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Prediction of ruminal pH of dairy cows fed pasture

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ABSTRACT

Rumen pH as low as 5.6 has been reported in cows fed highly digestible pasture, however, incidences of sub-acute acidosis have not been well documented and there are no easy or reliable means for farmers to measure ruminal pH. This study collated animal and dietary parameters (81 treatment means), from 20 studies of lactating dairy cows fed pasture, to evaluate the relationship between ruminal pH and animal parameters, and identify suitable predictors of ruminal pH. Mean ruminal pH (5.6-6.7) was negatively correlated ($P < 0.05$) with total volatile fatty acid concentration, milk yield, microbial N flow from the rumen, milk protein yield, milk fat yield, total non-structural carbohydrate content and acid detergent fibre content of the diet. No single dietary parameter, or group of parameters, was able to adequately predict ruminal pH. The increase in microbial nitrogen flow, milk, and milk fat production as ruminal pH decreased below 6.2 suggested that the performance of cows fed high quality pasture was not limited when mean ruminal pH decreased to 5.8. This implies that dairy cows fed pasture can tolerate a lower ruminal pH before sub-acute acidosis occurs than when forage-concentrate diets are fed.

Keywords: rumen pH; pasture; acidosis.

INTRODUCTION

Ruminal pH is an important regulator of digestion, as well as being a product of digestion (Owens & Goetsch, 1988). Sub-acute ruminal acidosis occurs when ruminal pH is less than 5.6 (Owens *et al*., 1998). Although ruminal pH values of less than 5.6 (Stockdale, 1994) have been measured in pasture-fed dairy cows, acidosis has not been well documented and there are no easy or reliable means for farmers to measure ruminal pH. Sustained periods of low pH can reduce digestion, ruminal motility, appetite and microbial growth and, therefore, energy intake and absorbed protein (Allen, 1997). This study collated animal and dietary parameters from studies of lactating dairy cows fed pasture to evaluate the relationship between ruminal pH and animal parameters, and to investigate possible predictors of ruminal pH.

METHODS

For analysis of the empirical relationship between ruminal pH and independent dietary and animal parameters, a database was developed from 20 pasture-based studies that comprised 81 treatment means (Bargo *et al.*, 2000; Carruthers & Neil, 1997; Carruthers *et al*., 1997; Dalley *et al*., 2001; Delagarde *et al*., 1997; Dillion *et al*., 1989; E.S. Kolver, 1992 unpublished data; Mackle *et al*., 1996; Mambrini & Peyraud, 1994; O'Mara *et al*., 1997; Penno, 2001; Peyraud *et al*., 1997; Stakelum, 1993; Stockdale, 1994; Van Vuuren *et al*., 1986; Van Vuuren *et al*., 1992; Van Vuuren *et al*., 1993; Wales *et al.*, 2001; Wanjaya *et al.*, 1993; Y.J. Williams, 2001 unpublished data). Only studies in which ruminal pH had been measured three or more times throughout the day using ruminally cannulated lactating dairy cows were used. Treatment means were only included if fresh pasture made up greater than 70% of the diet. This dataset represents 374 cows, and an average of 8.4 cows per treatment. The mean, standard deviation, range, and number of treatments used in this analysis are shown in Table 1. Some of the data were incomplete, which necessitated the following calculations or assumptions.

TABLE 1: Mean and range of ruminal pH and selected dietary and animal parameters for lactating dairy cows eating pasture-based diets.

Factor	Average	SD[1]	Range	Number[2]
Ruminal pH	6.16	0.22	5.6-6.7	81
Total VFA (m*M*)	131.6	19.7	89-182	61
Milk yield (kg/d)	18.7	4.88	9.5-28.2	60
Milk fat yield (kg/d)	0.80	0.16	0.48-1.08	59
Milk protein yield (kg/d)	0.60	0.14	0.33-0.95	59
Metabolisable energy (MJME/kg DM)	12.0	0.67	10.6-13.2	34
NDF digestibility (%)	71.0	6.89	58-79	15
Microbial N flow (g N/d)	224.8	58.0	107-318	22
ADF (% of DM)	22.4	4.01	14.6-28.7	34
NDF (% of DM)	41.6	6.03	25.4-52.8	73
TNC (% of DM)	20.4	7.58	6.7-35.8	46

