EFFECT OF BOVINE SOMATOTROPIN (bST) ON PERIPUBERTAL GROWTH RATES OF HOLSTEIN HEIFERS FED TWO PLANES OF NUTRITION

Efecto de la Somatotropina Bovina (bST) sobre la Tasa de Crecimiento Peripuberal de Novillas Holstein Alimentadas con Diferente Nivel Nutricional

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ABSTRACT

Three groups of Holstein heifers were utilized (N = I,39; II,63; III, 183) for growth rates of about 0.675 (control) or 0.900 (high) kg/d from 50 or 90 to 365 days of age. Heifers were fed either alfalfa silage or corn silage plus grain concentrate. Body weights and heights at withers were measured biweekly. Daily injections of 8.25, 12.36 mg of bST (I and II) from 220 to 340 days of age and 500 mg of bST/14 d (III); other heifers received injections of excipient or no injections. During both, the overall and bST injection periods body weight increase within the groups were greater for bST injected heifers than not injected for high or control diets. Total increases in height at withers for heifers on high diets were greater than in control fed heifers for groups I and II but not III. Before bST injections high fed heifers grew faster than control for all experiments. Total increases in height at withers during the bST injection period were greater for heifers on high diet for II but not for I and III. No improvement in height was detected for control heifers in any of the three experiments. Results indicated that injecting growing heifers with bST around the Peripubertal period increase body weight gain. Furthermore, no overall effect of bST was large nor persisted until the heifers were bred.

Key words: Heifers, bST, Bovine Somatotropin, body weight, height

RESUMEN

Se realizaron tres experimentos (N = I, 39; II, 63; III, 183) para evaluar tasas de crecimiento de 0,675 (control) o 0,900 (alta energía) kg/d desde 50 o 90 hasta 375 días de edad. Las novillas fueron alimentadas con ensilaje de alfalfa o ensilaje de maíz más concentrado. El peso vivo y la altura a la cruz fueron medidos cada dos semanas. Las novillas recibieron inyecciones diarias de 8,25, 12,36 mg de bST (I y II) desde 220 a 340 días de edad y 500 mg de bST/14 días (III); otras recibieron inyecciones de excipiente o no fueron inyectadas. Durante todo el período de crecimiento y cuando se inyectó bST, la ganancia de peso vivo, fué mayor para las novillas inyectadas con bST que para las novillas no inyectadas, alimentadas con la dieta de alta energía o la dieta control. El crecimiento total fue mayor para las novillas alimentadas con dieta de alta energía, para los grupos I y II pero no para el III. Durante el período previo al tratamiento con bST, las novillas con dieta de alta energía crecieron más rápidamente que las alimentadas con la dieta control. Durante el período de tratamiento, el aumento total en crecimiento fue mayor para las novillas que consumían dieta alta en energía para el grupo II pero no para el I o el III. No se observaron diferencias en el crecimiento de las novillas alimentadas con la dieta control. Los resultados indicaron que el tratamiento con bST a las novillas en crecimiento, alrededor del período peripuberal, aumentaba la tasa de ganancia de peso corporal de las novillas alimentadas con dietas control o de alta energía.

Palabras clave: Novillas, bST, Somatotropina bovina, peso corporal, alzada

INTRODUCTION

Dairy farmers invest money, labor and feed to raise replacements for their dairy herds. Growth of dairy heifers is affected by genetics, nutrition, health, environment and manage-

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ment, among others. Rates of growth should be based on body weight gain coinciding with the parameters of desired skeletal growth [51] Patterns of increases in body weight and wither height of dairy cattle are highly and positively correlated at birth and at 90 d of age [14]. It has been recommended that replacement dairy heifers should first calve at about 24 mo. of age and at 550 to 560 kg of body weight [20, 40, 56, 57]. However, Waldo et al. [58] suggested to reduce growth rates of dairy heifers to 0.8 to 0.85 kg/d from 212 to 360 kg of body weight. However, ADGs of 1.0 kg/d have been recommended by others [18, 32, 43, 63]. Nevertheless, growth rates exceeding 1.0 kg/d during the first 12 mo. of life may limit mammary gland development [23, 51, 54]. Although, growth rates during both the prepubertal and postpubertal periods have significant effects on calving weights, only the postpubertal ADGs have a significant effect on milk yield [28].

Growth is a long term process in animal production. Two physiologic processes control partitioning of nutrients: homeostasis which operates continuously and maintains steady state conditions in the body; homeorhesis which involves chronic redistribution of nutrients depending upon the priorities of specific tissues at specific times [5]. Changes in tissue distribution of growing replacement heifers may be a function of genetic selection for milk yield over the time [29]. Mechanisms responsible for hyperplasia or hypertrophy, or both, that underlie such increases in mass generally reflect those during developmental growth [47]. However, DiMarco et al. [11] suggested that the increase in body mass occurs in three phases: early postweaning when growth is hyperplasic; at prepubertal stage (200 to 300 kg live weight) when both mechanism, hyperplasia and hypertrophy are present and finally after 350 kg of body weight when hypertrophy dominates growth.

The endocrine system controls body growth. Weight gains and amount of Somatotropin (ST)/g of anterior pituitary tissue were positively correlated [1]. Somatotropin is considered to be anabolic, anti-INS and lipolytic [3]. Heifers from high genetic groups may have different growth characteristics and thus, concentrations of ST and ratios of height to weight from them have shown to be higher. Therefore, a unit of gain may be represented by different ratios of fat, protein and ash [6]. In short term growth studies ST markedly altered nutrient utilization resulting in an improved growth rates, feed conversion, and increased nitrogen retention in steer [37]. In long-term experiment in cattle, ST increased ADGs [9], significantly altered the normal allometric pattern of tissue growth, and this resulted in increased rates of skeletal muscle growth (protein deposition), and reduced rates of adipose tissue deposition [38]. Moreover, Prepubertal Holstein heifers fed on pastures and treated with exogenous ST for 21 weeks showed ADGs greater than controls [49]. Injections of bST increased ADGs of heifers 17 to 295% during the period from 1.5-18 mo. [12, 13, 15, 21]. Nevertheless, results of exogenous ST on growth rates and body composition were inconclusive [39]. However, Stelwagen et al. [52] reported that 20 mg bST/d were more efficient in weight gain of pregnant heifers during the last term of gestation than 40 mg/d injections. Clearly, manipulation of growth rates using repartitioning agents such as bST should be evaluated critically. Objectives of this research were to describe the relationship between the effect of different planes of nutrition during the prepubertal growth period and the use of bST during the Peripubertal growth period in a series of three growth studies.

