A SIMULATION MODEL OF FORAGE YIELD, QUALITY AND INTAKE AND GROWTH OF GROWING CATTLE GRAZING CORNSTALKS

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ABSTRACT

A simulation model was developed to predict corn crop residue yield and quality and intake and performance of growing cattle grazing cornstalks. The model is wholly deterministic and integrates the effects of weather, residue supply and animal components. Low temperatures increase animal energy requirements, whereas snow cover decreases residue available. Residual grain and leaf are calculated from grain yield. Residue quantity and quality are reduced daily by environmental losses and animal consumption. Daily performance is predicted based on the nutrients obtained from residue and supplemental feed. Under unlimited roughage supply, leaf, husk and grain are primary diet components. Grain consumption decreases as the supply diminishes and forage quality decreases with time. Intake is calculated based on digestibility and fecal output = .0365 W. Forage availability affects intake in a curvilinear fashion. Energy gain is predicted by NRC equations and protein gain from metabolizable protein supply. The model underestimated intake of calves measured with chromic oxide and in vitro DM disappearance. Simulated daily gain (y, kg) of calves grazing at several stocking rates was related to observed daily gain (x, kg) by the equation y = .012 + .853x (R² = .71, Sy·x = .077). The model overestimated response to protein supplementation. Severe cold weather was predicted to reduce gains or cause weight loss due to increased energy requirements for maintenance. The model can be used as an aid in both research planning and cattle management.

(Key Words: Maize Stover, Grazing, Simulation, Models, Growth Period, Cattle.)

Introduction

A high forage beef production system is being evaluated that utilizes cornstalk grazing by weanling calves (Klopfenstein et al., 1987). Variable amounts of residual grain and stover are left in the field after grain harvest (Fernandez-Rivera and Klopfenstein, 1989a) and all is available the 1st d of grazing. A response to high levels of protein supplementation of calves grazing cornstalks has been observed (Fernandez-Rivera et al., 1989).

The study of grazing systems is limited by the complexity of interactions among weather, soil, forage, animal and management. Modeling and simulation techniques provide an integrating framework for research activities (Cartwright, 1980). Areas where knowledge is lacking may be identified and new hypotheses may be tested. The effect of different management strategies on model output can aid in decision making (Freer and Christian, 1981).

This paper describes a model that integrates the effects of weather, residue, animal and management and predicts residue yield and quality, and intake and growth of growing cattle grazing cornstalks. The objective of the model was to gain an understanding of the biology of the process and to serve as an aid in research planning. In the future, the model will...
be used to aid in management and decision making by cattle producers.

Description of the Model

Program, Inputs and Outputs. The model is wholly deterministic and integrates the effects of weather, residue and animal components (Figure 1). The program is written in Lotus\(^4\) using macro commands and performs all calculations on a daily-step basis on a microcomputer with 640 k bytes of memory.

User inputs are type of cornstalk (dryland or irrigated), grain yield (if available residue is unknown), harvest date, date to start grazing, stocking rate, number of grazing days, sex of the animal, supplementation (amount, crude protein content and escape value of protein) and year for weather information. The output includes, for each grazing day, temperature, snow cover, lower critical temperature, leaf and grain available, intake of grain, leaf and cob, digestibility of dietary roughage, metabolizable energy of consumed feed, partition of feed for maintenance and gain, net energy available for gain, escape protein, microbial protein synthesis, metabolizable protein, potential gain from both net energy and metabolizable protein, and live weight. Each run may be stored for later retrieval.

The model is subdivided into four major components: residue, residue-animal interface, animal and weather.

