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Can a mathematical model accurately predict intake of grazing animals? Testing the Q-Graze model

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ABSTRACT

A decision support model, Q-Graze, was developed to assist farmers with grazing management decisions based on visual assessments of pasture quality. To evaluate the model's ability to predict dry matter intake and diet composition, it was tested against pre- and post-grazing herbage mass and composition data from a trial conducted at the Whatawhata Research Centre involving bulls and steers grazing mixed-species hill pasture. Q-Graze was able to predict apparent intakes of grass leaf, grass stem, legume, weed, dead material and total dry matter with means and residual standard deviations 6.4 ± 1.5, 0.6 ± 1.3, 1.3 ± 0.7, 1.2 ± 0.8, 1.5 ± 1.4 and 10.6 ± 2.3 kg DM per animal per day, respectively. These predictions accounted for R^2 = 83%, 15%, 76%, 73%, 54% and 55%, respectively of the variation in the apparent intakes calculated from the data. This indicates that Q-Graze is able to predict herbage intake and diet selection of cattle grazing mixed hill-country pastures to a high degree of correlation. The limiting factor was the measurement error of pre- and post-grazing herbage mass, rather than the model design. Model testing for additional animal and pasture types is currently being undertaken.

Keywords: diet selection; rotational grazing; model calibration; metabolisable energy; energy demand; cattle.

INTRODUCTION

Accurate feeding of livestock on pasture depends on the ability to predict what animals eat while grazing. However, predicting grazing behaviour and intake is complicated because of the interplay between herbage mass, bite size, bite composition, rate of digestion and energy metabolism. As a result, mathematical models are the most appropriate tool for assisting farmers to make grazing management decisions on farm.

Because the determinants of intake—feed availability and composition, animal digestive capacity and appetite—change through time, particularly under rotational grazing, integration of the ingestive, digestive and energetic constraints to intake must take place *instantaneously* (Demment *et al.*, 1995). Outcomes such as daily intake and grazing time can then be calculated by integrating through time. While rumen and metabolite dynamics are often modelled in this way (Hyer *et al.*, 1991; Illius & Jessop, 1996; Sauvant *et al.*, 1996), the effects of ingestive and behavioural constraints to intake are usually neglected in these models (Poppi *et al.*, 1994). On the other hand, models constructed to predict intake of grazing animals have tended to combine the ingestive, digestive and energetic constraints in an *ad hoc* fashion (Doyle *et al.*, 1989; Blackburn & Kothmann, 1991; Freer *et al.*, 1997), instead of instantaneously. Because of this, they fail to capture the dynamic interactions between herbage availability and composition, intake and pasture growth rates, and the nutritional status and appetite of the animals.

This paper describes the calibration of a dynamic intake model that integrates ingestive, digestive and energetic constraints to intake continuously through time. This model is embedded in a farmer decision support tool called "Q-Graze". The details of the model equations will be published elsewhere.

The Q-Graze Model

The Q-Graze decision support model was developed to calculate dry matter intake, diet composition and liveweight gain outcomes from grazing management decisions. The purpose of the model was to help farmers use field measurements of pasture quality to make grazing management decisions. The model was developed as part of a wider Meat NZ-funded project aimed at providing New Zealand sheep and beef farmers with tools to measure pasture quality and then to use this information to manage animal growth (Lambert *et al.*, 2000).

Q-Graze was coded as a Microsoft Excel spreadsheet. The farmer enters pasture, stock and grazing management information as shown in Figure 1, and the model then predicts changes in herbage mass and quality, intake and liveweight gain forward through time. This allows the farmer to check that liveweight gain targets will be met, and if not, to alter his or her grazing plan accordingly.

Underlying Q-Graze is a differential equation model of intake that calculates bite size, bite composition, bite handling time, ruminating time and grazing time of animals grazing mixed pasture. The flow of information used by the model to calculate instantaneous dry matter (DM) and metabolisable energy (ME) intake rates is shown in Figure 2. These are then integrated continuously through time to predict post-grazing herbage mass and composition (Figure 3), and daily dry matter intake.

