RESEARCHING THE PLANT-ANIMAL INTERFACE: THE INVESTIGATION OF INGESTIVE BEHAVIOR IN GRAZING ANIMALS1,2

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ABSTRACT

Profitable livestock production from forages largely depends on efficiency of converting forages into products. Efficient grazing management systems require an understanding of the roles of system components. However, experimentation should be conducted with regard to the system as a whole rather than on the systems components in isolation. This may necessitate development of computer models. The short-term intake of forage by grazing animals is controlled both by the structure of the forage and by effects of the ingested forage on gut fill as moderated by the hunger-satiety complex. Intake can be defined as the product of bite size, rate of biting and grazing time. Measurement of these variables is facilitated by the use of esophageally fistulated animals and automatic recording devices. Bite size has the greatest influence on intake, with rate of biting and grazing time being compensatory variables. Sward structure influences bite size to varying degrees. In temperate grass swards, leaf surface height appears to be the dominant influence on bite size. But in tropical grass swards, leaf density and leaf:stem ratio have a greater influence on bite size than does leaf surface height. Alternative techniques to conventional grazing trials are described. Diversity of environments and forages in the U.S. requires further research into the development of grazing systems. In the future, small-scale trials and computer simulation techniques likely will be used to a greater extent.

(Key Words: Cattle, Sheep, Intake, Bites, Biting Rate, Plant Morphology, Grazing.)

Introduction

Profitable livestock production from forages depends largely on the quantity and quality of forage produced, the animal's capacity to harvest and utilize that forage efficiently and on the livestock producer's ability to manage resources at his disposal. The greater the control the livestock producer exerts over forage production and consumption, matching animal requirement to seasonal forage production cycles, the better are the chances that the operation will be profitable.

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Investigating ingestive behavior of grazing ruminants provides valid data in its own right and is an integral part of the development of grazing systems. Forage-livestock research in the southeastern U.S. has concentrated on the components of grazing systems rather than on production as a whole (Hoveland, 1986). Understanding the components of any system is essential before one can initiate large-scale studies of that system. Unfortunately, most forage livestock research in the past has concentrated on measuring output of a particular grazing system rather than the interactions between the grazed forage and the grazing animal. Only by identifying those variables that are changeable within a system can progress be made in developing profitable management systems.

In the U.K., results from a number of detailed studies carried out at several research institutes indicate that sward height is the primary factor influencing intake and, hence, production. This finding has led to a series of studies of grazing systems based on the objective...
approach of managing pastures based on height of the sward (Maxwell, 1986). Management of pastures based on sward height has received a great deal of attention in Britain recently (Parsons, 1984; Hodgson et al., 1986).

Development of stochastic simulation models that predict forage production and animal consumption has been the objective of a number of scientists (Forbes and Oltjen, 1986). In many cases lack of suitable data has limited modeling efforts (Forbes et al., 1985), or has led to unrealistic assumptions regarding certain aspects of their models. Because grazing animals spend much of their time obtaining food, it seems logical to assume that the forage being grazed has a considerable influence on intake. Though it appears clear that intake is controlled over the long term by energy balance of the animal, short-term intake of meals probably is controlled by a combination of plant structural factors that influence rate of ingestion, the effect of the masticated forage on gut fill and social behavior and environmental factors affecting the appetite-satiety complex.

Measurement of Ingestive Behavior

**Bite Size.** Bite size has been measured both directly and indirectly. Direct measurement usually involves the use of esophageally fistulated animals (Stobbs, 1973a). The technique involves total collection of extrusa in a leakproof bag. A record is made of all bites taken during the collection. Bite size thus is the product of the dry weight of extrusa collected divided by the number of bites taken. Techniques for esophageal fistulation have been detailed by Torell (1954), Hamilton et al. (1960) and Chapman (1964). The site of the incision should be located as ventral as possible to reduce the possibility of extrusa bypassing the fistula as it is swallowed. The use of animals with relatively small dewlaps and light musculature of the neck aids in collection of total feed ingested. There are numerous descriptions in the literature of devices for occluding the esophageal fistula (Hamilton et al., 1960; Van Dyne and Torell, 1964; Holechek et al., 1982).

