Feeding strategies for improving productivity of growing steers fed grass silage

D. R. Ouellet[1], L. Faucitano[1], D. Pellerin[2], M. D'Amours[2], and R. Berthiaume[1]

[1]Dairy and Swine Research and Development Centre, Agriculture and Agri-Food Canada, P.O. Box 90 STN Lennoxville, Sherbrooke, Quebec, Canada J1M 1Z3 (ouelletd@agr.gc.ca); and [2]Département des sciences animales, Université Laval, Quebec, Quebec, Canada G1K 7P4. Contribution number 973 from the Dairy and Swine Research and Development Centre.. Received 14 January 2008, accepted 29 July 2008.

Ouellet, D. R., Faucitano, L., Pellerin, D., D'Amours, M. and Berthiaume, R. 2008. **Feeding strategies for improving productivity of growing steers fed grass silage.** Can. J. Anim. Sci. **88**: 685–692. Two experiments were conducted to determine the relationship between corn particle size and soybean meal treatment on growth, diet digestibility, and nitrogen balance of growing steers. In the first experiment, 40 medium-frame beef steers (250 ± 11 kg) were fed individually for 140 d a diet based on grass silage offered for ad libitum consumption and supplemented with either 3.5 kg of DM d^{-1} of cracked corn (CC) or ground corn (GC) and with 450 g of DM d^{-1} of solvent extracted (SS) or lignosulfonate-treated soybean meal (Soypass™; SP). Dry matter intake was not affected by treatments and averaged 8.6 ± 0.3 kg d^{-1} ($P > 0.10$). Average daily gain was higher for animals receiving the ground corn than those fed cracked corn. Feed to gain ratio was not affected by treatments. There was an interaction between treatments for plasma urea-N concentration, with source of soybean meal having no effect with CC. When compared with SS, SP supplement reduced plasma urea-N when fed with GC. No effect of soybean meal and its interaction with corn processing was observed on growth performance. In the second experiment four additional steers were used in a 4 × 4 Latin square design to evaluate diet digestibility and nitrogen balance. There was an interaction between treatments for starch apparent digestibility and N retained, the values being respectively, 90, 86, 93, and 92% (SEM = 1.2; $P < 0.01$) and 36, 42, 44 and 41 g d^{-1} (SEM = 2.8; $P < 0.03$) for CCSS, CCSP, GCSS and GCSP, respectively. Altogether, the results indicate a slight advantage to reduce particle size of corn in growing steers fed grass silage. However, soybean meal treatment resulted in limited effects on growth and digestion.

Key words: Rumen carbohydrate, undegradable protein, performance, steers

Ouellet, D. R., Faucitano, L., Pellerin, D., D'Amours, M. et Berthiaume, R. 2008. **Stratégies alimentaires pour améliorer la productivité des bouvillons alimentés avec de l'ensilage d'herbe.** Can. J. Anim. Sci. **88**: 685–692. Deux expériences ont été réalisées pour déterminer la relation entre la taille des particules de maïs grain et le traitement du tourteau de soya sur la digestibilité de la ration, la croissance et le bilan azoté de bouvillons. Dans la première expérience, quarante bouvillons d'ossature moyenne (250 ± 11 kg) ont été alimentés individuellement durant 140 jours avec une diète à base d'ensilage d'herbe offerte pour une consommation à volonté et complémentée avec soit 3,5 kg de matière sèche par jour de maïs moulu (MM) ou de maïs cassé (MC) et avec 450 g par jour de tourteau de soya extrait au solvant (SS) ou traitée au lignosulfonate (Soypass TM; SL). La matière sèche ingérée (8,6 ± 0,3 kg par jour) n'a pas été affectée par les traitements ($P > 0{,}10$). Le gain moyen quotidien a été supérieur pour les animaux recevant le maïs moulu que pour ceux alimentés avec le maïs cassé. L'efficacité alimentaire (ingestion sur gain) n'a pas été affectée par les traitements. Il y a eu une interaction entre les traitements pour la concentration de l'azote uréique plasmatique. La source de tourteau de soya n'ayant pas d'effet sur la concentration de l'urée plasmatique avec le maïs cassé. Alors que, comparé au SS, le supplément SL réduisait l'urée plasmatique lorsque alimenté avec le maïs moulu. Dans la seconde expérience, quatre bouvillons additionnels ont été utilisés dans un dispositif en carré latin 4 × 4 pour évaluer la digestibilité de la diète et le bilan azoté. Il y a eu une interaction entre les traitements pour la digestibilité apparente de l'amidon et l'azote retenue, les valeurs étant respectivement, 90, 86, 93, et 92% (erreur-type = 1,2; $P < 0{,}01$) et 36, 42, 44 et 41 g d^{-1} (erreur-type = 2,8; $P < 0{,}03$) for MCSS, MCSL, MMSS et MMSL, respectivement. L'ensemble des résultats présentés dans cette étude indique un léger avantage de réduire la taille des particules du maïs pour des bouvillons en croissance alors que des effets limités du traitement du tourteau de soya furent observés.

