Urea flux in beef steers: effects of forage species and nitrogen fertilization

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Urea flux in beef steers: Effects of forage species and nitrogen fertilization

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ABSTRACT: The effects of two forage species and N levels on urea kinetics and whole-body N metabolism were evaluated in eight Angus steers (initial BW 217 ± 15 kg). In a replicated, 4 × 4 Latin square design, steers were fed gamagrass (Tripsacum dactyloides L.) or switchgrass (Panicum virgatum L.), each of which had 56.2 (LO) or 168.5 (HI) kg of N fertilization per hectare. Diets provided adequate energy for 0.5 kg ADG. Nitrogen balance and urea kinetics were measured from d 22 to 27 of each period. Urine samples collected during intravenous infusion of bis15N urea were used to calculate production and recycling of urea N from relative abundance of urea isotopomers. Jugular blood serum was analyzed for serum urea N (SUN). Gamagrass differed from switchgrass (P < 0.05) in daily DMI (4,273 vs 4,185 g), N intake (72 vs 67 g), DM digestibility (61.0 vs 63.6%), fecal N (30.6 vs 28.3 g/d), urine urea N (10.5 vs 8.0 g/d), and percentage of urinary N present as urea N (53.5 vs 40.0%). After adjustment for differences in N intake, fecal N still tended to be greater (P < 0.09) for gamagrass than for switchgrass. The LO differed from the HI (P < 0.01) in daily N intake (63 vs 76 g), DM digestibility (61.3 vs 63.3%), urine N (13.6 vs 25.9 g/d), and N retained as a percentage of N digested (57.3 vs 43.5%). Compared to switchgrass, gamagrass had greater SUN, N digestibility, and N digested as N level increased (forage × N level interactions, P < 0.05). As N level increased, N retention increased from 19.5 to 23.5 g/d in gamagrass and decreased from 20.5 to 18.1 g/d in switchgrass (interaction, P < 0.07). The HI group was greater than the LO intake group (P < 0.03) in endogenous production of urea N (44.4 vs 34.0 g/d), gut entry rate of urea N (31.6 vs 28.2 g/d), and the amount of urea N that re-entered the ornithine cycle (9.4 vs 7.9 g/d). However, the percentage of urea N entering the gastrointestinal tract that was recycled was constant among treatments (29.1%), indicating that almost 70% of the urea N that entered the gastrointestinal tract was potentially available for anabolic purposes of the steers as a component of microbial products that were absorbed or excreted in the feces. In summary, N levels affected N metabolism of steers more when they were fed gamagrass than when they were fed switchgrass. Although the absolute amounts of N moving through the system changed with variations in intake, the proportions remained similar, with a greater efficiency of N use at low N intakes.

Key Words: Beef Steers, Gamagrass, Switchgrass, Urea Kinetics

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Introduction

As concerns for environmental damage instigated by agricultural processes increase, there is a greater need to develop more ecologically acceptable methods of producing agricultural products. Therefore, beef producers want to minimize N excretion and maximize N retained as salable beef or other products of beef production.

Urea, the major end product of ammonia and amino acid metabolism in beef cattle, is excreted in urine or recycled to the gastrointestinal tract (GIT) by diffusion across the gut wall or in saliva. The quantity of urea N that enters the GIT is equivalent to 30 to 77% of dietary N (Sarraseca et al., 1998; Huntington, 1989). Urea that is recycled to the GIT is hydrolyzed to yield ammonia, which is used as a source of N for microbial protein, reabsorbed into blood circulation, or lost as fecal N. Many of the cellulolytic bacteria prefer NH3 as the source for N (Russell et al., 1992), so recycled urea provides a mechanism by which N may be salvaged into bacterial matter that may be digested by the animal to provide amino acids for production purposes. The amount of recycled urea N that is retained for possible anabolic purposes of the ruminant can be influenced by dietary factors such as intake (Sarraseca et al., 1998), level of dietary concentrate (Huntington et al., 1996), and level of dietary N (Bunting et al., 1987). The purpose of this study was to determine the effects of dif-

1This research was supported in part by the North Carolina Institute of Nutrition.
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Animals and Experimental Procedures

Cr (1,080 mg/kg) as Cr-picolinate.