Residue Component. Grain yield is used to predict the amount of residue available after grain harvest (FORHA, kg/ha) with equations developed from data published by Perry and Smith (1975) and Fernandez-Rivera and Klopfenstein (1989a) as follows:

\[
\text{FORHA} = 2,600 + .344 (1.042 \times \text{GRN}), \quad \text{for GRN} < 4,497 \\
\text{FORHA} = 482 + .796 (1.042 \times \text{GRN}), \quad \text{for GRN} \geq 4,497
\]

where GRN is grain harvested (kg/ha). It is assumed that 96% of the total grain yield is harvested and 4.2% is left in the field (Fernandez-Rivera and Klopfenstein, 1989a). The intersection of these equations occurs at GRN = 4,497. Amounts of leaf (including blade, sheath and husk), stem and cob are calculated as 53, 35 and 12% of FORHA for dryland cornstalks and 47, 41 and 12% of FORHA for irrigated cornstalks (Fernandez-Rivera and Klopfenstein, 1989a). The user has the option of substituting actual data for available residue.

Environmental losses of leaf plus husk are estimated from data presented by Lamm and Ward (1981) for leaf disappearance in ungrazed fields. Environmental loss of leaf plus husk per unit area at any given day is calculated as .0076 of the biomass available. Environmental losses of the other plant parts are ignored.

Snow cover reduces residue availability. Actual availability of leaf plus husk (ALA, kg)
and grain (AGA, kg) per animal are calculated as:

$$\text{ALA} = \frac{s_h(\text{ALEAFHA})}{\text{SR}}$$

$$\text{AGA} = \frac{s_g(\text{GRAINHA})}{\text{SR}}$$

where $s_h$ and $s_g$ are factors to adjust availability of leaf plus husk and grain for snow cover, respectively, and ALEAFHA (kg/ha) is availability of leaf and husk after subtracting environmental loss. GRAINHA (kg/ha) is residual grain available and SR is stocking rate (animals/ha).

Because of difficulties in determining the effects of snow cover on residue availability, the assumption is made that leaf plus husk and ears are totally covered by snow depths of 25 and 15 cm, respectively. Then, $s_h$ and $s_g$ are calculated linearly from snow depth (SNOW, cm) as:

$$s_h = 1 - .040 (\text{SNOW}) \text{ if SNOW < 25; }$$
$$s_h = 0, \text{ if SNOW } \geq 25$$

$$s_g = 1 - .067 (\text{SNOW}) \text{ if SNOW < 15; }$$
$$s_g = 0, \text{ if SNOW } > 15$$

Leaf plus husk and grain consumption by the animal is subtracted daily from available residue.

Crude protein of leaf plus husk and grain is assumed to be 7 and 12.8%, respectively, for dryland cornstalks and 4.5 and 10%, respectively, for irrigated cornstalks (Fernandez-Rivera and Klopfenstein, 1989a). The user has the option of inserting actual CP values.

Under unlimited roughage supply, leaf plus husk and residual grain are the primary components of the diet of cattle grazing cornstalks. Although it was not quantified in samples taken by esophageally fistulated adult steers and calves, husk was consumed first during the grazing season (Fernandez-Rivera and Klopfenstein, 1989b; Fernandez-Rivera et al., 1989). Most of the husk disappeared from the field during 2 mo of grazing (Roth, 1987). Therefore, the digestibility of dietary roughage at the beginning of the grazing period is considered to be that of the husk. Digestibility of dietary roughage ($D_h$) at subsequent times is calculated as:

$$D_h = (73.1 - .071 [t_0]) - (1.766 - .000448 \{\text{IALA}\} t_g)$$

for dryland fields:

$$D_h = (64.6 - .055 [t_0]) - (.536 - .000305 \{\text{IALA}\} t_g)$$

for irrigated fields where $t_0$ is number of days between harvest and date to start grazing, $t_g$ is days of grazing and IALA is initial amount of leaf and husk available per animal (kg). In these equations, the first term of the right side estimates the husk digestibility at the date grazing started (McDonnell, 1982). The second term, which was derived from data presented by Fernandez-Rivera and Klopfenstein (1989b), estimates daily rate of decline and includes both animal selection and environmental losses. McDonnell (1982) observed that digestibility in ungrazed fields declined by .071 and .055 percentage units per day for husk from dryland and irrigated fields, respectively. The user has the option of using actual values for initial digestibility and rate of decline in digestibility.