Mots clés: Hydrate de carbone, protéines non dégradées, performance, bouvillons

Sustained growth rate of steers is conditional on the important contribution of metabolizable protein (MP) at the duodenum and energy supply. The MP is composed predominantly of microbial protein and the dietary N that escapes ruminal degradation (National Research Council 1996). On the other hand, energy supply refers mainly to fermentable organic matter

Abbreviations: **AA**, amino acids; **ADF**, acid detergent fiber; **ADG**, average daily gain; **CC**, cracked corn; **CP**, crude protein; **DM**, dry matter; **DMI**, dry matter intake; **GC**, ground corn; **MP**, metabolizable protein; **MPS**, microbial protein synthesis; **NPN**, non-protein nitrogen; **RUP**, rumen undegraded protein; **SS**, solvent extracted soybean meal; **SP**, lignosulfonate-treated soybean meal digested in the rumen to allow microbial growth and to produce volatile fatty acids or nutrients digested post-rumenally (Firkins et al. 2006). Still today, results from the interactions between dietary protein and energy supply are difficult to predict (Schroeder and Titgemeyer, 2008; Keane 2005) and they need to be investigated to define better feeding strategies to balance nutrients and insurance optimum use of them.

In growing steers fed grass silage, MP supply has been shown to be limited mainly because of the large fraction of N that rapidly generates ammonia in the rumen. This ammonia can be captured to produce microbial protein if fermentable energy is provided (Taniguchi et al. 1995). In beef production systems, corn is largely used as a dietary energy source (Galyean et al. 1979) but ruminal digestion of starch from dry corn has been reported to be low as compared with other grain sources (Huntington 1997). Galyean et al. (1979), however, reported that reduction of dry corn particle size increased starch digestion in the rumen, which in turn could improve microbial protein synthesis (MPS) from energy released from starch fermentation (Huntington 1997).

Another approach to improve growing performance of steers fed grass silage has been the addition of a supplement high in rumen undegraded protein (RUP) to the diet (Veira et al. 1994). This directly provides additional feed protein at the duodenum level (Bateman et al. 2005) although it may decrease MPS (Ipharraguerre and Clark 2005). As mentioned above, to capitalize on true protein at the duodenum level and on energy supply, diet formulation systems should combine maximal MPS, adequate RUP, and maximize energy utilization.

Thus, the objective of the present experiment was to compare the effect of combining two different sources of carbohydrate and protein supplements having different ruminal degradation rates on gain, efficiency and energy of the diet for growing steers fed grass silage. Diet digestibility, N balance and plasma amino acid (AA) profile were also evaluated.

MATERIALS AND METHODS

Animals and Treatments

This study was approved by the Kapuskasing Research Centre Animal Care Committee and was conducted in accordance with the guidelines of the Canadian Council on Animal Care (1993). Forty medium-frame beef steers (250 ± 11 kg) were used in an experiment designed as a rrandomized complete block with a 2×2 factorial arrangement of treatments. The treatments included two types of grain processing and two types of soybean meal: 3.5 kg of DM d^{-1} of cracked (CC) or ground corn (GC) and with 450 g of DM d^{-1} of solvent extracted (SS) or lignosulfonate-treated soybean meal (Soypass®; SP). All feed supplements were bought from the same lot at a local feed manufacturer. Diets of steers were completed by offering grass silage for ad libitum consumption during a growing phase of 20 wk. The silage was made from the primary growth of a mixed sward containing mainly orchard grass (*Dactylis glomereta* L.). The grass was at the mid- to end elongation stage at the time of harvest. The material was ensiled with an 85% solution of formic acid applied at approximately 2 kg t^{-1} of fresh material before being stored in a horizontal silo. Silage was offered in the morning and half of the supplement was put on the top of the silage in the feed bunk and mixed together by hand. The remainder of the supplement was fed at 1600 and mixed with the silage already present in the feed bunk. Water was continuously available.

Steers were housed in an unheated but insulated enclosed barn with wood shavings as bedding. Five pens of eight animals were used with two replicates within each pen. Pens were equipped with electronic head gates to allow measurement of individual feed intake, which was recorded daily throughout the experiment. Steers were adapted to the experimental silage and the Calan gate feeders for 14 d prior to day 0 when supplements were fed for the first time. On day 2, steers were injected with 500 000 IU of vitamin A and 75 000 IU of vitamin D. Cattle were also treated for external parasites [Cydectin®; moxidectin, Wyeth Santé Animale, Guelph, ON, MSD Agvet Division of Merck Frosst Canada Inc., QC (now Merial Canada, Montreal, QC)]. The steers received anabolic implants (Synovex-S; Syntex Agribusiness Inc.) on day 14 and were fed daily a feed additive (300 mg head^{-1} of lasalocid sodium; Bovatec, Hoffmann-La Roche Limited, Canada), salt and a mineral supplement to meet requirements (National Research Council 1996). Silage was sampled twice a week while other diet ingredients and orts were sampled once a week. Two-week composite samples were prepared and kept frozen for further analyses.

Individual steers were weighed (unshrunk) on 3 consecutive days upon initiation and completion of the trial. Mean weights were reduced 4% to account for digestive tract fill (Zinn and Shen 1998). Body condition score was assessed on days 0, 70, and 140 using a six-point scale (where 0 = emaciated and 5 = obese; Lowman et al. 1973). A blood sample was taken from all animals on day 0, before the first experimental meal, and on dsy 140 before the morning meal. Blood was obtained by jugular venipuncture into evacuated tubes containing heparin. Blood samples were immediately placed on ice and were centrifuged ($2500 \times g$ for 12 min at 4°C) and plasma was frozen at −20°C until analyzed. Net energy values for each diet were estimated from National Research Council (1996) and calculated from observed performance as described by Zinn and Shen (1998).