MATERIALS AND METHODS

Three experiments were conducted to evaluate growth rates of Holstein heifers fed different planes of nutrition and treated or not with recombinant somatotropin (bST). They were conducted at the Dairy Research Unit of the University of Florida. The experiments were conducted as separate trials during three years and had different experimental designs, feeding programs and bST regimen; therefore data were analyzed separately.

Experiment I

Animals. Forty-two Holstein heifers were assigned to experiment when they were about 80 d of age. Seven animals were assigned to each of six groups in individual pens that were 7.6 m wide and 14.7 m long. Three heifers were removed from the experiment because of illness. The pens provided linear feeding bunk space greater than.7 m per heifer. The animals were assigned to experiment as they became available but were assigned to avoid large size and weight differences within the groups. They were born over a period of 4 mo., 16 heifers were purchased from a local dairy and had been born within a 3-d period. All heifers were regrouped in four treatment groups.

Experimental design. Two groups (II and IV) received injections of bST for 112 d beginning day 220, and two groups were not injected (I and III). Two groups were fed diets that were formulated to support average daily weight gains (ADGs) of about 0.68 kg/d (I and II) and two groups were fed diets for 0.91 kg/d ADGS (III and IV). Heifers remained on these treatments until they were slaughtered between 349 and 365 d of age to recover the udders for compositional and developmental analysis.

Management. Injections of bST begun about day 220 and contined for 112 d, the bST was dissolved in sterile saline diluent (10 mg/2 ml; pH=8.4) and contained 8.24 mg of the bST monomer. Quantities that would be used within 5-7 d were reconstituted at one time and unused diluted bST was refrigerated until used. Hormone and diluent were provided by American Cyanamid Co., Princeton, NJ. Injections were in the morning at about the time of feeding. Heifers in the four groups were fed alfalfa silage and were supplemented with grain concentrate to provide the nutrients to support desired growth rates. All heifers were group fed. Silage was delivered to the feed bunk and amounts of concentrates needed were top-dressed and mixed with the silage to provide necessary nutrients. Amounts fed were adjusted to the average weight of the heifers in the group at 4 wk intervals. They were fed between 0900 and 1100 h once daily. Water was available free choice from a water cup in each pen.

Animal Measurements. All heifers were weighed and their height at the withers taken when they were assigned to the experiment. Thereafter they were weighed and heights measured at 2 wk intervals; this was done before the morning feeding on the same day of the week.

Experiment II

Animals. Sixty-four Holstein heifers weaned between 42-49 d of age were assigned to an experiment when they were at about 90 d of age. 16 heifers were assigned to each treatment group as they became available. One heifer from treatment I died as a consequence of bloat. All remaining heifers within a treatment group were housed and managed in a large pen with a feed bunk that provided greater than 0.7 m of linear space per heifer.

Experimental design. The four groups of heifers were arranged in a 2 x 2 factorial design that consisted of two feeding programs formulated to support ADGs of 0.68 or 0.91 kg/d; one half of the heifers within each of these groups were injected with recombinant bovine somatotropin (bST) or excipient from 220-340 d of age.

Management. Injections of bST begun at 220 d and continued through 340 d of age, two groups (II and IV) were injected subcutaneously over the shoulder area once daily with 15 mg of bST that contained 12.36 mg of the bST monomer. The bST was dissolved in sterile saline (15 mg/2 ml, pH=8.4), mixed, refrigerated, and used within 5 to 7 d after it was prepared. Heifers in groups I and III received equivalent injections of the sterile saline excipient. Hormone and diluent were provided by American Cyanamid Co., Princeton, NJ. Injections were in the am before the morning feeding. One heifer in group I died when it was about 9 months of age. The rations fed to heifers consisted of corn silage and grain concentrate. All heifers were started on corn silage feeding at about 80 d of age even if not assigned to experiment until they were older. The grain concentrate was top-dressed on the silage to provide CP, energy and minerals to support desired ADGs. Requirements for dry matter, energy and CP and macro-minerals of the heifers was determined using the NRC [40] computer program for heifers. The amount of feed delivered to the individual groups was based upon the average weight of the heifers in that group at the previous weigh day. Adjustments to feed offered for desired ADGs were made biweekly within several days after the weigh day. Heifers were fed once daily between 0900 and 1000 h. Dry matter content of the silage was determined biweekly to adjust the amount fed. The silage and grain concentrates were mixed using a pitchfork to prevent, insofar as possible, uneven consumption of the grain and silage portions by heifers in the group. Water was available free-choice from water cups in each pen.

Animal Measurements. All heifers were weighed and their heights at the withers measured when they were assigned to experiment and were fed experimental rations. Thereafter, at biweekly intervals on the same day of the week, all heifers were weighed and heights measured before the morning feeding.

Experiment III

Animals. One hundred and eighty five Holstein heifers were assigned to experiment when they were between 50 and 120 d of age; of these 80 were assigned at 50 d of age. Two heifers died around 4-5 months. of age and were not replaced. The heifers were assigned to two nutrition treatment groups. Ninety four were assigned to normal (0.68 kg BW gain/d) [40] and 89 to rapid (0.91 kg BW gain/d) growth rates (ADGs) determined by the amount and type of diet they were fed. Heifers were raised in individual pens that ranged from 10 to 16 heifers. They were assigned either when they were weaned or later as they became available. All heifers were housed and managed together throughout the experiment. Pens provided ample feedbunk space (0.7 m linear space/heifer), shade and free access to water from water troughs or automatic water cups.

