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Relationships between growth and body condition development during the rearing period and performance in the first three lactations in Holstein cows

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ABSTRACT: The relationship between growth and development of body condition during the rearing of replacement heifers and their subsequent performance in the production period of Holstein cows in the Czech Republic was studied. The data set used in this study covered 733 Holstein heifers born on one farm during the years 2004–2009. The evaluated effects considered were body weight (BW), average daily gain of live weight (ADG), and body condition score (BCS) of heifers. The results demonstrated the desirable effect of the higher achieved ADG in the period before sexual maturity on the lower age at first calving (AFC), the positive influence on milk yield in the first lactation, and the negative relationship to the conception rate of heifers before first calving. Similar effects were also found for growth in the period of 9–12 months of age. In heifers with a greater growth rate before puberty there was not a significant risk of excessive BCS during the breeding period. Heifers with the highest BCS (3.5 points (p.) and more) at 14 months of age had significantly the lowest milk yield in the first and second lactation compared to heifers with medium (3.5 p.) and low (3.25 p. or less) BCS. Over-conditioned heifers exhibited higher milk protein content in the first and second lactation. No effects on the third lactation were observed.

Keywords: average daily weight gain; body condition score; heifer performance; dairy cows

INTRODUCTION

Proper rearing of heifers is a prerequisite for obtaining healthy, resilient, and productive animals for herd replacement, and directly or indirectly affects the profitability of a dairy farm. Optimal rearing management enables shortening the length of the rearing period, consequently reducing cost without compromising cows' subsequent milk production, reproductive performance or longevity (Raguz et al. 2011). Most studies indicate the optimal age at first calving (AFC) of heifers in Holsteins and other dairy breeds to be 23 to 24 months of age (Shamay et al. 2005; Stevenson et al. 2008). In the Czech Republic, the AFC of Holstein heifers is almost 26 months, and its variability is significantly greater than in other countries with developed breeding practice (Krpalkova et al. 2014a). Higher AFC is associated with the risk of excessive body condition score (BCS) at calving followed by a pronounced negative energy balance (NEB) of dairy cows after their calving (Krpalkova et al. 2014b). The result of NEB effect at the beginning of lactation is a reduction in conception ability, which causes prolongation of the calving interval (Collard et al. 2000).

It also causes more problems in the herd management and increases the cost of herd replacement (Vacek et al. 2007; Heikkilla et al. 2008). The rearing of replacement heifers is usually, with regard to the type and intensity of nutrition, traditionally divided into two successive phases: before and after reaching sexual maturity (Abeni et al. 2000; Shamay

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et al. 2005). Opinions on the growth intensity in these periods vary considerably. Growth rate and development of the mammary gland of animals at pasture is positive but less stable than in animals in a barn (Velik et al. 2013). Studies concerning this issue have appeared since the 1950s. Tozer and Heinrichs (2001) and Sakaguchi et al. (2005) described the negative effect of a high-energy diet before puberty in all breeds, because overfeeding heifers at an early age leads to a limitation of mammary gland development. Szencziova et al. (2013) stated that udder morphology directly corresponds to yield and milking characteristics, as well as to mammary gland health. According to Hoffman et al. (1996), in terms of growth intensity, there is a critical period between the 3rd and approximately the 9–10th month of age. In this period, the mammary gland grows 3.5 times faster than other cells of the body, and excessive energy in the diet leads to the replacement of glandular cells by fat tissue (Bar-Peled et al. 1997; Daniels 2010). However, to achieve the recommended weight of 615 kg at 24 months of age, rapid growth is necessary (Hoffman et al. 1996). In accordance with the above-mentioned reasons, it is necessary to limit average daily gain (ADG) to less than 770 g in the period of 3–9 months of age (Lammers and Heinrichs 2000; Shamay et al. 2005). Szewcuk et al. (2013) concluded that no clear relationships between body weight (BW) and genotype combination were found. Daniels (2010) adds that if the growth of mammary gland at early age is inadequate, then maximum development has not been reached and the milk production of such animals is reduced in their production period.

The objective of this study was to evaluate the relationships between growth intensity and body condition development of replacement heifers during the rearing period and their production and reproduction performance in their productive life. The question is whether restrictions of the mammary gland development as a result of a high-energy diet actually negatively affect the subsequent milk production.