Dry matter, nitrogen, energy and starch apparent digestibility were measured in four additional steers (initial weight: 248 kg ± 9) used in a 4×4 Latin square design balanced for residual effect. Collection periods ran concurrently with the growing phase. Each period lasted 21 d. Steers were entered into the metabolic crates for a 7-d period to allow for adaptation to the crates and the diets. Steer weight was recorded on days 6 and 7. Based on expected intake and gain of the CCSS diet (National Research Council 1996), ingredient proportions were set at 54% for grass silage, 40% for corn source, 5% for soybean meal source, and 1% for mineral for all periods. On day 8 through day 21, diet offered to steers was fixed. Ninety percent of the lowest average intake (% kg DMI kg BW^{-1}) recorded during the ad libitum period, was offered to all steers. A 7-d total collection of feces and urine was conducted between day 15 and day 21. Urine was directed by gravity into a stainless steel pan containing enough concentrated sulfuric acid to decrease pH below 2. Representative samples of silage, feces (5%) and urine (1%) were collected daily and pooled on a weekly basis. In addition, 20 mL of acidified urine was diluted with 80 mL of distilled water and pooled on a weekly basis for analysis of purine derivatives.

Chemical Analyses

Corn particle distributions was determined by sieving samples into five different pore sizes, 8, 5.4, 3.8, 2.0, and 0.8 mm. The pH of grass silage samples was determined according to Playne and McDonald (1966). Dry matter of feed was obtained by drying at 100°C for 48 h. Concentrations of D- and L-lactate in silage were determined according to the methods of Gawehn and Bergmeyer (1974) and Gutmann and Wahlefeld (1974), respectively, with the following modifications: 3 mL of hydrazine-glycine buffer with NAD were mixed with 60 μL of silage extract (2 g of fresh silage mixed with 20 mL of 0.1 N HCl kept at 21°C overnight). Readings were taken at 340 nm (blank); then 25 μL of D-L LDH solution were added, and samples were sealed and left at 21°C for 1 h before reading at the same wavelength. Volatile fatty acids in silage were determined by gas chromatography (Varian model 3400; Varian Canada, Inc., Mississauga, ON) on an aliquot of the deproteinized extract using 2-ethyl-butyric acid as the internal standard. Protein N in silage was analyzed using an acidified extract (20 g of fresh sample in 200 mL of 0.01 N HCl agitated at 21°C for 22 h) and deproteinized with TCA (Siddons et al. 1979). Nitrogen determinations (N, protein N and NH_3-N) were done by the Kjeldahl method [Association of Official Analytical Chemists (1995), method 954.01]. The acid detergent fiber component was analyzed by refluxing [Association of Official Analytical Chemists (1995), method 973.18] and the neutral detergent fiber component was measured according to the procedures of Van Soest et al. (1991) with heat-stable α-amylase and without sodium sulfite. Gross energy of wet silage, wet feces, and wet urine was measured with an adiabatic bomb calorimeter (model 1241; Parr Instrument Co., Moline, IL). Starch in dietary ingredients (kit 207 748; Boehringer Mannheim, Xygen Diagnostics, Burgersville, ON) and plasma urea concentration [Stanbio Enzymatic Urea Nitrogen (PUN) procedure no. 2050, Stanbio Laboratory, TX] were analyzed by colorimetric methods. Ash content was determined by burning samples in an electric muffle furnace at 550°C for 24 h. For AA concentration, 200 μL of norleucine (0.5 M) were added to 1 mL of plasma and the mixture was deproteinized with 25 mg sulfosalisylic acid for 1 h at 4°C. The mixture was centrifuged at 25 000 × g for 15 min at 4°C and then the supernatant was analyzed by ion-exchange chromatography with ninhydrin as the colorimetric reagent (LKB 4400 Amino Acid Analyzer, LKB Biochrom Ltd., Cambridge, UK). Purine derivatives in urine were analyzed by HPLC (Balcells et al. 1992) and bacterial nitrogen entering the duodenum was estimated using the calculation as described by Chen and Gomez (1992).

Statistical Analyses

Data measured daily were averaged by week and analyzed using the mixed linear model (SAS Institute, Inc. 2000) according to a randomized complete block design with treatments and time as fixed factors, and block (pen) as random factor. For body condition score, plasma urea and AA concentrations, various variance-covariance matrices were attempted to perform the repeated measure analysis, and the one that produced the lowest Akaike Information Criterion value was used in the final analysis for each variable.

Coefficients of digestibility and data from nitrogen balance were tested using the 4 × 4 Latin square design with the mixed linear model with experimental period and treatment as fixed factors, and animal as a random factor.

RESULTS AND DISCUSSION

Concentration of CP and fiber in the grass silage indicated that the forage was harvested at an early stage of maturity (Table 1). The observed concentration of VFA and ammonia-N in the silage suggested adequate fermentation had occurred (Demarquilly 1990). More than 82% of particles in cracked corn were between 2 and 8 mm whereas 96% of particles in ground corn were smaller than 2 mm, of which 60% were smaller than 0.8 mm. There were no differences in chemical composition between the two sources of corn, except for the soluble protein content which was slightly lower for the ground corn and this fraction contained less non-protein nitrogen (NPN). As compared with SS, SP contained similar N, but was lower in soluble N and NPN; N bound to fiber increased. Steers ingested on average between 4.3 and 5.2 kg of silage per day resulting in CP intakes differing by less than 300 g d^{-1}. Intakes of NE_m and NE_g were similar between treatments as estimated according to National Research Council (1996; Table 2).

