Effect of Starch Type on Optimizing Amino Acids in Diets of Dairy Cows

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Introduction

"Starch makes milk" is an often heard statement from field nutritionists. This makes sense because starch (and sugar) feeding increases propionate production, propionate is the primary glucogenic volatile fatty acid, glucose is used by the mammary gland to produce lactose, and lactose is the principal determinant of milk yield. As a dense source of readily fermentable organic matter, starch is also an important energy source for rumen microbial growth and synthesis of microbial protein. Rumen microbial protein is a preferred source of absorbed AA, and both research and field experience indicate that maximizing its supply requires mixing and matching feedstuffs to achieve an optimal balance of fermentable carbohydrates (starch, sugars, pectins and digestible fiber), effective fiber, and rumen degradable protein (RDP). Fermentable carbohydrates provide the energy and RDP provides the ammonia and AA that are required for microbial growth and protein synthesis. When starch is digested in the small intestine, it's a source of absorbed glucose. Absorbed glucose also provides benefits, including sparing the use of absorbed AA for glucose synthesis. In this case, AA are conserved for milk protein synthesis.

Less appreciated is the effect that starch can have on optimizing AA usage for milk protein production. The purpose of this paper is to review experiments that examined the effect of providing different amounts and types of starch on the AA status of lactating cows and to examine the use of two commonly used nutritional models to determine the potential impact of feeding different types of starch on optimizing AA nutrition and cow performance.

Effect of starch amount on the AA status of lactating dairy cows

In a classic study, Broderick (2003) fed three levels of NFC (37, 41 and 46% of diet DM) and three levels of CP (15.1, 16.7 and 18.4%) to mid-lactation cows. Cows were blocked by parity and days in milk into seven groups of nine and assigned to an incomplete 9 x 9 Latin square trail with four, 4-wk periods. Diets were formulated from alfalfa and corn silages, high moisture corn, soybean meal, minerals and vitamins. Forage was 60% alfalfa and 40% corn silage on all diets; NFC contents of 37, 41 and 46% were obtained by feeding 75, 63 and 50% forage, respectively. Dietary CP contents of 15.1, 16.7 and 18.4% were obtained by replacing high-moisture corn with soybean meal. Effects of NFC were not confounded by CP. Increasing NFC resulted in linear increases in BW gain, yield of milk and milk components (except fat), milk protein percentage, milk/DM intake and milk N/N intake ratios, and linear decreases in milk fat percentage, milk urea and urinary N excretion. In contrast, increasing CP from 15.1 to 18.4% had only small positive effects on milk and milk protein yield but reduced milk N from 31 to 25% of dietary N and increased urinary N from 23 to 35% of dietary N.

Fanchone et al. (2013) examined the effects of 2 levels of dietary CP (11.0 and 14.3%) and 2 levels of starch (15.2 and 30.7%) on N partitioning, ruminal N metabolism, and digestion. Four Holstein cows, fitted with ruminal, duodenal and ileal cannula, were used in a 4 x 4 Latin square design. The cows were 71 $\pm$ 10 DIM at the start of the experiment. The 2 dietary levels of CP and starch were obtained by maintaining the same amounts of corn silage (40.5%), hay (10.0%) and dehydrated alfalfa (9.0%) in all diets but varying the amounts of molasses-supplemented chopped wheat straw, cereal-based concentrate (39% barley, 46% wheat, and 15% corn), soybean hulls, beet pulp, soybean meal, and urea. High starch feeding decreased rumen ammonia concentrations, tended to decrease rumen pH but only with the low CP diet (6.4 vs. 6.6), increased duodenal non-ammonia N flows, tended to increase microbial N flows to the duodenum (average increase was 55 g), decreased rumen protein balance (from an average of +7.2 to – 13.4 g CP/kg DM intake), and tended to increase efficiency of microbial protein synthesis (from 22.3 to 27.1 g N/kg OM fermented). The negative rumen protein balance indicates increased N recycling from the blood. As expected, additional starch feeding tended to increase passage of all AA to the small intestine. Milk protein concentrations were also increased with high starch (from 2.83 to 3.04%) and milk N/feed N tended to be higher (0.28 vs. 0.26). As usually observed, feeding more CP had no effect on milk protein content. The authors concluded that the high-starch diets resulted in better recycling of N and better use of rumen ammonia.

