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Original article

Long-term effect of level and pattern of winter concentrate allocation in dairy cows

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Summary — A total of 148 dairy cows were used in a long-term trial over their first four lactations. The experiment was designed to examine the effect of level and distribution of concentrate given during the winter period in addition to grass silage (ad libitum) and hay (4 kg/day) on milk production, reproduction, health and longevity. Cows in their first lactation were allocated to an experimental treatment in which they remained until in their fourth lactation or until culled (if this occurred before). Five treatments were compared: three levels of concentrate supply during the winter period (H, M and L) and, for levels M and L, two different allocation patterns (standard [S] or flat rate [F]). Winter concentrate allocation was individually predetermined for the first four lactations according to expected milk production. During summer, all animals grazed together as a single group. The occurrence of mastitis, reproductive performances (days open and interval between calving and first heat) and longevity were not significantly different between treatments. Foot lesions were more frequent in group H than in other groups. Effect of treatments on production performance was studied in cows having lactated for at least 12 weeks in the winter period in at least three successive lactations. Between the first and third lactation, live weight at calving increased by, respectively, 72, 44 and 36 kg in groups H, M and L, and milk yield over the first 12 weeks of lactation by, respectively, 8.3, 5.9 and 6.1 kg/day ($P < 0.01$). These differences were more pronounced in the highest producing cows. When considered over the first 40 weeks of lactation, the differences in production increase between the first and third lactation were no longer significant (1 175, 997 and 1 159 kg, respectively, in groups H, M and L), due to a greater compensation over the summer period for groups M and L during the third lactation. There was no significant difference in production and reproduction performances between groups S and F.

dairy cows / milk production / level of feeding / long-term effects

Résumé — Effet à long terme du niveau et de la répartition des apports de concentré hivernaux sur les performances des vaches laitières. *Au total 148 vaches laitières ont été utilisées au cours d'un essai à long terme s'étendant sur quatre lactations. Au cours de l'hiver, tous les animaux recevaient une ration de base composée d'ensilage d'herbe (à volonté) et de foin (4 kg/jour). Les vaches ont été affectées à un traitement expérimental en première lactation, et le sont restées jusqu'en qua-*

trième lactation ou jusqu'à leur réforme si elle intervenait avant. Cinq traitements hivernaux ont été comparés : trois niveaux d'apport de concentré (H, M et L), et, pour les niveaux M et L, deux modes de répartition du concentré (classique (S) ou uniforme (F)). Les apports de concentrés ont été prédéterminés individuellement à partir de la production au cours de chacune des quatre lactations expérimentales, estimée à partir de la production des trois premières semaines de la première lactation. Au pâturage toutes les vaches ont été conduites ensemble. La fréquence des mammites, les performances de reproduction et la longévité n'ont pas été significativement différentes selon les traitements. Les boiteries ont été plus fréquentes dans le lot H que dans les autres lots. L'effet des traitements sur les performances de production a été étudié sur les vaches ayant réalisé au moins trois lactations successives d'une durée hivernale supérieure ou égale à 12 semaines. Entre la première et la troisième lactation, l'augmentation de poids vif au vêlage a été de respectivement 72, 44 et 36 kg dans les lots H, M et L, et celle de la production laitière au cours des 12 premières semaines de lactation de respectivement 8,3, 5,9 and 6,1 kg/jour (p < 0,01). Ces écarts ont été accentués chez les vaches les plus fortes productrices. À l'échelle des 40 premières semaines de lactation, les différences d'augmentation de production entre la première et la troisième lactation ne sont plus significatives entre lots (respectivement 1 175, 997 et 1 159 kg dans les lots H, M et L), en raison d'un rattrapage au cours de la période estivale chez les lots M et L plus important en troisième lactation. Il n'y a pas eu de différence significative entre les performances des vaches des lots S et F.

vache laitière / production laitière / niveau d'alimentation / effets à long terme

INTRODUCTION

The short- and medium-term effects of level of feeding, in particular that of energy supply, on dairy cow performances have been studied extensively (see Broster and Broster, 1984). Over one lactation, production responses increase with the duration of underfeeding (Coulon and Rémond, 1991; Broster et al, 1993). Over several successive lactations, while recognizing the existence of cumulative effects (Broster and Broster, 1984), few studies have been undertaken to quantify them, and those which consider more than two successive lactations are rare. Moreover, their conclusions are contradictory (Broster et al, 1993). Yet these effects can be considerable (Coulon et al, 1990) and reveal that the extrapolation of results to several lactations is difficult (Broster et al, 1993). Furthermore, they can involve not only milk production and composition but also animal reproduction and health. In the current economic context, it is of particular importance to clarify these effects, especially in cases where the available forage is of medium quality, which leads to the use of large quantities of concentrate in order to meet animal requirements.

To analyse these effects, a long-term trial was initiated at the Institut National de la Recherche Agronomique (INRA) experimental farm of Marcenat (altitude 1 100 m) in the autumn of 1985. Five treatments were compared (three levels of concentrate supplementation and two distribution methods) over the first four lactations. The effects of treatments over the first lactation are reported in an earlier paper (Coulon et al, 1994). When winter energy undernutrition is pronounced, effects are observed on the yield and chemical composition of milk, animal growth and reproduction, especially in the highest-producing animals. This paper reports the results of this trial over the four experimental lactations.

MATERIALS AND METHODS

Animals and feeding

During the 7 years of the experiment, 148 dairy cows housed in individual stalls, half of which

were Montbéliarde and half Holstein-Friesian crossbreds, were used. They began their experimental period following their first calving, between 1985 and 1988 (respectively, 35, 40, 44 and 29 over the years 1985, 1986, 1987 and 1988). The mean date at first calving was 6 December (ranging between 11 November and 14 January) and their mean age at first calving was 36 months (ranging between 32 and 38 months). Between birth and first calving, all animals were managed similarly.

During the winter period (early November to early May) all animals received a diet composed of hay (4 kg/day given in the evening) and grass silage from native mountain grassland (in the morning, ad libitum). Grass was harvested between 5 and 28 June, using a drum harvester which cut the grass to 2.8 cm on average, and ensiled with a preservative (0.7 formic acid, 0.3 formalin) applied at a rate of 3.5 L/t fresh matter.

During the first 3 weeks of the first lactation (reference period), all the animals were fed similarly (Coulon et al, 1994), according to INRA recommendations (1989). At the end of the 3rd week, the cows were divided at random into five groups according to their calving date, live weight at calving and milk yield and composition during the first 3 weeks of lactation. In the standard pattern (S), three levels of concentrate supplementation (groups H, MS and LS) were compared. In addition, for the two lower supplementation levels, a flat rate (F) supplementation with the same amount of concentrate as that given to the matching standard group over the winter period, was tested (groups MF and LF). During the first four lactations (or until culling if earlier), each cow remained on the same winter treatment.

