Nutritional Implications of Somatotropin for Lactating Cows

WILLIAM CHALUPA and DAVID T. GALLIGAN
Center for Animal Health and Productivity
School of Veterinary Medicine
University of Pennsylvania
Kennett Square 19348

ABSTRACT

Milk yield, feed intake, physiology, health, and reproduction of cows supplemented with somatotropin are like those of genetically superior cows. Lactation curves are shifted upward and are more persistent. Holsteins, Jerseys, Brown Swiss, and Ayrshires respond. In most cases, responses in primiparous and multiparous animals are similar. Milk composition, ration digestibility, maintenance requirements, and the partial efficiency of lactation are not affected by somatotropin. More nutrients are directed to milk synthesis. Initially, body stores of fat, protein, and glycogen provide these nutrients, but after a few weeks, feed intake increases. Cows supplemented with somatotropin should be fed like high producing cows. When ration energy density is increased by feeding grain, buffers such as sodium bicarbonate should be included to prevent alterations of hydrogen balance in the rumen and tissues. Ration energy density can also be increased with ruminally inert fat like calcium salts of fatty acids. Rations should be balanced for rumen degradable and undegradable protein. Rations for high milk yields are expensive, but income over feed costs are greater. Cows should be moved to rations with lower nutrient densities on the basis of body condition and milk yield. Current feeding recommendations can be used for cows supplemented with somatotropin.

INTRODUCTION

The ability of bovine somatotropin (bST) to stimulate milk production has been known since 1937 (4). Until recently, somatotropin was available only from pituitary glands obtained from cattle at slaughter. Only small amounts were procurable and it was expensive. Thus, experiments were of a few days or weeks with small numbers of animals. With the development of recombinant technologies, substantial amounts of somatotropin are available for large-scale increases of productive efficiency of livestock. Research with larger numbers of animals has been completed and studies for multiple lactations are underway.

This report examines the importance of nutrition in cows supplemented with bST. For background, we review the production response to bST and how supplemented bST increases production. Evidence is presented to show that cows supplemented with bST are like genetically superior cows. Experiments with bST where nutritional regimens were varied are discussed. Nutritional strategies for high milk production in the cow supplemented with bST and in the genetically superior cow are presented.

THE PRODUCTION RESPONSE

Effects of bST on milk yield have been reviewed (8, 19, 21, 25, 60, 75). An example of responses is in Table 1. Most of the cows were Holsteins of British Friesians. Beginning at d 28 to 35 of lactation, they were injected daily for 266 d with buffered saline or 5.1, 10.3, 20.6, or 41.2 mg/d bST in buffered saline. Supplementation with 10.3, 20.6, and 41.2 mg/d bST increased 3.5% FCM 3.8, 5.0, and 5.7 kg/d. Under commercial conditions, cows supplemented with 10.3, 20.6, and 30.9 mg/d bST produced an additional 4.0, 5.0, and 5.0 kg/d 3.5% FCM (24). Where bST has been administered for 2 consecutive yr (2, 45), responses were comparable in both years. Milking three
TABLE 1. Responses of 3.5% fat-corrected milk (kg/d).

<table>
<thead>
<tr>
<th>Location</th>
<th>Bovine somatotropin, mg/d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Florida (37)</td>
<td>21.4</td>
</tr>
<tr>
<td>Kentucky (6)</td>
<td>27.0</td>
</tr>
<tr>
<td>Minnesota (85)</td>
<td>29.1</td>
</tr>
<tr>
<td>Ohio (74)</td>
<td>28.9</td>
</tr>
<tr>
<td>Pennsylvania (28)</td>
<td>24.2</td>
</tr>
<tr>
<td>Ontario (16)</td>
<td>26.7</td>
</tr>
<tr>
<td>United Kingdom (89)</td>
<td>22.0</td>
</tr>
<tr>
<td>TMR1</td>
<td>19.5</td>
</tr>
<tr>
<td>FLR2</td>
<td></td>
</tr>
<tr>
<td>LS Mean</td>
<td>24.9</td>
</tr>
<tr>
<td>SE</td>
<td>1.3</td>
</tr>
</tbody>
</table>

1Total mixed ration.
2Flat rate feeding.

times per day does not appear to affect responses (1). Although dependent upon factors such as dose, parity, phenotype, nutrition, and management, supplementation with bST usually increases production of 3.5% FCM by 4 to 5 kg/d.