Cabrita et al. (2007) also examined the effects of 2 levels of dietary CP (14 and 16%) and 2 levels of starch (15 and 25%). Twelve Holstein cows averaging 77 DIM and 39 kg/d of milk at the start of the experiment were used. Cows were assigned to three Latin squares. Diets contained 45% corn silage, 5% chopped wheat straw and 50% concentrate. The different dietary CP and starch levels were achieved mainly by increasing soybean meal in the high-CP diets and by substituting corn grain for citrus pulp in the high-starch diets. Significant CP x starch treatment interactions resulted for DM intake, milk yield, milk protein percentage and lactose yield with the low-CP low-starch diet having the lowest reported values. The authors concluded this was probably due to a shortage of both RDP to rumen microbes and glucogenic nutrients (propionate, AA, and absorbed glucose) to the animal. The high starch diets decreased plasma urea and increased plasma glucose, insulin and total protein concentrations.

Cantalapiedra-Hijar et al. (2014) sought to determine if the increase in milk protein associated with diets rich in starch is at least partially due to changes in splanchnic (portal-drained viscera and liver) AA metabolism and if these changes depended upon dietary CP content. Four isoenergetic diets were formulated that differed in CP (12.0 and 16.5%) and starch (4.4 and 34.5%) content. Differences in CP and starch content were obtained by varying the proportional contributions of most dietary feedstuffs (grass silage, grass hay, dehydrated corn plant pellets, corn, barley, wheat, wheat bran, soybean hulls, citrus pulp, beet pulp, tannin-treated soybean meal and urea). Five mid-lactation multi-catheterized Jersey cows were used in a 4 x 4 Latin square design. Increased starch feeding: 1) increased milk protein yield (+7%), 2) increased milk N/N intake (0.322 vs. 0.298), 3) lowered net portal appearance (i.e., less available to tissues other than splanchnic tissues) of acetate, total VFA and B-hydroxybutyrate and increased net portal appearance of oxygen, glucose, butyrate, and insulin, and 4) increased the percentage of N intake that was recovered as total AA in the portal vein (51.4 vs. 42.3%) but without greater recovery of the main AA used as energy fuels by the portal drained viscera (Glu, Gln, and Asp). While more total AA appeared in the portal vein, there were no observed differences in hepatic use, resulting in a 22% higher splanchnic release. Thus, the authors concluded that the higher transfer of N from feed to milk with diets rich in starch is not the consequence of a direct sparing AA effect of glucogenic diets but rather the result of lower energy requirements by the portal drained viscera along with a higher microbial N flow to the duodenum.

These and several other experiments indicate that feeding more starch increases microbial protein synthesis and increases the efficiency of use of dietary N. Therefore, as long as RDP is adequate, milk protein yield will continue to increase until production is suppressed by adverse ruminal effects of excessive NFC intake (Oliveira et al., 1993). It has been concluded that increasing the proportion of starch in the diet, while reducing the proportion of NDF, can lead to improvements in N utilization as great as that achieved by reducing CP to below 15% of diet DM (Sinclair et al., 2014).

Effect of starch type on the AA status of lactating dairy cows

Starch type affects the site, rate and extent of its digestion. While the bonds between the glucose units are readily cleaved by bacterial and mammalian enzymes, the starch is packaged in granules that are embedded in a protein matrix in the seed endosperm, which varies in solubility and resistance to digestion (Kotarski et al., 1992; McAllister et al., 1993). These differences in endosperm type have great effects on rumen starch fermentability, which varies from less than 30% to more than 90% - depending on the type and physical form of the grain (Nocek and Tamminga, 1991; Firkins et al., 2001). With respect to corn, the hard-textured corn hybrids (having the most highly vitreous endosperm) are the least digestible in the rumen whereas those with a floury more “open” endosperm are the most digestible (Correa et al., 2002; Ngonyamo-Majee et al., 2008; Taylor and Allen, 2005).

