Effects of Daily Gain in Pre- and Postpubertal Replacement Dairy Heifers on Body Condition Score, Body Size, Metabolic Profile, and Future Milk Production

F. Abeni,* L. Calamari,† L. Stefanini,* and G. Pirlo‡
*Azienda Sperimentale "V. Tadini", 29027 Gariga di Podenzano (PC), Italy
†Istituto di Zootecnica, Facoltà di Agraria
Università Cattolica Sacro Cuore, 29100 Piacenza, Italy
‡Istituto Sperimentale per la Zootecnia, 26100 Cremona, Italy

ABSTRACT

Two trials were conducted to evaluate the effect of moderate (0.7 kg) and accelerated (0.9 kg) average daily gain before (trial 1) and after (trial 2) puberty on body condition, metabolic profile, and first lactation milk production of Italian Holstein-Friesian heifers. There were 20 heifers in trial 1 and 22 in trial 2. Trials started when heifers averaged 150 and 300 kg of body weight in trial 1 and 2, respectively, and lasted 7 mo (experimental period). Across diet groups, half of the heifers were mated at first estrus after 370 kg and the other half after 420 kg of body weight gain. Actual average daily gains were 0.667 and 0.775 kg in trial 1 and 0.748 and 0.824 kg in trial 2 for moderate and accelerated experimental groups, respectively. Diets for high average daily gain did not affect body condition during growing phase in trial 1, whereas it did in trial 2. High average daily gain increased plasma glucose in trial 1 and plasma urea concentration in trial 2. Rearing diet did not affect milk production and milk protein percentage in both trials. High average daily gain decreased milk fat percentage in trial 2. Early calving negatively influenced milk production in both trials and milk fat percentage in trial 1. Early calving heifers showed higher protein percentage than those with late calving only in trial 1.
(**Key words:** dairy heifer, growth, metabolic profile, first lactation)

Abbreviation key: ADG = average daily gain, **AFC** = age at first calving, **ALP** = alkaline phosphatase, **AST** = aspartate amino transferase, **GGT** = gamma-glutamyl transferase, **E** = early breeding, **H1** = prepubertal accelerated gain diet, **H2** = postpubertal accelerated gain diet, **HG** = hearth girth, **L** = late breeding, **M1** = prepubertal moderate gain diet, **M2** = postpubertal moderate gain diet, **ME** = metabolizable energy, **NFC** = nonfiber carbohydrates, **WH** = wither height.

INTRODUCTION

A strategy for reducing costs of milk production could be to shorten the rearing period. Thus, heifers should calve when they are no more than 24 mo and of adequate body size. This goal requires an average daily gain (**ADG**) of between 0.7 and 0.8 kg in large size breeds, but between 90 and 300 kg of BW an ADG higher than 0.7 kg is considered detrimental for mammary growth (24). There is a broad agreement about the negative effect of high ADG on milk production at first lactation (24), even though there have been some experiments in which no effect was found (21, 29) or in which nutrition effect was observed with ADG over 1.0 kg (28).

Much more controversial are results on the effect of nutrition on growth between puberty and first calving. In some experiments, accelerated growth favored subsequent milk production (9, 15); in others the effect was negative (12) or absent (14).

Nutrition can also influence size and body condition of heifers that, when allowed free access to concentrates, have greater BW and height at withers (26). With well-balanced rations, accelerated growth does not seem to influence size to BW ratio, and administration of large amounts of nutrients produces heavier heifers that are taller at wither (3, 21, 25) and at hip (28) and that are longer (3).

Heifers fed high energy diets before puberty normally experience higher BCS at 300 kg of BW (21) or at calving than those fed low energy diets (28). A high energy level results in a greater deposition of fat in body tissues (10, 30). Some studies (3, 7) showed significant responses in BCS pattern of Holstein heifers fed different diets between 9 and 24 mo.

Excessive high energy diets could predispose cattle to metabolic diseases, namely acidosis and laminitis, but very little is known about plasma metabolites related to energy, protein, mineral, and vitamins metabo-

Received October 8, 1999.
Accepted February 2, 2000.
Corresponding author: F. Abeni. Current address: Istituto Sperimentale per la Zootecnia, via Pianezza 115, 10151 Torino, Italy; e-mail: isztor@inrete.it.
[1]Supported by funds of the Emilia-Romagna Region.

Table 1. Experimental design.

Period	1	2	3	4
Trial 1	From weaning to 150 kg of BW: Postweaning diet	From 150 kg of BW throughout 7 mo: M1[1] or H1[2]	Subsequent 7 mo: M2[3]	Until 2 mo before calving: Precalving diet
Trial 2	From weaning to 150 kg of BW: Postweaning diet	From 150 to 300 kg of BW: diet M1[1]	From 300 kg of BW throughout 7 mo: M2[3] or H2[4]	Until 2 mo before calving: Precalving diet

[1]M1 = Prepubertal moderate gain diet.
[2]H1 = Prepubertal accelerated gain diet.
[3]M2 = Postpubertal moderate gain diet.
[4]H2 = Postpubertal accelerated gain diet.

lism and about digestive tract and liver functionality in growing heifers. Park et al. (20) studied some blood parameters in Holstein heifers in a stair-step growth pattern for 14 mo from 205 kg of BW and found that plasma urea and cholesterol were higher in the compensatory than in the maintenance phase. Hall et al. (10) also found that blood urea concentration of growing beef heifers was higher with high than with low energy diets, but no effect on blood glucose concentration was observed.

The aim of this work was to evaluate the effect for Italian Holstein-Friesian heifers of different planes of nutrition before and after puberty on growth, body condition, metabolic profile and first lactation production.

MATERIALS AND METHODS

Heifers and Treatments

Two consecutive factorial designed studies were conducted at "Vittorio Tadini" Experimental Farm, Podenzano, Italy, with Italian Holstein-Friesian heifers born between December 1991 and June 1993. The experiment was conducted in accordance with European Union's Directives on protection of animals used for experimental purposes.

Trial 1—prepubertal heifers. Twenty heifers were raised on a four-period feeding regimen (Table 1). From weaning to 150 kg of BW, heifers received a common postweaning diet (Table 2) calculated for an ADG of 0.7 kg (18); subsequently they were allotted to two diets (Table 2) based on NRC (18) recommendations in order to obtain a moderate ADG of 0.7 kg (**M1**) or an accelerated gain of 0.9 kg (**H1**) before puberty. These diets were equivalent to 100 and 115% of NRC (18) recommendations, respectively. Heifers remained on experimental diets for 7 mo (experimental period of trial 1), then they were moved to a common postpubertal diet and fed a diet to allow a moderate ADG of 0.7 kg (**M2**; Table 2) for about 7 mo. Until 2 mo before calving, all heifers were fed a common diet (Table 3). During lactation, heifers received a diet designed to meet the requirements of a 600-kg cow producing 30 kg/d of 3.5% FCM (Table 3).