A key feature of the intake model is the calculation of feeding effort (*FE*), which is the proportion of time spent feeding (grazing or ruminating), that is, the time derivative of daily feeding time (grazing time plus ruminating time). In the model, feeding effort is predicted from the ratio of animals' daily energy demand and instantaneous energy intake rate. Daily dry matter intake and diet composition are then calculated by integrating the differential equation,

$$\frac{dDMI_i}{dt} = FE \; \frac{BW_i}{TBT} \qquad (1)$$

forward through time for one day, where DMI_i (kgDM animal^{-1} d^{-1}) is the daily dry matter intake of herbage component *i*, BW_i (kgDM bite^{-1}) is the average amount of herbage component *i* in each bite, and *TBT* is the total processing time per bite (prehension plus mastication plus

FIGURE 1: The Q-Graze model interface, showing all input variables.

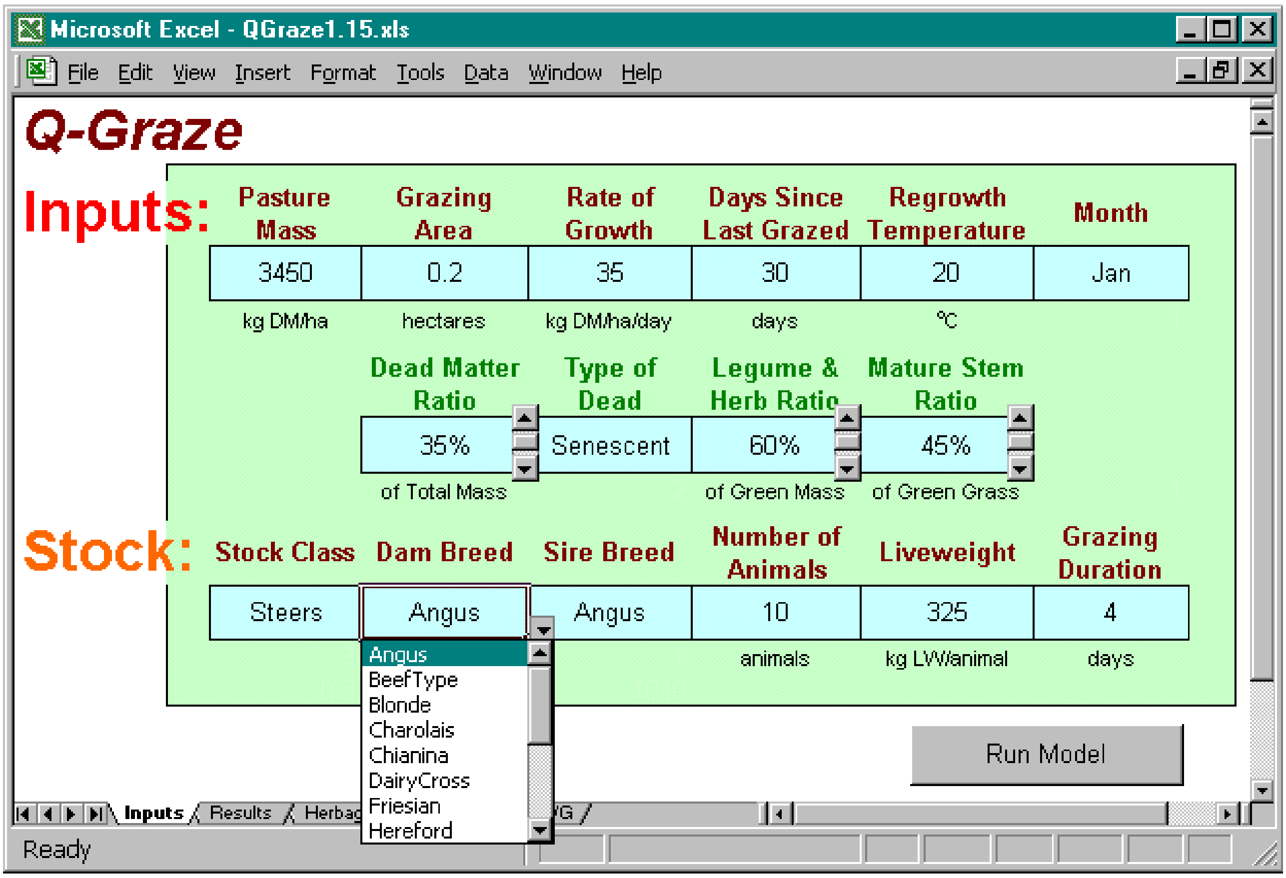
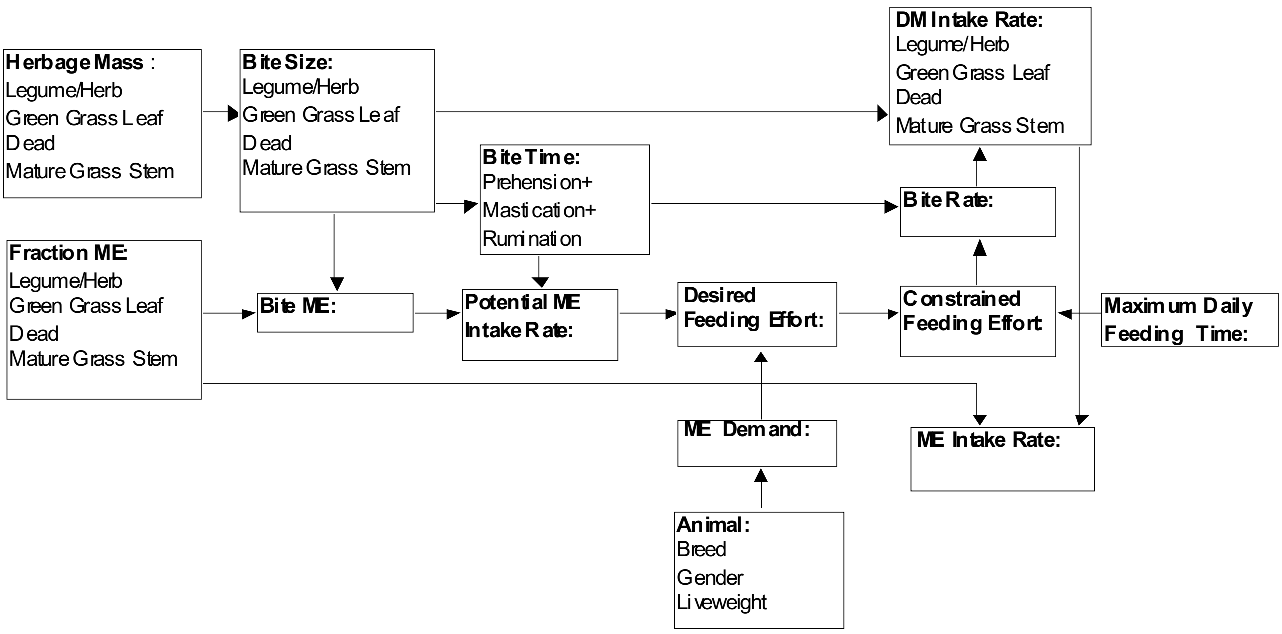


