THE INFLUENCE OF ADVANCING SEASON ON DIET QUALITY, INTAKE AND RUMEN FERMENTATION OF CATTLE GRAZING TALLGRASS PRAIRIE

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CHAPTER I

INTRODUCTION

The principal nutritional constraint on animal productivity from forages is the intake of digestible nutrients (Reid and Jung, 1982). The nutrient content of forage, its digestibility and conversion to fatty acids and microbial protein, and the quantity of forage that can be consumed determines the nutrient status of the grazing animal. Nutrient requirements of grazing animals are difficult to establish due to continually changing environmental conditions, differences in topography of pastures, and fluctuating body weights.

The nutritive value of forage changes throughout the seasons of the year. The primary change that occurs with increasing maturity is the development of lignified cell walls . Additionally, nitrogen content declines. Waller et al. (1972) found that crude fiber content of native tallgrasses in north-central Oklahoma increased 41% from May to March, while crude protein content declined 80%. Rao et al. (1973) noted acid detergent fiber of hand clipped samples of tallgrass prairie forage increased 17% from June through October, while crude protein levels declined almost 50%.

Raleigh (1970) found that digestible nitrogen intake, in relation to requirements of yearling steers for different rates of gain, became limiting in mid-June and digestible energy became limiting about two weeks later. Kansas bluestem forage becomes limiting in protein by mid-

July and energy by late August for 200 kg yearling steers gaining .5 kg/d (Rao et al. 1973).

Microbial metabolism in the rumen plays an important role in supplying available nutrients to the grazing ruminant. Ruminal fermentation end products are major sources of energy and protein for the animal. Microbial activity is dependent on the supply of readily fermentable carbohydrates, and nitrogen sources. Supplementation may enhance forage utilization by correcting microbial or tissue-level deficiencies. In general, high protein supplements increase forage intake and digestibility (Hibberd et al., 1987; Guthrie and Wagner, 1988), while high energy supplements substitute for forage intake (Chase and Hibberd, 1985). Determining the optimal level and type of supplementation depends upon the quality and quantity of forage available.

The development of management practices that will fully utilize nutrients from range forages requires better understanding of relationships between forage quality, intake and digestive physiology in grazing cattle. Therefore, the objectives of this research were to evaluate dietary composition, forage intake and rumen fermentation in beef steers grazing native tallgrass prairie rangeland throughout the spring and summer.

CHAPTER II

LITERATURE REVIEW

The quantity and quality of native forage can vary dramatically throughout the growing season (Losada et al., 1982; Reid and Jung, 1981). Nitrogen content declines and fiber increases with maturity (Waller et al., 1972; Rao et al., 1973; Wallace et al., 1972; Pieper et al., 1978), resulting in a decrease in digestibility and a corresponding decline in intake by grazing livestock (Cordova et al., 1978). Factors influencing forage intake include lag time, rate of digestion, extent of digestion and passage rate, which all relate to the amount of indigestible component in the forage. Diet digestibility, and thus rate of passage, is reduced if the nitrogen requirements of rumen bacteria are not met. Nitrogen requirements for maximum microbial growth are primarily a function of digestible organic matter intake (Van Soest, 1982). The level of nitrogen needed in the rumen to support maximum rate of passage, thus allowing maximum intake, varies with carbohydrate digestibility.

Forage Quality

It is the maturation process of plants that gives rise to indigestibility. Two mechanisms have been proposed to account for this change (Morrison, 1979). The first is a physical theory where cellulose is protected from attack by rumen microbes or their enzymes by the "cage" effect of the ligno-hemicellulosic complex. The "bars" of the

cage become closer together as the complex develops during the maturation process. Grinding forages partially destroys the cage by exposing ends of fibers, thereby increasing surface area and allowing more extensive microbial cellulolysis. The other theory proposes that components of hemicelluloses are more easily "recognized" by their respective hydrolases in young tissue. As the ligno-hemicellulosic complex builds up, polysaccarides are modified and enzyme recognition sites decrease in number. Morrison (1979) proposed that both mechanisms are involved with the physical impediments primarily affecting cellulose degradation and the enzyme impediment primarily affecting the other cell wall carbohydrates.

In addition to increased lignin content and reduced digestibility, the protein content of forages decreases with advancing maturity. Waller et al. (1972) evaluated clipped samples of four major native grasses in central Oklahoma over a 15 year period. These samples averaged 8.43% crude protein (CP) in the spring and steadily declined to a winter low of 2.46%. Kansas researchers studying changes in the nutritive value of bluestem grass, found that CP in esophageal masticate declined 49% from 7.35% in June to 3.75% in October (Rao et al., 1973). Allen et al. (1976) noted an 84% decline in CP from 17.74% in May to 2.89% in November for clipped samples of big and little bluestem. Using both hand-plucking and rumen evacuation methods, Raleigh (1970) determined that nitrogen content of sagebrush-bunchgrass range declined, while cellulose, lignin and crude fiber increased as grazing season progressed. McCollum et al. (1985) noted that the CP content of esophageal masticate samples of blue grama rangeland in southern New Mexico declined from 18.4% in the early growing season to 11.7% at the

onset of dormancy. Holechek et al. (1981) evaluated esophageal masticate samples of forest and grassland range in eastern Oregon over a three year period and found no seasonal variation in CP concentration. The absence of seasonal variation was attributed to selection of a diet containing more shrubs and forbs at the end of the grazing season.

The amount of available nitrogen present in forages is of great importance to livestock performance. Nitrogen availability (total N - acid detergent insoluble N (ADIN)) in blue grama rangeland decreased from 84% during active growth to 67% during dormancy (Krysl et al., 1987). Results from several New Mexico studies indicated that although levels of total nitrogen, soluble nitrogen and available nitrogen are affected by forage maturity, the ratios of nitrogen fractions to total nitrogen remain fairly constant (Krysl et al., 1987; Funk, 1986). The general range of ADIN noted in these studies was 11.2 - 16.7%. Available protein content reflected CP in these studies on blue grama rangeland. McMeniman et al. (1986) found that the intake and apparent digestibility of nitrogen are positively related to nitrogen concentration in the diet (r=.91; r=.94). Raleigh (1970) concluded that the first limiting nutrient for cattle on sagebrush-bunchgrass range was digestible nitrogen, which became limiting in mid-June. Digestible energy intake became limiting some two weeks later. In contrast, Holechek et al. (1981) concluded that digestible energy (predicted from IVOMD) was the first limiting nutrient for yearling heifers on mountain rangelands of eastern Oregon.

Environmental factors affecting quality of range forages include available moisture, light intensity and daylength, temperature, wind, relative humidity and evaporative demand, frost and nutrient composition

of the soil (Wilson, 1982). It has been noted that the most important environmental influence on nutritive quality is growing temperature (Wilson, 1982; Van Soest, 1982). The general response of a wide range of species in sub-tropical and temperate regions is that dry matter digestibility is highest in the spring, falls to a low in late summer, increases slightly in autumn, and decreases again in winter (Andrews and Crofts, 1979; Powell et al., 1978). Increasing temperature has its greatest overall effect on plant development by increasing metabolic rate thereby promoting the accumulation of relatively less digestible structural tissues (Van Soest, 1982).

The effect of moisture stress is of interest, particularly during periods of drought which may be experienced at some time in most forage regions of the world. Droughts severe enough to stop growth and cause leaves to shed surely effect forage quality. However, droughts of light to moderate severity may have no effect or actually increase digestibility (Wilson, 1982). Drought retards growth, delays aging of younger leaves and results in a correspondingly slower decline in nutritive quality (Wilson, 1981). Launchbaugh (1957) commented that drought years in the Kansas shortgrass prairie often produced high quality forage and animal gains well above average. Slight to moderate water stress does not usually result in lower forage nitrogen content (Funk, 1986). Usually, the concentration of nitrogen (Wilson and Ng, 1975), most minerals (Gerakis et al., 1975) and soluble carbohydrates (Ford and Wilson, 1981) is greater in water stressed forage. In contrast, McMeniman et al. (1986) reported apparent digestibilities of dietary nitrogen within the rumen ranging from 70-90% when the grass was

green, but fell to 58.5 and 37.6% when pastures were affected by drought.

Diet Selection

Grazing animals exhibit the ability to select the most nutritious plants or plant parts when grazing in a heterogenous plant community. Bredon et al. (1967) proposed that selective grazing explained a 66% increase in CP of esophageal masticate from cattle grazing tropical forage pastures over that of clipped pasture forage. Wallace et al. (1972) noted that diets consumed by grazing animals were of a higher quality than the average of the total forage. Comparing esophageal to hand-clipped samples, Rao et al. (1973) found forage selected by cattle grazing tallgrass prairie was generally higher in protein and more digestible than clipped samples. Several researchers have noted lower fiber levels in esophageal samples than in hand-clipped samples (Rao et al., 1973; Ellis and Pfander, 1965; Edlefson et al., 1960; Keisling et al., 1968; Coleman and Barth, 1972). Hodgson (1982) also noted this relationship and reasoned that the stratified distribution of plant components within the sward may affect the quality of the diet by influencing the opportunity for selection.

Palatability varies among species and plant parts. Generally leaves are more palatable than stems, although in early growing stages, stems are as digestible and palatable as leaves (Van Soest, 1982; Minson, 1982). In general, leaf cell walls are more digestible than stem cell walls so plants with higher leaf:stem ratios will be more digestible (Morrison, 1979). Minson (1982) summarized results from four studies in which the average digestibility of leaf and stem fractions of grasses

consumed by cattle and sheep differed by only 1%, yet intake of leaf was 15% higher than intake of stem. The higher intake of the leaf fraction was associated with a shorter retention in the rumen compared to the stem fraction. The mean retention time of leaf and stem of 26 forages was 24.6 and 33.3 hours, respectively (Laredo and Minson, 1973; Laredo and Minson, 1975; Poppi et al., 1981a and 1981b). The most probable reason for the longer retention time of stem is the greater proportion of large particles in masticated stem than in masticated leaf that results from the greater resistance of stem to physical breakdown (Minson, 1982).

Rangeland vegetation is a heterogenous mix of grasses, forbs and browse. Environmental conditions affect availability, palatability and nutritive value of range plant species, and therefore diet selectivity. Although cattle are generally considered to be grazers, forb and browse consumption may increase at certain times of the year (Cook, 1983). Both cattle and sheep used forbs in mountain ranges of Utah, with utilization increasing as the growing season progressed (Cook et al., 1967). McCollum (1983) noted a 60% increase in forb consumption by grazing steers as season progressed from early growing to early dormancy. Grasses tend to mature more quickly than forbs and become less palatable (Cook, 1983). Cook (1983) noted that forbs retained adequate or borderline digestible protein and phosphorus throughout most of the grazing season, whereas grasses were decidedly deficient in both nutrients after the heading stage. In Oklahoma, cattle will select forbs at various times of the year, particularly June, however, the occurence of forbs is low on tallgrass prairie (Dweyer, 1961).

Nutrient Availability

The amount of net energy derived from the feed consumed is the major determinant of nutritive value. Fifty percent or more of the potentially useful energy of forages may be found in the cellulose and hemicellulose fractions (Crampton et al., 1960). Extensive fermentation in the rumen enables the ruminant animal to utilize the structural carbohydrates, which are less available to monogastrics. The end products of carbohydrate fermentation are volatile fatty acids (VFA), lactic acid, carbon dioxide and methane. VFA provide 50-85% of the metabolizable energy for ruminants on forage diets (Owens and Goetsch, 1988). The proportions of particular VFA vary with type of diet, level of intake and frequency of meals (Sutton, 1979). In addition, the metabolism of the three major VFA differ significantly. Acetate and butyrate are used for oxidation. Acetate is the most important lipogenic precursor in ruminants. Propionate is a primary glucogenic substrate (Van Soest, 1982).

The non-structural carbohydrates in forages include the simple sugars glucose, fructose and sucrose, as well as the storage polysaccarides starch and fructans. Starch, the prevalent storage polysaccaride in tropical grasses, tends to accumulate in the leaves (Smith, 1973) and can account for 1-5% of plant tissue dry matter (Morrison, 1979; Van Soest, 1982). Fructans, the principal storage component in temperate grasses, comprise up to 25% of plant tissue dry matter (Morrison, 1979; Van Soest, 1982) and tend to accumulate in the stem (Smith, 1973). Simple sugars comprise 5-10% of plant dry matter in most forage species (Van Soest, 1982).

Lipids are present in leaves at levels up to 10% of dry weight

(Hawke, 1973), although usually less than 3% lipid is present. The concentration of utilizable lipid declines with the age of the plant and varies with proportion of leaves to stems (Hawke, 1973; Van Soest, 1982).

The energy supply from fermentable carbohydrates and other energy sources determines the rate of protein synthesis by ruminal microbes (Hogan, 1982). As forage matures, the availability of the structural carbohydrates declines, due to increased lignification and complexes formed as discussed previously. The cellular contents, which comprise the bulk of the protein, fructans, sugars, lipids and organic acids are totally available to digesting organisms and free from the effects of lignin or encrusted cell walls (Van Soest, 1982). However, these contents are translocated from stem and leaf to the inflorescence as grasses, forbs and browse flower and mature, causing a decline in forage quality (Hogan, 1982).

The capacity of the diet to provide adequate ammonia and essential and nonessential amino acids for tissue and microbial protein synthesis reflects the protein value of the diet (Hogan, 1982). Non-protein nitrogen (NPN) from the feed provides ammonia, and true protein provides amino acids and ammonia. Grasses have 14-34% of their total nitrogen as NPN (Van Soest, 1982). Dietary nitrogen sources are utilized by ruminal microbes which pass to the small intestine and comprise the primary protein source for ruminants. Ruminal microbes are composed of approximately 50% true protein, of which 67-87% is digestible (Van Soest, 1982; Owens and Bergen, 1983). Because the protein in most forages is quite susceptible to rumen degradation (Ulyatt, 1981; NRC, 1985), small amounts of plant protein N reach the small intestine of

ruminants on forage diets. Therefore, the contribution of microbial protein to total protein reaching the small intestine is relatively greater for grazing animals than animals on concentrate rations (NRC, 1984).

Ammonia is derived from degradation of dietary protein and microbial protoplasm, and hydrolysis of dietary NPN and urea recycled to the rumen (Owens and Bergen, 1983). Ammonia is destined for uptake by microbes, absorption through the rumen wall or flushing to the omasum (Owens and Bergen, 1983). Since ammonia is the main source of nitrogen used by bacteria for incorporation into cellular protein (Demeyer, 1981; Van Soest, 1982), low ammonia levels may result in nitrogen limitation (Satter and Slyter, 1974) and result in reduced bacterial yields. However, nitrogen recycling serves to augment low nitrogen diets, providing ruminal microbes with an ammonia source and resulting in more nitrogen reaching the duodenum than was ingested. Ammonia that is flushed from the rumen is subject to absorption and recycling, or absorption and excretion in the urine, or is excreted in the feces after being incorporated into microbial nitrogen in the large intestine.

Immature forages contain low levels of cell wall constituents that are readily fermentable, supplying ruminal microbes with a rich source of both energy and protein. As forages mature, energy becomes less available and protein levels decline. The protein content declines more rapidly than organic matter digestibility and the ratio of digestible organic matter to crude protein (DOM:CP) rises (Hogan, 1982). In a review (Hogan, 1982), data was presented from several studies involving 23 temperate grasses and clovers harvested at varying stages of maturity

and fed to sheep. These studies indicated that ammonia levels decline as the DOM:CP ratio increases, as occurs with advancing maturity.

Intake

The amount of forage consumed is the most important factor in meeting the nutrient requirements of the grazing animal (Allison, 1985). The changes in forage consumption with advancing season have a dramatic effect on the grazing animal's ability to select and consume a diet that supplies adequate nutrients for maintenance and performance, as well as for ruminal microbial use. Also, because of the heterogenous nature of range plants and selective grazing, nutritive value and digestibility of the range herbivore diet is difficult to assess. Crampton et al. (1960) based the nutritive value index for forages on voluntary intake and digestibility. Reviews on methodology to determine forage intake by range ruminants include those by Cordova et al. (1978) and Kartchner and Campbell (1979).

Several metabolic and sensory factors are known to affect meal size and frequency. Feeding behavior is also influenced by certain hormones and metabolites as well as gastrointestinal factors. Depending on the nutrient density and physical structure of the feedstuff, certain factors will prevail in signaling the end or beginning of a meal. The energy balance control center in the brain is the ventromedial nuclear region of the hypothalamus. Stimulation of this satiety center inhibits feeding (Hetherington and Ranson, 1939).

Energy requirements for maintenance and production in addition to limitations on gastrointestinal capacity are dominant factors controlling feed intake of beef cattle (Fox, 1986). Intake in relation

to body weight begins to decline at about 350 kg for an average frame steer, indicating that degree of fatness and/or a reduction in demand for growth influences voluntary intake (Fox, 1986).

Grovum (1986) suggests that intake of poor to moderate quality roughages is probably limited by distention of the reticulum and cranial sac of the rumen. With low quality roughage, nitrogen status (protein:energy) in the absorbed nutrients and palatability may play a role in determining intake. In contrast, VFA, osmotic pressure in reticulo-ruminal digesta, various hormones and distention may regulate intake of high quality roughage.

Since the studies of Campling and Balch (1961), Campling et al. (1961) and Balch and Campling (1962), fill has been accepted as the primary factor regulating forage intake in ruminants. Fill is affected by two major processes - rate of digestion and rate of passage of undigested residues (Ellis, 1978; Van Soest, 1982). McCollum and Galyean (1985b) noted that steers grazing blue grama forage had fairly constant fecal outputs throughout the grazing season, indicating that the steers ate to a constant fill. Thornton and Minson (1972) fed forage diets to sheep hourly and found level of fill to be relatively constant with little influence on intake. However, a correlation of .97 was found between rate of disappearance and voluntary intake (Thornton and Minson, 1972). Retention time of ruminal dry matter and lignin content of the diet were negatively correlated ($r=-.93$, $r=-.97$) with intake. They concluded that the fiber component of the diet, through its influence on retention time, was the main factor limiting dry matter intake.

Changes in diet composition affect rate of digestion, extent of

digestion and passage rates. McCollum and Galyean (1985b) noted an increase in forb consumption and organic matter intake in the early dormant season in southern New Mexico. Forbs are similar to legumes and contain less cell wall, more lignin (Kothmann, 1980; Van Soest, 1982) and are more rapidly digested than grasses (Short et al., 1974; Kothmann, 1980). When legumes and grasses were compared, Thornton and Minson (1973) found a 28% increase in intake of legumes over grasses at similar digestibilities. They stated that decreased retention time, increased organic matter in rumen digesta, and the ability of legumes to pack densely contributed to intake differences between the forage types.

Rate of passage is crucial, influencing not only feed intake on roughage diets, but also ruminal digestibility by modifying time available for ruminal digestion. Time for digestion is especially important with forage diets. Welch and Smith (1970) have shown that the fibrous nature of the feed influences rumination time. Longer retention time will increase total digestibility and reduce bypass (Owens and Isaacson, 1977). Cellulose and hemicellulose are poorly utilized at sites beyond the rumen (Hogan and Weston, 1967), while carbohydrates and high quality proteins are utilized more efficiently post-ruminally (Little and Mitchell, 1967). Hungate et al. (1959) stated that all but 4% of fermentation occurs in the rumen. Reports of Ulyatt and Egan (1979) and Hoover (1978) indicate that 6-40% of the hemicellulose and 3-27% of the cellulose are digested post-ruminally. Reports reviewed by Phillipson (1977) indicated about 10% or more of cellulose is digested in the cecum. Therefore, ruminal digestibility influences the end products of digestion through alteration of site and extent of absorption (Owens and Isaacson, 1977).

The passage of coarser feed particles from the rumen to the lower tract is impeded by the omasal filtration system (Owens and Isaacson, 1977). The selective retention of coarse particles and their further rumination reduces particle size which delays passage. The retention time of these particles is inversely related to the rate of production through rumination and digestion (Van Soest, 1982).

The level of rumen fill is not constant among diets but is influenced by other, presumably nutritional, factors (Egan, 1970). One such factor is protein content of the diet. Thornton and Minson (1973) suggested that the low protein content of some plants may reduce intake and gut fill. When crude protein content of a pasture falls below 8-10%, appetite is depressed and intake declines (Blaxter and Wilson, 1963; Minson and Milford, 1967). Milford and Minson (1965) observed that intake of tropical forage by sheep declined significantly when forage CP was less than 7%. Correlations of .72 and .63 were found between intake and CP for two tropical grass species when their CP content was below 7%. When these grasses contained over 7% CP, intake and %CP were not well associated. The authors stated that the failure of CP and intake to be correlated when CP was above 7% was probably due to nitrogen requirements of active rumen flora being satisfied at this level. Van Soest (1982) also suggests that diet crude protein concentrations below 7% do not meet the nitrogen needs of rumen microbial populations.

When legumes were added to tropical grass diets, intakes increased sharply with a rise in CP content from 3.6% to 6%. The rapid rise was followed by a less rapid linear increase as CP increased from 6% to 22%. This increase in intake above 6% CP was attributed to substitution of

legumes for Pangola grass (Minson and Milford, 1967). Intakes of higher quality roughage containing greater than 6% CP are probably limited by gut distention and various hormones and metabolites as discussed earlier.

Protein supplementation generally enhances voluntary intake of forages containing less than 7% CP (Allden, 1981). Hunter and Siebert (1985) fed speargrass (3.9% CP) and Pangola grass (6.2% CP) to steers. The Pangola grass was consumed in greater amounts than speargrass (17.0 vs 11.6g/kg BW). However, cattle on both diets responded to protein supplementation by increasing intake, indicating that nitrogen deficiencies were limiting rumen function on the unsupplemented diets or possibly amino acid deficiencies in the small intestine were limiting intake. McCollum and Galyean (1985a) noted higher voluntary intakes and faster particulate passage rates when steers consumed a cottonseed meal supplement with a prairie hay diet. Guthrie and Wagner (1988) reported a curvilinear increase in intake of prairie hay by heifers and steers as level of soybean meal supplement increased. Dry matter digestibilities increased with increasing level of supplement as well. Increased in situ forage digestion was noted by Barton and Hibberd (1984) when low protein levels were fed to steers on low quality native grass hay, however, intake was not affected. Higher levels of supplemental protein produced further increases in forage digestion and an increase in hay intake. Performance of cattle grazing native bluestem pasture in late summer has been improved with the feeding of small amounts of high protein supplement (Gill et al., 1984; Lusby and Horn, 1983).

Yield and physical presentation of available forage to grazing animals may have marked effects on feed intake under intensive pasture

conditions, but may have no measurable effects on feed intake on extensively managed pastures (Arnold, 1964; Arnold and Dudzinski, 1967; Greenhalgh et al., 1966). Consumption of forage tends to increase as yield increases. Several researchers have studied the effect of herbage availability on intake (Arnold and Dudzinski, 1967; Broster et al., 1963; Greenhalgh et al., 1967) and found intake to increase with increasing allowances. Greenhalgh et al. (1966) stated the relationship between herbage consumption and herbage allowance is probably curvilinear.

Dry matter intake is often limited by total feed available, terrain or inaccessibility of range forage and palatability (Raleigh, 1970). Arnold (1960) found that rumination time declined as forage availability declined. Ruminants spend more time grazing and less time ruminating when forage is scarce. This would impact digestibility of forages, as rumination increases digestibility. Chacon and Stobbs (1976), working with cattle grazing Setaria anceps, concluded that as amount of leaf material available was reduced, bite size, intake and biting rate declined. Animals with low quality diets apparently spend less time grazing and select small bites. Nastis and Malechek (1980) also found increased biting rate and grazing time as forage availability declined on crested wheatgrass. Both studies indicated that up to a certain point, animals increased grazing time and biting rate, and decreased bite size to compensate for declining forage availability. However, at very low availability, overall intake, bite size and rate were reduced. Consumption of dead material and stem increased with declining availability and therefore reduced nutrient intake.

Digestibility and Ruminal Fermentation

Digestion and Passage

Feed disappears from the digestive tract by the processes of digestion and passage. The primary site of digestion is the rumen. Relationships among plant components, microorganisms in the rumen and the animal determine forage utilization. The digestive process can be divided into rate of digestion, digestion lag and potentially digestible fraction (Mertens and Ely, 1982). The most important component affecting digestiblity and intake is the size of the potentially digestible fraction, which is also the component most highly related to chemical composition, specifically lignin (Mertens and Ely, 1982). Mertens and Ely (1982) reported a correlation of .78 between lignin content and the potentially digestible fraction (determined by 72 h cell wall indigestibility). The extent of ruminal fiber digestion is related to ruminal retention time as well as the degree of lignification. The animal alters the fermentative environment by mastication and rumination to decrease particle size, increasing surface area for microbial attack. Mertens (1977) noted that the rate of digestion is directly related to potential extent of digestion, and that the extent may be related to the morphological, crystalline or physical nature of the fiber. Also, factors inhibiting microbial growth or their fiber digesting enzymes may be involved (Mertens, 1977). If fiber digesting microbes grow more slowly than average, then an increase in passage rate would decrease their concentration and result in a decline in fiber digestion (Mertens, 1977). Faichney and Gheraldi (1986) observed depressed organic matter digestibility with increased intakes. They contributed this decline in

digestibility to shorter ruminal retention time. Any treatment which alters feed intake can be expected to alter ruminal retention time (Warner, 1981) and therefore extent of digestion. The limiting process of clearing indigestible fibers from the rumen is particle size reduction (Welch, 1982; Ellis et al., 1986). Particles broken down to sizes eligible for passage from the rumen prior to microbial digestion could be washed from the rumen, resulting in depressed digestibility. Poppi and Norton (1980) noted that the resistance to flow of particles of different sizes from the rumen was closely related to particle size with no difference between grasses and legumes or between young and mature forages. Waldo et al. (1965) pointed out that a portion of potentially digestible cell wall constituents is undigested due to rate of passage.