MATERIAL AND METHODS

Data. The data set used in this study covered 733 Holstein heifers born during the years 2004–2009. Records of BCS, BW, ADG, and the respective selected reproduction and production traits of the first three lactations (milk yield (kg) in 305 days of lactation; protein (%); fat (%); services per conception (*n*); AFC (days); days open (days); calving interval (days)) were collected over a 6-year period (2006–2011) at the university farm (Czech University of Life Sciences Prague (CULS)) at Lány (Central Bohemia, Czech Republic). The animals were generally kept under comparable conditions. All calves were housed in individual outside hutches equipped with buckets for water and a starter mixture. Calves had free access to water and the starter mix, and subsequently all heifers were fed the same maintenance diet and housed in a free-stall barn after weaning (approximately 3 months of age). The heifers' diet consisted of a total mixed ration composed of forage and grain (TMR) fed once daily. Two types of TMR were used. The first type (TMR1) was fed till 12 months of age and the second type (TMR2) since 12 months of age till the end of the rearing period. The ratio between metabolizable energy and digestible protein in TMR1 was 39–66 kcal/g and in TMR2 it was 40–45 kcal/g. Until 9 months of age, TMR1 was fed to heifers in 3 types of rations. The first ration type (39–50 kcal/g) was fed to heifers with high ADG above 0.8 kg/day, the second type to heifers with medium ADG 0.8–0.7 kg/day (51–60 kcal/g), and the third type (61–66 kcal/g) to heifers with low ADG below 0.7 kg/day. In months 9–12 of age the first type TMR1 contained 51–60 kcal/g. A live weight of 400 kg was crucial for the first insemination of heifers, and the approximate conception period was at 14 months of age. The optimal time for breeding was determined using farm records along with heat detection with a pedometer ALPRO™ (DeLaval International AB, Tumba, Sweden). Farm records of BCS, BW, and respective reproduction and production traits during the first 3 lactations measured within the milk recording system ICAR 2013 were used for evaluation. The evaluated factors considered in this investigation were BW, ADG, and BCS. The basic characteristics evaluated are listed in Table 1. BCS was ranked on a standard 5-point scale (Edmonson et al. 1989) and BW was measured at monthly intervals from 3 to 18 months of age (Table 1). ADG was calculated using the difference in BW between 2 consecutive months during the analyzed period. Animals were not of the same age at the data collection onset and therefore the dataset was unbalanced. Individual milk production in the first 3 lactations that lasted

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250 days or more was included in the analysis and all lactations were standardized to 305 days. Some heifers did not finish all the evaluated lactations and some were culled, but their data were used until they left the herd. Statistically significant results are listed in Tables 2–5.

Statistical analysis. The MIXED procedure of SAS (Statistical Analysis System, Version 9.2, 2008) under the models described in Equations 1 and 2, corrected for other significant effects, was applied to determine the impact of the heifers' rearing period on reproduction and production traits during three subsequent lactations. The Tukey's method was used for means comparison (Verbeke and Molenbergs 2000). Only fixed effects were included in the models, and animals were considered as independent observations.

$$Y_{ijklm} = \mu + A_i + S_j + B_k + BV_l + b\,(Age_{ijkl} - Age_{00000}) + e_{ijklm} \quad (1)$$

where:

Y_{ijklm} = value of the dependent variable in three lactations (milk yield (kg in 305 days of lactation), protein (%), fat (%), services per conception (*n*), days open (days), calving interval (days))

μ = overall mean

A_i = effect of the i^{th} year of calving (i = 2007, 2008, 2009, 2010, 2011)

S_j = effect of the j^{th} season of calving (j = spring, summer, autumn, winter)

B_k = explanatory variables (effect of the k^{th} category of BCS or ADG – Table 1)

BV_l = effect of the l^{th} estimated sire's breeding value for milk yield (kg) (l^{th} = ≥ 750, 749–300, ≤ 299)

b = vector of regression coefficients of AFC used for B_k and only for analysis of production and reproduction traits in the first three lactations

Age_{ijklm} = AFC in days

Age_{00000} = overall mean for AFC

e_{ijklm} = random error

Simplified Equation 2 was used for determining the effect of selected factors on a dependent observed variable during the rearing period:

$$Y_{ijkl} = \mu + C_i + D_j + B_k + e_{ijkl} \quad (2)$$

where:

y_{ijkl} = value of the dependent variable

μ = overall mean

C_i = the i^{th} year of birth (i = 2004, 2005, 2006, 2007, 2008, 2009)

D_j = effect of the j^{th} season of birth (j = spring, summer, autumn, winter)

B_k = same explanatory variables as in Eq. 1

e_{ijkl} = random error

The differences among the estimated variables were tested at the significance level of $P < 0.05$.