As compared with steers fed cracked corn, final shrunk body weight (BW) was higher ($P < 0.05$) and total DMI tended to be higher ($P = 0.09$) for steers

Table 1. Chemical composition of the feeds

	Grass silage[z]	Cracked corn	Ground corn	Solvent extracted soybean meal	Lignosulfonate-treated soybean meal (Soypass®)
DM (g kg^{-1})	23.5	88.8	87.1	88.7	90.9
N $\times$6.25 (% DM)	15.1	8.7	9.5	50.8	48.6
ADF (% DM)	30.7	3.0	3.5	6.3	8.6
NDF (%DM)	42.7	11.6	11.5	7.6	24.7
ADF-N (% DM)	0.10	0.02	0.03	0.3	0.4
NDF-N (% DM)	0.33	0.11	0.13	0.6	2.3
Starch (% DM)	0.23	62.0	61.9	4.9	3.8
ADL (% DM)	4.5	–	–	–	–
Ash (% DM)	8.5	1.5	1.4	6.3	6.5
Soluble protein (% CP)	50.5	27.1	23.6	22.1	4.5
NPN (% soluble protein)	94.5	27.4	11.8	37.8	5.1

[z]Grass silage had (% DM basis); 0.14% ammonia-N, 8.10% D-L-Lactic acid, 8.7% acetic acid, 0.01% propionic acid and 0.12% butyric acid. Silage pH was 3.9.

supplemented with ground corn resulting in similar total DMI between corn sources when expressed as a g per kg of metabolic body weight (Table 3). In an experiment where steers were fed 1:1 ground alfalfa hay and ground or cracked corn, Embry et al. (1966) reported no effect of corn particle size on BW and intake. An increase of starch digested in the rumen, often observed after reduction of particle size (Nocek and Tamminga 1991), may cause a decline in DMI (Huntington 1997). However, this was not observed in the present study when GC was compared with CC. Forage:corn ratio combined with the mode of distribution may have limited overconsumption of rapidly fermentable starch thus reducing the negative effect on total DMI.

As compared with steers receiving SS, animals supplemented with SP tended to have higher BW ($P = 0.07$) and this can be partly explained by a tendency of higher intake ($P < 0.10$), expressed as kg per d or g per kg of metabolic body weight (Table 3). As compared with unsupplemented grass silage, Huhtanen (1998) observed an increase in DMI with no improvement in diet organic matter digestibility of grass silage supplemented with rapeseed meal, suggesting that post-ruminal mechanisms were involved in regulation of silage DMI.

Average daily gain tended to be higher ($P = 0.06$) for steers fed GC vs. CC source. When intake was not negatively affected by reduction of grain particle size, positive effects of particle size reduction have been observed on ADG (Embry et al. 1966). This could be partly explained by a greater use of dietary starch and energy (Wilkerson et al. 1997). The estimations of the net energy of maintenance and gain of the GC diet were numerically higher than that of the CC diet; however, these differences were not statistically different. Body condition score was similar at the beginning of the experiment but tended to be higher ($P = 0.06$) at day 70 for animals fed GC vs. those fed CC (Table 3). However at day 140, body condition score tended to be higher ($P < 0.09$) for animals fed SP as compared with steers fed SS. These observations suggest that more fat deposition occurred between days 0 and 70 for animals fed GC than for those fed CC, then afterwards, although animals fed GC had a reduction in their body condition score, the animals fed CCSS were unable to compensate, while those fed CCSP showed a stable body condition score between day 70 and 140.

On average, 2.03% kg DMI kg BW^{-1} was offered during the feces and urine collection period. This level of intake represented 84% of DMI of steers kept in pens. There was an interaction ($P < 0.01$) between supplement sources for the apparent digestibility of starch (Table 4). For steers fed CC the substitution of SP for SS

Table 2. Feed ingredients intake and chemicals composition of diets

	Treatment[z]			
	CCSS	CCSP	GCSS	GCSP
DM intake (kg d^{-1})				
Grass silage	4.32	4.59	4.59	5.22
Corn grain source	3.5	3.5	3.5	3.5
Soybean meal source	0.45	0.45	0.45	0.45
Mineral[y]	0.077	0.077	0.077	0.077
Composition				
DM (%)	36.2	36.2	35.6	34.4
N $\times$6.25 (% DM)	14.3	14.3	14.8	14.7
Degradable N (% of total N)[x]	74.2	67.8	73.6	67.6
NE (Mcal kg^{-1})[w]				
Maintenance	1.94	1.91	1.95	1.90
Gain	1.11	1.09	1.12	1.08

[z]CCSS = supplement of cracked corn and solvent extracted soybean meal, CCSP = supplement of cracked corn and lignosulfonate-treated soybean meal, GCSS = supplement of ground corn and solvent extracted soybean meal, GCSP = supplement of ground corn and lignosulfonate-treated soybean meal.
[y]Mineral = 64.9% trace mineralized salt, 13% mono-dicalcium phosphate, 19.5% premix selenium 200, and 2.6% Bovatec.
[x]Degradable N estimated from National Research Council (1996). The rumen undegradable protein for the SS and SP were estimated at 35 and 72% of total protein (National Research Council 2001).
[w]Estimated based on National Research Council (1996) Level 2.