In addition to endosperm type, ruminal fermentability of starch is also affected by grain processing (e.g., rolling, grinding, and steam-flaking), conservation method (dry or ensiled), ration composition, and the physiological status of the cow. Reducing the mean particle size of corn grain increases starch digestibility (Firkins et al., 2001) by increasing the surface area for bacterial attachment or enzymatic degradation (Huntington, 1997). Ensiling high-moisture corn (Hoffman et al., 2011) or steam treatment of dry corn (Rooney and Pflugfelder, 1986), breaks down the hydrophobic starch-protein matrix, allowing for a corresponding increase in starch digestibility (Owens et al., 1986; Theurer et al., 1999; Firkins et al., 2001).

Factors such as starch type, processing and conservation method, particle density, and feed intake also affects the passage rate (kp) of starch from the rumen. The longer the residence time in the rumen, the greater the extent of digestion. A summary of some experiments by Michigan State researchers where passage rates of dietary starch was measured is presented in Table 1. Rate of passage is obviously a contributing factor, along with digestion rate, in determining extent of digestion.

Based on a meta-analysis of published data, Ferraretto et al. (2013) observed that: 1) ruminal starch digestion tended to be greater ($P = 0.12$) and total tract starch digestion was greater ($P = 0.001$) for ensiled and steam-processed corn than dry rolled or ground corn, 2) milk/feed ratios were greater ($P = 0.001$) for ensiled corn than dry corn, 3) milk protein concentration was greater ($P = 0.05$) and MUN concentration tended to be lower ($P = 0.08$) for steam-processed corn than the other treatments, 4) reducing particle size of both dry and ensiled corns increased total tract starch digestion ($P = 0.001$), and 5) reducing particle size of the dried corns tended to reduce MUN concentrations ($P = 0.07$). Several researchers have observed greater microbial N flow to the small intestine for cows that were fed more digestible sources of starch (Firkins et al., 2001; Theurer et al., 1999).

Collectively, these results confirm the importance of corn processing and method of storage on rumen digestion and potential impact on ruminal protein metabolism.

Use of nutritional models to assess the impact on optimizing AA nutrition in lactating dairy cows fed different amounts and types of starch

Two dairy nutrition models common to Brazil (2001 NRC and CNCPS v6.5) were used to assess the ability of the models to predict lactation responses in an experiment (Oba and Allen, 2003a,b) that was conducted to measure the effects of dietary starch concentration (21 and 32%) and type of corn grain [high-moisture (HMC) and dry ground corn (DGC)] on productivity and ruminal digestion kinetics. This experiment was selected because of its wide range in digestible starch intakes (3.7 to 6.6 kg/d) and the detailed results on feeding behavior and digestion kinetics. The NRC (2001) evaluation of the diets was conducted with Formulate*2* Dairy Ration Optimizer (Central Valley Nutritional Associates, California, USA). Formulate2 provides 100% model accurate, fully NRC compliant diet solutions wholly within the NRC model framework.

The ingredient and nutrient composition of the diets and selected measured animal data are presented in Table 2. Some important observations include: 1) the experimental corn grains provided 70 and 36% of total dietary starch in the high and low starch diets, 2) DM intake was lower for the HMC compared to the DGC treatment in the high-starch diets (20.8 vs. 22.5 kg/d) but similar for the HMC and DGC treatments in the low-starch diets (19.7 vs. 19.6), 3) cows experienced losses in BW and body condition score (BCS) with the low-starch diets, 4) meal size was smaller for HMC compared to DGC in high-starch diets (1.9 vs. 2.3 kg) but similar for HMC and DGC in low-starch diets (2.1 vs 2.0 kg), 5) milk yield was greater when cows were fed high-starch diets compared to low-starch diets (38.6 vs 33.9 kg/d) regardless of grain treatment, 6) starch digestibility in the rumen was greater for HMC treatments compared with DGC treatments, but total tract starch digestibility was not affected because of compensatory digestion in the intestine, and 7) the difference in ruminal starch digestibility between the HMC and DGC treatments was greater for high-starch diets (71.1 vs 46.9%) compared with low-starch diets (58.5 vs. 45.9%). It might be concluded from these results that DM intake was lower for HMC than DGC when high starch was fed because of an over-supply of fermentable starch. The model evaluation results are shown in Table 3.