168.5 (6 d of sample collection.

tive stage of maturity. One field of each forage was
grown and harvested as described by Burns et al.

Desired growth (0.5 kg/d; NRC, 1996).

period. Steers also were fed a supplement (Table 1)
each steer received each of the hays in a given 4-d! experimental hays in a randomized fashion such that
ing this pre-experimental period the steers received the
experimental hays in a given 4-d period. Steers also were fed a supplement (Table 1) that provided all vitamins and minerals necessary for
desired growth (0.5 kg/d; NRC, 1996).

Diets were formulated to provide adequate energy for 0.5 kg ADG, and metabolizable protein was slightly

fering amounts of N and digestible carbohydrate in two
two warm-season grasses on N metabolism, and urea kine-
tics in particular, in growing beef steers.

Materials and Methods

The experimental design was a replicated 4 × 4 Latin square design with a 2 × 2 factorial arrangement of
forage species and N level in the forages. Gamagrass
(Tripsacum dactyloides L.) and switchgrass (Panicum
virgatum L.) were fertilized with either 56.2 (LO)
or 107.5 (HI) kg of N per hectare and harvested at vegeta-
tive stage of maturity. One field of each forage was
grown and harvested as described by Burns et al.
(1997). Periods lasted 27 d, with 21 d of adaptation and
6 d of sample collection.

Eight Angus steers (initial weight 217 ± 15 kg; final
weight 252 ± 9 kg) were used in this experiment. Care,
handling, and sampling of these steers were approved
by the North Carolina State University Animal Care
and Use Committee. Steers were purchased at a North
Carolina feeder calf sale and quarantined for 28 d; they
were trained to be led by halter and accustomed to close
human interaction during quarantine. Steers were then
blocked by BW into two groups of four steers each and
housed in indoor, individual tie stalls (115 × 178 cm).
Steers had ad libitum access to water. The diurnal pat-
tern consisted of 12 h of light and 12 h of dark. The
steers were allowed to exercise in an outdoor pen two
to three times a week for 3 to 4 h between collection
periods. Steers were adapted to the facilities, infusion
equipment, and urine collection apparatus during a 21-
d adaptation period before the experiment began. Dur-
ing this pre-experimental period the steers received the
experimental hays in a randomized fashion such that
each steer received each of the hays in a given 4-d period. Steers also were fed a supplement (Table 1) that provided all vitamins and minerals necessary for desired growth (0.5 kg/d; NRC, 1996).

Diets were formulated to provide adequate energy for 0.5 kg ADG, and metabolizable protein was slightly

below requirements for maintenance (LO) or adequate
for 0.5 kg ADG (HI) by NRC (1996) recommendations
for a 250-kg growing steer. Those criteria were met by
feeding 3.78 kg DM of hay and 0.44 kg DM of supple-
ment (Table 1) daily. The hay was offered in two equal
portions at 1000 and 1630 and the supplement was
offered with the 1000 feeding. Prior to sample collec-
tions, stalls were thoroughly cleaned. Wooden panels
were attached to one side of the pens to minimize cross-
contamination of feces between steers. These panels
allowed visual contact among steers. Clean, plastic
tarp were positioned behind each steer to facilitate
quantitative collection of feces. Steers were then fitted
with two temporary catheters in the same exterior jugu-
lar vein with tips 10 cm apart in the vena cava 48 h
prior to the beginning of the digestion trial. The catheter
whose tip was closest to the heart was used for
infusions, and the other catheter was used for blood
sampling. Patency of catheters was maintained with
Na-heparin (100 units/mL) in 0.9% sterile saline.

Total collections of urine, feces, and orts were con-
ducted for 6 d following adaptation to the respective
diet. Feed was sampled daily during the 6 d of sample
collection. Urine was aspirated into polypropylene jugs
from a urine collection harness. The urine harness con-
sisted of a urine receptacle (Belko, Kingsville, MD) fit-
ted with cotton belting and elastic with foam rubber
pads to allow for movement and comfort of the steers.
Urine jugs contained 200 mL of 6 N HCl daily. Feces
and urine were collected daily and weighed, and an
aliquot (5% of daily output) was retained. Feces were
scraped back and placed in a plastic storage receptacle
throughout each day to minimize problems with steer
movements that might have affected the total collec-
tions. After the final day of collection, steers were re-
moved from the pens and the pens were thoroughly
scraped. Scrapings were included in the final day’s out-
put of feces. Urine pH was measured with pH-sensitive
paper prior to collection of aliquots to ensure pH < 4.
Urine aliquots were pooled within steer and kept frozen
at <−4°C. Fecal aliquots were dried with forced air
at 60°C for 48 h and then pooled within steer.