Shape of lactation curves is affected by parity and days open. Current data, however, are not yet sufficient to derive mathematical expressions for describing lactation curves of bST-supplemented cows. Inspection of graphs of milk yield shows that bST supplementation had two distinct modifications on the shape of the lactation curve (59). The first modification effect is an immediate increase in milk production, which results in a vertical shift in the position of the lactation curve. The second modification effect is an increase in persistency. Using data from others (6, 18, 28, 74, 85) on responses of Holstein cows to supplemental bST, Marsh et al. (59) modified the model of Oltenacu et al. (73) so that the lactation curves of cows supplemented with bST could be described mathematically.

Effects of parity on responses to bST are not resolved completely. Pooling data (6, 28, 74, 85) suggested that higher supplemental bST is needed to achieve similar production responses in primiparous vs. multiparous animals (19, 21). In some reports (46, 79), response to bST increased with parity. However, in others (10, 24, 44, 52, 80), primiparous animals responded like multiparous cows.

Most research has been with Holsteins. Pooled data (6, 28, 73, 85) showed that responses in Jerseys, Ayrshires, and Brown Swiss were similar to responses of Holsteins (19, 21). Pell et al. (77) reported that Jerseys supplemented biweekly with 500 mg bST in a sustained release preparation for 34 wk produced an additional 5.6 kg/d 3.5% FCM.

Genotype (production potential based upon genetics, i.e., estimated transmitting ability, cow index, predicted difference for milk yield) did not affect responses to bST (53, 63, 72). Phenotype (production prior to supplementation with bST), however, may affect responses to bST (53, 87). Regression analyses indicated that low producers responded relatively better to bST than medium or high producers (53).

Sullivan et al. (87) grouped cows on the basis of production 2 wk prior to supplementation with bST. When supplemented with 500 mg/14 d bST in a sustained release preparation, cows with pretreatment production of 39, 32, and 27 kg/d produced an additional 4.8, 2.4, and 6.5 kg/d milk. However, McDaniel (63) concluded that production in previous lactations did not affect responses to bST. More information is needed before the impact of phenotype on increases of milk production to bST can be defined.

In general, bST does not change milk composition when cows are fed rations to provide positive balances of energy and protein (17, 21, 25, 60, 75). When cows are in negative energy balance, fatty acids are mobilized from adipose tissue and milk fat test increases, but when cows are in negative protein balance, concentration of protein in milk decreases. Increased
concentration of protein in milk has been reported in some studies (10, 80). Milk from Jerseys supplemented with bST had 11.3% more whey protein, 2.3% less casein as a percentage of total protein, and NPN as a percentage of total N was 11.5% higher (50).

Cows usually adjust their feed intake upward within a few weeks of supplementation with bST (8, 19, 21, 60, 75). Covariate adjustment for the increased production of FCM showed that most of the increased feed consumption was accounted for by higher milk yields (19, 21, 59). Thus, cows supplemented with bST adjust their feed intake upward in response to increased production in a predictable manner. Current equations [e.g., (69)] used to estimate feed intake can be applied to cows supplemented with bST.

Although most attention has been directed toward increases in milk yield, economic benefits are derived from improvements in feed efficiency. Even though feed consumption increases, more dietary nutrients are captured in milk [e.g., (9, 19, 21)]. Increased gross efficiency of milk production could be due to increased digestibility, reduction in maintenance energy costs, changes in the partial efficiency of milk synthesis, or redistribution of nutrients away from body stores to the mammary gland. In all (33, 36, 76, 83, 90, 93) but one study (68), bST had little effect upon digestibility. Neither maintenance requirements (83, 90) nor the partial efficiency of milk synthesis (23, 83, 90) are altered when lactating cows are supplemented with bST. The amount of energy lost as heat appears to depend upon energy balance (83, 90). When cows were in negative energy balance, supplementation with bST increased heat energy loss (90). The increased heat energy loss, however, was what would be predicted for cows producing more milk. When energy balance was not negative, supplementation with bST did not affect energy lost as heat (83). Thus, bST increases the capture of dietary nutrients in milk by diluting maintenance requirements and by partitioning nutrients into milk rather than into body reserves.

Small production responses in a long-term study at the University of Missouri (67) were attributed to a period of high ambient temperature and humidity, which reduced feed intake. This along with the increased heat production reported by Tyrrell et al. (90) lead to the speculation that supplemental bST might not stimulate production during heat stress. In the Climatology Laboratory at the University of Missouri, cows were subjected to thermoneutral (15 to 22°C), hot (25 to 35°C), and cold (~5 to 5°C) daily cycles of temperature (47, 54, 57). Under all cycles, cows supplemented with bST produced more heat, but heat loss also increased so that no adverse heat balance problems occurred (57). Heat and cold stressed cows had production responses to bST similar to cows in the thermoneutral environment (47, 54). In other short-term studies in Florida (86, 94) and Missouri (66), heat-stressed cows responded positively to exogenous bST. In addition, cows in a full-lactation study conducted in Florida (37) produced an additional 3.6, 4.5, and 7.3 kg/d 3.5% FCM when supplemented with 5.1, 10.3, and 20.6 mg/d bST. Responses of “stressed” cows to bST may depend largely upon the effect the “stress” has on feed intake. During periods of high temperature and humidity, nutritional interventions such as additional water, dietary potassium, and the use of low heat increment feeds like fat should be considered (14).