FIGURE 2: Flow of information used to calculate instantaneous feeding effort, and dry matter (DM) and metabolisable energy (ME) intake rates in the Q-Graze intake model.



rumination). The variables on the right hand side of Equation 1 change continuously through time in response to changing herbage and animal state (Figure 2).

In order to prepare Q-Graze for field testing by farmers, it was necessary to calibrate it to field data to check that the model was able to reproduce intake and liveweight gain responses measured in the field (Rykiel, 1996). The current paper reports the results of the first stage of this exercise, the calibration of the dry matter intake sub-model.

Calibration Data

Because few trials directly measure animal intake, the model was calibrated using pre- and post-grazing herbage mass and composition data from a trial conducted at the Whatawhata Research Centre, near Hamilton, during 1995 and 1996. This trial examined the effects of time of year on the growth rates of Friesian bulls and Angus steers grazing mixed-species pasture in a hill-country environment, without supplementation. Mobs of ten bulls or steers were rotationally grazed at each of three allowances (low, medium or high, defined by target post-grazing residual), and detailed pasture and animal measurements collected over three eight-week measurement periods (winter, spring and summer). Cattle were managed so that treatments had similar pre-grazing herbage masses (2400 kgDM ha^{-1} in winter and spring, 3500 kgDM ha^{-1} in summer) and grazing durations (average 3.5 d); and land area was adjusted to provide contrasting post-grazing residuals (600, 1050 and 1500 kgDM ha^{-1}, respectively, for the low, medium and high treatments in winter and spring, and 1500, 2000 and 2500 kgDM ha^{-1} for the same treatments in summer). This resulted in 288 grazing records (3 seasons by 3 allowances by 2 stock classes by 16 grazing breaks per period) covering a variety of pasture conditions. For each grazing break (2 to 6 days in duration) animal live weight estimates were available, as were pre-grazing herbage mass, composition and ME measurements, and pasture growth rate estimates. At the conclusion of each break post-grazing herbage mass, composition and ME were again measured.