Following the first 24 h of the balance trial, samples
were collected to establish baseline enrichments of 15N.
Urea kinetics subsequently were measured during d 2
through 4 of the balance trial. Steers were infused with
sterile 0.9% saline containing bis-15N-urea (Cambridge
Isotope Laboratories, Andover, MA; Lot T1-41568).

Bis15N-urea was infused to allow subsequent determi-
nation of urea-N isotopomers (14,14N-, 14,15N-, and 15,15N-
urea). Infusion rate was maintained at 85 mL/h, which
delivered 0.137 mmol of urea N/h using a peristaltic
pump (Model 1000, Medical Technology Products, Hun-
tington Station, NY). Urine was sampled at 2-h inter-
vals from 48 to 56 h of infusion for determination of
15N enrichments, and blood for measurement of serum
urea N (SUN) was collected at the same time. In square
1, 71 of a possible 80 and in square 2, 76 of a possible
80 urine samples were collected between 48 to 56 h of

Table 1. DM composition of the supplement

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracked corn</td>
<td>90.81</td>
</tr>
<tr>
<td>Mono-dicalcium phosphate</td>
<td>3.49</td>
</tr>
<tr>
<td>CaCO3</td>
<td>1.85</td>
</tr>
<tr>
<td>NaCl</td>
<td>1.96</td>
</tr>
<tr>
<td>Vitamin premixa</td>
<td>0.73</td>
</tr>
<tr>
<td>Cane molasses</td>
<td>0.51</td>
</tr>
<tr>
<td>Rice meal by-product</td>
<td>0.46</td>
</tr>
<tr>
<td>Trace mineral premixb</td>
<td>0.19</td>
</tr>
</tbody>
</table>

a Contained per kilogram of supplement DM: 5,000 IU of vitamin A, 625 IU of vitamin D, and 114 IU of vitamin E.

b Cu (502 mg/kg) as CuSO4; Mg (50,240 mg/kg) as MgO; Zn (1,500 mg/kg) as ZnSO4; Co (5 mg/kg) as CoCO3; Se (5 mg/kg) as Na2SeO4; and Cr (1,080 mg/kg) as Cr-picolinate.
infusion; missing samples were due to lack of urination during the 2-h interval. There were at least three urine samples (in 2 of 16 periods) for each steer and period. The average enrichments of the individual urine samples (corrected for baseline enrichments) within steer and period were used in subsequent ANOVA. The enrichments at this time seemed to be at a plateau. 

The average enrichments of the individual urine samples (in 2 of 16 periods) for each steer and period. During the 2-h interval. There were at least three urine samples were sequentially determined using the diacetyl monoxime method of Marsh et al. (1957). The N fractions of the forages were described by their solubility in acid or alkali reactions. The enrichments of urea as m/z 29 and m/z 30 atoms percent excess for non-monomolecular reactions to correct the m/z 29 and m/z 30 atoms percent excess for non-monomolecular reactions. The enrichments of urea as m/z 29 and m/z 30 were then applied to the model of Sarraseca et al. (1998) to calculate urea-N entry rate (UER), the rate at which urea enters the GIT. Urea-N entry rate is an estimate of the de novo production of urea N by the steer, and by calculating the GER we were able to estimate the rate of urea entry into the GIT. The unique nature of this study lies in the estimation of ROC, in that it allows us to demonstrate possible manipulations of N movements into the GIT and demonstrate just how efficiently the N from endogenous urea was utilized.

Statistical Analysis

The GLM procedure of SAS (SAS Inst. Inc., Cary, NC) was used for statistical analysis of data. The model for balance trial data and urea kinetic data included the following independent variables: square, steer(square), period(square), forage species, N level, and the forage x N level interaction. When treatment effects were significant (P < 0.05), a difference was determined and a tendency for treatment to elicit a response was noted when P < 0.15.