The amounts of concentrate given were predetermined for the whole winter period according to milk potential (highest weekly milk yield, MP) estimated for each lactation from the production of the reference period (mean production of the first 3 weeks of the first lactation, RMP) according to the following relationships, elaborated from well-feeding dairy cows: lactation 1: MP = 4.2 + 1.02 x RMP, $n = 63$, $R = 0.93$; lactation 2: MP = 20.3 + 0.56 x RMP, $n = 57$, $R = 0.46$; lactations 3 and 4: MP = 22.8 + 0.63 x RMP, $n = 57$, $R = 0.53$.

Irrespective of the year, it was considered that the roughages covered the maintenance requirements for energy and nitrogen and those necessary to produce 3 kg (group H), 7 kg (groups MS and MF) or 11 kg (groups LS and LF) of milk in primiparous cows. In multiparous cows, corresponding values were 6, 10 and 14 kg of milk. The concentrate was distributed in two daily meals, at a level of 0.4 kg for each kg milk over these production levels.

In the three standard groups, the concentrate amounts were increased by 1.5 kg/week from calving until reaching the maximal amounts, which were maintained until the 7th week of lactation. Proportionally, a 0.08 (primiparous) or 0.10 (multiparous) monthly decrease in milk production was assumed henceforth.

In the F groups, the amounts of concentrate allocated were determined as follows: for each level of milk production, the total amounts given to MS and LS cows during the winter period lasting from 21 December to 6 May (turnout to pasture) for primiparous and from 1 January to 6 May for multiparous (ie, 136 and 126 days, respectively), were computed. The daily amounts given to MF and LF cows were determined by dividing the total amount by 136 (primiparous) or 126 (multiparous), whatever the calving dates, and after deduction of the flushing amount. Flushing was performed in the flat rate groups to favour reproduction, at the 8th, 9th and 10th weeks of lactation. The additional amounts of concentrate given during that period were 1.5 and 2.5 kg/day for groups MF and LF, respectively.

During the first 6 weeks of lactation, 1 kg/day of protected soya-bean meal (table I) was given to replace 1 kg concentrate. Two hundred and fifty g mineral additive (0.1 P, 0.16 Ca) containing trace elements were fed to all animals. During the last 3 weeks of the first pregnancy, all cows received, respectively, 1, 2 and 3 kg/day concentrate. During the following pregnancies, these quantities differed among treatments. Group H cows received 1, 2 and 3 kg/day, group M cows received 0, 1 and 2 kg/day and group L cows received 0, 0 and 1.5 kg/day.

Turnout to pasture occurred during the 1st week of May. At pasture, all animals were managed similarly (ie, a rotational system of grazing, 3.5 cows per ha in the spring, 1.8 cows per ha in the autumn) and concentrate supply was the same for all groups (for details, see Coulon et al, 1994).

Housing occurred during the first week of November, or about 2 weeks before calving for early calving cows. During the last 2 weeks on pasture, hay was offered to all cows during milking. Inseminations were performed on observations of natural oestrus, after at least 40 days of

Table I. Composition of foods [1].

	Hay	*Grass silage*	*Concentrate*	*Protected meal* [2]
Dry matter (DM) (%)	85.7	22.4[3]	87.6	86.0
Crude protein (g/kg DM)	123	132	184	486
Crude fibre (g/kg DM)	299	283	96	70
Organic matter digestibility	0.62	0.69		
UFL (/kg DM)[4]	0.71	0.81	1.04	1.06
PDIN (g/kg DM)[5]	75	80	122	355
PDIE (g/kg DM)[6]	79	67	121	358

[1] Means of the 7 years.The same concentrate was used over the 7 years. Grass silage quality was better in years 6 and 7 (organic matter digestibility = 0.73), but hay quality was poorer (organic matter digestibility = 0.60). Characteristics of the basal diet were quite similar over the 7 years of the trial, except in year 3 where silage quality was poor (organic matter digestibility = 0.65) and hay quality only mediocre (organic matter digestibility = 0.60); [2] 0.5 soya-bean, 0.5 rapeseed; [3] corrected to allow for dry matter losses during oven-drying according to Dulphy and Demarquilly (1981); [4] UFL: feed unit for lactation (Vermorel, 1989); [5] PDIN: true protein truly digestible in the small intestine when energy in the rumen is not limiting (Vérité and Peyraud, 1989); [6] PDIE: true protein truly digestible in the small intestine when degraded N in the rumen is not limiting (Vérité and Peyraud, 1989).

lactation. Those animals that had had no natural oestrus 12 weeks postcalving underwent oestrus induction (De Fontaubert, 1988). As no calving was allowed after April, cows that were not pregnant by 15 July were culled at the end of the current lactation.

Measurements

Individual milk yields were recorded at each milking and samples for fat and protein concentration were taken twice weekly from both morning and evening milkings. Concentrate intake was individually measured daily, and forage intake was measured on 2 successive days in the week during the winter period (by weighing amounts of forage offered and refused). The dry matter (DM) content of forage (offered and refused) was determined once a week for hay and on each control day of measure for grass silage.The characteristics of the feeds used are specified in table I. Details of calculation are given in Coulon et al (1994). The cows were weighed on 2 consecutive days in weeks 1 and 6 of lactation, 2 weeks before and 2 weeks after turning out to pasture, and at rehousing; they were also weighed twice a month during the winter period and once a month at pasture. Their body condition (rated 0 to 5) was scored by handling at calving, at weeks 6 and 12 of lactation, 2 weeks before turning out to pasture, at drying-off and at stabling. Linear body measurements were recorded every year, during winter.

Energy and nitrogen balances were computed from the difference between feed input and the animals' requirements, using the UFL (energy) and PDI (nitrogen) systems (INRA, 1989). In particular, energy supply was corrected for the decrease in diet energy value resulting from the increased feeding level and higher proportion of concentrate in the diet (Vermorel, 1989).

All health problems were recorded. For data analysis they were summarized as: mastitis (clinical and subclinical), foot lesions (mainly interdigital inflammation) and other health problems (mainly digestive disorders and placental retention). Culling causes were recorded according to the following manner: reproduction (barren cows or calving expected after 15 April) and other causes (disease or accident).