Pre- and post-grazing herbage mass was measured using calibrated visual assessment (Haydock & Shaw, 1975). Pre- and post-grazing herbage samples were collected for all grazings by hand plucking to ground level. This was necessary to estimate the composition to herbage removed. These samples were subsequently subsampled and dissected into grass leaf, green grass reproductive stem, dead grass reproductive stem, legume, weed and dead material. For the purpose of fitting the intake model, dead stem data was combined with dead material data, and a weed fraction was added to the model. The pre-grazing herbage masses and composition were similar between the winter and spring seasons. However, pre-grazing herbage masses in late summer were higher, and had a higher proportion of grass stem and dead material.

Model accuracy was assessed by comparing model predictions of apparent dry matter intake (ADMI) and diet composition with the field measurements. Apparent dry matter intake of a herbage component k was defined as,

$$ADMI_k = \frac{Pre_k - Post_k}{NT}\, A \qquad kgDM\ animal^{-1}\ d^{-1} \quad (2)$$

where Pre_k and $Post_k$ are the pre- and post-grazing herbage mass of component k, N is the mob size, T is the grazing duration and A is the paddock area. This calculation assumes that intake is the only mechanism affecting herbage dynamics—the effects of animal trampling and fouling, and of herbage growth, turnover and decomposition on herbage mass dynamics are ignored.

EVALUATING THE MODEL

Q-Graze was used to simulate all 288 grazing breaks, and to predict post-grazing herbage mass and composition (Figure 3). The model was then calibrated to the data set by adjusting 11 internal parameters in order to minimise the combined sum of $(Post_k - Post_k^*)^2$ over all five herbage components. Where $Post_k^*$ is the post-grazing herbage mass of components k predicted by the model. These parameters were then used to calculate predicted apparent DM intake ($ADMI_k^*$) for comparison to the data (Equation 2), using the formula,

$$ADMI_k^* = \frac{Pre_k - Post_k^*}{NT}\, A \qquad kgDM\ animal^{-1}\ d^{-1} \quad (3)$$

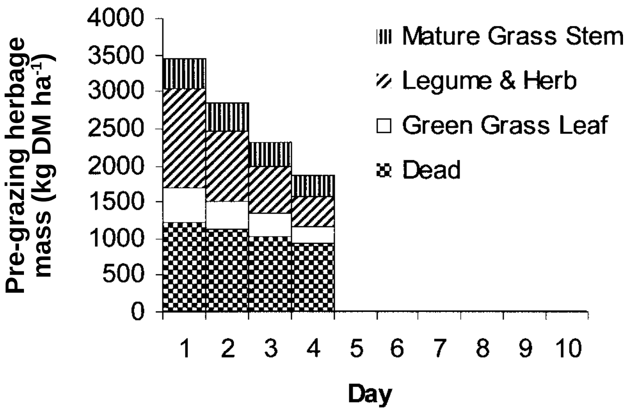
where the asterisk refers to a model predicted value (as opposed to a measurement value). Table 1 gives the average values of $ADMI_k$ and the best-fit values of $ADMI_k^*$.

The accuracy of computer models can be evaluated by calculating the standard deviation of the residuals (RSD). The RSD_k for each herbage component k was calculated as,

$$RSD_k = \sqrt{\frac{1}{(288-11)}\sum_{j=1}^{288}\left(ADMI_k - ADMI_k^*\right)^2} \qquad \text{kgDM animal}^{-1}\ \text{d}^{-1} \quad (4)$$

where j = 1 to 288 is the number of the grazing record. The best-fit value of RSD_k for each herbage component is reported in Table 1. RSD is related to the more common R^2 statistic, which indicates the percentage of the variation (sum of squared deviations from the mean) in the data ($ADMI_k$) which is explained by the model. Equivalent values of R^2 are also given in Table 1.