The effect of bST on animal health is an important concern. In the long-term study of Cornell (39), no adverse effects were noted. In some studies (18), daily administration of high (41.2 mg/d) levels of bST were associated with decreased pregnancy rate and increased incidence of mastitis. In other studies, however, cows supplemented with bST showed no health or reproductive problems (8, 9, 19, 24, 37, 46, 52, 80). In general, health and reproduction in cows supplemented with bST appear to be like that of genetically superior cows (19, 39, 40) and can be managed with modern production medicine programs (92). Although adverse effects usually have not been observed at anticipated use (i.e., 10 to 20 mg/d), studies with large numbers of animals are in progress to define completely the impact of bST on health and reproduction.

**ACTIONS OF SOMATOTROPIN**

The galactopoietic action of bST reflects greater utilization of nutrients for milk synthesis. This is accomplished by effects in the mammary gland and by alterations of metabolic processes to provide more nutrients for milk synthesis.
Several lines of evidence indicate that exogenous somatotropin does not act directly on the mammary gland. Somatotropin receptors have not been identified in the mammary gland (75), tissue culture studies showed no response of mammary tissue to somatotropin (13), and infusion of somatotropin into the mammary artery of sheep did not increase milk yield (64).

Bovine somatotropin could affect mammary tissue indirectly by its action on the liver and other tissues such as kidney to stimulate production of insulin-like growth factors (42, 75). Exogenous bST increases somatomedins in the lactating cow (31, 76), and somatomedin receptors have been detected in mammary tissues from pigs and dairy cows [ (43); R. J. Collier, unpublished results cited in (75)].

Even though treatment with bST increases mammary parenchyma in heifers (84), increases in production within a few days indicate that changes in the amount of secretory tissue in lactating cows supplemented with bST are not great. Using a computer simulation model for lactating cows, Baldwin and Bauman (7) demonstrated that production responses to bST reported by Bauman and McCutcheon (11) could be accounted for by increased metabolic activity of the mammary gland. Maximum velocity for many enzymes involved in milk synthesis are in excess of requirements but activities of some enzyme systems (i.e., pyruvate dehydrogenase, citrate cleavage, and NADP malate dehydrogenase) are low (91). However, to date there are no published reports on changes of key mammary enzyme systems in cows treated with bST.

Exogenous somatotropin increases cardiac output and mammary blood flow (30). It is thought that blood flow response is due to hormonal stimulation of mammary metabolism and is a response to increased metabolic rate and not a cause of increased milk yield (11, 42, 73). Never the less, increased blood flow to the mammary gland plays a major role in production responses to bST by providing additional oxygen and nutrients and by removing excess carbon dioxide and metabolites (29, 30, 60).

Metabolic Processes

Although production responses are not due merely to additional nutrients (11, 42, 73), more nutrients are needed for the increased synthesis of protein, fat, and lactose. Initially, body stores of protein, fatty acids, and glycogen may provide additional nutrients, but nutrients for prolonged increases of production are derived from coordinated changes of metabolism in many tissues and from increased feed intake (11, 73). Most evidence supports the "pull" concept: that the mammary gland of the bST-treated cow is dictating the need for additional nutrients (73). Overall, bST causes "exquisite coordination of metabolism to meet nutrient needs for increased synthesis of milk components" (12).

Metabolism of carbohydrate, protein, and lipid are altered by bST (11, 73). To explain long-term responses to exogenous bST, it is necessary to differentiate between acute and chronic alterations in metabolism. Increases in circulating glucose, insulin, and FFA are referred to as the diabetogenic and lipolytic properties of somatotropin (11). It is now known that these acute effects were due to contaminant peptides. Pure preparations of somatotropin do not cause acute changes in circulating concentrations of glucose, insulin, or FFA in lactating cows (11, 73). The FFA are, however, chronically increased when supplementation with bST forces animals into negative energy balance (11).

Carbohydrate Metabolism. Volume of milk produced is regulated by the amount of glucose extracted from blood by the mammary gland (51). Glucose for increased production of milk and lactose could be provided by increased glucose production, mobilization of glycogen reserves, or reduced oxidation of glucose by other tissues. Because they are limited, glycogen reserves are not likely a major source of additional glucose. Cows supplemented with bST show increased gluconeogenesis in the liver and decreased use of glucose as an energy source by the mammary gland and other tissues (11, 12, 48, 60, 78).

