The prediction of grass silage intake by beef cattle receiving barley-based supplements

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Abstract

Data on the intake by beef cattle of 11 silages either unsupplemented or supplemented with barley-based concentrates were provided from six studies carried out at the Institute. An empirical model was developed from these data which described an exponential decrease in silage intake as concentrate intake was increased, with y-axis intercepts corresponding to unsupplemented silage intakes and a common x-axis intercept of 73.2 (S.E. = 2.00) g/kg W\textsuperscript{0.75} corresponding to concentrate intake when offered as a sole feed. The model curvature (r parameter) was also shown to be constant for all silages (1.025 (S.E. = 0.0038)). When the model was validated against external data (11 published studies), the relationship between actual and predicted silage DMI gave an R\textsuperscript{2} of 0.89 with an intercept and slope not significantly different from 0 and 1, respectively. Seventy-six percent of silage DMIs predicted using the developed model were within 0.5 kg DM of the observed intakes in the validation data. The developed model showed an improvement over a previously published model, as indicated by a significant reduction in the mean squared prediction error. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Beef cattle; Predicted grass silage ad libitum intake; Concentrate supplementation; Empirical model; Substitution rate

1. Introduction

Estimates of voluntary intake form an important part of feed rationing systems for ruminants and many approaches have been adopted for the development of empirical models to predict the ad libitum dry matter intake of grass silage (SDMI) in beef and dairy systems. While some models aim to directly predict the total intake in mixed diets (Vadiveloo and Holmes, 1979; Agricultural Research Council, 1980; Rook and Gill, 1990), Lewis (1981) has argued that a more logical approach in mixed grass silage/concentrate diets may be to adopt a two-stage prediction. The first stage being to derive a model to predict the intake potential of silage when given as the sole feed, and the second to correct this model for the substitution effect of concentrates. This concept is supported by recognition that the extent to which the intake of grass silage is reduced by supplementary concentrates depends, to a large extent, on the intake
of the forage given as a sole feed (Wilkinson, 1985; Thomas, 1987).

A number of models for predicting the intake of silage as a sole feed are available in the literature. Such models have included the independent variates of silage digestibility and dry matter concentration (Baumgardt et al., 1976; Lewis, 1981), whole diet gross energy concentration and metabolisability (Agricultural Research Council, 1980), silage ammonia nitrogen concentration (Lewis, 1981), silage neutral detergent fibre concentration (Baumgardt et al., 1976) and near infrared reflectance spectroscopy (NIRS) (Steen et al., 1998). The latter approach has proved to be both accurate and simple and particularly suitable for use within a technical support role for the agricultural industry. The objective of this paper is to develop this approach further by providing a prediction model that will adjust ad libitum silage intake for the effect of level of supplementary concentrates offered in the diet of the beef animal. If this can be accurately achieved then the combined prediction of silage intake as a sole feed and the effect of concentrate level on that intake would enable more accurate feed rationing systems to be developed. While Lewis (1981) has followed a similar approach, this has proved to have limited accuracy in previous independent validations (Agricultural and Food Research Council, 1991).

2. Materials and methods

The approach adopted in the present study was to develop an empirical model from data obtained from six studies carried out with growing cattle at this Institute and to validate the model against 11 published studies carried out outside the Institute. Because of the effect of liveweight on feed intake, all data were expressed in the form (kg silage DM intake/kg liveweight\(^{0.75}\)) \times 1000 and (kg supplement DM intake/kg liveweight\(^{0.75}\)) \times 1000.

2.1. Model development

The data used to develop the model were derived from six studies carried out at the Agricultural Research Institute of Northern Ireland (Forbes and Irwin, 1970; Forbes and Jackson, 1971; Steen and McIlmoyle, 1982; Steen and Kilpatrick, 1999; Steen and Kilpatrick, unpublished; Patterson et al., unpublished). In the studies, 11 silages (187–510 g/kg DM) were offered to a total of 681 heifers, bulls and steers of mixed breeds (initial liveweight 250–575 kg) for periods ranging from 28 to 230 days. Of the 11 silages examined, eight were offered as a sole feed and with 2, 3 or 4 levels of concentrate supplementation. The other three silages were only offered to the animals supplemented with 3, 4 or 5 levels of concentrates. The concentrate supplements offered in the studies were mostly barley based (600–975 g/kg barley) and in all cases were offered separately to the silage portion of the diet. In all studies the animals were housed in open pens and were offered silage through a barrier. Silage was refreshed twice daily.