Residue-Animal Interface Component. This section of the model estimates intake of residual grain and roughage, the effect of grain intake on roughage digestibility and the availability of nutrients resulting from feed consumption.

Daily grain intake ($I_g$, kg/hd) is calculated, based on data of grain disappearance over time, from an experiment conducted during 1984 (Fernandez-Rivera and Klopfenstein, 1989a) in which residual grain availability varied from 45 to 405 kg/ha, by the equation:

$$I_g = .85 \left(4.010 \left[1 - e^{-0.024[\text{AGA}]}\right]\right)$$

where .85 is the proportion of grain disappearance assumed to be consumed. An inadequacy of this equation is that it does not consider the time required for inexperienced animals to learn to find and consume the grain (Fernandez-Rivera and Klopfenstein, 1989b). Difficulties in predicting residual grain availability and intake by sheep grazing wheat stubble was reported by Orsini and Arnold (1986).

Residue intake is predicted assuming that the animal consumes cob only when availability of leaf plus husk is insufficient to allow a maximal leaf plus husk intake. Potential leaf plus...
husk intake (Imax), or the maximal leaf plus husk intake under unlimited supply, is predicted by a modified equation from Konandreas and Anderson (1982) as:

\[
Imax = \frac{0.0365W^{0.75} - 0.2(I_g + I_s)}{1 - D_h}
\]

where \(W\) is weight (kg), \(I_s\) is supplement (kg/d), and \(D_h\) is leaf plus husk digestibility as a fraction. The factor \(0.0365W^{0.75}\) is an estimate of total fecal output and was estimated from data obtained by Roth (1987). Grain and supplement are assumed to be 80% digestible. A modification of the equation of Konandreas and Anderson (1982) was the subtraction of feces of grain and supplement origin from the total output.

Actual consumption of leaf plus husk (Ih) is calculated as:

\[
I_h = Imax(1 - e^{-0.00375[A_{LEAF_H}]})
\]

based on availability-intake relationships as discussed by Hodgson (1976), Freer (1981) and NRC (1987) and on residue availability observed by Fernandez-Rivera and Klopfenstein (1989a).

Considerable proportions of cob have been observed in esophageal extrusa samples at the end of the grazing period when leaf availability is limiting (Fernandez-Rivera and Klopfenstein, 1989b; Fernandez-Rivera et al., 1989). Whereas cows eat cobs with the grain early in the grazing season, calves do not. Daily cob intake (Ic, kg) is calculated by the equation:

\[
I_c = \left(\frac{0.0365W^{0.75} - 0.2(I_g + I_s) - (1 - D)I_h}{0.65}\right)G
\]

Because the relationship of cob availability to intake has not been established, for practical purposes, we assumed an unlimited cob supply with 35% digestibility. Cob intake is, however, adjusted for snow cover.

Negative associative effects between starch level and fiber digestibility have been observed for corn residues (McDonnell, 1982). This effect commonly is observed when starch or concentrate levels in the diet are above 20% (Mertens, 1979). In the model, a decrease in digestibility of .375 percentage units per unit of corn above 20% is considered. This rate of decline in digestibility was estimated by McDonnell (1982). Therefore, adjusted digestibility of leaf and husk dry matter (Dh, %) is calculated as:

\[
D_h = D_h' - 0.375(G - 20) \text{ for } G > 20
\]

\[
D_h = D_h' \text{ for } G < 20
\]

where \(D_h'\) is unadjusted leaf plus husk digestibility (%) and \(G\) is proportion of grain in the diet (%). Similarly, adjusted cob digestibility (Dc) is calculated as:

\[
D_c = 35 - 0.375(G - 20) \text{ for } G > 20
\]

\[
D_c = 35 \text{ for } G < 20
\]

Daily intake of ME (Mcal) and metabolizable protein (MP, g) are estimated based on the California Net Energy System (NRC, 1984) and Metabolizable Protein System of Burroughs et al. (1974), respectively.