RESULTS AND DISCUSSION

The evaluated parameters are described in Table 1. The relationships between the growth rates of heifers in the prepubertal rearing period are described in Table 2. Heifers with ADG of 900 g/day or more in most of the prepubertal period (3–9 months of age) were also the first to calve (an average age of 714 days) and produced the highest milk yield in the first 305 days of lactation (8695 kg). Their parameters were similar to those of heifers exhibiting the highest ADG, i.e. 800 g/day or more, during early growth (3–6 months of age). Significantly different parameters showed the group of heifers with the lowest growth rate (ADG to 750 g) which calved until 751 days, and yielded only 8281 kg of milk in the first lactation. Shamay et al. (2005) concluded that ADG of about 700 g/day is optimal for achieving maximum performance. Higher ADG in all the evaluated age groups led to lower AFC and higher milk yield in the first lactation (Figure 1). Froidmont et al. (2013) confirmed the strong positive relationship between BW at first calving and milk yield in

Table 1. Evaluated parameters in heifers' rearing period (explanatory variables)

Item	*n*	Mean	SD	Minimum	Maximum
ADG, 3–9 months of age (g/day)	538	830	189	392	1,250
ADG, 9–12 months of age (g/day)	670	931	216	412	1,170
ADG, 12–15 months of age (g/day)	698	932	173	569	1,210
BCS, at 12 months (points)	460	3.33	0.33	2.50	4.500
BCS, at 14 months (points)	475	3.43	0.31	2.50	4.250

ADG = average daily weight gain, BCS = body condition score

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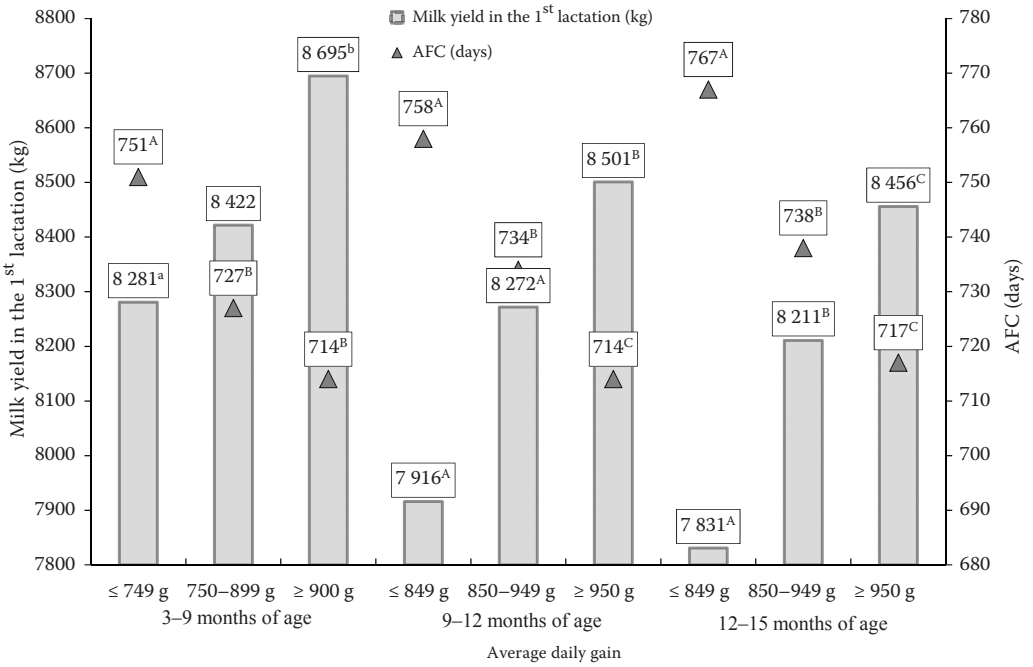

Figure 1. Relationship between ADG, AFC, and milk yield in the first lactation

ADG = average daily weight gain, AFC = age at first calving
[a–c]significant difference within a row at $P < 0.05$
[A–C]significant difference within a row at $P < 0.01$

the first lactation. AFC in the group with a mean daily increase in BW (899–750 g) was significantly different only from heifers with the lowest rate of growth, but their milk yield was not significantly different from that of the slowest growing group. Similar results were presented by Foldager and Krohn (1994) and Froidmont et al. (2013). In these trials, increases in nutrient intake during the first 56 days after birth showed a higher milk yield in the range of 450–1360 kg during the first lactation.