The author has successfully used split L-shaped plugs (Hamilton et al., 1960) machined from high-density polyethylene for several years. An advantage of using such plugs is that replacement plugs of a variety of sizes can be shaped to fit the dimensions of the fistula. Spacers or larger plugs can be inserted as the fistula expands. Standard-sized plugs, such as those described by Ellis et al. (1984), cannot be reduced or expanded in size and complicate replacement into shrunken fistulas.

Before collecting extrusa samples researchers often fast their animals for varying lengths of time. When animals are to graze particularly short or unpalatable swards, it is usual and convenient to fast animals overnight before grazing early the next morning (Wilson, 1976; Gardener, 1980; Stuth and Angell, 1982; Pfister et al., 1984). Cohen (1979) found that fasting up to 23 h did not influence digestibility or N content of extrusa samples. However, bite size is increased by overnight fasting (Chacon and Stobbs, 1977), leading to the suggestion that fasting should be kept to a minimum and that samples should be collected at several times of the day. Rate of intake (the product of bite size and rate of biting) in sheep is increased by overnight fasting (Sidahmed et al., 1977; Jung and Koong, 1985).

To ensure maximum collection of extrusa, Stobbs (1973a) used foam rubber plugs to occlude the esophagus below the fistula. Other workers have had less success with this method (Jamieson, 1975; Forbes, 1982). Occluding devices will make animals more likely to ruminate during sample collection (Forbes, 1982), or to refuse to graze. Furthermore, foam plugs can be swallowed, although this appears to be harmless to the animal. Jamieson (1975) found that even with foam plugs, 100% recovery of ingested material was not ensured. Recovery of extrusa is aided, though not necessarily achieved, by correct placement of the fistula and by having large a fistula as is practical. Fistulas of less than 5 cm i.d. are likely to become blocked or to be bypassed entirely by the swallowed bolus. At the end of the collection period care must be taken to ensure that all material ingested has been swallowed before the bag is removed, particularly if the sample is small. Reliability of results obtained from esophageal fistulated animals often has been questioned because it is uncertain whether such animals represent nonfistulated counterparts. Forbes and Beattie (1987) suggested that esophageally fistulated and nonfistulated animals of similar background and nutritional history would not be expected to differ in grazing behavior.

Using the equation $I = BS \cdot RB \cdot GT$, where $I =$ herbage intake per period, $BS =$ bite size, $RB =$ rate of biting per grazing time and $GT =$ grazing time per period, the value of any one
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A variable can be calculated if the values of the remaining variables are known. Consequently, bite size can be determined by dividing daily herbage intake by total daily bites (RB \* GT; Jamieson and Hodgson, 1979b). Generally, bite size determined from daily herbage intake and total daily bites (Jamieson and Hodgson, 1979b; Forbes, 1982) results in a smaller value than when bite size is determined from extrusa collection (Table 1). Jamieson and Hodgson (1979b) suggested that the lower value for bite size obtained from estimates of daily herbage intake and total daily bites resulted from overestimations both of rate of biting and of bite size derived from extrusa collection. Coefficients of variation (CV) of 16 to 32% and 7–30% for sheep and cattle bite size, respectively, have been reported by Hodgson (1982a). Forbes (1982) reported a CV of 47.8% in bite size determined by direct measurement of extrusa compared with a CV of 18 to 29% for the same technique reported by Jamieson (1975).

Bite size varies widely with the type and stage of growth of the forage being grazed (Table 2). Individual values may be substantially greater than the mean values reported here. The largest bites (3.24 mg OM/kg live weight, LW) were reported from lactating cattle grazing perennial ryegrass swards with a herbage mass ranging from 6.0 t/ha to over 10 t/ha (Hodgson and Jamieson, 1981). Smallest intakes per bite (.18 mg OM/kg LW) were reported by Chacon and Stobbs (1976) from dry Jersey cows grazing a tropical grass sward with a herbage mass ranging from 2.5 to 7.2 t/ha.

The importance of bite size in relation to the herbage intake of grazing cattle has been stressed by Stobbs (1973a), who calculated that herbage intake by cows weighing 400 kg (LW) grazing tropical swards might be restricted if mean bite size fell below .3 g OM. Assuming that potential forage intake is proportional to BW, the lighter the animal, the lower the bite size that restricts herbage intake.