Microbial Protein Synthesis

In addition to producing the primary energy supply via fermentation and VFA production, microbial cells provide a high quality protein source to the host animal (Owens and Zinn, 1988). Dependent on several dietary and animal factors, 40-80% of the total protein reaching the small intestine is of microbial origin (Owens and Bergen, 1983). Amino acid content and biological value of microbial proteins have been shown to remain relatively constant on a variety of diets (Purser, 1970). Digestibilities of bacterial and protozoal nitrogen fed to rats have been estimated at 74-79% and 87-91%, respectively. Increases in the ratio of essential to non-essential amino acids resulting from the conversion of feed protein to microbial protein have been demonstrated

when low quality proteins are fed to ruminants (Ben-Ghedalia et al., 1974).

Efficient microbial protein synthesis requires an adequate supply of nitrogen. In vitro and in vivo experiments have indicated that this is achieved when ammonia-N concentration in the rumen is about 2-5 mg/100 ml (Satter and Slyter, 1974; Okorie et al., 1977). The percentage of microbial-N derived from ruminal ammonia has been reported to range from 40-100% under various conditions (Pilgrim et al., 1970; Nolan et al., 1976; Al-Rabbat and Heaney, 1978). In grazing animals, nitrogen available to rumen microbes is derived from the breakdown of plant protein, plant non-protein nitrogen, urea nitrogen recycled to the rumen from the blood and saliva, and sloughed epithelial cells. The amount of nitrogen recycled to the rumen through the saliva is higher for grazing animals or those consuming unprocessed forages than those fed concentrates or processed forage diets (Van Soest, 1982).

Microbial protein synthesis can occur in the rumen on diets in which urea is the sole nitrogen source (Hume, 1970). However, a deficiency of preformed amino acids may result in inefficient microbial growth. Hume (1970) fed sheep diets with nitrogen provided by urea, gelatin, casein and zein, resulting in microbial synthesis of 17.1, 19.8, 23.3 and 22.5 g CP/100 g organic matter digested. He suggested that microbial production on the urea and gelatin diets was limited by the rate of synthesis of one or more amino acids by rumen bacteria.

An adequate supply of readily available carbohydrate is required to provide ATP for bacterial growth. Energy from fermentation must be supplied at a rate that matches the synthetic abilities of rumen microbes in order to promote efficient utilization of degraded dietary

nitrogen (Oldham et al., 1977). Stern et al. (1978) increased microbial growth in continuous cultures by increasing the supply of nonstructural carbohydrates in isocaloric diets with similar VFA production and dry matter digestibilities. Stern and Hoover (1979) concluded that the extent and rate of degradation in the rumen of both nitrogen and carbohydrate sources are important determinants of the efficiency of microbial growth.

Dilution rate of bacteria alters efficiency of bacterial growth. Accelerating fluid dilution rate promotes elevated microbial CP synthesis because the microbial maintenance requirement is reduced (Isaacson et al., 1975). Hogan and Weston (1970) reported that increasing dilution rates in sheep from .06 to .1/h increased efficiency of microbial production from 31 to 37 g N/kg OMD. Increasing roughage:concentrate ratio in the diet results in increased liquid dilution rate and increased protein synthesis (Cole et al., 1976; Whitelaw et al., 1984). Substrate energy directed toward microbial maintenance was shown to decrease from 55 to 15% as fluid dilution rate was raised from 2 to 12%/h (Isaacson et al., 1975), increasing the amount of energy derived from substrate which may be used to support microbial growth. Since bacterial mass is inversely related to growth rate (Isaacson et al., 1975), lower bacterial numbers would be expected at higher dilution rates.

Techniques for Measurement of Digestion, Ruminal Fermentation and Microbial Activity

Microbial Markers

The extent of dietary protein degradation in the rumen and subsequent synthesis of microbial protein can greatly alter amounts and kinds of amino acids available for absorption in the small intestine of ruminants. In order to clarify the effects of dietary regimens in altering the proportion of microbial protein reaching the lower tract, reliable estimates of microbial protein synthesis are essential.

Estimates of microbial protein formation obtained with different markers can differ widely. Even with individual marker methods, there is often considerable variability both within and between animals (Dufva et al., 1982). The validity of any marker technique is difficult to establish since there is no absolute method for measuring amounts of microbial protein in vivo (Theurer, 1980).

Ellis and Pfander (1965) fed sheep diets devoid of nucleic acids and found that 14-18% of total microbial nitrogen in ruminal fluid could be attributed to nucleic acid nitrogen. Of this, RNA nitrogen comprised 10.4-14.8% and DNA nitrogen varied from 2.2-4.1%. Total nucleic acid nitrogen and RNA were highly correlated with total microbial nitrogen ($r=.80$ and $r=.72$, respectively). Similarly, Smith et al. (1969) reported a relatively constant portion (19%) of total microbial nitrogen was in the form of microbial nucleic acid N using rumen fluid from calves fed various roughage:concentrate diets. The relative consistency of RNA-N/total N ratio allows RNA-N or nucleic acids to be used as a marker.

The physiological stage of bacteria can effect nucleic acid content. Adams et al. (1976) reported values of 10-15% nucleic acid in mature, dry bacterial cells, while as much as 21% of rapidly growing bacteria were composed of nucleic acids. Bergen et al. (1982) have shown that the RNA to protein ratio increases with increased microbial growth rate. Therefore, the ratio should be quantified each time an experiment is conducted.

Estimates of nucleic acid N leaving the rumen and available for postruminal use relies on the ability to acquire a satisfactory sample. Sampling at the duodenum poses the risk of digestion of nucleic acids and absorption of their constituents. Schelling et al. (1980) stated that nucleic acid digestion occurs fairly early in the small intestine. Also, backflow of ingesta into the proximal duodenum is a potential source of contamination. Therefore, cannula placement is extremely important. Abomasal sampling has a potential stratification problem. However, careful abomasal sampling would be the safest approach (Schelling et al., 1980).

Since several studies have demonstrated negligible amounts of feed nucleic acids surviving rumen degradation, all nucleic acid nitrogen passing to the lower tract is assumed to be the contribution of microbial protein. This assumption can be a problem with high bypass feeds. Additionally, information on the amount of endogenous protein secretions to the small intestine is scarce.

Analytical procedures to determine microbial protein synthesis via nucleic acids are generally laborious and recoveries are not complete. Progress has been made with the use of the purine and pyrimidine bases as indicators of microbial protein synthesis. A commonly used procedure

is one detailed by Zinn and Owens (1980) for estimation of purines (RNA). Data from Zinn and Owens (1980) support the use of nucleic acids as a microbial marker. However, they caution that measurement of the ratio of nucleic acid to protein in isolated microbes should be determined for each trial. They observed ratios of nucleic acid N : total N in isolated ruminal bacteria to range from .16 for very low quality forage diets to .20 for typical high concentrate diets.

2,6-diaminopimelic acid (DAPA) is a cell wall constituent of several rumen bacteria and reportedly absent in plant material or protozoa. Several researchers (Ibrahim et al., 1970; Hutton et al., 1971; Ling and Butlery, 1978) found no DAPA in dietary constituents using acid ninhydrin, which is more color specific than the ninhydrin normally used in automated analysis. In contrast, Theurer (1980) detected DAPA (or another acid with similar evolution time) in hydrolysates of bacteria, protozoa and all feedstuffs analyzed. Protozoal DAPA is generally attributed to engulfed bacteria. Whitelaw et al. (1984) found estimates of bacterial N based on DAPA concentrations to be highly variable and frequently impossibly high. They suggested this was most likely due to non-representative sampling of the rumen microbial population, occurring particularly when conditions within the rumen are unstable.

2-amino ethylphosphonic acid (AEP) in protozoa was reported by Horiguchi and Kandatsu (1960) and suggested as a marker by Abou Akkada et al. (1968). However, data from Rahnema (1977:in Theurer, 1980) indicate absence of AEP in protozoa, and Whitelaw et al. (1984) found considerable concentrations of AEP in rumen bacteria, thus precluding its use as a protozoal marker.

D-alanine occurs in relatively constant amounts in cell walls of most bacteria (Schleifer and Kandler, 1972) and has been used as a bacterial marker. Garrett et al. (1980) reported on an enzymatic procedure for the analysis of D-alanine.

Rahnema (1977:in Theurer, 1980) compared various amino acids for estimating bacterial protein in abomasal digesta of steers fed a grain diet. There was excellent agreement among four of the methods for ranking treatment means: corrected DAPA (adjusted for feed concentration of this acid), lysine, DAPA and leucine, or lysine and leucine. However, it is not known which of these amino acids or combinations would most accurately reflect the actual bacterial protein content of digesta.

In Situ Methods

Estimation of ruminal forage digestion can be made using the nylon bag technique (Lowrey, 1970). This technique involves the use of nylon bags containing diet samples attached to a suspension device. At various time intervals, the bags are submersed into the liquid strata of ruminal contents and the lines are secured to the rumen cannula to allow bag movement with contents.

Various factors affecting this technique for examination of ruminal digestion have been identified. Bags introduced at different times and removed as a group results in less variation within procedure than introduction all at once and removal at specific subsequent time intervals (Nocek, 1985). Sample size effects on digestion appear to be negligible as long as sample weight:bag surface area is kept constant (Playne et al., 1978). If this ratio is too small, overestimates of

ruminal digestion will occur, and if too large, underestimates are likely (Santos et al., 1984). Nocek (1985) recommended 12.6 mg/cm^2 as comparing most favorably with literature in vivo estimates for ruminal nitrogen digestion.

Pore size and size of sample grind will effect the influx of digesting agents and ruminal particles, and efflux of sample material and digested residues. Weakley (1983) concluded that bag materials of small pore (5 um) size limit influx of digesting agents regardless of efflux of digested residues. Van Hellen and Ellis (1977) recommended a pore size of no larger than 10 um. However, Nocek (1985) found that 40-102 um pore sizes were similar in estimated ruminal protein availability and compared more favorably with in vivo literature estimates than smaller sizes. The specific ingredient and nutrient being investigated could necessitate different pore sizes. Uden and Van Soest (1984) noted that there will always be a trade off between mechanical losses and gains of material and suppression of fermentation in the bag. They recommended grinding samples to no less than 2 mm, 37 um pore size bags and sample size of 6-7 mg/cm^2 bag surface.

Bacterial contamination could effect nitrogen digestion rates when in situ techniques are used. Certain ruminal bacteria attach to plant particles (Akin and Amos, 1975) and the impact of this contamination was investigated by Nocek (1985) using soybean meal. No significant differences were detected between nitrogen disappearance rate constants with or without correction for bacterial contamination. However, Nocek and Grant (1987) reported that correction for bacterial nitrogen altered rates of nitrogen digestion and suggested consideration of this correction should be made when establishing nitrogen digestion rates for

forages by in situ techniques. In addition, Vogel (1988) noted increased bacterial nitrogen contamination with increasing time in the rumen using wheat forage samples in situ, however, correction of N disappearance estimates for microbial N did not significantly alter extent of N disappearance at any incubation time.

In Vivo Methods - Markers

Estimation of forage digestibility in vivo for grazing animals requires the use of indigestible markers. These markers may be internal (occur naturally in the forage) or external (administered in known amounts). Lignin is the most common internal marker used to estimate digestibility. Lignin is considered indigestible and therefore should be completely recovered in the feces. Digestibility can be calculated through the use of a ratio of lignin to other constituents. However, lignin recovery in immature forages can be incomplete, and best results are seen in forages with >7% lignin in the dry matter (Van Soest, 1982). Fahey and Jung (1983) reviewed use of lignin as a digestion marker, including a thorough discussion of factors influencing lignin recovery and analytical considerations. Some recently studied internal markers include indigestible acid detergent fiber (Penning and Johnson, 1983), indigestible neutral detergent fiber (Lippke et al., 1986) and acid insoluble ash (Van Kuelen and Young, 1977). Galyean et al. (1986) summarized recent studies comparing digestibility estimates of various internal markers with in vivo digestibilities in ruminants.

External markers are used more commonly for fecal output, with intake calculated as the quotient of fecal output and indigestiblity of the diet. If actual intake is known, ruminal digestion can be estimated

by collection of digesta or feces and calculation of marker concentration and organic matter flow at the point of collection. Particulates, dyes, metal oxides, microorganisms, water-soluble markers, rare earths and radioactive markers have been used as external markers for determining digestibility of forage diets (Kotb and Luckey, 1972). Chromic oxide is the most commonly used external marker. The primary problems with chromic oxide is wide variation in fecal recovery. Langlands (1975) suggested that low chromic oxide recoveries in grazing situations are likely due to physical loss of feces, marker regurgitation, analytical errors or failure to establish marker equilibrium. Reviews of this marker are provided by Kotb and Luckey (1972), Langlands (1975) and Raleigh et al. (1980).

CHAPTER III.

STEERS GRAZING TALLGRASS RANGELAND I. CHEMICAL COMPOSITION AND DIGESTIBILITY OF DIETS DURING SPRING AND SUMMER.

Abstract

Four trials were conducted on tallgrass prairie in north-central Oklahoma during grazing seasons in each of two consecutive years to determine the effects of advancing season on diet nutrient content and digestibility. Trials were conducted in mid-May, late June, mid-August and late September. Forage samples were collected by esophageally fistulated beef steers and analyzed for crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and in vitro organic matter disappearance. In situ organic matter and nitrogen disappearance were analyzed by incubating esophageal masticate in dacron bags for 6, 12, 18, 24, 36, 48 and 72 hours in the rumens of fistulated steers grazing the study pasture. Diet CP levels were highest in May of both years (avg = 13.4%) and declined with each successive trial. However, in 1987, CP increased ($P<.05$) from 6.8% in August to 8.0% in September. Neutral detergent fiber increased an average of 7.8% and ADF increased an average of 17.7% across season. In vitro organic matter digestion values declined similarly both years. Digestibilities in May and June were not different (avg=55.55%; $P>.05$), but digestibility declined in August (50.49%; $P<.05$) and September (42.27%; $P<.05$). Potential organic matter degradability (POMD) and potential nitrogen degradability (PND),

as indicated by 72 h in situ incubation, declined with advancing season both years. Total seasonal decline in POMD was 22% in 1986 and 15% in 1987. Total seasonal decline in PND was 45.4% in 1986 and 24.2% in 1987. Crude protein digestibility (CP X PND) ranged from 9.68 in May to 2.98 in September, 1986, and from 11.12 in May to 4.04 in August, 1987. Cotton string disappearance at 72 h incubation varied 18% among 1986 trials, but only 9.5% among 1987 trials. Results suggest that the decline in ruminal digestibility of forage as the grazing season progresses is mainly due to indigestible forage components.

Introduction

The quantity and quality of native forage varies quite dramatically throughout the growing season because of maturation and environmental conditions (Losada et al., 1982; Reid and Jung, 1981) . Forage maturity is accompanied by a decline in nitrogen and an increase in fiber that result in reduced organic matter and nitrogen digestion. Feeding nitrogen supplements can increase performance of grazing livestock when protein content of forage is low (Gill et al., 1984; Lusby and Horn, 1983). Protein requirements are 10.5-11.4% for 230-272 kg stocker calves gaining .9 kg/d, and 9.7% for 455 kg cows of average milking ability (NRC, 1984). Considering these requirements, protein levels of native pasture in the spring and summer become limiting in June for growing stockers and by mid to late July for cows nursing calves (Waller, 1972). Before optimal levels of supplementation can be determined, digestive processes of grazing animals must be more fully understood and variability in nutrient content of forage throughout the grazing season must be determined. The objectives of this study were to

determine the degree to which the availability of nutrients declines in the diets of beef steers grazing tallgrass prairie rangeland during the spring and summer.

Materials and Methods

Experimental Area

The study was conducted on Section 5 of the OSU Range Research Area, located approximately 8 km SW of Stillwater, Oklahoma. A 49 ha pasture was used in 1986 and 24 ha of the same area were grazed in 1987. The pasture was moderately stocked (approximately 1.25 AUM/ha). Herbaceous vegetation in the pastures is composed primarily of big bluestem (Andropogon gerardii), indiangrass (Sorghastrum nutans) and switchgrass (Panicum virgatum), and little bluestem (Schizachyarium scoparium). Average annual precipitation at Stillwater is 831 mm., of which approximately 65% falls from April through September (Myers, 1982). Average temperature during the growing season (May-September) is 24 C, with an average minimum of 18 C and average maximum of 31 C. Precipitation and temperatures for 1986 and 1987 are presented in Appendix A and B.

Trials

Trials were initiated in May and were repeated at approximately six week intervals throughout the summer. There were four trials: mid-May, late June, mid-August and late September. Trial dates are presented in Appendix C.

Diet samples - Collection and Analysis

Three or four mature Hereford steers fitted with esophageal cannulae were used to obtain esophageal masticate samples. Cattle were maintained on an area adjacent to the study pasture with similar vegetation and placed on the study pasture during collection periods. Diet samples were taken early (approximately 0630 h) the day preceding each trial and late (approximately 1700-1800 h) the first day of each trial. Steers were fasted twelve hours prior to collection times to insure grazing readiness. Each steer was harnessed with a screen-bottom collection bag and allowed to graze freely for 30-45 minutes. The cattle were herded into different areas of the study pasture during each collection period in an attempt to obtain samples representative of the entire pasture. Masticate samples were placed in plastic bags and refrigerated immediately after collection. Following the second collection, samples were composited within steer. Additional aliquots from each of the samples were composited across steers and prepared for in situ disappearance analysis. All samples were dried in a forced air oven at 40 C for 48 hours. After air equilibration, samples were ground through a 2-mm screen in a Wiley mill and stored in air-tight containers. Laboratory analysis included dry matter and ash (AOAC, 1975), macro-kjeldahl N (AOAC, 1975), in vitro organic matter digestion (IVOMD) (Tilley and Terry, 1963), neutral detergent fiber (NDF) and acid detergent fiber (ADF) (Goering and Van Soest, 1970). Rumen fluid for IVOMD procedure was obtained from a donor steer receiving a prairie hay diet.

Six ruminally cannulated beef steers (Hereford X Angus and Hereford X Limousin X Angus) were used for in situ incubations in 1986, and eight

ruminally cannulated beef steers (Hereford, Hereford X Angus and Hereford X Limousin X Angus) were used in 1987. The steers grazed the experimental pasture year round. Duplicate dacron bags (7.5 X 11.5 cm) containing 2.222 g (as-is) ground (2 mm) esophageal masticate samples were attached to polyethylene lines equipped with a large nut as a weight. Lines were introduced individually into the rumen beginning on day 7 of each trial and incubated for 6, 12, 18, 24, 36, 48 and 72 hours. Duplicate bags containing .5 g of cotton string were included with the 72, 48, 36 and 24 h rumen lines to compare seasonal effects of ruminal environment on cellulose disappearance. All bags were removed from the rumen simultaneously at 0800 on day 10 and washed with water until effluent ran clear. Bags with forage residue were dried at 55 C for 48 hours and weighed. Forage was removed and placed in foil pans and dried 24 h in a 105 C oven to obtain 100% dry weight. Forage residues were analyzed for dry matter, ash, and macro-kjeldahl N (AOAC, 1975), and disappearance of organic matter and nitrogen were calculated. Cotton strings were removed from bags, washed clean, placed in foil pans and dried at 105 C for 24 hours. Strings incubated for 72 h were washed and dried in the bag to avoid loss of residue. Dry string residues were weighed and dry matter disappearance (DMD) values were calculated.

Statistical Analysis

Data were analyzed using the General Linear Models procedure of the Statistical Analysis System. The initial model contained year, trial and year X trial. Year X trial interactions were observed for CP and ADF, therefore the data were analyzed within year using a model containing trial as the sole variable. In situ disappearance data were

analyzed within year and incubation period with trial and steer in the model. Trial differences were evaluated by F-test and means were separated by least significant difference.

Results and Discussion

Chemical Composition and Digestibility of Diets

Constituents and in vitro digestibilities of esophageal samples are presented in Tables 1 and 2. Organic matter varied slightly among trials, but no consistent pattern was noted. Waller et al. (1972) noted increases in OM content throughout the season when hand-pulled samples of native grasses were taken monthly at an area near the site of the current study. Their values were averaged over a 15 year period and consisted of the major four grass species in the area, big bluestem, little bluestem, indiangrass and switchgrass. Salivary contamination of esophageal samples can contribute 1-4% ash (Holechek et al., 1981). Considering this contribution, the OM levels observed in the current study are comparable to data of Waller et al. (1972), although the trend of increasing OM with advancing season was not noted in this study.

The majority of growth of native grasses occurs from April to July (Gillen and McNew, 1987). The crude protein content of tallgrasses declines dramatically with advancing maturity and declining growth rate (Waller et al., 1972; Rao et al., 1973). The CP content of the masticate samples collected in the current study also declined with advancing season (Tables 1 and 2). Highest CP levels occurred in May of both years, averaging 13.4%.

In 1986, CP declined ($P<.05$) with each succeeding trial from May to August, ranging from 13.33% to 7.62%, respectively. Crude protein

levels in August and September were not different (P>.10). In 1987, CP was again low (P<.05) in August, but by September, CP content had increased (P<.05) to 8.03%. The diet CP values correspond with the fiber content (Tables 1 and 2) and ruminal ammonia values (Chapter IV). The reason for the extreme drop (35.79%) from June to August and increase of 18% from August to September is not clear. Weather patterns will affect forage chemical composition. Temperatures and precipitation amounts are presented in Appendix Table 3. During the first week of August, 1987, high temperatures and dry conditions caused soil moisture to drop to a yearly low (Nat'l Oceanic and Atmospheric Admin., 1987). Increased temperature results in more rapid metabolic activity, which promotes conversion of photosynthetic products to structural components (Van Soest, 1982). This has the effect of decreasing nitrate, protein and soluble carbohydrate, and increasing structural cell wall.

Crude protein levels of esophageal masticate samples reported in this experiment are higher in all grazing periods than hand-pulled samples reported by Waller et al. (1972). Animals have the ability to graze forage of higher nutritional content than the average of the sward (Hodgson, 1982; Arnold, 1982; Wallace, 1972; Rao et al., 1973). The seasonal pattern of diet CP content during the growing season is similar to forage CP reported by Waller (1972) and to tallgrass ranges in Kansas (Rao et al., 1973; Allen et al., 1976).

Neutral detergent fiber (NDF) or cell wall content of esophageal masticate samples are presented in Tables 1 and 2. In 1986, cell wall content increased (P<.05) from June through August and then declined 8.5% (P<.05) in September to levels similar to May. In 1987, NDF increased (P<.05) from May to June, stabilized through August, and

declined (P<.05) 3% by September to levels similar to May. Kansas research on bluestem pastures found similar values and a similar trend with NDF increasing through August, and then declining in September (Rao et al., 1973).

Acid detergent fiber (ADF) represents primarily the cellulose and lignin components of the plant cell wall. In 1986, ADF increased throughout the season, although significance was noted only between May and September. In 1987, ADF increased (P<.05) through August, and then stabilized through September. The results from 1986 agree with results recorded over a 15 year period by Waller et al. (1972) in which crude fiber increased linearly from May through October. The decline (P<.05) from August to September in 1987 corresponds to results of Rao et al. (1973) in Kansas. When hand-clipped samples were compared to masticate samples, differences in ADF due to animal selection became more apparent as season progressed (Rao et al., 1973).

The general increase in fiber levels observed through mid-August indicate an increase in structural components of the forage. Cell wall content of forage increases at high temperatures (Van Soest, 1982) because of increased metabolic rate and subsequent conversion of soluble nutrients to structural tissues or, in temperate grasses especially, a much lower accumulation of soluble carbohydrates (Smith, 1973). Moir et al. (1977) noted that cell wall digestibility decreased as temperature increased, and suggested that this was probably due to greater lignification that occurs at higher growth temperatures (Ford et al., 1979; Van Soest, 1982). Wilson (1981) summarized published data on effects of low soil moisture on digestibility, cell wall content and lignin content of grasses and legumes, and found that overall, water

stressed herbage is likely to be of high quality. The studies reported by Wilson (1981) were, however, conducted at constant temperatures and water levels.

In vitro diet OM digestibility declined with advancing season both years of the study (Tables 1 and 2). The September trial in 1986 was conducted during a period of excessive rainfall. During this trial, 303 mm of rain was recorded, with 126 mm falling on September 30. Diet samples collected during this trial may not have been an accurate representation of forage normally grazed in late September due to leaching. Periods of decreased light can cause a decline in soluble carbohydrate levels in plants, and usually an accompanying increase in cell wall content, contributing to lower digestibility (Wilson, 1982). In both years, digestibility did not decline significantly until August. In 1986, a total seasonal decline in IVOMD of 30.85% was noted, while a 21.51% decline was noted in 1987.