Experimental design. The two growth rate groups were arranged so there were 4 different groups. From these 109 heifers were assigned to received no other treatment. Heifers remaining were arranged so that 76 received injections of recombinant bovine somatotropin (bST, 500 mg/14 d, subcutaneous). There were multiple injected and not injected heifers in each pen, although not perfectly balanced. After completion of injections (365 d of age) all heifers were assigned to diets intended to support ADGs of 0.68-0.73 kg/d until the time they were bred. Breeding was initiated at the first estrus after heifers were 13 months. of age and were 340 kg or greater.

Management. Injections of bST started at 220 ± 3 d of age and continued for 10 injection cycles at 2-wk intervals. Therefore, heifers were under the effects of bST from about day 220 through day 360. The bST, was prepared in an oil emulsion (500 mg/2 ml) and was subsequently marketed under the name POSILAC for enhancement of lactation, was provided by Monsanto Co, St. Louis, MO. Injections were subcutaneous on alternating sides of the body just in front of or behind the scapula. Heifers were injected in the morning before time of feeding. The feeding programs for the heifers from birth through the time they were assigned to rations to support desired ADGs differed depending upon the age they first were assigned to experiment. Heifers that were assigned at younger ages were fed a starter ration that consisted of grain concentrate containing about 10% ground alfalfa. These heifers and all others were on this diet until about 80 d of age and then they, along with other heifers assigned, were changed to a corn silage-alfalfa hay roughage mixture (6:1) and grain concentrate diet. Amounts of the roughage and concentrates fed depended upon the desired ADGs of the heifers in the pen, as established from NRC [40]. By 100-120 d of age all heifers had completed the change to the corn silage-alfalfa grain concentrate diet. The grain concentrate fed to heifers in the pens was top-dressed on the roughage mixture and not mixed further. The total amounts of feed delivered to individual pens was calculated to support the ADGs desired [40] and was based upon average weights of heifers in the pen at the previous weighing. Nutrient requirements for this weight were calculated using the NRC [40] program considering DM, CP and TDN. Adjustments to feed offered in order to obtain the desired ADGs were made biweekly within several days after they had been weighed. The roughage mixture was fed in the morning between 0900 and 1100 h daily. Water was available free choice from water cups or troughs located in the pens.

Animal Measurements. All heifers were weighed and heights at withers measured when they were assigned to experiment and thereafter, biweekly on the same day of the week they were weighed and heights measured. This was done in the morning before feeding. Because the large number of animals were on trial at the same time it often was necessary to delay the feeding beyond 1100 h on days they were weighed this usually represented less than a 2 h delay.

Statistical Analyses

Data for body weight and height at withers for all three growth experiments were analyzed by least squares analysis of variance using the general linear models procedures of SAS [50]. Analyses were performed in two ways. First, data collected either from 90 to 365 (experiments I and II) or 50 to 365 (experiment III) d of age were analyzed; this represented the overall growth period for each of the experiments. After these analyses were completed, data were divided into two segments that represented the growth periods from 50 or 90 to 220 d of age (before bST injections) and the second from 220 to 365 d of age or the period when bST was injected. Therefore, three different models were used in the analyses. The overall model included the effect of treatment, season of birth, and the interaction treatment*season of birth adjusted by the initial weight or height as necessary. The model utilized for data before bST injections included the effect of diet, season of birth and the interaction diet*season of birth also adjusted by the initial weight or height as covariate. Model to analyze data during the bST injection period included the effect of diet, bST, season of birth, the two-way interactions of diet*bST, diet*season of birth, bST*season of birth, the three-way interaction of diet*bST*season of birth adjusted by initial weight or height (weight or height at 220 d of age) as necessary in the analyses. No effect of season of birth was included for any of the growth periods for experiment I due to heifers were born during the same season in a range of 4 months. All main effects were tested for significance by using the random error term. A second series of analyses was performed to calculate regression curves and to describe changes in weight and height during the defined growth periods. Two models were utilized (basic model and reduced model).

RESULTS AND DISCUSSION

As expected, during the growth period before bST injections, significant differences were observed for the effect of diet for all three experiments for both weight and height ($P<0.1$, 0.05; 0.0001, 0.01; 0.001, 0.01 for each experiment respectively, TABLES I, II, IIII. Although, ADGs were less than expected on all three experiments, heifers fed the high energy diet had ADGs of 0.61, 0.68 and 0.74 kg compared to 0.53, 0.47, and 0.68 kg for those fed the control diet. Average daily increase in height (ADI) also were higher for high diet fed heifers (0.15, 0.15, and 0.16 versus 0.12, 0.13, and 0.15). Results for these three experiments are presented in TABLES IV,V,VI.

Many factors can affect the rate of growth of animals at different ages. Health, management and nutrition of the heifers likely are the factors involved in obtaining the results we observed in our three experiments. Management and nutrition often are difficult to control because of changes in environmental conditions. Variations in quality of roughage may have occurred, especially because the length of the experiments covered periods when roughage sources changed. For example, new corn silage was made and fed during each year of experiments II and III and during experiment I great variation in the individual analysis of the alfalfa silage indicated variable feed quality. Thus, ratio of protein-energy intake could have differed from expected when feed requirements for the groups were calculated and as a consequence the ADGs were more variable and less than expected or desired. When a reduction in energy and protein intake occur the whole body responds by adapting with a decrease in the rate of protein accretion and degradation in order to conserve energy for maintenance and to decrease the expenditure of energy for the metabolically expensive process of protein synthesis [24, 45].

Increase in total body weight gain reflects increases in weight of many organs; their individual mass also change during growth and function of the animal. Skeletal and muscle enlargement occurs during growth and because of this height measurements become important in describing growth rates. Changes in distribution of tissues of heifers during the growing period could be a function of genetic selection of dairy animals for milk production over many years [29]. Moreover, it has been reported that there is a negative correlation in genetically larger cows with feed efficiency and other body measurements. However these were no of interest in our experiments.

