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Influence of Energy Supplementation on Nitrogen Kinetics in the Rumen and Urea Metabolism

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Abstract

Firstly, this paper reviewed the effects of supplementary energy supply on nitrogen utilization, nitrogen kinetics in the rumen and urea metabolism in ruminants. Improving the utilization of dietary nitrogen by increasing microbial yield is possible through energy supplementation, but the type of supplement and level of intake required differ between diets. Secondly, the effects of sucrose supplementation on rumen fermentation and nitrogen kinetics were examined in sheep fed freshly cut lucerne, lucerne chaff and hay cubes. In this experiment, the method of isotope dilution of ^{14}C-urea, ^{15}N-urea, ^{3}H-glucose and ^{15}N-ammonium salt was used for the estimation of parameters of metabolism. Supplementation with sucrose decreased the urinary N excretion, resulting in an increase in N retention. Supplementation with sucrose resulted in a lower rumen ammonia and plasma urea concentration. The fermentation of sucrose in the rumen resulted in a decrease in rumen pH and in the ratio of acetate to propionate. Sucrose supplementation increased the proportion of urea transferred to the rumen, the non-ammonia N (NAN) concentration in the rumen and the NAN flow from the rumen to the lower digestive tract. Urinary allantoin excretion rate increased with sucrose supplementation. The plasma glucose concentration did not change but the plasma insulin concentration increased with sucrose supplementation. The influence of an energy-rich supplement on the utilization of N and N kinetics in the rumen and whole body of domestic ruminants is discussed.

Discipline: Animal industry
Additional key words: nitrogen metabolism, rumen fermentation, ruminant, sucrose, urea recycling

Energy supplementation

Energy supplementation of pasture and herbage-based diets is traditionally used to boost intake for survival when food availability is very low. It can be used to maintain the live weight during short-term feed shortages. Energy supplementation can be used to improve the growth rate and animal production. Under certain conditions, energy supplementation can optimize the rumen function with the overall aim of increasing the supply of microbial amino acids to the host animal relative to VFA, in order to improve the nitrogen retention and thus production. In this paper, we analyze the effects of energy supplementation on the rumen fermentation, nitrogen kinetics in the rumen and urea metabolism in sheep and cattle fed herbage diets.

1) Factors influencing the effectiveness of energy-rich supplements

(1) Factors influencing the effectiveness of cereal grains as energy supplements

Cereal grains such as barley, maize, wheat, and oats are often used as energy supplements but it is sometimes difficult to predict the response, which varies with the type of grain used and even the cultivar. The response also varies between intact and processed grain, and is influenced by the method of processing such as rolling, grinding and steam flaking. The method of processing and level of feeding will also affect the proportion of the grain digested in the rumen versus the intestine.

(2) Factors influencing the effectiveness of soluble carbohydrates as energy supplements

Soluble carbohydrate sources such as sucrose, glucose, molasses, and sugar beet pulp can also be used effectively. Again the response will vary with the type of supplement, its solubility and the rate of fermentation. Because of the more rapid fermentation of some soluble carbohydrates, the response will also depend on the timing of administration with respect to feeding of the basal diet.

2) Effects of energy supplements

It has often been shown that energy supplements can exert a negative effect on food intake. There is a change in the pattern of rumen fermentation as the supplementary carbohydrate is preferentially attacked. This can lead to a decrease in pH and ammonia concentration with an associative effect on the onset and rate of fiber digestion.

In some cases positive effects of energy-rich supplements are observed, including an increase in ruminal fermentation following soluble carbohydrate supplementation which was found to improve rumen ammonia-N utilization. This increase in activity leads to an increase in microbial protein production. The overall effect can be a stimulation of basal intake. These positive effects of supplementation will now be discussed in more detail.

Influence of sucrose supplementation on nitrogen kinetics in the rumen and urea metabolism in sheep fed lucerne

We have examined the influence of sucrose supplementation on rumen fermentation and nitrogen metabolism in sheep fed freshly cut lucerne[1)], lucerne chaff[3)] or hay cubes[5)]. We therefore studied lucerne in three different

Table 1. Experimental procedures

Experiment 1	9 Sheep Fresh lucerne + Ruminal infusion of sucrose solution ^{14}C-urea – intravenous single injection ^{15}N-urea – intravenous single injection $(^{15}NH_4)_2SO_4$ – intraruminal continuous infusion
Experiment 2	4 Sheep Lucerne hay cubes + Addition of sucrose to diets ^{15}N-urea – intravenous continuous infusion $^{15}NH_4Cl$ – intraruminal continuous infusion
Experiment 3	4 Sheep Lucerne chaff + Ruminal infusion of sucrose solution ^{14}C-urea – intravenous single injection 6-^{3}H-glucose – intravenous single injection

