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Original article

The effect of two contrasting grazing managements and level of concentrate supplementation on the performance of grazing dairy cows

Luc DELABY[a*], Jean-Louis PEYRAUD[a]
with the technical collaboration of Jean Rémi Peccatte[b], Nathalie Foucher[b] and Guillaume Michel[b]

[a] INRA, UMR Production du Lait, 35590 Saint-Gilles, France
[b] INRA, Domaine expérimental du Pin au Haras, 61310 Exmes, France

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Abstract — The grazing management of dairy cows is characterised by practices that vary greatly in terms of stocking rate, nitrogen fertilisation and supplementation. The objective of this 6-year experiment was to establish the response by dairy cows to increasing amounts of concentrate supplement under two contrasted rotational grazing systems. Each year, 30 cows were assigned to a Severe grazing system aimed at maximising milk production per hectare with high annual nitrogen input (280 kg N·ha^{-1}) and a high stocking rate. Another 30 cows were assigned to a Lax grazing system characterised by a lower input (120 kg N·ha^{-1}) and stocking rate aimed at offering a greater quantity of grass per animal per day. From 1995 to 1997, four moderate levels of concentrate supplementation (0, 1.4, 2.8 and 4.0 kg) adjusted according to the milk yield of the cows at turnout were compared. From 1998 to 2000, higher quantities of concentrate (0, 2, 4 and 6 kg) maintained at a flat rate between cows were compared. The Lax grazing system led to a 0.8 to 1.0 kg increase in milk yield ($P < 0.0001$) per cow per day without any significant modification of milk fat and milk protein content, compared to the Severe grazing system. Compared with the Severe treatment, the Lax treatment reduced cow grazing days by 160 days per ha and milk production by 3225 kg per ha. In both systems, concentrate supplementation made it possible to increase milk yield, with an efficiency of close to 1 kg of milk per kg of concentrate, as well as increasing milk protein content and live weight gain. The milk fat content decreased only in the last three years of the experiment, following an increased concentrate supplementation. All these animal responses remained linear up to the maximum amount of concentrate offered; there was no variation between cows supplemented with the same concentrate level. This multi-annual experiment confirms the importance of making the best possible use of herbage produced by adapting the stocking rate to achieve a post grazing sward height of 5 to 6 cm during the grazing season. With an increased genetic potential of the dairy herd, high individual cow performance at grazing can be attained by the use of concentrate supplementation.

dairy cows / grazing management / supplementation / milk production

* Corresponding author: luc.delaby@rennes.inra.fr

Résumé — Effets des conditions de pâturage et de l'apport de concentré sur les performances des vaches laitières. L'alimentation des vaches laitières au pâturage se caractérise par une grande diversité des pratiques à la fois en terme de chargement, de fertilisation azotée et de complémentation. L'objectif de cette expérience pluriannuelle est de décrire la réponse des vaches laitières à l'apport de doses croissantes de concentré dans deux situations contrastées de pâturage. Chaque année, la moitié des 60 vaches utilisées a été affectée soit à un scénario Severe visant à maximiser les performances par hectare grâce à une fertilisation azotée annuelle (280 kg $N \cdot ha^{-1}$) et un chargement élevés, soit à un scénario Lax caractérisé par une fertilisation (120 kg $N \cdot ha^{-1}$) et un chargement plus faibles afin d'offrir une plus grande quantité d'herbe par jour aux animaux. En 1995 et 1997, 4 doses modérées de concentré (0, 1,4, 2,8 ou 4,0 kg) et différentes selon la production laitière des vaches ont été comparées ; tandis que, de 1998 à 2000, des quantités plus élevées (0, 2, 4 et 6 kg) et constantes entre vaches ont été utilisées. Par rapport au scénario Severe, le scénario Lax a permis de produire 0,8 à 1,0 kg de lait en plus ($P < 0{,}0001$) par vache sans modification significative des taux butyreux et protéique du lait. La réduction du chargement avec le traitement Lax a sensiblement réduit les performances laitières par hectare (– 160 jours de pâturage et – 3225 kg de lait). Dans les deux scénarios, l'apport de concentré a permis d'accroître la production laitière, avec une efficacité proche de 1 kg de lait par kg de concentré, le taux protéique et le gain de poids vif. Le taux butyreux a diminué lors des 3 dernières années d'expérience avec l'apport de quantités plus élevées de concentré. Toutes ces réponses sont restées linéaires jusqu'à la dose maximale de concentré et n'ont pas varié entre vaches dans le cas d'un apport constant de concentré. À l'échelle de la saison complète de pâturage, cette expérience pluriannuelle confirme l'intérêt de valoriser au mieux l'herbe produite grâce à un chargement adapté qui permet des hauteurs en sortie de parcelle comprise entre 5 et 6 cm. Avec l'accroissement du potentiel génétique, la réalisation de performances individuelles élevées au pâturage est rendue possible par l'utilisation du concentré.

vaches laitières / pâturage / complémentation / production laitière

1. INTRODUCTION

Over the last twenty years, the increased size of dairy farms associated with the fixed milk production quotas and Common Agricultural Policies reform has led to a greater diversity in grazing management practices with varying nitrogen fertilisation of grassland for dairy cows. Depending on the grazing area and the availability of milk quota per hectare on the farm, there are a wide range of possible scenarios of pasture utilisation. Thus, it is currently possible to reduce the level of nitrogen input and to use more land area without penalising individual cow performance or milk composition, provided a reduction in the productivity per hectare is accepted [8, 18]. Schematically, two opposite strategies exist: (i) the maximisation of grassland productivity at the expense of individual cow performance with a high stocking rate [22]; (ii) the maximisation of the cow performance by reducing stocking rate and increasing the quantity of herbage offered and consumed [11]; this can be achieved either with or without frequently topping pastures or using a leader/follower grazing system.

Over the same period, the genetic potential of dairy herds has continued to increase. Although milk production at pasture, without concentrate increases linearly with the potential of the animal [9], it is impossible to satisfy the energy needs of high genetic merit cows with grass alone. Consequently, while the responses to supplementation have been small in the past [26, 27], they are now more marked [10, 13, 45] with efficiency equal to or higher than 1 kg milk per kg of concentrate consumed. Faced with such developments, doubts are sometimes cast on the quantities of concentrate recommended in France and on the traditional methods of concentrate allocation in proportion to the production level of the cows [21].

Few authors have studied the response to concentrate supplementation at grazing by integrating the level of concentrate consumed, the individual production potential of animals and grazing management characteristics. The aim of the present 6-year study was to establish the concentrate supplementation response curve and possible interaction with the potential of the animals, in two contrasting grazing systems.

2. MATERIALS AND METHODS

Two systems of sward utilisation, combining nitrogenous fertilisation level and herbage allowance were applied from April to October during six consecutive years (1995-2000) on the INRA experimental farm of Le Pin au Haras in Normandy (48°44' N – 0°09' E – Orne, France). The aim of the **Severe** grazing treatment was to maximise the use of the herbage produced and to obtain improved milk production per hectare. An annual fertilisation of about 300 kg N·ha^{-1} combined with a high stocking rate (5.6 cows·ha^{-1} in the spring and 2.6 cows·ha^{-1} in the summer-autumn) was imposed on this system. The aim of the **Lax** grazing treatment was to use more land area by reducing the level of nitrogen fertilisation and to stimulate herbage consumed by increasing the herbage allowance. The nitrogen fertilisation level was fixed at 120 kg N·ha^{-1}·yr^{-1} and the stocking rate was reduced to 3.6 cows·ha^{-1} in the spring and 1.8 cows·ha^{-1} in the summer-autumn.

Four concentrate supplementation levels were applied across these two grazing systems. Over the first three years of the study, the quantities of concentrate offered were moderate, between 0 and 3.5 kg (R0, R1, R2 and R3). Over the last three years, the quantities offered were increased, from 0 to 6 kg (C0, C2, C4 and C6).

The same experimental protocol was applied throughout the six years, only the concentrate supplementation levels and the methods of concentrate allocation were changed. Unless specifically stated, the experimental procedure and measurements described below relate to the entire trial period.

2.1. Grass swards

The area used consisted of permanent drained pasture (13.8 ha) and reseeded pasture (14.4 ha). The permanent pastures were made up of perennial ryegrass (*Lolium perenne*) and rough meadow grass (*Poa trivialis*) each in a similar proportion (20%), fine bent (*Agrostis capillaris* – 15%) and Yorkshire fog (*Holcus lanatus* – 15%), foxtail (*Alopeccurus pratensis* – 10%) and timothy (*Phleum pratense* – 10%) and white clover (*Trifolium repens* – 5 to 10%). The permanent pasture area was divided into 3 blocks of 4.6 ha, and then each block was subdivided into 2 paddocks of 1.8 and 2.8 ha each for the Severe and Lax grazing systems, respectively.