Data analysis

Analysis of the results was performed from various points of view. Effect of breed and parity on

health, reproduction and production performances was studied over all the experimental lactations. The effect of dietary treatments on longevity was studied in two ways: on the one hand, by retaining only those cows having calved before 15 April (predetermined protocol) and, on the other hand, by retaining only cows with at least 12 weeks of winter lactation (calving before 15 February). The effect of dietary treatments on reproduction and health was studied over all lactations presenting more than 12 winter weeks. The effect of dietary treatments on health disorders was studied considering only those having appeared during the winter period, extended to the 1st month at pasture to account for problems appearing after turnout to pasture and which could have been linked to the winter period.

Analysis of the health disorders was conducted considering, on the one hand, the rate of lactation affected by a given disorder (number of lactation affected by at least one disorder of a given type/ total number of lactation) and, on the other hand, the rate of recurrence of the affected lactations (number of lactations affected more than once by the same disorder/number of lactation affected).

The effect of dietary treatments on production performances (milk production and composition, consumption, live-weight variations, nutritional balances) was studied in cows having achieved at least three experimental lactations each comprising at least 12 winter weeks ($n = 79$). To assemble a sufficient number of cows per group, and insofar as the pattern of production performances differed little from one group to another between the third and fourth lactation, the main part of the results reported will concern the evolutions of performances between the first and third lactation. Analysis of these results was performed for the winter experimental period (first 12 weeks of lactation), and over the first 40 weeks of lactation. In order to test the interaction between the number of lactations (ie, duration of treatment allocation) and the experimental treatment, we computed, for each variable, the variation observed between the first and third lactation; these new variables, along with performances over the first lactation, were processed by analysis of variance (GLM procedure, SAS, 1987). The factors introduced were winter treatments, breed and year. The winter treatment x breed and winter treatment x year interactions were found to be nonsignificant in all cases, and thus are not shown in the tables of results. For each analysis, the milk production value during the reference period was introduced as a covariate. As the production results during the first lacatation have already been shown in detail in a previous paper (Coulon et al, 1994), only a brief summary will be included in the present paper. Even though the production of some lactations was strongly affected by health disorders (particularly mastitis), no lactation was removed from the treatment for health reasons. In the case of a brief effect (1 to 2 weeks), the corresponding production values were corrected by interpolation. In other cases, more rare and equally distributed amoung the different groups, no modifications were made to the data.

RESULTS

Health disorders (table II)

A total of 621 health disorders, concerning 282 lactations, were recorded over the 459 experimental lactations. The cases of mastitis represented 49% of these disorders and lameness 32%. Thirty-eight percent of all disorders and 42% of mastitis occurred during the first 2 months of lactation. The highest producing cows were slightly more frequently affected by mastitis and by foot lesions (respectively, 0.40 and 0.27 affected lactations in cows whose reference production was > 18 kg/day vs 0.33 and 0.22 for those whose reference production was < 16 kg, $P > 0.10$). The highest producers also presented a higher recurrence rate, in particular for foot lesions (0.41 vs 0.24, $P < 0.05$). Montbéliarde cows were less frequently affected by foot lesions and above all by mastitis, and their rate of recurrence was less ($P < 0.05$). For lameness, these differences between breeds disappear when comparing animals having similar production levels (reference production between 15 and 20 kg/day). For mastitis, at comparable reference milk production levels, the frequency of affected lactations remains greater in Holstein cows (0.41 vs 0.30, $P < 0.10$).

Table II. Health disorders (during the winter period for group effect, during the whole lactation for the other factors effects).

	Group					*Sig* [1]	*Breed*		*Sig* [1]	*Lactation*				*Sig* [1]	*Milk reference production (kg/day)*		
	H	*MS*	*MF*	*LS*	*LF*		*HO*	*MO*		*1*	*2*	*3*	*4*		*< 16*	*> 18*	
No of lactations	89	89	97	92	92		232	227		148	129	102	80		172	205	
Mastitis																	
Lactational incidence rate	0.39	0.30	0.29	0.34	0.32	NS	0.42	0.31	*	0.30	0.35	0.39	0.48	+	0.33	0.40	NS
Recurrence rate [2]	0.35	0.37	0.32	0.29	0.38	NS	0.48	0.39	NS	0.24	0.56	0.48	0.50	*	0.38	0.50	NS
Foot lesion																	
Lactational incidence rate	0.28	0.18	0.16	0.10	0.13	**	0.28	0.24	NS	0.30	0.26	0.20	0.25	NS	0.22	0.27	NS
Recurrence rate	0.12	0.13	0.13	0.56	0.08	*	0.47	0.28	*	0.43	0.32	0.50	0.25	NS	0.24	0.41	*
Other health problems																	
Lactational incidence rate	0.19	0.18	0.20	0.21	0.16	NS	0.21	0.21	NS	0.24	0.18	0.25	0.15	NS	0.20	0.19	NS
Recurrence rate	0.12	0.19	0.16	0.11	0.27	NS	0.18	0.19	NS	0.31	0.13	0.04	0.25	*	0.23	0.11	NS

[1] Significance, χ^2 test; NS: nonsignificant; $P < 0.1$; * $P < 0.05$; ** $P < 0.01$. [2] Within lactation.

The number of lactations affected by mastitis increased regularly between the first and fourth lactation, and the recurrence rate was significantly lower ($P < 0.05$) in primiparous than in multiparous cows. On the contrary, the number of lactations affected by lameness and the recurrence rate showed a tendency to decrease between the first and fourth lactation. There was no significant difference between groups in the proportion of lactations affected by mastitis. However, the proportion of lactations affected by lameness increased with concentrate allocation (respectively, 0.28, 0.17 and 0.11 lactations affected in levels H, M and L, $P < 0.01$) .

The frequency of health disorders other than mastitis and lameness was not different between groups, breed, production level or parity.

Longevity

Seventy-two of the 148 cows participating in the experiment were culled before their fourth lactation. Fourty-seven of these cullings were linked to reproduction problems (barren cows or calving after 15 April), and 25 to accidents or disease (table III). There were no great differences between groups, although F groups presented fewer cullings for reasons of reproduction (6 and 9, respectively, in groups MF and BF vs 10 and 11 in other groups, $P > 0.10$). Cullings which were not linked to reproduction were equally distributed amongst groups. They occurred above all during the first lactation (12 out of 25). Reproduction-linked cullings were, however, few between the first and second lactation (10) and occurred mainly during the second and third lactation (23) and between the third and fourth lactation (14). Finally, 76 cows equally distributed amongst the groups began a fourth experimental lactation. Breed, production level, live weight and body condition at first calving did not differ according to animal longevity (table IV). If we consider only cows having always achieved at least 12 weeks of winter lactation, only 65 cows began a fourth experimental lactation. According to the latter criterion, the final numbers per group were slightly smaller in group H (10) in comparison to other groups (13 to 15 according to the group).