Propionate and perhaps glycerol are sources of the additional glucose (75). Amino acids can be used for synthesis of glucose, but because there is additional demand for amino acids for increased synthesis of milk protein, amino acids are probably not important precursors for additional gluconeogenesis observed in cows supplemented with bST.

Lipid Metabolism. Alterations of lipid metabolism depend upon energy balance. When
TABLE 2. Comparison of changes that occur when cows are supplemented with bovine somatotropin (bST) and those observed in genetically superior cows.1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Genetically superior cow</th>
<th>bST Cow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed intake</td>
<td>Higher intake.</td>
<td>Intake increases to</td>
</tr>
<tr>
<td></td>
<td>Intake increases</td>
<td>match higher yields</td>
</tr>
<tr>
<td></td>
<td>after parturition.</td>
<td>of milk.</td>
</tr>
<tr>
<td>Digestibility of feed</td>
<td>Minor differences.</td>
<td>Minor differences.</td>
</tr>
<tr>
<td>Body reserves</td>
<td>Greater use in</td>
<td>Increased use during</td>
</tr>
<tr>
<td></td>
<td>early lactation.</td>
<td>first weeks of bST.</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Minor differences.</td>
<td>No differences.</td>
</tr>
<tr>
<td>Partial efficiency milk synthesis</td>
<td>Minor differences.</td>
<td>No differences.</td>
</tr>
<tr>
<td>Mammary glands</td>
<td>More secretory tissue.</td>
<td>More secretory cells, or</td>
</tr>
<tr>
<td></td>
<td>Activity per cell not</td>
<td>higher synthetic rate, or</td>
</tr>
<tr>
<td></td>
<td>known.</td>
<td>both</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Increased.</td>
<td>Increased.</td>
</tr>
<tr>
<td>Reproduction</td>
<td>Improved management</td>
<td>Insufficient data.</td>
</tr>
<tr>
<td></td>
<td>needed.</td>
<td>Improved management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>needed?</td>
</tr>
</tbody>
</table>

1Adapted from Pecl and Bauman (75).

bST causes animals to be in negative energy balance, circulating FFA are elevated and irreversible loss of FFA is increased (11, 12, 60, 75). Cows in positive balances of energy do not have elevated plasma FFA, but whether irreversible loss of FFA is increased has not been resolved (11, 48, 60, 83). The picture that emerges is one of modifications of lipid metabolism to allow the bST-supplemented cow to use alternative sources of energy when feed intake does not provide sufficient energy for increased milk production (12, 62).

In addition to fatty acids mobilized from body reserves, milk fat contains a large percentage of fatty acids derived from lipoprotein triacylglycerol (32). Lipoprotein lipase, located at the capillary endothelium, hydrolyzes triacylglycerol containing chylomicrons and very low density lipoproteins for incorporation into milk fat (82). Even though yield of fat is increased by bST, lipoprotein lipase activity in mammary tissue and milk from cows injected with bST is not affected (5, 55). Changes in milk lipoprotein lipase activity during long-term administration of bST are similar to those normally observed during the lactation cycle in that activity increases from parturition until about 25 wk postpartum and then decreases (5).

Protein Metabolism. Although concentration of protein in milk usually is not changed, cows treated with bST produce more protein. Although additional amino acids are provided when feed intake is adjusted upward, sparing amino acids from oxidation (47, 59, 73) provides additional amino acids for synthesis of milk protein.

Mineral Metabolism. Concentrations in milk of nutritionally important mineral elements (Ca, P, Na, Fe, Cu, Mn) are not affected by bST (39). Small increases were observed in concentration of Mg and concentration of Zn in milk decreased slightly (39). Because of increased milk yield, minerals secreted in milk are increased. Blood concentrations of minerals are not changed so alterations must occur in absorption, endogenous secretions in the intestine, or mobilization from tissues.

SOMATOTROPIN AND PRODUCTION RESPONSES

In terms of physiology, feed intake, and body weight changes, cows supplemented with bST are like genetically superior cows (Table 2). Two approaches were followed to evaluate further the similarities of the bST supplemented cow and the genetically superior cow.

In the first approach, we used data obtained with multiparous Holsteins in experiments conducted under identical protocols in Kentucky (6), Minnesota (85) and Pennsylvania (28). A
companion experiment was conducted at Ohio (74), but because the cow population included Ayrshires, Brown Swiss, and Jerseys, there were insufficient numbers of multiparous Holsteins for inclusion of the Ohio data. In our analyses, we compared responses of 3.5% FCM, feed intake, and body weight of multiparous Holsteins supplemented with 0 vs. 10.3 mg/d bST for 266 d beginning at d 28 to 35 of the lactation cycle (Figure 1).