Table 2. Effect of live weight daily gain in 3–9-month heifers

Parameter	ADG ≥ 900 g	ADG 899–750 g	ADG ≤ 749 g
Number of heifers (*n*)	131	247	160
Live weight at 14 months of age (kg)	458 ± 3.59^{A}	432 ± 2.55^{B}	399 ± 3.59^{C}
Live weight at 15 months of age (kg)	486 ± 6.09^{a}	452 ± 5.51^{b}	429 ± 5.78^{b}
BCS at 14 months of age (points)	3.40 ± 0.04^{AB}	3.46 ± 0.03^{A}	3.30 ± 0.04^{B}
BCS at 15 months of age (points)	3.56 ± 0.06^{A}	3.47 ± 0.05^{B}	3.43 ± 0.05^{AB}
Daily gain of live weight at 12–15 months of age (g)	1150 ± 30^{A}	970 ± 20^{B}	880 ± 30^{C}
Daily gain of live weight at 12–18 months of age (g)	1140 ± 30^{A}	970 ± 30^{B}	880 ± 30^{C}
No. of AI per conception per heifers	2.21 ± 0.11^{A}	1.64 ± 0.10^{B}	1.42 ± 0.11^{C}
AFC (days)	714 ± 8.91^{A}	727 ± 7.93^{A}	751 ± 8.84^{B}
Milk yield in the 1st lactation (kg)	8695 ± 190^{a}	8422 ± 171^{ab}	8281 ± 185^{b}
Protein (%) in the 1st lactation	3.26 ± 0.03^{ab}	3.27 ± 0.03^{a}	3.22 ± 0.03^{b}
No. of AI per conception in the 1st lactation	2.29 ± 0.30^{a}	1.85 ± 0.30^{b}	2.10 ± 0.30^{ab}

AFC = age at first calving, ADG = average daily weight gain, AI = artificial insemination, BCS = body condition score
different superscript letters mean significant difference within a row: [a–c]($P < 0.05$), [A–C]($P < 0.01$)
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Growth intensity showed no significant impact on milk yield in the second and third lactation. Most studies have documented the negative impact of high ADG during heifers' rearing period on milk production only in the first lactation (Ettema and Santos 2004; Daniels 2010).

The fastest growing heifers during an early stage of rearing had significantly the highest number of inseminations per pregnancy, even after first calving (Table 2). For heifers with a greater growth rate before puberty there was no significant risk of excessive BCS during the breeding period. A significant relationship was found between the rate of growth in 9–12 months of age and body condition development after puberty (Table 3). Gergovska et al. (2011) came to similar conclusions that heifers with ADG of 950 g or more had significantly the highest BCS at 15 months of age (3.57 p.). It is also important that the BCS of these heifers were significantly higher at 14 months (3.44 p.), but only compared to the slowest growing heifers (3.33 p.). Heifers with daily gain of 850–949 g had similar BCS (3.46 p.) at 15 months of age (adult breeding) like heifers with low gain (3.42 p.) and therefore they were not overly fatty. A significant relationship was also found between the rate of growth in the period 9–12 months of age, when heifers with ADG of 950 g or more had the significantly highest milk yield in the first lactation (8501 kg) and had the lowest age at the first service (436 days) and therefore at calving (714 days). But they also had the significantly highest BCS at 15 months of age (3.57 p.) and the highest number of services needed for conception (2.24). According to Macdonald et al. (2005) the differences in BW at calving did not affect milk yield in lactation due to different diet before sexual maturity, while differences in body weight gain caused in different animals after puberty affected milk yield in the subsequent lactation. Whereas Van Amburgh et al. (1998) stated several reasons for the positive relationship between milk yield and AFC, including differences in prepubescent growth, according to Heinrichs and Gabler (2003) AFC is influenced by events around the birth as well as nutrition, health, and environmental factors during the first 4 months of life.

The intensity of growth at the age of 12–15 months was, in addition to similar effects such as