Reproduction (table V)

Over the entire group of experimental lactations, reproduction performances did not differ greatly between groups. Group H cows showed a slightly higher proportion of late cyclicity (> 60 days) than cows of other groups (55% vs 40 to 48% in other groups,

Table III. Longevity (all experimental lactations taken into account).

Group	*H*				*MS*				*MF*				*LS*				*LF*			
Lactation	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
No of cows	29	25	19	14	30	27	17	15	29	26	19	17	30	25	20	15	30	23	21	15
Culling cause																				
Reproduction	1	6	4		1	7	2		1	4	1		2	5	4		5	1	3	
Health or accident	3	0	1		2	3	0		2	3	1		3	0	1		2	1	3	

Table IV. Characteristics of the cows depending on longevity.

No of experimental lactation	*1*	*2*	*3*	*4*
No of cows	22	30	20	76
Calving date in first lactation	8 Dec	6 Dec	15 Dec	3 Dec
Live weight at first calving (kg)	577	580	588	579
Body condition score at first calving	2.7	2.5	2.9	2.8
Reference milk production (kg/day) [1]	17.4	17.8	17.4	17.6
Breed (no of cows)				
Holstein	8	16	10	38
Montbéliarde	14	14	10	38

[1] Production during the first 3 weeks of the first lactation.

$P > 0.10$) but the success rate of the first insemination was better (63% vs 52 to 59%), in such a way that the calving–insemination interval was similar between the different groups. In particular, the flat allocation of feed concentrate at the beginning of lactation associated with flushing (groups F) did not incur a significant improvement in reproduction performances.

Reproduction performances improved with the age of the animal. The proportion of cows cycled within 60 days of lactation thus progressed from 28% in the first lactation to 88% in the fourth lactation ($P < 0.01$), and the proportion of short calving–insemination intervals (< 80 days) from 26 to 46% ($P < 0.01$). This effect persists when we consider only those cows having achieved four experimental lactations (respectively, 29 and 45% of short calving–insemination intervals in the first and fourth lactation).

Reproduction performances were slightly better in Montbéliarde cows than in Holsteins (respectively, 42 and 32% of short calving–insemination intervals, $P < 0.10$). This difference does not seem to be only due to the lower production level of Montbéliardes as it remains intact when considering cows with similar production levels (respectively, 44 and 34% of short intervals in cows whose reference production level is between 15 to 20 kg/day). The effect of production level on reproduction performances is, moreover, small: cows whose reference production level was below 16 kg/day did, however, show slightly, but nonsignificantly, shorter calving–insemination intervals than those whose reference production level was above 18 kg/day (respectively, 43 and 36% of short intervals, $P > 0.10$).

Production performances

Effect of the pattern of concentrate allocation

Throughout the first three lactations, as observed in the first lactation in all cows entered in the experiment (Coulon et al, 1994), the pattern of concentrate allocation did not significantly affect mean animal performances. Whatever the level of concentrate allocation, its pattern of distribution did, however, modify the pattern of milk production during the winter, significantly diminishing the production peak (by around 3 kg/day in group BF as compared to group BS, fig 1). The increase in production between the first and third lactation was

Table V. Reproduction performances.

	Group					Sig [1]	Lactation				Sig [1]	Breed		Sig [1]	Reference milk production (kg)		Sig [1]
	H	*MS*	*MF*	*LS*	*LF*		*1*	*2*	*3*	*4*		*HO*	*MO*		*< 16*	*> 18*	
No of lactations [2]	75	82	81	85	81		148	126	96	76		226	219		167	199	
Days open (days)						NS					**			+			NS
< 60	9	9	9	12	12		5	19	19	17		30	29		28	33	
60–79	20	18	19	23	18		34	28	26	18		42	64		44	38	
80–109	24	33	29	26	29		59	41	25	31		83	73		55	74	
> 110 [3]	22	22	24	24	22		50	38	26	10		71	53		40	64	
Interval between calving and first heat (days) [4]						NS					**			NS			NS
< 40	11	19	16	19	16		9	19	36	31		44	51		40	43	
40–59	23	25	28	32	26		32	48	38	36		74	79		64	63	
60–79	24	19	25	19	21		59	26	15	9		57	52		39	47	
> 80	17	19	12	15	18		48	33	7	0		51	37		24	46	
No of inseminations						NS					NS			NS			NS
1	47	48	46	44	48		84	69	51	49		123	129		95	108	
> 1	28	32	35	41	33		62	56	44	27		99	90		71	88	

[1] Significance, χ^2 test; NS: nonsignificant, + $P < 0.01$; * $P < 0.05$; ** $P < 0.01$; [2] all experimental lactations excepting for group effect where only lactation with at least 12 weeks on winter treatment were used; [3] including barren cows; [4] cyclicity was measured by progesterone blood analysis, performed every 10 days from the 30th day of lactation.

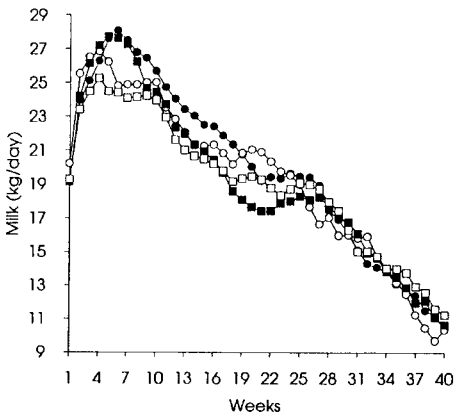

Fig 1. Pattern of milk production of cows in their third lactation according to the pattern of winter concentrate allocation. (●) group MS; (O) group MF; (■) group LS; (□) group LF.

similar for both patterns of allocation (table VI). The greater increase in production in group LS than in group LF was due to a difference in the increase in concentrate allocation between these two groups between the first and third lactation, partially linked to a longer interval between calvings in group LF (table VI). In the rest of this report of the production results, for clarity's sake, only the effect of the level of allocation will be described, by comparing performances of H cows to those of groups MS + MF (group M) and LS + LF (group L).

Effect of level of concentrate allocation

In the first lactation, during the first 12 weeks of lactation, group H animals produced,

Table VI. Effect of pattern of concentrate allocation (difference between the third and first lactation).