[1] Standard deviation.
[2] Number of treatment means from the literature (Bargo *et al.*, 2000; Carruthers & Neil, 1997; Carruthers *et al*., 1997; Dalley *et al.*, 2001; Delagarde *et al*., 1997; Dillion *et al*., 1989; E.S. Kolver, 1992 unpublished data; Mackle *et al*., 1996; Mambrini & Peyraud, 1994; O'Mara *et al.*, 1997; Penno, 2001; Peyraud *et al*., 1997; Stakelum, 1993; Stockdale, 1994; Van Vuuren *et al*., 1986; Van Vuuren *et al*., 1992; Van Vuuren *et al*., 1993; Wales *et al.*, 2001; Wanjaya *et al.*, 1993; Y.J. Williams, 2001 unpublished data).

Twenty-four treatment means were derived from the study of Penno (2001) by pooling data on a seasonal basis for cows in early, mid and late lactation. Estimates of metabolisable energy (ME), neutral detergent fibre (NDF, % of DM) and acid detergent fibre (ADF, % of DM) of supplements used by Penno (2001) were based on National Research Council (1989) values, except for chopped hay and soybean meal NDF, which were obtained from the feed library of the Cornell Net Carbohydrate Protein System model (Version 3.1). The total non-structural carbohydrate content (TNC, % of DM) of supplements used by Penno (2001) were estimated based on DM less ash, crude protein, NDF and fat.

The NDF content of beetpulp (O'Mara *et al*., 1997) was estimated based on data from Frank O'Mara (*pers. comm*.). For the studies of Carruthers & Neil (1997) and Carruthers *et al.* (1997) it was assumed that the supplements of dextrose and starch contained no NDF. It should also be noted that the TNC values for the studies of Carruthers & Neil (1997), Carruthers *et al*. (1997), Mackle *et al*. (1996), Peyraud *et al*. (1997) and Stakelum (1993) excluded starch, whereas those of E.S. Kolver (1992, unpublished data) and Van Vuuren *et al*. (1993) included starch.

The relationships between ruminal pH and each animal and dietary parameter were evaluated by regression analysis using Genstat5 (Version 4.1). A number of subsets of the database were used to determine whether significantly greater variation could be explained by multiple regression. However, multiple regression analysis did not significantly increase the amount of variation in pH that could be explained. When stepwise regression was used to derive an equation predicting ruminal pH from dietary parameters, there was no significant improvement compared to using TNC alone as a predictor.

RESULTS

Mean ruminal pH ranged from 5.6 to 6.7. Ruminal pH was negatively correlated with ruminal total volatile fatty acid (VFA) concentration, TNC, milk yield, microbial N flow from the rumen, milk protein yield, ADF and milk fat yield (Table 2). In contrast ruminal pH was positively correlated with NDF digestibility. Ruminal pH was not significantly correlated with ME or NDF.

TABLE 2: Relationship between ruminal pH and various dietary and animal parameters for lactating dairy cows fed pasture-based diets.

	P	r^2	m	SE
Animal factors (x)				
Total VFA (m*M*)	<0.001	0.53	-0.0087	0.0011
NDF digestibility(%)	0.050	0.26	0.0154	0.0071
Milk yield (kg/d)	<0.001	0.24	-0.0234	0.0054
Microbial N flow (g N/d)	0.021	0.24	-0.0017	0.0007
Milk protein yield (kg/d)	<0.001	0.23	-0.8130	0.1970
Milk fat yield (kg/d)	<0.001	0.21	-0.6840	0.1750
Dietary factors (x)				
TNC (% of DM)	<0.001	0.28	-0.0130	0.0032
ADF (% of DM)	0.012	0.18	-0.0214	0.0081
NDF (% of DM)	0.088	0.04	NS	NS
Metabolisable energy (MJME/kg DM)	0.247	0.04	NS	NS

m = increase in ruminal pH per unit increase in x.
NS: not shown as P was not significant.