Trial 2—postpubertal heifers. Twenty-two heifers were raised on a four-period feeding regimen (Table 1). They were fed a postweaning diet (Table 2) from weaning to 150 kg of BW and M1 (Table 2) from 150 to 300 kg of BW. At this weight, they were allotted either to M2 or to accelerated gain diet (**H2**; Table 2) designed to achieve an ADG of 0.7 or 0.9 kg, respectively. These diets were equivalent to 100 and 115% of NRC (18) recommendations, respectively. The heifers were fed these diets for 7 mo (experimental period of trial 2); then heifers of both groups were fed a common diet (Table 3) until 2 mo before calving. After parturition, they received the same lactation diet as trial 1 (Table 3).

In both trials, heifers were allotted to groups on the basis of season and pedigree index for milk production, estimated by the National Association of Italian Holstein-Friesian Breeders, Cremona, Italy.

Management and Diets

Growing heifers were housed in an open barn and kept in four pens (one per treatment per trial) with straw bedding. The heifers started the trial individually, according to attainment of the proper weight (150 and 300 kg of BW for trial 1 and trial 2, respectively). Diets were offered as TMR ad libitum once daily at 0800 a.m., to obtain less than 5% of orts. Dry matter intake was measured as the group mean. The feeding fence was long enough to avoid competition among heifers.

Half the heifers were artificially inseminated, after gynecological inspection, at first observed estrus following attainment of 370 kg of BW (early breeding; **E**) and the remaining after 420 kg of BW (late breeding; **L**).

Two months before predicted calving date, heifers were moved to another open barn. For the first 45 d they were fed grass hay, then they received a steaming-up regimen with increasing amount of concentrates.

After calving, heifers were housed in a free barn for lactating cows, with cubicles and paddock.

Measurements

In trial 1, from weaning to the end of the experimental period, heifers were weighed every 3 wk. In trial 2, heifers were weighed every 3 wk from 300 kg of BW to the end of the experimental period. Heifers of both trials were weighed just after calving. At the same times, two technicians separately evaluated BCS of heifers using the Agricultural Development and Advisory Service scoring system (1) and the average value was considered. In trial 1, wither height (**WH**) and hearth girth (**HG**) were also measured.

In both trials, to obtain basal values of metabolic profile every 63 d during the experimental periods, blood was sampled before feeding from the jugular vein by the Vacutainer system with Li-heparin as anticoagulant (2, 4). Heifers were captured by voluntary head introduction in feeding gate. Four blood samples were obtained in both trials for each heifer. All precautions were taken to avoid any possible heifer stress, which could alter results of some blood parameters. During lactation, milk production was recorded monthly and with the same frequency milk was sampled for fat and protein content determination.

Chemical and Biochemical Analyses

Concentrates were sampled every 2 mo and forages were sampled every time changes took place to measure the main nutrients (CP, ether extract, crude fiber, NDF, ADF, and ash) according to the methods of the Feed Evaluation Commission of the Italian Scientific Association of Animal Production (16). Nonfiber carbohydrates (**NFC**) were calculated by subtracting NDF, CP, ether extract, and ash from 100% DM. The nutritive value was estimated according to NRC (18) using Leroy's formula as reported by Crovetto (6) to evaluate metabolizable energy (**ME**) of feedstuffs.

Packed cell volume was determined by microhemocitometer on a small quantity of blood, before four plasma subsamples were separated by centrifugation at 3500 $\times g$ for 15 min and subsequent storing after freezing (–20°C). On frozen samples, the following parameters were determined: glucose, urea, Ca, inorganic P, ceruloplasmin, total protein, albumin, globulin, aspartate

Table 2. Composition, chemical analysis, and nutritive value of TMR fed from weaning to 150 kg of BW and during the two trials.

Composition	Post-weaning diet	Experimental diet			
		M1[1]	H1[2]	M2[3]	H2[4]
		(% of DM)			
Ingredient					
Grass hay	54.3	44.6	38.0	55.2	48.4
Corn silage	19.5	27.5	23.4	34.0	29.9
Cereals mix	. . .	3.5	12.1	4.3	10.3
Commercial concentrate mix[5]	26.2	24.4	20.8	6.5	6.1
Protein concentrate[6]	. . .	. . .	5.7	. . .	5.3
Nutrient					
CP	14.35	13.81	14.91	10.68	12.18
Crude fiber	24.55	23.40	20.78	25.84	23.46
NDF	44.89	39.44	36.43	48.77	45.10
ADF	28.15	22.78	20.81	28.16	25.91
NFC[7]	33.84	34.95	36.56	29.75	31.49
ME,[8] Mcal/kg of DM	2.317	2.411	2.516	2.349	2.437

[1]M1 = Prepubertal moderate gain diet.

[2]H1 = Prepubertal accelerated gain diet.

[3]M2 = Postpubertal moderate gain diet.

[4]H2 = Postpubertal accelerated gain diet.

[5]One kilogram contained 60,000 IU of vitamin A, 2,500 IU of vitamin D_3, 60 mg of vitamin E, 5 mg of vitamin K, 5 mg of vitamin B_1, 5 mg of vitamin B_2, 0.06 mg of vitamin B_{12}, 105 mg of niacin, 5 mg of pantothenic acid, 500 mg of choline, 55 mg of Fe, 25 mg of Cu, 115 mg of Mn, 1.5 mg of Co, 150 mg of Zn, and 4.1 mg of I.

[6]One kilogram contained 80,000 IU of vitamin A, 5,000 IU of vitamin D_3, 40 mg of vitamin E, 10 mg of vitamin B_1, 12 mg of vitamin B_2, 18 mg of vitamin B_6, 0.02 mg of vitamin B_{12}, 200 mg of niacin, 550 mg of DL methionine, 900 mg of choline, 250 mg of Mn, 350 mg of Zn, 3 mg of Co, 15 mg of Cu, 10 mg of Fe, 10 mg of I, and 0.15 mg of Se.

[7]NFC = Nonfiber carbohydrates.

[8]ME = Metabolizable energy.

Table 3. Composition, chemical analysis, and nutritive value of TMR fed to all heifers in trial 1 and trial 2 in the last rearing period and in lactation.

Composition	Diets	
	Last rearing period	Lactation
	(% of DM	
Ingredient		
Grass hay	61.6	...
Alfalfa hay	...	19.2
Corn silage	25.3	33.6
Cereals mix	8.7	...
Commercial concentrate mix[1]	...	47.2
Protein concentrate[2]	4.4	...
Nutrient		
CP	11.15	17.04
Crude fiber	25.52	16.10
NDF	49.52	35.32
ADF	30.04	22.00
NFC[3]	28.15	36.07
ME,[4] Mcal/kg DM	2.323	2.684

[1]One kilogram contained 40,000 IU of vitamin A, 2,500 IU of vitamin D_3, 20 mg of vitamin E, 5 mg of vitamin B_1, 6 mg of vitamin B_2, 9 mg of vitamin B_6, 0.01 mg of vitamin B_{12}, 100 mg of niacin, 275 mg of DL methionine, 450 mg of choline, 125 mg of Mn, 175 mg of Zn, 1.5 mg of Co, 7.5 mg of Cu, 5 mg of Fe, 5 mg of I, and 0.075 mg of Se.