The SDMs (g/kg \(W^{0.75}\)) were analysed using Genstat analysis of variance procedures (Genstat 5 Committee, 1989). Silage \(\times\) concentrate means from the analysis of variance were used in a regression analysis to investigate the relationship between \(y = \text{silage intake and } x = \text{concentrate intake on a } g/kg \ W^{0.75} \) basis. An exponential relationship of the form \(y = a + br^x\) was examined, where \((a + b)\) represented silage intake, when silage was offered as a sole feed. Three sets of models were fitted:

1. with separate \(a, b\) and \(r\) parameters for each of the 11 silages;
2. as (1) but with a common \(r\) parameter;
3. as (2) but extending to take account of the constraint that the intercept of the equation on the \(x\)-axis, equating to the concentrate intake at which the silage intake was zero, should be constant for all silages i.e. the concentrate intake when concentrate as the sole feed was independent of silage type. This introduced the following constraint and modified equation: \(\log_e (-a/b_i)/\log_e (r) = k\) giving \(y = -b_i(r^x - r^i)\) where \(k\) is a constant and is equal to concentrate intake for zero silage intake and \(i\) is silage type for \(i = 1\ldots11\).

Statistical tests, based on comparison of residual sum of squares, were carried out to compare the goodness of fit of the three sets of models.
2.2. Model validation

The developed model was validated against data from 11 published studies, carried out at various locations outside this Institute (Leaver, 1973; Drennan and Lawlor, 1976; Flynn, 1978; Drennan, 1979; Aston and Tayler, 1980; Petchey and Broadbent, 1980; Veira et al., 1983, 1985, 1990; Drennan and Keane, 1987a,b). These studies incorporated 15 grass silages (189–254 g/kg DM) offered to a total of 919 steers, bulls and weanlings of mixed breeds and ranging from 93 to 491 kg liveweight for periods of 84–154 days. Silages were offered either unsupplemented or with barley-based supplements (>875 g/kg fresh barley) at 1, 2, 3 or 4 levels (0–63.3 g/kg W non-significantly different from zero and \( r \) values non-significantly different from unity i.e. 45° lines through the origin. This is shown in Fig. 2.

In the validation exercise, predicted silage intakes \((P)\) in supplemented diets, using the developed model, were compared against actual observed silage intakes \((A)\), using the mean-square prediction error (MSPE) defined as

\[
MSPE = \frac{1}{n} \sum (A - P)^2
\]

where \(n\) is the number of pairs of values of \(A\) and \(P\) being compared. The MSPE can be regarded as the sum of the mean bias, the line bias and the random variation about the regression line (Rook et al., 1990). Results are presented in terms of the proportional contribution of each of these three components to the MSPE. The square root of the MSPE is the mean prediction error (MPE) and is reported as a proportion of the mean observed silage intake. Finally the predicted silage intakes using the present model were compared against silage intakes predicted using the Lewis (1981) model. Again the MSPE was used as the parameter of accuracy.

3. Results and discussion

3.1. Model development

The wide range of SDMIs recorded for the 11 silages when offered as the sole feed (50.6 to 88.8 g DM/kg W\(^{0.75}\)), together with the range of concentrate supplementation offered to the animals (8.8 to 68.0 g DM/kg W\(^{0.75}\)) facilitated the development of the model in establishing the relationship between silage and concentrate DMI. A strong exponential relationship was identified, which when fitted in its unconstrained form, showed an \( R^2 \) value of 0.99. Statistical tests used to compare the parameters for the individual silages showed that a common \( r \)-value of 1.025 (S.E.=0.0038) could be assumed for the exponential relationship.

When fitted in its constrained form, the \( R^2 \) value was 0.98, with a corresponding estimate for \( k \) of 73.2 (S.E. = 2.00) g concentrate DM/kg W\(^{0.75}\). The difference in goodness of fit between the unconstrained and constrained forms was non-significant (\( P > 0.05 \)). The SDMIs for the 11 silages used to develop the model are presented in Fig. 1. The plotted points represent the observed SDMIs at the range of CDMIs for the 11 silages while the plotted curves represent the predicted SDMIs for the same 11 silages in accordance with the above constrained equation.

3.2. Model validation

In order to apply the developed model to the data validation set, it was necessary to evaluate the silage-specific parameters in the model using the silage dry matter intake when silage \(i\) was offered as the sole feed (SDMI\(_{\text{max}}\)), thus:

\[
SDMI_{\text{max}} = b_i(r^k - 1)
\]

giving the equation:

\[
y = SDMI_{\text{max}}(r^k - r^i)/(r^k - 1).
\]

This equation was applied to calculate the predicted silage intakes for the validation data using the SDMI\(_{\text{max}}\) for the particular silages and the values for \(k\), the concentrate intake for zero silage intake estimated from the development data set, and the estimated value for \(r\). This gives the equation (ARINI model):

\[
y = SDMI_{\text{max}}(1.19 - 0.19 \times 1.025^k).
\]

The relationship between actual and predicted silage intakes was found to be linear with intercepts non-significantly \((P > 0.05)\) different from zero and regression coefficients non-significantly \((P > 0.05)\) different from unity i.e. 45° lines through the origin.
Fig. 1. The observed and predicted silage DMI of 11 silages in supplemented diets with various levels of DMI when offered as a sole feed.

Fig. 2. Actual versus predicted silage DMI using the ARINI model from 11 published feeding studies carried out at various locations outside the Institute.