	Group				*Residual*	*Significance*		
	MS	*MF*	*LS*	*LF*	*SD*	*Level*	*Pattern*	*L x P*
No of cows	15	15	18	17				
Live weight at calving (kg)	33	53	34	37	32	NS	NS	NS
Body condition score at calving	–0.6	–0.5	–0.5	–0.6	0.5	NS	NS	NS
Calving date (days)	–17	–28	–2	–18	31	NS	+	NS
Weeks 1–12								
Milk (kg/day)	5.9	5.9	6.8	5.2	1.9	NS	+	+
Fat concentration (g/kg)	–0.8	–0.1	0.0	–0.5	1.5	NS	NS	NS
Protein concentration (g/kg)	–0.5	–0.2	0.1	0.0	1.2	NS	NS	NS
Roughages (kg DM/day)	2.0	2.1	2.0	2.4	1.0	NS	NS	NS
Concentrates (kg DM/day)	1.5	1.4	1.7	1.0	0.5	NS	**	*
Energy balance (UFL/day)	0.0	0.0	–0.2	–0.3	0.9	NS	NS	NS
Weeks 1–40								
Milk (kg)	1 036	957	1 201	1 101	465	NS	NS	NS
Concentrates (kg)	184	200	270	234	112	*	NS	NS
Live-weight changes (kg)								
During winter	1	13	12	25	32	NS	NS	NS
At pasture [1]	0	5	–9	–6	37	NS	NS	NS

[1] Between week 40 of lactation and 2 weeks after turnout. NS: nonsignificant, + $P < 0.1$; * $P < 0.05$; ** $P < 0.01$.

respectively, 0.4 and 1.2 kg/day of milk more than cows belonging to groups M and L ($P < 0.01$). The protein concentration of their milk was higher (by, respectively, 0.6 and 1.3 g/kg, $P < 0.01$) (table VII). Throughout this period, the differences in amounts of concentrate ingested were, respectively, 1.1 and 2.1 kg DM/day, that is a marginal efficiency (additional kg milk per additional kg DM of concentrate) of 0.36 and 0.57 kg milk. Expressed as additional UFL intake, this efficiency reaches, respectively, 0.40 and 0.64 kg of milk. This low apparent efficiency, on a short-term basis, can be linked to the liveweight losses which were different ($P < 0.05$) between groups during the first 12 weeks of lactation (respectively, –6, –17 and –28 kg in groups H, M and L). Milk fat concentration was not significantly different between groups (table VII). A smaller deficit in energy balance for a shorter duration was observed during the first part of lactation in group H cows than those in groups M and L, so that as computed over the first 12 weeks of lactation, the cumulative deficit was, respectively, 17, 91 and 122 UFL. Over the weeks 1–40 of lactation, the difference in milk production between group H and groups M and L reached, respectively, 145 and 412 kg, and the marginal efficiency 0.92 and 1.06 kg of milk/kg DM of concentrate. The protein concentration in group H was 0.7 and 1.4 g/kg higher than in groups M and L. These results are in agreement with those observed in all primiparous cows entered in the experiment (Coulon et al, 1994).

Between the first and third lactation, the quantities of forage ingested increased slightly more, but not significantly, in groups M and L (respectively, +2.0 and +2.2 kg DM/day) than in group H (+1.6 kg DM/day)(table VII).This difference was mainly due to a greater increase in concentrate allocation for the latter group (+2.0 kg DM/day vs +1.5 for other groups) so that the increase in quantities of total DM intake was identical in all three groups. The energy supply therefore also increased in a similar fashion in all three groups (respectively +3.4, +3.2 and 3.2 UFL/day).

The increase in milk production between the first and third lactation was greater in group H than in groups M and L (respectively, +8.3 kg/day during the first 12 weeks of lactation vs +5.9 and +6.1, $P < 0.01$)(table VII, fig 2) However, this increase was not significantly different between levels of concentrate allocation over the whole lactation

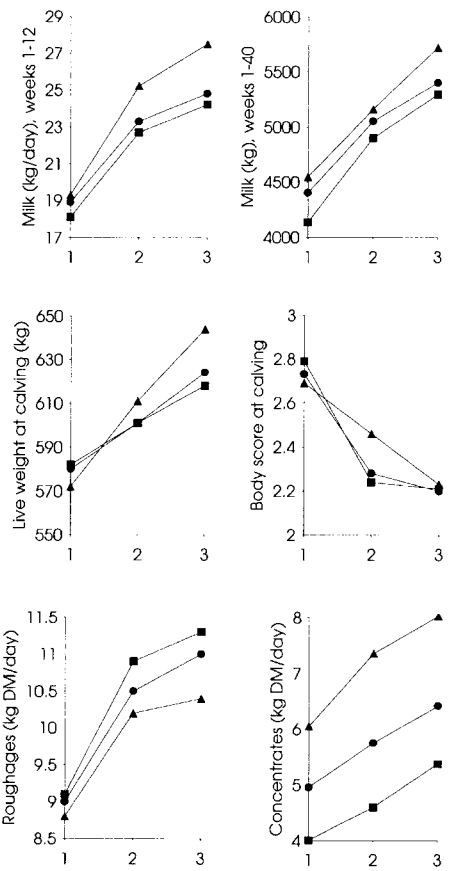

Fig 2. Level of milk production over the first 12 weeks of lactation (kg/day) and the first 40 weeks of lactation (kg), live weight and body score at calving, and roughage and concentrate intakes during the first 12 weeks of lactation, between the first and the third lactations according to level of concentrate allocation. (▲) group H; (●) group M; (■) group L.

Table VII. Milk production, food intake and live-weight data.