[1]One kilogram contained 80,000 IU of vitamin A, 5,000 IU of vitamin D_3, 40 mg of vitamin E, 10 mg of vitamin B_1, 12 mg of vitamin B_2, 18 mg of vitamin B_6, 0.02 mg of vitamin B_{12}, 200 mg of niacin, 550 mg of DL methionine, 900 mg of choline, 250 mg of Mn, 350 mg of Zn, 3 mg of Co, 15 mg of Cu, 10 mg of Fe, 10 mg of I, and 0.15 mg of Se.

[3]NFC = Nonfiber carbohydrates.

[4]ME = Metabolizable energy.

amino transferase (**AST**), gamma-glutamyl transferase (**GGT**), total cholesterol, total bilirubin (4); Mg was determined by colorimetric reaction (xilidile blue, Roche, Basel, Switzerland); Zn by colorimetric reaction (Wako Chemicals GmbH, Neuss, Germany); Na, K and Cl by specific electrodes; alkaline phosphatase (**ALP**) by a kinetic-enzymatic kit (Boehringer Mannheim, Germany). Plasma assays were made at 37°C utilizing an automated analytical instrumentation (Monarch 2000, Instrumentation Laboratory, Lexington, MA).

Milk-component analysis was performed by infrared spectroscopy (Associazione Provinciale Allevatori, Piacenza, Italy).

Statistical Analysis

Data on growth and blood parameters were analyzed separately by trial, according to the following statistical model:

$$Y_{ijkl} = \mu + D_i + N_j + S_k + T_{l(i)} + (DN)_{ij} + \Sigma_{ijkl}$$

where Y_{ijkl} = dependent variable, μ = mean effect, D_i = diet effect (i = M or H), N_j = control effect number (j = 1 to 4), S_k = effect of season when the control was made (k = 1 to 4), $T_{l(i)}$ = effect of the animal in the treatment group, $(DN)_{ij}$ = interaction between diet and control number, and Σ_{ijkl} = residual error.

To evaluate first-lactation performances, a model including covariables was used (the BW at calving when the dependent variable was milk production; the pedigree index for fat percentage when the dependent variable was fat percentage; the pedigree index for protein percentage when the dependent variable was protein percentage) as follows:

$$Y_{ijkl} = \mu + D_i + F_j + M_k + (DF)_{ij} + bx_{ijkl} + \Sigma_{ijkl}$$

where Y_{ijkl} = dependent variable, μ = mean effect, D_i = diet effect (i = M or H), F_j = first breeding age effect (j = "early" or "late"), M_k = month of lactation effect (k = 1 to 10), $(DF)_{ij}$ = interaction between diet and age at first calving, b = effect of covariables, and Σ_{ijkl} = residual error. Interaction between diet effect and breeding age is neither discussed nor presented in tables.

Analysis of variance was conducted using the GLM procedure of SAS (23).

RESULTS

Diets. Intake of DM was observed as group mean and was similar to the planned value according to NRC (18). Composition, chemical analysis, and nutritive value of TMR are reported in Tables 2 and 3.

In trial 1, estimated ME was higher by 0.105 Mcal/kg of DM and CP percentage was higher by 1.1% on DM in H1 than in M1 diet. Similarly, in trial 2, estimated ME was higher by 0.088 Mcal/kg of DM and CP percentage was higher by 1.5% on DM in H2 diet than in M2 diet. In the experimental period of trial 1, CP to ME ratios of M1 and H1 were 57.3 and 59.3 g of CP/Mcal of ME; these values are 8.0 and 9.0% higher than the corresponding ratios calculated from NRC (18) recommendations for an ADG of 0.7 and 0.9 kg (53.2 and 54.5 g of CP/Mcal of ME, respectively). In the experimental period of trial 2, CP to ME ratios of M2 and H2 were 45.5 and 50.0 g of CP/Mcal of ME; these values are 13.0 and 4.0% lower than the corresponding ratios calculated from NRC (18) recommendations for an ADG of 0.7 and 0.9 kg (52.2 g of CP/Mcal of ME for both cases).

Growth. Growth patterns of heifers of trial 1 and trial 2 are presented in Figures 1, 2, and 3.

In trial 1, in the experimental period, heifers fed H1 diet gained 0.775 kg/d and M1 heifers 0.667 kg/d ($P = 0.0128$). The average BW of the first control of the experimental period was not significantly different between groups; the differences were significant from the second control ($P < 0.001$) and at the end of experimen-

tal period heifers fed H1 were significantly heavier than M1 heifers ($P < 0.001$). No difference in BCS pattern was detected between groups. Wither height was higher for H1 than M1 group (for overall means $P = 0.066$). Heath girth was also higher for H1 than M1 group (for overall means $P < 0.001$) and the difference within single control became significant ($P < 0.05$) from the second control of the experimental period.

In trial 2, heifers on H2 diet grew by 0.824 kg of ADG from the beginning (364 d of age on average) to the end of experimental period (574 d on average); heifers fed M2 diet grew by 0.748 kg/d and there was no significant difference with H2 group. Body weight differed between groups at the third and at the fourth control ($P < 0.001$). Body condition score of H2 heifers was higher than that of M2 ($P < 0.001$). Heifers on H2 diet showed higher BCS from the second control; the largest difference was at the fourth control when BCS of H2 was 0.6 point higher than M2.

Metabolic profile. The metabolic profiles of heifers of both trials are reported in Table 4.

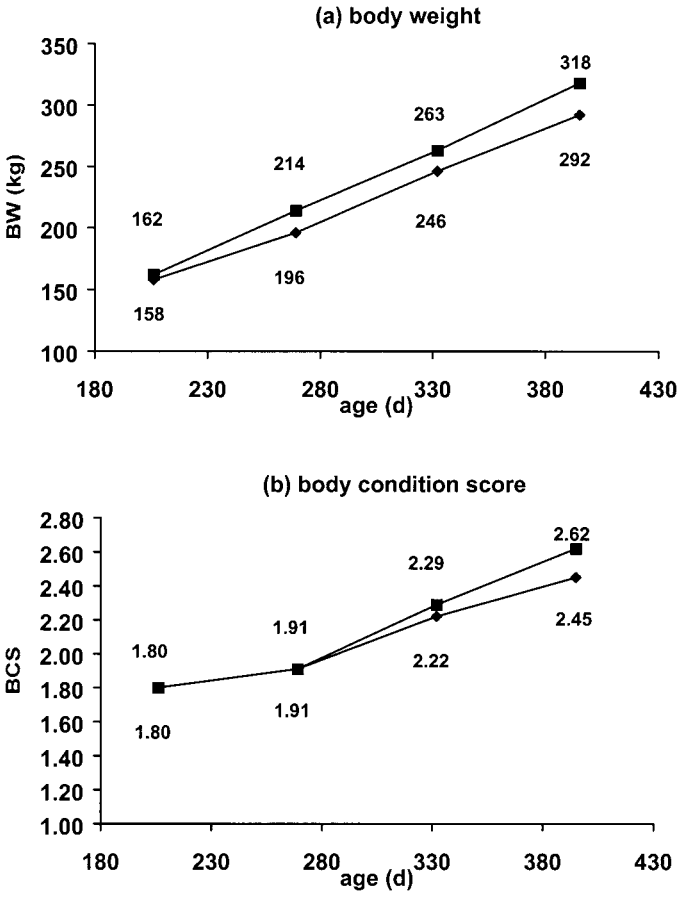

Figure 1. Relationships between body weight (a), body condition score (BCS; b), and age for group with medium (◆) and high (■) daily gain in trial 1.