Potential disappearance of forage organic matter (POMD), obtained from 72 h in situ incubation, decreased as season progressed (Table 3). In 1986, POMD remained around 76% from May through June, declined ($P<.05$) to 72.3% in August, and dropped to 59.4% ($P<.05$) by September, resulting in a 22% decrease over the season. In 1987, significant declines ($P<.05$) were noted in the first three trials. POMD declined from 78.2% in May to 75.3% in June to 67.9% in August. Further decline to 66.0% in September was not significant ($P>.10$). Total decline in POMD in 1987 was 15%. Once again, the decline was most severe in 1986, primarily due to the lower POMD in September.

Potential nitrogen disappearance (PND), estimated by the 72 h in situ disappearance, was similar to the pattern of POMD. In 1986, PND

remained around 72% from May through June, declined (P<.05) to 65% in August and dropped sharply (P<.05) to 39.6% by September, resulting in a 45.4% decline for the season. In 1987, a significant drop (P<.05) in PND was noted from 83% in May to 75.2% in June. A decline (P<.05) from June to August resulted in 59.4% PND, with no significant change occurring through September. Total decline in PND in 1987 was 24.2%. From combined values for CP and 72 h nitrogen disappearance estimated levels of digestible protein in 1986 were 9.68% in May, 6.63% in June, 4.95% in August and 3.00% in September. Similarly, digestible protein estimates in 1987 were 11.12% in May, 7.97% in June, 4.04% in August and 5.05% in September. A correlation of .87 was noted between CP concentration in the diet and digestible CP. CP intake was also highly correlated with digestible CP (r=.88; P<.05). These results are similar to McMeniman et al. (1986) who noted correlations of .91 and .94 between nitrogen concentration in the diet and apparent nitrogen digestibility and nitrogen intake.

Several trials in north-central Oklahoma have shown that gains of cattle grazing tallgrass prairie in mid-late summer are improved with protein supplements (Lusby and Horn, 1983; Gill et al., 1984). Responses have been recorded on pastures with forages containing 7.7% CP and less. Feeding energy supplement produced no increase in gains over controls, indicating that protein was the first limiting nutrient (Lusby and Horn, 1983). Lusby et al. (1982) noted that protein supplements stimulate forage digestibility and intake. The combination of declining CP content and potential OM digestibility of forage as season progressed in this study indicate a decreasing availability of substrate for rumen microbes. Responses to a ruminally degradable protein supplement such

as soybean meal indicate correction of a ruminal protein deficiency. In the present study, microbial efficiency was not affected by advancing season (Chapter IV).

Cotton string cellulose disappearance (Table 5) indicated no significant changes in ruminal environment among the first three trials both years. The difference noted between August and September in 1986 indicates an increase in digestive function toward the end of the season, which is contrary to our expectation. If any changes in ruminal environment occur throughout the season, it would be expected that lower crude protein levels combined with lower ruminal ammonia values that occur with advanced maturity would contribute to a decline in digestive capabilities. The cotton string disappearances noted in 1987 are closer to what would be expected. Although significant differences were noted between the two early trials and September, a decline of only 9.5% occurred throughout the 1987 season, with the trend being decreasing digestive capabilities with advancing season. These results may reflect declining ammonia-N concentrations noted in the August and September trials of 1987 as discussed in Chapter IV.

TABLE 1. CHEMICAL COMPOSITION AND DIGESTIBILITY OF ESOPHAGEAL MASTICATE SAMPLES GRAZED FROM TALLGRASS PRAIRIE, 1986.

Component	TRIAL Mid May	Late June	Mid Aug	Late Sept	SEM[d] (n=3)
	----------% of dry matter----------				
OM	87.25	87.32	90.33	89.75	1.69
	----------% of organic matter---------				
CP	13.33[a]	9.20[b]	7.62[c]	7.52[c]	.41
NDF	76.23[ab]	78.59[b]	81.59[c]	74.85[a]	.92
ADF	42.92[a]	43.87[ab]	44.96[ab]	47.65[b]	1.43
IVOMD	58.34[a]	55.97[a]	51.57[b]	40.34[c]	.78

[abc] Means within a row with different superscripts are different.

[d] Standard error of the mean, n = 4 in trial 1, n = 3 in other trials.

TABLE 2. CHEMICAL COMPOSITION AND IN VITRO DIGESTIBILITY OF ESOPHAGEAL MASTICATE SAMPLES GRAZED FROM TALLGRASS PRAIRIE, 1987.

Component	TRIAL Mid May	Late June	Mid Aug	Late Sept	SEM[d] (n=3)
	----------%of dry matter----------				
OM	91.42[a]	90.53[ab]	90.08[bc]	89.07[c]	.42
	----------% of organic matter--------				
CP	13.40[a]	10.59[b]	6.80[d]	8.03[c]	.39
NDF	76.72[a]	82.35[b]	83.03[b]	80.53[a]	1.65
ADF	40.01[a]	44.08[b]	49.72[c]	47.89[c]	1.17
IVOMD	56.32[a]	54.78[a]	49.40[b]	44.20[c]	1.55

[abc] Means within a row with different superscripts are different.

[d] Standard error of the mean, n = 4 in Sept trial, n = 3 in other trials.

TABLE 3. FORAGE ORGANIC MATTER DISAPPEARANCE DETERMINED BY IN SITU TECHNIQUE.

Hours of Incubation	Year	TRIAL Mid May	Late June	Mid Aug	Late Sept	SEM[d]
6	1986	18.22[b]	24.16[a]	24.23[a]	23.45[a]	.85
	1987	25.17[a]	21.92[b]	15.49[c]	26.26[a]	.98
12	1986	29.37[b]	31.17[ab]	33.80[a]	31.18[ab]	1.62
	1987	38.21[a]	36.05[ab]	27.24[c]	34.77[b]	1.27
18	1986	40.91[b]	39.32[b]	45.68[a]	33.11[c]	1.78
	1987	47.15[a]	43.05[a]	37.64[b]	45.23[a]	1.81
24	1986	48.02[a]	49.47[a]	47.87[a]	39.05[b]	1.89
	1987	56.95[a]	53.78[ab]	44.80[c]	49.92[bc]	1.96
36	1986	56.56[ab]	60.61[a]	58.37[a]	51.04[b]	2.46
	1987	68.80[a]	62.39[b]	57.09[b]	58.84[b]	2.18
48	1986	68.37[a]	67.55[ab]	65.57[b]	57.17[c]	1.08
	1987	74.39[a]	70.26[b]	61.74[c]	63.68[c]	1.22
72	1986	75.95[a]	76.65[a]	72.28[b]	59.39[c]	.58
	1987	78.19[a]	75.34[b]	67.91[c]	66.02[c]	.97
Rate of OM disappearance, %/h						
	1986	4.62	4.30	4.58	6.50	
	1987	6.32	5.49	5.22	6.71	

[abc] Means within a row with different superscripts are different ($P<.05$).

[d] Standard error of the mean, n = 5 in 1986 Sept trial, n = 6 in other 1986 trials. SEM from Sept used. n = 8 for all 1987 trials.

TABLE 4. FORAGE NITROGEN DISAPPEARANCE DETERMINED BY IN SITU TECHNIQUE.

Hours of Incubation	Year	TRIAL Mid May	Late June	Mid Aug	Late Sept	SEM[d]
6	1986	13.40[c]	18.10[b]	22.27[a]	19.26[ab]	1.22
	1987	22.70[bc]	25.28[b]	20.77[c]	34.57[a]	1.72
12	1986	18.66[c]	24.21[b]	35.11[a]	21.86[bc]	2.16
	1987	40.14[b]	34.51[bc]	31.43[c]	49.64[a]	2.70
18	1986	30.72[b]	30.25[b]	42.58[a]	22.45[c]	2.15
	1987	49.85[a]	40.87[b]	38.17[b]	48.79[a]	2.25
24	1986	42.27[a]	38.73[a]	41.68[a]	20.67[b]	2.68
	1987	60.67[a]	49.68[bc]	43.69[c]	52.28[b]	2.21
36	1986	52.00[a]	52.72[a]	53.03[a]	33.99[b]	3.03
	1987	73.18[a]	62.44[b]	56.79[bc]	53.33[c]	2.40
48	1986	66.64[a]	60.30[b]	60.63[b]	38.02[c]	2.32
	1987	79.53[a]	69.09[b]	57.00[c]	61.34[c]	2.20
72	1986	72.59[a]	72.12[a]	64.99[b]	39.63[c]	1.57
	1987	83.01[a]	75.25[b]	59.43[c]	62.90[c]	1.74
Rate of N disappearance, %/h						
	1986	5.27	3.71	5.05	6.13	
	1987	6.79	5.54	7.72	6.40	

[abc] Means within a row with different superscripts are different ($P<.05$).

[d] Standard error of the mean, n = 5 in Sept trial, 1986, n = 6 in other 1986 trials. SEM from Sept trial used. n = 8 for all 1987 trials.

TABLE 5. COTTON STRING CELLULOSE DISAPPEARANCE DETERMINED BY IN SITU TECHNIQUE.

Hours of Incubation	Year	TRIAL Mid May	Late June	Mid Aug	Late Sept	SEM[d]
24	1986	17.71	20.19	18.88	19.60	3.17
	1987	26.09^{bc}	29.43^{ab}	21.62^{c}	31.95^{a}	2.00
36	1986	32.14	37.27	39.86	41.87	5.59
	1987	53.22^{ab}	39.34^{b}	47.26^{b}	63.75^{a}	4.98
48	1986	52.05^{b}	53.14^{b}	49.54^{b}	65.60^{a}	4.53
	1987	71.10^{ab}	64.53^{b}	69.24^{b}	79.85^{a}	3.66
72	1986	84.27^{ab}	81.84^{ab}	74.63^{b}	88.04^{a}	4.43
	1987	95.44^{a}	96.95^{a}	92.47^{ab}	87.71^{b}	2.03

^{abc} Means within a row with different superscripts are different ($P<.05$).

^{d} Standard error of the mean, n = 5 in Sept trial, 1986, n = 6 in other 1986 trials. SEM from Sept trial used. n = 8 for all 1987 trials.

CHAPTER IV

STEERS GRAZING TALLGRASS RANGELAND. II. FORAGE INTAKE, DUODENAL NUTRIENT FLOW, MICROBIAL PROTEIN SYNTHESIS AND RUMINAL ENVIRONMENT

Abstract

Intake, ruminal fermentation and nutrient flows to the small intestine of ruminally fistulated beef steers grazing tallgrass rangeland were measured during four periods in both the 1986 and 1987 growing seasons (May-September). Forage intake (g OM/100 g BW) remained around 2.1 during the first three trials of 1986 and decreased to 1.9 in September. In 1987, intake declined throughout the season, ranging from 1.8 in May to 1.4 in September. Duodenal flow of organic matter (g/d) increased with advancing season in 1986 due to increased absolute organic matter intakes (g/d) of growing steers. No differences were noted among 1987 trials. Apparent ruminal digestion of organic matter declined 17% throughout the 1986 season and 25.2% in 1987. True ruminal organic matter digestion remained fairly stable throughout the 1986 season (avg=54.9). In 1987, true ruminal organic matter digestion declined in the latter half of the summer. Nitrogen intake declined with advancing season. Duodenal flow of nitrogen exceeded nitrogen intake in all trials. Ammonia nitrogen levels remained above 2 mg/100 ml rumen fluid in all trials except August, 1987, when concentrations dropped to 1.4 mg/100 ml. However, microbial efficiency (g microbial

N/kg OM truly fermented) did not change across trials either year (avg=18.9), indicating that nitrogen and fermentable organic matter was sufficient for microbial growth across season. September tended to have the lowest concentration of ruminal volatile fatty acids in both years. Molar proportions of acetate were inconsistent among 1986 trials, however in 1987, acetate tended to increase with advancing season. Propionate varied inconsistently in 1986, but tended to decrease across the 1987 season. Butyrate proportions increased from May to June, stabilized through August and declined by September, 1986. No significant changes occurred in molar proportions of butyrate across the 1987 season.

Introduction

Changes in diet composition that occur as the growing season progresses affect the total amount of nutrients available to the grazing ruminant. Performance depends upon intake and nutritive value of the forage and also end-products of microbial fermentation in the rumen. Volatile fatty acids provide 50-85% of the metabolizable energy for ruminants on forage diets (Owens and Goetsch, 1988) and microbial protein provides 40-80% of the total protein reaching the small intestine (Owens and Bergen, 1983). Supplementation may enhance forage utilization by correction of microbial or tissue level deficiencies, in addition to increasing forage intake. The influence of declining forage quality on basic digestive processes of ruminants must be better understood before optimal level and type of supplementation can be determined.

Studies were conducted in 1986 and 1987 to investigate the seasonal

changes in forage intake and nutrient utilization that occur on tallgrass prairie in central Oklahoma.

Materials and Methods

Study Area

The study was conducted on Section 5 of the Downey Range Research Area, located approximately 8 km SW of Stillwater, Oklahoma. A 49 ha pasture was used in 1986. The pasture was divided in half prior to the 1987 trials and the experimental cattle were restricted to 24 ha. The pastures were stocked at a light to moderate rate in both years. Vegetation in the pastures was typical of tallgrass prairie. Predominant grass species were big bluestem (Andropogon gerardii), little bluestem (Schizachyarium scoparium), indiangrass (Sorghastrum nutans) and switchgrass (Panicum virgatum). Average annual precipitation is 831 mm., of which approximately 65% falls from April through September. Average temperature during the growing season (May-September) is 24 C, with an average minimum of 18 C and average maximum of 31 C. Precipitation and temperatures for 1986 and 1987 are presented in Appendix B.

Field Trials

Trials were initiated at the beginning of the grazing season in May and repeated at approximately six week intervals throughout the growing season, resulting in four trials each year (mid-May, late June, mid-August and late September). Trial dates are presented in Appendix C.

Six steers (three Angus X Hereford and three Limousin X Angus X Hereford) equipped with ruminal and duodenal T-type cannulae were used

in 1986. One steer died in late August of 1986 and therefore only five steers were used for the September trial. Four of these steers were used in the second year of the study. In addition, four Hereford steers equipped with ruminal and duodenal T-type cannula were used in 1987. The steers were placed on the study pasture a minimum of two weeks before the first trial began and remained on the pasture throughout the grazing season. Cannulae were placed in the crossbred steers in March of 1986, two months before the first sampling. All steers used in 1987 had cannulae fitted at least a year before the first sampling. All steers were halterbroken and docile. Steers were weighed without shrink on three consecutive days at the beginning of each trial. Average weights are presented in Appendices D and E.

Gelatin capsules containing chromium sesquioxide were administered daily via rumen cannula to estimate fecal output and digesta flow to the duodenum. During both years of the study, steers received 5 g of chromic oxide twice daily (0800 h and 2000 h) on days 1-8 of each trial. Fecal grab samples were collected on day 6 (1200 h and 2000 h), day 7 (0800 h and 1600 h) and day 8 (0200 h). Samples were refrigerated until the end of the sampling period, at which time they were composited within steer and dried in a forced air oven (50° C) for 48 hours. After air-equilibration, samples were ground through a 1 mm screen in a Wiley mill and stored in plastic bags.

Duodenal samples were obtained on day 7 (1600 h), day 8 (0200, 1200 and 2000 h) and day 9 (0800 h). At each sampling period, 200 ml duodenal digesta were obtained from each steer. Digesta was transferred to a composite jar according to steer and refrigerated until the end of sampling. The composites for each steer were mixed thoroughly, poured

into plastic tubs and frozen (-15° C). Following lypholization, the samples were ground in a blender and stored in plastic bags.

Rumen samples were collected on day 9 (0800, 1400 and 2000 h) and day 10 (0200 and 0800 h). Ruminal contents were thoroughly mixed before samples were withdrawn. The samples were strained through four layers of cheesecloth. A 100 ml aliquot of fluid was acidified (2 ml 20% sulfuric acid) and immediately frozen (-15° C) in a whirlpak.

Ruminal fluid for microbial pellet isolation was obtained from steers on day 9 (1400 h) and day 10 (0800 h). Ruminal contents were thoroughly mixed before samples were withdrawn. Whole ruminal contents were strained through four layers of cheesecloth. A 500 ml composite sample of fluid was poured into plastic bottles and immediately placed on ice to stop microbial action. This fluid was centrifuged at 1000 X g for 5 minutes to remove feed particles and protozoa. The supernatant was combined with a 37% formaldehyde solution (25 ml/100 ml), centrifuged at 20,000 X g for 20 minutes, washed with .9% NaCl, recentrifuged at 20,000 X g for 20 minutes, washed with distilled water and recentrifuged. The supernatant was withdrawn. The resulting bacterial suspension was frozen, lypholized, ground with mortar and pestal, and stored in whirlpaks.

Laboratory Analyses

Laboratory analyses of fecal samples included dry matter, ash, kjeldahl nitrogen (AOAC, 1975) and chromium concentration (Williams et al., 1962). Analyses of duodenal digesta included chromium concentration (Williams et al., 1962), kjeldahl-nitrogen (AOAC, 1975), and purine concentration (Zinn and Owens, 1980). Ammonia-nitrogen (NH_3-

N) was determined by magnesium oxide distillation (AOAC, 1975). The isolated bacterial pellet was analyzed for kjeldahl-nitrogen (AOAC, 1975) and purine concentration (Zinn and Owens, 1980).

Ruminal fluid samples were thawed overnight at room temperature. Two 40-ml aliquots from each sample were centrifuged at 1000 X g for 15 minutes. A 20-ml aliquot of supernatant was analyzed for ammonia nitrogen using a phenol-hypochlorite procedure (Broderick and Kang, 1980). Two ml of 25% (w/v) metaphosphoric acid were added to a 10 ml aliquot of fluid and centrifuged at 25,000 X g for 20 minutes. A 1 ml aliquot was withdrawn and .2 ml 2-ethylbutyric acid (internal standard) were added. Volatile fatty acid (VFA) analyses were performed by gas chromatography.

Calculations

The following calculations were made:

$$\text{Fecal output(g OM/d)} = \frac{\text{Dosage of chromium(g/d)}}{\text{Chromium conc. in feces(g/g OM)}}$$

$$\text{Forage intake(g OM/d)} = \frac{\text{Fecal output(g OM/d)}}{1-(\text{IVOMD}/100)}$$

$$\text{Duodenal OM flow(g/d)} = \frac{\text{Daily dosage of chromium(g)}}{\text{Chromium conc in duodenal digesta(g/g OM)}}$$

$$\text{Duodenal nutrient flows(g/d)} = \text{Duodenal OM flow (g/d) X nutrient conc. in duodenal digesta (g/g OM)}$$

$$\text{Duodenal microbial N flow(g/d)} = \frac{\text{RNA-N flow}}{\text{RNA-N conc. of bact pellet/total N conc. of bact pellet}}$$

$$\text{Duodenal forage-N flow(g/d)} = \text{Total duod-N flow} - (\text{mic-N flow} + NH_3\text{-N flow})$$

$$\text{Microbial efficiency} = \frac{\text{Duodenal microbial-N flow(g)/kg OM}}{\text{truly fermented}}$$

$$\text{Apparent ruminal OM digestion} = \text{OM Intake} - \text{duodenal OM flow}$$

True ruminal OM digestion = OM Intake - (Duodenal OM flow - microbial OM flow)

Apparent ruminal N digestion = N Intake - duodenal N flow

True ruminal N digestion = N Intake - (forage-N flow)

Lower tract OM digestion = Duodenal OM flow - fecal OM

Lower tract N digestion = Duodenal N - fecal N

Statistical Analysis

Data were analyzed using the General Linear Models procedure of the Statistical Analysis System. The initial model contained year, trial, steer within year and year X trial. Year X trial interactions were observed for intake, nutrient flows and VFA, therefore all data were analyzed within year. Fecal and duodenal data from 1986 were analyzed with a model containing trial and steer. In 1987, steers were blocked according to weight due to the use of additional large steers. The model contained trial, block, and steer within block. Ruminal ammonia nitrogen and VFA data were analyzed with a model containing trial, period, steer and trial X period. Trial differences were evaluated by F-test and means were separated by least significant difference.

Results and Discussion

When expressed as percent of body weight (g/100g), intakes remained fairly stable (avg=2.08) throughout the first three trials of 1986 and then declined ($P<.05$) to 1.88 in September. In 1987, intake was lower ($P<.05$) in August and September (avg=1.45) than in May and June (avg=1.77). In 1987, a significant block effect was noted when intake was expressed on a BW basis. Forage intake, averaged over the summer, by steers in the heavy block (average 636 kg), was 21.1% lower than the

smaller (average 457 kg) steers. If the heavy steers are excluded, intakes were 2.1, 1.9, 1.7 and 1.5 g/100g BW in May, June, August and September, respectively. Steers in the heavy block were four-year old, obese Herefords. Body fat levels and lack of growth requirements probably explain the lower intake as a function of body weight.

Intake is influenced by the increase in fiber content that occurs as plants mature. In 1986, diet ADF tended to increase as the summer progressed, changing from 42.9% in mid-May to 44.9% in mid-August and 47.6% in late September (Chapter III). Intake reflected this change. In 1987, intake also reflected the ADF content of the diet, which increased ($P<.05$) from mid-May through mid-August and stabilized through late September (Chapter III).

Total organic matter flow to the duodenum and forage organic matter flow increased ($P<.05$) with advancing season in 1986 (Table 6) as a result of increasing absolute intakes of the growing steers which gained an average of 89 kg during the summer. Microbial organic matter flow was higher ($P<.05$) in the latter three trials than the May trial. However, when expressed as percent of total flow, the contribution of microbial organic matter was similar among trials (18.5-22.3%). In 1987, no differences ($P>.05$) occurred among trials for total organic matter flow (Table 7). Significantly less microbial OM flowed to the duodenum in August than all other trials. The greatest flow of microbial OM ($P<.05$) occurred in May. When expressed as percent of total flow, microbial OM in August contributed the least (12.3%) and in May contributed the most (19.4%) among trials. The contribution made by microbial OM to total flow in 1987 is comparable with that found by Funk

(1986), who reported about 15% of OM reaching the small intestine was attributed to microbes.

Although there was a tendency for OM digestion to decline with advancing season, no significant changes occurred among trials for either apparent or true OM digestion in 1986. Increased retention time of digesta allows more time for OM digestion, which may account for the similarity among seasons. However, in 1987 ruminal OM digestion declined with advancing season. Apparent ruminal OM digestion and true ruminal OM digestion declined ($P<.05$) 21% and 18.9%, respectively, from the early growing season to the late growing season. Values from this study are comparable with those reported by Funk (1986). Generally, increases in cell wall constituents and concomitant declines in cell contents result in decreased ruminal OM digestion. The less digestible fiber fractions of the diet (ADF) increased with advancing season both years (Chapter III). Ruminal OM digestion patterns reflected this change. McMeniman et al. (1986) reported lower apparent ruminal OM digestibilities for grazing sheep with the onset of the dry season and advanced maturity of Pangola grass.

No differences were noted in lower tract OM disappearance (% of OM intake) with advancing season in 1986 and 1987 (Tables 6 and 7). When expressed as percent of OM entering the duodenum, disappearance declined across the season ($P<.05$) 82.5% in 1986 and 24.9% in 1987. Digestion of microbial cells constitutes a large portion of OM digested in the small intestine of forage-fed animals, while both undigested fiber and microbial cells are available for fermentation in the large intestine. Lower tract OM digestion values obtained in the early season of 1986 and across the 1987 season are similar to those reported in the early season

for cattle grazing blue grama rangeland in New Mexico (Funk, 1986). The percentage of total OM digestion occurring in the lower tract have been reported to range from 4% with low intake forage diets of sheep to 37% with high intake cattle diets (NRC, 1985).

Nitrogen intake (NI) declined with advancing season both years (Tables 8 and 9). In 1986, NI declined 28.6% while in 1987 NI decreased 51.6% from May to August. Differences in total nitrogen intake between years is not only due to differences in nitrogen concentration in the diet, but also to differences in total organic matter intake (g/d). In 1986, total organic matter intake increased as the season progressed as a result of weight gain by the steers. Steers used in 1987 were larger and weights were relatively stable.

Apparent ruminal nitrogen disappearance was negative in all trials. Forages containing less than 2-2.5% nitrogen are normally associated with a net gain of nitrogen reaching the duodenum relative to ingested nitrogen that results from nitrogen recycling into the rumen (Egan et al., 1975). Forages evaluated in this study ranged from 2.1 to 1.1% N (Chapter III). The sources of nitrogen in the duodenum are mainly undegraded forage nitrogen and microbial nitrogen. Ruminal digestion of forage N (true ruminal digestion) was highest in May and lowest in August both years. A negative value was noted in August both years for true N digestion. Up to 20% of the total nitrogen reaching the duodenum may be derived from endogenous sources (Steinhour and Clark, 1980). The contribution of endogenous nitrogen was not considered when calculating forage N digestion, which may account for the negative digestion in August. True ruminal N digestion compared with potential N disappearance from in situ bags was not in good agreement. The same

general trend of declining N digestibility with advancing season is noted with both techniques, but the average N digestibility as indicated with the marker technique is 40% lower than the average in situ values at 72 hr of incubation.