Results

There were distinct differences in chemical composition between forage species and N levels (Table 2). Switchgrass decreased in hemicellulose with increased N level, but gamagrass had a very small increase in hemicellulose with increased N level. This was accom-
Table 2. Chemical composition, in vitro true dry matter digestibility (IVTDMD), and N fractions of gamagrass and switchgrass hay with low or high N content

<table>
<thead>
<tr>
<th></th>
<th>Gamagrass</th>
<th></th>
<th>Switchgrass</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>% of DM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>34.2</td>
<td>34.4</td>
<td>35.0</td>
<td>33.8</td>
</tr>
<tr>
<td>Cellulose</td>
<td>31.9</td>
<td>33.3</td>
<td>34.2</td>
<td>32.2</td>
</tr>
<tr>
<td>Lignin</td>
<td>4.1</td>
<td>4.5</td>
<td>3.9</td>
<td>3.8</td>
</tr>
<tr>
<td>IVTDMD</td>
<td>67.6</td>
<td>65.7</td>
<td>66.2</td>
<td>69.2</td>
</tr>
<tr>
<td>CP</td>
<td>9.4</td>
<td>12.1</td>
<td>8.8</td>
<td>11.1</td>
</tr>
<tr>
<td>N Fractionsa,b,c,d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of CP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>20.6</td>
<td>27.0</td>
<td>21.3</td>
<td>24.3</td>
</tr>
<tr>
<td>B1</td>
<td>3.0</td>
<td>3.6</td>
<td>6.0</td>
<td>7.6</td>
</tr>
<tr>
<td>B2</td>
<td>24.6</td>
<td>25.4</td>
<td>27.6</td>
<td>28.7</td>
</tr>
<tr>
<td>B3</td>
<td>47.0</td>
<td>40.1</td>
<td>39.2</td>
<td>35.2</td>
</tr>
<tr>
<td>C</td>
<td>4.9</td>
<td>4.0</td>
<td>5.9</td>
<td>4.1</td>
</tr>
<tr>
<td>N Fractionse,f</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intake, g/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>12.4</td>
<td>20.5</td>
<td>12.4</td>
<td>16.5</td>
</tr>
<tr>
<td>B1</td>
<td>2.2</td>
<td>3.2</td>
<td>3.8</td>
<td>6.0</td>
</tr>
<tr>
<td>B2</td>
<td>18.4</td>
<td>23.1</td>
<td>19.7</td>
<td>23.2</td>
</tr>
<tr>
<td>B3</td>
<td>28.0</td>
<td>30.7</td>
<td>22.8</td>
<td>24.1</td>
</tr>
</tbody>
</table>

aArithmetic means from duplicate analysis of samples from each diet.
bUsing the method of Licitra et al. (1996).
cArithmetic means of triplicate analysis of a composite sample.
dN fractions from Level 2 NRC (NRC, 1996).
eCalculated as (N intake from hay g/d) \times \text{N fraction} + (N intake from supplement g/d) \times \text{N fraction}.
fN fractions for supplement using cracked corn values (NRC, 1996).

Compared by a decrease in cellulose in switchgrass with higher N level, whereas cellulose increased in gamagrass with higher N level. Lignin increased with N level in gamagrass, but it remained nearly the same in switchgrass.

Similar to the changes in cellulose, IVTDMD decreased with increased N level in gamagrass, but it increased with N level in switchgrass. Crude protein was higher in gamagrass than in switchgrass and CP increased with increased N level. The most substantive change was the increase in the readily soluble portion (A) of CP. Gamagrass had less true soluble protein (B1) than switchgrass, and this was primarily compensated with an increase in the amount of slowly digested (B3) proportion of CP.

Interactions between forage species and N level affected N digestion and metabolism by the steers (Table 3). There was a greater increase in N digested as N level increased by steers fed gamagrass than by those fed switchgrass (interaction, P < 0.03). There was a greater increase in N digestibility as N level increased by steers when fed gamagrass than when fed switchgrass (interaction, P < 0.04). Retained N tended to increase with increased N level in steers fed gamagrass, whereas the percentage decreased with increased N level in steers fed switchgrass (interaction, P < 0.07). There was a greater (interaction, P < 0.02) increase in SUN as N level increased by steers fed gamagrass than by steers fed switchgrass. There was a tendency (interaction, P < 0.09) for N intake to increase more between the LO and HI levels of gamagrass than between the LO and HI levels of switchgrass.