Intake of digestible DM (DDMI, kg/d), total digestible nutrients (TDNI, kg/d) and ME (MEI, Mcal/d) are calculated as:

\[
DDMI = I_hD_h + I_cD_c + 0.8(I_g + I_s)
\]

\[
TDNI = 0.92(I_hD_h + I_cD_c) + 0.8(I_g + I_s)
\]

\[
MEI = 0.82 \times 4.4 \times TDNI
\]

The .92 adjustment is based on an assumption of 8% ash in the diet and a dry matter digestibility for ash equal to that of the dietary organic matter. The ME value of feed consumed (M, Mcal/kg) is calculated as:

\[
M = \frac{MEI}{I}
\]

where I is total dry matter intake (Ih + Ig + Ic + Is). Similarly, the following dietary energy relationships are defined based on NRC (1984).

\[
N_m = 1.37M - 0.138M^2 + 0.0105M^3 - 1.12
\]

\[
N_g = 1.42M - 0.174M^2 + 0.0122M^3 - 1.65
\]

where \(N_m\) and \(N_g\) are the net energy for maintenance and net energy for growth values (Mcal/kg) of feed consumed.

Protein escaping ruminal degradation (EP, g/d) is calculated as:
SIMULATED CORNSTALK GRAZING

EP = .10(I_hCP_h) + .38(I_gCP_g) + I_sCP_sEP_s

where CP_h and CP_g are CP values of leaf and grain (g/kg), respectively, and CP_s and EP_s are CP (g/kg) and escape value of CP (fraction), respectively, of the supplement. Microbial protein synthesis (CP_m, g/d) and MP are calculated by the equations:

CP_m = 104.4(TDNI)

MP = .9(EP) + .8(CP_m - 15[I1])

Animal Component. In this section of the model, driven by the pool of nutrients available to the animal (MP and MEI), potential daily gain from both MP and net energy available for growth are predicted.

Net energy requirements for maintenance (NE_m) under no cold stress and minimal physical activity are .077 Mcal W^{-75} (NRC, 1984). Extra energy is required for maintenance due to cold stress (NRC, 1981) and physical activity (Osuji, 1974; Holmes et al., 1978).

In order to predict the effects of environmental temperature on NE_m, the following equation to calculate lower critical temperature (LCT, °C) was developed from data of Teter and DeShazer (1976) and Teter et al. (1973):

\[ LCT = \frac{8.81 - .077W^{75}m}{.229} \]

where m is the ratio M:N_m. Then, if T < LCT, heat production (Mcal/d) at both T and LCT are calculated based on Teter and DeShazer (1976) and Teter et al. (1973) as follows:

\[ H_T = 10.62 - .276(T) \]
\[ H_{LCT} = 10.62 - .276(LCT) \]

It is assumed that all of the increase in heat production due to cold is used for warmth. This was ignored in the model proposed by Johnson (1986). Therefore, the extra ME required for maintenance (EME_m, Mcal/d) is calculated as:

\[ EME_m = H_T - H_{LCT} \]

Feed maintenance (F_m, kg/d) is, therefore, defined as:

\[ F_m = \frac{.077W^{75}}{N_m} \] if T > LCT
\[ F_m = \frac{.077W^{75}}{N_m} + \frac{EME_m}{M} \] if T < LCT

Net energy available for growth (NE_g, Mcal/d) is calculated by:

\[ NE_g = N_g(I - F_m) \]

For positive values of NE_g, potential daily gain from energy intake (G_e, kg) is predicted based on NRC (1984):

\[ G_e = 13.91NE_g^{9116W^{-6837}} \text{ for steers} \]
\[ G_e = 10.96NE_g^{8936W^{-6702}} \text{ for heifers} \]

If energy intake is insufficient to meet maintenance requirements (NE_g < 0), weight change (loss) is predicted considering an energy value of 6 Mcal/kg tissue catabolized (Moe et al., 1971) as follows:

\[ G_e = \frac{1(N_m) - .077W^{75}}{6} \]

To calculate potential daily gain from protein (G_p, kg), MP requirements for maintenance (MP_m, g^{-1}) are calculated by an equation from Burroughs et al. (1974):

\[ MP_m = \frac{.0125(70.4W^{734})}{.47} \]