**Rate of Biting.** As an indicator of sward conditions, rate of biting was first measured over 40 yr ago (Johnstone-Wallace and Kennedy, 1944), but only recently has it been combined with bite size and grazing time to both determine and explain herbage intake. Measurement of rate of biting may be done by manual or

**Table 1. Mean Bite Size of Calves and Lambs Grazing Perennial Ryegrass and Cows and Sheep Grazing Indigenous Grass Determined from Direct Measurement of Extrusa or Calculated from Daily Herbage Intake and Total Daily Bites**

<table>
<thead>
<tr>
<th>Item</th>
<th>Observationsb</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calves and lambs</td>
<td>Calculated bite size (mg OM * bite(^{-1}) * kg LW(^{-1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calves</td>
<td>1.26</td>
<td>1.07</td>
<td>.84</td>
<td>.72</td>
<td>.63</td>
<td>.63</td>
<td>.74</td>
<td></td>
</tr>
<tr>
<td>Lambs</td>
<td>2.31</td>
<td>1.47</td>
<td>.97</td>
<td>.86</td>
<td>1.44</td>
<td>.80</td>
<td>.79</td>
<td></td>
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<tr>
<td>Measured bite size (mg OM * bite(^{-1}) * kg LW(^{-1}))</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calves</td>
<td>1.66</td>
<td>1.34</td>
<td>.78</td>
<td>.67</td>
<td>.88</td>
<td>.47</td>
<td>.76</td>
<td></td>
</tr>
<tr>
<td>Cows and sheep</td>
<td>Calculated bite size (mg OM * bite(^{-1}) * kg LW(^{-1}))</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cows</td>
<td>.29</td>
<td>.49</td>
<td>.58</td>
<td>.60</td>
<td>.61</td>
<td>.45</td>
<td>.52</td>
<td></td>
</tr>
<tr>
<td>Sheep</td>
<td>.44</td>
<td>.84</td>
<td>1.29</td>
<td>.78</td>
<td>1.20</td>
<td>.72</td>
<td>.58</td>
<td></td>
</tr>
<tr>
<td>Measured bite size (mg OM * bite(^{-1}) * kg LW(^{-1}))</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cows</td>
<td>.34</td>
<td>.50</td>
<td>1.47</td>
<td>1.69</td>
<td>1.03</td>
<td>.36</td>
<td>.54</td>
<td></td>
</tr>
<tr>
<td>Sheep</td>
<td>.58</td>
<td>.90</td>
<td>1.69</td>
<td>1.03</td>
<td>.96</td>
<td>.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Data for calves and lambs adapted from Jamieson and Hodgson (1979b); data for cows and sheep adapted from Forbes (1982).

\(^b\)Observations refer to the consecutive measurement periods described in the original reference.
TABLE 2. RANGES OF BITE SIZE REPORTED IN THE LITERATURE FROM MEASUREMENT OF THE WEIGHT OF EXTRUSA COLLECTED OR DETERMINATION OF DAILY HERBAGE INTAKE AND TOTAL DAILY BITES

<table>
<thead>
<tr>
<th>Reference</th>
<th>Forage</th>
<th>Class of animal</th>
<th>mg OM • bite(^{-1}) • kg LW(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring wt of extrusa collected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chacon and Stobbs (1976)</td>
<td>Tropical grass</td>
<td>Cows</td>
<td>0.18–0.83</td>
</tr>
<tr>
<td>Chacon et al. (1976)</td>
<td>Oats</td>
<td>Cows</td>
<td>0.54–0.79</td>
</tr>
<tr>
<td>Jamieson and Hodgson (1979a)</td>
<td>Ryegrass</td>
<td>Calves</td>
<td>0.31–4.09</td>
</tr>
<tr>
<td>Jamieson and Hodgson (1979b)</td>
<td>Ryegrass</td>
<td>Calves</td>
<td>0.47–1.66</td>
</tr>
<tr>
<td>Hendricksen and Minson (1980)</td>
<td><em>Lablab purpureus</em></td>
<td>Cows</td>
<td>0.24–1.09</td>
</tr>
<tr>
<td></td>
<td>Ryegrass</td>
<td>Calves</td>
<td>1.48–2.46</td>
</tr>
<tr>
<td>Forbes (1982)</td>
<td>Temperate grass</td>
<td>Cows</td>
<td>0.34–1.69</td>
</tr>
<tr>
<td>Forbes and Hodgson (1985)</td>
<td>Ryegrass</td>
<td>Cows</td>
<td>0.59–1.43</td>
</tr>
<tr>
<td>Forbes and Coleman (1986)</td>
<td>Old World</td>
<td>Steers</td>
<td>0.42–1.83</td>
</tr>
<tr>
<td></td>
<td>Bluestem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forbes (unpublished)</td>
<td>Orchardgrass</td>
<td>Steers</td>
<td>1.01–3.40</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>Steers</td>
<td>0.45–2.93(^a)</td>
</tr>
<tr>
<td></td>
<td>Bromegrass</td>
<td>Heifers</td>
<td>1.64–2.98(^a)</td>
</tr>
<tr>
<td></td>
<td>Bermudagrass</td>
<td>Heifers</td>
<td>0.67–2.22(^a)</td>
</tr>
<tr>
<td>Determining herbage intake/d and total bites/d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jamieson and Hodgson (1979b)</td>
<td>Ryegrass</td>
<td>Calves</td>
<td>0.63–1.26</td>
</tr>
<tr>
<td>Forbes (1982)</td>
<td>Temperate grass</td>
<td>Cows</td>
<td>0.29–0.98</td>
</tr>
<tr>
<td>Zoby and Holmes (1983)</td>
<td>Ryegrass</td>
<td>Cows</td>
<td>0.34–1.06</td>
</tr>
</tbody>
</table>