Table 3. Performance of steers fed grass silage supplemented with different sources of corn and soybean meal

	Treatment[z]					Probability		
Item	CCSS	CCSP	GCSS	GCSP	SEM	Corn source	Soybean meal source	Corn X Soybean meal
Initial body weight (kg)[y]	248	252	249	251	11.2	0.98	0.15	0.87
Final body weight (kg)[y]	431	440	442	451	12.0	0.04	0.08	0.99
Intake (kg d^{-1})	8.3	8.5	8.5	9.2	0.27	0.09	0.09	0.47
Intake (g kg body weight$^{-0.75}$)	104.9	108.4	106.8	113.9	3.02	0.22	0.09	0.56
ADG (kg d^{-1})	1.31	1.36	1.39	1.45	0.05	0.06	0.22	0.92
Feed to gain ratio (kg of DMI kg of gain^{-1})	6.32	6.31	6.16	6.40	0.18	0.82	0.46	0.43
Body condition score[x]								
Day 0	2.55	2.66	2.55	2.60	0.06	0.64	0.20	0.64
Day 70	3.15	3.25	3.35	3.34	0.08	0.06	0.55	0.49
Day 140	3.00	3.21	3.20	3.21	0.06	0.11	0.09	0.11
Dietary net energy (Mcal kg^{-1})[w]								
Maintenance	1.83	1.83	1.87	1.82	0.03	0.74	0.38	0.48
Gain	1.20	1.19	1.23	1.18	0.04	0.74	0.38	0.48
Observed/expected dietary net energy (Mcal kg^{-1})								
Maintenance	0.95	0.96	0.96	0.96	0.02	0.74	0.80	0.67
Gain	1.08	1.09	1.10	1.09	0.03	0.74	0.82	0.74
Estimated urinary N loss (g d^{-1})[v]	56	57	61	60	3	0.10	0.84	0.68

[z]CCSS = supplement of cracked corn and solvent extracted soybean meal, CCSP = supplement of cracked corn and lignosulfonate-treated soybean meal, GCSS = supplement of ground corn and solvent extracted soybean meal, GCSP = supplement of ground corn and lignosulfonate-treated soybean meal.
[y]Body weight reduced 4% to account for fill.
[x]Body condition score was assessed using a six-point scale (from 0 = emaciated to 5 = obese; Lowman et al. 1973).
[w]Calculated as described by Zinn and Shen (1998).
[v]Calculated as described by Kohn et al. (2005; Urinary N = renal clearance rate × final blood urea N/final body weight).

decreased starch digestibility from 90.2 to 85.9%, while, for steers fed GC, there was no change related to protein sources, resulting in an average value of 92.5%. Theurer et al. (1999) reported that ruminal starch digestibility was highly correlated with total tract starch digestibility. Thus, this suggests a negative effect on ruminal starch degradability when removing ruminal N provided by the SS supplement, although the basal diet was providing substantial soluble N from silage. In contrast, higher total tract digestibility of total non-structural carbohydrate was observed when dietary undegradable CP was increased (Bruckental et al. 2002) or following abomasal infusion of casein (Richards et al. 2002).

Apparent digestibility of NDF tended to be lower ($P = 0.07$) and was numerically lower for ADF for GC than for CC supplemented diets (Table 4). Overton et al. (1995) suggested that differences in fiber digestibility in the total tract are similar to differences found in ruminal fiber digestibility. This result agrees with the observation made by Firkins et al. (2001), who reported that increasing the digestibility of the grain by grinding decreased ruminal NDF digestibility.

There was no effect of treatment on apparent digestibility of N, but there was an interaction ($P < 0.05$; Table 4) between treatments for N retained. Although it is recognized that balance studies may overestimate N retention, results showed that for steers fed CC, the substitution of SP for SS increased N retention, while a small decrease was observed for animals fed GC. This beneficial effect of SP with CC diet is in agreement with ADG observed for steers during the growth experiment although steers fed CCSP ingested 200 g DM more as compared with those fed CCSS. Estimates of MP calculated from National Research Council (1996) indicated that MP originating from bacteria was slightly higher for CCSP and CCSS (647 and 636 g d^{-1} for CCSP and CCSS, respectively) and MP from UIP was 74 g d^{-1} more for steers fed CCSP (327 vs. 253 g d^{-1}, for CCSP and CCSS, respectively). Using the model developed by Kohn et al. (2005) to evaluate urinary N loss from renal clearance, blood urea N and BW, our results at the end of the growing phase indicated that there were a tendency ($P < 0.10$) for steers fed GC to lose more urinary N than those fed CC (Table 3). When N loss was expressed as percent of N intake, an interaction ($P < 0.03$) between corn and protein sources was observed (74.5, 70.8, 69.8 and 71.3 SEM = 2.3 for CCSS, CCSP, GCSS, and GCSP, respectively) indicating that the diet that minimized N loss was GCSS; on the other hand, the diet maximizing N loss was CCSS.