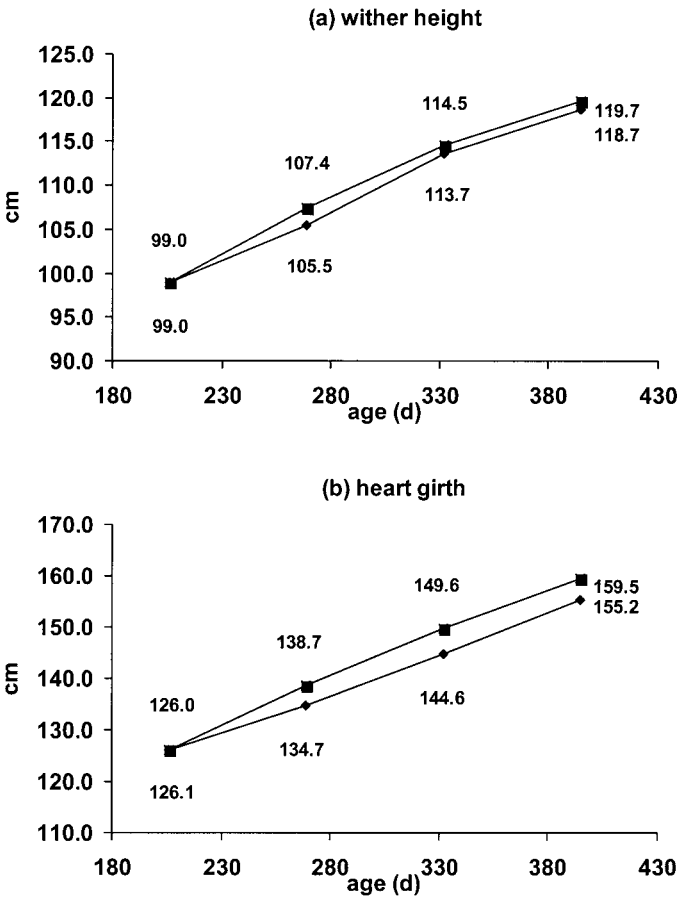

Figure 2. Relationships between wither height (a), heart girth (b), and age for group with medium (◆) and high (■) daily gain in trial 1.

In trial 1, plasma glucose concentration was significantly higher in heifers fed H1 diet than heifers on M1 diet (for overall means of the experimental period; $P < 0.001$); in both groups, values increased from the first to the fourth control of experimental period (Figure 4a). Plasma urea concentration had a decreasing pattern, but no significant difference was observed between groups (Figure 4b). No differences were detected between groups for plasma mineral concentrations, with the exception of Mg ($P = 0.026$), which was higher in H1 than M1 group. Ceruloplasmin ($P < 0.001$), total protein, and globulin ($P < 0.05$) were significantly higher in plasma of H1 than in M1 heifers; however, AST was higher in M1 ($P < 0.05$).

In trial 2, plasma glucose concentration showed a decreasing pattern after puberty (Figure 5a), but no difference associated with ADG was observed (Table 4). Plasma urea concentration was higher in H2 than M2 heifers ($P = 0.016$). The difference between groups reached maximum value at the third control of the experimental period (Figure 5b). In addition, heifers fed

H2 diet exhibited significantly higher ($P < 0.05$) plasma concentrations of inorganic P, Zn, and GGT, and lower ($P < 0.05$) Ca and K than M2 heifers.

Reproductive performance. Reproductive parameters are reported in Table 5. In trial 1, one heifer in each group showed reduced ovarian development and they were not bred and were eliminated. There was no difference for age at first service, age at conception, BW at conception, age at first calving (**AFC**), pregnancy length, BW at calving, and services per conception between heifers fed M1 or H1 diet. Heifers belonging to E group were younger at first service ($P < 0.01$), at conception ($P < 0.01$), and at calving ($P < 0.01$) than heifers belonging to L group.

Reproductive problems observed in trial 1 are reported in Table 6. Only one heifer in E group experienced dystocia. There were also three cases of retained placenta: two in E and one in L group.

Even in trial 2, no difference concerning reproductive parameters appeared between heifers fed for high or medium ADG (Table 5). Age at first service ($P < 0.05$), at conception ($P < 0.01$), and at calving ($P < 0.01$) was lower for E than L heifers. Early bred heifers were lighter at conception ($P < 0.001$) and at calving ($P = 0.058$). One H2-L heifer did not get pregnant and two heifers in E and two in L group confirmed pregnant by rectal palpation, but aborted in early stage of gestation. Three heifers belonging to E group experienced dystocia. No case of retained placenta was recorded in trial 2.

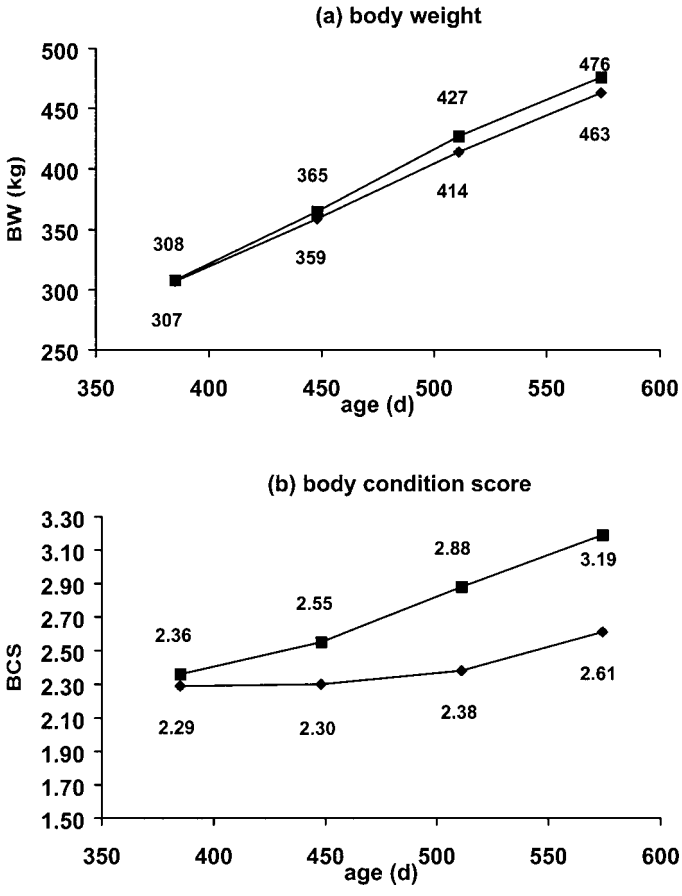

Figure 3. Relationships between body weight (a), body condition score (BCS; b), and age for group with medium (◆) and high (■) daily gain in trial 2.