For analyses of the impact of bST on responses of productivity, data on 34 cows were available (9 at KY, 13 at MN, 12 at PA). As shown in the left panels of Figure 1 (all cows, n = 34), multiparous Holsteins supplemented with 10.3 mg/d bST showed an immediate response (P<.01) in milk yield that persisted for the remainder of the lactation cycle. This resulted in an additional 4.9 kg/d 3.5% FCM during the 266-d experiment. Feed consumption, however, did not increase during the first 4 wk of bST supplementation; there were modest increases during the next 12 wk and substantial increases during the remainder of the
During the 266-d experiment, multiparous Holsteins supplemented with 10.3 vs. 0 mg/d bST consumed 1.2 kg/d more feed (21.5 vs. 20.3 kg/d).

For analyses of bST-supplemented versus genetically superior cows, data from eight pairs of multiparous Holsteins were available (three at KY, three at MN, two at PA). In this analysis, we compared responses of cows with higher genetic potential that were not supplemented with bST to responses of cows with lower genetic potential for milk production that were supplemented with 10.3 mg/d bST. As shown in the right panels of Figure 1, there were no differences in production of 3.5% FCM (27.5 vs. 27.5 kg/d) or feed consumption (21.0 vs. 21.2 kg/d) of bST-supplemented versus cows with higher genetic potential for milk production.

Weight gains of all cows and the cows paired on the basis of milk production were not affected by bST supplementation (Figure 1). Although this may indicate that increased feed consumption of cows supplemented with 10.3 mg/d bST provided sufficient nutrients for the additional 4.9 kg/d 3.5% FCM milk, impacts on body composition should be considered. During the 266-d experiment, cows were fed diets formulated to provide net energy and protein for maintenance and about 35 kg/d milk.

In the second approach, we used DairyORACLE, a microcomputer simulation model of a dairy enterprise (58). Equations for lactation curves (73) were adjusted (59) to reflect cows supplemented with bST using data obtained with primiparous and multiparous Holstein cows in experiments conducted in Kentucky (6), Minnesota (85), Pennsylvania (28), and Ohio (75). Feed intake was predicted on the basis of body weight and milk yield using NRC (69) with consumption not maximized until wk 7 of lactation and with a 4-wk lag in increased consumption due to bST. Nutrient densities of rations were calculated on the basis of nutrients required for maintenance and production (71) and estimated feed consumption (69). We allowed cows to lose about 60 kg of body weight in early lactation and required their body weight at dry-off to equal their body weight at parturition. In Figure 2, cows with the genetic potential for 9000 kg of milk supplemented with 0 or 10 mg/d bST beginning at d 29 of lactation are compared with cows with the genetic potential for 10,000 kg milk that are not supplemented with bST. As described earlier, bST causes an immediate increase in milk yield and cows are more persistent. Our simulation shows that total milk yields of the genetically superior cow and the cow with lower genetic potential for milk production but supplemented with 10 mg/d bST are equal. Because bST supplementation did not start until d 29 of lactation, the genetically superior cow shows slightly higher peak yield of milk, but for the bST supplemented cow greater persistency in late lactation is shown. Even though feed intake is adjusted upward in response to increased milk production, our simulation shows that in order to avoid large losses of body weight, cows supplemented with bST must be fed rations similar to those fed to higher producing cows.

EFFECT OF NUTRITION ON RESPONSES TO SOMATOTROPIN

Based on short-term studies where cows supplemented with bST did not adjust their feed intake upward, Kalter et al. (49) speculated that consumption of concentrates would have to increase substantially. Marsh et al. (59) used DairyORACLE to simulate the productivity to bST on nine commercial herds in southeastern Pennsylvania. Supplementation with 10.3 mg/d bST during d 30 to 305 of the lactation cycle was estimated to increase annual herd milk sales by 8.5 to 17.6%. Forage consumption was estimated to be increased by .6 to 10.5%. Grain requirements were estimated to increase by 10.2 to 31.2%.

Production responses to bST have been obtained in pasture-fed cows (76) and in cows fed a flat rate of grain and forage ad libitum (89). Cows fed corn-based diets produced more milk than cows fed barley based diets (34), but type of grain did affect responses to bST (35).