CNCPS Model Evaluation

Model predicted ME-allowable milk was greater than observed in the high-starch treatments (average of +1.8 kg/d) and lower than observed in the low-starch treatments (average of -5.2 kg/d). Both the direction and magnitude of these predicted differences between predicted and actual milk is consistent with the reported BW gains (average of 0.29 kg/d) and the reported BW losses (average of 0.72 kg/d) for the high-starch and low-starch diets, respectively) (Table 2).

While this would not be done in commercial practice because BW changes would not be known, the reported BW changes were entered into the model. When this was done, ME-allowable milk decreased from 40.3 to 37.5 kg/d for the high-starch HMC diet and from 40.4 to 38.2 kg/d for the high-starch DGC diet, whereas ME-allowable milk increased from 28.4 to 32.7 kg/d for the low-starch HMC diet and from 29.1 to 34.0 kg/d for the low-starch DC diet (data not shown in Table 3). As a result, predicted ME-allowable milk came closer to actual yields (37.5 vs 38.8, 38.2 vs 38.4, 34.0 vs 33.4, and 34.0 vs. 34.3 kg/d for the high-starch HMC, high-starch DGC, low-starch HMC, and low-starch DGC diets, respectively. Again, these adjustments to ME-allowable milk for changes in BW would not be commonly done because changes in BW would not be known.

Predicted MP-allowable milk was considerably greater than observed in the high-starch treatments (+2.6 and +4.0 kg/d for HMC and DGC, respectively) but close to reported values in the low-starch diets (+ 0.6 kg/d for HMC and -0.6 kg/d for DGC) (Table 3). When the reported BW changes were entered into the model, the predicted MP-allowable milk yields decreased for the high-starch diets (from +2.6 to +1.7 kg/d and from +4.0 to +3.5 kg/d for HMC and DGC, respectively) and increased for the low-starch diets (from +0.6 to +3.8 kg/d and from -0.6 +3.0 kg/d for HMC and DGC, respectively). Regardless, either way of calculating MP-allowable milk indicated that other than for the low-starch DGC diet, ration RUP was oversupplied.

High moisture corn has a higher rate of digestion than dried ground corn in the CNCPS feed dictionary (35 vs 15%/h, respectively). This resulted in the higher predicted yield for microbial MP for HMC than for DGC in both the high-starch (1131 vs 1040 g/d) and low-starch (1018 vs 964) diets (Table 3). This was most pronounced in the high-starch treatment where corn grain had higher dietary inclusion. The predicted microbial MP/starch intake ratio was higher for the HMC treatments because of the higher levels of predicted starch digestion in the rumen (Table 3). This demonstrates the behavior of the CNCPS when different types of starch are fed.

As noted in Table 2, Oba and Allen (2003b) measured slower passage rates for starch in the HMC treatments (17 and 14%/h for the high and low starch diets) than in the DGC treatments (21 and 18%/h for the high and low starch diets). The CNCPS uses different passage rates for forages, concentrates and soluble material, but does not differentiate based on other feed characteristics such as viscosity or specific gravity. Factors such as these may well have affected the passage rates in the study by Oba and Allen (2003b). Slower passage rates for the HMC diets could be expected to have further increased the extent of starch digestion and contributed to the cows producing as much milk with the high-starch HMC diet (38.8 kg/d) as they did with the high-starch DGC diet (38.4 kg/d), even though DM intake was significantly lower (20.8 vs 22.5 kg/d).