	H	*M*	*L*	*Residual SD*	*Significance*
No of cows	14	30	35		
Lactation 1					
Live weight at calving (kg)	572	580	582	40	
Body condition score at calving	2.7	2.7	2.8	0.4	
Milk in weeks 1–3 (kg/day)	17.2	17.6	17.2	3.9	
Lactation length (day)	296	304	303	25	
Calving date	7 Dec	31 Nov	5 Dec		
Weeks 1–12					
Milk (kg/day)	19.3	18.9	18.1	1.1	**
Fat concentration (g/kg)	34.1	35.2	34.6	2.5	NS
Protein concentration (g/kg)	28.8	28.2	27.5	1.4	**
Roughages (kg DM/day)	8.8	9.0	9.1	0.9	NS
Concentrates (kg DM/day)	6.1	5.0	4.0	0.4	**
Energy balance (UFL/day)	–0.2	–1.1	–1.5	0.8	**
Weeks 1–40					
Milk (kg)	4 546	4 401	4 134	350	**
Fat concentration (g/kg)	35.9	36.5	35.8	2.7	NS
Protein concentration (g/kg)	30.4	29.7	29.0	1.5	*
Concentrates (kg)	980	823	592	93	**
Live-weight changes (kg)					
Between calving and week 12	–6	–16	–28	22	**
During winter	11	–14	–16	24	**
At pasture [1]	44	43	60	21	**
Difference between third and first lactations					
Live weight at calving (kg)	72	44	36	31	**
Body condition score at calving	–0.5	–0.5	–0.6	0.5	NS
Calving date (days)	–1	–21	–10	32	NS
Weeks 1–12					
Milk (kg/day)	8.3	5.9	6.1	2.2	**
Fat concentration (g/kg)	–1.2	–0.4	–0.2	1.7	NS
Protein concentration (g/kg)	–0.5	–0.3	0.1	1.1	NS
Roughages (kg DM/day)	1.6	2.0	2.2	1.0	NS
Concentrates (kg DM/day)	2.0	1.5	1.4	0.6	**
Energy balance (UFL/day)	–0.7	0.0	0.0	1.0	+
Weeks 1–40					
Milk (kg)	1 175	997	1 159	472	NS
Fat concentration (g/kg)	–0.5	+0.4	+0.1	1.3	NS
Protein concentration (g/kg)	–0.2	0.5	0.7	0.9	*
Concentrates (kg)	316	199	253	122	*
Live-weight changes (kg)					
Between calving and week 12	–3	+13	+18	25	*
During winter	–17	8	18	31	**
At pasture [1]	–1	2	–8	35	NS

[1] Between week 40 of lactation and 2 weeks after turnout. NS: nonsignificant; + $P < 0.1$; * $P < 0.05$; ** $P < 0.01$.

(respectively, +1175, +997 and +1159 kg, $P > 0.1$), due to a greater compensation in production at pasture in groups M and L, in multiparous than in primiparous cows (fig 3). The effect of plane of nutrition on milk protein concentration was less marked in multiparous than in primiparous cows, so that milk protein concentration tended to increase between the first and third lactation in M and L cows (+0.5 and +0.7 g/kg over the entire lactation, $P < 0.01$), whereas it remained stable in H cows (–0.2 g/kg, $P > 0.1$) The same tendency was observed, but was not significant, for milk fat concentration (table VII).

The increase in animal live weight at calving was greater between the first and third lactation in group H than in groups M and L (respectively, +72, +44 and +36 kg, $P < 0.01$) (fig 3). The differences observed in the 12th week of lactation were smaller, because of a greatly reduced mobilization of body reserves during the second and third lactation in M and L cows (respectively, 13 and 18 kg less weight loss than in the first lactation), contrary to H cows (3 kg more weight loss than in the first lactation). In the third lactation, cows in all three groups therefore displayed similar energy balances throughout the first 12 weeks of lactation (respectively, –0.9, –1.1 and –1.5 UFL/day). Nitrogen balance was almost always positive in animals belonging to the different groups, and this balance did not differ greatly from one lactation to another (respectively, +295, +172 and +116 g PDI/day in the first lactation in groups H, M and L and +238, +184 and +93 g PDI/day in the third lactation).

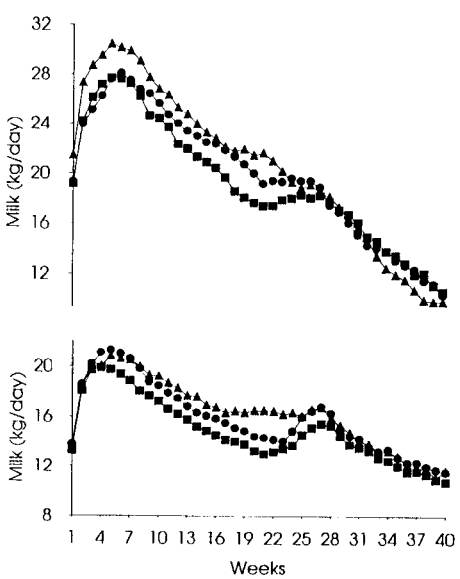

Fig 3. Pattern of milk production of cows in their first (bottom) and third lactation (top) according to the level of winter concentrate allocation. (▲) group H; (●) group M; (■) group L.

The main linear body measurements of the animals progressed in much the same way, according to group, during the first three lactations: on average, withers height remained constant throughout all three lactations (respectively, 132, 133 and 133 cm in group H vs 132, 132 and 131 cm in group L), chest depth increased slightly (respectively, 71.7, 72.2 and 73.5 cm vs 71.9, 72.1 and 74.5 cm) as did hook width (respectively, 53.3, 52.5 and 53.9 cm vs 53.3, 52.5 and 54.0 cm).

At pasture, when in their first lactation, L cows regained more weight than H and M cows (respectively, +60 kg vs +43 and +43 kg); in the third lactation, live-weight gains were identical between all groups (respectively, +43, +45 and +52 kg in groups H, M and L).

The development of performances between the first and third lactation was highly different according to the production level of the animals (fig 4). In group H cows, the increase in milk production during the first 12 weeks of lactation was 9.5 kg in the highest producing cows (reference milk production above16 kg/day) versus 7.6 kg in the lowest producers (reference milk production below 16 kg/day). On the contrary, in group L cows, milk production increased similarly in highest and lowest producers

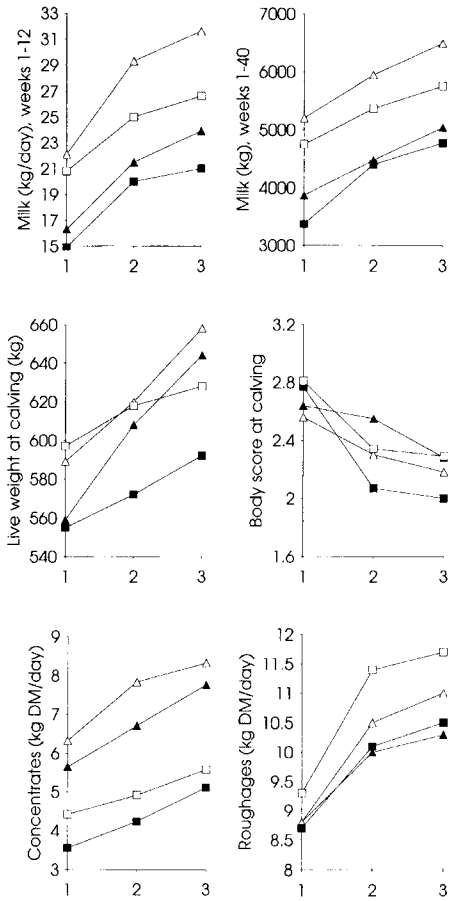

Fig 4. Level of milk production over the first 12 weeks of lactation (kg/day) and the first 40 weeks of lactation (kg), live weight and body score at calving, and roughage and concentrate intakes during the first 12 weeks of lactation, between the first and the third lactation according to the level of concentrate allocation and reference milk production (RMP). (▲) group H with RMP < 16 kg/day; (Δ) group H with RMP > 16 kg/day; (■) group L with RMP < 16 kg/day; (□) group L with RMP > 16 kg/day.