Table 4. Least-square means of metabolic parameters.

	Trial 1		Trial 2	
Parameter	M1[1]	H1[2]	M2[3]	H2[4]
PCV[5], L/L	0.301	0.303	0.321	0.321
Glucose, mmol/L	4.477[b]	4.722[a]	4.376	4.470
Urea, mmol/L	4.048	4.218	3.606[d]	4.079[c]
Ca, mmol/L	2.636	2.648	2.608[c]	2.566[d]
Inorganic P, mmol/L	2.573	2.537	2.165[d]	2.277[c]
Mg, mmol/L	0.883[d]	0.911[c]	0.966	0.958
Na, mmol/L	140.6	140.2	141.0	141.0
K, mmol/L	4.244	4.212	4.123[c]	3.969[d]
Cl, mmol/L	103.0	103.1	104.9	104.7
Zn, μmol/L	15.76	15.50	14.15[d]	15.08[c]
Ceruloplasmin, μmol/L	2.823[b]	3.221[a]	2.835	2.794
Total protein, g/L	66.86[d]	68.59[c]	71.31	71.35
Albumin, g/L	34.51	34.76	34.25	34.54
Globulin, g/L	32.35[d]	33.83[c]	37.05	36.81
AST[6], IU/L	75.37[c]	70.98[d]	67.55	66.60
GGT[7], IU/L	21.04	20.25	20.46[d]	21.48[c]
Total cholesterol, mmol/L	3.156	3.086	3.256	3.266
ALP[8], IU/L	158.2	163.3	147.5	149.4
Total bilirubin, μmol/L	3.388	3.426	3.310	3.569

[a,b]Means differ for $P < 0.001$. [c,d] = Means differ for $P < 0.05$.
[1]M1 = Moderate prepubertal gain diet.
[2]H1 = Accelerated prepubertal gain diet.
[3]M2 = Moderate postpubertal gain diet.
[4]H2 = Accelerated postpubertal gain diet.
[5]PCV = Packed cell volume.
[6]AST = Aspartate amino transferase.
[7]GGT = Gamma-glutamyl transferase.
[8]ALP = Alkaline phosphatase.

First lactation. In Table 7 milk production and milk composition of trial 1 and trial 2 are reported. Average daily gain before puberty (trial 1) did not significantly influence milk production and fat and protein concentration, even if there was a tendency to a higher fat content in moderate ($P < 0.08$). Age at calving affected milk production positively and milk fat and protein concentration negatively, but milk production was not significantly different between E and L heifers when AFC was corrected for BW.

Nutrition after puberty (trial 2) had no effect on milk production and milk protein concentration (Table 7), but milk fat concentration was higher in M2 than in H2 heifers. Milk production was positively associated with higher BW at breeding both when milk production was corrected for BW at calving and when not. Milk

fat concentration tended to be higher when heifers were bred at lighter weight; however, milk protein concentration was not.

DISCUSSION

In trial 1, heifers fed for higher ADG showed a significant difference in BCS after 10 to 12 mo of age (Figure 1). Differences for BCS were more evident in trial 2, where experimental diets were fed to postpubertal heifers (Figure 3). These results are very similar to those obtained by Daccarett et al. (7) who found that Holstein heifers fed for 115% of NRC (18) requirements tended to increase BCS, compared with those fed for 100% of NRC (18) requirements, from 9 mo of age. Differences between the results obtained by Daccarett et al. (7) and those of our trials could be attributed to differences in protein to energy ratio, that was higher at the early stage of our trial than that calculated from the data reported by Daccarett et al. (7).

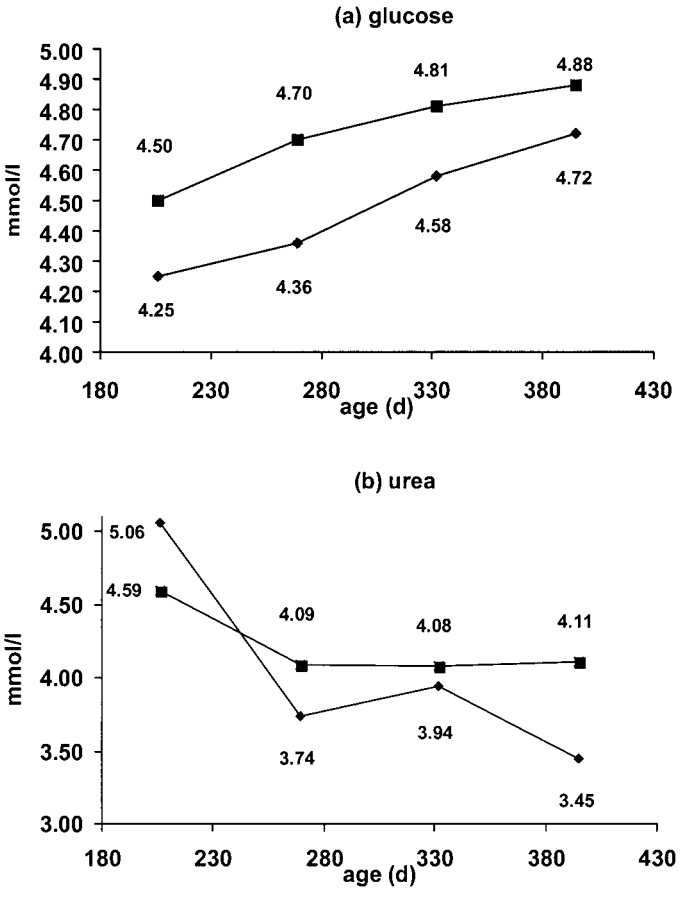

Figure 4. Relationships between plasma concentration of glucose (a), urea (b), and age in the experimental period of trial 1 for group with medium (◆) and high (■) daily gain.