Researchers at the USDA Forage Research Center (88) recently evaluated the effects of forage and grain on responses to bST. Forage (alfalfa silage) composed 38 vs. 58%, 48 vs. 68%, or 68 vs. 88% of the ration (DM basis) during early (wk 1 to 12), middle (wk 13 to 26), and late (wk 27 to 44) stages of the lactation cycle. During wk 13 to 43 of lactation, half of the animals in each dietary group (8 primiparous and 8 multiparous Holsteins) were supplemented with either 0 or 20.6 mg/d bST.
Production (3.5% FCM) reported was for 305 d of lactation. Primiparous cows on the lower forage program supplemented with 20.6 vs. 0 mg/d bST produced an additional 851 kg 3.5% FCM. Those on the higher forage program produced an additional 646 kg 3.5% FCM when supplemented with 20.6 mg/d bST. Responses of multiparous cows supplemented with bST followed the same trend (1801 kg in animals fed the low forage regimen; 1548 kg in animals fed the high forage regimen). Hemken et al. (45) reported that ration energy concentration (60:40 vs. 40:60 forage to concentrate) did not affect responses to bST.

Energy density of diets is usually increased by incorporating more grain and less forage. Unless supplemented with dietary buffers, high grain diets can cause milk fat depression and sufficient alterations of hydrogen balance in the rumen and tissues to cause disturbances of digestion, metabolism, and production (26). In both early and late lactation (19, 20), milk yield responses of bST were additive to responses of sodium bicarbonate.

An alternative to feeding more grain is to increase energy density of diets with rumenally inert forms of fat such as calcium salts of long-chain fatty acids (27). Direct incorporation of long-chain fatty acids into milk is more efficient than de novo synthesis of fatty acids by the mammary gland (51). In a recent study (81), cows in early lactation were supplemented with 0 or .77 kg/d calcium salts of long-chain fatty acids (Megalac®3 and injected daily with 0 or 41.2 mg/d bST. In the absence of supplemental fat, bST increased production of FCM 3.1 kg/d. With supplemental fat, bST increased production of 3.5% FCM 6.5 kg/d. However,

3Megalac® is the registered trademark of Church and Dwight Co. Inc., Princeton, NJ for the calcium salts of long-chain fatty acids.
responses to bST were not increased (56) when cows were supplemented with Unifat-37 (Rouse Marketing Associates, Cincinnati, OH).

Responses to bST were similar in cows fed rations containing cottonseed vs. soybean meal (61). McGuffey et al. (65) evaluated the influence of concentration and degradability of ration CP on responses of cows to bST. Soybean meal and distillers dried grains were varied to formulate isocaloric (1.7 Mcal/kg net energy) rations with low (14%) and high (17%) concentrations of CP that contained low (33%) and high (40%) amounts of ruminally undegraded protein. Beginning at approximately 30 d in milk, cows fed these four rations were supplemented at 28-d intervals for 112 d with a sustained release formulation to provide 640 mg bST. Cows not supplemented with bST were fed the low (14%) protein ration with low (33%) undegradable protein. Concentration of fat, protein, and total solids in milk were not affected (P >.1) by bST or by concentration or degradability of ration protein. When supplemented with bST, cows fed diets with high (40%) vs. low (33%) amounts of undegradable protein produced an additional 4.4 vs. 2.7 kg/d 3.5% FCM (P = .03); cows fed diets with high (17%) vs. low (14%) concentrations of CP produced an additional 4.1 vs. 3.0 kg/d 3.5% FCM (P = .10). We applied linear regression analysis to the data (65) and found that 92% of the variation in responses of 3.5% FCM to supplemental bST was accounted for by variations in intake (kg/d) of ruminally undegraded intake protein but 42% of the FCM response to supplemental bST was accounted for by variations in intake (kg/d) of crude protein. Thus, while both concentration and undegradability of ration protein affected responses of cows to supplemental bST, undegradability of protein had greater impacts.

Because cows supplemented with bST direct more nutrients to milk, it is important to monitor body condition so that body reserves can be replenished during late lactation or during the dry period. Supplementation with 40 mg/d bST during wk 11 to 18 of lactation did not affect body composition (15). Cows supplemented with for 266 d with 20.6 and 41.2 vs. 0 and 10.3 mg/d bST had lower amounts of empty body fat and lower body condition scores, but amounts of empty body protein and mineral were not affected (85). Impact of bST on body composition and body condition score probably depends upon production potential of cows and ration energy density. In a study by Soderholm et al. (85), cows supplemented with 0, 10.3, 21.6, and 41.2 mg/d bST produced 29.9, 33.4, 37.5, and 36.7 kg/d 3.5% FCM. The ration contained 1.68 Mcal/kg net energy. This study (85) again demonstrates the coordination of metabolism in cows supplemented with bST to meet nutrient needs for milk production (12) and shows that the bST cow is like the genetically superior cow (75). Although upward adjustments of feed intake provide additional nutrients, movement of cows to feeding programs with lower nutrient densities should be on the basis of milk yield and body condition. Restoration of body condition is more efficient in late lactation than during the dry period, but rather than stop bST supplementation during the last few weeks of lactation and lose benefits of increased yield, it may be more economical to replenish body reserves at lower efficiencies during the dry period.