(respectively, +5.8 and +6.1 kg). Over the entire lactation, the highest producing cows of group H increased their production to the same extent as the lowest producers (respectively, +1 277 and +1 165 kg between the first and third lactation) whereas in groups M and L, the increase was much greater amoung the lowest producers (respectively, +1 004 and +1 393 kg in the highest and lowest producing cows of group L). A parallel can be drawn between these differences in reactions and the lesser body reserve mobilization in the highest producing cows in groups M and L in the third lactation than in the first (–14 kg vs –35 kg during the first 12 weeks of lactation in group L), whereas the opposite case is observed in H cows (–22 vs –15 kg).

Effect of breed

In the first lactation, Montbéliarde cows produced 4.8 kg/day less milk than Holsteins during the first 12 weeks of lactation and 1 056 kg over the entire lactation ($P < 0.01$). These differences, which were independent of experimental treatment, remained unchanged throughout subsequent lactations (5.5 kg/day and 945 kg in the fourth lactation; fig 5). They were essentially due to the difference in production potential between the two breeds of animal (4.5 kg/day difference in reference milk production), but could also be linked to the lower intake capacity of Montbéliardes, particularly in multiparous cows: despite an identical live weight and once corrected by the effect of production level, the quantities of forage ingested were indeed smaller by around 0.7 kg DM/day in multiparous Montbéliardes ($P < 0.05$). The increase of live weight in cows over the first four lactations was similar between both breeds.

DISCUSSION

The results obtained from the present trial have highlighted a considerable increase in the effect of plane of nutrition during winter on dairy cow production performances between the first and third lactations. When

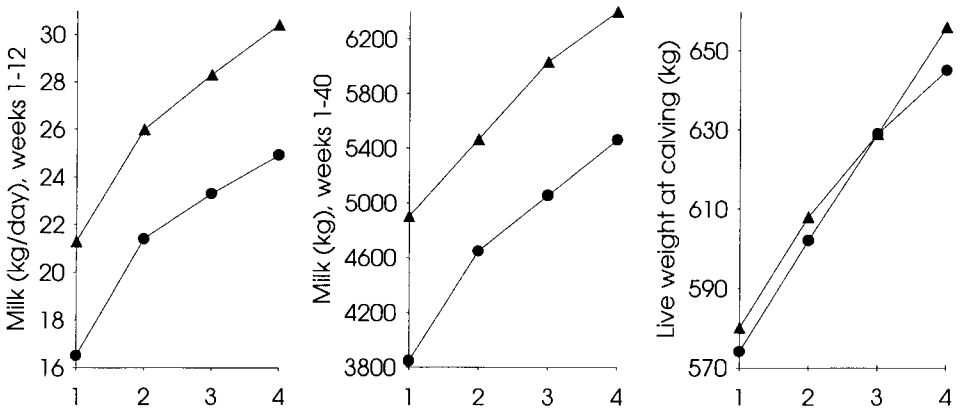

Fig 5. Level of milk production during the first 12 weeks of lactation (kg/day), the first 40 weeks of lactation (kg) and of live weight at calving over the first four lactations according to breed. (▲) Holstein; (●) Montbéliarde.

observed over the first 12 weeks of lactation, part of this effect is due to experimental protocol. Indeed, the reservation of 3 weeks at the beginning of the first lactation as a reference period, leads to a reduction in treatment period and also in the differences in concentrate allocation, between groups in their first lactation compared to subsequent lactations where treatment was applied from the beginning of lactation. However, the calculation of marginal efficiency expressed by supplementary UFL, which enables this bias to be accounted for, displays a considerable increase in this efficiency (calculated between groups L and H) over the three experimental lactations (respectively, 0.64, 1.08 and 1.63 kg supplementary milk/UFL over lactations 1, 2 and 3). The major part of this variation in efficiency between lactations is due to the changes in body reserve mobilization in animals in their second or third lactation as compared to their first. Thus, whereas H cows mobilized body reserves more at the beginning of lactation when multiparous than when primiparous, as commonly observed (Strickland and Broster, 1981), the opposite was observed in cows of underfed groups. This difference was particularly marked in the highest producing cows, which resulted in a much larger increase in marginal efficiency (respectively, 0.81 and 2.17 kg milk/supplementary UFL in first and third lactations, vs 0.61 and 1.14 in lowest producing cows). Thus, as from the second lactation, all groups displayed an identical energy balance over the first 12 weeks of lactation. It is notable that this differing mobilization of body reserves in multiparous cows is not due to an inferior body score of the underfed cows at calving. At the beginning of the third lactation, H and L animals were in poor, but identical, body condition (2.2). It is possible that the diminished mobilization of body reserves in cows which had been underfed right from their first lactation was rather the consequence than the cause of a diminished milk production, for reasons linked to the preceding lactations as much as the current lactation. Thus, the concentrate allocation at the end of gestation, lower in groups M and L, as compared to group H, is maybe partly responsible for the differences in performances at the beginning of lactation. The difference in production between groups in the third lactation is,

moreover, obvious as from the first week of lactation (around 2 kg/day between groups H and L; fig 2).

In our trial, the high and increasing efficiency of ingested energy is no doubt also due to the type of basal ration offered, based on a medium quality grass silage. In our trial, as commonly observed with this type of ration (Gordon 1984; Coulon et al, 1987; Berg and Ekern, 1993), the substitution rate between forage and concentrate was low (around 0.2 to 0.3 over the first 12 weeks of lactation). The grass silage offered ad libitum was not ingested in sufficiently higher quantities by M and L cows to compensate for their energy deficit. The phenomena of substitution between forage and concentrate, as well as the initial body score and age of the animals (primiparous or multiparous) at the start of the experiment, provide a partial explanation of the contradictory published results. Cumulative effects from one lactation to another, are or not observed depending on whether the experimental treatments are applied from the first lactation (Broster et al, 1985, 1989; Coulon et al, 1990; Berg and Ekern, 1993) or on multiparous cows (Wiktorsson, 1971, 1979).