Then, if MP > MP_m, based on data of Roth (1987), G_p is predicted as:

\[ G_p = .00137(MP - MP_m) \]

If metabolizable protein is insufficient to meet maintenance requirements (MP < MP_m), G_p (weight loss) is calculated from protein composition of weight gain (Burroughs et al., 1974) as follows:

\[ G_p = \frac{MP - MP_m}{.16 - .0001W} \]

Finally, daily gain is predicted as the smaller of G_e and G_p.
Weather Component. Following the instructions of the user, a subroutine is called to provide information on snow cover and temperature from the National Oceanic and Atmospheric Administration.

Options are a 30-yr average for temperature and typical snow cover, or weather for a given year (1978 to 1986). Temperature information is that for Mead, NE and snow cover is that for Omaha, NE (Eppley Airfield Station). Weather data include the period from October 1 to February 28. Daily information on temperature and snow cover could be entered to adapt the model to other locations or grazing periods.

Testing of the Model

In no case were data used for validation that had been used for model development.

Digestibility. Predicted DM digestibility of the roughage fraction of the diet was compared with values observed in samples collected from esophageally fistulated calves grazing a dryland cornstalk field (Fernandez-Rivera et al., 1989a). Although digestibility did not decrease linearly over time, the model predicted a constant rate of decline during the grazing season (Figure 2). Predicted DM digestibility was 1 to 2 percentage units less than observed DM digestibility for most of the grazing season.

Residue Intake. Information on corn residue intake by grazing cattle is very limited. Changes in forage intake and diet composition over time were determined for calves grazing dryland cornstalks during 1986 (Fernandez-Rivera et al., 1989). Intake of residue (leaf, cob and grain) for the 7-d periods preceding November 19, December 5 and December 16 were 8.5, 7.8 and 6.7 kg/d, respectively. For the same periods, the simulated intakes were 7.5, 5.9 and 5.0 kg/d, respectively. The model assumed that supplement intake substituted for residue intake. Konandreas and Anderson (1982) assumed, however, that forage intake was not affected by supplement. This is a topic on which research is needed.

The model predicted that when 1,500 and 128 kg/ha of leaf and husk and residual grain, respectively, were available in dryland fields grazed at 2.47 calves/ha, the animal would consume large amounts of grain during the 1st mo of grazing (Figure 3). Predicted leaf plus husk intake decreased with time of grazing. Cobs were not consumed during the first 3 wk, but at the end of the grazing season, more than .5 kg of cobs were consumed daily according to the model.

Effect of Stocking Rate on Daily Gain. An experiment was designed to test the model under different stocking rates during November and December of 1986. Treatments included dryland cornstalks grazed at 1.24, 1.86 and 2.47 cobs/ha and irrigated cornstalks grazed at 2.47 and 4.69 calves/ha for 58 d, and dryland cornstalks grazed at 3.58 calves/ha for 44 d. The model slightly overemphasized the effect of stocking rate (Table 1, Figure 4).

Effect of Protein Supplementation on Daily Gain. The simulated effect of protein supplementation was tested with results from an experiment in which the response to increasing levels of escape protein (33 to 258 g/d) was studied (Fernandez-Rivera et al., 1989a). The same amount of supplement (.826 kg/d) but...
TABLE 1. OBSERVED AND SIMULATED DAILY GAINS OF CALVES GRAZING CORNSTALKS