The ADI was significantly affected by the plane of nutrition in all three experiments, TABLES I, II, III. Heifers on high

TABLE I

LEAST SQUARES ANALYSES OF VARIANCE FOR AVERAGE DAILY GAIN (ADGS) AND AVERAGE DAILY HEIGHT INCREASE OF 39 HOLSTEIN HEIFERS

Sources Growth Periods		Average Daily Gain			Average Daily Height Increase		
	DF	MS	F	P > F	MS	F	P F
Before bST							
Diet (D)	1	0.0740	2.9	0.0990	0.0045	4.9	0.0335
Initial[1]	1	0.0608	2.4	0.1337	0.0082	9.1	0.0052
Error	36	0.0258			0.0009		
During bST							
Diet	1	0.2839	9.2	0.0047	0.0029	5.2	0.0488
bST	1	0.0914	2.9	0.0948	0.0001	0.2	0.6769
Diet*bST	1	0.1737	5.6	0.0237	0.0002	0.4	0.6266
Initial[1]	1	0.1857	6.0	0.0196	0.0058	9.6	0.0066
Error	34	0.0309			0.0006		
Overall period							
Treatment (T)	3	0.1510	7.6	0.0005	0.0007	3.5	0.0401
Initial[1]	1	0.0333	1.7	0.2055	0.0033	16.5	0.0006
Error	34	0.0200			0.0002		

[1]Initial = weight or height in the respective analysis.

plane of nutrition were taller at 210 d of age than heifers fed control diets. These results suggested that during this growth period energy from feed was utilized primarily to increase body size; height instead of weight. This agreed with the fact that growth of large bones occurs through enlargement of the epiphyseal plate. There is a hyperplasic growth or protein accumulation through cell division. There also are changes after weaning in the mass of organs by protein accretion and this has been demonstrated to be hypertrophic growth or increase in cell size [2, 11, 41].

As soon as body size increases during development there is a sequence of changes that also occur within the body. Water spaces in the body (intra or extracellular, intra or extra vascular), energy expending and energy storing (body protein and fat) compartments change their proportion [17]. It has been reported that the energy stored per unit of weight gain increases because fat deposition involves little deposition of water. Thus, fat deposition is a reflection of the degree to which energy intake exceeds the energy expenditure associated with maintenance of physiological viability and protein deposition [47, 62]. Such changes may have occurred in heifers on all three experiments during this growth period. This would explain why ADGS were lower than expected whereas, ADI were adequate.

During this growth period before bST injections, season of birth of the heifers had no important effect in experiment II on any of the measures for weight and height. However, growth curves for weight and height indicated that heifers born during the hot season grew faster. Conversely, in experiment III season of birth of the heifers had a significant effect on all weight and height measures, TABLES II and III. Results showed that greatest growth rates were for heifers born during the cold season. Nevertheless, heifers born during the hot season, grew faster from 90 to 210 d of age than heifers born during the cool season. It is difficult to explain this occurrence. There are several possible reasons, including need of heifers to use more energy for heat dissipation during the hot period of the year. Compensatory growth may have occurred for heifers born during the hot season. This could have been the case if their intake of feed was reduced during the hot days and nights in the season they were born but was increased when the cool weather arrived and heifers were older and in a more rapid growth phase. This is in contrast to what likely happened to heifers born in the cool season (March or April). They probably were stressed after the first 2-3 mo. of life, thus, reducing feed efficiency for growth. Some support for this possibility comes from the fact that there was an interaction of season of birth and plane of nutrition (diet). This was significant for both weight and height (experiment III), and showed that heifers that were born during the hot season and fed high energy diet during the growth period from 50 to 210 d of age grew faster than those born during any other season no matter the level of nutrition fed.

During the bST injections period results varied from one experiment to another. As expected there were significant differences in BW of heifers on high energy diets compared to those fed control diets in all three experiments, TABLES I, II and III. Both groups of heifers from each of the three experi-

TABLE II

LEAST SQUARES ANALYSES OF VARIANCE FOR AVERAGE DAILY GAIN (ADGS) AND AVERAGE DAILY INCREASE OF 63 HOLSTEIN HEIFERS

Sources Growth Periods	DF	Average Daily Gain MS	F	P F	Average Daily Height Increase MS	F	P F
Before bST							
Diet (D)	1	0.6860	28.8	0.0001	0.0100	8.1	0.0063
Season of birth (S)	2	0.0490	2.1	0.1370	0.0032	2.6	0.0857
D*S	2	0.0020	0.9	0.4372	0.0003	0.2	0.8315
Initial1	1	0.0070	0.3	0.5995	0.0045	3.7	0.0611
Error	56	0.0239			0.0012		
During bST							
Diet	1	0.0662	5.3	0.0261	0.0003	0.7	0.3983
bST	1	0.0260	2.1	0.1566	0.0011	2.9	0.0954
Diet*bST	1	0.0010	0.1	0.7777	0.0018	4.7	0.0350
Season of birth (S)	2	0.0009	0.1	0.9349	0.0028	7.0	0.0021
Diet*S	2	0.0023	0.2	0.8368	0.0005	1.3	0.2947
bST*S	2	0.0047	0.4	0.6922	0.0003	0.8	0.4592
Diet*bST*S	2	0.0059	0.5	0.6285	0.0190	4.9	0.0116
Initial1	1	0.0607	4.8	0.0327	0.0002	0.4	0.5151
Error	50	0.0126			0.0004		
Overall period							
Treatment (T)	3	0.1486	13.39	0.0001	0.0017	8.5	0.0002
Season of birth (S)	2	0.0107	0.96	0.3910	0.0003	1.6	0.2055
T*S	6	0.0803	0.72	0.6326	0.0002	0.99	0.4444
Initial1	1	0.0002	0.00	0.9687	0.0022	10.3	0.0024
Error	50	0.0111			0.0002		

ments grew at about the growth rates that were expected based upon the amount of feed offered (0.68 and 0.91 kg/d) [40] for normal growth and accelerated growth. Eventhough observed ADGs for heifers fed control diets in the experiments II and III, TABLES V and VI, were somewhat higher than expected, they still fell within the range of growth rates previously reported and recommended for dairy heifers by various researchers [16,18, 20, 26, 27, 32, 35, 43, 56, 57, 58, 63]. With these ADGs heifers fed high energy diets could be bred earlier than those on control diets.