Table 2. Food intake and rumen indices in sheep fed freshly cut lucerne with or without ruminal infusion of sucrose

		Water	Sucrose	Significant difference[a)]
DM intake	(g/day)	972	945	ns
N intake	(gN/day)	33.0	32.1	ns
Sucrose infusion	(g/day)	–	190	
OM intake	(g/day)	868	1,033	*
Digestible N intake	(gN/day)	24.5	21.9	**
Ruminal pH		6.6	6.1	*
Ammonia	(mgN/*l*)	264	142	***
Acetate	(mM)	49	39	***
Propionate	(mM)	28	40	***

a): ns; not significant, * $P<0.05$, ** $P<0.01$, *** $P<0.001$.

Table 3. Urea kinetics in sheep fed freshly cut lucerne with or without ruminal infusion of sucrose

		Water	Sucrose	Significant difference[a)]
Plasma urea concentration	(mgN/*l*)	258	172	**
Urea irreversible loss	(gN/day)	26.6	26.0	ns
Urea excretion rate	(gN/day)	18.9	13.0	**
Urea degradation rate	(gN/day)	7.7	13.0	**
Urea recycled/produced	(%)	28	50	**
N balance	(gN/day)	1.4	5.5	**

a): ns; not significant, ** $P<0.01$.

forms. Table 1 shows an outline of the method adopted in our experiments using rumen-fistulated sheep. Sheep were fed hourly fresh lucerne and lucerne chaff and infused intraruminally with either water or a similar volume containing sucrose in Exp. 1 and 3. In Exp. 2, sheep were fed every 2 hr lucerne hay cubes with the addition of sucrose. In these experiments, intravenous infusions of ^{14}C-urea, ^{15}N-urea and ^{3}H-glucose, and an intraruminal infusion of $^{15}NH_4$ salt were performed and parameters of metabolism were estimated by isotope dilution methods.

Table 2 shows the food intake and rumen indices in sheep fed freshly cut lucerne, with or without ruminal infusion of sucrose. Dry matter and N intake were almost the same for both treatments. The sucrose infusion rate was 190 g per day. Consequently, the organic matter intake increased to 1,033 g per day. Although the N intake was similar in both groups, the digestible N intake was lower in the sucrose group. Ruminal pH and ammonia concentration decreased with sucrose supplementation. Although the total VFA concentration did not change, a decrease in acetate and an increase in propionate levels were observed.

Table 3 shows the urea kinetics in sheep fed freshly cut lucerne, with or without ruminal infusion of sucrose. Plasma urea N level decreased, but urea irreversible loss did not change with sucrose treatment. Urea excretion in urine decreased with a concomitant increase in the urea degradation rate in the digestive tract. The ratio of the urea degradation rate to the urea production rate increased dramatically from 28 to 50%. The sucrose infusion resulted in an increase in N balance through a more efficient retention of the absorbed N at the tissue level.

Fig. 1 depicts diagramatically the N metabolism in the rumen of sheep fed fresh lucerne, with or without sucrose (corresponding values for sucrose supplementation are indicated in parentheses). Organic matter intake and the amount of organic matter apparently digested in the rumen increased with sucrose supplementation. All the sucrose was digested in the rumen as evidenced by the fact that sucrose did not appear in the abomasum. The amount of N entering the rumen was virtually the same in the control and sucrose-infused sheep. The transfer rate from feed and endogenous non-ammonia N to ammonia-N and transfer to microbial NAN decreased with sucrose infusion. The transfer of urea N from the blood to rumen ammonia increased more than 2-fold by supplementation with sucrose. However, the transfer rate from the ammonia-N pool to microbial NAN did not change. Dietary N by-pass to the lower digestive tract increased from 2.5 to 8.4 gN/day. Therefore, the total NAN flow from the rumen increased from 22 to 26 gN/day in the sucrose-supplemented sheep.

Table 4 shows the food intake and rumen indices in sheep fed lucerne hay cubes with or without sucrose addition. Ruminal pH and ammonia concentration decreased with sucrose treatment. The total VFA level did not change,