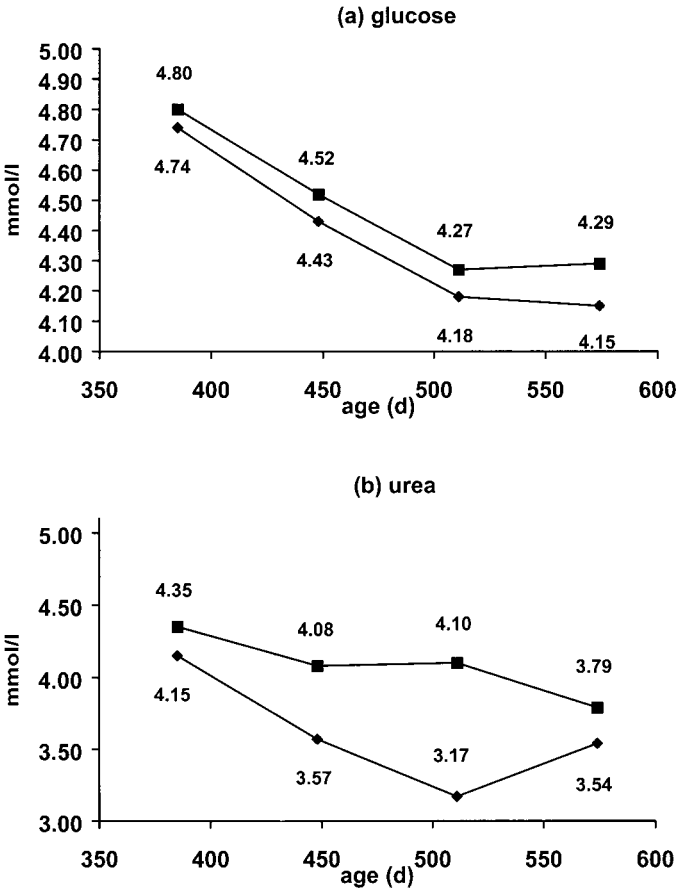

Figure 5. Relationships between plasma concentration of glucose (a), urea (b), and age in the experimental period of trial 2 for group with medium (◆) and high (■) daily gain.

Kertz et al. (13) obtained no difference in WH from 187 to 369 d of age between heifers of control and accelerated gain groups, but there was a significant difference in HG from 286 to 369 d of age. Our results are in agreement with those of Kertz et al. (13), even if their heifers had higher ADG (0.83 vs. 0.93 kg/d) than ours. Difference in BW can be explained in younger heifers by difference in WH (not significant) and HG (significant).

From 7 to 14 mo of age (trial 1), increasing energy and protein concentration in the diet improved ADG without promoting fat deposition. Afterwards (trial 2), heifers started to deposit fat more easily. This is also the result of Bortone et al. (3), who found an evident tendency to increase BCS in the second year of life when 115% of NRC (18) requirements were supplied. Also from our trial on postpubertal heifers, results showed that differences in BW were related to differences in BCS between H2 and M2. These results indicate that increasing energy and protein content in order to obtain

Table 5. Least-square means of reproductive parameters of heifers which reached first lactation.

Item	Diet				AFC[1]				Effect	
	M[2]		H[3]		E[4]		L[5]		Diet	AFC[1]
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*P*	
Trial 1										
Heifers, no.	8		9		7		10			
Age at first service, d	558	18.1	555	16.6	519	18.9	594	15.6	NS	<0.01
Age at conception, d	596	24.8	587	22.8	524	26.0	660	21.5	NS	<0.002
BW at conception, kg	428	13.0	425	11.9	411	13.6	441	11.3	NS	NS
Age at calving, d	876	25.7	871	23.6	808	26.9	940	22.3	NS	<0.003
Pregnancy length, d	280	4.3	285	3.9	284	4.5	280	3.7	NS	NS
BW at calving, kg	559	28.5	540	22.9	527	29.5	573	21.6	NS	NS
Services per conception[6]	1.4		1.8		1.1		1.9			
Trial 2										
Heifers, no.	9		8		10		7			
Age at first service, d	547	35.6	561	38.8	478	33.6	630	40.6	NS	<0.02
Age at conception, d	618	29.8	570	32.5	487	28.1	701	34.0	NS	<0.001
BW at conception, kg	457	13.3	445	16.6	402	12.6	500	17.2	NS	<0.001
Age at calving, d	893	30.2	848	32.9	761	28.4	980	34.4	NS	<0.001
Pregnancy length, d	275	3.6	279	3.9	274	3.4	279	4.1	NS	NS
BW at calving, kg	579	17.4	551	21.7	536	16.4	594	22.5	NS	<0.06
Services per conception[6]	1.9		1.1		1.1		2.1			

[1]AFC = Age at first calving.
[2]M = Group with a diet for a medium average daily gain in the rearing trial.
[3]H = Group with a diet for a high average daily gain in the rearing trial.
[4]E = Group bred at early age.
[5]L = Group bred at late age.
[6]Arithmetic mean.

higher ADG affects fat deposition in heifers of different ages to differing degrees.

In trial 1, the ADG was lower than in trial 2. However, the observed ADG of the groups with lower gain was very close to the expected ADG. On the other hand, in the groups with higher gain, the observed ADG was lower than that expected. These results show that energy and protein supply were not adequate to meet requirements for ADG exceeding 0.8 kg. Energy and protein concentration of H1 and H2 diets (Table 2) was higher than those of M1 and M2 diets. Most probably, actual DM intake was not enough for high ADG groups in both trials and requirements were not met. However, we cannot present individual feeding intake data, but our observations on group feeding intake permit us to assert that DM ingested was very close to that suggested by NRC (18). With regard to energy source, carbohydrates employed in these diets (with a large amount of starch) could have induced a lipogenetic effect of the ration, especially in the older animals. This

Table 6. Reproductive problems of heifers.

Item	Trial 1				Trial 2			
	M[1]	H[2]	E[3]	L[4]	M[1]	H[2]	E[3]	L[4]
	Heifers (no.)							
Total	10	10	10	10	11	11	12	10
Pregnant	9	9	8	10	11	10	12	9
Not pregnant	1	1	2	. . .	. . .	1	. . .	1
Aborted	. . .	. . .	. . .	. . .	2	2	2	2
Eliminated because of accident	1	. . .	1	. . .	. . .	. . .	. . .	. . .
Dystocia	. . .	1	1	. . .	2	1	3	. . .
Retained placenta	2	1	2	1	. . .	. . .	. . .	. . .

[1]M = Group with diet for a medium average daily gain in the rearing trial.
[2]H = Group with a diet for a high average daily gain in the rearing trial.
[3]E = Group bred at early age.
[4]L = Group bred at late age.

Table 7. Least square means for milk production and milk composition of the two trials during the 305-d lactation period.