\(^a\)Milligrams DM • bite\(^{-1}\) • kg LW\(^{-1}\).

Automatic means; both techniques demand an adequate definition of a “bite.” Jamieson and Hodgson (1979a) developed a method to manually record the time taken for an animal to make 20 consecutive bites, discarding any records where the animal lifted its head before completing 20 bites. This method gave values 16% higher than those derived from recording the number of bites taken over a 2-min period. Forbes and Hodgson (1985) modified the 20-bite technique to include the time taken for herbage selection and mastication of large mouthfuls. Though rate of biting is normally expressed as bites per minute, it usually is easier to record the time elapsed for a predetermined number of bites (Hodgson, 1982a). During manual recording, head movements together with the associated sounds are the usual criteria for defining biting; however, it is not always possible to approach grazing animals closely enough to hear the bites without disturbing them; hence, head movements determined from a distance through binoculars typically are used to record rate of biting. It is important also to be aware that changes in sward structure may alter the characteristics of biting. In tall swards the characteristic “head-jerk” seen in grazing sheep is much reduced (Chamber et al., 1981), which may lead to an underestimation of the number of bites taken. It is important to measure rate of biting on several occasions throughout the day and over several days to avoid both diurnal and day-to-day differences. Forbes (1982) found a general increase in rate of biting of both cows and sheep with time of the day on three of five swards examined. On the remaining two swards no diurnal effect was apparent. Other evidence suggests that rate of biting declines with time within individual grazing periods (Hancock, 1950; Stobbs, 1974).

Automatic recorders of biting activity for grazing animals have been described by Canaway et al. (1955), Stobbs and Cowper (1972), Chambers et al. (1981) and Penning (1983). Stobbs and Cowper (1972) and Penning (1983) developed their bite meters to record jaw movements, whereas Chambers et al. (1981) relied on both head and jaw movements. R. B. Razor and E. M. Smith (unpublished data) have used audio tape recorders to record the sounds of herbage being torn off. Such a system requires a means to automatically decode the
sounds to avoid the effort of manually decoding the tapes. Ahrens and Searcy (1984) outlined a system that uses inductive loop transducers to record movements of the upper lip during grazing.

Automatic bite meters that record jaw movements (Stobbs and Cowper, 1972; Penning, 1983) record both true biting movements and jaw movements associated with the manipulation of herbage, both before and after biting. The ratio of manipulative movements to bites tends to increase with increasing sward height (Chambers et al., 1981), suggesting that estimates of biting rate as well as bite size based on measurement of jaw movements are unreliable. Chambers et al. (1981) suggested that bite meters should incorporate systems to record both head movements and jaw movements. Coefficients of variation for rate of biting are usually much lower than bite size, ranging from 8 to 11% in sheep and 4 to 12% in cattle (Hodgson, 1982a).