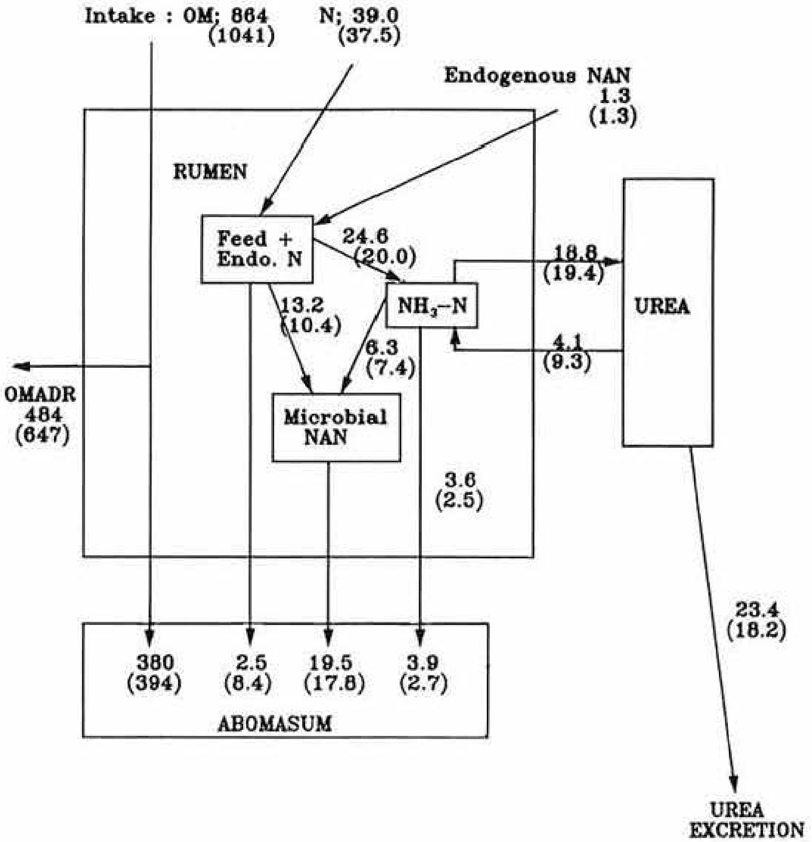

Fig. 1. Intake (g/day) and nitrogen kinetics (gN/day) in sheep fed freshly cut lucerne with (in parentheses) or without ruminal infusion of sucrose OMADR: Organic matter apparently digested in the rumen.

but there was a decrease in acetate and an increase in propionate levels in rumen fluid with sucrose supplementation, as observed in the fresh lucerne experiments. N balance increased from −1.1 to +2.0 gN/day with the addition of sucrose. The increase in N retention was as large as that in the fresh lucerne experiment.

Table 5 shows the N kinetics in sheep fed lucerne hay cubes with or without sucrose supplementation. The plasma urea level decreased, but urea irreversible loss did not change with sucrose supplementation. The urea degradation rate in the digestive tract and the transfer rate of urea into the rumen increased with sucrose supplementation. The rumen NAN concentration and outflow of NAN from the rumen to the lower digestive tract also increased by sucrose supplementation, however the capture of ammonia N into microbial N did not increase. Urinary allantoin excretion rate, which is a marker of bacterial protein production, increased significantly during sucrose supplementation. The plasma insulin concentration increased significantly by sucrose supplementation. In this experiment with sheep fed lucerne hay cubes, sucrose supplementation resulted in an increase in urea recycling, but a decrease in rumen ammonia concentration, suggesting an increased utilization of ammonia N for microbial protein synthesis. These results

Table 4. Food intake and rumen indices in sheep fed lucerne hay cubes with or without sucrose supplementation

		Water	Sucrose	Significant difference[a)]
DM intake	(g/day)	1,183	1,183	
Sucrose supplement	(g/day)	-	204	
N intake	(gN/day)	33.8	33.8	
N balance	(gN/day)	−1.1	+2.0	**
Ruminal pH		6.7	6.4	**
Total VFA	(mM)	139.2	161.2	ns
Acetate	(mol%)	72.4	63.3	*
Propionate	(mol%)	16.9	23.7	*
Ammonia	(mgN/l)	274	173	**

a): ns; not significant, * $P<0.05$, ** $P<0.01$.

Table 5. N kinetics in sheep fed lucerne hay cubes with or without sucrose supplementation

		Water	Sucrose	Significant difference[a)]
Plasma urea concentration	(mgN/l)	310	230	**
Urea degradation rate	(gN/day)	7.6	9.4	*
Transfer rate of urea to rumen	(gN/day)	2.0	4.8	**
Capture of ammonia into microbial N	(gN/day)	13.4	14.4	ns
Ruminal non-ammonia N concentration	(gN/l)	0.71	1.53	**
Ruminal outflow of NAN	(gN/day)	18.0	23.0	*
Urinary allantoin excretion	(g/day)	2.3	2.7	*
Plasma insulin concentration	(U/ml)	20.9	33.8	*

a): ns; not significant, * $P<0.05$, ** $P<0.01$.

