MATHEMATICAL SIMULATION OF FEED INTAKE BY GRAZING BEEF CATTLE

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Story in Brief

Various computer programs are available to stocker operators to assist in economic decisions about stocker cattle. However, accuracy of economic forecast is limited by imprecise predictions of feed intake, affecting weight gains. The conceptual basis and differential equations of a mathematical model to predict forage intake has been developed which can account for the effect of supplementation in the grazing beef steer. A previously evaluated dynamic rumen function model was employed as the fermentation component of the model and the model is based on the assumption that forage intake by the grazing ruminant is limited by rumen fill. Mathematical equations that describe nutrient utilization, synthesis and passage are described.

(Key Words: Mathematical Model, Forage Intake, Stocker Cattle)

Introduction

Considerable evidence exists which suggests that feed intake of cattle grazing predominantly forage based diets, below 66% in digestibility is limited by the capacity of the reticulo-rumen and the rate of clearance from this organ (Conrad, 1966; Ellis, 1978). This implies that rate of passage, rate of digestion and ruminal fill are important factors regulating feed intake. When supplements are added to a forage diet, changes in forage intake occur due to changes in digestion and passage associated with the additional nutrients. Because of the complexity of the interaction between the supplement and forage, simple regression relationships are inadequate to define relationships beyond the range of data for which the relationship is developed.

Previously, a dynamic rumen model was evaluated to determine its potential use in predicting intake of grazing ruminants and accounting for supplementation affects on forage intake. The model responded appropriately with regard to energy supplementation. Therefore, the structure of the rumen model has been adopted as the fermentation component of a feed intake model for beef cattle. The work presented here is based on the hypothesis that rumen fill governs intake for cattle consuming forage based diets. This mechanistic approach to control of forage intake should be adaptable to various supplement compositions and different forage types. A description of differential equations used in the model are described.

Materials and Methods

The dynamic model of rumen function (France et al., 1982) was utilized as the fermentation component for a feed intake model.

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Initially, the rumen model simulated a mature wether sheep (50 kg) eating a reference Italian ryegrass forage diet at 1.5% of body weight (Hyer and Oltjen, 1987). Genetic size scaling rules (Taylor, 1980) based on mature body size relationships were utilized to adjust the rate and state variables of this model to beef cattle. State variables and nutrient fractions have been described previously (Hyer and Oltjen, 1987) however, a definition of each dietary fraction is given in Table 1. To simulate the processes of digestion and passage as they occur within the rumen, nutrient fractions are partitioned into those that flow from the rumen at the particulate rate of passage (PPR) and at the liquid rate of passage (LPR) (Table 2). Those components that are rapidly solubilized flow with the faster LPR and the fibrous fractions of the feed pass out at the PPR. It was assumed that 50 percent of the microbial population flows with the liquid and 50% with the particulate phase.

It was assumed that forage intake is limited by a level of fill in the rumen. Rumen fill (RF) is considered to be the sum of the nutrient pools within the rumen. Once rumen fill is determined, an iterative procedure is used to adjust organic matter intake so that a given level of rumen fill at steady state conditions is reached. Three days are required to achieve steady state with an integration interval of .002 d.

Table 1. Principal variables used in the model.

Symbol	Description
AH	alpha hexose pool (starch)
BH	degradable beta-hexose pool (digestible cellulose)
BUG	pool of microbial matter (microbial mass)
NBH	non-degradable rumen beta-hexose (indigestible cellulose)
NPN	non-protein nitrogen pool (NPN)
NPROT	rumen non-degradable protein pool (bypass protein)
PROT	rumen degradable protein pool (degraded protein)
RV	rumen metabolic volume
WSC	water soluble carbohydrate pool (soluble carbohydrate)

Table 2. Nutrient fractions flowing with the particulate and liquid phase.

Liquid	Particulate
NPN	AH
WSC	BH
BUG[1]	NBH
	BUG[1]
	PROT
	NPROT

[1] 50% of the microbial mass flows with each phase.

Results and Discussion

A differential equation is used to describe the change of each nutrient pool. The metabolic volume of the rumen (RV, l) is defined as the effective volume where various reactions occur within the rumen (France et al., 1982).

$$RV = 75 * (BW/MBW)$$

where BW is empty body weight (kg) and MBW is mature BW (kg). Hence, RV for a mature medium framed steer (MBW, 750 kg) is 75 l. The ratio of BW to MBW adjusts rumen volume by mature body size. This adjustment also assumes that RV increases in proportion to BW to the first power.

Over time, steady state conditions occur within the rumen:

$$dRV/dt = DV + SV - v$$

where DV and SV are rates of fluid inflow from dietary and salivary sources, respectively and v is the rate of outflow of fluid and associated digesta from the rumen. Osmotic pressure effects on absorption rates are not directly measured in the model. It was assumed that in a steady state situation over one day, osmotic pressure effects sum to zero.