From birth to the period when hormonal changes occur that are a prelude to onset of puberty there is an accelerated isometric growth; heifers gain size in length and height by hyperplasia (DNA accumulation, cell divisions) [2]. Bone grows first and this growth is followed by muscles. Around the time of puberty (hormonal changes indicating onset of puberty) and shortly thereafter longitudinal growth of long bones essentially is completed, but individual bones within an animal cease linear growth at different times. Thereafter, an allometric growth phase begins and organs grow at different rates; tissues are deposited primarily by hypertrophy (cell expansion). Protein accretion dominates growth at this time [41], but fat deposition becomes an important part of body weight gain until maturity at which time protein storage decreases and fat deposition dominates [62]. Because puberty usually occurs around 9 months. of age for heifers when they are between 250 to 285 kg body weight, results from these three experiments indicate that energy from feed was used for maintenance and also for tissue synthesis and storage. Thus, the composition of gain during this growth period from 210 to 365 d of age probably represents a growth phase of energy storage seen as protein accretion and fat deposition.

TABLE III

LEAST SQUARES ANALYSES OF VARIANCE FOR AVERAGE DAILY GAIN (ADGS) AND AVERAGE DAILY INCREASE OF 183 HOLSTEIN HEIFERS

Sources Growth Periods		Average Daily Gain			Average Daily Height Increase		
	DF	MS	F	P F	MS	F	P F
Before bST							
Diet (D)	1	0.1575	7.8	0.0006	0.0064	8.9	0.0033
Season of birth (S)	2	0.1263	6.2	0.0025	0.0008	1.1	0.3498
D*S	2	0.0863	1.8	0.1711	0.0007	1.0	0.3757
Initial[1]	1	0.0015	2.40.1	0.7885	0.0097	13.4	0.0003
Error	176	0.0201			0.0007		
During bST							
Diet	1	0.1339	10.5	0.0015	0.0010	5.5	0.0207
bST	1	0.5876	45.9	0.0001	0.0007	3.0	0.0855
Diet*bST	1	0.0031	0.2	0.6231	0.0002	0.7	0.4225
Season of birth (S)	2	0.2083	16.3	0.0001	0.0016	6.7	0.0015
D*S	2	0.0045	0.4	0.7029	0.0002	0.8	0.4469
bST*S	2	0.0191	1.5	0.2282	0.0008	3.1	0.0462
D*bST*S	2	0.0060	0.5	0.6279	0.0003	1.1	0.3236
Initial[1]	1	0.1244	7.9	0.0021	0.0165	9.2	0.001
Error	170	0.0128			0.0002		
Overall period_							
Treatment (T)	3	0.0417	4.9	0.0029	0.0008	6.4	0.0040
Season of birth (S)	2	0.0981	11.4	0.0001	0.0008	6.5	0.0020
T*S	6	0.0161	1.9	0.1891	0.0003	2.4	0.0335
Initial[1]	1	0.0830	9.6	0.0022	0.0064	52.3	0.0001
Error	170	00.0086			0.0001		

Injections of bST. These three experiments focused on whether recombinant Somatotropin (bST) stimulated growth rates of heifers when they were managed in small groups. Results showed that injections of 8.24 mg bST/d (experiment I) resulted in significant increases in body weight, TABLE I, but not in height at withers, TABLE I. Heifers injected with bST were heavier than not injected heifers. Additionally, observed interaction between bST and plane of nutrition on weight indicated that heifers injected with bST responded positively by increasing ADGs and therefore. Total weight gain (TWG), whether fed a normal or high plane of nutrition (TABLE IV). Heifers fed high energy diet and injected with bST grew faster than their counterparts on the same plane of nutrition but not injected. Importantly, heifers fed control diet and injected with 8.24 mg of bST/d, (TABLE IV) were 13% heavier than the non-injected heifers fed the same diet.

Results of experiment II did not agree with experiment I even though the amount of bST injected was greater (12.36 mg of bST/d); no significant effects of bST on body weight, TABLE II, or height were detected. However, there was a tendency ($P<0.11$) for greater height gain (ADI); TABLE II. Moreover, the interaction plane of nutrition and bST was significant for height measures in this experiment, TABLE II. Heifers fed control diet and injected with 12.36 mg of bST were taller on average than non-injected heifers as well as, heifers fed high energy diet and injected with bST were taller than contemporaries on same plane of nutrition, TABLE V.

Ability of bST to stimulate live weight gain of ruminants has been variable [25] and sometimes growth rates were not affected either positively or negatively [31]. Many factors may influence response to bST. For example, response may be related to quantity and quality of the feedstuffs fed to the treated heifers [22, 33]. This varied in the present experiments both

TABLE IV

LEAST SQUARES MEANS AND SE FOR AVERAGE DAILY GAIN (ADGS) AND THE AVERAGE DAILY INCREASE IN HEIGHT (ADI) DURING THREE GROWTH PERIODS GROWTH PERIODS FOR 39 HOLSTEIN HEIFERS