The reseeded swards were sown in the spring of 1995 with perennial ryegrass (cv Aragon). One third of these swards were re-sown yearly between the autumn of 1998 and the autumn of 2000 with perennial ryegrass (cv Aragon) and white clover (cv Donna). The 3 blocks of reseeded swards (4.8 ha each) were divided into 2 paddocks of 2.0 and 2.8 ha that were assigned, respectively, to the Severe and Lax treatments.

On the permanent and reseeded pastures composed of pure ryegrass, the nitrogen fertiliser was applied as ammonium nitrate (33.5% N) before the first grazing between the 15/03 and the 10/04 of each year, and then after each grazing or each cutting. With the Severe grazing treatment, the nitrogen input for each rotation was 80, 60, 60, 60 and 40 kg N per hectare, while, with the Lax grazing treatment, 4 applications of 30 kg N were carried out per hectare. After 1998, on the reseeded swards with white clover, a single annual nitrogen input of 60 or 30 kg N·ha^{-1} was carried out in March with the Severe and Lax treatments, respectively.

2.2. Animals

Each year, 60 dairy cows (including 33% primiparous cows calving at 3 years old) of the Holstein and Normande breeds (57% and 43% of cows, respectively) were divided into 8 groups of 7 or 8 cows balanced on the basis of individual cow performance observed over 2 weeks during the turnout period (Tab. I).

In addition to breed and parity, the 8 groups were balanced for stage of lactation, milk yield, fat yield (FY) and protein yield (PY), as well as the milk fat and milk protein content, body weight and body condition score evaluated at the beginning of April. Each of these eight groups was then randomly assigned to one of the eight treatments, the 30 cows under the same grazing management grazed as a single herd throughout the grazing season. On average, during the reference period, cows had been lactating for 82 days (±28) and had a mean weight of 665 kg (±65), producing 31.8 kg of milk (±6.4) with a milk fat content of 40.1 $g \cdot kg^{-1}$ (±3.9) and milk protein content of 31.7 $g \cdot kg^{-1}$ (±2.6).

2.3. Supplementation

During the first three years of the trial, apart from group R0, which did not receive concentrate, individual supplementation was assigned at a proportional level beyond a milk yield threshold at turnout fixed at 20 kg of 4% fat-corrected milk for multiparous and to 17 kg of 4% fat-corrected milk for primiparous cows. The supplementation levels, which correspond to levels R1, R2 and R3, were defined with 1 kg of concentrate for 9, 4.5 or 3 kg milk above the threshold value. Averaged over the grazing season, the animals received 0, 1.4, 2.8 and 4.0 kg concentrate per cow and day, respectively, for groups R0, R1, R2 and R3. The vitamin/mineral supplement (VMS) was offered at a rate of 300 g per cow per day for groups R0 and R1 and 150 g per cow per day for groups R2 and R3.

During the last three years, the levels of concentrate supplementation were 0.0, 2.0, 4.0 and 6.0 kg per cow per day for groups C0, C2, C4 and C6, respectively. Concentrate was offered in constant quantities to all cows of the same group independently of their reference milk yield. The quantities of VMS offered remained similar to the levels mentioned above, with 300 g for the

Table I. Dairy cow characteristics in April at the beginning of the 5-year experiments.

Years	1995 and 1997	1998 to 2000	5-year mean
Number of cows	119	174	293
Days in milk	82 (29)	82 (27)	82 (27.9)
Milk (kg)	31.6 (6.57)	32.0 (6.36)	31.8 (6.44)
Fat content ($g \cdot kg^{-1}$)	40.4 (3.81)	39.9 (3.95)	40.1 (3.90)
Protein content ($g \cdot kg^{-1}$)	31.5 (2.60)	31.9 (2.59)	31.7 (2.59)
Body weight (kg)	666 (64.4)	665 (65.1)	665 (64.7)
Body condition score (points)	2.4 (0.80)	2.6 (0.60)	2.5 (0.75)

Mean and standard error into brackets.

groups C0 and C2 and 150 g for the groups C4 and C6.

The concentrate and VMS were offered by means of automatic dispensers (ACD – C16 compact feed system – Westfalia) that were accessible to the animals for 1 h to 1 h 30 after each milking.

The concentrate and the VMS formulation remained identical over the six years of the experiment. The experimental concentrate was composed of the following (in % fresh weight): wheat (16.0), grain maize (15.5), barley (14.0), beet pulp (16.0), citrus pulp (16.0), protected soya bean meal (18.0), sugar-cane molasses (2.5), fat (1.0) and salt (1.0). The VMS was composed of 60% minerals corresponding to 12/16/5 of P/Ca/Mg and 40% feed additives based on the by-products of cereals, oil meal and molasses, which represents a final content of P/Ca/Mg of 7/11/3 g per 100 g. The chemical composition of the concentrate conformed to expected values [25] with OM, CP, CF, NDF and ADF contents of 942, 180, 76, 221, 92 $g \cdot kg^{-1}$ DM, respectively. Assuming OM digestibility was 0.88, the calculated values of UFL, PDIE and PDIN were 1.17, 156 and 136 $g \cdot kg^{-1}$ DM, respectively.

2.4. Grazing management

A simplified rotational grazing system [20] was applied. This comprised three paddocks of permanent pasture in the spring, which was then extended to three paddocks of reseeded swards in the summer/autumn. The decision to move cows from a given paddock was decided according to the daily milk yield variation for each group during their residency time in the paddock [22]. A paddock change took place when the milk yield average of the herd over the last three days in the paddock reached 85% and 92% of the maximum production under the Severe and Lax grazing treatments, respectively. This difference in the coefficients allowed the maintenance of a long-term difference in herbage quantity offered between the two grazing systems.

The two herds of 30 cows corresponding to the two grazing systems were managed independently during each grazing rotation. However, in order to begin each grazing rotation on the same date for both herds, the area of the last paddock was occasionally reduced and the excess grass was harvested and conserved as haylage.

Each year, turnout took place at the beginning of April when ground conditions allowed and the grass supply on the permanent pasture was sufficient. During the second rotation, in May, the grass was cut, wilted and ensiled from the reseeded pasture. After this date, all other grass surpluses were harvested as hay or haylage. A single topping was carried out each year on all the permanent paddocks between the end of the 1st and the 3rd grazing rotation.

2.5. Measurements

2.5.1. Swards

The herbage mass present before grazing was estimated by cutting 6 or 8 strips (10 m × 0.5 m) with a motor scythe on paddocks in the Severe or Lax grazing treatments, respectively. The exact length of each strip was measured systematically. All the mown herbage mass was then collected, weighed by strip and a composite sample was taken. This sample was weighed, dried in a ventilated drying oven (48 h at 80 °C) to determine the dry matter content (DM) of the herbage and was stored. In order to calculate the density of the herbage, (in kg $DM \cdot cm^{-1} \cdot ha^{-1}$), 10 grass height measurements (in cm) were carried out on each strip before and after mowing using an electronic plate meter (30 × 30 cm – 4.5 $kg \cdot m^{-2}$ [42]).

The grass height was measured with a plate meter (150 measurements per hectare) on all the plots before and after grazing, as well as after topping.

When surplus grass was harvested, the harvested area was measured and the harvested herbage was weighed. The ammonium nitrate quantity spread at each rotation was weighed. Rainfall as well as minimum and maximum temperatures under shelter were recorded daily at the official weather station located near the experimental area.

2.5.2. Animals

The milk yield of each cow was measured every day using flow meters (Westfalia) at each of the two daily milkings beginning at about 06.30 h and 16.00 h. Each week, six individual milk samples were taken during six consecutive milkings in order to determine fat and protein content for each cow (LiLaNo – 50008 St Lô, France) with an infra analyser (Milkoscan, Foss Electric, DK-3400 Hillerod, Denmark).

The animals were weighed every Wednesday after the morning milking. The body condition score was evaluated according to the method suggested by Agabriel et al. [1] by the same two assessors on three occasions during the grazing season, i.e. at turnout (April), at the half-way stage (July) and at the end of the trial (October).