Initial passage rate estimates were determined to be 4 and 10%/hour for the PPR and LPR (M.L. Galyean, personal communication). Rates of passage (ROP) were related to dry matter intake (DMI (kg/d) by a linear relationship:

$$PPR\ (\%/h) = .04 *(.25 + .75 * (DMI/DMI_{ref}))$$

$$LPR\ (\%/h) = .10 * (.50 + .50 * (DMI/DMI_{ref}))$$

where: $DMI_{ref}\ (g/d) = (BW/\ MBW * 8055)$.

Estimates for the intercept and slope of each equation were determined from literature values.

The non-degradable components of the diet in the rumen (NBH and NPROT, g/l) are undigested and must flow from the rumen:

$$dNBH/dt = 1/RV * (DNBH - NBH * PPR * 24 * RV)$$

$$dNPROT/dt = 1/RV * (DNPROT - NPROT * PPR * 24 * RV)$$

DNBH and DNPROT represent the dietary proportion (g/d) of the NBH and NPROT. The rate at which NBH and NPROT pass out of the rumen is a function of the nutrient pool (NPROT, NBH) and PPR. The remainder of the nutrient pools and the microbial population within the rumen change according to the following:

Substrate pool change = inflow - outflow + synthesis - utilization

where synthesis occurs due to the degradation of forage components by enzymes and utilization is the rate at which the microbial populations utilize nutrients (France et al., 1982). The dynamic properties of AH, DBH and DPROT (g/l) are:

dAH/dt = 1/RV*(DAH - AH * PPR * 24 * RV)-KAH * AH * BUG

dBH/dt = 1/RV*(DBH - BH * PPR * 24 * RV)-KBH * BH * BUG

dPROT/dt = 1/RV*(DPROT - PROT * PPR * 24 * RV) - KPROT * PROT * BUG

again DAH, DBH, and DPROT are dietary inputs (g/d) of AH, BH and PROT, respectively. The utilization rate of each nutrient is dependent on the quantity of available substrate in the nutrient pool (AH, BH and PROT), the concentration of the microbial population (BUG, g/l) and the rate constants for nutrient use (KAH, KBH, KPROT). Rate constants were estimated by solving the equations for a 50 kg sheep eating the reference Italian ryegrass forage at 1000 g/d. Estimates of .407, .460 and .262 were calculated for KAH, KBH and KPROT, respectively. Each rate constant was multiplied by 10 to the -.27 power to account for the differential rates between a mature wether (MBW, 75 kg) and a mature steer (Taylor, 1980).

Inputs of NPN into the animal are from the diet (DNPN), the saliva (SNPN), the degradation of degradable protein by the microbial population (DGNPN) and the non-protein nitrogen released by microbial catabolism (MCNPN). Utilization of NPN is by outflow from the rumen (ONPN) and usage by the microbial population for maintenance and growth (MGNPN):

dNPN/dt = 1/RV * (DNPN+SNPN+DGNPN - MGNPN-NPN*LPR) + MCNPN

Inflow to the soluble carbohydrate pool (WSC, g/l) can come from four sources: dietary (DWSC), degradation of AH (DGAH) and BH (DGBH) by enzymes and soluble carbohydrate released by microbial catabolic activity (MCSC). Outflow is by flow from the rumen (FWSC) and microbial growth (MGWSC):

dWSC/dt = 1/RV * (DWSC+DGAH+DGBH-FWSC-MGWSC) + MCWSC

Microbial growth (GBUG) is represented:

GBUG = U * RV * BUG

where: U= Um*1/(1+Kc/WSC+Kn/NPN+Kcn/(WSC*NPN))

which is the specific growth rate of the population dependent on the availability of NPN and WSC. Um is the maximum value of U as WSC and NPN go to infinity and Kc, Kn and Kcn are constants (France et al., 1982). When substrate is limiting for microbial growth and maintenance, microbial catabolism (DBUG) occurs:

DBUG= λ * RV * BUG

where: $\lambda = \lambda_u$ * 1/(1+Ku*U) lambda (λ) is the specific rate of catabolism per day and is a function of U and a constant (Ku), where λ_u is the maximum rate of obtained when G=0. The rate of change of the BUG:

$$dBUG/dt = 1/RV*(U*BUG+\lambda*BUG-PBUG*BUG*LPR)-1/RV*(1-PBUG)*PPR*24*BUG*RV$$

where PBUG is equivalent to the portion of the BUG that passes from the rumen according to the liquid rate of passage.

Rumen fill (RF) is determined by taking the sum of each of the nutrient and microbial pools within the rumen on a concentration basis:

$$RF = AH + BH + BUG + NBH + NPN + NPROT + PROT + WSC$$

RF was estimated using flow rates from the reference forage diet (Hyer et al., 1987).

Primary driving equations for a broad based feed intake model that quantifies supplementation effects on forage intake have been developed. Integration of digestion and passage with rumen fill parameters allows the effects of small amounts of supplements to be integrated into the model. Further work will be directed toward evaluation of the model with different forage types.

The feed intake model has application to both research and production situations. As a research tool, a conceptual basis for the quantification of energy supplementation effects on forage intake has been developed. As additional information on forage type and substitution effects becomes available, the model can be further evaluated and refined. As a production tool, the intake model can be implemented into larger cattle production models or current economic models for stocker operators.

Literature Cited

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