Growth Periods	Treatments			
Before bST	Control Diet (n = 19)		High Energy Diet (n = 20)	
Initial[1] weight (kg)	88.88 ± 3.04		85.42 ± 2.17	
ADGs (kg)	0.53 ± 0.04		0.61 − ± 0.04	
Initial[1] height (cm)	86.76 ± 0.83		85.69 ± 0.90	
ADI (cm)	0.12 ± 0.01		0.15* ± 0.01	
During bST	Control Diet		High Energy Diet	
	0 mg bST (n = 12)	8.24 mg/d bST (n = 7)	0 mg bST (n = 14)	8.24 mg/d bST (n = 6)
Initial[1] weight (kg)	158.44 ± 7.90	153.89 ± 11.70	165.68 ± 5.20	167.39 ± 6.30
ADGs (kg)	0.55 ± 0.01	0.80** ± 0.07	0.84 ± 0.07	0.88 ± 0.05
Initial[1] height (cm)	103.17 ± 0.90	102.28 ± 2.10	103.14 ± 1.10	106.25 ± 1.10
ADI (cm)	0.10 ± 0.01	0.10 ± 0.01	0.11 ± 0.01	0.12† ± 0.01
Overall				
Initial[1] weight (kg)	88.10 ± 3.60	90.21 ± 5.69	84.45 ± 2.71	87.69 ± 3.59
ADGs (kg)	0.55 ± 0.04	0.65 ± 0.05	0.79 ± 0.04	86.08 ± 1.30
Initial[1] height (cm)	86.67 ± 1.10	86.93 ± 1.10	85.40 ± 1.30	0.81 ± 0.06
ADI (cm)	0.12 ± 0.01	0.11 ± 0.01	0.12 ± 0.01	0.14 ± 0.01

[1]initial = Unadjusted means −$P \leq 0.10$ *$P \leq 0.05$ **$P \leq 0.01$

across experiment and likely within experiment because roughages offered changed as new batches of silage were made and fed. For experiment III the results were similar to those found in experiment I and comparable to those reported previously [3, 9, 10, 12, 13, 15, 21, 36, 37, 39, 46, 49, 52, 53, 55, 60, 61, 64]. Injections of 500 mg of bST/14 d, a daily quantity that was about 3 times greater than injected in experiment II, showed significant differences for all measures of weight and height, TABLES III and VI. Heifers injected with bST had average TWG that was 8% greater and total height increase (THI) that was 1.11 cm greater than for non-injected heifers. Importantly, ADGs of heifers injected with bST was 163 kg/d greater than for non-injected heifers. In addition, ADI of injected heifers was 0.06 cm greater than for non-injected heifers, TABLE VI. In experiment III, as observed in experiment I, the interaction of bST and plane of nutrition reaffirmed the positive effect of bST on growth rates. Heifers injected with 500 mg of bST/14 d and fed high energy diet were at the end of the experiment (375 d) 26 kg heavier and 1.12 cm taller than those heifers on same diet but not injected. The same pattern was seen for heifers on control diet; bST-injected heifers weighed 22 kg more and were 1.38 cm taller than the non-injected. Nevertheless, what is important is that heifers on control diet and injected with bST grew faster (ADGs) than heifers on high plane of nutrition and not injected with bST, and also faster than expected (0.68 kg/d [40]). TWG of these control fed and injected heifers was 17 kg greater and THI was 55 cm more than heifers fed high plane of nutrition but not injected. These results suggest that bST injections had a positive effect on growth rates of Holstein heifers and effects were manifested in heifers fed to grow at normal or at accelerated rates.

One major interpretation of results of these growth experiments using bST is that ST is necessary for growth, and necessary for partitioning of nutrients to muscle or adipose tissues. Short-term actions of ST have been described [44] as protein sparing or for the preservation of protein at the expense of fat mobilization to provide the energy needed when decreases in feed intake occur. Long-term actions of ST are to direct nutrients to target processes such as growth or lactation. Biological actions of bST have been reported to influence ADGs, skeletal growth, feed conversion efficiency and body composition in such a way that protein accretion is increased at the expense of fat deposition [21, 39, 49]. Results showed that ADGs, and to some extent ADI were increased by a direct effect of bST in heifers on both planes nutrition during the growth period from 210 to 365 or 375 d of age in experiment I and II or III, respectively. These findings suggest that the total increase in whole body growth rates of full-fed heifers (as normal or rapid growth rates) was mediated by ST through a balance of short- and long-term actions. Thus, the overall body growth induced by injections of bST might be due to a combination of many factors that are involved in regulation of animal metabolism. This includes changes in pattern of nutrient absorption from diet (feed conversion efficiency), changes in me-

TABLE V

LEAST SQUARES MEANS AND SE FOR AVERAGE DAILY GAIN (ADGS) AND THE AVERAGE DAILY INCREASE IN HEIGHT (ADI) DURING THREE GROWTH PERIODS FOR 63 HOLSTEIN HEIFERS

Growth Periods	Treatments			
Before bST	Control Diet(n = 31)		High Energy Diet(n = 32)	
Initial[1] weight (kg)	96.61 ± 1.86		94.50 ± 2.82	
ADGs (kg)	0.47 ± 0.03		0.68*** ± 0.03	
Initial[1] height (cm)	88.39 ± 0.63		88.75 ± 0.78	
ADI (cm)	0.13 ± 0.01		0.15 – ± 0.01	
During bST	Control Diet		High Energy Diet	
	0 mg bST (n = 15)	12.5 mg bST/d (n = 16)	0 mg bS (n = 16)	12.5 mg bST/d (n = 16)
Initial[1] weight (kg)	152.10 ± 5.48	145.57 ± 3.47	162.37 ± 5.21	177.74 ± 3.40
ADGs (kg)	0.85 ± 0.03	0.88 ± 0.03	0.92 ± 0.03	0.97 ± 0.01
Initial[1] height (cm)	99.07 ± 1.00	99.38 ± 0.67	100.97 ± 0.85	103.25 ± 0.76
ADI (cm)	0.11 ± 0.01	0.12 ± 0.01	0.11 ± 0.01	0.13 † ± 0.01
Overall				
Initial[1] weight (kg)	95.38 ± 2.81	97.78 ± 2.53	93.65 ± 4.85	95.35 ± 3.05
ADGs (kg)	0.68 ± 0.03	0.69 ± 0.03	0.79 ± 0.03	0.89 ± 0.06
Initial[1] height (cm)	87.83 ± 0.89	88.91 ± 0.89	87.88 ± 1.21	89.63 ± 0.94
ADI (cm)	0.11 ± 0.01	0.11 ± 0.01	0.12 ± 0.01	0.14† ± 0.01