Table 3. Effect of live weight daily gain in 9–12- and 12–15-month heifers

Parameter	ADG ≥ 950 g	ADG 949–850 g	ADG ≤ 849 g
9–15-month heifers			
Number of heifers (*n*)	189	256	225
BCS at 14 months of age (points)	3.44 ± 0.03^{a}	3.44 ± 0.03^{a}	3.33 ± 0.03^{b}
BCS at 15 months of age (points)	3.57 ± 0.03^{A}	3.46 ± 0.04^{B}	3.42 ± 0.03^{B}
No. of AI per conception	2.24 ± 0.06^{A}	1.75 ± 0.05^{B}	1.34 ± 0.06^{C}
Age at the 1st AI (days)	436 ± 5.82^{A}	457 ± 4.63^{B}	484 ± 5.12^{C}
AFC (days)	714 ± 4.99^{A}	734 ± 4.22^{B}	758 ± 4.75^{C}
Milk yield in the 1st lactation (kg)	8501 ± 108^{A}	8272 ± 84^{B}	7916 ± 101^{B}
12–15-month heifers			
Number of heifers (*n*)	197	328	173
BCS at 15 months of age (points)	3.57 ± 0.04^{A}	3.41 ± 0.03^{B}	3.36 ± 0.04^{B}
No. of AI per conception	2.14 ± 0.06^{A}	1.73 ± 0.05^{B}	1.44 ± 0.06^{C}
Age at the 1st AI (days)	442 ± 5.23^{A}	462 ± 3.91^{B}	494 ± 5.42^{C}
AFC (days)	717 ± 4.79^{A}	738 ± 3.75^{B}	767 ± 5.14^{C}
Milk yield in the 1st lactation (kg)	8456 ± 101^{A}	8211 ± 76^{B}	7831 ± 110^{C}
No. of AI per conception in the 1st lactation	2.45 ± 0.18^{A}	1.94 ± 0.13^{B}	2.16 ± 0.19^{C}
Days open in the 1st lactation (days)	168 ± 19.71^{a}	147 ± 18.94^{b}	156 ± 19.32^{ab}
Calving interval after the 1st calving (days)	453 ± 16.92^{A}	411 ± 15.71^{B}	431 ± 17.62^{AB}

AFC = age at first calving, ADG = average daily weight gain, AI = artificial insemination, BCS = body condition score
different superscript letters mean significant difference within a row: $^{a–c}(P < 0.05)$, $^{A–C}(P < 0.01)$
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Table 4. Effect of body condition score (BCS) in 12-month heifers

Parameter	BCS ≥ 3.5 points	BCS = 3.25 points	BCS ≤ 3 points
Number of heifers (*n*)	112	68	81
No. of AI per conception per heifer	1.97 ± 0.10^{a}	1.79 ± 0.11^{ab}	1.64 ± 0.11^{b}
Protein (%) in the 1st lactation	3.3 ± 0.02^{a}	3.24 ± 0.02^{ab}	3.19 ± 0.03^{b}
Fat (%) in the 1st lactation	4.04 ± 0.05^{a}	3.88 ± 0.05^{b}	3.92 ± 0.05^{ab}

AI = artificial insemination

different superscript letters mean significant difference within a row: $^{a–c}$($P < 0.05$), $^{A–C}$($P < 0.01$)

values are presented as Least Squares Means + standard error

the age at first calving, milk yield, and number of inseminations per pregnancy (NIPP), also closely related to reproduction during the first lactation (Table 3). Heifers with the greatest ADG of live weight after the first year of life had the highest milk yield in the first lactation (+245 to +625 kg of milk; $P < 0.05$). However, they also had the highest number of inseminations per pregnancy (+0.29 to +0.70 services; $P < 0.05$) and the longest first calving interval as well (+22 to +42 days; $P < 0.05$). Logically, these heifers also had the significantly highest BCS at 15 months of age.

Focusing on the relationship between the development of BCS during rearing and the following parameters of milk production and reproduction, a greater variability of BCS in 11-month heifers can be observed. The differences appear till the 12th month of age (Table 4). It is interesting that heifers with the highest BCS already evaluated in the first year of life had the highest fat and protein content in the first lactation. It was also demonstrated with our model calculation including the effect of sire's breeding value for milk yield (Equation 1). This corresponds to the findings of Stadnik and Louda (1999). However, it is inconsistent with the conclusion of Kadokawa and Martin (2006). On the other hand, Le Cozler et al. (2008) reported that heifers with high genetic