If the effect of energy undernutrition is felt very early in multiparous cows, it is also probable that it has been underestimated after peak production, due to a persistent lack of production in H cows in their third lactation, as would seem to outline the shape of the production curve between weeks 7 and 16 of lactation (fig 2). The large quantities of concentrate (> 9 kg DM/day) offered to the animals without particular precautions concerning its distribution, might have led to a poor digestive utilization of the ration, without necessarily having incurred any visible health disorders (acidosis). Therefore, peak production displayed a more marked increase in effect from one lactation to another (respectively, +9.5, +6.5 and +6.5 kg/day increase between the first and third lactation for groups H, M and L).

As commonly observed (Sutton, 1989; Coulon and Rémond, 1991), energy undernutrition is accompanied by an important decline in milk protein concentration. This decrease was, however, greater in first lactation than during the following ones (1.3 g/kg difference between groups H and L in the first lactation vs 0.8 in the third lactation), as already observed by Berg and Ekern (1993), but stands contrary to the results stemming from short-term comparisons between primiparous and multiparous cows (Coulon and Rémond, 1991). This difference between the first lactation and the following ones is in all likelihood due to a dilution effect: between the first and the third lactation the increase in protein yield was greater in group H (+ 222 g/day over the first 12 weeks of lactation) than in group L (+168 g/day).

When calculated over the entire lactation, the cumulative effect of plane of nutrition disappears. This may be due to the slightly diminished length of winter treatment allocation in the third lactation in groups L and M as compared to group H. However, the main part of this absence of cumulative effect is linked to a compensation effect observed in multiparous cows at pasture. This effect is particularly pronounced amongst lowest producing multiparous cows which practically compensated for, during the season at pasture, the production deficit accumulated over the winter (fig 6). This effect is not observed in primiparous cows, either because their growth is promoted at pasture at the cost of milk production, despite late calving (3 years), or because they have not yet acquired a sufficiently developed intake capacity.

Whereas in the first lactation we observed a tendency towards better reproduction results in H cows, linked to a more successful first insemination (Coulon et al, 1994), over the four lactations, differences between groups are no longer apparent. Besides, in extreme situations, most authors

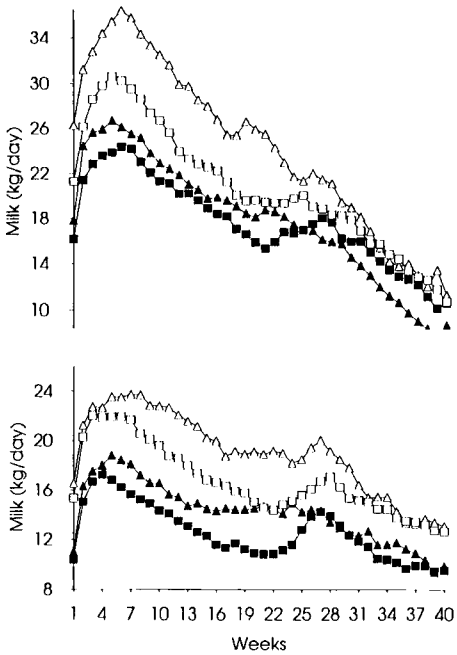

Fig 6. Pattern of milk production of cows in their first (bottom) and third lactation (top) according to the level of concentrate allocation and reference milk production (RMP). (▲) group H with RMP < 16 kg/day; (Δ) group H with RMP > 16 kg/day; (■) group L with RMP < 16 kg/day; ( ) group L with RMP > 16 kg/day.

(Gordon, 1984; Reeves et al, 1986; Broster et al, 1993; Coulon and D'Hour, 1994) agree upon the fact that it is very difficult to pinpoint an effect of nutrition level on reproduction performances, due to the mostly restricted numbers of cows and the complex relationship between nutrition and reproduction (Ducker and Morant, 1984). In our trial, despite total high numbers of animals (404 experimental lactations of more than 12 winter weeks), no effect of dietary treatment was established. This can be partly explained by the fact that as from the second lactation, the different groups displayed an identical deficit in energy balance. The intensity and length of this deficit are indeed the essential nutritional causes of reproduction problems (Lamond, 1970; Nebel and McGilliard, 1993), even though a considerable variability exists in individual responses of reproduction parameters for a same energy deficit observed.

As far as health is concerned, as commonly observed (Coulon et al, 1987, 1989; Broster et al, 1989), dietary treatments had little consequence on the frequency of mastitis occurrence which appears to be more closely linked to the number of lactations or to the production potential of animals (Fraser and Leaver, 1988; Dunklee et al, 1994; Lescourret et al, 1995). However, as revealed by specific studies (Peterse et al, 1984; Manson and Leaver, 1989), or large-scale observations (Fraser and Leaver, 1988), foot lesions occurred more frequently in animals fed larger quantities of concentrate. The presence of a great number of bacterial toxins with this type of diet could be the cause of these infections (Manson and Leaver, 1989).

This long-term trial was conducted under fairly difficult environmental conditions using cows with relatively high production potential and having entered the experiment from their first lactation. Under these conditions, it was possible to ascertain clearly a cumulative effect of winter period energy undernutrition, close to that observed in cows of moderate production potential fed a grass silage-based diet (Coulon et al, 1990). The disappearance of this effect when considering the entire lactation shows the full importance of the summer period, even when calvings have taken place at the beginning of winter. The results of this long-term trial demonstrate the difficulties in extrapolating, over several lactations, the phenomena highlighted on a short-term basis: this is the case for the relationship between body reserve mobilization, energy undernutrition and initial body score, as well as the response of milk protein concentration to variations in food energy supply. Over

three lactations, group H cows produced 1 100 kg more milk than those in group L, ie, an apparent efficiency close to 0.9 kg/kg DM of supplementary concentrate. True efficiency is higher considering the observed parallel weight gains. This milk, moreover, presented greater milk protein concentrations, particularly in the first lactation. However, group H animals did not show a greater longevity than those of other groups, and certain health disorders occurred more frequently in these animals. It is possible that with these type of cows, the environmental conditions may have limited the expression of their production potential: when animals from this trial were fed during the fifth lactation in a liberal fashion (with a complete diet composed of 60% good quality maize silage and 40% concentrate), even group H cows increased their production (+3.7 kg/day during the first 12 weeks of lactation [Coulon and Ollier, 1996]).

Finally, this trial confirmed that the pattern of concentrate allocation had few long-term effects on the global performances of dairy cows, as we observed over the first lactation (Coulon et al, 1994) and as commonly reported (Ostergaard, 1979; Andries et al, 1988).

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