Table 6. Rumen indices, plasma urea and glucose kinetics in sheep fed lucerne chaff with ruminal infusion of water or sucrose solution

		Water	Sucrose	Significant difference[a)]
Ruminal pH		6.7	6.5	*
Ammonia concentration	(mgN/*l*)	214	104	*
Total VFA concentration	(mM)	80.7	88.3	ns
Acetate	(mol%)	55	44	*
Propionate	(mol%)	21	33	*
Plasma urea concentration	(mgN/*l*)	208	167	*
Urea irreversible loss	(gN/day)	21.1	19.1	ns
Urea excretion rate	(gN/day)	15.1	10.7	*
Urea degradation rate	(gN/day)	6.0	8.4	*
Urea degraded/produced	(%)	29	44	*
Plasma glucose concentration	(mg/*l*)	567	659	*
Glucose pool size	(g)	7.3	10.1	*
Glucose irreversible loss	(g/d)	113	188	*

a): ns; not significant, * $P<0.05$.

were similar to those obtained in the experiments using freshly cut lucerne in which there was no change in microbial protein production.

Table 6 shows the rumen indices, plasma urea and glucose kinetics in the experiment with sheep fed lucerne chaff, with or without ruminal infusion of a sucrose solution. Ruminal pH and ammonia concentration decreased with sucrose infusion. The molar % acetate decreased and propionate increased with sucrose infusion. The addition of sucrose resulted in a lower plasma urea concentration. Also less urinary urea was excreted, while more urea was recycled to and degraded in the gut. The ratio of the amount of urea degraded in the digestive tract to urea irreversible loss increased from 29 to 44% as a result of sucrose infusion. The sucrose supplement increased the plasma glucose pool size and glucose irreversible loss. These findings indicate that sucrose supplementation accelerated the glucose metabolism presumably due to the increased rumen propionate production.

Effects of energy-rich supplementation on rumen indices and N kinetics in ruminants

Our experimental results can be compared with representative earlier work carried out by other investigators. Potthast et al.[6] studied N transactions in the digestive tract of sheep fed a synthetic diet, with or without sucrose supplementation. Although the N intake was the same in both groups and urea irreversible loss did not change, in the sucrose-fed group urea excretion in urine decreased and there was a concomitant increase in degradation in the digestive tract. Degradation in the rumen also increased and the percentage of recycled urea that entered the rumen to total digestive tract entry increased with sucrose treatment. Incorporation of ammonia into microbial protein also increased in the sucrose supplemented sheep. These results are different from those which are obtained in sheep fed a lucerne diet.

Norton et al.[2] reported on rumen indices and N kinetics in sheep fed pelleted grass cubes, with or without flaked barley. The digestible organic matter intake increased in the treatment group but N intakes were similar in their experiment. Rumen fluid pH decreased with flaked barley addition. There was no change in ammonia or total VFA concentrations nor in the molar proportions of acetate or propionate. However, the molar proportion of butyrate and bicarbonate production increased with the treatment. There were decreases in the plasma urea levels and urinary urea excretion and increases in the degradation of urea in the rumen and in N balance in the sheep supplemented with the flaked barley.

Rooke et al.[7] investigated the effects of intraruminal infusion of glucose syrup on N digestion in cattle fed a grass silage diet. There were no significant changes in the rumen fluid pH or VFA concentrations but the ammonia levels decreased from 51 to 28 mgN/*l* and microbial total N entering the small intestine increased with the treatment. These results indicate a more efficient utilization of rumen ammonia-N.

In summary, the experiments described in this paper indicate that energy supplementation stimulates rumen microbial activity, and rumen ammonia is utilized more efficiently. In addition, more urea was recycled to the rumen when sucrose was infused.

Conclusion

We consider that under certain conditions, energy-rich supplements can be used productively to increase and alter rumen fermentation and microbial growth and thereby increase the efficiency of utilization of basal diets by ruminants[4].

As we have attempted to show, the supplementary energy alters the rumen function in a number of ways:

(1) More energy is available within the rumen resulting in the increase of the potential for microbial growth and protein synthesis.

(2) More urea-N is transferred to the rumen, less is excreted, and more rumen ammonia-N is, in fact, utilized by the microbes.

(3) More dietary protein by-passes rumen fermentation, resulting in more amino acid-N becoming available to the host animal.

(4) More propionate is absorbed and may be utilized for glucose production in the liver.

(5) The overall result is that more amino acid-N is available for the protein metabolism and N retention by the host animal.

In conclusion, further experimentation is obviously required to analyze all the mechanisms involved but with careful selection of the type, form and level of supplement, we consider that it is possible to alter the nature of the products of rumen fermentation to more closely match those required by the host animal so as to meet its requirements for various forms of production.

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