Grazing Time. Like rate of biting, grazing time may be recorded manually or automatically. Unlike rate of biting, however recording of grazing time must continue for hours, and becomes extremely laborious. Few studies of grazing time involving manual recording continue for more than two consecutive days (Stockdale and King, 1983). Typically, activity is recorded at intervals of 5 to 10 min (Hodgson, 1982a), although Gary et al. (1970) found no significant differences between estimates of grazing time made at 1-, 15-, 30- and 45-min intervals.

Allden (1962) first proposed the use of the Kienzle Vibracorder to record grazing time in sheep. Stobbs (1970) used vibracorders to record grazing time in cattle. Such instruments now are in widespread use (Jones and Cowper, 1975; Chacon and Stobbs, 1976; Jamieson and Hodgson, 1979a,b; Hinch et al., 1982; Forbes and Hodgson, 1985; Forbes and Coleman, 1987. Electronic devices for recording grazing time also have been used for a number of years (Canaway et al., 1955). Such devices usually combine records of both head position and jaw movements. A mercury switch is used to determine when the animal’s head is lowered. Biting is recorded by means of one of a variety of devices to record jaw movements (Stobbs and Cowper, 1972; Chambers et al., 1982; Penning, 1983). Chambers et al. (1981) employed mercury switches to distinguish between head up and head down activities, a jaw switch to count jaw movements and an accelerometer to record head movements to differentiate between prehensive and manipulative bites. Coefficients of variation for grazing time usually range from 5 to 7% for both sheep and cattle (Hodgson, 1982a).

The Influence of Sward Structure on Ingestive Behavior and Herbage Intake

The influence of sward characteristics and the modification of ingestive behavior on herbage intake in grazing animals have been reviewed recently (Hodgson, 1982b; Forbes, 1987). In temperate grasses, as sward surface height increases, bite size linearly increases (Allden and Whittaker, 1970; Hodgson, 1981; Forbes, 1982; Penning, 1986; Figure 1). Penning (1987) reported that bite size increased by 1 mg DM per millimeter increase in sward surface height. However, as sward height continues to increase and as the sward becomes reproductive, sward surface density begins to decline. Consequently, bite size and herbage intake decline. In circumstances in which a relatively tall sward is progressively grazed down, such as in strip-grazing or grazing of stockpiled grass, bite size progressively declines (Forbes and Hodgson, 1985). This probably is a result of grazing lower into the sward horizon that contains vegetative pseudostems and large amounts of dead material (Barthram and Grant, 1984).

Stobbs (1973a,b) found that on some tropical grass swards the relation between bite size and sward height was negative rather than positive. He ascribed this to the low density of leaf at the sward surface. In some tropical forages bite size is more closely related to leaf density at the sward surface or to the leaf:stem ratio than to sward height (Stobbs, 1973a,b, 1975 Chacon and Stobbs, 1976). A similar conclusion was drawn by Hendricksen and Minson (1980) from the results they obtained with cattle grazing a tropical legume. They found that a reduction in bite size from 410 mg OM to 90 mg OM per bite over a 12-d period resulted in a linear reduction in herbage intake of over 925 g OM/d. In their study, cattle concentrated their grazing on the green leaf fraction of the sward.

Because the quantity of forage an animal can prehend at any one bite even under ideal

* Argo Instruments, Winchester, VA.
conditions, is a very small fraction of the total daily requirement, reductions in bite size caused by adverse sward conditions must be recompensed if daily intake is to be maintained. Animals generally will attempt to compensate for reductions in bite size by increasing either rate of biting or grazing time (Chacon et al., 1978; Hendricksen and Minson, 1980; Forbes and Coleman, 1987) or, rarely, both (Jamieson and Hodgson, 1979b). Frequently the degree of compensation is inadequate (Allden and Whitaker, 1970; Chacon and Stobbs, 1976; Jamieson and Hodgson, 1979a; Le Du et al., 1979; Hendricksen and Minson, 1980), and under some circumstances there is no compensation (Forbes and Hodgson, 1985). Selective grazing is a major cause for declines in bite size. Though the digestibility of the diet can be increased by selection, this may not be advantageous to production if concomitant declines in rate of biting reduce daily forage intake to less than desired levels (Hodgson and Maxwell, 1981).

