrate level plasma metabolite concentrations at 40, 80 and 120 days in milk

	Treatment						Significance			
mmol/l	L0	L4	M0	M4	H0	H4	SED	DHA	Conc	Lin
R1										
Glucose	2.83	3.37	3.14	3.40	3.15	3.32	0.128	0.148	0.001	0.157
NEFA	0.66	0.50	0.42	0.33	0.51	0.35	0.070	0.001	0.01	0.01
BHB	1.56	0.78	0.90	0.58	0.76	0.59	0.275	0.03	0.04	0.01
Urea	6.42	6.02	5.58	5.62	5.60	5.36	0.403	0.04	0.442	0.01
R2										
Glucose	3.40	3.57	3.34	3.59	3.24	3.54	0.111	0.512	0.01	0.260
NEFA	0.43	0.27	0.38	0.16	0.51	0.24	0.081	0.185	0.001	0.716
BHB	0.54	0.51	0.42	0.41	0.56	0.45	0.062	0.03	0.295	0.689
Urea	7.06	6.94	6.57	6.94	6.71	7.08	0.425	0.737	0.461	0.755
Carryover period										
Glucose	3.41	3.51	3.36	3.53	3.60	3.49	0.121	0.501	0.628	0.358
NEFA	0.43	0.27	0.38	0.16	0.51	0.24	0.037	0.01	0.093	0.101
BHB	0.30	0.33	0.27	0.31	0.33	0.29	0.036	0.577	0.897	0.843
Urea	2.31	2.68	2.77	2.31	245	2.81	0.269	0.804	0.616	0.526

L = low herbage allowance; M = medium herbage allowance; H = high herbage allowance; 0 = no concentrate; 4 = 4 kg DM/cow/day concentrate; DHA = daily herbage allowance; Conc = concentrate; Lin = linear; NEFA = non-esterified fatty acids; BHB = β-hydroxybutyrate.

lower PGSSH were recorded with decreasing herbage allowances (O'Donovan et al., 2004; Kennedy et al., 2006), as PGSSH during R1 ranged from 3.3 (low DHA) to 4.7 cm (high DHA) and 3.8 (low DHA) to 5.7 cm (high DHA) during R2 (Table 2). Maher et al. (2003) reported that offering a high DHA (24 kg DM/cow/day) significantly increased post-grazing sward height (6.5 cm) compared to the medium (5.5 cm) and low (4.4 cm) allowance treatments. Higher PGSSH resulted in reduced sward utilisation which would reportedly lead to poorer sward quality in subsequent grazing rotations (Kennedy et al., 2006; O'Donovan et al., 2004).

4.2. Animal measurements

Dry matter intake is a major factor limiting milk production in early lactation (Kertz et al., 1991) and is at its lowest level directly post-partum (Ingvartsen and Andersen, 2000). The increase in DMI from week 1 post-partum to time of peak intake has been reported to vary between 2 and 111% (Bines, 1979). In this study a difference in the range of DMI was also evident between R1 and R2 (40 and 80 DIM), when animals were offered a low, medium or high DHA (Table 6). When GDMI of R1 and R2 were compared there was an increase of 18, 23 and 22% for the low, medium and high DHA treatments, respectively. When TDMI was considered the levels of increase were 16, 20 and 19%, respectively. There was no increase in GDMI when DHA was increased from a medium to high allowance. Thus, a high DHA during the first 80 days of lactation appears to be excessive as the increase in DMI of these animals was similar to those offered a medium DHA. Overall, this indicates that offering animals a low DHA restricts DMI >80 days into lactation however it also signifies that high levels of pasture intake with low post-grazing residuals can be achieved at a medium DHA. Wales et al. (1999) reported that allowance had a greater effect on DMI in spring than in summer mainly due to the major decline in nutritive characteristics that occurs in the summer. Conversely, Friggens et al. (1998) and NRC (2001) stated that depending on the quality of the diet intake may be the result of a constraint imposed by the diet. It can therefore be assumed that it was the constraint imposed by the diet that affected DMI as the chemical analysis of the herbage showed that a high quality uniform sward was offered to all animals (Kennedy et al., 2007).

The results of this study demonstrate that TDMI increased by 16% in R1 and 18% in R2 when concentrate was included in the diet. This concurs with the review paper of Bargo et al. (2003) which stated that TDMI can be increased by up to 24% when up to 10 kg DM of concentrate is included in the diet. Stockdale (2000b) and Delaby et al. (2001) also reported that including concentrate in the early lactation diet increased TDMI relative to that achieved with pasture only diets. However, cows offered concentrate consumed less herbage than their unsupplemented counterparts. On average the substitution rates of the present study ranged from 0.27 to 0.46 kg DM herbage/kg DM concentrate which is similar to the range of 0.33 to 0.43 kg DM herbage/kg DM concentrate reported by Stockdale (1999, 2004).