Compared with switchgrass, when steers were fed gamagrass DMI increased 90 g/d (P < 0.04) and N intake increased 5 g/d (P < 0.01). Fecal DM increased 151 g/d (P < 0.01), fecal N increased 2.3 g/d (P < 0.01), urine urea N increased 2.5 g/d (P < 0.03), and urea as a percentage of total urinary N increased 14.1 percentage units (P < 0.03). Dry matter digestibility decreased (P < 0.01) and SUN increased 0.9 mM (P < 0.01) as a main effect of forage when steers were fed gamagrass. When steers were fed gamagrass, the percentage of GER decreased 4.8 percentage units (P < 0.05).

Compared with LO, when steers were fed HI N intake increased 15 g/d (P < 0.01), fecal DM decreased 75 g/d (P < 0.01), urine N increased 12 g/d (P < 0.01), and urinary urea increased 7 g/d (P < 0.01, Table 3). Dry matter digestibility increased 2 percentage units (P < 0.01), N digested increased 12.9 g/d (P < 0.01), N digestibility increased 7 percentage units (P < 0.01), and the proportion of N digested that was retained decreased 14 percentage units (P < 0.01) when steers consumed HI. Serum urea N increased 2.3 mM (P < 0.01, Table 3), UER increased 10.35 g/d (P < 0.01), GER increased 3.42 g/d (P < 0.03), and ROC increased 1.47 g/d (P < 0.03) when steers consumed HI. The data also indicate that GER as a percentage of UER decreased 11.47 percentage units (P < 0.01), and ROC as a percentage of UER tended to increase 2.17 percentage units (P < 0.09) when steers were fed HI.
Discussion

N Digestibility and Whole Body N Metabolism

This study was conducted with the hypothesis that there would be significant interactions between different grass species with different levels of N in the plant material. This was based on the premise that differences in the available carbohydrate available for digestion could be manipulated through selection of different forage species to improve urea N capture in the rumen. Forage × N level interactions in forage composition (Table 2) were not evident for in vivo DM digestibility (Table 3). Further, IVTDMD predicted no difference between forages, and the forage × N level interaction was largely due to decreased IVTDMD as N level increased for gamagrass. Increased N intake for gamagrass compared to switchgrass was due to the increased N concentration in gamagrass and the slightly greater DM intake. The increased N intake associated with switchgrass was also associated with an increase in fecal N (Table 3). A subsequent ANOVA was conducted, comparing forage species with N intake as a covariate. In that analysis there were no differences between forages (P > 0.15), except for a trend for greater (P < 0.09) fecal N for gamagrass. The differences in N fractions between forages (Table 2) or the increased N supply was not sufficient to improve in vivo DM digestibility of gamagrass vs switchgrass. We conclude that N availability did not limit ruminal fiber digestion of switchgrass, and that increased in vivo DM digestibility for switchgrass vs gamagrass was due to less lignin in switchgrass.

By design, the N intake was greater for steers receiving HI than for those receiving LO. However, gamagrass had a higher concentration of N than switchgrass, which resulted in a trend for greater N intake between the HI and LO treatments of gamagrass than between the HI and LO treatments of switchgrass (Table 3).

The subsequent decrease in fecal DM and increase in apparent DM digestibility with the increased N level support increased fiber digestibility with increased dietary CP, as shown by Willms et al. (1991). Griswold et al. (1996) demonstrated that an increase in the amount of N present as non-urea N increased the extent of structural carbohydrate digestion in a continuous culture system. Thus, due to the moderate increases in the amount of N in the B1 and B2 fractions of the HI vs LO forages (Table 2), HI forages should have higher degradability of fiber. The increases in the concentrations of these soluble and readily available, insoluble forms of N are likely the cause of the increased digestion of the forages, rather than the increased levels of NPN in the forages (Rihani et al., 1993).