The organic matter digestibility of the herbage intake (dHI) by the animals which did not receive concentrate was estimated using the method of the faecal index. At each grazing rotation on the permanent pasture, faecal grab samples were taken from each cow every two days after each milking. These individual samples were pooled within grazing treatment, and then one homogeneous sample of about 500 g was collected and dried in a drying oven (48 h at 80 °C). At the end of the trial, the composite daily samples on each treatment were mixed to obtain a sample that was representative of the residency time on the paddock. From the nitrogen content of faeces (Nf in % OM) and nitrogen in the herbage offered (Nh in % OM), the digestibility of the herbage eaten was estimated from the equation developed by Peyraud et al. (unpublished results):

$$dHI = 98.72 - 48.98 / Nf - 6.94 \times (Nh/Nf) + d$$

with d = + 0.49 in the spring and – 0.49 in the autumn ($N = 31$, $R^2 = 0.887$ and $rse = 1.12$).

The activity of the animals was recorded individually during the diurnal phase on 24 cows (3 cows per treatment) in each rotation on the 3rd or 4th day while grazing permanent pasture. On the day before observation, three animals, selected at turnout, were fitted with plastic banners numbered from 1 to 3 and with different colours according to their level of concentrate supplementation. Observation of the animals was carried out from sunrise to sunset at intervals of 10 min [34], to record three types of activity: grazing, walking or involved in another activity. The activity observed was regarded as being effective over a time-span of 10 min.

The daily intakes of concentrate were calculated from the number of doses consumed by each cow recorded by the ACD and the average weight of the dose was checked twice weekly on each device. These control doses were preserved so, each year, an average sample could be made up representative of the concentrate offered during the trial.

The additional quantities of conserved forage distributed during periods of grass shortage, as well as the refusals, were all weighed each day for each herd of 30 cows to determine the mean DM intake within the grazing system.

2.5.3. Chemical analyses

The composite samples of herbage taken before each grazing were ground (0.8 mm screen) before determining the contents of organic matter (OM), crude protein (CP: N

Dumas × 6.25) and crude fibre (CF). The OM digestibility of the herbage offered (dHO) was calculated from the pepsin-cellulase digestibility according to the method proposed by Aufrère and Demarquilly [2]. The OM, CP, CF and NDF-ADF contents were determined on each crushed sample of concentrate. After grinding through a 0.8-mm screen, the composite samples of faeces were analysed in order to determine the OM and N contents.

All of the chemical analyses were performed at the Laboratory of Development and Analyses (LDA – 22440, Ploufragan, France). The nutritive values (UFL and PDI) of the different types of feed were calculated according to the predictive equations of INRA [24].

2.5.4. Calculations and statistical analyses

The very unfavourable climatic conditions in 1996 (Tab. II) disrupted and shortened the grazing season. Consequently, the results presented relate to five years of study (1995 and 1997 to 2000). To evaluate the effect of the two grazing systems on both the productivity of the paddocks and animal performance, the data were first analysed by pooling the five years together. Then, the effect of concentrate supplementation on the performance of the dairy cows and its possible interaction with the grazing treatment were analysed in two periods corresponding to different methods of allocating the concentrate, one concerning the two years 1995 and 1997 and the other the three years from 1998 to 2000.

Each analysis was carried out over the period of the spring (from the end of April to the beginning of July) and over the whole grazing season (from the end of April to mid October).

Periods in stall housing or with inputs of additional forages imposed by grass shortages of limited duration (5 weeks in 1995

Table II. Main climatic conditions during the 6 years of experiment in comparison with the 25-year mean.

Month		April	May	June	July	Augt	Sept	Oct	Total
Temperature (°C)	1995	8.5	12.3	14.6	19.3	19.1	13.1	13.1	
	1996	8.2	9.7	15.7	16.5	16.9	12.2	10.9	
	1997	7.5	12.3	14.7	16.7	20.7	14.2	10.9	
	1998	8.4	14.1	15.0	16.1	16.7	15.5	11.4	
	1999	9.5	14.0	15.0	18.9	18.3	16.3	10.6	
	2000	8.7	14.0	16.6	15.9	18.1	15.2	10.9	
Mean	**1970-94**	**7.5**	**11.1**	**14.3**	**16.6**	**16.1**	**13.8**	**10.0**	
Rain (mm)	1995	46	51	22	75	40	89	13	336
	1996	14	95	8	14	30	23	52	236
	1997	24	79	150	28	59	7	52	399
	1998	124	12	88	37	17	127	97	502
	1999	76	31	27	24	123	105	51	437
	2000	103	79	8	230	32	70	182	704
Mean	**1970-94**	**52**	**68**	**56**	**53**	**42**	**62**	**63**	**396**

and 1998, 7 weeks in 1999) were excluded from the calculations.

2.5.4.1. Production and utilisation of the swards

The calculation method specified by Delaby and Peyraud [8] can be applied to assessing the productivity of swards and their utilisation. It was used here to evaluate the pre-grazing herbage mass (in kg $DM \cdot ha^{-1}$), the produced herbage mass (in kg $DM \cdot ha^{-1}$) and the removed herbage mass (in kg $DM \cdot cow^{-1} \cdot day^{-1}$). This latter measure incorporates an estimation of herbage growth during the time the animals were in the paddock.

The grazing outcomes were calculated each year according to the methodology of Hoden et al. [19].

2.5.4.2. Animal performances

For each cow, the average daily milk yield, the milk fat and protein content as well as the quantities of concentrate intake were calculated from the experimental data recorded after the period of turnout (2 to 3 weeks), during the spring (72 days on average over 5 years) or during the whole grazing season (148 days on average over 5 years).

The body weight at the end of the spring and at the end of each grazing season corresponds to the average of the two last weighings carried out in late June/early July and in October, respectively for each year. The average daily bodyweight changes were calculated from the difference between the averages of the first two weighings carried out after randomisation and the weight at the end of the spring or at the end of the grazing season. Variations in body condition score were calculated from the difference between the initial score at randomisation and the final score assigned to each cow in October.

The average daily durations of each behavioural activity observed on the 24 cows were calculated for each year based on 2 observation days in the spring and 4 or 5 observation days during the grazing season. After validation, the final results comprised 116 individual recordings.

2.5.4.3. Statistical analyses

The whole data set was analysed by variance analysis and linear regression, including the calculation of the adjusted means, according to the generalised linear model. The effects of the various factors were evaluated by means of the F test. The form of the response expression in relation to concentrate input was characterised using the method of orthogonal polynomial contrasts [41].

The results of herbage production, as well as the chemical composition and nutritive value of herbage offered and the utilisation of swards by the animals (corresponding to 90 grazing sequences), were analysed according to a partially hierarchised linear model involving the following factors: $Y_{ijk} = A_i + P_j(A_i) + S_k + A_i \times S_k + e_{ijk}$ with A = year effect (i = 1 to 5), P(A) = within-year grazing sequence effect (j = 1–15, 16, 17, 20 or 22 according to year), S = system effect (k =1–2) and e = residual.

In the course of the trial or during the analysis of the results, six cows were eliminated for veterinary reasons (1 in 1997, 2 in 1998, 2 in 1999 and 1 in 2000) or because of their excessively early stage of lactation at turnout (1 in 1998) that would lead to instability in the reference period. Finally, the analysis of milk performance covered 293 cows, which involved 119 cows in the first two years and 174 cows in the last three years.

An initial general analysis of the animal's results over the five years was carried out according to a partially hierarchised linear model: $Y_{ijklmn} = M_i + A_j(M_i) + S_k + C_l(M_i) + B_m + L_n + S_k \times M_i + S_k \times A_j(M_i) + S_k \times C_l(M_i) + b \times Cov_{ijklmn} + e_{ijklmn}$, with M = the concentrate allocation method effect (i = 1 to 2), A(M) = within-method year effect (j = 1–2 or 1–3), S = system effect (k = 1–2), C(M) = within-method concentrate effect (l = 1–4), B = breed effect (m = 1–2), L = lactation number effect (n = 1–2), Cov = the average value observed for variable Y during the reference period and e = residual.

Then, for each concentrate allocation method (in 1995 and 1997 for the first and from 1998 to 2000 for the second), the following model was applied: $Y_{ijklm} = A_i + S_j + C_k + B_l + L_m + A_i \times S_j + A_i \times C_k + S_j \times C_k + b \times Cov_{ijklm} + b_k C_k \times Cov_{ijklm} + e_{ijklm}$, with A = year effect (i = 1–2 or 1–3), S = system effect (j = 1–2), C = concentrate effect (k = 1–4), B = breed effect (l = 1–2), L = lactation number effect (m = 1–2), Cov = average value observed for the variable Y during the reference period and e = residual. The interaction of the slope $b_k C_k \times Cov_{ijklm}$ was only considered in the model when applied to 1995 and 1997.