Microbial efficiency (g microbial N/kg OM truly fermented) values did not change (avg=18.9; $P>.05$) across the season (Table 8 and 9). Microbial growth is dependent upon the quantities of fermentable organic matter and nitrogen available in the rumen. Up to 80% of nitrogen utilized by microbes can be supplied by ammonia. True ruminal organic matter digestion did not change significantly throughout the 1986 season (Table 6), and ruminal NH_3-N levels remained above 2 mg/100 ml (Table 10), a level which has been suggested as minimal for microbial growth. In 1987, true ruminal organic matter digestion declined the last two trials. However, no differences in microbial efficiency were noted, indicating that the balance of N and energy was sufficient for microbial growth.

Microbial efficiency values reported by Funk (1986) were intermediate to those observed in the current study. Higher values were reported by Walker et al. (1975) with sheep fed roughage rations and McMeniman et al. (1986) noted higher efficiency values across seasons with grazing sheep. However, McMeniman et al. (1986) found significant declines in microbial efficiency associated with the decline of OM digestibility and NH_3-N levels.

Ruminal NH_3-N concentrations in 1986 were lower ($P<.05$) in late September than in earlier trials (Table 10). Ammonia-N concentrations in June were lower ($P<.05$) than May and August. In 1987, NH_3-N levels were lowest ($P<.05$) in August. September NH_3-N levels were lower

(P<.05) than May and June trials (Table 11). Other researchers have noted relationships between NH_3-N and CP (Krysl, 1986; Playne and Kennedy, 1976). Correlations of .55 and .92 were found for NH_3-N and CP in 1986 and 1987, respectively. However, when both years were pooled, CP and NH_3-N were not well related (r=.38; P>.35) (Chapter III). This lack of relationship is similar to that reported by McCollum (1983). The correlation between NH_3-N and CP intake (g/100g BW) were the most significant (r=.68; P<.10). In 1987, little variation in NH_3-N concentrations were noted throughout the day. In 1986, NH_3-N levels fluctuated throughout the day in all trials. Variations in water intake and grazing patterns relative to sampling times may have influenced NH_3-N concentrations.

Previous research has suggested that ruminal microbes require between 2 and 5mg NH_3-N/100ml rumen fluid for growth (Satter and Slyter, 1974). Ruminal ammonia concentrations in August, 1987 suggest that microbial growth may have been limited. Also, cotton string disappearance at 72 h indicated a 4.6% decline in ruminal digestive capacity from June to August, 1987 (Chapter III). However, a further decline of 5.1% in cotton string disappearance from August to September could not be accounted for by NH_3-N deficiencies.

No consistent pattern was observed either year in total concentration of ruminal volatile fatty acids (TVFA) (Tables 12 and 13). Concentrations tended to be lowest in September of both years. Concentrations were higher across all trials than those reported by Scott (1988; avg=70.2) for cows grazing tallgrass prairie and Krysl (1986; avg=81.5) for steers grazing blue grama rangeland.

Digestibilities were also higher from the current study than these studies, which may account for the differences in TVFA.

Molar proportions of acetate were inconsistent among trials in 1986. Proportions were greater in June and September (avg=77.2) than in May and August (avg=74.9). However, in 1987, acetate tended to increase as the summer progressed, reflecting the increasing fiber content of the diet (Chapter III). Acetate is a product of cell wall fermentation and increased levels are normally associated with declining forage quality (Van Soest, 1982).

Propionate followed no consistent pattern in 1986. Molar proportions of propionate were highest in May (avg=13.8), lowest in June (avg=11.8) and similar in August and September ($P>.05$). In 1987, propionate tended to decrease with advancing season, reflecting the declining OM digestibilities (Chapter III). Propionate is associated with soluble carbohydrate fermentation and generally declines with advancing season (Van Soest, 1982).

In 1987, butyrate remained stable from May to August and declined ($P<.05$) by September. No significant changes occurred across the 1987 season in molar proportions of butyrate. Butyrate is normally present in higher concentrations with actively growing forage (McCollum, 1983; Krysl, 1986).

Acetate:propionate ratios were higher in all trials than typical ratios of 4:1 to 3:1 reported by Van Soest (1982) for animals on forage diets. Acetate proportions were higher, propionate lower and butyrate similar across seasons to that reported by Funk (1986) and Krysl (1986) with grazing steers (avgs: A=69.7, P=17.7, B=10.1). Scott (1988) reported similar acetate proportions, higher propionate and lower

butyrate when averaged across May, June and July for cows grazing tallgrass prairie range. Acetate proportions were higher while propionate and butyrate were lower across seasons than that reported by Weller et al. (1969) for grazing sheep (avgs: A=63.2, P=21.9, B=14.9). Considering the wide variation within and between grazing animals in the amount and nature of herbage consumed each day (Weller et al., 1969), differences in daily production of VFA which are not directly related to the quality of the diet may result. Results from 1987 are in agreement with Topps et al. (1965) who found an increase in acetate, decrease in propionate and no changes in butyrate concentrations in cattle grazing tropical herbage throughout the growing season.

Results from these studies suggest that the decline in livestock performance that is associated with advancing season results from an increase in indigestible forage constituents. Declines in NH_3-N levels in the rumen failed to affect microbial activity. These results suggest that microbial efficiency is not affected when ruminal NH_3-N levels drop below 2 mg/100 ml rumen fluid. However, only one trial resulted in ruminal NH_3-N levels this low. The expected decline in organic matter intake associated with dietary crude protein levels below 7.0% was not noted in this study.

Previous studies have demonstrated that daily gain of yearling cattle grazing tallgrass prairie in the late growing season increases .13 to .23 kg/day when .5kg/day of a protein concentrate supplement is offered. The mechanism behind the response is still unclear. Diet protein concentrations and ruminal NH_3-N concentrations did not approach threshold values normally associated with a N deficiency in the rumen. Although there were no differences in microbial efficiency, there was a

consistent trend toward lower efficiencies in mid-season (June and August) suggesting that ruminal nutrient balances were inadequate. The combined influences of supplemental nutrients and increased forage intake possibly supply more N at the duodenum.

TABLE 6. EFFECT OF ADVANCING SEASON ON ORGANIC MATTER DIGESTION IN STEERS GRAZING TALLGRASS PRAIRIE, 1986

	TRIAL				
Component	Mid May	Late June	Mid Aug	Late Sept	SEM[d] (n=5)
Steer Wt, kg	274	322	353	382	
Intake, g/d	5620.4[a]	6784.0[b]	7394.0[c]	7146.1[bc]	210.96
Intake, %BW	2.05[ab]	2.11[a]	2.09[a]	1.88[b]	.07
Passage, g/d					
Duodenal	3002.4[a]	3577.6[ab]	4216.8[bc]	4449.1[c]	301.62
Forage	2364.1[a]	2778.0[ab]	3421.0[bc]	3627.1[c]	249.88
Microbial	638.3[a]	799.6[b]	795.8[b]	822.1[b]	56.22
Fecal	2341.5[a]	2987.0[b]	3580.7[c]	4274.4[d]	89.67
Digestion, % of intake					
Ruminal, apt	46.1	47.2	43.0	37.7	4.31
Ruminal, true	57.6	59.0	53.8	49.2	3.56
Lower tract	12.3	8.8	8.5	2.6	4.32
Digestion, % entering segment					
Lower tract	22.3[a]	16.4[ab]	14.6[ab]	3.9[b]	6.83
Passage, %BW					
Fecal	.85[a]	.93[b]	1.01[c]	1.12[d]	.03

[abc] Row means with different superscripts are different ($P<.05$)

[d] Standard error of the mean, n = 5 in late Sept trial, n = 6 in other trials.

TABLE 7. EFFECT OF ADVANCING SEASON ON ORGANIC MATTER DIGESTION IN STEERS GRAZING TALLGRASS PRAIRIE, 1987.

Component	TRIAL Mid May	Late June	Mid Aug	Late Sept	SEM[d] (n=7)
Steer wt, kg	510	530	564	579	
Intake, g/d	8909.9[a]	8913.5[a]	8504.8[a]	7893.5[b]	235.96
Intake, %BW	1.80[a]	1.73[a]	1.53[b]	1.38[b]	.06
Passage, g/d					
Duodenal	5272.6	5312.9	5620.2	5487.6	132.53
Forage	4247.8[c]	4484.9[bc]	4926.8[a]	4669.5[ab]	116.71
Microbial	1024.8[a]	828.0[b]	693.4[c]	818.2[b]	42.74
Fecal	3892.0[b]	4036.2[b]	4303.2[ab]	4404.4[a]	115.53
Digestion, % of intake					
Ruminal, apt	40.5[a]	40.4[a]	33.6[b]	30.3[b]	2.03
Ruminal, true	52.1[a]	49.7[a]	41.9[b]	40.7[b]	1.68
Lower tract	15.8	14.4	15.8	13.9	2.03
Digestion, % entering segment					
Lower tract	26.1[a]	23.8[ab]	23.1[ab]	19.6[b]	2.36
Passage, % BW					
Fecal	.79	.78	.77	.77	.03

[abc] Row means with different superscripts are different ($P<.05$)

[d] Standard error of the mean, n = 7 in late June trial, n = 8 in other trials.

TABLE 8. EFFECT OF ADVANCING SEASON ON NITROGEN DIGESTION AND MICROBIAL PROTEIN SYNTHESIS IN STEERS GRAZING TALLGRASS PRAIRIE, 1986.

Component	TRIAL Mid May	Late June	Mid Aug	Late Sept	SEM[d] (n=5)
Nitrogen intake, g/d					
	119.9[a]	99.8[b]	90.2[bc]	85.6[c]	4.45
Nitrogen passage, g/d					
Duodenal	155.3	154.0	168.7	142.3	9.91
Forage	92.3[ab]	87.1[ab]	99.7[a]	80.4[b]	5.71
Microbial	58.4	62.6	63.5	57.1	4.04
Ammonia	4.5	4.3	5.5	4.9	.47
Fecal	72.7	71.1	73.6	75.3	2.35
Digestion, % entering segment					
Ruminal, apt	-31.2[a]	-54.8[ab]	-86.8[c]	-65.3[bc]	11.60
Ruminal, true	22.0[a]	12.6[a]	-10.4[bc]	6.5[ab]	6.71
Lower tract	53.3[a]	53.8[a]	56.1[a]	43.8[b]	3.30
ME, g/kg TFOM[e]	18.4	15.8	16.1	19.1	2.91

[abc] Row means with different superscripts are different (P<.05).

[d] Standard error of the mean, n = 5 in late Sept trial, n = 6 in other trials.

[e] Microbial efficiency, g microbial-N/kg OM truly fermented

TABLE 9. EFFECT OF ADVANCING SEASON ON NITROGEN DIGESTION AND MICROBIAL PROTEIN SYNTHESIS IN STEERS GRAZING TALLGRASS PRAIRIE, 1987.

	TRIAL				
Component	Mid May	Late June	Mid Aug	Late Sept	SEM[d] (n=7)
Nitrogen intake, g/d					
	191.0[a]	151.4[b]	92.5[c]	101.4[c]	5.76
Nitrogen passage, g/d					
Duodenal	215.1[a]	198.5[a]	165.1[b]	161.5[b]	6.55
Forage	190.2[a]	175.8[a]	149.9[b]	144.0[b]	6.07
Microbial	99.3[a]	80.6[b]	63.0[c]	72.2[bc]	4.04
Ammonia	6.1[a]	6.2[a]	4.2[b]	5.7[a]	.39
Fecal	90.4[a]	89.3[a]	69.7[b]	75.3[b]	2.95
Digestion, % entering segment					
Ruminal, apt	-13.2[a]	-31.6[b]	-79.2[d]	-59.7[c]	6.84
Ruminal, true	42.1[a]	25.7[b]	-6.0[c]	17.4[b]	4.61
Lower tract	57.9[a]	54.9[ab]	57.3[a]	53.1[b]	1.75
ME, g/kg TFOM[*]	21.6	18.3	18.4	23.0	1.84

[abc] Row means with different superscripts are different ($P<.05$).

[d] Standard error of the mean, n = 7 in mid-June trial, n = 8 in other trials.

[*] Microbial efficiency, g microbial N/kg OM truly fermented.

TABLE 10. EFFECT OF ADVANCING SEASON ON RUMINAL AMMONIA-N CONCENTRATIONS IN STEERS GRAZING TALLGRASS PRAIRIE, 1986.

	TRIAL				
Item	Mid May	Late June	Mid Aug	Late Sept	SEM[d] (n=5)
Time of Day	----------mg/100 ml----------				
0800	9.18[a]	4.71[bc]	5.19[b]	3.51[c]	.74
1400	5.90[a]	3.91[b]	7.03[a]	1.80[c]	.45
2000	7.09[a]	3.00[b]	7.73[a]	2.07[b]	.46
0200	6.18[a]	2.96[b]	5.69[a]	2.27[b]	.59
0800	-	4.15[b]	7.72[a]	3.42[b]	.55
Average	7.09[a]	3.74[b]	6.67[a]	2.62[c]	.26

[abc] Row means with different superscripts are different ($P<.05$)

[d] Standard error of the mean, n = 5 in late Sept trial, n = 6 in other trials.

TABLE 11. EFFECT OF ADVANCING SEASON ON RUMINAL AMMONIA-N CONCENTRATIONS IN STEERS GRAZING TALLGRASS PRAIRIE, 1987.

	TRIAL				
Item	Mid May	Late June	Mid Aug	Late Sept	SEM[d]
Time of Day	----------mg/100 ml----------				
0800	3.76[a]	3.82[a]	1.44[c]	2.59[b]	.30
1400	3.88[a]	3.22[a]	1.65[b]	3.11[a]	.31
2000	3.73[a]	3.59[a]	1.33[b]	2.20[b]	.28
0200	3.72[a]	3.44[a]	1.30[c]	2.38[b]	.37
0800	3.75[a]	3.81[a]	1.44[b]	2.22[b]	.38
Average	3.77[a]	3.57[a]	1.43[c]	2.50[b]	.14

[abc] Row means with different superscripts are different ($P<.05$)

[d] Standard error of the mean, n = 8.

TABLE 12. EFFECT OF ADVANCING SEASON ON RUMINAL CONCENTRATIONS OF TOTAL VOLATILE FATTY ACIDS AND MOLAR PROPORTIONS OF ACETATE, PROPIONATE AND BUTYRATE IN STEERS GRAZING TALLGRASS PRAIRIE, 1986.

	TRIAL				
Item	Mid May	Late June	Mid Aug	Late Sept	SEM[d] (n=5)
Time of Day	---------- Total VFA, mM----------				
0800	97.0[b]	124.6[a]	134.9[a]	89.1[b]	9.30
2000	121.0	131.6	117.0	119.3	9.30
Average	109.0[b]	128.1[a]	126.0[a]	104.2[b]	6.67
	-------Acetate, moles/100 moles-------				
0800	75.1[b]	76.3[ab]	75.0[b]	77.1[a]	.66
2000	74.9[b]	77.2[a]	74.5[b]	78.1[a]	.66
Average	75.0[b]	76.8[a]	74.7[b]	77.6[a]	.47
	------Propionate, moles/100moles-------				
0800	14.1[a]	12.3[b]	12.9[b]	13.0[b]	.35
2000	13.6[a]	11.3[b]	12.9[a]	11.9[b]	.35
Average	13.8[a]	11.8[c]	12.9[b]	12.4[b]	.25
	-------Butyrate, moles/100 moles-------				
0800	10.2[b]	11.4[a]	11.6[a]	9.4[b]	.51
2000	11.5[a]	11.4[a]	11.9[a]	10.0[b]	.51
Average	10.8[a]	11.4[a]	11.8[a]	9.7[b]	.37

[abc] Row means with different superscripts are different ($P<.05$)

[d] Standard error of the mean, n = 5 in late Sept trial, n = 6 in other trials.

TABLE 13. EFFECT OF ADVANCING SEASON ON RUMINAL CONCENTRATIONS OF TOTAL VOLATILE FATTY ACIDS AND MOLAR PROPORTIONS OF ACETATE, PROPIONATE AND BUTYRATE IN STEERS GRAZING TALLGRASS PRAIRIE, 1987.

	TRIAL				
Item	Mid May	Late June	Mid Aug	Late Sept	SEM[d]
Time of Day	----------Total VFA, mM----------				
0800	138.5[ab]	126.2[ab]	140.0[a]	106.3[b]	12.21
2000	118.3[ab]	148.2[a]	118.5[ab]	107.8[b]	12.21
Average	128.4[ab]	137.2[a]	129.2[ab]	107.1[b]	8.63
	-------Acetate, moles/100 moles-------				
0800	78.7[b]	78.0[b]	81.2[ab]	82.7[a]	1.18
2000	79.7	82.0	82.2	81.9	1.18
Average	79.2[b]	80.0[b]	81.7[a]	82.3[a]	.84
	-----Propionate, moles/100 moles------				
0800	11.2[a]	11.5[a]	10.2[ab]	9.3[b]	.71
2000	10.5	9.3	9.4	9.3	.71
Average	10.9[a]	10.4[ab]	9.8[ab]	9.3[b]	.50
	------Butyrate, moles/100 moles-------				
0800	9.2[ab]	10.2[a]	8.6[b]	7.9[b]	.53
2000	9.2	8.5	8.4	8.7	.53
Average	9.2	9.3	8.5	8.3	.38

[abc] Row means with different superscripts are different ($P<.05$)

[d] Standard error of the mean, n = 8.

CHAPTER V

STEERS GRAZING TALLGRASS PRAIRIE IN THE SPRING AND SUMMER. III. CORRELATIONS AND PREDICTION EQUATIONS

Abstract

Stepwise regression techniques were used to develop prediction equations for intake, potential organic matter and nitrogen disappearance, in vitro organic matter disappearance, ruminal ammonia-nitrogen and duodenal crude protein flow. Maximum r^2 and minimum mean square error were used as selection criteria. Data were from eight trials conducted in the late spring and summer of 1986 and 1987 on rangeland in north-central Oklahoma. Additional data points from 1985 trials were included in some analyses. Organic matter intake (OMI; g/kg BW) was best estimated by 36 and 24 h in situ disappearance and the ratio of acid detergent fiber to neutral detergent fiber (ADF/NDF). Nitrogen disappearance at 36 AND 24 h accounted for 92% and ADF/NDF accounted for 72% of the variability in intake. Potential organic matter and potential nitrogen disappearance, determined by 72 h in situ incubation, were best predicted by short term in situ variables, $(ADF/NDF)^2$ and in vitro organic matter disappearance (IVOMD). In vitro organic matter disappearance accounted for 94% of the variation in potential organic matter disappearance, whereas the ADF to neutral detergent fiber (NDF) ratio (ADF/NDF) accounted for 89% of potential nitrogen disappearance and 74% of IVOMD in 1986 and 1987. In situ

organic matter disappearance at 24 h and nitrogen disappearance data at 6 h accounted for 94%, 97% and 92% of potential organic matter disappearance, potential nitrogen disappearance and IVOMD, respectively. No single variable accounted for a significant amount of the variation in ruminal ammonia-N concentrations ($P>.10$). Acid detergent fiber and digestible crude protein (DCP) accounted for 78% of NH_3-N variability ($P<.05$). When restricted to wet lab variables, the equation for prediction of crude protein flow to the duodenum used ADF/NDF and ADF ($r^2=.96$). In situ nitrogen disappearance at 36 h accounted for 90% of the variation in crude protein flow. When restricted to intake variables, actual crude protein flow (g/d) was best predicted by crude protein intake (CPI) and digestible organic matter intake (DOMI; $r^2=.62$). When flow was expressed as g CP flow/g CP intake (CPF/CPI), CPI (g/d) and DOMI (g/d) provided the best fit ($r^2=.91$). Digestible organic matter to crude protein ratio (DOM/CP) explained 89% of CPF/CPI variability. Results from this study suggest that the ratio of ADF to NDF is a good wet lab predictor of intake. Thirty-six and 24 h in situ data reflect intake better than wet lab variables. Potential disappearance, both in situ and in vitro, are reflected by short term (24 h or less) in situ disappearance. The ratio of ADF to NDF has more influence on potential disappearance than either constituent by itself. Ruminal NH_3-N is best predicted by a combination of wet lab and in situ variables. Absolute intestinal CP flow can be predicted from DOMI and CPI or 36 h in situ data. DOM/CP is a good predictor of CP flow relative to CP intake.

Introduction

It has been proposed that the amount of feed consumed by a ruminant is primarily determined by an interaction between energy demand of the animal and the amount of digesta which can accumulate in the rumen (Weston, 1982). The continual changing environment and pattern of food supply subjects the grazing animal to conditions in which intake is the determining factor for meeting maintenance and production needs.

The amount of protein reaching the small intestine of ruminants, together with the energy available to the animal, play a primary role in the determination of performance. Factors affecting protein supply include protein intake, protein degradation and microbial protein synthesis. The estimation of protein reaching the small intestine is important for designing supplementation programs that will maximize the utilization of nutrients from forages available to grazing animals.

The amount of protein reaching the small intestine relative to protein intake has been related to the digestible organic matter to crude protein ratio of the diet (DOM/CP) (Weston and Hogan, 1973), the dietary crude protein percentage (CP) (Kaufmann, 1977), and to crude protein and digestible organic matter intake (CPI, DOMI, respectively) (Hogan and Weston, 1981; Verite et al., 1979; Corbett and Pickering, 1981). Ruminal ammonia nitrogen (NH_3-N) has also been used to predict nitrogen losses or gains across the rumen (Oyaert and Bouckaert, 1960).

Studies with grazing animals involve limitations and uncontrollable influences not encountered in studies with penned animals. When concepts and data are transformed into mathematical equations, it is possible to evaluate the proposed hypotheses about how the ruminant system functions under various conditions. Numbers may limit the

precision and therefore the mathematical significance of the results. However, if the general behavior of the predictions is satisfactory, most likely, concepts are suitable and additional data can be collected to refine the prediction equations. Ultimately, it would be desirable to develop relationships for field application.

Materials and Methods

Data from trials conducted in mid-May, late June, mid-August and late September of 1985, 1986 and 1987 with cattle grazing tallgrass prairie rangeland were used to develop prediction equations. OM intake, potential OM and N disappearance (72 h in situ values), in vitro OM disappearance, ruminal ammonia-N and duodenal crude protein flow were used as dependent variables.

Prediction equations were developed using stepwise regression techniques with the MAXR-square option in the Statistical Analysis System. Simple and multiple regression using the General Linear Models procedure were also utilized. Criteria for model selection with stepwise regressions included maximum r^2, minimum mean square error and variables with entry level $P<.15$. No equation using more than half the original degrees of freedom for error was accepted. First and second degree relationships were examined when the stepwise procedure was used. Conventional variables were used to predict crude protein flows to the duodenum and compared to other research results. Adjustments for body weight were made due to the use of growing steers the first year of the study. Trial averages were used as data points, resulting in 8 observations for 1986 and 1987 data, and 12 observations when 1985 data was included. Diet and in situ data for 1986 and 1987 are listed and

discussed in Chapter III. Data from 1985 are listed in Appendix F. Intake, ruminal measurements and intestinal flow data from 1986 and 1987 are from Chapter IV.

Due to the method of calculating intakes in the current study (Fecal output/1-IVOMD), regressions for intake using digestible organic matter would not be valid. Therefore, IVOMD was not utilized to predict intake.

Results and Discussion

When the variable list was restricted to wet lab variables, organic matter intake (OMI; g/kg BW), was best predicted by the ratio ADF:NDF (r^2=.72; P<.05) (Table 14). Organic matter intake was more highly correlated to in situ data than wet lab variables. Thirty-six and 24 h in situ disappearance values, which are indicative of rate and extent of disappearance, were best related to OMI. The second degree terms for N disappearance at 36 and 24 h incubation accounted for 92% of the variation in intake. Including 24 h organic matter disappearance data with 36 and 24 h N in situ data explained 97% of intake variability. The combination of (ADF/NDF)2 and 36 and 24 h in situ N disappearance values accounted for 98% of the variation in organic matter intake.

Using data from three years, the second degree term for ADF:NDF ratio accounted for 73 and 77% of the variation in potential organic matter disappearance (POMD; Table 15) and in vitro organic matter disappearance (IVOMD; Table 16), respectively. Excluding 1985 data, this ratio explained 89% of potential nitrogen disappearance (PND; Table 17) and 74% of IVOMD. Conventional IVOMD accounted for 94% of the variation in POMD. Short term in situ disappearance data were

indicative of POMD, PND and IVOMD, with 24 h organic matter disappearance (OMD24) and 6 h nitrogen disappearance (ND6) accounting for 94, 97 and 92% of the variability, respectively. The relationship between short term and potential disappearance is in agreement with Mertens (1977) who stated that the rate of OM digestion is directly related to potential extent of digestion.

Regression equations for prediction of ruminal ammonia-N (NH_3-N) were not significant for any single variable (Table 18). When wet lab and in situ values were combined, the combination ADF^2 and digestible crude $protein^2$ (DCP: 72 h in situ N disappearance * CP)) accounted for 78% of NH_3-N variation. When the variable list was restricted to in situ values, indices of extent of OM and N disappearance (72 h in situ data) and rate of OM disappearance (12 and 24 h in situ data) were best related to NH_3-N (r^2=.95).

Wet lab variables utilized to estimate nitrogen flow into the small intestine included ADF:NDF and $(ADF:NDF)^2$ (r^2=.81; Table 19). Further reduction of the crude protein flow model added ADF^2 and CP for a maximum r^2 of .99. Higher fiber content, and therefore less digestible organic matter, combined with declining CP content results in longer retention time in the rumen. An increase in retention time and corresponding decrease in passage rate from the rumen is associated with declines in microbial protein synthesis, which contributes 60-80% of the protein reaching the small intestine (NRC, 1985).