The SDMI predicted for the validation set using the above model, showed a mean difference between actual and predicted intake of $8.9\% \pm 12.87$ and a mean bias of $1.0\% \pm 15.72$.

Substitution rates characteristic of the ARINI model are shown in Table 1. A feature of this model is the increasing substitution rate as concentrate DMI is increased and as silage intake as a sole feed is increased. The accuracy of the ARINI model was compared with that of the Lewis (1981) model
Table 1
Example substitution rates (SR) and corresponding marginal substitution rates (MSR) as determined by the ARINI model (all intakes are expressed as g/kg W0.75).

<table>
<thead>
<tr>
<th>Concentrate DMI</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDMI as sole feed</td>
<td>SDMI</td>
<td>SR</td>
<td>SDMI</td>
<td>SR</td>
<td>MSR</td>
<td>SDMI</td>
</tr>
<tr>
<td>50.0</td>
<td>47.3</td>
<td>0.27</td>
<td>43.8</td>
<td>0.31</td>
<td>0.04</td>
<td>39.4</td>
</tr>
<tr>
<td>60.0</td>
<td>56.8</td>
<td>0.32</td>
<td>52.6</td>
<td>0.37</td>
<td>0.05</td>
<td>47.2</td>
</tr>
<tr>
<td>70.0</td>
<td>66.2</td>
<td>0.38</td>
<td>61.3</td>
<td>0.43</td>
<td>0.05</td>
<td>55.1</td>
</tr>
<tr>
<td>80.0</td>
<td>75.7</td>
<td>0.43</td>
<td>70.1</td>
<td>0.49</td>
<td>0.06</td>
<td>63.0</td>
</tr>
<tr>
<td>90.0</td>
<td>85.1</td>
<td>0.49</td>
<td>78.9</td>
<td>0.56</td>
<td>0.07</td>
<td>70.8</td>
</tr>
</tbody>
</table>

* kg of silage DM reduced per kg of concentrate offered.

+ The difference in SR by increasing the concentrate intake by 10 g/kg W0.75.

which was developed from a similar standpoint. The validation parameters are shown in Table 2, together with the MSPE and the proportion of MSPE attributable to mean bias, line bias and random error. The mean bias and the MPE are expressed as a proportion of the observed silage intake. The mean predicted intake using the Lewis (1981) model was considerably lower than the actual mean intake with a bias of 4.29 g/kg W0.75 compared to 1.01 g/kg W0.75 for the ARINI model. This large mean bias was responsible for the inaccuracies encountered with the Lewis model when validated using these data, with the mean bias accounting for 30% of the calculated MSPE. The result was that the MPE for the Lewis model was 0.140 compared to 0.088 for the ARINI model. Furthermore, the R² of the predicted versus actual SDMIs for the validation data set showed a significant improvement from 0.76 to 0.89 with the ARINI as compared to the Lewis model indicating that the new model accounts for more of the variance.

The poor relative performance of the Lewis (1981) model in the present validation exercise may have been due to the fact that the validation data were derived from experiments in which animals of a wide range of weights were used. This large variation necessitates accurate correction of intakes for liveweight differences — a correction which is not taken into account in the Lewis (1981) model. In addition, the Lewis equation is based on a series of parallel curves, of SDMI versus concentrate DMI, for silages with differing intakes as a sole feed whereas, the ARINI model uses a series of convergent curves. It is expected that the use of convergent curves, to describe the decreasing SDMI as CDMI is increased, is biologically more appropriate as it reflects the decreasing significance of the silage quality (and hence its intake as a sole feed) as silage represents a decreasing proportion of the total diet.

4. Conclusions

A model has been developed to predict the SDMI at a given level of concentrate supplementation providing the intake of the silage when consumed as a sole feed is known or may be accurately predicted from silage compositional parameters. Validation of the model with independent data revealed that 76% of SDMI predictions were within 8% of the actual

Table 2
Prediction precision of ARINI model as compared to the Lewis (1981) model (actual mean intake = 55.7 (S.E. 2.71; n = 33) g DM/kg W0.75)

<table>
<thead>
<tr>
<th>Model</th>
<th>Predicted intake</th>
<th>Proportion of MSPE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.E.</td>
<td>MSPE</td>
</tr>
<tr>
<td>ARINI</td>
<td>54.7</td>
<td>2.88</td>
<td>26.0</td>
</tr>
<tr>
<td>Lewis</td>
<td>51.4</td>
<td>3.08</td>
<td>65.1</td>
</tr>
</tbody>
</table>

* g DM/kg W0.75.

+ (g DM/kg W0.75)².
intakes. The developed model has been designed for use in animals offered silage and concentrates of similar composition, and in accordance with the feeding regimen, to that adopted in the studies from which the model was derived, i.e. silage = 187–510 g/kg DM, concentrates = 600–975 g/kg barley and silage provided ad libitum, separate to the concentrate supplementation.

References