	Diet				AFC[1]				Effect	
	M[2]		H[3]		E[4]		L[5]		Diet	AFC[1]
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*P*	
Trial 1										
Heifers, no.	8		9		7		10			
Milk production, kg/d	25.39	0.64	26.77	0.56	24.14	0.68	28.03	0.52	NS	<0.001
Milk production[6], kg/d	26.18	0.67	27.34	0.48	26.25	0.72	27.27	0.45	NS	NS
Fat[7], %	3.53	0.12	3.25	0.10	3.62	0.12	3.16	0.09	<0.08	<0.004
Protein[8], %	3.42	0.03	3.37	0.03	3.46	0.04	3.32	0.03	NS	<0.002
Trial 2										
Heifers, no.	9		8		10		7			
Milk production, kg/d	26.97	0.57	26.27	0.73	25.44	0.44	27.80	0.87	NS	<0.03
Milk production[6], kg/d	26.10	0.49	26.50	0.59	25.20	0.48	27.41	0.65	NS	<0.02
Fat[7], %	3.56	0.09	3.31	0.09	3.56	0.08	3.32	0.10	<0.05	<0.06
Protein[8], %	3.27	0.04	3.19	0.04	3.20	0.04	3.27	0.04	NS	NS

[1]AFC = Age at first calving.
[2]M = Group with diet for a medium average daily gain in the rearing trial.
[3]H = Group with a diet for a high average daily gain in the rearing trial.
[4]E = Group bred at early age.
[5]L = Group bred at late age.
[6]From a statistical model with BW at calving as covariable.
[7]From a statistical model with pedigree index for fat percentage as covariable.
[8]From a statistical model with pedigree index for protein percentage as covariable.
NS = Not significant.

hypothesis is supported by larger amount of cereal grains in the H1 and H2 diets (Table 2), and it seems to be confirmed by higher levels of plasma glucose in both trials for H groups (Table 4).

Different timing of fat deposition can be explained by the growth pattern of tissue development. In early stages of development, energy and protein are easily converted in body mass. Maximum growth potential occurs before puberty; after this stage, protein deposition is less efficient and the nutrients in excess are either converted to lipid, excreted, or catabolized (19). The observed ADG of heifers fed H2 diet was lower than expected, probably because they got fatter (higher BCS), with higher energy deposition per kilogram of body gain.

Plasma glucose was higher for groups fed diets for high daily gain; the difference was significant only in trial 1. Differences were higher in the first half of trial 1, whereas they were reduced at the end of the treatment period (Figure 4a). This may be the result of the higher energy availability, as confirmed by higher ADG of those groups. This is in agreement with the results of Park et al. (20), who observed an increase in plasma glucose during a compensatory growth phase, even if at higher BW (380.4 kg) and ADG (1.71 kg) than ours, indicating that this metabolite can be affected by the energetic status of heifers. However, Hall et al. (10) found no difference in serum glucose level at puberty, in beef heifers, in response to diet calculated for different ADG (0.6 vs. 1.0 kg). Our results indicate that blood glucose seems to be a better index of energy intake for younger than for older heifers.

In both trials, urea values reflected protein supply, according with other studies (10, 20). From Hall et al. (10), blood urea nitrogen in beef heifers seemed to be related to CP intake. The result of our experiments is also in agreement with that obtained on dairy heifers on compensatory gain by Park et al. (20), who observed a higher blood urea concentration when CP supply was 40% higher than NRC (18) requirement. Urea level can also be influenced by the energy availability of diet (2), as found on heifers by McShane et al. (17). However, in the present experiment, the higher values of blood urea in H1 and H2 than in M1 and M2 did not appear to be determined mainly by protein catabolism with energetic finality, but they appeared to be related more to CP to ME ratio. Only in the first control of trial 1, urea values were higher in M1 than in H1, nevertheless CP content of M1 diet was lower than that of H1 diet. This result could indicate that in M1 group urea level was influenced, in the first period, by low energy availability, with utilization of amino acids as energy source, as indicated by the lower plasma glucose found in H1 heifers.

It is difficult to explain differences in mineral plasma components, particularly for Mg in trial 1 and Ca, inor-

ganic P and K in trial 2. The differences were slight and all parameters were, however, still in reference ranges and did not suggest treatment-linked metabolic variations. The hypothesis that the different mineral supply or availability of concentrates played a role appears more consistent. Calamari et al. (5) observed variations in Mg absorption among diets with similar amounts of this mineral, but with different forages and concentrates as source, and supposed that the differences were caused by different digestibility.

Interesting are the values of plasma protein components in H1 heifers in relation to those of M1 heifers. In fact, there was a higher value in total proteins, which was due to an increase in globulin, and in ceruloplasmin, a globulin that is involved in inflammatory-like conditions (4). Normally, globulin level is higher in older animals; in fact, the values in postpubertal heifers (trial 2) were higher than those of prepubertal heifers (trial 1). The differences in globulin and ceruloplasmin between M1 and H1 heifers, observed in trial 1, were already significant at the beginning of the controls. This result seems to indicate that the higher values in H1 were due to the differences in heifers' condition before the trial began rather than to the feeding regime. Nevertheless, all these parameters were in the standard ranges, suggesting a good metabolic status of heifers of all groups. In addition, the substantial lack of differences between M and H groups in both trials for parameters such as albumin, total cholesterol and total bilirubin, and the small difference for transferases (AST and GGT), demonstrated the consistency of high feeding regimen with good liver functionality.

In trial 1, no difference in milk production was found between diet treatments. This may mean that the highest ADG that we obtained before puberty is not detrimental for milk ability of heifers. Many experiments have shown that rate of gain before puberty higher than 0.7 kg/d had negative effects on milk production of Holstein heifers (24). However, recent results (27) have shown that an increase in ADG less than 1.0 kg in the prepubertal period does not negatively influence future milk production. This could be the case of our trial.

Daily gain after puberty did not affect future milk production. This result is in agreement with those of Lacasse et al. (14) and Hoffman et al. (12). In postpubertal heifers raised differently, Lacasse et al. (14) found an increase in fat percentage for groups with higher plane of nutrition in the isometric phase of mammary development after puberty, whereas Hoffman et al. (12) found no difference. Our results appear in contrast with both of them, perhaps because there was the influence of some other factors such as milk production and energy balance during lactation. It is very difficult to explain the common reduction in milk fat content in accelerated gain heifers of both trials.

Age at first calving significantly influenced milk production in both trials. This result can be explained by the lower weight at calving of early-bred heifers than that of late-bred heifers (8). Age at first calving also influenced milk fat percentage, which was lower for late calving heifers, when milk production was higher. This result is inconsistent with the study of Harville and Henderson (11), who found a positive correlation between AFC and milk fat percentage. Even the higher milk protein percentage observed in early calving heifers of trial 1 could be due to the reduction in milk production.

CONCLUSIONS

The ADG seems to affect body condition of growing dairy heifers, but its effect becomes evident only in postpubertal heifers.

This work showed that the metabolic profile of pre- and postpubertal Italian Holstein-Friesian heifers can be essentially unaffected by ADG, with the exception of glucose and urea, which appeared to be reliable markers of energy and protein supply. However, a better evaluation of their usefulness, with higher number of observations in different feeding studies, is necessary. Liver functionality seemed not to be impaired with diets for an ADG of up to about 0.8 kg.

Accelerated ADG in the prepubertal phase seemed not to affect first lactation performance for milk production and fat content, whereas accelerated ADG after puberty influenced fat content.

Late calving heifers had higher milk production and a lower fat milk percentage than early calving heifers. Results concerning milk fat and protein concentration require further investigations.