<table>
<thead>
<tr>
<th>Field</th>
<th>Stocking rate, Ob-</th>
<th>Daily gain, kg</th>
<th>Simu-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hd/ha</td>
<td>Observed</td>
<td>lated</td>
</tr>
<tr>
<td>Drylanda</td>
<td>1.24</td>
<td>.66</td>
<td>.60</td>
</tr>
<tr>
<td>Drylanda</td>
<td>1.86</td>
<td>.64</td>
<td>.55</td>
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<tr>
<td>Drylanda</td>
<td>2.47</td>
<td>.55</td>
<td>.38</td>
</tr>
<tr>
<td>Drylandb</td>
<td>3.58</td>
<td>.37</td>
<td>.33</td>
</tr>
<tr>
<td>Irrigateda</td>
<td>2.47</td>
<td>.49</td>
<td>.54</td>
</tr>
<tr>
<td>Irrigateda</td>
<td>4.69</td>
<td>.37</td>
<td>.30</td>
</tr>
</tbody>
</table>

a58 d of grazing.
b44 d of grazing.

different protein concentrations and protein degradation values were used. The model underestimated the response to protein at low levels of protein supplementation and predicted a response at high levels of supplementation where no response would be expected (Figure 5). Predicted daily gains were higher than observed daily gains at all protein levels.

The model predicted a linear response to protein supplementation for the first 3 wk of grazing. However, for the 4th and 5th wk, a diminishing response pattern was predicted. The model predicted no response to supplemental protein after the 5th wk of grazing (Figure 6). The reason for the diminishing response to protein with time appears to be decreased energy intake. After the 4th wk of grazing, energy became the first limiting nutrient (Figure 7). Research at this station showed that protein requirements of growing cattle grazing cornstalks were higher than the NRC (1984) recommendations (Fernandez-Rivera et al., 1989). The model suggests that this is due to a response to protein early in the grazing period when energy is high (Figure 5). Similar, but lower-cost, gains possibly may be obtained with less protein at the end of the grazing season. These results also indicate that the equation to predict daily gain from MPg is inadequate, because it was derived with excessive protein at the end of the grazing season. Research to adequately evaluate protein needs of growing cattle at different energy intakes is required.

Effect of Residue Digestibility on Animal Performance. Corn hybrids may be selected for higher digestibility. When a difference of five percentage units was maintained over 60 d of grazing (70 or 65% of initial digestibility with a daily rate of decline of .33 percentage units), a
Figure 7. Potential daily gain from energy and from protein when either 68 or 258 g/d of ruminal escape protein (EP) were supplemented to steers grazing corn crop residues.

difference of .13 kg in daily gain was predicted. This is in close agreement with results of Roth (1987). Advantages of high digestibility residues may, however, be offset by low residue availability (Roth, 1987).

Effect of Grazing Management on Daily Gain. Most of the residual grain is consumed during the first weeks of grazing. Consequently, energy is limiting at the end of the grazing period. Strip-grazing presumably could overcome this problem.

Two experiments were conducted during 1978 and 1979 with growing heifers to compare continuous grazing of a whole field during 56 d to grazing of a field divided into four strips, each strip grazed during 14 d (Faulkner, 1980). For both years, actual and simulated data indicated no advantage of strip-grazing. However, results may differ with stocking rate, residue availability and protein supplementation.

Effects of Weather on Animal Performance. Daily gain of a 250-kg calf grazing an irrigated cornstalk field at 4.9 hd/ha, with 3,500 and 350 kg/ha of leaf and residual grain, respectively, supplemented with .807 kg supplement (56.8% CP, 52.2% escape protein) during 1 wk of grazing would be .66 kg/d at 0°C and no snow cover. Because of the increased energy requirements for maintenance, and the decreased intake associated with snow cover, daily gain would decrease during severe weather (Table 2).

Conclusions

The model presented herein integrates the elements affecting the performance of calves grazing cornstalks. Although possibilities for future improvement exist, especially in the simulation of daily gain from available protein, the model predictions were reasonably adequate. At this stage of development, this model may be used as an aid in understanding the biology of the process and directing research activities, primarily by identifying areas where knowledge is lacking. The study of strategies of protein supplementation, protein-energy interactions and the importance of residual grain are warranted.

The effect of weather on quantity and quality of residual grain and forage available to the animal is not clear but is very difficult to study. The metabolizable protein supplied on a daily basis and the animal requirements also need clearer definition.

With further research and model refinement, the model should prove useful to cattle producers as an aid in decision making about stalk grazing for calves.

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