Equations developed with intake variables as predictors of crude protein flow are listed in Table 20. Research with sheep has shown that crude protein flow (non-ammonia nitrogen flow X 6.25) is related to digestible organic matter intake (DOMI; in vitro OM digestion * OM

intake) and crude protein intake (CPI) (Hogan and Weston, 1981; Verite et al., 1979; Corbett and Pickering, 1981; Table 20). Data from the current study indicate that DOMI accounts for 86% of the variability in CP flow to the duodenum (Table 20, equation 1). The addition of CPI increased the r^2 to .96 (Table 20, equation 2).

When expressing crude protein flow as a percent of crude protein intake (CPF/CPI), a commonly used variable is the ratio of digestible organic matter to crude protein (DOM/CP; 72 h in situ OM digestion:crude protein ratio). According to the equation generated by Weston and Hogan (1973; Table 20), CP flow to the duodenum exceeds CP intake when the DOM/CP ratio exceeds 3.72. Assuming an average 67% DOM, this equation indicates N losses above 14.2% CP (Weston and Hogan, 1973). Using the same variables (Table 20, equation 3), data from the current study found this value to be 4.39; diets having a higher ratio associated with a N gain and those with a lower ratio exhibiting N losses across the rumen. Substituting the average DOM (72 h in situ OM disappearance) value of 71.5%, the breakpoint for N loss or gain across the rumen is 16.3% CP. Actual CPI and DOMI explained 91% of the variability in CPF/CPI (Table 20, equation 4). Kaufmann (1977) used CP% of diet to predict apparent N digestion in the rumen of dairy cows (Table 20). He found losses of N to occur above 15.7% CP. Using dietary CP%, data from the current study found this point to be 15.14% CP (Table 20, equation 5).

The determination of organic matter intake and nutrient availability from forage are primary factors in determining the nutrient status of grazing cattle. Nutrient availability can be measured by wet lab procedures. Intake, on the other hand, requires the use of indigestible markers and cannulated animals. Results from this study

indicate that ADF:NDF ratio, which is an index of gut fill, may be used to predict intake. In addition, indices of rate and extent of digestion (24 and 36 h in situ digestions) will increase the confidence of intake predictions. The discovery of the relationship between short term in situ digestions (24 h and less), ADF:NDF ratio and potential OM and N digestibility (72 h in situ digestions) allows for the prediction of extent of OM and N digestibility with less laborious techniques.

The determination of N supply to the lower tract of grazing animals would allow livestock managers to determine whether protein or energy supplemention would be more beneficial. Considering the most convenient and feasible measurement for the prediction of duodenal N flow, wet lab variables are the most attractive. The combination of ADF:NDF, $(ADF:NDF)^2$ and ADF^2 revealed a significant relationship ($r^2 = .96$). The use of DOM/CP, DOMI and CPI indicated that these variables can be used to predict N flow, which is in agreement with other researchers.

TABLE 14. PREDICTIONS EQUATIONS FOR ORGANIC MATTER INTAKE (g OM/kg BW)[a] DERIVED BY STEPWISE REGRESSION USING WET LAB AND IN SITU VARIABLES FROM MASTICATE SAMPLES COLLECTED DURING DIFFERENT GRAZING SEASONS.[b]

Equation	n	r^2	$sy \cdot x$
wet lab variables			
1. $32.4180 - 29.4051$ ADF/NDF	8	.72	.89
in situ variables			
1. $11.9862 + .0012$ $(ND36)^2$	8	.78	.79
2. $11.3859 + .0023$ $(ND36)^2 - .0015$ $(ND24)^2$	8	.92	.51
3. $5.5511 + .0020$ $(ND36)^2 - .0020$ $(ND24)^2 + .1609$ OMD24	8	.97	.34
4. $18.0095 + .0025$ $(ND36)^2 - .0022$ $(ND24)^2 + .0030$ $(OMD24)^2 - .2193$ OMD36	8	.99	.24
wet lab and in situ variables			
1. $11.9862 + .0012$ $(ND36)^2$	8	.78	.79
2. $11.3859 + .0023$ $(ND36)^2 - .0015$ $(ND24)^2$	8	.92	.51
3. $15.8571 + .0020$ $(ND36)^2 - .0015$ $(ND24)^2 - 10.3753$ $(ADF/NDF)^2$	8	.98	.30

[a] Grams organic matter per kilogram body weight

[b] ADF/NDF = Acid detergent fiber to neutral detergent fiber ratio, ND36 = 36 h in situ nitrogen disappearance, ND24 = 24 h in situ nitrogen disappearance, OMD24 = 24 h in situ organic matter disappearance.

TABLE 15. PREDICTION EQUATIONS FOR POTENTIAL ORGANIC MATTER DISAPPEARANCE (%) DERIVED BY STEPWISE REGRESSION USING WET LAB AND IN SITU VARIABLES FROM MASTICATE SAMPLES COLLECTED DURING DIFFERENT GRAZING SEASONS.[a]

Equation	n	r^2	$sy \cdot x$
wet lab variables			
1. $106.8712 - 105.5274\ (ADF/NDF)^2$	12	.73	3.09
2. $97.1555 - 93.4769\ (ADF/NDF)^2 + 45.0217\ CP/NDF$	12	.79	2.87
in situ variables			
1. $24.3241 + .9680\ OMD24$	8	.67	4.11
2. $28.0091 + 1.1584\ OMD24 - .5864\ ND6$	8	.94	1.89
3. $-76.3094 + 5.3313\ OMD24 - .0119\ ND6^2 - .0440\ OMD24^2$	8	.99	.89
wet lab and in situ variables			
1. $18.3932 + 1.0309\ IVOMD$	8	.94	1.80
2. $12.3184 + .8169\ IVOMD + .3516\ OMD24$	8	.99	.30

[a] ADF/NDF = Acid detergent fiber to neutral detergent fiber ratio, CP/NDF = Crude protein to neutral detergent fiber ratio, OMD24 = 24 h in situ organic matter disappearance, ND6 = 6 h in situ nitrogen disappearance, IVOMD = In vitro organic matter disappearance.

TABLE 16. PREDICTION EQUATIONS FOR IN VITRO ORGANIC MATTER DISAPPEARANCE (%) DERIVED BY STEPWISE REGRESSION USING WET LAB AND IN SITU VARIABLES FROM MASTICATE SAMPLES COLLECTED DURING DIFFERENT GRAZING SEASONS.[a]

Equation	n	r^2	sy·x
wet lab variables			
1. $89.6910 - 116.8064\ (ADF/NDF)^2$	12	.77	3.04
2. $81.6441 - 102.7553\ (ADF/NDF)^2 + 196.7255\ (CP/NDF)^2$	12	.85	2.65
in situ variables			
1. $14.2479 + .7646\ OMD24$	8	.47	5.02
2. $18.9369 + 1.0000\ OMD24 - .7304\ ND6$	8	.92	2.07
3. $-78.3940 + 5.1476\ OMD24 - .7327\ ND6 - .0436\ OMD24^2$	8	.99	.61
wet lab and in situ variables			
1. $92.1102 - 124.8917\ (ADF/NDF)^2$	8	.74	3.50
2. $202.6475 - 206.3330\ ADF/NDF - 1.0309\ OMD12$	8	.95	1.81
3. $108.8519 + .7361\ CP - 147.8761\ (ADF/NDF)^2 - .0151\ OMD12^2$	8	.99	.69

[a] ADF/NDF = Acid detergent fiber to neutral detergent fiber ratio, CP/NDF = Crude protein to neutral detergent fiber ratio, CP = Crude protein, OMD24 = 24 h in situ OM disappearance, ND6 = 6 h in situ N disappearance, OMD12 = 12 h in situ OM disappearance.

TABLE 17. PREDICTION EQUATIONS FOR POTENTIAL NITROGEN DISAPPEARANCE (%) DERIVED BY STEPWISE REGRESSION USING WET LAB AND IN SITU VARIABLES FROM MASTICATE SAMPLES COLLECTED DURING DIFFERENT GRAZING SEASONS.[a]

Equation	n	r^2	$sy \cdot x$
wet lab variables			
1. 41.7318 + 117.3142 CP/ADF	12	.48	8.38
2. -92.3712 + 143.8128 CP/ADF + 1.6407 NDF	12	.64	7.30
3. -4350.5432 + 292.1340 CP/NDF + 109.2132 NDF - .6793 NDF^2	12	.79	5.95
in situ variables			
1. -40.5885 + 2.1992 OMD24	8	.88	4.88
2. -36.3854 + 2.4102 OMD24 - .6547 ND6	8	.97	2.79
3. -169.6550 + 8.0892 OMD24 - .6578 ND6 - .0597 $(OMD24)^2$	8	.99	.59
wet lab and in situ variables			
1. 159.4376 - 285.8905 $(ADF/NDF)^2$	8	.89	4.74
2. -54.0333 + .9436 IVOMD + 1.4777 OMD24	8	.99	1.30

[a] CP/ADF = Crude protein to acid detergent fiber ratio, NDF = Neutral detergent fiber, CP/NDF = Crude protein to neutral detergent fiber ratio, OMD24 = 24 h in situ organic matter disappearance, ND6 = 6 h in situ nitrogen disappearance, IVOMD = In vitro organic matter disappearance.

TABLE 18. PREDICTION EQUATIONS FOR RUMINAL AMMONIA NITROGEN (MG/100 ML)[a] DERIVED BY STEPWISE REGRESSION USING WET LAB AND IN SITU VARIABLES FROM MASTICATE SAMPLES COLLECTED DURING DIFFERENT GRAZING SEASONS.[b]

Equation	n	r^2	$s_{y.x}$
wet lab variables			
1. $11.1314 - .0035\ ADF^2$	8	.33	1.76
2. $-134.2412 - .0770\ ADF^2 + 6.5555\ ADF$	8	.59	1.51
3. $32.4972 - .0098\ ADF^2 - .0978\ IVOMD - 260.5705\ (CP/NDF)^2$	8	.77	1.14
4. $-38.0453 + 2815.3288\ (CP/NDF)^2 - 292.9882\ (CP/ADF)^2 - 92.0958\ (ADF/NDF)^2 - .3390\ CP^2$	8	.92	.85
in situ variables			
1. $-1.4210 + .0010\ OMD72^2$	8	.25	1.87
2. $-3.9805 + .0023\ OMD72^2 - .0010\ ND72^2$	8	.59	1.50
3. $-29.7175 + .3921\ OMD72 - .0018\ ND72^2 + .4049\ OMD12$	8	.82	1.13
4. $-30.9660 + .5787\ OMD72 - .0014\ ND72^2 + .0110\ OMD12^2 - .0052\ OMD24^2$	8	.95	.70
wet lab and in situ variables			
1. $11.1314 - .0035\ ADF^2$	8	.33	1.76
2. $25.0954 - .0090\ ADF^2 - .0564\ DCP^2$	8	.78	1.12
3. $28.8929 - 1.0681\ ADF - .1365\ DCP^2 + .4981\ OMD36$	8	.95	.57
4. $12.7263 - 1.1092\ ADF - .2210\ DCP^2 + 1.1519\ OMD36 - .0027\ NDF^2$	8	.99	.27

[a] Milligrams ammonia nitrogen per 100 milligrams rumen fluid

[b] ADF = Acid detergent fiber, NDF = Neutral detergent fiber, CP = Crude protein, IVOMD = In vitro organic matter disappearance, CP/NDF = CP to NDF ratio, CP/ADF = CP to ADF ratio, ADF/NDF = ADF to NDF ratio, DCP = digestible crude protein (ND72*CP), OMD36 = 36 h in situ organic matter disappearance.

TABLE 19. PREDICTION EQUATIONS FOR CRUDE PROTEIN FLOW TO THE DUODENUM (G/D) DERIVED BY STEPWISE REGRESSION USING WET LAB AND IN SITU VARIABLES FROM MASTICATE SAMPLES COLLECTED DURING DIFFERENT GRAZING SEASONS.[a]

Equation	n	r^2	$s_{y.x}$
wet lab variables			
1. 2554.2090 - 2666.6780 ADF/NDF	8	.66	93.39
2. 13137.1871 - 39745.9834 ADF/NDF + 32302.2536 $(ADF/NDF)^2$	8	.81	75.79
3. 20326.6729 - 65313.7876 ADF/NDF - 52259.9610 $(ADF/NDF)^2$ + .4221 $(ADF)^2$	8	.96	38.81
4. 21191.2933 - 75385.0468 ADF/NDF + 60825.2129 $(ADF/NDF)^2$ + 59.2130 ADF + 27.9958 CP	8	.99	9.29
in situ variables			
1. 662.4988 + .1182 $(ND36)^2$	8	.90	50.04
2. 555.4299 + .0962 $(ND36)^2$ + .1627 $(OMD12)^2$	8	.94	42.54
3. 550.9091 + .0613 $(ND36)^2$ + .4485 $(OMD12)^2$ - .3804 $(OMD6)^2$	8	.98	29.38
4. 217.4805 + .1047 $(ND36)^2$ + 29.7955 OMD12 - .4051 $(OMD6)^2$ - 4.5106 ND48	8	.99	15.91
wet lab and in situ variables			
1. 662.4988 + .1182 $(ND36)^2$	8	.90	50.04
2. 555.4299 + .0962 $(ND36)^2$ + .1627 $(OMD12)^2$	8	.94	42.54
3. 550.9091 + .0613 $(ND36)^2$ + .4485 $(OMD12)^2$ - .3804 $(OMD6)^2$	8	.98	29.38
4. 217.4805 + .1047 $(ND36)^2$ + 29.7955 OMD12 - .4051 $(OMD6)^2$ - 4.5106 ND48	8	.99	15.91

[a] ADF/NDF = Acid detergent fiber to neutral detergent fiber ratio, ADF = Acid detergent fiber, CP = Crude protein, ND36 = 36 h in situ N disappearance, OMD12 = 12 h in situ OM disappearance, OMD6 = 6 h in situ OM disappearance, ND48 = 48 h in situ N disappearance.

TABLE 20. PREDICTION EQUATIONS FOR CRUDE PROTEIN FLOW TO THE DUODENUM DERIVED BY SIMPLE, MULTIPLE OR STEPWISE REGRESSION, USING INTAKE AND RUMINAL VARIABLES FROM SAMPLES COLLECTED DURING DIFFERENT GRAZING SEASONS.[a]

Equation	n	r^2	$s_{y.x}$
g/d			
1. 296.5780 + .1867 DOMI	8	.86	59.56
2. 352.1781 + .1158 DOMI + .3056 CPI	8	.96	35.42
% of crude protein intake			
3. .3801 + .1412 DOM/CP	8	.89	.09
4. 1.7604 - .0014 CPI + .0002 DOMI	8	.91	.09
5. 2.2974 - .0857 CP	8	.84	.11

Other research:

Equation	Species	Diet	n	r2	sy.x
g/d					
6 + .36 CPI + .16 DOMI[b]	sheep	forage			
.41 CPI + .124 DOMI[c]	sheep	forage			
.13 CPI + .174 DOMI[d]	sheep	forage			
% of crude protein intake					
.33 + .18 DOM/CP[e]	sheep	forage		.96	
.342 + 10.32/CP[f]	dairy	conc/ roughage	45		

[a] DOMI = Digestible organic matter intake (g/d), CPI = Crude protein intake (g/d), DCPIGPKG = Digestible crude protein intake (g/kg BW), OMIGPKG = Organic matter intake (g/kg BW), DOM/CP = Digestible organic matter to crude protein ratio, CP = Crude protein.