FIGURE 3: Sample output from Q-Graze, showing herbage dynamics over a grazing break of 4 days for the scenario specified in Figure 1. On each day, the herbage mass at the beginning of that day is displayed. Weed material has been pooled with legume and herb in this graph.



The value of RSD reflects not only model deviations from the data, but also any measurement error in the data. The RSD_k values in Table 1 could therefore be due either to lack of model fit or to measurement errors in Pre_k and $Post_k$ of magnitude E_k (also given in Table 1). The actual herbage measurement errors in the Whatawhata trial are unknown. For purposes of comparison, therefore, the standard errors (KE_k) of the herbage fraction measurements of Korte *et al.* (1984) are also given in Table 1.

TABLE 1: Comparison of apparent daily dry matter intakes calculated from the Whatawhata trial ($ADMI_k$) with predictions made by the Q-Graze model ($ADMI_k^*$). RSD_k is the standard deviation of the residuals. R^2 is the percentage of the $ADMI_k$ data variation explained by the model. E_k is the herbage mass measurement error that would generate the same value of RSD_k. KE_k is the standard error of herbage measurements of Korte *et al.* (1984).

Fraction	$ADMI_k$ (kgDM d^{-1})	$ADMI_k^*$ (kgDM d^{-1})	RSD_k (kgDM d^{-1})	R^2	E_k (kgDM ha^{-1})	KE_k (kgDM ha^{-1})
Grass leaf	6.5	6.4	1.5	83%	82	183
Dead	1.7	1.5	1.4	54%	80	239
Legume	1.2	1.3	0.7	76%	38	136
Weed	1.1	1.2	0.8	73%	45	154
Grass stem	0.3	0.6	1.3	15%	71	204
Total	10.6	10.6	2.3	55%	130	417

DISCUSSION

The calibration results (Table 1) show that the model was able to accurately reproduce the values of total *ADMI* observed in the 288 grazing records in the data set. The average error of these predictions was around 20% of total *ADMI*, and explained R^2 = 55% of the variation in the data, which, considering the complexity of the factors affecting dry matter intake (Woodward *et al*., 2000), represents an excellent result.

The model predictions of individual herbage component $ADMI_k$ were relatively less accurate than the predictions of total *ADMI*. This was because the fitting procedure was designed to give the best fit of total *ADMI* by weighting the herbage components equally, so that the RSD_k of the components were approximately equal. This meant that the relative accuracy of individual herbage component $ADMI_k$ declined with the quantity of that component in the diet. Therefore, because grass leaf comprised 60% of the total diet on average, due to its relative abundance and the fact that animals select leaf in preference to stem or dead material (Penning *et al.*, 1994; Prache, 1997), it was the only intake component predicted with a high degree of accuracy .

Given the large variances observed in herbage mass measurements in other studies (e.g., Korte *et al*., 1984—KE_k, Table 1), it is likely that a significant portion of the RSD_k values could be explained by herbage mass measurement errors alone. The reported values of R^2 nevertheless indicate that the model was able to explain a large proportion of the variation in the observed $ADMI_k$ of the herbage components, except in the case of grass stem. The low R^2 for grass stem simply reflects the fact that very little of this component was eaten (Table 1), resulting in highly inaccurate values of $ADMI_k$ for this component.

The authors are not aware of any other study that has attempted to evaluate the dry matter intake and diet composition predictions of a grazing model against experimental data. Doyle *et al*. (1989), Blackburn & Kothmann (1991) and Freer *et al*. (1997) all presented dry matter intake models for grazing livestock, but none of these authors provided validation of their model against field data.

The overall level of agreement between the model predictions of apparent intake and composition and the data indicated that the Q-Graze intake model predicted the bulls' and steers' daily intake and selection with a relatively high degree of accuracy. Statistical analysis showed that the accuracy of the model was limited not by the model design itself, but by the low accuracy of the pre- and post-grazing herbage mass data. An improved calibration would be possible only with greatly improved data. However the accuracy of herbage mass measurements is limited by the inherent variability in all pastures, so that highly accurate measurements might not be achievable in practice (Cosgrove *et al*., 1998).