[1]initial = Unadjusted means – $P \leq 0.10$ ***$P \leq 0.001$

tabolism of nutrients at the level of liver to generate more substrates (increase gluconeogenesis) passing to the circulation and increasing availability to tissues, and finally through changes in target-tissue metabolism related to the direct effects of ST on growth of tissues. Also it may be via indirect effects through other hormones such as IGF-I or INS. As a result of these activities cells of various tissues undergo mitosis and protein synthesis; hypertrophy or cell expansion by protein accretion occurs because there is an increase in synthesis that exceeds the increase in degradation. This occurs at the same time that fat deposition decreases due to increased resistance of adipose tissue to INS which reduces lipogenesis and maintains lipolysis. Thus, non-esterified fatty acids are metabolized in the liver and become an energy source for tissues to utilize.

Findings of the present experiments indicate that heifers fed control diets for normal growth rates and injected with bST grew as fast as (experiment I) or faster (experiment III) than heifers fed high energy diets. Because of the proposed actions of ST on growth it appeared that there was more efficient utilization of the energy from feed ingested, unless the appetite of the injected heifers was increased and they ate proportionally more feed than non-injected animals in the same pen. This could not have occurred in experiment I or III where heifers in the individual pens were either injected or non-injected with bST. Moreover, heifers fed high energy diets and injected with bST in all three experiments likely were more efficient than those non-injected. This occurs when lactating cows are injected with bST to increase milk yield [4]. However, differences in ADGs between these two groups of heifers were not very large. This may have resulted, in part, because rather low doses of bST were injected during the first two experiments and this may not have increased circulating concentrations of ST sufficiently to see greater actions on growth rates when the heifers already were fed for accelerated growth. Thus, when higher energy diets are fed, greater doses of injected bST may be needed to provoke the desired increase in growth rates beyond the 0.91 kg/d rate.

During this growth period when bST was injected, season of birth was evaluated. In experiment II significant differences were observed for the effect of season of birth on all height measures, TABLE II. For experiment III there was a consistent effect of season of birth on both weight and height measures, TABLE III. Heifers that were born during the cold season (November -January) were taller compared with those born during the cool or hot seasons. Additionally, in experiment III it was observed that heifers born during the cold season weighed more at 375 d of age than those from the cool and hot seasons, and again, differences in feed intake and feed conversion may have affected heifer growth rates, such that there was more efficient utilization of nutrients to support growth. Heifers born during these cold months in Florida (November to January) likely would be affected by heat stress during the late Spring through mid-autum; times that corresponded to the period when they approached puberty. However, those born in

TABLE VI

LEAST SQUARES MEANS AND SE FOR AVERAGE DAILY GAIN (ADGS) AND THE AVERAGE DAILY INCREASE IN HEIGHT (ADI) DURING THREE GROWTH PERIODS FOR 183 HOLSTEIN HEIFERS

Growth Periods	Treatments			
Before bST	Control Diet (n = 93)		High Energy Diet (n = 90)	
Initial[1] weight (kg)	62.25 ± 1.11		64.96 ± 1.07	
ADGs (kg)	0.68 ± 0.02		0.74*** ± 0.02	
Initial[1] height (cm)	80.09 ± 0.47		80.30 ± 0.45	
ADI (cm)	0.15 ± 0.01		0.16** ± 0.01	
During bST	Control Diet		High Energy Diet	
	0 mg bST (n = 52)	500 mg bST/14 d (n = 41)	0 mg bST (n = 59)	500 mg bST/14 d (n = 31)
Initial[1] weight (kg)	159.07 ± 2.97	151.64 ± 3.18	164.50 ± 2.63	156.30 ± 4.14
Initial[1] height (cm)	100.65 ± 0.62	101.17 ± 0.74	101.68 ± 0.57	101.97 ± 0.94
ADI (cm)	0.10 ± 0.01	0.11 ± 0.01	0.11 ± 0.01	0.12 ± 0.01
Overall				
Initial[1] weight (kg)	60.54 ± 1.67	64.39 ± 1.33	64.21 ± 1.49	66.36 ± 1.36
ADGs (kg)	0.73 ± 0.01	0.75 ± 0.01	0.79 ± 0.01	0.81 ± 0.02
Initial[1] height (cm)	79.54 ± 0.67	80.78 ± 0.72	80.25 ± 0.58	80.39 ± 0.72
ADI (cm)	0.12 ± 0.01	0.13 ± 0.01	0.13 ± 0.01	0.13 ± 0.01

[1]initial = Unadjusted means *P ≤ 0.05 **P≤ 0.01 ***P ≤ 0.001.

the hot or cool months would be exposed to greater heat stress early in their lives, as well as the time around puberty. Perhaps they had expended a greater amount of their intake energy to dissipate the extra heat produced by increased respiration under increased environmental temperatures. Environmental factors such as temperature, day length, parasites, exercise etc., likely affect growth rates either by influencing feed intake and nutrient supply above maintenance or by altering blood flow, hormone concentrations and nutrient availability to specific organs [42].

Finally, a three-way interaction of season of birth*diet*bST effect on height was observed in experiment II. Results showed that heifers from the hot season and fed control diet and injected with 12.36 mg of bST/d grew faster than those on high plane of nutrition that did not receive injections of bST. Heifers from the same season on high energy diet and injected with bST were taller than those on control diet also injected with bST. The same tendency was observed for the other seasons. This suggests that growth as a physiological function must be responsible for this triple interaction because heifers fed both high and control diets and born during the cold season showed a tendency to increase height in parallel whether injected or not injected with bST.