3. RESULTS

3.1. Climatic conditions and report of the five grazing seasons

Cumulated monthly rainfall was variable between years for given months and average monthly temperatures were generally higher than normal, in particular in May, June and August, compared with the values recorded during the years 1970–1994 (Tab. II). These temperatures nevertheless remained favourable for grass growth. The years when feed shortages occurred were due to reduced rainfall in the late spring (June 1995, May 1998) or in the summer (August 1998, July 1999) despite a cumulative rainfall over seven months close to or higher than the average for the years 1970–1994 (396 mm).

On average, the grazing season began on April 7 and ended after 5 grazing rotations at the beginning of November. On the permanent pastures, the annual nitrogen input was 287 and 129 kg N per hectare, whilst on the reseeded pastures, it was 208 and 112 kg N·ha^{-1} for the Severe and Lax treatments, respectively.

The duration of each grazing rotation and the plot areas used in the two grazing systems are detailed in Table III. The first grazing rotation lasted on average 40 days, and took place almost exclusively on permanent pastures. After silage harvesting, during the 3rd week of May, reseeded pastures were grazed at the end of the second grazing rotation, and then during rotations 3 and 4. During the 5th rotation, only the permanent pastures were grazed. This rotation lasted for 22 days. At this time, the process of drying off cows had started and ground conditions had made grazing impossible. The grazing areas in both of the systems were at a minimum during the first grazing rotation (19.4 and 29.8 ares·cow^{-1} for Severe and Lax, respectively) and expanded in the summer during the third grazing rotation (34.9 and 52.3 ares·cow^{-1}, respectively).

Table III. Mean starting dates, grazing duration and area grazed at each rotation on the two grazing treatments (5-year mean).

Rotation number	1	2	3	4	5
Starting date	07/04	18/05	03/07	27/08	11/10
Grazing duration (days)	40 ± 7	47 ± 5	50 ± 8	39 ± 4	22 ± 5
Total grazed area (·cow^{-1})					
Severe	19.4 ± 1.1	28.7 ± 5.9	34.9 ± 4.3	32.7 ± 3.0	22.0 ± 6.0
Lax	29.8 ± 2.5	44.1 ± 8.2	52.3 ± 5.1	48.5 ± 4.2	33.6 ± 8.4

3.2. Effect of the grazing system on sward productivity, herbage utilisation and animal performance

Grass growth and herbage produced in the spring and during the whole grazing season were lower on the Lax grazing treatment compared with the Severe grazing treatment ($P < 0.0001$ – Tab. IV). Pre-grazing height and herbage mass above 5 cm were significantly lower under the Lax grazing treatment (i.e. on average –0.8 cm and –118 kg DM·ha^{-1}, respectively, over the entire grazing season).

On average, over the 5 years, the paddocks of the Severe and Lax grazing treatments produced 12 120 and 10 155 kg of DM·ha^{-1}, respectively. With reduced nitrogen

Table IV. Sward productivity, chemical composition and nutritive values of herbage offered according to the grazing treatment (5-years mean).

Grazing treatment	Severe	Lax	Rse	Signif.
Spring (07/04 to 04/07 – 89 days)				
Herbage production (kg DM·ha^{-1}·rotation^{-1})	2974	2468	385.6	<0.001
Grass growth (kg DM·ha^{-1}·day^{-1})	78.0	65.9	10.13	<0.001
Pre-grazing biomass (above 5 cm – kg DM·ha^{-1})	2612	2307	398.8	0.001
Pre-grazing height (cm)	14.3	12.9	1.32	<0.001
DM (%)	19.0	21.2	1.38	<0.001
OM (g·kg^{-1} DM)	902	899	10.2	0.158
CP (g·kg^{-1} DM)	199	159	13.1	<0.001
CF (g·kg^{-1} DM)	231	237	13.2	0.047
OM digestibility	0.766	0.737	0.021	<0.001
UFL (g·kg^{-1} DM)	0.95	0.90	0.04	<0.001
PDIE (g·kg^{-1} DM)	101	91	3.9	<0.001
PDIN (g·kg^{-1} DM)	125	100	8.2	<0.001
All season (07/04 to 12/10 – 189 days)				
Herbage production (kg DM·ha^{-1}·rotation^{-1})	2424	2031	354.5	<0.001
Grass growth (kg DM·ha^{-1}·day^{-1})	61.6	51.9	9.05	<0.001
Pre-grazing biomass (above 5 cm – kg DM·ha^{-1})	2210	2092	392.0	0.047
Pre-grazing height (cm)	12.4	11.6	1.13	<0.001
DM (%)	21.1	23.8	1.55	<0.001
OM (g·kg^{-1} DM)	896	892	10.0	0.010
CP (g·kg^{-1} DM)	202	161	12.3	<0.001
CF (g·kg^{-1} DM)	230	240	11.3	<0.001
OM digestibility	0.742	0.705	0.021	<0.001
UFL (g·kg^{-1} DM)	0.91	0.84	0.04	<0.001
PDIE (g·kg^{-1} DM)	99	88	3.8	<0.001
PDIN (g·kg^{-1} DM)	127	101	7.7	<0.001

For all these parameters, the Year × System interaction was non-significant.
Severe: grazing system with high nitrogen input (208 kg N·ha^{-1}) and stocking rate; Lax: grazing system with low nitrogen input (120 kg N·ha^{-1}) and stocking rate; DM: dry matter; OM: organic matter; CP: crude protein; CF: crude fibre; UFL: feed unit for lactation; PDIE: protein digestible in intestine from microbial origin and dietary origin according to energy supply; PDIN: protein digestible in intestine from microbial origin and dietary origin according to nitrogen supply.

input and increased grazing area (approximately 50%), the number of cow grazing days per hectare decreased by 497 to 337 days for the Severe and Lax grazing systems (Tab. V). Consequently, the areas under the Lax treatment yielded 3324 kg less milk per hectare (–30.7%) and the DM of harvested forage decreased by 1.0 t per hectare.

Over the total grazing area used, the two grazing treatments produced a similar quantity of milk, 123 314 and 127 562 kg for the Severe and Lax treatments, respectively, while each system yielded approximately 33 t of forage on a DM basis.

Compared to the Severe treatment, the herbage offered to the animals under the Lax treatment (Tab. IV) has a higher DM content (23.8 vs. 21.1% – $P < 0.0001$), a lower CP content (161 vs. 202 g·kg^{-1} DM – $P < 0.0001$), a slightly higher CF content (240 vs. 230 g·kg^{-1} DM – $P < 0.0001$) and a lower OM digestibility (0.705 vs. 0.742 – $P < 0.0001$). These differences were of a

Table V. Overall productivity of the total grazed area according to the grazing treatment (5-year mean – 189 grazing days per year – 30 cows per system).

Grazing treatment	Severe	Lax
Total grazing area (ha)	11.4	16.8
Cow grazing days (·ha^{-1})	497	337
Milk yield (kg·ha^{-1})	10817	7593
Concentrate intake (kg DM·ha^{-1})	1274	866
Conserved forage intake (kg DM·ha^{-1})	915	617
Forage harvested (t DM·ha^{-1})	2.90	1.95

Table VI. Pasture utilisation according to the grazing treatment (5-year mean).

Grazing treatment	Severe	Lax	Rse	Significance
Spring (07/04 to 04/07 – 89 days)				
Area offered (m^2·cow^{-1}·day^{-1})	59	91	9.8	<0.001
Herbage allowance (kg DM·cow^{-1}·day^{-1})[1]	17.3	24.0	3.69	<0.001
Post-grazing height (cm)	5.7	6.8	0.51	<0.001
Herbage removed (kg DM·cow^{-1}·day^{-1})	15.6	17.9	2.47	<0.001
OM herbage intake digestibility[2]	0.788	0.792	0.005	0.167
All season (07/04 to 12/10 – 189 days)				
Area offered (m^2·cow^{-1}·day^{-1})	74	113	10.5	<0.001
Herbage allowance (kg DM·cow^{-1}·day^{-1})[1]	17.7	26.2	4.18	<0.001
Post-grazing height (cm)	5.5	6.6	0.48	<0.001
Herbage removed (kg DM·cow^{-1}·day^{-1})	15.7	18.6	2.52	<0.001
OM herbage intake digestibility[2]	0.776	0.777	0.020	0.918

[1] Including estimated grass growth during the paddock duration; [2] estimated with the faecal index technique obtained on the two zero-concentrate groups of cows; Rse: residual square error.

similar order of magnitude during the spring period. Consequently, the nutritive value of the offered herbage (UFL and PDI) was significantly lower for the Lax treatment while remaining of good quality (Tab. IV).