The greater increment in N digested and N digestibility in response to N level for gamagrass vs switchgrass (Table 3) is associated with greater increments in intake of the A and B2 fractions of N (Table 2) and higher SUN (Table 3). In agreement with other studies (Bunting et al., 1987; Huntington 1989; Sarraseca et al., 1998) both urinary N excretion and urinary urea excretion increased with the increased N intake (Table 3). The tendency for urea as a percentage of total urinary N to decrease with increasing levels of N in steers fed gamagrass but to increase in steers fed switchgrass is consistent with the presence of antinutritional factors in switchgrass that inhibit N retention. One possible factor is phenolic acid monomers, which can constitute 1 to 2.5% of NDF in switchgrass hay (Jung and Vogel, 1992). These phenolic acid monomers are detoxified by conjugation with glycine in the liver (Cremin et al., 1995), which would result in an increase in hippuric acid production. Hippuric acid would then be released from the splanchnic system into circulation, excreted in the urine, thereby reducing the available N present for anabolic processes of the steers. This concept is supported by the overall decrease in urine N present as urea in steers fed switchgrass.

<table>
<thead>
<tr>
<th>Item</th>
<th>Gamagrass Low</th>
<th>High</th>
<th>Switchgrass Low</th>
<th>High</th>
<th>SE</th>
<th>Grass (G)</th>
<th>N level</th>
<th>G × N</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI, kg/d</td>
<td>4,278</td>
<td>4,267</td>
<td>4,140</td>
<td>4,227</td>
<td>0.040</td>
<td>0.041</td>
<td>0.362</td>
<td>0.241</td>
</tr>
<tr>
<td>N intake, g/d</td>
<td>64.0</td>
<td>80.5</td>
<td>62.2</td>
<td>72.3</td>
<td>1.73</td>
<td>0.011</td>
<td>0.001</td>
<td>0.086</td>
</tr>
<tr>
<td>Feces DM, kg/d</td>
<td>1,732</td>
<td>1,609</td>
<td>1,533</td>
<td>1,506</td>
<td>0.032</td>
<td>0.001</td>
<td>0.010</td>
<td>0.150</td>
</tr>
<tr>
<td>Feces N, g/d</td>
<td>30.8</td>
<td>30.4</td>
<td>27.7</td>
<td>29.0</td>
<td>0.78</td>
<td>0.011</td>
<td>0.010</td>
<td>0.254</td>
</tr>
<tr>
<td>Urine N, g/d</td>
<td>13.7</td>
<td>26.7</td>
<td>14.0</td>
<td>25.2</td>
<td>1.16</td>
<td>0.033</td>
<td>0.001</td>
<td>0.484</td>
</tr>
<tr>
<td>Urine urea N, g/d</td>
<td>7.3</td>
<td>13.8</td>
<td>4.3</td>
<td>11.7</td>
<td>1.08</td>
<td>0.034</td>
<td>0.001</td>
<td>0.664</td>
</tr>
<tr>
<td>Urea, % of urine N</td>
<td>55.1</td>
<td>51.9</td>
<td>31.5</td>
<td>47.3</td>
<td>5.75</td>
<td>0.030</td>
<td>0.297</td>
<td>0.126</td>
</tr>
<tr>
<td>DM digestibility, %</td>
<td>59.5</td>
<td>62.4</td>
<td>63.0</td>
<td>64.2</td>
<td>0.68</td>
<td>0.001</td>
<td>0.010</td>
<td>0.239</td>
</tr>
<tr>
<td>N digested, g/d</td>
<td>33.2</td>
<td>50.2</td>
<td>34.5</td>
<td>43.3</td>
<td>1.75</td>
<td>0.135</td>
<td>0.001</td>
<td>0.033</td>
</tr>
<tr>
<td>N digestibility, %</td>
<td>51.8</td>
<td>62.4</td>
<td>55.2</td>
<td>59.1</td>
<td>1.52</td>
<td>0.057</td>
<td>0.001</td>
<td>0.044</td>
</tr>
<tr>
<td>N retained, g/d</td>
<td>19.5</td>
<td>23.5</td>
<td>20.5</td>
<td>18.1</td>
<td>1.53</td>
<td>0.198</td>
<td>0.630</td>
<td>0.065</td>
</tr>
<tr>
<td>N retained, % of N digested</td>
<td>57.6</td>
<td>45.6</td>
<td>57.0</td>
<td>41.4</td>
<td>2.18</td>
<td>0.416</td>
<td>0.001</td>
<td>0.532</td>
</tr>
<tr>
<td>SUN, mM</td>
<td>4.1</td>
<td>6.9</td>
<td>3.7</td>
<td>5.4</td>
<td>0.2</td>
<td>0.001</td>
<td>0.001</td>
<td>0.015</td>
</tr>
</tbody>
</table>
Effects of Forage and N Level on Urea Metabolism and Recycling

