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Interaction between dietary content of protein and sodium chloride on milk urea concentration, urinary urea excretion, renal recycling of urea, and urea transfer to the gastrointestinal tract in dairy cows

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ABSTRACT

Dietary protein and salt affect the concentration of milk urea nitrogen (MUN; mg of N/dL) and the relationship between MUN and excretion of urea nitrogen in urine (UUN; g of N/d) of dairy cattle. The aim of the present study was to examine the effects of dietary protein and sodium chloride (NaCl) intake separately, and their interaction, on MUN and UUN, on the relationship between UUN and MUN, on renal recycling of urea, and on urea transfer to the gastrointestinal tract. Twelve second-parity cows (body weight of 645 ± 37 kg, 146 ± 29 d in milk, and a milk production of 34.0 ± 3.28 kg/d), of which 8 were previously fitted with a rumen cannula, were fitted with catheters in the urine bladder and jugular vein. The experiment had a split-plot arrangement with dietary crude protein (CP) content as the main plot factor [116 and 154 g of CP/kg of dry matter (DM)] and dietary NaCl content as the subplot factor (3.1 and 13.5 g of Na/kg of DM). Cows were fed at 95% of the average ad libitum feed intake of cows receiving the low protein diets. Average MUN and UUN were, respectively, 3.90 mg of N/dL and 45 g of N/d higher for the high protein diets compared with the low protein diets. Compared with the low NaCl diets, MUN was, on average, 1.74 mg of N/dL lower for the high NaCl diets, whereas UUN was unaffected. We found no interaction between dietary content of protein and NaCl on performance characteristics or on MUN, UUN, urine production, and renal clearance characteristics. The creatinine clearance rate was not affected by dietary content of protein and NaCl. Urea transfer to the gastrointestinal tract, expressed as a fraction of plasma urea entry rate, was negatively related to dietary protein, whereas it was not affected by dietary NaCl content. We found no interaction between dietary protein and NaCl content on plasma urea entry rate and gastrointestinal urea entry rate or their ratio. The relationship between MUN and UUN was significantly affected by the class variable dietary NaCl content: UUN = $-17.7 \pm 7.24 + 10.09 \pm 1.016 \times$ MUN $+ 2.26 \pm 0.729 \times$ MUN (for high NaCl); $R^2 = 0.85$. Removal of the MUN × NaCl interaction term lowered the coefficient of determination from 0.85 to 0.77. In conclusion, dietary protein content is positively related to MUN and UUN, whereas dietary NaCl content is negatively correlated to MUN but NaCl content is not related to UUN. We found no interaction between dietary protein and NaCl content on performance, MUN, UUN, or renal urea recycling, nor on plasma urea entry rate and urea transfer to the gastrointestinal tract. For a proper interpretation of the relationship between MUN and UUN, the effect of dietary NaCl should be taken into account, but we found no evidence that the effect of dietary NaCl on MUN is dependent on dietary protein content.

Key words: milk urea nitrogen, urinary urea nitrogen excretion, dietary NaCl, dietary protein

INTRODUCTION

Ammonia emitted from livestock manure has negative environmental effects, including ecosystem acidification, eutrophication of surface waters, and formation of fine particulate matter formation in the atmosphere (Draaijers et al., 1989; Howarth et al., 1996). Moreover, indirect emissions of nitrous oxide (N_2O), which is a major greenhouse gas, occur after atmospheric deposition of ammonia from stables and manure storage (IPCC, 2006). Livestock farming (in particular cattle operations) is considered to be a major contributor to ammonia emission (Pain et al., 1998; Hutchings et al., 2001). The primary source of ammonia emission in dairy production is excreted urinary urea N (**UUN**; g of N/d). Decreasing the dietary CP content (g/kg of DM) is one of the most effective strategies to decrease total N excretion and ammonia emission from animal manure (Hristov et al., 2011) and may reduce the environmental impact.