NRC (2001) (Formulate2) Model Evaluation

The default NRC processing adjustment factors (PAF) for HMC and DGC were used in the diet evaluations. Model predicted NEl-allowable milk was nearly “spot on” relative to actual milk for both high-starch diets (38.3 vs 38.8 and 38.8 vs 38.4 kg/d for HMC and DGC, respectively). However, the model under-predicted NEl-allowable milk for both of the low-starch diets (29.7 vs 33.4 and 30.4 vs 34.3 kg/d for HMC and DGC, respectively). These under-predictions of NEl-allowable milk for the low-starch diets indicates a possible BW loss, and that occurred.

Like the CNCPS model, the NRC model predicted BW gain with the high-starch diets and BW loss with the low-starch diets. Therefore, both models predicted an undersupply of fermentable carbohydrates with the low starch diets, indicating the diets needed more fermentable carbohydrates (e.g., starch) and less NDF. It is noteworthy that DM intakes were significantly lower for the two low-starch diets as compared to the high-starch DGC diet. As noted earlier, DM intake was probably lower for the high-starch HMC diet than for the high-starch DGC diet because of too much fermentable starch.

The microbial MP/starch intake ratio averaged 0.18 for the high-starch diets and 0.25 for the low-starch diets. These predicted microbial MP/starch intake ratios are similar to those predicted by the CNCPS model; 0.17 and 0.24, respectively.

Like the CNCPS model, the NRC model also predicted an oversupply of MP for all diets. These predictions are probably accurate as all diets contained 18% CP or more (Table 2). Moreover, both models predicted an over-supply of RDP. For NRC, the average over-supplies were 247 g/d for the high-starch diets and 442 g/d for the low-starch diets. Neither plasma nor milk urea N concentrations were reported, but both were probably higher than current target values.

Even though the NRC model predicted an oversupply of MP for all diets, it was of interest to evaluate the diets for MP-Met allowable milk, adjusted for differences in milk true protein, using Formulate2. It is understood that MP is merely the sum total of predicted absorbed AA, and that in its prediction of supply (or requirements), no consideration is given to AA balance; therefore, its true adequacy for meeting the needs of the most limiting AA for protein synthesis and animal production is not known.

Researchers at the University of New Hampshire, after the release of the model, observed that the model predicted true protein yield from MP more accurately than milk yield, and that true protein yield was predicted more accurately from predicted supplies of the most limiting AA (Met or Lys) than from MP (Schwab et al., 2004). These observations resulted from entering over 300 diets published in the Journal of Dairy Science into the model. The model evaluation results were then reviewed to increase the likelihood that Met or Lys were the most limiting factors to animal productivity. Measured milk and milk protein yields from the selected experiments were then regressed on model-predicted supplies of MP-Lys and MP-Met. This exercise produced normal looking dose-response plots that showed changes in milk and milk true protein yield relative to model-predicted flows of MP, MP-Lys and MP-Met; but most importantly, it yielded equations that could be used to generate MP-Lys and MP-Met requirements for stipulated yields of milk and milk protein. These equations, therefore, provide the basis for what is called the “Amino Acid Calculator” in Formulate2. Because it is the most accurate yield prediction of the model, predicted true protein yield is used to work back to a more accurate milk yield, at any given milk true protein percentage. As one might expect, because milk protein levels vary, this approach to predicting milk yield is more accurate than predicting milk yield “directly” from MP, or from MP-Met or MP-Lys.

The model-predicted Lys/Met ratio in MP of the high starch and low starch diets averaged 3.54/1 and 3.65/1, respectively. A ratio greater than 3.0/1 indicates that Met is more limiting than Lys. Therefore, model-predicted yields of MP-“Met” allowable milk were calculated. Predicted yields were 37.5, 40.4, 32.9, and 33.6 kg/d for the high-starch HMC and DGC diets and the low-starch HMC and DGC diets, respectively. The actual milk yields for the same diets were 38.8, 38.4, 33.4, and 34.3 kg/d. These MP-Met predicted milk yields are within -1.3, +2.0, -0.5, and -0.7 kg/d of actual yields and more closely align to actual yields than MP-allowable milk, indicating that MP supplies were not excessive, at least for the high-starch DGC diet and the two low-starch diets.