Table 5. Effect of body condition score (BCS) in 15- and 18-month heifers

Parameter	BCS ≥ 3.75 points	BCS = 3.5 points	BCS ≤ 3.25 points
14-month heifers			
Number of heifers (*n*)	75	82	118
No. of AI per conception per heifer	1.80 ± 0.11^{ab}	1.99 ± 0.11^{a}	1.74 ± 0.10^{b}
Protein (%) in the 1st lactation	3.31 ± 0.03^{A}	3.30 ± 0.02^{A}	3.21 ± 0.02^{B}
Fat (%) in the 1st lactation	4.10 ± 0.06^{a}	3.98 ± 0.05^{ab}	3.92 ± 0.05^{b}
Protein (%) in the 2nd lactation	3.34 ± 0.05^{a}	3.26 ± 0.04^{ab}	3.19 ± 0.05^{b}
Milk yield in the 1st lactation (kg)	7819 ± 158^{a}	8294 ± 140.1^{b}	8278 ± 118^{b}
Milk yield in the 2nd lactation (kg)	8857 ± 313^{a}	9730 ± 280^{b}	9356 ± 326^{ab}
Days open in the 1st lactation (days)	110 ± 23.02^{A}	156 ± 21.61^{A}	169 ± 20.61^{B}
Days open in the 2nd lactation (days)	158 ± 16.03^{a}	149 ± 16.41^{a}	210 ± 21.42^{b}
Calving interval after the 1st calving (days)	414 ± 16.42^{a}	448 ± 16.40^{ab}	475 ± 19.51^{b}
Calving interval after the 2nd calving (days)	395 ± 28.91^{a}	382 ± 25.82^{a}	478 ± 29.03^{b}
15- and 18-month heifers			
Number of heifers (*n*)	75	82	118
No. of AI per conception per heifer (15 months)	1.81 ± 0.14^{ab}	2.68 ± 0.12^{a}	1.67 ± 0.13^{b}
No. of AI per conception in the 1st lactation (15 months)	2.19 ± 0.31^{ab}	2.37 ± 0.27^{a}	1.65 ± 0.24^{b}
No. of AI per conception per heifer (18 months)	2.36 ± 0.18^{a}	1.84 ± 0.21^{b}	1.87 ± 0.23^{ab}

AI = artificial insemination

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potential for milk production appear to be less sensitive to the high energy content of their diet without significant adverse effects. Hohenboken et al. (1995) argued that the relationship between ADG and milk production depends on the breed and its genetic potential. Moreover, according to them, higher growth positively affects the age of sexual maturity. According to Hoffman et al. (1996), intensive growth with low efficiency of insemination may bring negative consequences. Heifers have undesirably higher BW and BCS at first calving if they do not get pregnant until 15–16 months of age.

A closer relationship with performance was found in heifers' BCS at 14 months of age (Table 5). Heifers with the highest body condition at 14 months of age (BCS 3.75 p. or more) had significantly ($P < 0.05$) the lowest yield in the first and second lactation (7819 and 8857 kg), i.e. by 475 and 873 kg less than heifers with medium BCS (3.5 p.), or by 459 and 499 kg less than heifers with the lowest BCS (3.25 p. or less) at 14 months of age. On the other hand, this group of over-conditioned heifers had a higher milk protein content in the first and second lactation compared to heifers with the lowest BCS (3.25 p. and less) and also had higher fat content in the first lactation. It is interesting that these heifers with BCS 3.75 p. or more and with medium BCS (3.5 p.) had significantly ($P < 0.01$) the shortest period of days open compared with the second and third group, i.e. heifers with the lowest BCS, which had significantly ($P < 0.05$) the longest days open period (+13 to +61 days) and calving interval after the second calving (+83 to +96 days), respectively. The results are in line with the findings of Stadnik et al. (2002) with the exception of heifers achieving higher BCS at 15 months of age. In our study, heifers with excessive BCS at 15 and 18 months had significantly the highest number of inseminations required for conception during subsequent lactations (Table 5). Hoffman et al. (1996) reported that heifers have undesirably higher BW and BCS at first calving if they do not get pregnant until 15 to 16 months of age.

CONCLUSION

The relationship between the growth and development of body condition of Czech Holstein cows during the rearing of heifers and their subsequent performance in a production period were studied. The desirable effect of higher achieved daily live weight gain in the period before sexual maturity on lower AFC, a positive influence on milk yield in the first lactation, and a negative relationship to the conception rate of heifers before calving were demonstrated. Similar effects were also found for growth in the period of 9–12 months of age. In heifers with a greater growth rate before puberty there was no significant risk of excessive BCS during the breeding period. Heifers with the highest body condition at 14 months had a significantly lower milk yield in the first and second lactation than heifers with medium (3.5 p.) and low (3.25 p. or less) BCS, but they had the shortest days open period in the first lactation. Over-conditioned heifers had higher milk protein content in the first and second lactation. In terms of the highest milk production and acceptable reproduction parameters, heifers with moderate BCS at 14 months of age seemed the most suitable. The factors evaluated in the present study had no effect on the third lactation heifers' performance.

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