A greater grazing area was offered per cow per day in the Lax grazing treatment (Tab. VI), making it possible to compensate for the lower herbage mass present per hectare and providing more herbage per cow per day than in the Severe grazing treatment (26.2 vs. 17.7 kg DM·cow^{-1}·day^{-1}, respectively, $P < 0.0001$). Compared to the Severe treatment, the herbage removal was greater and the post-grazing height was significantly higher on swards under the Lax treatment (+2.3 to 2.9 kg DM·cow^{-1}·day^{-1} and +1.1 cm – $P < 0.001$). The OM digestibility of the herbage eaten, estimated from the faecal index for unsupplemented cows, did not differ significantly between the Severe and Lax treatments, with an average recorded value of 0.78 over the grazing season (Tab. VI).

In the spring and throughout the grazing season (Fig. 1), cows of the Lax treatment produced significantly more milk (+0.9 and +0.8 kg, respectively – $P < 0.0001$), with higher fat yield (+35 and +30 g – $P < 0.001$) and protein yield (+38 and +28 g – $P < 0.0001$) (Tab. VII). The mean milk fat content did not differ significantly between treatments (38.9 g·kg^{-1} in the spring and 40.0 g·kg^{-1} during the complete grazing season). The milk protein content was a little higher for animals under the Lax treatment in the spring (+0.4 g·kg^{-1} – $P < 0.001$), but remained similar between treatments during the grazing season (+0.2 g·kg^{-1} – $P < 0.09$).

The body weight at the end of the spring period and the body weight change were significantly higher for animals on the Lax grazing treatment. These effects became less marked in the summer/autumn, to such an extent that, at the end of the grazing season, there were negligible differences in body weight and body condition score between treatments (671 and 677 kg and 2.35

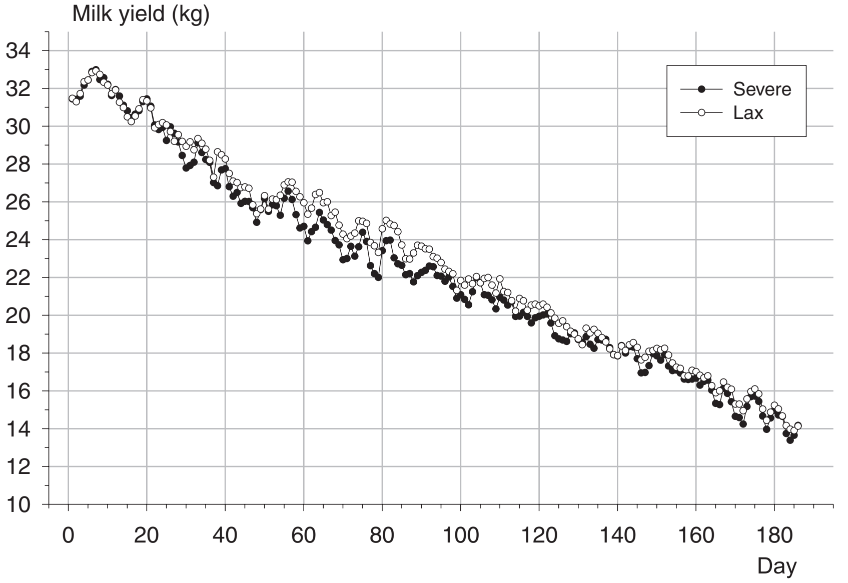

Figure 1. The effect of the grazing treatments on the daily milk yield during the grazing seasons (5-year mean).

Table VII. Dairy cow performance according to the grazing treatment (5-year mean).

Grazing treatment (n of cows)	Severe (146)	Lax (147)	Rse	Significance
Spring (24/04 to 04/07 – 72 days)				
Milk yield (kg·day^{-1})	24.5	25.4	1.45	<0.001
Milk fat content (g·kg^{-1})	38.9	38.9	1.68	0.859
Milk protein content (g·kg^{-1})	31.4	31.8	0.93	<0.001
Fat yield (g·day^{-1})	949	984	62.5	<0.001
Protein yield (g·day^{-1})	767	805	45.1	<0.001
Fat corrected milk yield (kg·day^{-1})	24.1	24.9	1.42	<0.001
Final body weight (kg)	654	662	19.2	<0.001
Body weight change (kg·day^{-1})	0.070	0.181	0.246	<0.001
Grazing time (min·day^{-1})	407	393	30.4	0.012
All season (24/04 to 12/10 – 148 days)				
Milk yield (kg·day^{-1})	20.7	21.5	1.63	<0.001
Milk fat content (g·kg^{-1})	40.0	40.0	1.90	0.875
Milk protein content (g·kg^{-1})	32.5	32.7	1.14	0.085
Fat yield (g·day^{-1})	823	853	65.0	<0.001
Protein yield (g·day^{-1})	670	698	48.6	<0.001
Fat corrected milk yield (kg·day^{-1})	20.6	21.4	1.55	<0.001
Final body weight (kg)	671	677	31.9	0.106
Body weight change (kg·day^{-1})	0.130	0.158	0.176	0.181
Body condition score at the end	2.35	2.40	0.424	0.375
Body condition score change	–0.25	–0.20	0.422	0.357
Grazing time (min·day^{-1})	409	392	26.8	0.002

and 2.40 for the Severe and Lax grazing treatments, respectively – $P > 0.10$) and the average body weight gain did not differ significantly ($P > 0.10$).

On average, the total observation time excluding the milking process was 678 min in the spring and 666 min over the grazing season. Both in the spring, as well as over the grazing season, the grazing time observed was shorter by approximately 15 minutes per day ($P < 0.01$) for the cows under the Lax treatment. These 15 minutes were distributed equally between the time spent walking and doing other activities.

3.3. The effect of supplementation on dairy cow performance

During the years 1995 and 1997, the average concentrate intake was 0.24, 1.32, 2.38, 3.54 kg DM per cow per day in the spring and 0.12, 1.25, 2.34 and 3.54 kg DM per cow per day during the whole grazing season for the treatments R0, R1, R2 and R3, respectively. Over the last three years, from 1998 to 2000, the mean daily consumption of concentrate was similar in the spring and during the grazing season overall, i.e. 0.15, 1.69, 3.43 and 5.00 kg DM per

Table VIII. Dairy cow performance according to the grazing treatment and the mean level of concentrate supplementation (Year 1995 and 1997).