Field experience has shown that milk yield predictions based on MP-Met predicted true protein yield from diets that are low to mid-range in starch content generally correlate very well with actual on-farm milk yields. Because of this proven predictive reliability in the field, on those occasions where there is significant disparity between true protein predicted milk yield and actual milk yield, adjustments to the NRC predicted microbial CP yield can be made to reconcile the two and thus account for significant changes in rumen fermentation.

In summary, both models predicted the impact on milk yield and BW change of feeding high-starch vs low-starch diets to early and mid-lactation cows. Both nutritional models indicated a surplus of rumen available N for microbial cell growth and synthesis of microbial protein.

Conclusions

Increasing starch supply, either by increased feeding or by increasing rumen and intestinal digestibility of that which is fed, can be expected to increase AA availability to the mammary gland (and other peripheral tissues) because of variable increases in intestinal AA supply (because of increased microbial protein synthesis), a reduced AA need for glucose synthesis and a reduced need for AA as energy-sources for splanchnic tissues. Both ration formulation models predicted the primary directional changes in animal performance that resulted from feeding the high and low starch diets in the experiment by Oba and Allen (2003a,b).

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Table 1. Effect of dietary treatment on passage rate (kp) of starch from the rumen (Allen, 2013)

Experiment	**Treatment**	**Kp, %/h**	***P*-value**
Oba and Allen, 2000b	Bm3 corn silage	12.9	0.02
	Control corn silage	10.6	
	29% diet NDF	14.5	<0.0001
	38% diet NDF	9.0	
Oba and Allen, 2003	High-moisture corn	15.4	0.07
	Dry ground corn	19.7	
Voelker and Allen, 2003b	High-moisture corn	15.9	0.01
	24% beet pulp	23.5	
Ying and Allen, 2005	High-moisture corn	7.1	<0.0001
	Dry ground corn	16.3	
	Vitreous endosperm	16.0	<0.001
	Floury endosperm	7.5	
Taylor and Allen, 2005	Vitreous endosperm	21.2	0.10
	Floury endosperm	16.2	
Allen et al., 2008	Vitreous endosperm	25.7	<0.001
	Floury endosperm	16.0	

Note: Kp were determined by dividing duodenal flux (g/h) by rumen pool size (g) and multiplying by 100