FEEDING STRATEGIES FOR HIGH MILK PRODUCTION

As with the genetically superior cow, realization of the full benefits of bST requires competent nutritional management. Even though feed intake is adjusted upward in a predictable manner, rations need to contain sufficient nutrients to support increased milk yields.

Concentrations of nutrients in diets are determined by requirements and feed intake. Over the range of 20 to 60 kg/d milk, the feed intake range estimated from NRC (71) is 17 to 28 kg/d (Figure 3). At feed intakes of 17 to 28 kg/d, 1.45 to 1.85 Mcal/kg are required for cows producing 20 to 60 kg/d milk (Figure 3). So that fiber concentrations are not compromised, rations to support more than about 35 kg/d milk need to contain supplemental fat. When diets contain proper balances of degradable and undegradable protein, 13 to 18% intake protein in DM will meet requirements for maintenance plus production of 20 to 60 kg/d milk (Figure 3). For diets that do not contain supplemental fat (i.e., 20 to 30 kg/d milk), 37% of the dietary protein should escape ruminal degradation (Figure 3). Because ruminal microbes do not use fat as a source of energy for growth, diets that contain more than 3% fat should contain more undegraded intake protein than calculated from
SOMATOTROPIN AND NUTRITION

Figure 3. Ration concentrations of A) net energy (NE) and B) protein for maintenance (650 kg) and 20 to 60 kg/d milk with 3.7% fat. NE = Net energy; UIPIP = undegraded intake protein as a proportion of intake protein; IPDM = intake protein as a proportion of dry matter.

NRC (71). Based upon the regression equation describing the relationship between net energy intake and flow of bacterial crude protein to the small intestine developed by NRC (70), we provide an additional 72 g undegraded intake protein per megacalorie of net energy from fat above 3% fat in the diet. Thus, as the concentration of fat increases from 3 to 8% of DM, undegradable protein is increased from 37 to 49% of intake protein.

Example rations were formulated using an interactive microcomputer program (41) modified to contain a linear package (3) so that least cost formulations could be obtained. For simplicity, alfalfa was constant at 10% of DM. Palmquist (Ohio Agricultural Research and Development Center, Wooster, personal communication) suggests that the upper limit of dietary fat is equivalent to the amount of dietary fat in milk (i.e., 40 kg/d milk with 3.5% fat = 1.4 kg/d dietary fat). About one-third of dietary fat will come from common feed ingredients (i.e., forages, grains, proteins), one-third may come from whole oil seeds (i.e., cottonseed, soybeans), and the remainder should come from ruminally inert fats (i.e., Megalac®). Both whole cottonseed (7% DM) and Megalac® (5% DM) were included in diets formulated for 35 kg/d milk (Figure 3). Whole cottonseed was constrained to not exceed 10% of DM so that not more than one-third of the dietary fat came from oil seeds. Because total fat was constrained to not exceed the total fat secreted in milk, diets do not contain more than 3.5% Megalac®, which when added to fat from forages, corn, and protein supplements yields rations with a maximum of 8% fat (Figure 4). Acid detergent fiber in DM is greater than 20% for rations formulated for up to 50 kg/d milk (Figure 5). Even with rations formulated to support 55 and 60 kg/d milk, ADF is still in excess of 17%.

As shown in Figure 6, diets that contain specialty ingredients like whole cottonseed, Megalac®, and blood meal are more expensive. DairyORACLE (58, 59), with the modifications and constraints described earlier, was used to simulate milk yields and estimate feed consumption of cows with different genetic potentials for milk production (8000 to 12,000 kg/305-d lactation) that are supplemented beginning at d 29 of lactation with 0 or 10.3 mg/d bST. Rations in Figure 4 were fed so that body weight during early lactation did not decrease by more than 60 kg and body weight at the end of 305 d of lactation was the same as at parturition. The plot of milk value minus feed costs (Figure 7) shows that over the estimated production range of 9000 to 12,500 kg milk, income over feed costs continues to increase at a constant rate. Regression analysis shows the increase is $1.16/kg milk, regardless of whether increases are due to genetics or to supplementation with bST. As long as cows respond to additional nutrients, either because of genetics or supplemental bST, use of more expensive specialty feed ingredients increases income over feed costs.