Recent evidence has shown that in both sheep (Barthram and Grant, 1984) and cattle (T.D.A. Forbes, unpublished data) the depth of the grazed horizon and, hence, bite size, is markedly influenced by the relative heights of the horizon containing dead material and vegetative stems vs the leaf structure. In swards with no flower horizon or swards with only short flower stems, such as bermudagrass, bite size increases steadily with increasing leaf surface height (Figure 2). However, bite size declines markedly with the appearance of the flower horizon in bromegrass (Figure 3). This decline in bite size after the appearance of flower heads presumably occurs because bite size is reduced as the animals become more selective and because the density of leaf in the surface horizon is reduced greatly.

Generally, as animals graze down through the sward, selectively removing leaf in preference to stem and dead material (Van Dyne et al., 1980), they change both the structure and composition of the sward. On continuously grazed swards with low stocking rates, animals graze certain areas more heavily than others and return to these areas more frequently. Consequently, as the sward matures, the animals concentrate their grazing on patches of relatively short grass, ignoring taller, ungrazed areas. At higher stocking rates, where the rate of herbage consumption exceeds the rate of forage regrowth, the animals are forced to use all the available forage. This results in a decline in the digestibility of the diet as the animals graze into the lower horizons of the sward (Hodgson, 1981).
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Figure 3. Changes in bite size (g DM/bite) in relation to increases in bromegrass leaf and flower surface height (cm). (+) bite size; (A) leaf surface height; (o) flower surface height; (A) first appearance of flower-heads.

1981), and also a decline in bite size as the height of the sward declines (Figure 1). Increases in rate of biting and grazing time may initially compensate, but eventually intake declines. In rotationally grazed pastures the same process occurs but over a much shorter time period, with the animals removing the surface horizons over the course of 1 or 2 d. The aim of rotational grazing systems, particularly those with large numbers of pastures (> 20 pastures), is to provide the animals with a continuous supply of young leaf without forcing the animals to graze too deeply into the sward and without continually regrazing the same areas.

Hodgson (1981) concluded that the height of the sward exerts a greater influence on herbage intake than either the density of the surface horizon or the proportion of green material at the surface. In swards without a tall flower canopy (Figure 2) that conclusion is correct. Bite size follows the increase in sward height. However, in the presence of a tall flower canopy (Figure 3), rate of ingestion is more likely to be related to sward density or leaf:stem ratio as postulated by Stobbs (1973a,b) because rate of biting declines with increasing sward height. Bite size increases initially with increasing sward surface height, until the appearance of a flower horizon, whereupon it declines.

Hodgson (1981) concluded that under the range of heights the examined, there was no critical height above which the rate of herbage intake showed no further increase. Forbes and Coleman (1987) found that, although there was a close relationship between mass and height, consistently better results were obtained when animal variables were regressed on herbage mass rather than on height, with bite size reaching a maximum at about 5 t/ha.

The Role of Ingestive Behavior Measurement in Grazing Research

Although it is apparent that some generalizations may be drawn from the results of past grazing trials, conflicting results that have not been fully resolved have important consequences for the development and implementation of grazing management systems. Results obtained from grazing trials on temperate grasses indicate that sward height is the dominant sward variable, and bite size is the dominant animal variable that influences short-term herbage intake (Jamieson and Hodgson, 1979a,b; Hodgson, 1981). In tropical swards, in contrast, leaf density and leaf stem ratio have more influence on bite size and herbage intake than sward height does (Stobbs, 1973b). Furthermore, in warm-season grasses, green herbage mass has more influence on bite size and herbage intake than sward height does (Forbes and Coleman, 1987). It is uncertain whether these differences are absolute or reflect conditions at opposite ends of a continuous spectrum of response (Hodgson, 1982b), or simply are artifacts of the experimental protocol. Although both rate of biting and grazing time are used as compensatory variables (Chacon and Stobbs, 1976; Hodgson, 1981) to either maintain a rate or level of intake over the course of a day, there are occasions when either one or the other variable has no compensatory role (Forbes and Hodgson, 1985; Forbes and Coleman, 1987). To better understand these and other differences in response, it will be necessary to devise and conduct grazing experiments that allow a greater degree of both sward and animal manipulation than has been attempted in the past.