During the overall growth period significant differences due to treatment (plane of nutrition and bST injections) were detected on weight and height, TABLES I, II and III. During the overall growth period (from 90 to 365 d of age for experiments I and II, and from 50 to 375 d for experiment III) heifers had greater final body weight at 365 d of age and increased height at withers when they had been injected with either 8.24, 12.36 or 35.7 mg/d (equivalent to 5.15, 7.73 and 23.44 μg/100 kg body weight) of bST. This resulted because of increased ADGs and ADI, respectively, in response to bST injections, TABLES IV, V and VI. The greater ADGS, and ADI in these experiments agreed with previous findings [9, 12, 13, 15, 21, 36, 38, 49, 55]. Although these results were associated with the utilization of high energy diets, heifers on control diet and injected with bST also were larger than contemporaries not injected with bST. Previously it had been reported that daily injections of heifers with 15 mg of bST/d starting at 7 months. of age and lasting for a period of 120 d, had no effect on growth rate during the prepubertal period. Although the ADGs were similar to previous findings, onset of puberty was later [39]. In order to elucidate the effect of treatment (plane of nutrition and bST) on weight during the overall growth period, a second mathematical model was used for analysis of data from each of the three experiments to partition the degrees of freedom for treatment into sources of variation (diet, bST and the diet*bST interaction). Results showed that diet was responsible for the treatment effect on weight or height in all three experiments. Additionally, using this model it was shown that there was a significant diet*bST interaction and, as a result, at the end of the growth period the predicted final body weight of heifers injected with bST was greater whether or not the heifers had been fed control or high energy diets.

The three experiments reported have been interpreted as having shown that treatment of heifers with bST, as a means to direct nutrient partitioning, did enhance prepubertal growth rates, and as a consequence, the heifers reached greater body size and heavier body weight at 365 d of age. This suggested that the enhanced growth rate was due to bST injections via an increase in concentrations of ST in plasma during the time period they were being injected. Plasma concentrations of ST have been reported to be positively correlated with weight gain [1]. Thus, changes in body composition, nitrogen retention, live weight gain, and lean content of carcass may have occurred [3, 10, 36-38, 46, 55, 60, 61, 64], although we did not measure these. Treatment with bST induced increased in peripheral concentration of ST, IGF-I and Insulin [19]. The possibility that the bST treated heifers ate more of the available feed can not be excluded. Because amount of feed offered that was refused was not measured it is possible that differences in total feed intake occurred. Perhaps bST heifers had greater appetites than the not injected groups of heifers. Increased intake of feed may be related to increased or decreased concentrations of specific hormones.

Somatotropin (ST) has been reported to act directly on growth of tissues [46] and indirectly via other hormones such IGF-I or INS [48]. High capacity binding of ST to the somatogenic receptor has been correlated with growth rate in ruminants [8]. Moreover, ST receptors are highly influenced by nutrition, with increased number and affinity demonstrable at high levels of nutrition [7]. Administration of ST induces IGF-I secretion from the liver, the main source of circulating IGF-I. However, it also is produced in other peripheral tissues. ST stimulates differentiation of cells to a stage of maturation where they can produce and respond to IGF-I, and as a consequence the IGF-I produced by these cells stimulates mitogenesis [30]. In addition to this, ST increases INS resistance in adipose tissue which reduces insulin induced lipogenesis and maintains lipolysis [34]. Thus, plasma levels of INS, non-esterified fatty acids and glucose increase and as result there is less fat deposition and leaner growth [60].

Season of birth of heifers during the overall growth period had a significant effect on all traits for weight and height measured in experiment III (TABLE III). ADI of heifers was greater for heifers born during the cold season, intermediate for the cool season and least for the hot season. These results agree with previous findings [35]. Results of their studies likely resulted from differences in feed conversion or differences in voluntary intake of the straw. The same pattern was observed for ADGs of heifers in experiment III. Although the interaction of season of birth and treatment on ADGs suggested that bST injections (500 mg/14 d) increased ADGs, whatever the season of birth and independent of plane of nutrition, the effect of bST on ADGs was greater for heifers born during the cold season. This supported the possibility of differences in feed conversion and feed intake due to external temperatures and heat stress. Quality of feed likely was not important because we used stored silages and purchased grains.

CONCLUSIONS

Results from these three experiments indicated that injecting Holstein heifers with bST during the Peripubertal growth period did increase growth rates, irrespective of whether heifers were fed for a normal or for an accelerated growth rate. These results indicate there may be a great opportunity for bST to be used in heifer raising programs on dairy farms. Researchers have demonstrated that to produce economical benefits, dairy heifers should be incorporated into the herd at about 22 to 23 months of age and at about 550 to 600 kg body weight. These goals may be reached if ADGs are large enough to reach breeding weight of 340 to 350 kg at 11 -13 months of age. Improving growth rates of heifers during the peripubertal growth period, to the extent that it does not affect milk production negatively during first lactation, has been a challenge for dairy farmers. Because injections of bST into heifers fed control diets for a normal growth in these three experiments resulted in an increased final body weight and height at 365 or 375 d of age without over-conditioning the heifers, suggests that bST can be included in heifer management programs as a means to improve growth rates, perhaps it accomplishes this by increasing feed conversion efficiency and nutrient redistribution to priority organs. Thus, energy storage as protein accretion (skeletal and muscle growth) instead of fat deposition may result in larger heifers at age of breeding without detrimental effects on milk yield during first lactation. However, feeding heifers high levels of energy plus using injections of bST may not be economical. Although our results showed TWGs and THIs of heifers fed high plane of nutrition and injected with bST were greater than their contemporaries also fed the high diet or control diets, injected or not with bST, the extent of these increases were not as great as those of heifers fed control diet and injected with bST. Thus, the use of bST may be more attractive for heifers fed a plane of nutrition that supports normal ADGs (0.68 kg/d). Finally, before incorporating use of bST in heifers rearing programs one must know whether it has positive or negative effects on first and subsequent lactations and whether savings in cost of raising injected heifers will offset dollar cost of the bST.

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