Using urinary purine derivatives to estimate bacterial-N flux at the duodenum indicated that steers fed SP tended to have higher ($P = 0.09$) flows as compared with steers fed SS (78 and 71 g N d^{-1} SEM = 5 for SP and SS, respectively). None of the measurements examined during the balance experiment could explain this observation. However, a meta-analysis presenting the impacts of dietary RUP on microbial N reaching the duodenum indicated an increased outflow of microbial N with heated or extruded soybean meal as compared

Table 4. Apparent total tract nutrient digestibility and nitrogen (N) balance of steers fed grass silage supplemented with different sources of corn and soybean meal

	Treatment[z]					Probability		
Item	CCSS	CCSP	GCSS	GCSP	SEM	Corn source	Soybean meal source	Corn × soybean meal
DM (%)	71.3	71.9	73.3	71.9	1.2	0.12	0.48	0.10
Starch (%)	90.2	85.9	92.6	92.3	1.2	<0.001	0.01	0.01
N (%)	60.0	62.4	64.0	62.4	1.6	0.20	0.77	0.20
ADF (%)	67.2	68.3	66.3	64.8	2.3	0.33	0.92	0.55
NDF (%)	66.2	68.7	65.4	63.1	1.5	0.07	0.93	0.14
N intake ($g\ d^{-1}$)	143	146	148	143	5.0	0.78	0.82	0.36
Feces ($g\ d^{-1}$)	57	55	54	55	2.9	0.37	0.86	0.43
Urine ($g\ d^{-1}$)	50	49	50	47	4.4	0.82	0.47	0.77
N retained ($g\ d^{-1}$)	36	42	44	41	2.8	0.06	0.35	0.03
Total purine derivatives ($mmol\ d^{-1}$)	113	120	110	121	6	0.85	0.08	0.62
Allantoin ($mmol\ d^{-1}$)	89	92	86	96	5	0.86	0.15	0.35
Uric acid ($mmol\ d^{-1}$)	24	28	24	24	3	0.33	0.32	0.31
Duodenal microbial N (g of N d^{-1})	72	78	69	79	5	0.83	0.09	0.64

[z]CCSS = supplement of cracked corn and solvent extracted soybean meal, CCSP = supplement of cracked corn and lignosulfonate-treated soybean meal, GCSS = supplement of ground corn and solvent extracted soybean meal, GCSP = supplement of ground corn and lignosulfonate-treated soybean meal.

with solvent-extracted soybean meal, while corn gluten meal, fishmeal or animal meal sources decreased microbial N (Ipharraguerre and Clark 2005). Still, results presented in the present study should be taken with caution given that feedstuffs containing high RUP may interfere with the purine derivatives method (Vicente et al. 2004).

An interaction ($P < 0.05$) between treatments was observed for the average value of plasma urea-N concentration (Table 5); steers receiving GCSS and GCSP having, respectively, the highest and lowest concentration of plasma urea-N as compared with CCSS and CCSP. There was, however, no interaction ($P > 0.10$) observed between day × treatment indicating a similar decrease of plasma urea-N concentration during the experimental period. Metabolizable protein intake was similar between diets given that the highest difference was only 190 g d^{-1} (889 to 1082 g d^{-1}; National Research Council 1996). Similarly, in lactating dairy cows, Blouin et al. (2002) observed no difference in plasma urea-N concentration with an intake difference of 275 g per d of MP (1654 and 1930 g d^{-1} of MP). This

Table 5. Plasma urea-N (mg 100 mL^{-1}) and amino acid (μM) concentration on day 0 and 140 of steers fed grass silage supplemented with different sources of corn and soybean meal

	Treatment[z]									Probability[y]		
	CCSS		CCSP		GCSS		GCSP		SEM	Corn source	Soybean meal source	Corn × soybean meal
Item	d 0	d 140	d 0	d 140	d 0	d 140	d 0	d 140				
Urea-N	14.45	9.96	14.49	10.16	15.98	10.65	13.56	10.20	0.54	0.38	0.09	0.05
Total AA	2180	1781	2199	1862	2154	1792	2388	1783	14	0.76	0.30	0.68
Essential AA	723	748	743	860	773	793	842	790	54	0.32	0.12	0.60
Non-essential AA	1446	1006	1457	1034	1374	990.0	1549	1004	89	0.90	0.27	0.46
Branched-chain AA	388	455	389	502	392	470	446	452	22	0.68	0.15	0.79
Leucine	116.9	162.6	115.4	170.4	115.4	164.2	131.0	148.1	7.0	0.73	0.76	0.72
Valine	192.3	206.8	193.4	231.7	195.4	220.1	226.0	215.8	11.8	0.27	0.09	0.99
Isoleucine	78.7	86.1	80.1	100.0	81.7	85.6	88.8	85.7	6.3	0.86	0.19	0.64
Arginine	85.3	65.4	98.7	85.9	81.8	66.4	112.5	86.7	16.2	0.77	0.05	0.68
Histidine	47.1	46.8	51.0	54.9	66.2	52.1	58.6	67.3	11.8	0.15	0.51	0.89
Lysine	98.8	88.2	96.4	119.7	103.5	114.2	106.6	98.8	15.2	0.61	0.67	0.29
Methionine	11.5	11.3	11.8	14.5	9.6	11.8	13.4	8.9	2.1	0.29	0.41	0.63

[z]CCSS = supplement of cracked corn and solvent extracted soybean meal, CCSP = supplement of cracked corn and lignosulfonate-treated soybean meal, GCSS = supplement of ground corn and solvent extracted soybean meal, GCSP = supplement of ground corn and lignosulfonate-treated soybean meal.
[y]Time effect ($P < 0.05$) was observed for the concentration of urea-N, total AA, non essential AA, branched-chain AA, leucine, valine, arginine, and

contrasts with results presented with steers fed rations formulated from low to moderate MP (i.e., 369 to 561 g d^{-1}; Huntington et al. 2001).