Typically, a grazing experiment designed to explore some facet of the plant-animal interface will involve two or three treatments imposed on
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a single or, rarely two forages and replicated twice. Pastures must be large enough to support a minimum of two to three animals over the grazing season. Consequently, it often is difficult to obtain a suitable area of land, with the result that either replication of pastures is dropped or the replication effect is larger than the treatment effect, resulting essentially in separate, unreplicated trials. As a result of the large pasture sizes, sward measurements frequently provide inadequate descriptions of the pastures. Similarly, the scale of the experiment may prevent adequate numbers of observations to be made on the animals. Though providing some insight into the gross workings of the system, results seldom provide sufficient detail regarding the responses of the animals to changing sward conditions and are seldom sufficient for the development of simulation models of the type proposed by Forbes et al. (1985).

Jamieson (1986) was critical of certain aspects of grazing systems research in range-lands. His comments are equally applicable to research in more intensively farmed regions. He proposed that research into certain grazing management systems be abandoned while developing research programs to provide information about adaptive management techniques based on biological indicators. In the U.K., management of pastures based on sward height is a direct consequence of such research on the effects of sward height on ingestive behavior (Maxwell, 1986).

Conventional grazing trials do not provide sufficient data to clarify conditions that control animal performance. Realizing this, a number of novel techniques have been developed recently that use small-scale and short duration trials to impose a considerable amount of control over both sward conditions and animal responses. In the most extreme case, Black and Kenny (1984) overcame the confounding effect of sward height on sward density by making artificial swards. Freshly cut grass tillers were inserted into holes drilled into 30-cm x 45-cm boards. Density was varied by altering the number of tillers per hole and the number of holes per board, whereas height was varied by trimming leaves to a uniform height. Thus, forage height and density could be altered independently. In another approach, Burlison and Hodgson (1985) restrained sheep in small cages on grass and allowed them to graze small areas in front of them. Bite size, bite depth and bite volume were determined.

At the University of Kentucky two separate approaches with somewhat different objectives have been taken. The first approach used a small group of esophageal fistulated cows to obtain data on the influence of changes in sward height on the height of the grazed horizon and bite size. Small 2-m × 2.5-m plots were laid out in a randomized complete block design, with four replications. Normally, two measurements were made each week, with the length of each trial varied according to the type of forage being grazed and the season. Sward measurements were made on d 2 and 4 of each 5-d week, animal measurements were made on d 3 and 5. Sward measurements included determination of sward mass (kg/ha), height (cm) and bulk density (mass/sward height) and the height of the grazed horizon. At present, animal measurements are restricted to bite size (g DM/bite) and bite volume (ml). Animals are managed to reduce the influence of satiety, environment and social behavior. Swards are managed to be as uniform as possible. Data obtained are used in the further development of a computer simulation model (Forbes et al., 1985). Obtaining data on individual animal response variables using this technique is more cost-effective and provides more useful information that data collected during the course of an extensive grazing trial.

The second approach is the use of tether-grazed cattle. Used for centuries in Europe as a grazing method, it is a new and controversial concept in research. An experimental group of cattle (in our case, 12 head) was grazed by tethering them in the center of plots whose area is determined by the length of the tether (Ballerstedt et al., 1986; Doughterty et al., 1987). Randomized complete block designs have been used with replications nested within allowance levels (Ballerstedt et al., 1986). Other designs have been used, but the one currently favored is the cross-over design of Berenblut (1964) that allows for determination of carry-over effects. Normally, a series of plots is set up by driving metal poles into the ground with distances between poles being 1 m longer than twice the greatest tether length. Tether lengths are adjusted according to herbage mass and assigned herbage allowance. Herbage mass is determined each day by harvesting a strip of forage (1.5 × 90 m) parallel to plots using a Haldrup forage harvester. Animals graze the experimental plots for a maximum of 2 h each morning (0800 to 1000) and afternoon (1400
to 1600) and are restrained in a corral with access to water, shade and minerals when not grazing. Actual grazing time and rate of biting are recorded. Herbage intake after grazing is determined by cutting individual plots with the forage harvester; bite size is determined from the estimates of herbage intake and total bites. Esophageally fistulated animals have been used in related experiments to determine bite size.

Together, these two approaches are providing data from designed, replicated experiments that can then be used confidently in the development of stochastic simulation models. These techniques do not represent grazing management as practiced by farmers, nor are they intended to. They do, however, create controlled conditions in which to obtain some understanding of the complex interactions between forages and animals. Based on an understanding of these interactions, a set of objectively based decision rules can be developed with which to design improved grazing systems.

**Literature Cited**


Managing 17:7.