Only total VFA concentration was highly correlated ($P < 0.001$; $r^2 = 0.53$) with ruminal pH (n = 61). Ruminal pH was poorly correlated with dietary components, with TNC the dietary component most strongly correlated ($P < 0.001$; $r^2 = 0.28$) with pH.

DISCUSSION

Contrary to traditional thinking (Hoover, 1986; Mertens, 1997), ruminal pH was negatively correlated with animal parameters (microbial N flow, milk yield, milk protein yield and milk fat yield) when ruminal pH was less than 6.2. The negative relationship between ruminal pH and microbial N flow is consistent with the relationship determined when pasture was fermented *in vitro* (de Veth & Kolver, 2001). In the study of de Veth & Kolver (2001) microbial N flow was optimised at pH 6.1. Although the data analysed in the present study had a relatively narrow mean pH range (5.6-6.7), the regression relationships indicated that the performance of dairy cows fed 81 pasture-based diets in six countries was not adversely affected by a mean ruminal pH of 5.8 to 6.2. Based on the current diagnostic measures of reduced intake and milk production, these results indicate that dairy cows fed good quality pasture are not in a state of sub-acute acidosis when ruminal pH is low (5.8 to 6.2).

Although a large amount of variation in ruminal pH was not explained by any single animal or dietary parameter analysed, it is likely that ruminal pH was correlated with a number of these parameters. The lack of relationship observed here may have occurred because insufficient data were analysed, preventing identification of parameters correlated with ruminal pH. In addition, because many of the parameters are inherently linked, different parameters are likely to have explained the same variation. For example, milk fat and protein yield were probably autocorrelated when dairy cows were fed highly digestible pasture.

Although the use of collated data from different studies and the estimation of some parameters may have introduced variability, we have tried to minimise the impact of such factors. The diets used in the studies varied, however, all studies fed temperate pasture species and only treatment means were used if fresh pasture made up greater than 70% of the diet. While some of the data was incomplete and necessitated assumptions, where possible estimated parameters were derived from published feed tables. Non-linear correlation was also evaluated in this study, with only milk volume, milk fat, and milk protein yield showing a quadratic response. However, no more variation was explained than that explained by linear analysis.

The lack of a strong relationship between ruminal pH and dietary parameters is consistent with the findings of others. Analyses of similar data sets based on concentrate diets (Pitt *et al*., 1996; Allen, 1997) have shown a poor relationship between ruminal pH and NDF. Pitt *et al*. (1996) reported that only 30% of the variation in ruminal pH was explained by NDF content. They found that the relationship was not stronger because NDF does not account for fibre effectiveness. When an estimate of effective neutral detergent fibre (eNDF) was made, 52% of the variation in ruminal pH was accounted for by eNDF.

Of the dietary parameters analysed, only TNC and ADF were significantly related to ruminal pH. The regression coefficients of these relationships were negative, suggesting that either reducing TNC or ADF would increase pH. The negative relationship between ruminal pH and TNC was expected, as higher levels of dietary TNC decrease chewing and ruminating, reduce rumen motility, change organic acid production, and reduce buffering capacity of the feed, all of which lead to lowered ruminal pH (Owens & Goetsch, 1988).

The negative relationship between ruminal pH and ADF was surprising. The ADF fraction of the diet, cellulose and lignin, plays an important role in the buffering of the rumen. The anomaly between what was found in this study and that which would be expected from a biological basis may relate to the small number of treatment means (n = 34) and the narrow range of ADF (14.6-28.7 %/DM). However, in a similar analysis with lactating cows fed concentrate-forage diets Allen (1997) found the relationships between most of the dietary factors and ruminal pH were poor and the opposite to that expected.

CONCLUSION

This analysis highlights the multifaceted nature of ruminal pH regulation. While no single dietary parameter may be used to predict ruminal pH with high reliability, the analysis clearly shows that high milk yield, VFA production and microbial growth occur in association with a ruminal pH considered low by overseas recommendations.

Further development of the database described here will allow dietary recommendations to be refined for pasture-based systems. However, it is likely that a single adequate predictor of ruminal pH may not be found until an accurate estimate of eNDF in pasture, and understanding of how eNDF varies as quality changes, is obtained.

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