Plasma concentration of total AA decreased ($P<0.01$) from day 0 to day 140. This was mainly caused by the decline in non-essential AA ($P<0.01$). This may be associated with rapid growth due to tissue uptake of AA (Oltjen and Putnam 1966). The plasma concentration of branched-chain AA increased during the experiment ($P<0.01$). This resulted from an increased concentration of leucine, valine and isoleucine ($P<0.01$, $P<0.08$, and $P<0.04$, respectively). There was an interaction ($P=0.04$) between treatment and sampling day for branched-chain AA and leucine indicating that steers fed SS had a higher increase as compared with those fed SP. In steers fed purified diets supplemented with urea as compared with isolated soy protein, a limited amount of volatile fatty acids were produced in the rumen explaining a decline in plasma concentration of branched-chain AA (Oltjen and Putnam 1966). Between day 0 and day 140, plasma concentration of arginine tended to decrease. Plasma concentration of arginine was higher ($P<0.05$) in steers fed SP than those fed SS. This can be associated with the increase in plasma leucine concentration (Delaney et al. 2001). There was no effect of treatment, time or treatment × time interaction on plasma concentration of histidine, lysine, and methionine.

CONCLUSIONS

Supplementing ground corn to growing steers fed grass silage diet had a positive effect on average daily gain when compared with cracked corn. There was no beneficial effect of substituting lignosulfonate soybean meal for solvent-extracted soybean meal on animal performance. No interaction was observed between treatments on intake, ADG or feed to gain ratio measured during the growing phase of steers. During the digestion experiment, a slight advantage was observed when lignosulfonate soybean meal was fed in combination with ground corn on nitrogen retention.

ACKNOWLEDGEMENTS

The authors thank G. Roy for help in the project management. The authors acknowledge the valuable technical assistance of M. Pelletier, M. Mercier and S. Provencher and M. Portelance and his barn staff for assistance in the care of the animals. We are grateful to the *Fédération des Producteurs de Bovins du Québec*, Agriculture and Agri-Food Canada, and the *Département des Sciences Animales de l'Université Laval* for the financial support.

Association of Official Analytical Chemists. 1995. Official methods of analysis of the AOAC International, 16th ed. AOAC, Washington, DC.

Balcells, J., Guada, J. A., Peiro, J. M. and Parker, D. S. 1992. Simultaneous determination of allantoin and oxypurines in biological fluids by high-performance liquid chromatography. J. Chromatogr. **575**: 153–157.

Bateman, H. G., Clark, J. H. and Murphy, M. R. 2005. Development of a system to predict feed protein flow to the small intestine of cattle. J. Dairy Sci. **88**: 282–295.

Blouin, J. P., Bernier, J. F., Reynolds, C. K., Lobley, G. E., Dubreuil, P. and Lapierre, H. 2002. Effect of supply of metabolizable protein on splanchnic fluxes of nutrients and hormones in lactating dairy cows. J. Dairy Sci. **85**: 2618–2630.

Bruckental, I., Abramson, S., Zamwell, S., Adin, G. and Arieli, A. 2002. Effect of dietary undegradable crude protein level on total nonstructural carbohydrate (TNC) digestibility and milk yield and composition of dairy cows. Livest. Prod. Sci. **76**: 71–79.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. Volume 1. E. D. Olfert, B. M. Cross, and A. A. McWilliam, eds. CCAC, Ottawa, ON.

Chen, X. B. and M. Gomez, M. J. 1992. Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives — an overview of the technical details. International feed resources unit, RRI, Aberdeen, Occasional Publication.

Delaney, S. J., Hill, A. S., Backus, R. C., Czarnecki-Maulden, G. L. and Rogers, Q. R. 2001. Dietary crude protein concentration does not affect the leucine requirement of growing dogs. J. Anim. Physiol. a. Anim. Nutr. **85**: 88–100.

Demarquilly, C. 1990. Utilisation des conservateurs: quand et pourquoi les utiliser. Résultats zootechniques obtenus avec des ensilages d'herbe préparés avec des conservateurs efficaces. Symposium International sur l'ensilage d'herbe, Conseil de Recherche en Agro-Alimentaire de l'Abitibi-Temiscamingue, Rouyn-Noranda, QC. pp. 93–104.

Embry, L. B., Goodrich, R. D. and Gastler, G. F. 1966. Ground and rolled corn grain in beef cattle rations. Animal Science Department, Agricultural Experiment Station, South Dakota State University. Bulletin 538. 11 pp.

Firkins, J. L., Hristov, A. N., Hall, M. B., Varga, G. A. and St-Pierre, N. R. 2006. Integration of ruminal metabolism in dairy cattle. J. Dairy Sci. **89**: E31–E51.

Firkins, J. L., Eastridge, M. L., St-Pierre, N. R. and Noftsger, S. M. 2001. Effects of grain variability and processing on starch utilization by lactating dairy cattle. J. Anim. Sci. **79**(E. Suppl.): E218–E238.

Galyean, M. L., Wagner, D. G. and Owens, F. N. 1979. Corn particle size and site and extent of digestion by steers. J. Anim. Sci. **49**: 204–210.