[b] Hogan and Weston, 1981

[c] Verite et al., 1979

[d] Corbett and Pickering, 1981

[e] Weston and Hogan, 1973

[f] Kaufmann, 1977

FIGURE 1. CRUDE PROTEIN CONTENT OF FORAGE GRAZED BY STEERS

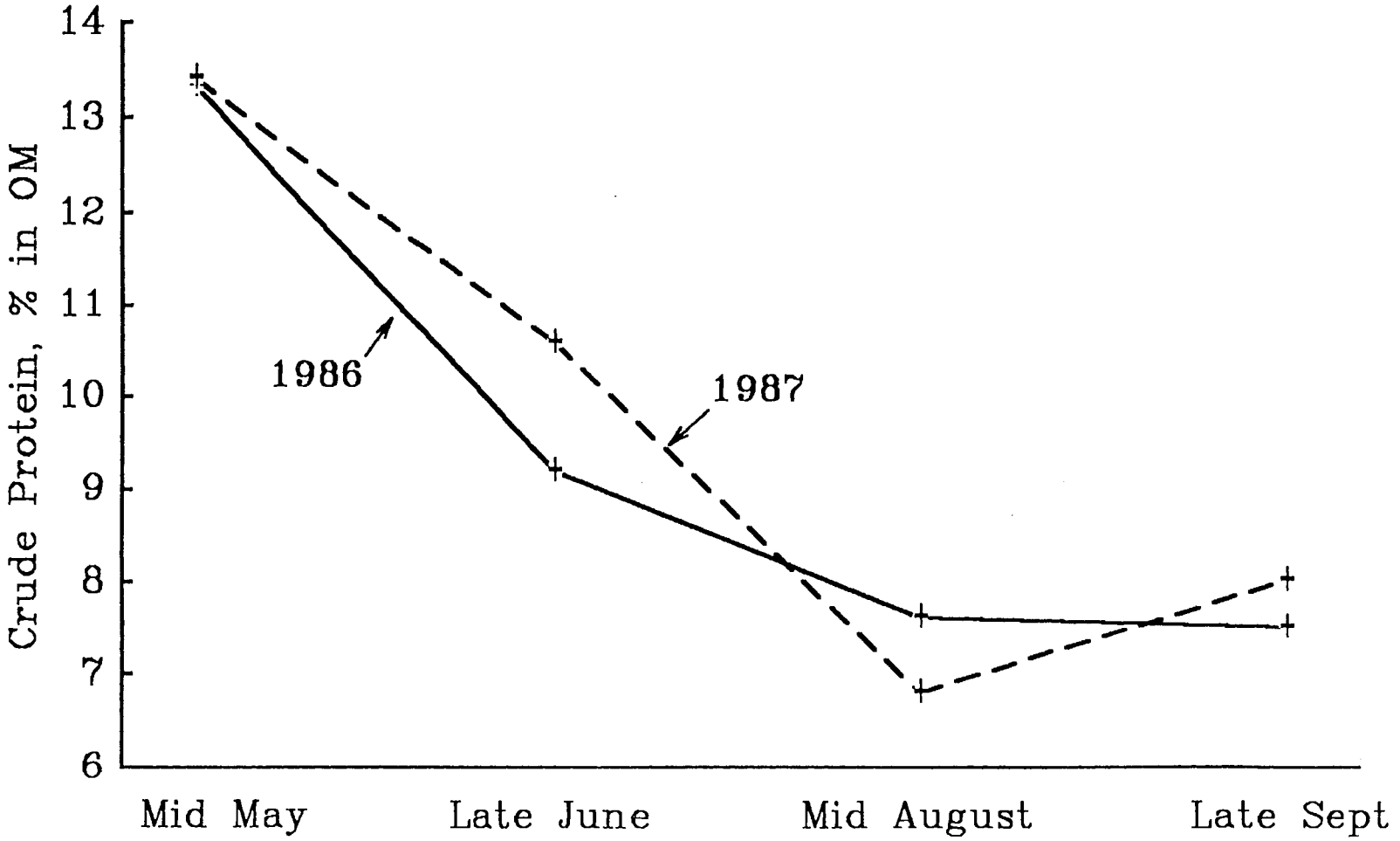


FIGURE 2. NEUTRAL DETERGENT FIBER IN FORAGE GRAZED BY STEERS

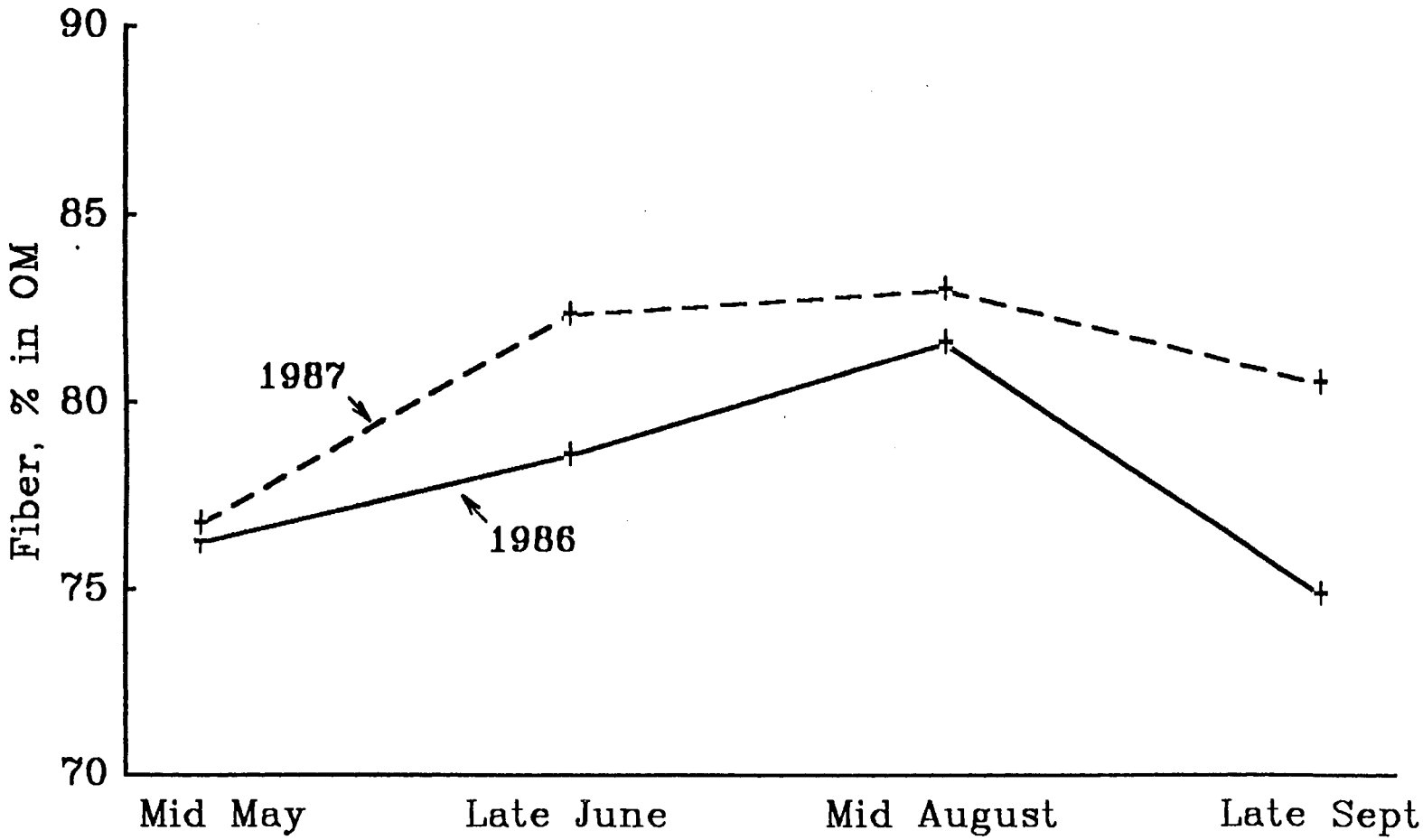


FIGURE 3. ACID DETERGENT FIBER IN FORAGE GRAZED BY STEERS

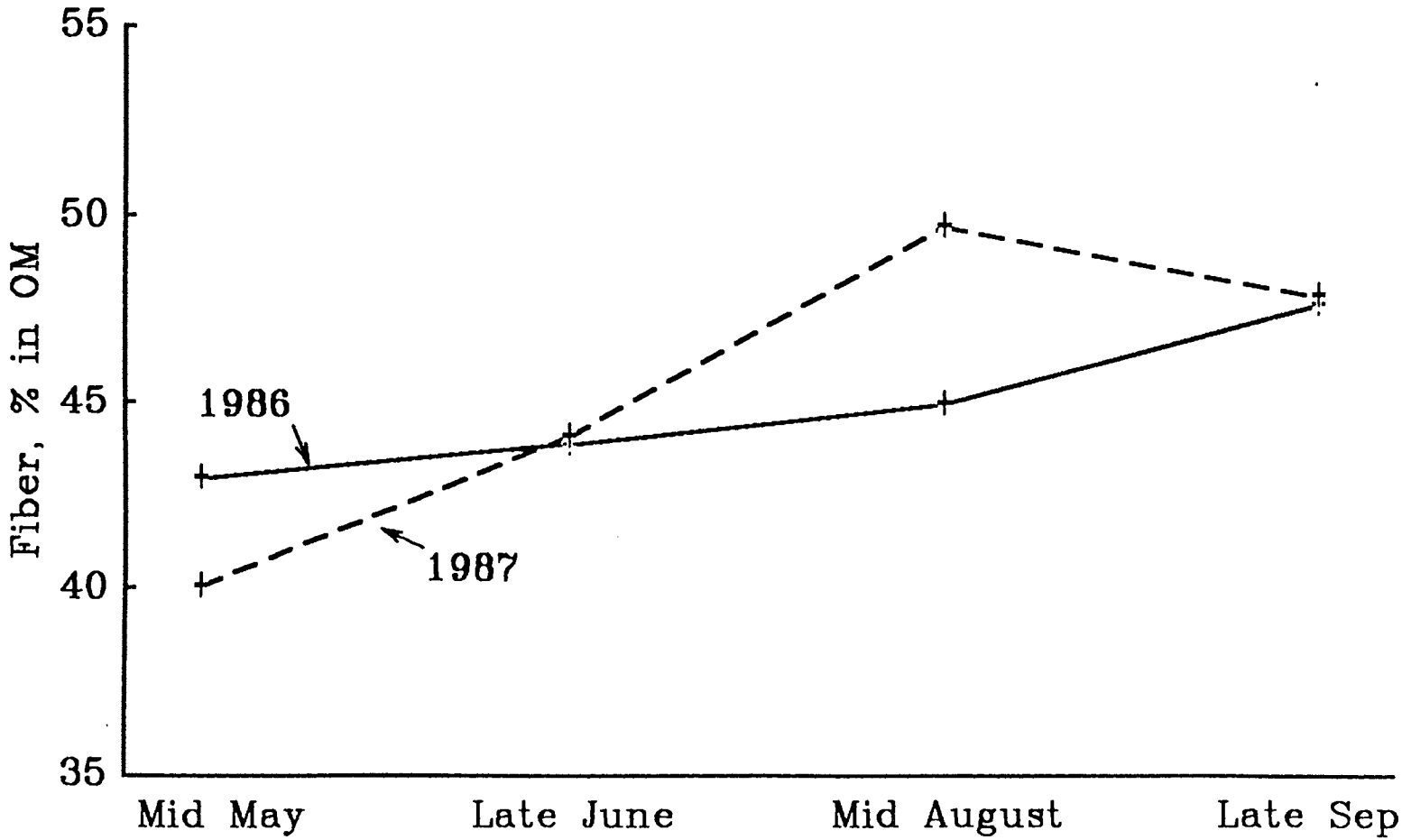


FIGURE 4. IN VITRO DIGESTION OF FORAGE GRAZED BY STEERS

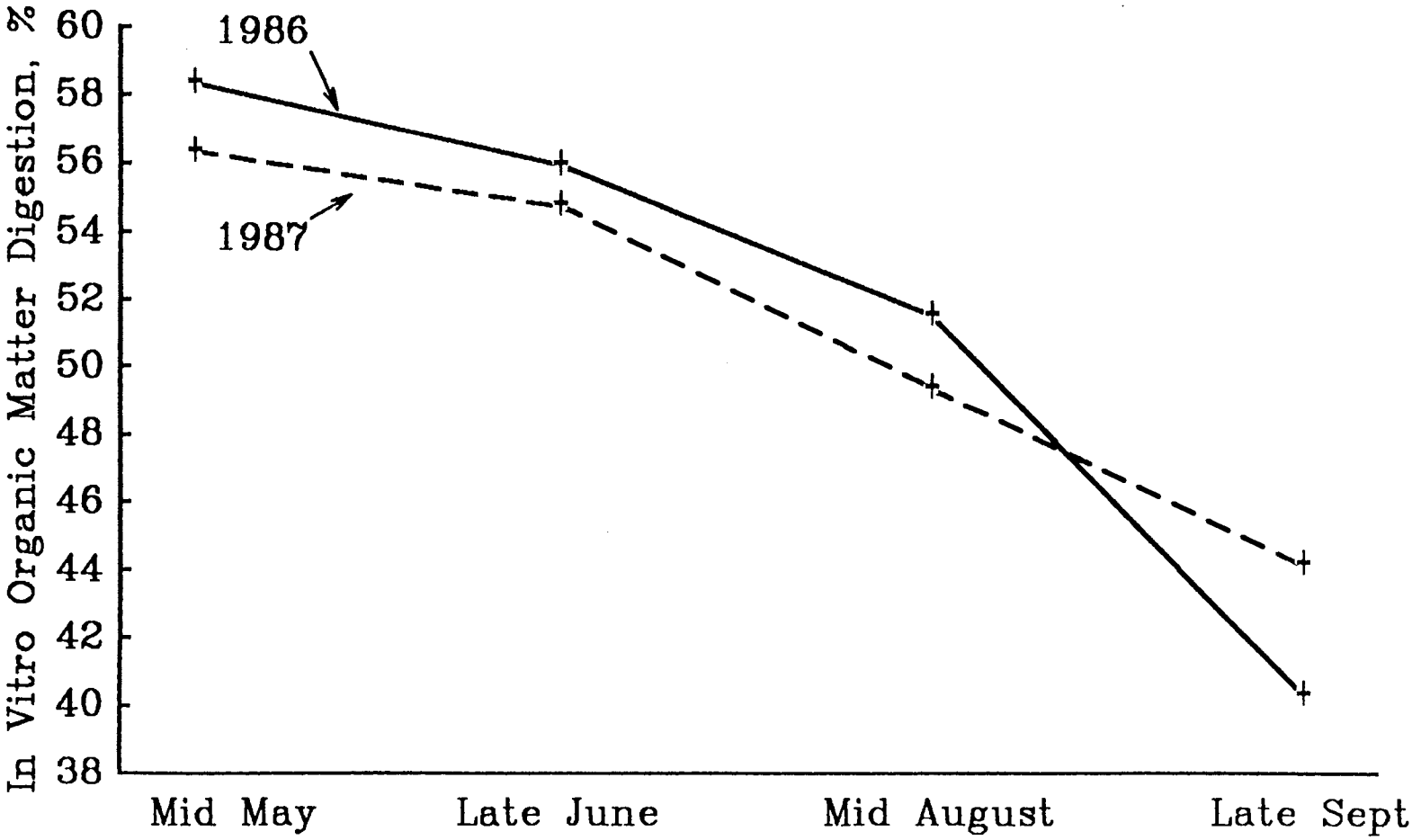


FIGURE 5. POTENTIAL RUMINAL DIGESTION OF FORAGE GRAZED BY STEERS

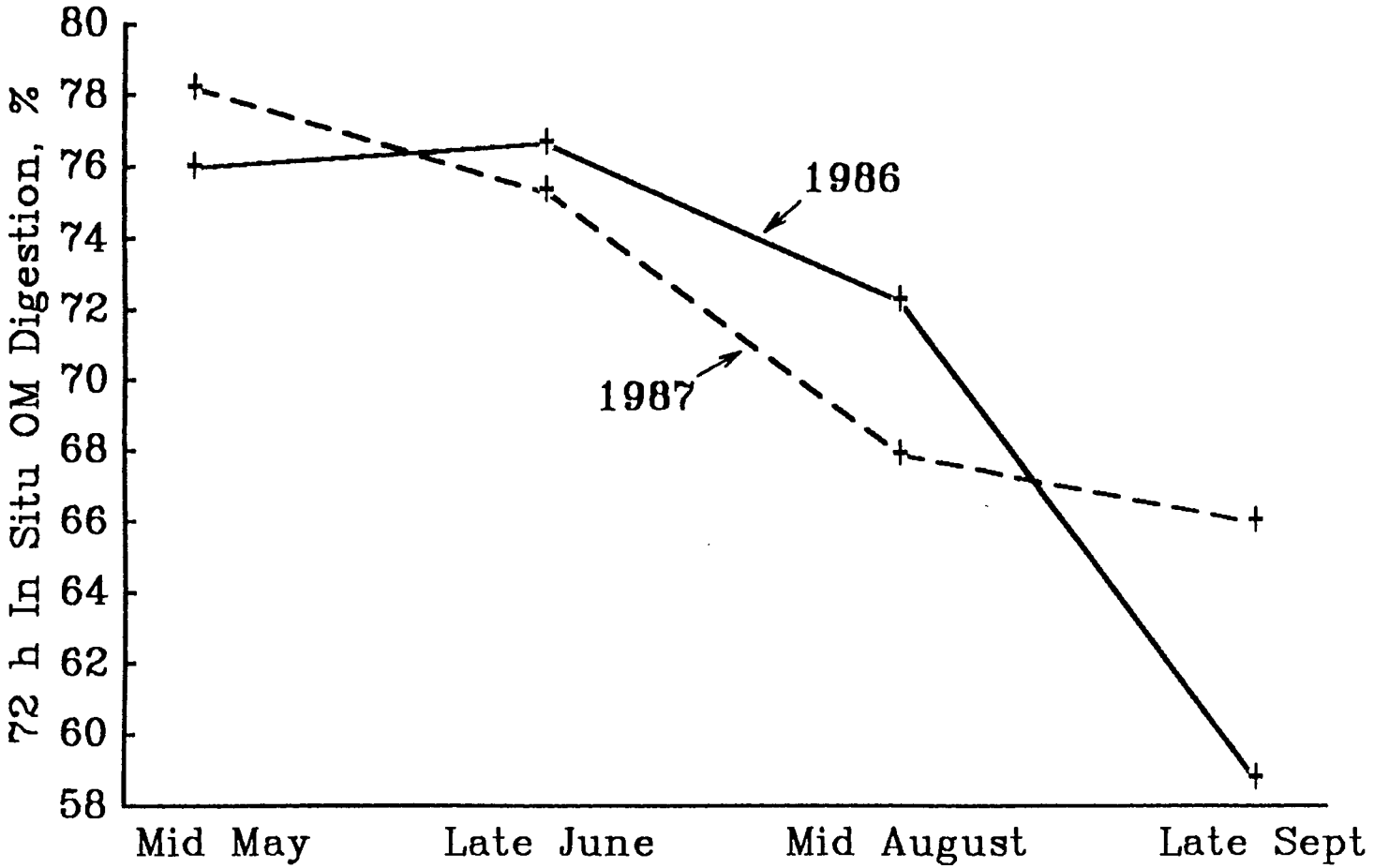


FIGURE 6. POTENTIAL RUMINAL DIGESTION OF FORAGE NITROGEN GRAZED BY STEERS

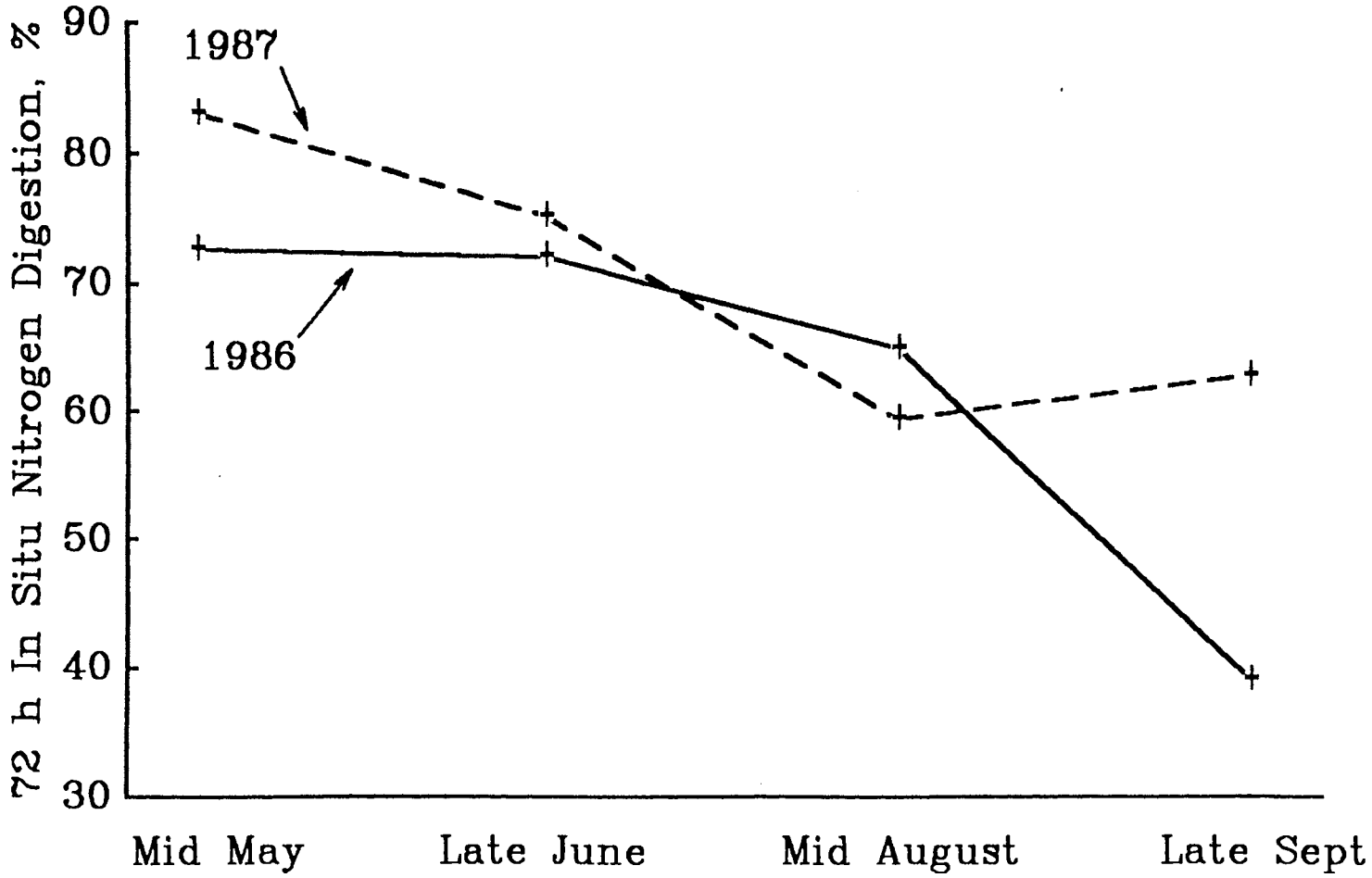


FIGURE 7. POTENTIAL RUMINAL DIGESTION OF COTTON STRING

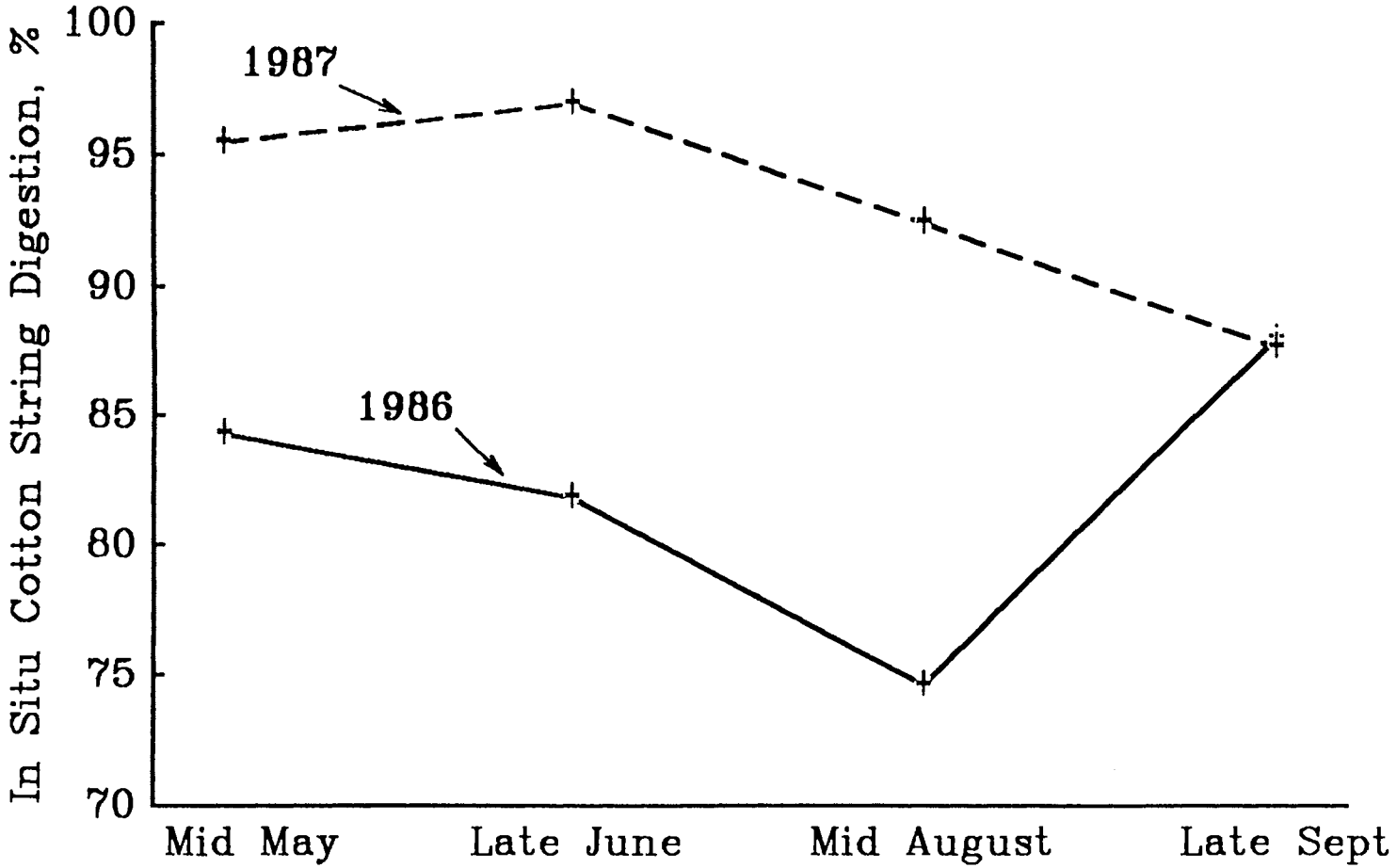


FIGURE 8. FORAGE INTAKE BY STEERS, g/100g BW

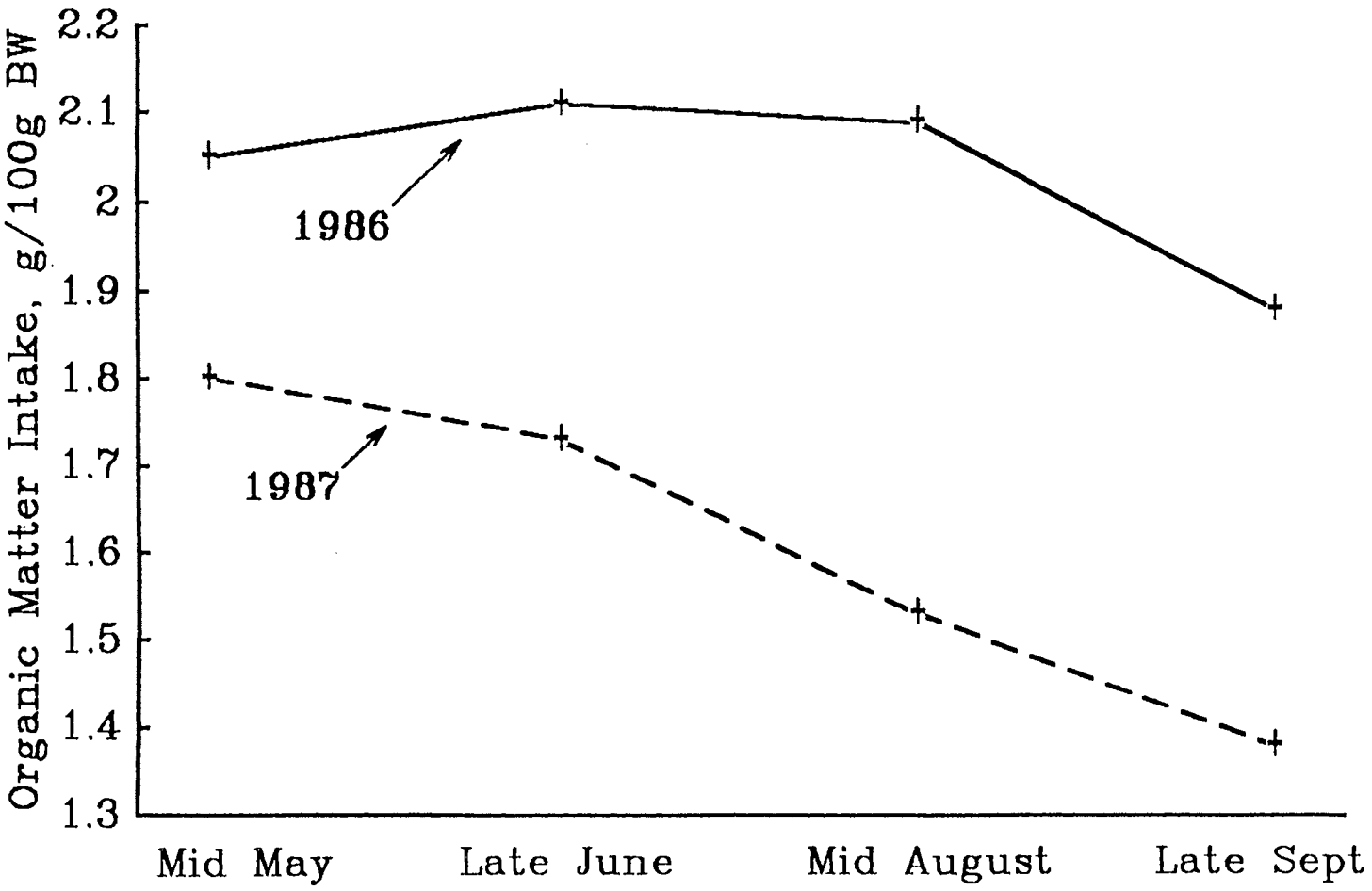


FIGURE 9. DUODENAL OM FLOW OF STEERS

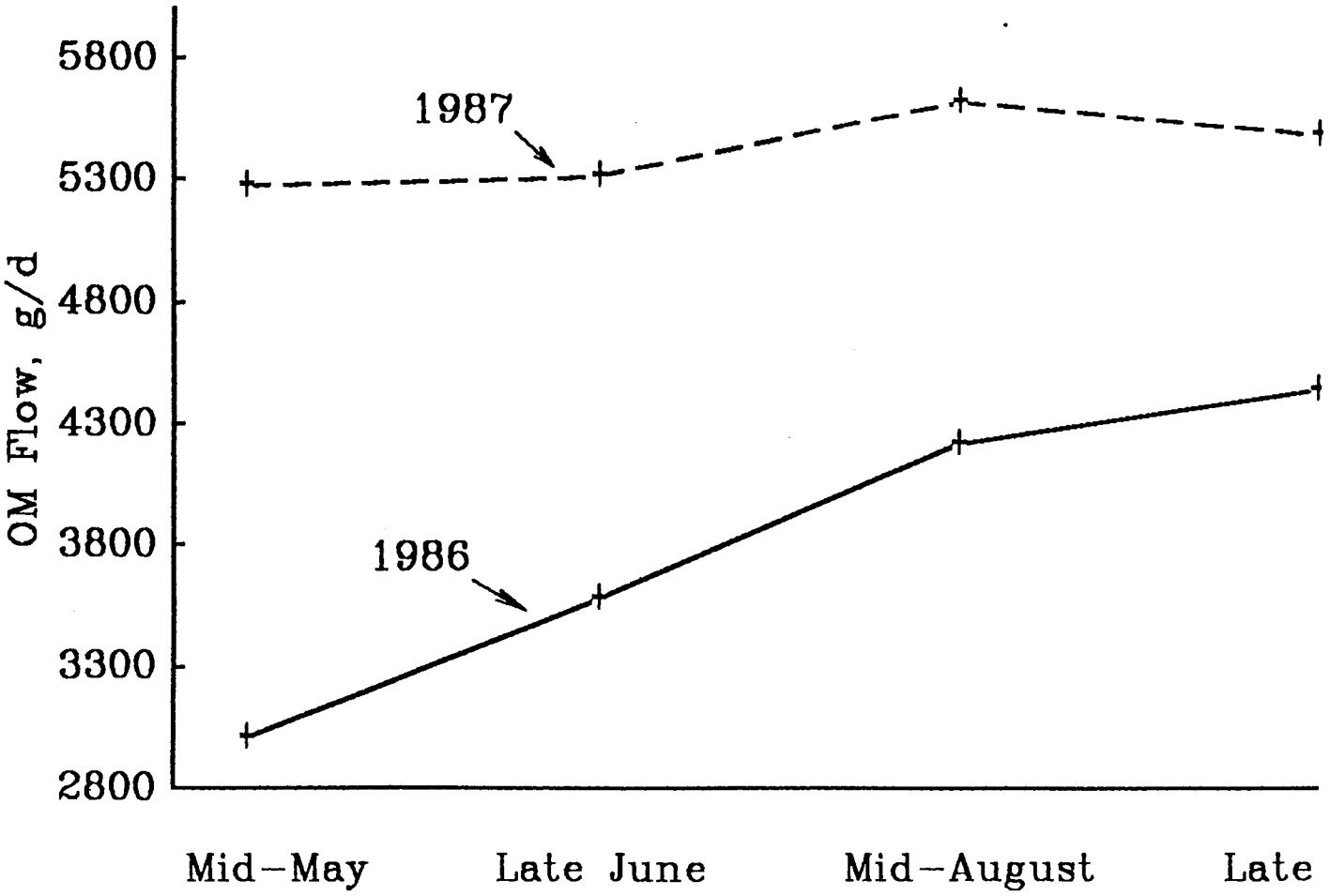


FIGURE 10. APPARENT RUMINAL NITROGEN DIGESTION OF FORAGE GRAZED BY STEERS

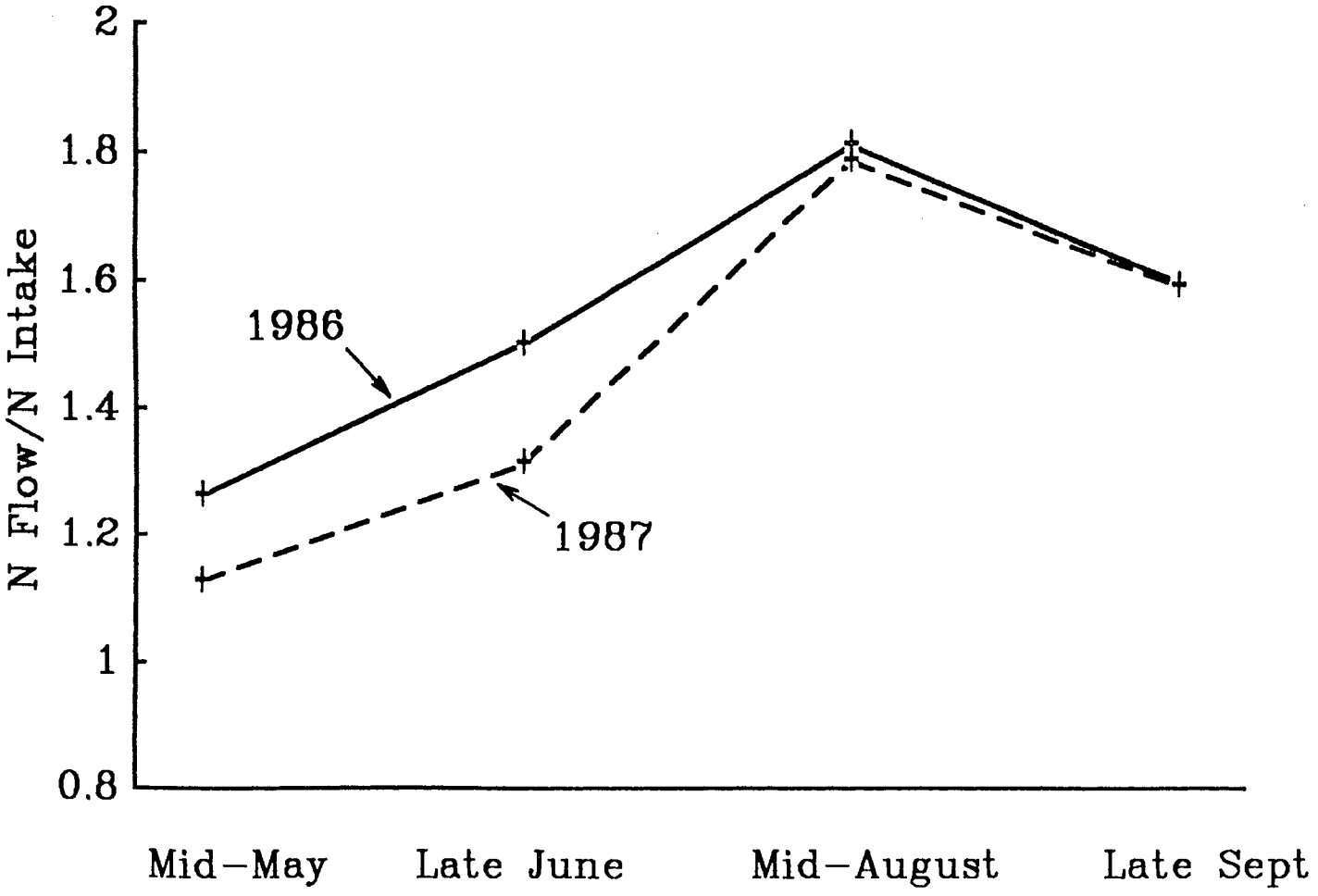


FIGURE 11. TRUE RUMINAL OM DIGESTION, % OM INTAKE

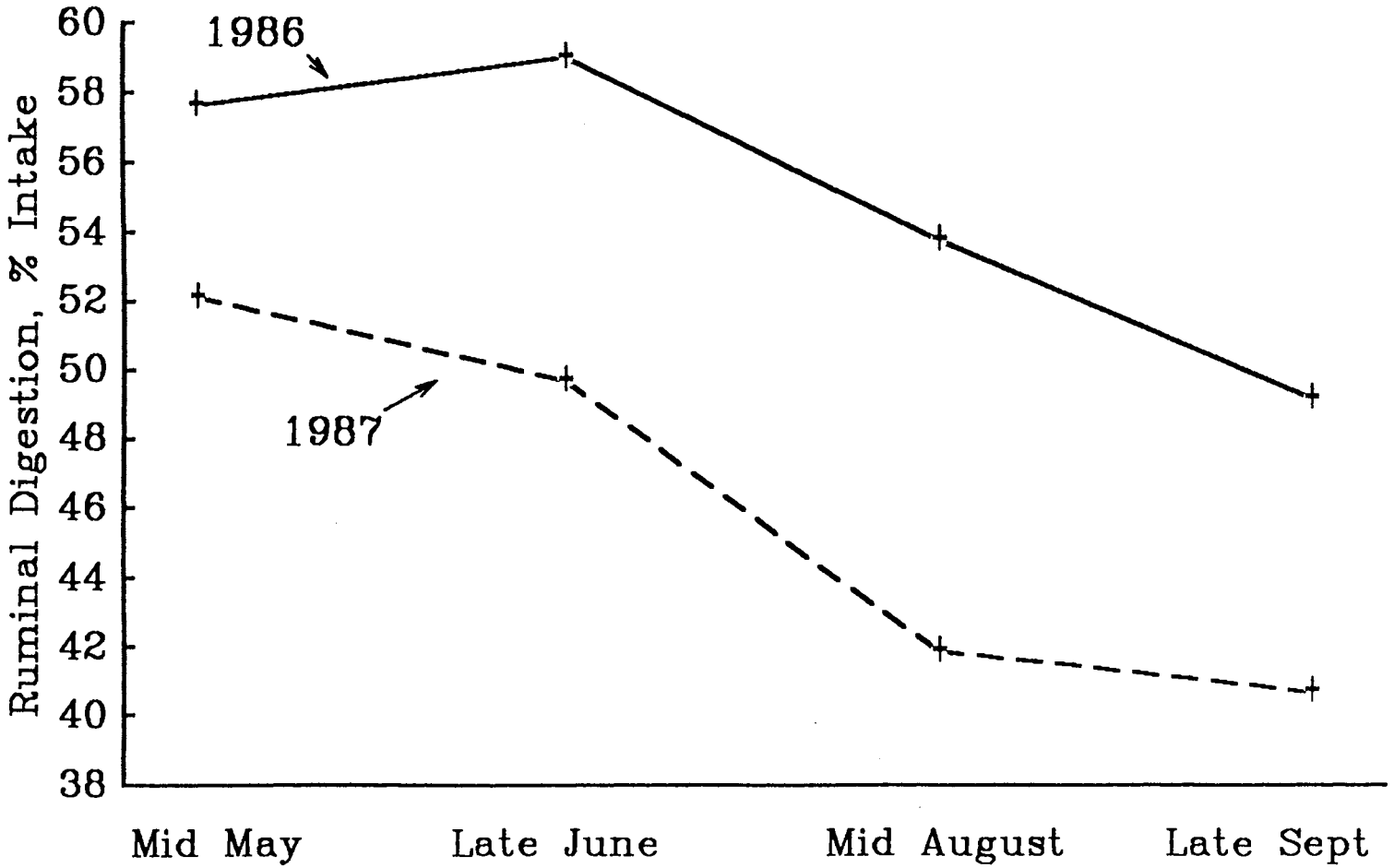


FIGURE 12. MICROBIAL EFFICIENCY OF STEERS

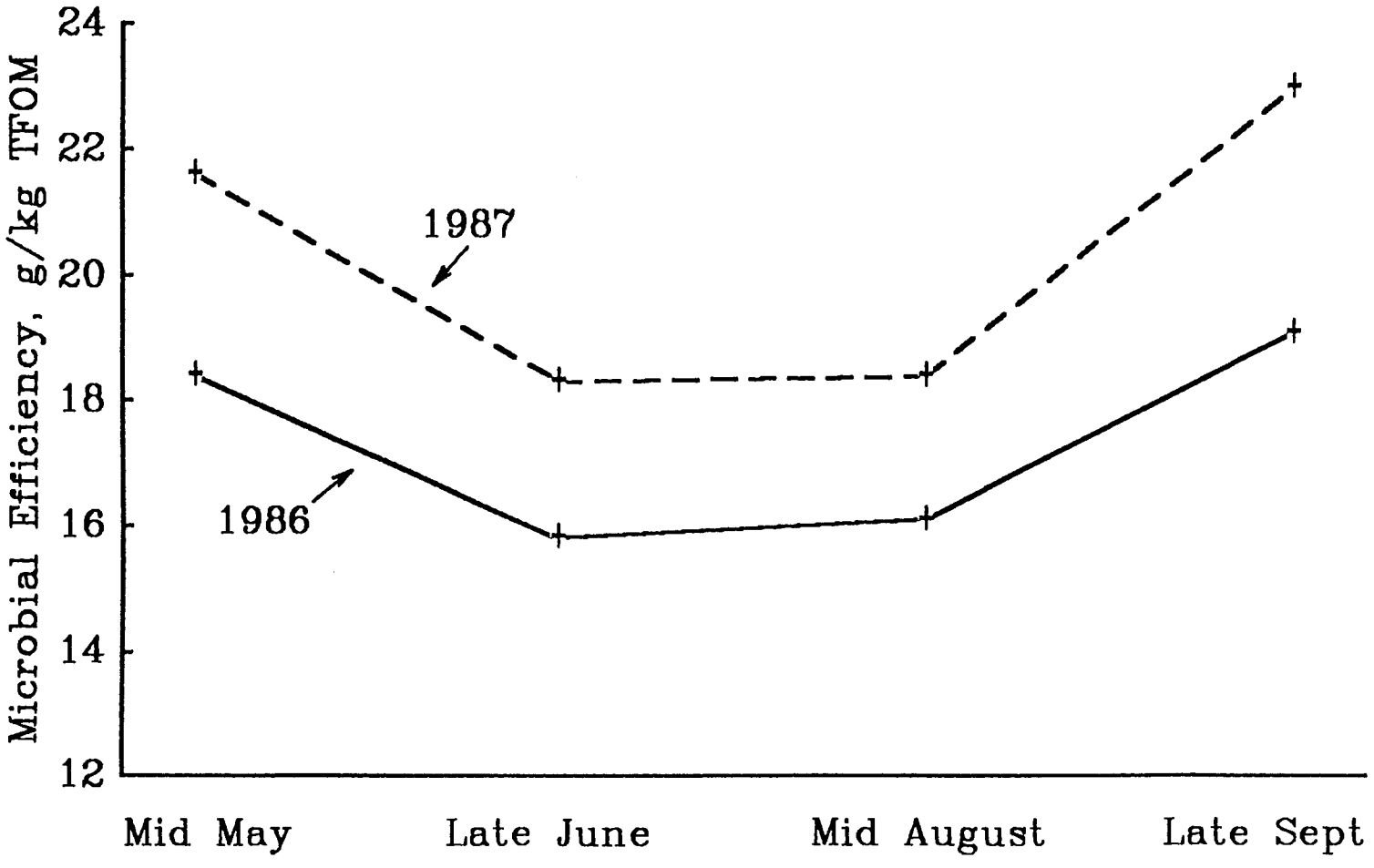


FIGURE 13. LOWER TRACT OM DIGESTION BY STEERS

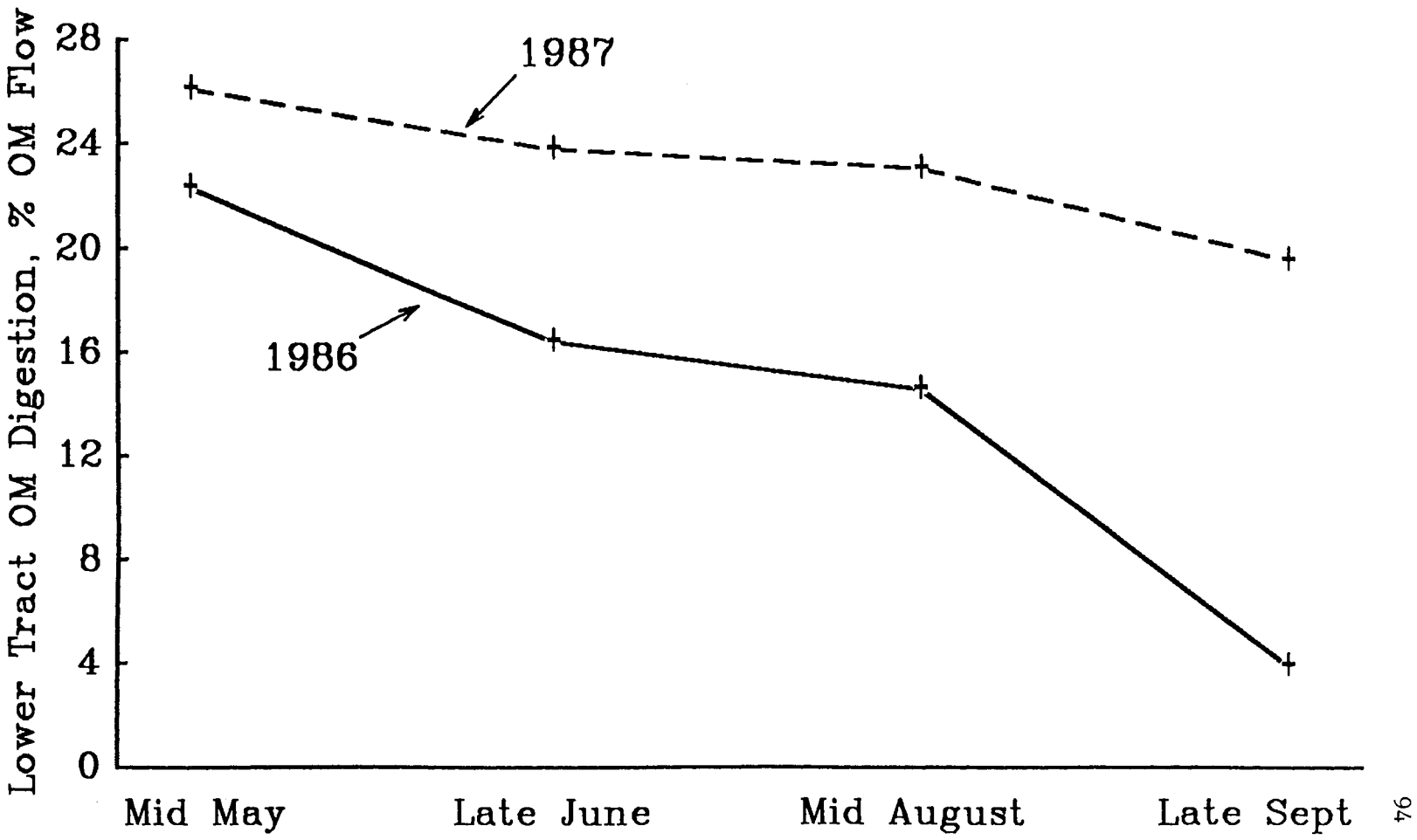


FIGURE 14. LOWER TRACT N DIGESTION BY STEERS

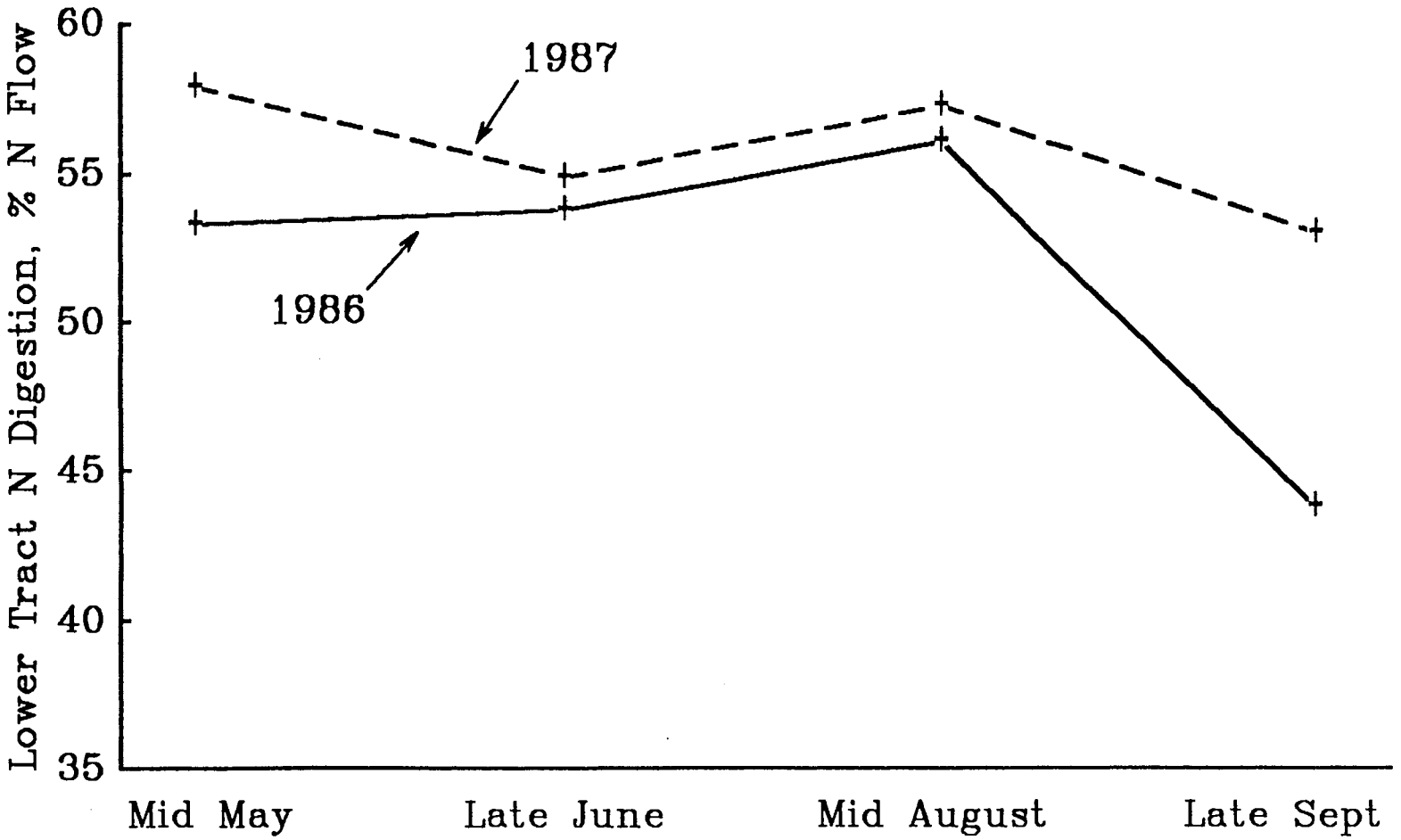


FIGURE 15. RUMINAL AMMONIA-N CONCENTRATION OF STEERS

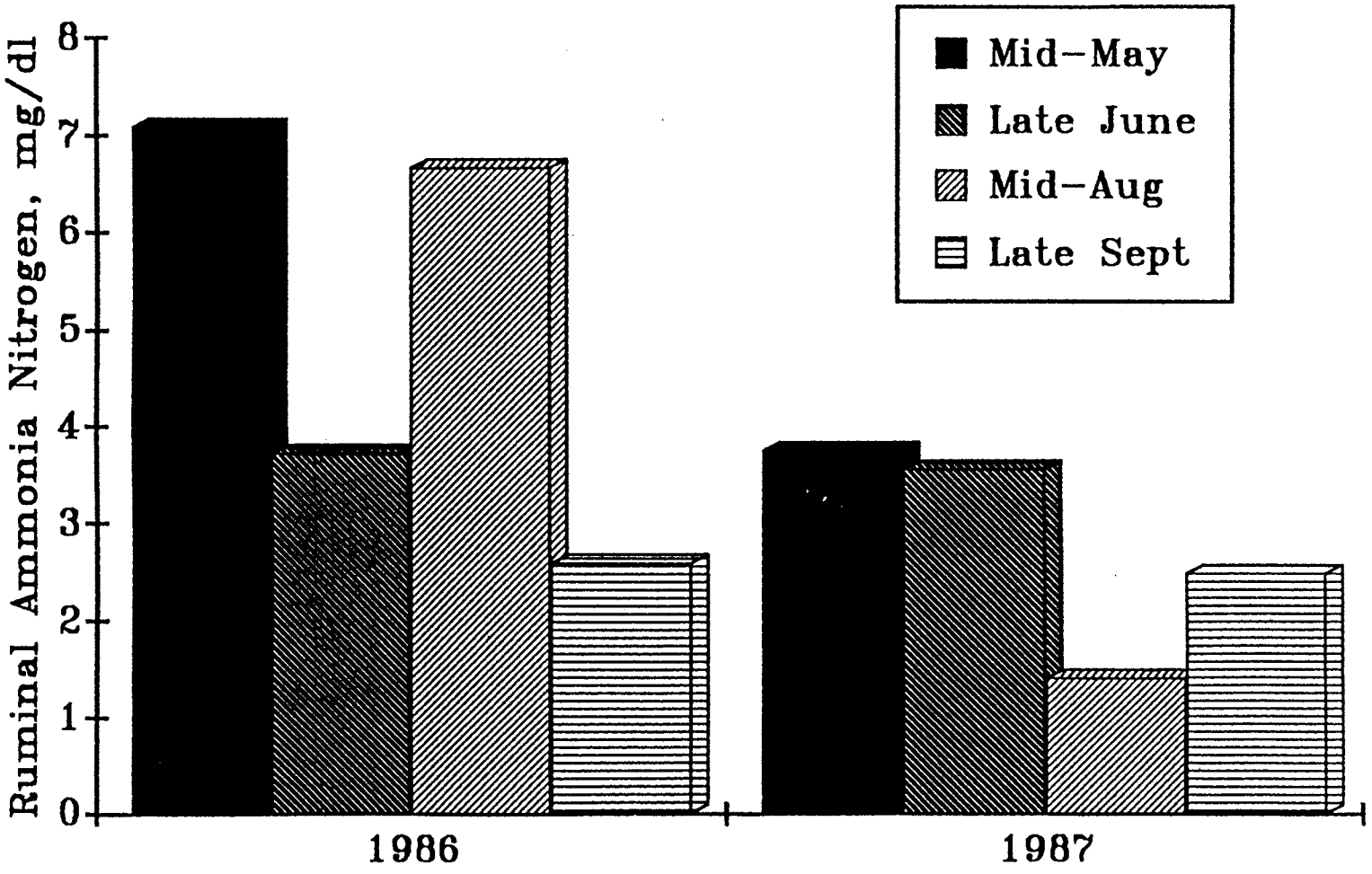


FIGURE 16. TOTAL VFA CONCENTRATION OF STEERS

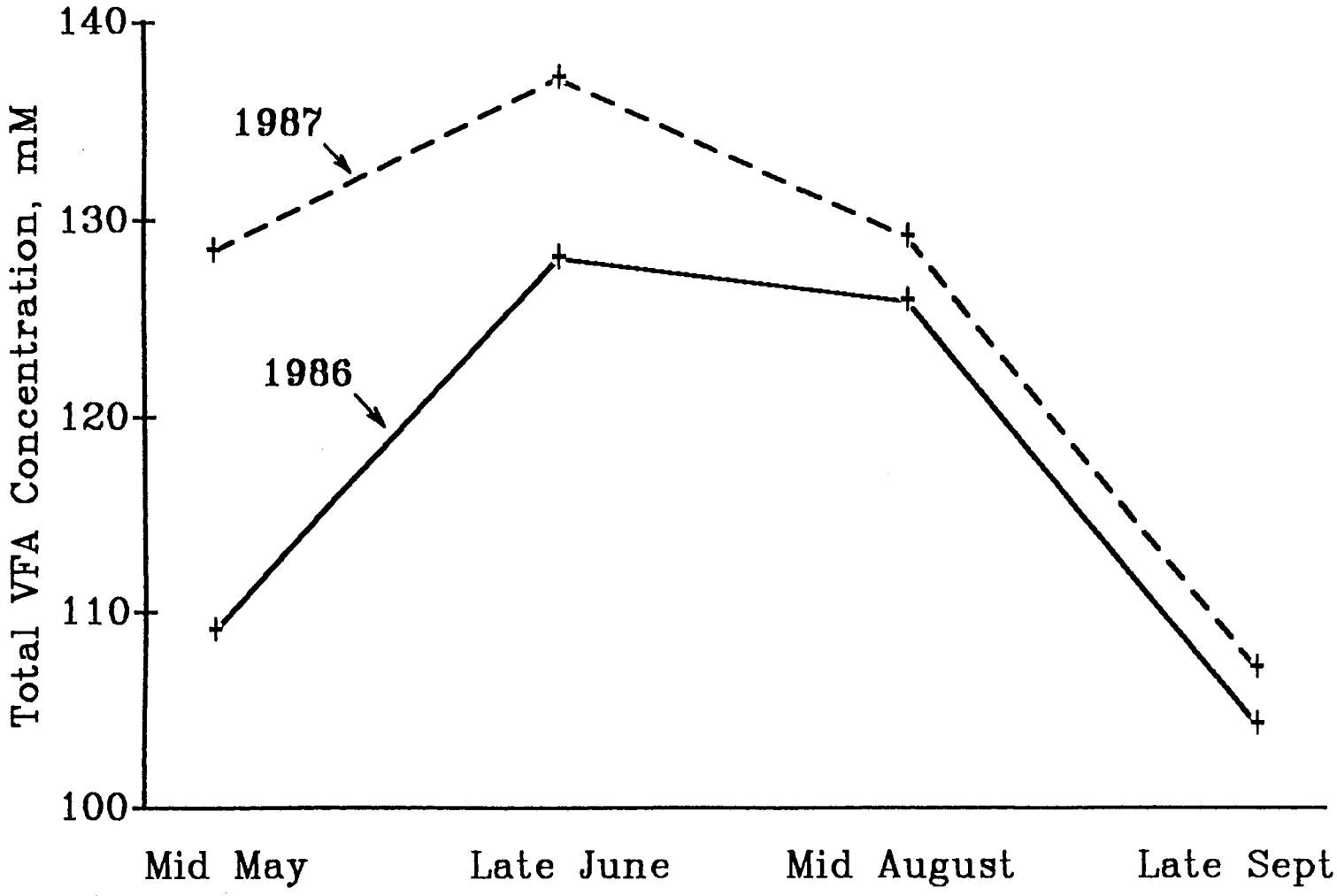


FIGURE 17. RUMINAL ACETATE CONCENTRATION OF STEERS

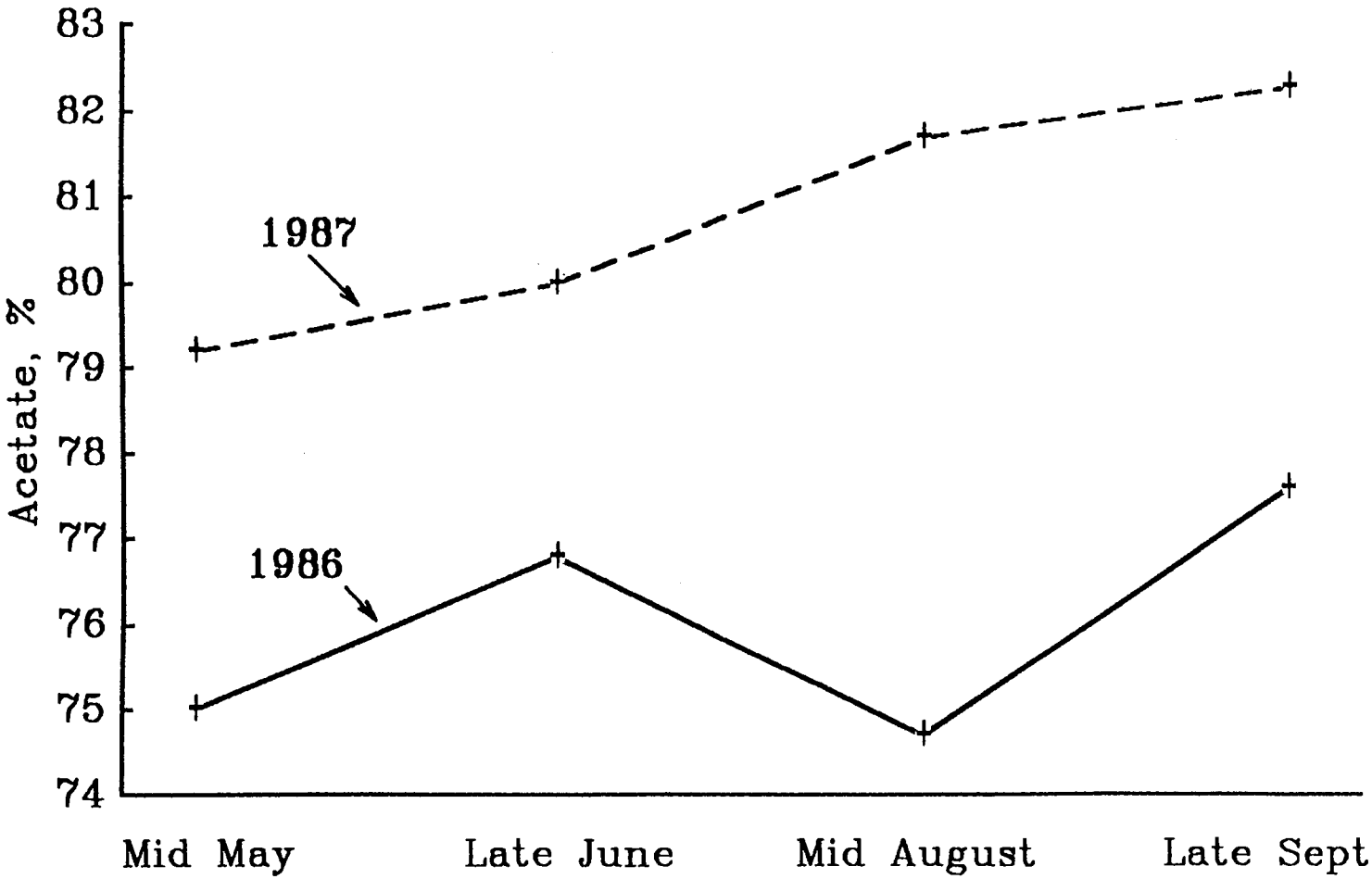


FIGURE 18. RUMINAL PROPIONATE CONCENTRATION OF STEERS

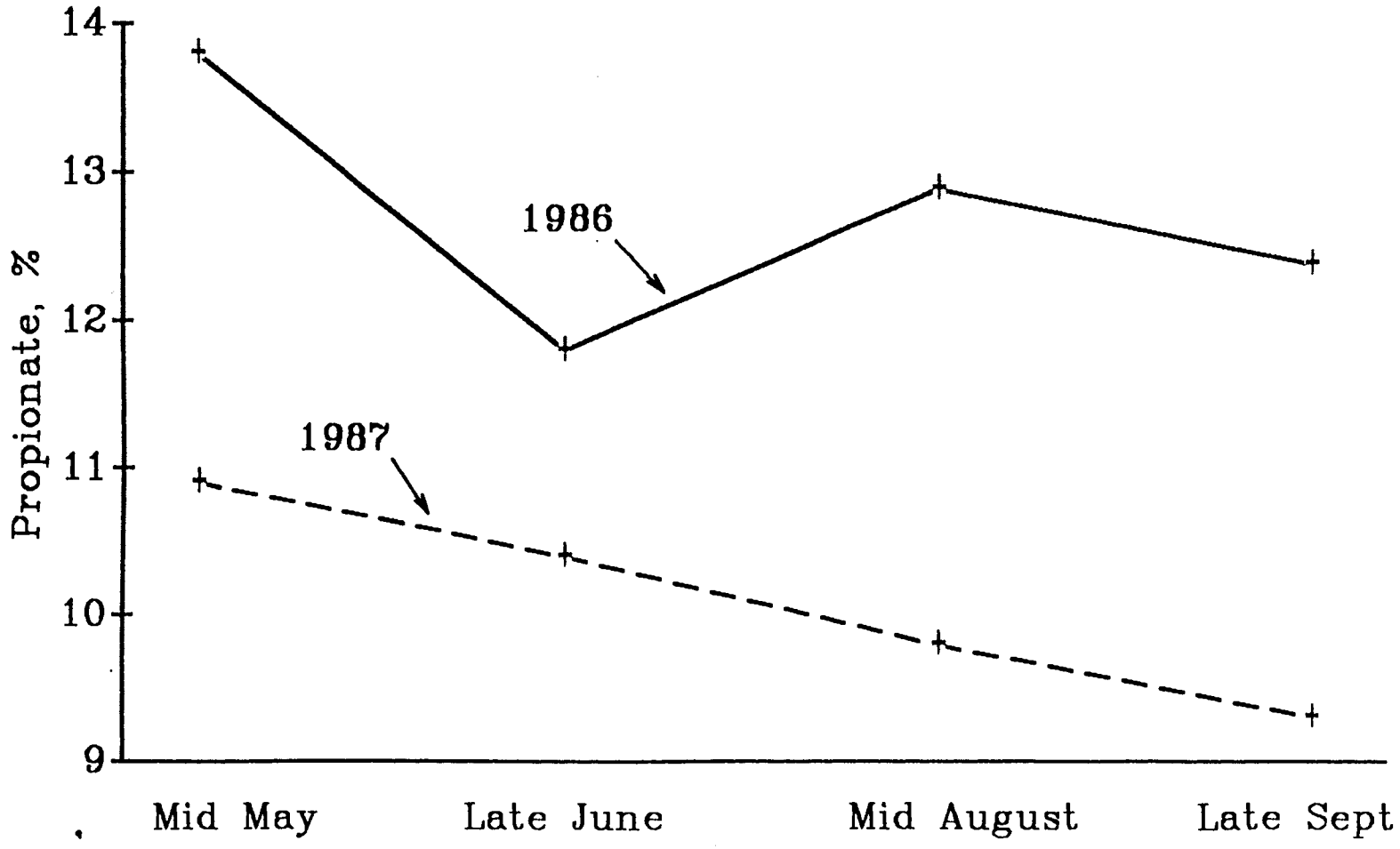


FIGURE 19. RUMINAL BUTYRATE CONCENTRATION OF STEERS

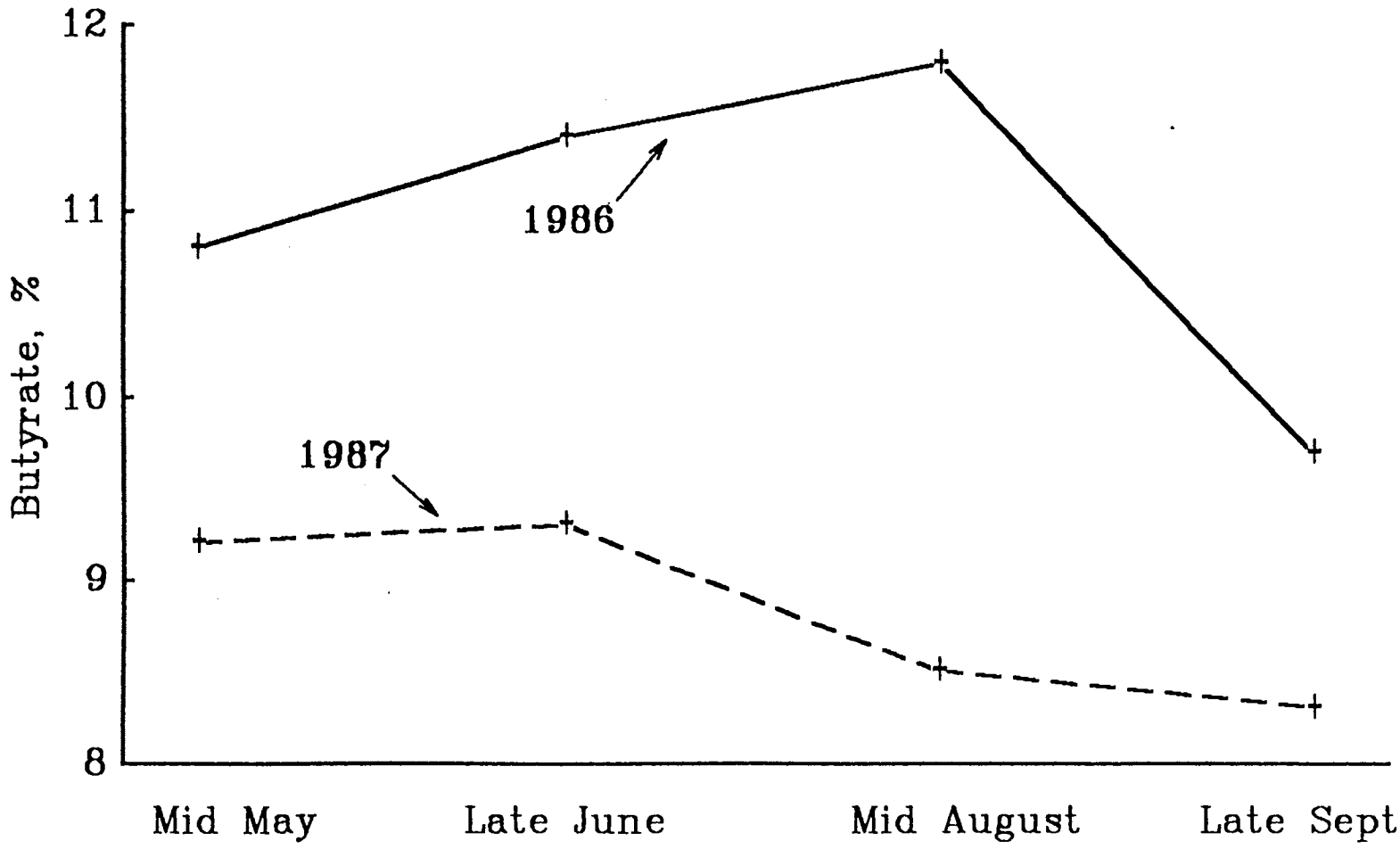
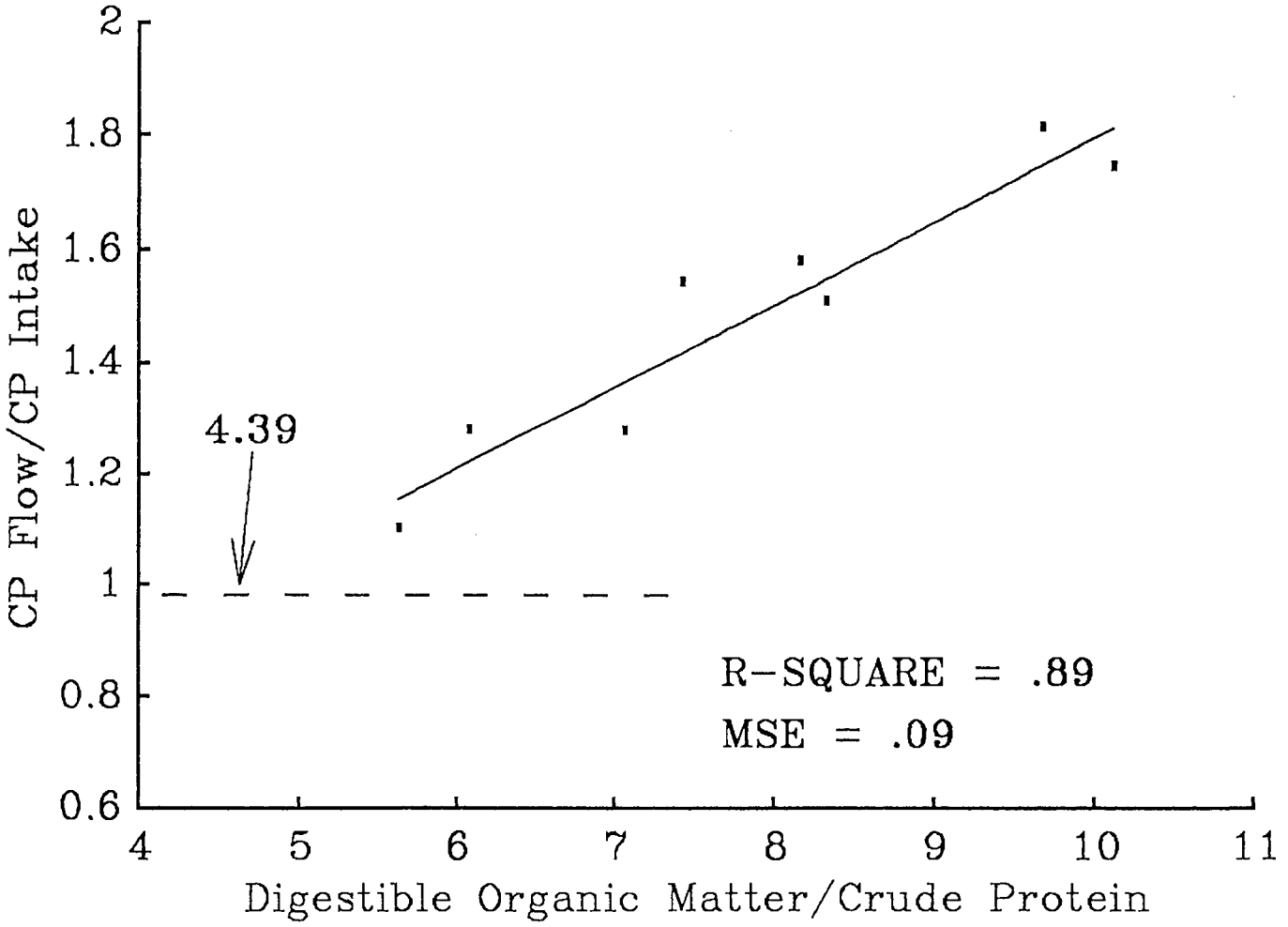


FIGURE 20. CRUDE PROTEIN FLOW/CRUDE PROTEIN INTAKE VS DIGESTIBLE OM/CRUDE PROTEIN



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APPENDIXES

APPENDIX A

MONTHLY PRECIPITATION (MM) AND DEVIATIONS FROM NORMAL AT OKLAHOMA AGRICULTURAL EXPERIMENT STATION, AGRONOMY DEPARTMENT, STILLWATER, FOR NOVEMBER, 1985, THROUGH SEPTEMBER, 1987

	Precip	Deviation
1985		
Nov	71.6	26.4
Dec	6.9	-24.1
1986		
Jan	0.0	-22.9
Feb	19.8	
March	26.7	-29.0
April	93.7	28.2
May	125.5	-3.6
June	84.3	-15.2
July	49.3	-47.0
August	178.6	106.7
Sept	213.4	113.5