ECONOMIC IMPACT SOMATOTROPIN

Data in Figure 7 and Table 3 shows that bST is a management tool that can be used to increase profitability. Over all genetic potentials for milk production, daily supplementation
Figure 4. Ration ingredients to provide net energy and protein for maintenance (650 kg) and 20 to 60 kg/d milk with 3.7% fat. Abbreviations and cost ($/kg): SBM = soybean meal 48% crude protein ($0.27); WCS = whole cotton seed, ($0.20); BM = blood meal, ($0.61); MEG = Megalac® ($0.88); corn ($0.11); corn silage ($0.08); alfalfa, ($0.11). Rations also contained minerals and vitamins to meet requirements suggested by NRC (69), sodium bicarbonate, and magnesium oxide.

Figure 5. Concentrations of acid detergent fiber and fat in rations formulated to provide net energy and protein for maintenance (650 kg) and 20 to 60 kg/d milk with 3.7% fat.

Figure 6. Cost of rations to provide net energy and protein for maintenance (650 kg) and 20 to 60 kg/d milk. Ingredient costs are in Figure 4.

with 10 mg/d bST beginning at 29 d of the lactation cycle was estimated to increase milk yield 1000 to 1500 kg and increase income over feed costs $193 to $252. Comparable improvements can be achieved by increasing the genetic potential for milk yield by using superior sires. Improved profitability with bST, however, is immediate and only requires investment in bST and cost of administration.

In our computer simulations (Figure 7, Table 3), the daily value of bST (break-even cost) was $.70 to $.91. Break-even cost includes extra feed costs but does not include compensation for additional management, time, supplies, and labor needed to administer bST. Break-even cost should be interpreted as the maximum possible price the dairy farmer should pay for the product. Marsh et al. (59) used DairyORACLE to evaluate the economic impact of bST on nine commercial dairies in southeastern Pennsylvania. Herds were selected according to size (small, 30 to 60 cows; medium, 95 to 105 cows; and large, 123 to 241 cows) and average milk production per cow (low, 5594 to 6209 kg; medium, 8007 to 8240 kg; and high, 9168 to 9936 kg). Simulations for 6 consecutive yr replicated five times for each dairy showed that the break-even cost for daily supplementation with 10.3 mg/d bST during d 30 to 305 of lactation was $.27 to $.64/d.
TABLE 3. Computer simulation of the effects of bovine somatotropin (bST) on milk yield, income over feed costs, and the value of 10 mg/d bST. (1)

<table>
<thead>
<tr>
<th>Genetic potential</th>
<th>Estimated milk, bST, mg/d</th>
<th>Milk - feed, bST, mg/d</th>
<th>Value of bST</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg milk/305 d)</td>
<td>0 10</td>
<td>0 10</td>
<td>($/305 d)</td>
</tr>
<tr>
<td>8000</td>
<td>8027 9086</td>
<td>1300 1493</td>
<td>.70</td>
</tr>
<tr>
<td>9000</td>
<td>9132 10,334</td>
<td>1503 1696</td>
<td>.70</td>
</tr>
<tr>
<td>10,000</td>
<td>10,036 11,357</td>
<td>1645 1850</td>
<td>.74</td>
</tr>
<tr>
<td>11,000</td>
<td>10,412 12,495</td>
<td>1791 2034</td>
<td>.88</td>
</tr>
<tr>
<td>12,000</td>
<td>12,087 13,679</td>
<td>1967 2219</td>
<td>.91</td>
</tr>
</tbody>
</table>

1 Feed costs were based on information in Figures 4 and 6. Milk was valued at $.24/kg.

Bovine somatotropin had greater value on higher producing herds practicing better management, but herd size did not affect the value of bST. Our simulations and those by Marsh et al. (59) considered income from milk and additional feed costs. Marsh et al. (59), however, also included cash income from sales of bull and surplus heifer calves, cull animals, and surplus springing heifers and variable expenses such as livestock purchases, breeding expenses, veterinary and medical expenses, utilities, fuel, dairy chemicals, and supplies. We estimated that the break-even cost of bST with cows with the genetic potential for 9000 to 10,000 kg milk was $.70 to $.74/d. The total herd break-even cost estimated by Marsh et al. (59) for herds producing 9168 to 9936 kg milk was $.50 to $.64/d. Because Marsh et al. (59) valued milk at $.23/kg vs. our value of $.24 kg, the break-even values they calculated might be expected to be 4% less than ours. Although these comparisons suggest that the economic benefit of bST calculated only on the basis of milk value and feed costs may slightly overestimate the value of bST in the total dairy enterprise, our simulations and those by Marsh et al. (59) demonstrate that bST is an attractive management tool to improve profitability.

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