Further testing of Q-Graze, including the liveweight gain sub-model, is currently being carried out against additional data sets. This will enable the model to be used with confidence at other New Zealand sites, and with sheep. With modification, the model is also suitable for predicting grazing intakes of cows and calves or ewes and lambs, and for predicting intakes of animals eating a wider range of feed types, including green feed crops, hay or silage. Intake of continuously grazed animals may also be estimated, provided the model is combined with a suitable model to predict non-grazing tissue turnover. As shown in this paper, adaptation of the model to these systems depends on the existence of suitable data sets for calibration.

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REFERENCES

Blackburn, H.D.; Kothmann, M.M. 1991: Modelling diet selection and intake for grazing herbivores. *Ecological modelling 57*: 145-163.

Cosgrove, G.P.; Betteridge, K.; Thomas, V.J.; Corson, D.C. 1998: A sampling strategy for estimating dairy pasture quality. *Proceedings of the New Zealand society of animal production 58*: 25-28.

Demment, M.W.; Peyraud, J.-L.; Laca, E.A. 1995: Herbage intake at grazing: A modelling approach. *In*: Journet, M.; Grenet, E.; Farce, M.-H.; Theriez, M.; Demarquilly, C. *ed*. Recent Developments in the Nutrition of Herbivores: Proceedings of the IV International Symposium on the Nutrition of Herbivores, Clermont-Ferrand, France, 11-15 September 1995, 121-141.

Doyle, C.J.; Baars, J.A.; Bywater, A.C. 1989: A simulation model of bull beef production under rotational grazing in the Waikato region of New Zealand. *Agricultural systems 31*: 247-278.

Freer, M.; Moore, A.D.; Donnelly, J.R. 1997: GRAZPLAN: Decision support systems for Australian grazing enterprises: II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural systems 54*: 77-126.

Haydock, K.P.; Shaw, N.H. 1975: The comparative yield method for estimating dry matter yield of pasture. *Australian journal of experimental agriculture and animal husbandry 15*: 663-670.

Hyer, J.C.; Oltjen, J.W.; Galyean, M.L. 1991: Development of a model to predict forage intake by grazing cattle. *Journal of animal science 69*: 827-835.

Illius, A.W.; Jessop, N.S. 1996: Metabolic constraints on voluntary intake in ruminants. *Journal of animal science 74*: 3052-3062.

Korte, C.J.; Watkin, B.R.; Harris, W. 1984: Effects of the timing and intensity of spring grazings on reproductive development, tillering, and herbage production of perennial ryegrass dominant pasture. *New Zealand journal of agricultural research 27*: 135-149.

Lambert, M.G.; Paine, M.S.; Sheath, G.W.; Webby, R.W.; Litherland, A.J.; Fraser, T.J.; Stevens, D.R. 2000: How do sheep and beef farmers measure pasture quality? *Proceedings of the New Zealand Grassland Association 62*: 117-121.

Penning, P.D.; Parsons, A.J.; Orr, R.J.; Hooper, G.E. 1994: Intake and behaviour responses by sheep to changes in sward characteristics under rotational grazing. *Grass and forage science 49*: 476-486.

Poppi, D.P.; Gill, M.; France, J. 1994: Integration of theories of intake regulation in growing ruminants. *Journal of theoretical biology 167*: 129-145.

Prache, S. 1997: Intake rate, intake per bite and time per bite of lactating ewes on vegetative and reproductive swards. *Applied animal behaviour science 52*: 53-64.

Rykiel, E. J. 1996: Testing ecological models: the meaning of validation. *Ecological modelling 90*: 229-244.

Sauvant, D.; Baumont, R.; Faverdin, P. 1996: Development of a mechanistic model of intake and chewing activities of sheep. *Journal of animal science 74*: 2785-2802.

Woodward, S.J.R.; Webby, R.W.; Johnstone, L.J.C. 2000: A decision tool for calculating herbage mass and metabolisable energy requirements of growing cattle and sheep. *Proceedings of the New Zealand Grassland Association 62*: 13-18.