REFERENCES

1 Agricultural Development and Advisory Service. 1986. Condition scoring of dairy cows. Publ. 612, Agric. Dev. Advisory Serv., Min. Agric., Fisheries Food (Publ.), Lion House, Alhwick, Northumberland, England.

2 Bertoni, G., and R. Lombardelli. 1991. Effects of feeding on endocrine and metabolic profile in dairy animals (in Italian). Pages 1161–1189 *in* Proc. IX Congresso Nazionale Associazione Scientifica di Produzione Animale, Roma, Italy.

3 Bortone, E. J., J. L. Morrill, J. S. Stevenson, and A. M. Feyerherm. 1994. Growth of heifers fed 100 or 115% of National Research Council requirements to 1 year of age and then changed to another treatment. J. Dairy Sci. 77:270–277.

4 Calamari, L., G. Bertoni, M. G. Maianti, and V. Cappa. 1989. The usefulness of new hematochemical parameters in the assessment of the metabolic profile of dairy cows (in Italian). Zoot. Nutr. Anim. 15:191–210.

5 Calamari, L., E. Trevisi, G. Pirlo, and L. Migliorati. 1993. Effect of forage type on the metabolic condition and health of dairy

cows (in Italian). Pages 183–188 *in* Proc. X Congresso Nazionale Associazione Scientifica di Produzione Animale, Bologna, Italy.
6 Crovetto, G. M. 1993. L'energia. Pages 291–314 *in* La vacca da latte. G. Succi and I. Hoffman (a cura di). CittàStudi, Milano, Italy.
7 Daccarett, M. G., E. J. Bortone, D. E. Isbell, J. L. Morrill, and A. M. Feyerherm. 1993. Performance of Holstein heifers fed 100% or more of National Research Council requirements. J. Dairy Sci. 76:606–614.
8 Foldager, J., and K. Sejrsen. 1987. Mammary gland development and milk production in dairy cows in relation to feeding and hormone manipulation during rearing. Pages 102–116 *in* Research in Cattle Production, Danish Status and Perspectives. Landhusholdringsselskabet, Frederiksberg, Denmark.
9 Foldager, J., and K. Sejrsen. 1991. Rearing intensity in dairy heifers and the effect on subsequent milk production. Rep. Natl. Inst. Anim. Sci. No. 693. Natl. Inst. Anim. Sci., Tjele, Denmark.
10 Hall, J. B., R. B. Staigmiller, R. A. Bellows, R. E. Short, W. M. Mosely, and S. E. Bellows. 1995. Body composition and metabolic profiles associated with puberty in beef heifers. J. Anim. Sci. 73:3409–3420.
11 Harville, D. A., and C. R. Henderson. 1966. Interrelationships among age, body weight, and production traits during first lactation of dairy cattle. J. Dairy Sci. 49:1254–1261.
12 Hoffman, P. C., N. M. Brehm, S. G. Price, and A. Prill-Adams. 1996. Effect of accelerated postpubertal growth and early calving on lactation performance of primiparous Holstein heifers. J. Dairy Sci. 79:2024–2031.
13 Kertz, A. F., L. R. Prewitt, and J. M. Ballam. 1987. Increased weight gain and effects on growth parameters of Holstein heifer calves from 3 to 12 months of age. J. Dairy Sci. 70:1612–1622.
14 Lacasse, P., E. Block, L. A. Guilbault, and D. Petitclerc. 1993. Effect of plane of nutrition of dairy heifers before and during gestation on milk production, reproduction, and health. J. Dairy Sci. 76:3420–3427.
15 Little, W., and R. D. Harrison. 1981. Effects of different rates of live weight gain during rearing on the performance of Friesian heifers in their first lactation. Anim. Prod. 32:362 (Abstr.).
16 Martillotti, F., M. Antongiovanni, L. Rizzi, E. Santi, and G. Bittante. 1987. Metodi di analisi per la valutazione degli alimenti di impiego zootecnico. Quaderno metodologico n. 8, IPRA-CNR, Roma, Italy.
17 McShane, T. M., K. K. Schillo, M. J. Estienne, J. A. Boling, N. W. Bradley, and J. B. Hall. 1989. Effects of recombinant DNA-derived somatotropin and dietary energy intake on development of beef heifers: II. concentrations of hormones and metabolites in blood sera. J. Anim. Sci. 67:2237–2244.
18 National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. Natl. Acad. Sci., Washington, DC.
19 Owens, F. N., P. Dubeski, and C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71:3138–3150.
20 Park, C. S., G. M. Erickson, Y. J. Choi, and G. D. Marx. 1987. Effect of compensatory growth on regulation of growth and lactation: response of dairy heifers to a stair-step growth pattern. J. Anim. Sci. 64:1751–1758.
21 Pirlo, G., M. Capelletti, and G. Marchetto. 1997. Effects of energy and protein allowances in the diets of prepubertal heifers on growth and milk production. J. Dairy Sci. 80:730–739.
22 Radcliff, R. P., M. J. Van de Haar, A. L. Skidmore, L. T. Chapin, B. R. Radke, J. W. Lloyd, E. P. Stanisiewski, and H. A. Tucker. 1997. Effects of diet and bovine somatotropin on heifer growth and mammary development. J. Dairy Sci. 80:1996–2003.
23 SAS. 1988. SAS/STAT User's Guide. Release 6.03 Edition. Ed. Cary, NC, USA.
24 Sejrsen, K., and S. Purup. 1997. Influence of prepubertal feeding level on milk yield potential of dairy heifers: A review. J. Anim. Sci. 75:828–835.
25 Stelwagen, K., and D. G. Grieve. 1990. Effect of plane of nutrition on growth and mammary gland development in Holstein heifers. J. Dairy Sci. 73:2333–2341.
26 Swanson, E. W. 1960. Effect of rapid growth with fattening of dairy heifers on their lactational ability. J. Dairy Sci. 43:377–387.
27 Van Amburgh, M. E., and D. M. Galton. 1994. Accelerated growth of Holstein heifers. Effects on lactation. Pages 147–154 *in* Proc. Cornell Nutr. Conf. Feed Manuf., Rochester, NY. Cornell Univ., Ithaca, NY.
28 Van Amburgh, M. E., D. M. Galton, D. E. Bauman, R. W. Everett, D. G. Fox, L. E. Chase, and H. N. Erb. 1998. Effects of three prepubertal body growth rates on performance of Holstein heifers during first lactation. J. Dairy Sci. 81:527–538.
29 Waldo, D. R., A. V. Capuco, and C. E. Rexroad, Jr. 1998. Milk production of Holstein heifers fed either alfalfa or corn silage diets at two rates of daily gain. J. Dairy Sci. 81:756–764.
30 Waldo, D. R., H. F. Tyrrell, A. V. Capuco, and C. E. Rexroad, Jr. 1997. Components of growth in Holstein heifers fed either alfalfa or corn silage diets to produce two daily gains. J. Dairy Sci. 80:1674–1684.