Oct	168.9	95.3
Nov	106.9	61.7
Dec	36.6	5.6
1987		
Jan	64.0	41.1
Feb	136.6	106.2
March	85.6	30.0
April	15.7	-49.8
May	172.5	43.4
June	175.3	75.7
July	74.2	-22.1
August	53.6	-18.3
Sept	112.0	12.2

APPENDIX B

MONTHLY PRECIPITATION (MM.) AND AVERAGE MINIMUM, AVERAGE MAXIMUM AND AVERAGE TEMPERATURES (C) AT OKLAHOMA AGRICULTURAL EXPERIMENT STATION, AGRONOMY DEPARTMENT, STILLWATER, FROM MAY THROUGH SEPTEMBER, 1986 AND 1987.

	May		June		July		August		Sept	
	'86	'87	'86	'87	'86	'87	'86	'87	'86	'87
	Precipitation, mm									
	126	173	84	175	49	74	179	54	213	112
	Daily Temperature Averages, C									
Max	24.8	29.0	30.3	31.0	34.8	31.9	31.8	33.8	28.4	28.9
Min	14.3	15.9	19.3	19.0	22.3	21.0	19.4	21.1	18.6	14.6
Avg	19.5	22.5	24.8	25.1	28.6	26.4	25.6	27.5	23.5	21.8

APPENDIX C

DATES OF TRIALS AT THE RANGE RESEARCH AREA.

Sampling Period	Date
Mid-May	May 7-16, 1986
	May 15-24, 1987
Late June	June 23-July 2, 1986
	June 22-July 1, 1987
Mid-August	August 11-20, 1986
	August 3-12, 1987
Late September	Sept 26-Oct 5, 1986
	Sept.17-26, 1987

APPENDIX D

STEER WEIGHTS DURING EACH TRIAL IN 1986[a]

Steer	TRIAL			
	Mid May	Late June	Mid August	Late Sept
	weight, kg			
517	297	339	370	406
709	286	343	370	404
734	265	317	343	-
779	275	327	348	375
790	239	276	317	339
852	280	333	370	388
Mean	274	322	353	382

[a] averaged over two days, no shrink

APPENDIX E

STEER WEIGHTS DURING EACH TRIAL IN 1987[a]

Steer	TRIAL			
	Mid May	Late June	Mid August	Late Sept
	weight, kg			
709	455	477	515	543
779	399	426	464	482
790	364	395	430	464
852	416	449	505	521
41	627	640	680	673
42	626	637	665	682
43	589	601	627	629
44	605	617	630	640
Mean	510	530	564	579

[a] averaged over two days, no shrink

APPENDIX F

CORRELATIONS BETWEEN VARIABLES USED IN INTAKE, RUMINAL AMMONIA NITROGEN AND INTESTINAL FLOW REGRESSION EQUATIONS.[a]

	CPF/CPI	CPF	CPFGPKG	MCPF	ME	NH_3-N
NH_3-N	-.16	.00	.88	-.14	-.39	-
DOM/CP	.94	-.42	-.39	-.52	-.51	-.25
DOM/DCP	.74	-.76	-.30	-.78	-.33	-.21
DOMI	-.41	.93	-.09	.81	.16	-.15
CPI	-.88	.90	.21	.91	.44	.08
FCP	-.69	.07	-.31	.45	-.28	-.05
DCP	-.83	.86	.31	.89	.35	.14
CP	-.93	.58	.55	.61	.35	.38
NDF	.34	.17	-.14	.02	-.15	-.06
ADF	.81	-.67	-.63	-.65	-.16	-.55
OMD72	-.54	.61	.63	.49	-.17	.49
OMD48	-.74	.80	.49	.75	.13	.39
OMD36	-.61	.90	.14	.91	.30	.04
OMD24	-.66	.85	.20	.84	.34	.16
OMD18	-.40	.76	.16	.76	.40	.32
OMD12	-.52	.75	-.01	.84	.46	.08
OMD6	-.15	.15	-.04	.37	.28	.02
ND72	-.39	.82	.04	.80	.13	-.04
ND48	-.65	.82	.33	.77	.29	.31
ND36	-.53	.92	.08	.85	.31	.04
ND24	-.47	.79	-.03	.78	.50	.04
ND18	-.24	.76	-.23	.78	.57	-.04
ND12	-.00	.50	-.57	.62	.68	-.31