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Milk urea N (mg of N/dL) is correlated with UUN, which has led to the development of several predictive models to estimate UUN from MUN (Burgos et al., 2007; Powell et al., 2011). These models assume a fixed increase of UUN per unit increase of MUN. However, several factors can affect the relationship between MUN and UUN, including BW and cow genetics, time of sampling, protein content of the diet, and the quantity of urine produced (Kauffman and St-Pierre, 2001; Aguilar et al., 2012; Spek et al., 2013). In a study by Spek et al. (2012), MUN was negatively related to NaCl intake, whereas UUN was not affected. From a physiological perspective, renal regulation of urea excretion can explain the effect of dietary CP and urine volume on the relationship between MUN and UUN. Several studies in goat, sheep, and steers show that renal processes such as the glomerular filtration rate (**GFR**) and recycling of urea from the glomerular filtrate are affected by CP (Thornton, 1970; Rabinowitz et al., 1973; Eriksson and Valtonen, 1982) and NaCl (Thornton, 1970; Godwin and Williams, 1984). Because both NaCl and protein intake may affect GFR and urea recycling, they might have an interactive effect on the process of renal urea excretion and MUN. The interaction between NaCl and protein on plasma urea nitrogen concentration (**PUN**; mg of N/dL) and on renal handling of urea was studied by Thornton (1970) in 2-yr-old steers. Addition of NaCl (200 g of NaCl/d) reduced PUN by 42% from 3.48 to 2.02 mg of N/dL at the high CP level (66.9 g of CP/kg of DM), whereas it reduced PUN by only 19% from 1.15 to 0.93 mg of N/dL at the low CP level (41.6 g of CP/kg of DM). Urinary urea N excretion more than doubled upon NaCl addition at the low CP level, but NaCl addition did not affect UUN at the high CP level. Such differences suggest an interactive effect of protein and NaCl intake on the change in UUN per unit of change in PUN. Because MUN is a good indicator of PUN (Roseler et al., 1993), a similar interaction can be expected for MUN. It is unclear, however, whether such an interaction can be expected in lactating dairy cattle because dietary concentrations of CP in dairy cattle rations in practice are 3 to 4 times higher than the 40 to 70 g of CP/kg of DM investigated by Thornton (1970). Furthermore, DMI in dairy cattle is substantially higher than that in steers in the study of Thornton (1970).

The aim of the present study was to examine the effects of protein and NaCl intake separately, and their interaction, on MUN, PUN, UUN, the relationship between MUN and UUN, and the GFR and reabsorption of urea from the glomerular filtrate. Another aim was to study the effect of dietary CP and NaCl on urea transfer to the gastrointestinal tract.

MATERIALS AND METHODS

Cows, Housing, and Experimental Design

The experiment was approved by the Institutional Animal Care and Use Committee of the Animal Sciences Group, Wageningen University and Research Centre (Lelystad, the Netherlands). Twelve second-parity cows, of which 8 had a rumen fistula, were selected based on milk production and presence of a rumen fistula. At the start of the experiment, the cows had BW of 645 ± 37 kg, milk production of 34.0 ± 3.28 kg/d, and were 146 ± 29 d in milk (means ± SD). Cows were housed in a tiestall to quantitatively collect urine and feces. Cows were blocked into 3 groups, according to milk production and presence of a rumen fistula. Cows within blocks were randomly assigned to 1 of 4 treatments. Treatments consisted of 2 dietary concentrations of protein (116 and 154 g of CP/kg of DM) and for each protein content 2 concentrations of NaCl (3.1 and 13.5 g of Na/kg of DM). The ingredients and chemical composition of the diets is presented in Table 1. The experiment had a split-plot arrangement with cow and dietary CP content as the main plot factors and NaCl content as the subplot factor. Each cow received in total 2 dietary treatments. Cows were assigned to either a low or a high protein diet, and within protein level received a low and a high dietary NaCl content, resulting in n = 24 observations. Because of practical limitations, measurements could be carried out on only 6 animals per day. Therefore, the 12 cows were divided into 2 groups of 6 cows each; 7 d after the first group of 6 cows entered the experiment, the second group of 6 cows entered the experiment. This resulted in a partial balanced design with 4 treatments and 6 cows per measurement period and a total number of 4 measurement periods. For each cow, the total length of the study was 38 d. The first 13 d consisted of an adaptation period to the diet with ad libitum feed access; from d 14 until the end of the experiment, cows were fed at 95% of the average ad libitum feed intake based on the cows receiving the low protein diets, excluding NaCl addition. The first 2-d measurement period (collection d 24 and 25) was followed by a 10-d adaptation period to the new diet (high or low NaCl) and followed by a second 2-d measurement period (collection d 37 and 38).

Cows were milked twice daily at 0500 and 1700 h throughout the experiment. During the noncollection days, cows were fed 2 equal meals twice daily at 0500 and 1700 h, whereas during collection days, 67% of the daily feed allowance was provided in 8 equal meals every 2 h, starting at 0500 h until 1900 h, to minimize variation in PUN and MUN caused by variation in feed