Table 2. Ingredient and nutrient composition of diets and animal productivity (Oba and Allen, 2003b)							
	High starch		Low starch		*P* value		
Item	HMC[1]	DGC[2]	HMC	DGC	Starch[3]	Corn[4]	INT[5]
Diet ingredients, %DM							
HM	32.0	-	11.0	-			
DG	-	31.6	-	10.8			
Corn silage	20.8	20.9	31.8	32.0			
Alfalfa silage	22.2	22.3	34.0	34.1			
Protein mix	21.4	21.5	19.5	19.5			
Min and vit	3.6	3.7	3.7	3.6			
Composition, %DM							
DM	48.8	53.0	42.8	43.8			
Starch	31.1	32.2	21.0	21.3			
NDF	23.1	24.2	30.1	30.5			
ADF	15.2	15.4	20.8	20.9			
Lignin	2.2	2.2	3.3	3.3			
CP	18.0	18.0	18.3	18.3			
EE	5.2	5.5	4.8	4.9			
Forage NDF	16.5	16.5	25.3	25.4			
Grain starch, %total	69	70	35	36			
Productivity							
DM intake, kg	20.8[b]	22.5[a]	19.7[b]	19.6[b]	<0.001	0.12	0.07
Milk, kg/d	38.8	38.4	33.4	34.3	<0.001	0.78	0.45
Milk fat, %	3.05[b]	3.59[a]	3.95[a]	3.73[a]	<0.01	0.37	0.06
Milk protein, %	2.98[a]	3.02[a]	2.94[ab]	2.87[b]	<0.01	0.67	0.07
Milk lactose, %	4.93	4.93	4.83	4.87	<0.001	0.21	0.42
BW change, kg/d	0.36	0.21	-0.68	-0.80	<0.01	0.76	0.83
BCS change in 21 days	0.10	0.04	-0.09	-0.12	<0.01	0.76	0.83
Starch digestility							
Starch intake, kg/d	6.2[b]	7.0[a]	3.9[c]	4.1[c]	<0.001	<0.001	<0.01
Rumen dig, %	71	47	59	46	<0.08	<0.001	0.13
Intestinal dig, %	86	90	84	87	0.13	0.06	0.99
Total tract dig, %	96	94	93	93	<0.01	0.16	0.26
Starch digestion kinetics							
Ruminal kd, %/h	28	15	17	12	<0.001	<0.001	<0.01
Ruminal kp, %/h	17	21	14	18	0.20	0.07	0.95
Feeding behavior							
Meal size, kg	1.9[b]	2.3[a]	2.1[c]	2.0[c]	0.53	0.21	0.06
Eating time, min/d	253	260	300	287	<0.001	0.77	0.38
Chewing time, min/d	427	438	493	478	<0.001	0.87	0.31
Plasma metabolites							
Glucose, mg/dl	61.0	60.7	59.6	57.8	<0.01	0.53	0.76
Insulin, *u*IU/ml	14.8	13.6	11.1	10.3	<0.001	0.54	0.51
Ruminal pH	6.12	6.13	6.25	6.32	<0.01	0.41	0.48

[1]MM =high-moisture corn
[2]DG = dry ground corn
[3]Starch = effect of dietary starch concentration
[4]Corn = effect of conservation method of corn
[5]INT = interaction of dietary starch concentration and conservation method of corn

Table 3. Model evaluation of Oba and Allen (2003) diets				
	High starch		Low starch	
	HMC	DGC	HMC	DGC
DM intake, kg/d	20.8	22.5	19.7	19.6
CNCPS v6.5 evaluation				
Actual milk, kg/d	38.8	38.4	33.4	34.3
ME milk, kg/d	40.3	40.4	28.4	29.1
MP milk, kg/d	41.4	42.4	34.0	33.7
Microbial MP, g/d	1131	1044	1018	964
RUP MP, g/d	1378	1602	1192	1199
Total MP, g/d	2509	2646	2210	2163
Actual BW change, kg/d	+0.36	+0.21	-0.68	-0.80
Predicted BW change, kg/d	+0.22	+0.33	-0.85	-0.88
Starch digested in rumen, %	82	71	83	79
Starch kd for treatment feed, %/h	35.0	15.0	35.0	15.0
Predicted starch kp, %/h	6.95	7.42	6.37	6.34
Microbial MP:Starch intake	0.18	0.15	0.24	0.23
Microbial MP, % total MP	45	39	46	45
NRC (2001) evaluation using Formulate*2*[1]				
Actual milk, kg/d	38.8	38.4	33.4	34.3
NEl milk, kg/d	38.3	38.8	29.7	30.4
MP milk, kg/d	40.4	44.3	35.1	35.9
Microbial MP, g/d	1184	1261	1072	1073
RUP MP, g/d	1129	1287	975	976
Endogenous MP, g/d	98	107	100	93
Total MP, g/d	2411	2655	2147	2142
Actual BW change, kg/d	+0.36	+0.21	-0.68	-0.80
Predicted BW change, kg/d	+0.30	+0.05	-0.23	-0.70
Microbial MP:Starch intake	0.18	0.18	0.26	0.25
Microbial MP, % total MP	49	48	50	50
[1] The PAF of corn silage for all diets was adjusted from 0.94 to 1.00				