ND6	.10	.25	-.72	.41	.66	-.45

[a] CPF/CPI = Crude protein flow to crude protein intake ratio (g/g), CPF = Crude protein flow to the duodenum (g/d), CPFPCBW = Crude protein flow to the duodenum (g/kg body weight/d), MCPF = microbial crude protein flow to the duodenum (g/d), ME = microbial efficiency (g microbial protein/kg OM truly fermented), NH_3-N = ruminal ammonia nitrogen (mg/100 ml rumen fluid), DOM/CP = Digestible organic matter to crude protein ratio, DOM/DCP = Digestible organic matter to digestible crude protein ratio, DOMI = Digestible organic matter intake (g/d), CPI = Crude protein intake (g/d), FCP = Fecal crude protein (g/d), DCP = Digestible crude protein (%), CP = Crude protein (%), NDF = Neutral detergent fiber, ADF = Acid detergent fiber, OMD72 - OMD6 = 72 h through 6 h in situ organic matter disappearance (%), ND72 - ND6 = 72 h through 6 h in situ nitrogen disappearance (%).

APPENDIX G

CORRELATIONS BETWEEN VARIABLES USED IN POTENTIAL ORGANIC MATTER AND NITROGEN DISAPPEARANCE, IN VITRO ORGANIC MATTER DISAPPEARANCE AND INTAKE REGRESSION EQUATIONS.[a]

	OMD72	ND72	IVOMD	OMINTK
CP	.71	.36	.74	.34
ADF	-.80	-.55	-.77	-.41
NDF	.12	.39	.05	-.36
ADF/NDF	-.94	-.83	-.85	-.20
CP/ADF	.73	.39	.75	.33
CP/NDF	.65	.26	.69	.36
IVOMD	.97	.56	-	.50
OMD72	-	.73	.97	.38
OMD48	.93	.80	.85	.88
OMD36	.77	.95	.63	-.22
OMD24	.82	.90	.68	-.17
OMD18	.63	.76	.47	-.19
OMD12	.37	.70	.17	-.29
OMD6	-.03	.33	-.22	-.19
ND72	.73	-	.56	-.25
ND48	.87	.80	.79	-.05
ND36	.77	.88	.66	-.26
ND24	.67	.80	.54	-.39
ND18	.42	.75	.24	-.54
ND12	.01	.55	-.20	-.78
ND6	-.24	.33	-.44	-.82

[a] ADF = Acid detergent fiber, NDF = Neutral detergent fiber, CP = Crude protein, ADF/NDF = ADF to NDF ratio, CP/ADF = CP to ADF ratio, CP/NDF = CP to NDF ratio, IVOMD = In vitro organic matter disappearance, OMD72 - OMD6 = 72 h through 6 h in situ organic matter disappearance, ND72 - ND6 = 72 h through 6 h in situ nitrogen disappearance, OMINTK = grams organic matter intake per kilogram body weight.

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APPENDIX H

1985 DATA USED IN REGRESSION ANALYSES.

Component	TRIAL			
	Mid-May	Late Ju	Mid-Aug	Late Sept
CP	12.63	10.43	7.89	7.72
NDF	74.40	78.37	76.57	76.45
ADF	46.12	47.60	47.70	48.26
IVOMD	48.70	45.34	44.25	42.26
OM Intake, g/100g BW	1.32	1.45	1.28	1.40

VITA

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Doctor of Philosophy

Thesis: THE INFLUENCE OF ADVANCING SEASON ON DIET QUALITY, INTAKE AND RUMEN FERMENTATION OF CATTLE GRAZING TALLGRASS PRAIRIE

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