Grazing treatment	Severe				Lax					Significance			
Concentrate (n of cows)	R0(14)	R1(16)	R2(16)	R3(14)	R0(14)	R1(16)	R2(15)	R3(14)	Rse	Grazing	Conc.	Inter.	Conc.× Cov.
Spring (20/04 to 04/07 – 76 days)													
Concentrate intake (kg DM)	0.24	1.37	2.44	3.45	0.24	1.26	2.31	3.62					
Milk yield (kg)	22.5	24.5	25.1	25.8	24.3	25.0	26.4	27.1	1.24	<0.001	<0.001	0.215	0.002
Milk fat content ($g \cdot kg^{-1}$)	40.4	40.0	40.1	39.2	40.0	39.5	38.8	39.2	1.47	0.038	0.063	0.365	0.783
Milk protein content ($g \cdot kg^{-1}$)	30.8	30.6	31.3	31.8	31.2	31.7	31.4	31.7	0.94	0.039	0.022	0.117	0.984
Fat yield (g)	908	978	1002	1006	973	980	1017	1058	55.2	0.002	<0.001	0.101	0.025
Protein yield (g)	690	747	779	816	755	788	822	854	38.1	<0.001	<0.001	0.531	0.006
Fat corrected milk (kg)	22.6	24.5	25.1	25.4	24.3	24.7	25.8	26.7	1.25	<0.001	<0.001	0.119	0.007
Final body weight (kg)	646	637	655	668	651	668	661	664	21.6	0.021	0.022	0.013	0.114
Body weight change ($kg \cdot d^{-1}$)	–0.059	–0.089	0.093	0.254	0.007	0.205	0.169	0.148	0.242	0.069	0.006	0.023	0.051
Grazing time ($min \cdot day^{-1}$)	412	413	400	388	387	366	338	402	27.6	0.001	0.075	0.027	
All season (20/04 to 12/10 – 158 days)													
Concentrate intake (kg DM)	0.12	1.29	2.41	3.44	0.12	1.20	2.27	3.64					
Milk yield (kg)	18.2	20.1	20.8	21.6	19.8	20.3	22.2	22.7	1.43	<0.001	<0.001	0.244	<0.001
Milk fat content ($g \cdot kg^{-1}$)	41.2	40.9	41.1	40.4	40.5	40.5	39.6	40.4	1.72	0.038	0.632	0.418	0.929
Milk protein content ($g \cdot kg^{-1}$)	31.7	31.5	32.2	32.8	31.8	32.5	32.0	32.7	1.11	0.400	0.013	0.089	0.614
Fat yield (g)	748	817	851	865	802	815	876	910	60.0	0.008	<0.001	0.271	0.006
Protein yield (g)	574	628	665	701	628	655	704	734	40.5	<0.001	<0.001	0.631	<0.001
Fat corrected milk (kg)	18.5	20.3	21.1	21.6	20.0	20.3	22.0	22.7	1.40	0.002	<0.001	0.233	0.001
Final body weight (kg)	652	655	673	699	642	675	670	691	32.3	0.980	<0.001	0.244	0.514
Body weight change ($kg \cdot d^{-1}$)	0.010	0.068	0.144	0.281	–0.050	0.124	0.122	0.219	0.175	0.510	<0.001	0.525	0.390
BCS at the end	2.05	2.00	2.44	2.53	1.78	2.22	2.39	2.54	0.46	0.802	<0.001	0.278	0.307
BCS change (points)	–0.49	–0.54	–0.15	0.03	–0.79	–0.34	–0.14	0.03	0.47	0.816	<0.001	0.275	0.249
Grazing time ($min \cdot day^{-1}$)	440	428	417	399	402	375	367	400	24.5	<0.001	0.049	0.079	

BCS: body condition score; R0, R1, R2, R3: 0, 1.4, 2.8, and 4.0 kg concentrate per cow per day; Conc.: concentrate; Inter.: interaction; Cov.: pre-experimental value used as covariate.

cow for the levels C0, C2, C4 and C6, respectively.

Whatever the methods of concentrate allocation, no significant interaction was detected between the grazing system and concentrate intake on milk production or milk composition. Similarly, the response to Severe or Lax grazing treatments and the various levels of concentrate supplementation did not differ significantly between Holstein and Normande breeds.

In the spring of 1995 and 1997 as during the whole grazing season, concentrate input produced a significant and linear increase ($P < 0.001$) in yield (milk, 4%-fat corrected milk, fat and protein) as well as in milk protein content (Tab. VIII). The level of milk production at turnout had a significant effect on the level of response in milk, milk fat and milk protein yield to concentrate intake, such that high-producing cows gave a stronger response to concentrate supplementation ($P < 0.0001$).

In the spring, the milk fat content decreased with increasing concentrate input ($P < 0.063$), but this moderate effect disappeared when considering the performance over the whole grazing season ($P > 0.62$).

On average, concentrate supplementation led to a reduction in grazing time. However, in the spring and over the whole grazing season, the animals differed significantly between grazing treatments, in particular under the Lax treatment, the cows in group R3 had a longer grazing duration.

On both grazing treatments, the body weight at the end of the spring increased with the level of concentrate supplementation (Tab. VIII). The body weight changes over this period remained negative up to a level corresponding to the R2 supplementation level in cows under the Severe grazing treatment, while they already had attained high positive values at the R1 level on the Lax treatment. Over the complete grazing season, concentrate input had a significant linear effect on body weight gain and consequently body weight at the end of the trials. The animals maintained their body condition at the R3 supplementation level, but lost 0.1 to 0.8 body condition units on treatments R0, R1 and R2.

During the last three years, the input of concentrate led to a significant increase ($P < 0.001$) in the milk yields (4%-fat corrected milk, milk fat and protein yield) as well as the protein content (Tab. IX). Conversely, the milk fat content decreased significantly ($P < 0.0001$) with increasing quantities of concentrate. All these responses remained linear ($P < 0.0001$) up to the maximum supplementation level. Over the entire grazing season, the responses were +0.96 kg milk, +28 g fat yield, +35 g protein yield and –0.38 $g \cdot kg^{-1}$ milk fat content per kg DM concentrate intake. Although the response of milk protein content to concentrate supplementation was on average +0.20 $g \cdot kg^{-1}$ per kg DM concentrate intake, it was three times greater ($P < 0.05$) under the Severe treatment (+ 0.29 $g \cdot kg^{-1}$) compared with the Lax treatment (+ 0.11 $g \cdot kg^{-1}$). In contrast to the first two years, the responses of the milk, fat and protein yields did not vary with the level of production of the animals at turnout.

The grazing time decreased significantly with the concentrate supplementation (–40 min per day between the extreme levels), stabilising at around 400 minutes in the spring and 380 min over the whole grazing season in cows under the C4 and C6 treatments.

Similarly, the changes in body weight and body weight at the end of the period increased linearly with the concentrate supplementation ($P < 0.0001$ – Tab. IX). Thus, at the end of the trial, the body weight of the cows increased on average by 7.9 kg per kg DM concentrate intake, corresponding to an additional daily body weight gain of +0.04 kg per kg of concentrate intake. Finally, concentrate supplementation made it possible to maintain body condition

Table IX. Dairy cow performance according to the grazing treatment and the level of concentrate supplementation (Year 1998 to 2000).

Grazing treatment	Severe				Lax					Significance		
Concentrate (n of cows)	C0(22)	C2(22)	C4(22)	C6(20)	C0(22)	C2(21)	C4(23)	C6(22)	Rse	Grazing	Conc.	Inter.
Spring (27/04 to 06/07 – 71 days)												
Concentrate intake (kg DM)	0.13	1.71	3.43	4.95	0.17	1.68	3.44	5.05				
Milk yield (kg)	22.3	23.8	25.5	26.5	23.2	23.9	25.9	27.4	1.45	0.007	<0.001	0.461
Milk fat content ($g \cdot kg^{-1}$)	39.2	38.4	37.8	36.6	39.4	39.3	37.9	37.4	1.76	0.060	<0.001	0.512
Milk protein content ($g \cdot kg^{-1}$)	31.1	31.1	31.9	32.4	31.7	32.0	32.4	32.2	0.88	0.001	<0.001	0.057
Fat yield (g)	870	912	959	960	915	938	975	1018	63.8	<0.001	<0.001	0.418
Protein yield (g)	690	735	807	855	733	758	832	877	42.4	<0.001	<0.001	0.646
Fat corrected milk (kg)	22.0	23.2	24.6	25.0	23.0	23.6	25.0	26.3	1.43	<0.001	<0.001	0.388
Body weight at the end (kg)	645	653	657	668	652	661	669	670	17.0	0.006	<0.001	0.659
Body weight change ($kg \cdot d^{-1}$)	–0.093	0.075	0.118	0.242	0.132	0.165	0.289	0.277	0.240	<0.001	<0.001	0.269
Grazing time ($min \cdot day^{-1}$)	441	414	388	415	434	423	414	388	31.0	0.959	0.003	0.093
All season (27/04 to 13/10 – 141 days)												
Concentrate intake (kg DM)	0.07	1.69	3.43	4.94	0.09	1.69	3.41	5.05				
Milk yield (kg)	19.0	20.3	22.3	23.3	19.2	20.8	22.5	24.1	1.66	0.115	<0.001	0.783
Milk fat content ($g \cdot kg^{-1}$)	40.0	39.4	38.8	38.2	40.7	40.5	39.3	38.9	1.92	0.011	<0.001	0.924
Milk protein content ($g \cdot kg^{-1}$)	32.3	32.3	33.0	33.6	32.8	33.0	33.4	33.2	1.13	0.089	<0.001	0.138
Fat yield (g)	755	801	862	881	781	835	877	928	64.9	0.003	<0.001	0.706
Protein yield (g)	610	651	732	780	625	679	744	794	48.5	0.018	<0.001	0.878
Fat corrected milk (kg)	18.9	20.2	21.9	22.5	19.4	20.8	22.1	23.6	1.55	0.011	<0.001	0.712
Body weight at the end (kg)	651	668	670	699	673	668	693	704	31.2	0.009	<0.001	0.194
Body weight change ($kg \cdot d^{-1}$)	0.006	0.117	0.121	0.280	0.178	0.109	0.262	0.307	0.172	0.002	<0.001	0.043
BCS at the end	2.26	2.37	2.55	2.68	2.31	2.55	2.70	2.79	0.39	0.039	<0.001	0.886
BCS change (points)	–0.43	–0.32	–0.14	0.00	–0.37	–0.14	0.01	0.10	0.39	0.035	<0.001	0.914
Grazing time ($min \cdot day^{-1}$)	429	400	372	394	417	407	397	373	28.3	0.981	<0.001	0.091

C0, C1, C2, C3: 0, 2, 4 and 6 kg concentrate per cow per day; BSC: body condition score.

score, while unsupplemented cows lost approximately 0.4 of a body condition score during the grazing season.