Many previous studies (Delaby et al., 2001; Bargo et al., 2002; Maher et al., 2003) have reported that a high DHA increased milk yield. There was no effect of DHA offered on milk yield in R1 indicating that a low DHA is sufficient up to 40 DIM, once high quality pastures are available to animals. There tended to be an effect of DHA ($P=0.11$) offered on milk production in R2 (80 DIM) which implies that DHA should be increased before animals reach 80 DIM. However, this study did concur with many previous studies (Bargo et al., 2002; Delaby et al., 2001; Horan et al., 2005) which reported an increase in milk production when animals were supplemented with concentrate. The response to concentrate during R1 was 1.03 kg milk/kg DM concentrate, during R2 this increased to 1.48 kg milk/kg DM concentrate which demonstrates the greater degree of diet restriction endured by the unsupplemented animals. These response levels were higher than those previously reported by Horan et al. (2005; 1.00 milk/kg concentrate DM) and Kennedy et al. (2002; 0.66 kg milk/kg concentrate DM), both experiments had a similar concentrate input and animals of similar genetic merit. The results of this study have the possibility to reform grazing management practices for the early lactation dairy cow in Ireland. Given the current recommendations the first grazing rotation should be approximately 50 days in length (O'Donovan, 2000), it now appears that a low DHA is sufficient for the first grazing rotation and this should then be increased to a medium DHA by the second grazing rotation, which would coincide with 80 DIM. Furthermore, it is also evident that spring calving dairy cows in early lactation should be supplemented with a medium level of concentrate for the first 80 DIM given the high response levels achieved in this study.

Although there was no difference in milk yield between DHA treatments following R1 animals offered a low DHA had the lowest BW at the end of R1 and this continued during R2, which indicates a greater mobilisation of body reserves. Clark et al. (2005) reported that plasma glucose and plasma BHB were the best predictors of EB (mobilisation of body reserves). However, plasma BHB comes from either body tissue mobilisation or from the conversion of butyric acid in the ruminal epithelium and considering cows that eat more will produce more butyric acid it is not the best determinant of energy balance. The same can be said for blood glucose, over 90% of which is produced in the liver from propionate and amino acids (predominantly). A greater supply of precursors will result in greater blood glucose. Therefore, the most effective indicator of energy balance, particularly in a pasture-based scenario, is plasma NEFA. In this study plasma NEFA concentrations were lower when either a medium or high DHA was allocated compared to a low DHA during R1 indicating a lesser degree of body fat mobilisation (Patton et al., 2006). Additionally, animals supplemented with concentrate during R1 and R2 had lower plasma NEFA concentrations indicative of a lesser degree of mobilisation of body reserves. When actual EB was calculated for this study it was clear that the nutrient demands of lactation exceed dietary intake potential in the early post-partum period (R1), similar to that reported by McNamara et al. (2003) and Patton et al. (2006). There was no effect of DHA on UFL intake in R1 again indicating that allocating a medium to high DHA when animals are approximately 40 DIM is a profligate practice. However, the mobilisation of body reserves of animals offered a low DHA was not detrimental as body condition score was not significantly different between the treatments. Interestingly, when the entire data set was examined (previously reported in Kennedy et al., 2007) animals offered a low DHA during R1 and R2 gained more BW than their counterparts when all animals were offered the same DHA. This is reaffirmed by the results of the carryover period, where no difference in BW between treatments was recorded and by the fact that plasma NEFA concentrations decreased and there was no difference in EB. However, increasing the proportion of concentrate in the diet in early lactation has been shown to increase energy intake and improve energy balance (Coffey et al., 2004; Reist et al., 2002) which was similar to the results achieved with this study therefore suggesting that animals in early lactation should be supplemented with concentrate.

5. Conclusion

Rising costs associated with milk production necessitate a larger proportion of the dairy cow's diet being comprised of grazed grass. This study has clearly shown that offering a low quantity of herbage in early lactation does not compromise milk yield or composition at 40 DIM. Therefore, in order to embrace the dual objectives of grassland management i) adequately feeding the dairy cow while ii) simultaneously maintaining sward quality a low daily herbage allowance in early lactation is sufficient.

In conjunction with a low DHA animals should also be supplemented with concentrate as this study showed significantly increased milk yield when animals were offered 4 kg DM/cow/day concentrate at 40 and 80 DIM. Therefore the results of this study indicate that animals should be offered a low DHA up to 80 DIM after which DHA should be increased however animals should also be supplemented with concentrate during the first two grazing rotations.

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