The overall nutrient supply from our diets was not sufficient for the steers to use all of the increment in N supply for tissue growth; this conclusion is supported by decreased N retention as a percentage of N digested (Table 3), increased UER, decreased GER as a percentage of UER, and decreased ROC as a percentage of UER (Table 4). Therefore, only a limited fraction of this extra urea N was returned to the gut and partially recycled as N in microbial products. The ROC as percentage of GER (Table 4) was less than those of yearling goats fed various intakes of a grass pellet diet (36.9 to 40.7%, Sarraseca et al., 1998). Our data indicate that between 65 and 70% of the urea N entering the GIT could be incorporated into microbial constituents for later use by the steers; some of the N could be excreted in feces (Sarraseca et al., 1998; Lobley et al., 2000). However, these potential values are much higher than those obtained by Bunting et al. (1987), who reported that 55 to 58% of the SUN that entered the rumen was incorporated into microbial N in lambs fed a corn-based diet. Of course, dietary factors, such as availability of readily fermentable carbohydrate in the rumen, can focus recycling of urea into the rumen vs the lower GIT (Kennedy, 1980; Huntington, 1989) and may play a role in directing more urea N that enters the GIT to return to the circulation (Lobley et al., 2000).

In an effort to clarify the trend for increased urea production for gamagrass vs switchgrass (Table 4), N intake was included as a covariate in a subsequent ANOVA; that analysis indicated that there were no significant forage effects on any of the variables in Table 4. We conclude that differences seen between gamagrass and switchgrass in urea N production were due to differences in N concentration and subsequent N intake by the steers. Therefore, the chemical composition of gamagrass and switchgrass at similar stages of maturity are not sufficiently distinct to provide detectable differences in urea kinetics and production traits.

### Table 4. Urea transfers in steers fed gamagrass or switchgrass hay with low or high N content

<table>
<thead>
<tr>
<th>Urea transfers, g N/d&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Gamagrass</th>
<th>Switchgrass</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>UER&lt;sup&gt;b&lt;/sup&gt;</td>
<td>35.4</td>
<td>45.7</td>
<td>32.6</td>
</tr>
<tr>
<td>GER&lt;sup&gt;c&lt;/sup&gt;</td>
<td>28.1</td>
<td>32.0</td>
<td>26.3</td>
</tr>
<tr>
<td>ROC&lt;sup&gt;d&lt;/sup&gt;</td>
<td>8.42</td>
<td>9.27</td>
<td>7.38</td>
</tr>
<tr>
<td>% Contributions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GER/UER</td>
<td>79.5</td>
<td>70.4</td>
<td>86.6</td>
</tr>
<tr>
<td>ROC/GER</td>
<td>30.1</td>
<td>29.3</td>
<td>26.1</td>
</tr>
<tr>
<td>ROC/UER</td>
<td>23.9</td>
<td>20.2</td>
<td>22.6</td>
</tr>
</tbody>
</table>

<sup>a</sup>As measured during a continuous, intravascular infusion of bis 15N-urea.  
<sup>b</sup>Urea-N entry rate.  
<sup>c</sup>The rate at which urea enters the gastrointestinal tract.  
<sup>d</sup>The rate at which NH₃-N from hydrolysis of urea is returned to the ornithine cycle.

### Implications

Increasing N fertilization of gamagrass and switchgrass swards will increase the N concentration of harvested hays, and it will increase DM and N digestibility by steers fed those hays. However, neither efficiency of N use nor recycling of urea to the digestive tract was improved with increased N intake. Therefore, although increasing the amount of N presented to beef steers will increase the available amount of N available to them, this does not equate with an increased use of this N. Hence, once the N intake exceeds the maintenance requirements of the steer, a greater proportion is excreted as urea in the urine and not captured as the salable product, beef.

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