4. DISCUSSION

During this 5-year experiment, the Lax grazing treatment provided a greater quantity of grass by virtue of the greater land area utilised. Despite reducing nitrogen fertilisation, this system produced a moderate increase milk yield per cow without any large difference in milk fat or protein contents. However, this superior animal performance was achieved at the expense of milk production per hectare. Concentrate supplementation had a more marked effect on milk yield, milk composition and body weight than increased herbage allowance. These responses to concentrate supplementation were similar between the two grazing systems and remained linear up to a level of 6 kg of concentrate input.

4.1. The effect of the grazing system on sward productivity, herbage utilisation and animal performance

The reduction of nitrogen input had the expected effect on sward productivity as that already described by Delaby and Peyraud [8]. On permanent pasture, the total herbage mass produced was reduced by 2 t DM·ha^{-1}·yr^{-1}, corresponding to a marginal yield of 12.5 kg DM·kg^{-1} N for a nitrogen input of between 120 and 280 kg N. Although the post grazing height was higher (+1.1 cm) under the Lax treatment, with a possibly more favourable leaf content in the defoliated sward [14, 33], the effect of nitrogen fertilisation influenced daily grass growth, which was on average 10 kg DM·ha^{-1}·day^{-1} less on the Lax treatment than on the Severe treatment.

The chemical composition and the nutritive value of the herbage offered reflect both nitrogen fertilisation and grazing management. In agreement with the literature, the reduction of the nitrogen input increased the DM content and reduced the CP content of the herbage offered [6, 12]. The reduction in stocking rate was more important than the reduction of grass production under the Lax treatment, which resulted in an increase in the CF content and a reduction in OM digestibility. This unfavourable effect on the nutritive value of the offered herbage caused by the reduction of the stocking rate has already been well described in the literature. Laxely grazed swards are characterised by a deterioration of sward quality during the grazing season because of an increase in stem and dead tissue content and a reduced leaf content [15, 23, 30, 40].

The increase in the daily herbage allowance on the Lax treatment allowed a systematic increase in the daily milk yield as well as an increase in milk fat and protein synthesis. However, the marginal milk yield response remained moderate (an increase of 1 kg milk for 8 kg of grass DM offered). This response lies within the range of values, 0.04 kg [4] to 0.30 kg [28, 32] of milk per kg of extra herbage DM offered, derived in recent long-term grazing trials (Tab. X). This result is close to the milk production response obtained by Delaby et al. [10] from experiments carried out during the spring at Rennes (France).

The increases in the milk protein content also remained small, being lower than the responses described by Coulon and Rémond [5] but consistent with the results reported in Table X. Although the milk fat content sometimes decreases with increasing herbage allowance as reported by Hardy [18] and Maher et al. [28], none of the authors found any significant difference. The results obtained during the five years of the present experiment confirmed the small long-term influence of the herbage allowance on milk fat content.

During the spring, the animals under the Lax treatment regained more body weight,

Table X. The effect of increasing herbage allowance on the dairy cow performance at grazing during long-term experiments.

Authors [Ref] Duration[1]	Herbage allowance (kg DM·cow^{-1}·day^{-1})	Pre-grazing height (cm)	Post-grazing height (cm)	Milk (kg)	Milk response[2] (kg·kg DM^{-1})	Fat (g·kg^{-1})	Protein (g·kg^{-1})
Hoden [22]	13.0	10.7	5.0	21.1		37.6	30.6
162 d	16.1	11.6	5.9	21.7	0.19	37.8	30.6
	17.7	11.7	6.1	22.1	0.21	37.7	30.5
Buckley [4]	21.3	18.3	6.2	26.2		39.0	33.8
203 d	23.8	18.9	6.8	26.3	0.04	39.4	34.5
Maher [28]	16.0	18.4	4.4	20.6		38.3	32.5
120 d	20.0	18.1	5.5	22.2	0.40	38.4	32.8
	24.0	18.1	6.5	22.9	0.29	37.5	33.6
O'Brien [32]	17.0	/	6.5	15.6		42.6	34.9
196 d	21.0	/	7.6	16.8	0.30	42.1	35.6
Hardy [18]	15.2	12.6	5.7	21.3		38.8	29.6
83 d	20.9	14.3	7.1	22.6	0.23	37.6	29.5

[1] The pre- and post-grazing heights are not directly comparable because in the experiments of Buckley, Maher and O'Brien, the grass height is measured with sward stick while the plate meter is used in the Hoden and Hardy experiments; [2] the milk response is calculated according to the milk yield of the lowest level of herbage allowance.

which corresponds to the distribution of the additional energy intake between milk yield and body tissues. The end of the grazing season in this trial also corresponded to the end of lactation, therefore as might be expected, all animals regained body weight and body condition score to such an extent that no difference could be detected between treatments.

The quantity of herbage removed was greater on the Lax treatment. On average, the variation between the two treatments was approximately 0.34 kg DM per kg DM offered. Taking into account the high daily herbage allowance on the Severe treatment (close to 18 kg DM per cow), this response was more marked than the results reported elsewhere in the literature [11, 36]. The method for calculating herbage removal depends on the difference between the pre- and post-grazing heights with the same herbage density assumed, so evidently the between treatment difference seems over-estimated considering the milk yield response. Despite the reduced rate of growth and accumulation of the senescent material, the greater daily herbage DM allowance provided on the Lax treatment gave the animals the opportunity to be more selective and consume herbage of a higher digestibility. The digestibility of ingested grass, evaluated from the faecal index, was thus similar in both treatments (0.78). Selection of better quality grass was achieved by reducing the defoliation depth and not grazing the refusal areas. This brought about an increase in grass height after grazing in the Lax treatment despite a lower pre grazing height than the Severe treatment.

However, the increased grass removal on the Lax treatment was obtained by a considerable under-utilisation of the offered herbage. The utilisation ratio, as defined by the ratio between the consumed herbage and the offered herbage, was 89 and 71% under the Severe and Lax treatments. These results were consistent with the literature review carried out by Delagarde et al. [11], and confirmed the low grass intake increase when the herbage allowance is increased above 20–22 kg DM. During the grazing season, a higher daily herbage allowance results in a large reduction in the number of cow grazing days (–160 days·ha^{-1}), which also reduces the milk production per unit area of land.

Finally, the principle of increasing daily herbage allowance in order to increase intake and milk production by dairy cows has limited application in practice. Such practices will always reflect poor utilisation of the grown herbage, this can only be adapted and adopted when the grass area of the farm is not a limiting factor.

4.2. The effect of supplementation on individual dairy cow performance at grazing

In the absence of concentrate, the milk yield observed at grazing increases regularly with the potential of the animals but shifts away more and more from the expected milk yield, which is estimated from the production at turnout by assuming a weekly average persistency of 98% [9]. Thus, in the two grazing systems, the discrepancy between the expected and observed milk becomes even greater as the expected milk yield rises (Fig. 2). However, since the quantities of herbage offered and removed are higher on the Lax treatment, the average discrepancy between the expected and observed milk yield is less (4.9 kg) than on the Severe treatment (5.6 kg). Despite the increase in grazing time, nearly all the unsupplemented animals on the two grazing treatments failed to satisfy their requirements for production, as evaluated from the expected milk yield profile (Fig. 2).

Under these conditions, the average response to concentrate supplementation is high, irrespective of the method of concentrate allocation used. The laws of general responses to supplementation calculated from the five years experimental results are shown in Table XI. According to these equations, the intake of 1 kg DM of concentrate increases the daily milk yield by an average of 0.94 kg. This milk yield response to concentrate supplementation remains linear up to the maximum quantity of concentrate offered (6 kg fresh weight). It is identical in both systems and does not vary with the level of milk production at turnout.