Gawehn, K. and Bergmeyer, H. U. 1974. D-(−)-Lactate. Page 1492–1495 *in* Methods of enzymatic analysis. Vol. 3. 2nd English ed. H. U. Bergmeyer, ed. Academic Press, Inc., New York, NY.

Gutmann, I. and Wahlefeld, A. W. 1974. L-(+)-lactate: determination with lactate dehydrogenase and NAD. *in* Methods of enzymatic analysis. 2nd English ed. Vol. 3. H. U. Bergmeyer, ed. Academic Press, Inc., New York, NY. pp. 1464–1468.

Huhtanen, P. 1998. Supply of nutrients and productive responses in dairy cows given diets based on restrictively fermented silage. Agric. Food Sci. Finl. **7**: 219–250.

Huntington, G., Poore, M., Hopkins, B. and Spears, J. 2001. Effect of ruminal protein degradability on growth and N metabolism in growing beef steers. J. Anim. Sci. **79**: 533–541.

Huntington, G. B. 1997. Starch utilization by ruminants: from basics to the bunk. J. Anim. Sci. **75**: 852–867.

Ipharraguerre, I. R. and Clark, J. H. 2005. Impacts of the source and amount of crude protein on the intestinal supply of nitrogen fractions and performance of dairy cows. J. Dairy Sci. **88** (E. Suppl.): E22–E37.

Keane, M. G. 2005. Comparison of sugar-beet pulp and barley with and without soya bean meal as supplements to silage for growing steers. Ir. J. Agric. Food Res. **44:** 15–26.

Kohn, R. A., Dinneen, M. M. and Russek-Cohen, E. 2005. Using blood urea nitrogen to predict nitrogen excretion and efficiency of nitrogen utilization in cattle, sheep, goats, horses, pigs, and rats. J. Anim. Sci. **83**: 879–889.

Lowman, B. G., Scott, N. and Somerville, S. 1973. Condition scoring of cattle. Bulletin no. 6. East of Scotland College of Agriculture, Edinburgh, UK.

National Research Council 2001. Nutrient requirements of dairy cattle. 7th rev. ed. National Academy Press, Washington, DC.

National Research Council 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.

Nocek, J. E. and Tamminga, S. 1991. Site of digestion of starch in the gastrointestinal tract of dairy cows and its effect on milk yield and composition. J. Dairy Sci. **74**: 3598–3629.

Oltjen, R. R. and Putnam, P. A. 1966. Plasma amino acids and nitrogen retention by steers fed purified diets containing urea or isolated soy protein. J. Nutr. **89**: 385–391.

Overton, T. R., Cameron, M. R., Elliott, J. P., Clark, J. H. and Nelson, D. R. 1995. Ruminal fermentation and passage of nutrients to the duodenum of lactating cows fed mixtures of corn and barley. J. Dairy Sci. **78**: 1981–1998.

Playne, M. J. and McDonald, P. 1966. The buffering constituents of herbage and silage. J. Sci. Food Agric. **17**: 264–268.

Richards, C. J., Branco, A. F., Bohnert, D. W., Huntington, G. B., Macari, M. and Harmon, D. L. 2002. Intestinal starch disappearance increased in steers abomasally infused with starch and protein. J. Anim. Sci. **80**: 3361–3368.

SAS Institute, Inc. 2000. SAS statistical analysis system. Release 8.02. 2000. SAS Institute, Inc., Cary, NC.

Schroeder G. F. and Titgemeyer, E. C. 2008. Interaction between protein and energy supply on protein utilization in growing cattle: A review. Livest. Sci. **114**: 1–10.

Siddons, R. C., Evans, R. T. and Beever, D. E. 1979. The effect of formaldehyde treatment before ensiling on the digestion of wilted grass silage by sheep. Br. J. Nutr. **42**: 535–545.

Taniguchi, K., Huntington, G. B. and Glenn, B. P. 1995. Net nutrient flux by visceral tissues of beef steers given abomasal and ruminal infusion of casein and starch. J. Anim. Sci. **73**: 236–249.

Theurer, C. B., Huber, J. T., Delgado-Elorduy A. and Wanderley, R. 1999. Invited review: Summary of steam-flaking corn or sorghum grain for lactating dairy cows. J. Dairy Sci. **82**: 1950–1959.

Van Soest, P. J., Robertson, J. B. and Lewis, B. A. 1991. Symposium: Carbohydrate methodology, metabolism and nutritional implications in dairy cattle. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. **74**: 3583–3597.

Veira, D. M., Butler, G., Proulx, J. G. and Poste, L. M. 1994. Utilization of grass silage by cattle: Effect of supplementation with different sources and amounts of protein. J. Anim. Sci. **72**: 1403–1408.

Vicente, F., Guada, J. A., Surra, J., Balcells, J. and Castrillo, C. 2004. Microbial contribution to duodenal purine flow in fattening cattle given concentrate diets, estimated by purine N labelling (^{15}N) of different microbial fractions. Anim. Sci. **78**: 159–167.

Wilkerson, V. A., Gleen, B. P. and McLeod, K. R. 1997. Energy and nitrogen balance in lactating cows fed diets containing dry or high moisture corn in either rolled or ground form. J. Dairy Sci. **80**: 2487–2496.

Zinn, R. A. and Shen, Y. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves J. Anim. Sci. **76**: 1280–1289.