These results are in agreement with the recent work of Sayers et al. [39] where with

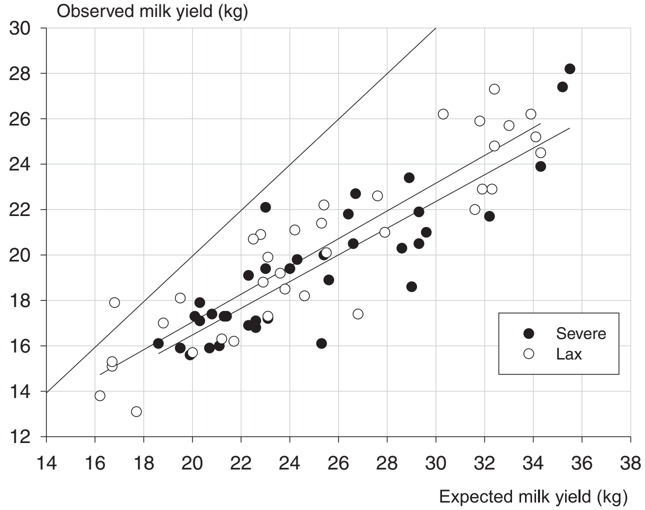

Figure 2. Relationship between expected and observed milk yield throughout the grazing season without concentrate supplementation, according to the severity of grazing.

Table XI. General response laws of milk yield, milk composition and body weight change according to grazing treatment, performance at turnout and concentrate intake (Pooled data of the five years – n = 293 cows).

	Intercept	Grazing treatment[1]	Performance at turnout[2]	Concentrate intake (kg DM)	R^2	Rse
Milk yield (kg)	3.28	± 0.31	+ 0.52	+ 0.94	0.86	1.53
Fat content ($g \cdot kg^{-1}$)	7.58	/	+ 0.82	– 0.28	0.75	1.92
Protein content ($g \cdot kg^{-1}$)	8.85	± 0.13	+ 0.73	+ 0.22	0.77	1.14
Body weight change ($g \cdot j^{-1}$)	397	/	– 11.5	+ 44	0.28	181

[1] The Lax treatment always had a positive effect and the Severe a negative effect; [2] the performance at turnout are milk yield, fat content, protein content and milk yield for the four equations, respectively.

large amounts of concentrate (5 and 10 kg DM) offered, a marginal response was observed, on average, greater than 0.60 kg of milk per kg of concentrate. Since the 1990's, several authors have reported high responses to supplementation (review of Peyraud and Delaby [35] – Tab. XII), which contrasts with the weak responses described in the older bibliographical reviews of Leaver [27] and Journet and Demarquilly [26]. These milk production responses, higher than in the past and similar in both Lax and Severe treatments, are a possible consequence of an increased cow milk yield potential which may be partially disjointed from the cow's maximum grass intake capacity. This is clearly the case since the grazing strategy imposed ensured high herbage nutritive value and the regrowth quality is at least as severe as that imposed in the past, however such conditions do not support maximum grass dry matter intake [11].

The absence of any significant interaction between the grazing treatment and the amount of concentrate offered conforms with most results in the literature, which were obtained in the same range of herbage allowance [10]. Only these studies that impose very low herbage allowance show a significant interaction, and thus a higher response to the concentrate under very severe grazing conditions [3, 17].

As shown in the work of Hoden et al. [22], the allocation of concentrate according to milk yield at turnout results in larger milk production responses in the more productive cows, which therefore received more concentrate. This milk production response is clearly a consequence of the method of concentrate allocation because (i) we do not observe this result when the concentrate is allocated at a constant level between cows and (ii) it induces a low concentrate input in moderate producing cows (0 to 2 kg fresh weight maximum), which is poorly discriminate.

In agreement with the majority of the authors (Tab. XII), the input of concentrate on both grazing systems increased the milk protein content by +0.22 $g \cdot kg^{-1}$ per kg of concentrate consumed. This response was independent of the protein content of the milk or the milk yield of the animals at turnout. The positive response of milk protein content represents an increase reflecting enhanced milk protein synthesis, facilitated

Table XII. The effect of the level of concentrate intake on the dairy cows performance at grazing during long-term experiments.

Authors [Ref] Duration	Concentrate (kg DM intake)	Milk yield (kg)	Efficiency[1]	Fat ($g \cdot kg^{-1}$)	Protein ($g \cdot kg^{-1}$)	BW change ($g \cdot day^{-1}$)
Hoden [22]	0.44	20.7		37.8	30.3	+ 23
162 d	3.26	22.6	0.67	37.6	30.9	+ 80
Rook [38]	0.00	21.5		42.0	29.0	/
77 d	3.52	25.0	1.00	43.6	30.0	/
Wilkins [45]	0.00	22.9		36.9	27.9	– 190
70 d	1.76	25.4	1.42	37.8	28.5	– 100
	3.52	26.0	0.88	38.7	29.4	+ 86
Wilkins [44]	0.00	23.8		37.5	31.6	+ 137
77 d	3.42	25.8	0.58	38.3	32.7	+ 490
O'Brien [31]	0.00	11.3		41.8	37.7	+ 71
70 d	3.58	13.9	0.73	39.4	38.4	+ 370
Delaby [7]	0.00	23.2		38.3	29.4	+ 480
56 d	1.78	25.5	1.29	37.6	30.0	+ 560
	3.56	26.4	0.90	36.6	30.0	+ 700
Dillon [13]	0.00	24.1		36.8	33.0	– 254
63 d	1.80	25.4	0.72	36.1	33.2	+ 40
	3.60	26.3	0.61	35.7	33.0	+ 71
O'Brien [32]	0.00	17.4		41.8	35.3	+ 420
196 d	2.70	18.6	0.44	41.2	35.8	+ 555
Mathieu [29]	0.00	26.1		39.0	31.0	/
63 d	1.70	28.2	1.23	37.4	31.5	/
	3.40	29.1	0.88	35.8	32.2	/
Delaby [10]	0.00	22.1		39.9	29.9	– 176
56 d	2.65	25.1	1.13	38.5	30.6	+ 33
	5.34	27.6	1.03	36.9	30.9	+ 171
Wales [43]	0.00	20.1		38.0	28.0	/
42 d	4.50	24.5	1.00	35.7	30.3	/
Gibb [16]	0.00	19.3		38.3	30.3	/
140 d	2.16	22.7	1.57	42.1	32.0	/
	4.32	23.5	0.97	45.1	33.6	/
	5.40	27.8	1.57	37.6	29.1	/

[1] The efficiency, expressed in kg of milk by kg of concentrate DM intake, is calculated according to the milk yield of the lowest level of concentrate.

by the additional energy input associated with concentrate supplementation [5].

The reduction of milk fat content (– 0.28 g·kg^{-1} per kg of DM concentrate) as affected by concentrate supplementation was consistent with most of the results in the literature. This negative effect of the concentrate was, however, weaker than that reported in 1997 [7] and 2001 [10] by Delaby et al. (– 0.50 to 0.60 g·kg^{-1} per kg of DM concentrate). With high amounts of starch rich concentrate, the reduction in milk fat content sometimes follows modifications of rumen fermentation trends (a decrease of the acetate/propionate ratio [37]). In the present study, however, this effect was diluted since the synthesis of milk fat increased linearly with concentrate supplementation.

In addition to the increase in the milk yield, the input of concentrate led to an increase in body weight gain of 44 g·day^{-1} per kg of DM concentrate and allowed maintenance of the body condition score of the cows up to the end of the grazing season. Animals receiving supplementation do not use all of the additional energy provided to improve milk yield. Particularly at the end of lactation, since part of the energy content of the concentrate is used for the reconstitution of body fat reserves.

5. CONCLUSION

At grazing, the individual milk yield and milk composition depend initially on the animal and its productive potential (breed, genetic index and stage of lactation). Increasing the herbage allowance is proposed as a way of stimulating intake and individual milk production performance, but above 16–20 kg of DM offered, this approach has only moderate effects. This strategy of offering high grass allowances leads to a lower utilisation of the herbage resource, which is prejudicial to the subsequent quality of herbage offered and milk output per hectare. The results of this study confirmed the advantage of the animal's grazing to a maximum post-grazing height of 5–6 cm, thus allowing a compromise between animal performance and good use of the pasture. Under these conditions, if the objective is to increase milk production per cow per day, the input of concentrate may be a possibility. Supplementation at grazing is nowadays more efficient (0.9 kg milk/kg DM intake), and the concentrate can be offered with the same effectiveness in constant quantity between cows up to levels of 4–6 kg fresh weight.

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