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Influence of Energy Supplementation on Grazing Ruminants: Requirements and Responses¹

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ABSTRACT: Energy requirements of grazing livestock seem to be poorly defined. Requirements generated from measurements in pen-fed animals present both theoretical and practical concerns when they are applied to grazing situations. In mature ruminants a majority of energy used for maintenance seems to be consumed by visceral tissues. Moreover, factors that affect visceral energy use are poorly understood. Energy supplementation to meet requirements and production demands is often practiced during periods of summer dormancy and in winter months. Source of supplemental energy varies widely and includes grains, readily digestible fiber sources, and high-quality forages. Intake and digestibility can

be reduced or unaffected by energy supplementation. In some cases, lower levels of energy supplementation have been shown to increase utilization of grazed forage. Reductions in ruminal pH, often cited as the major cause of reduced fiber digestion, may not always explain reductions in intake and digestibility associated with energy supplementation. Livestock production is usually either enhanced or unaffected by energy supplementation. Additional research regarding energy requirements of grazing ruminants, visceral energy use, and mechanisms associated with reductions in intake and digestibility of grazed forage resulting from energy supplementation is warranted.

Key Words: Energy, Supplementation, Grazing, Requirements

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Introduction

Supplementation in most areas where domestic ruminants graze is a major factor to consider when making management decisions. Providing nutrients to offset deficiencies or to meet production demands is more often practiced during periods of summer dormancy or during the fall and winter months. Supplementation can take the form of substitution when grazed nutrients are removed from animal diets in exchange for supplement. Both supplementation and substitution can be desirable at specific times, depending on several factors including forage quantity and quality and production demands. In situations in which energy availability from grazed forage is too low to meet production demands, some form of energy supplementation is often practiced.

Optimizing energy supplementation of grazing ruminants dictates knowledge of animal requirements. Unfortunately, energy requirements of grazing ruminants are poorly characterized. Pen-fed estimates

of energy requirements often fall short of predicting expected gain responses associated with energy supplementation.

Objectives of this paper are to review data relating to the influence of energy supplementation on grazing ruminants. Emphasis is placed on animal requirements and responses. In addition, we hope to identify areas where information is lacking and additional research is needed.

Requirements

Maintenance requirements in the net energy system typically used for beef cattle are derived by extrapolating a regression of heat production on daily ME intake to an intake of zero. Data presented by Lofgreen and Garrett (1968) and others have resulted in the relationship adopted by the NRC (1984; $NE_m = 77 \text{ kcal } W^{.75}$, where W equals body weight, kg). This equation has proven to be quite functional for predicting maintenance requirements of penned cattle. However, when working with grazing cattle, estimates associated with pen-fed systems do not always align with production responses.

When evaluating maintenance requirements, it is useful to assess where energy is being used. Animal

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Table 1. Tissue energy expenditures
(adapted from Ferrell, 1988)

Tissue	Weight, % of EBW ^a	Energy expenditures, % of total
Nervous	2.0	12.0
Skin	6.3	2.7
Viscera ^b	6.2	50.5
Muscle	41.0	23.0
Adipose	15.0	7.0
Other	29.5	4.8

^aEBW = Empty body weight.

^bRepresents heart, kidney, liver, and digestive tract.

data from Ferrell (1988) demonstrate that although visceral tissues (liver, digestive tract, heart, and kidney) are a small portion of body weight (6%), they consume approximately 50% of maintenance energy. The largest tissue that consumes maintenance energy is muscle (41% of body weight; Ferrell, 1988); however, muscle (Table 1) consumes only 23% of the total energy for maintenance. It is important to note that visceral tissue is of considerable importance to maintenance energy demands. In addition, data from pen-fed sheep indicate that muscle tissue does add considerably to the requirement (Ferrell, 1988). In the case of grazing ruminants, energy consumed by muscle tissue could be considerably larger, depending on amount of work required for forage consumption and processing.

Energetic costs of eating over and above standing can range from less than 20 to over 300 kcal per animal per kg of DM ingested (Robbins, 1993). Factors influencing this range include amount of time spent eating, maturity of forage, and ruminating. Moreover, cost of locomotion can also add considerably to maintenance energy requirement (Robbins, 1993). Data from Osuji (1974; Table 2) indicate that energy expenditure by grazing sheep can be 30% greater than that by confined sheep. The majority of this increase seems to be associated with muscular work, specifically the work of eating, standing, and walking. Energy expenditure associated with the work of grazing is related to grazing time and forage availability. As grazing time increases and forage availability declines, work associated with grazing activity increases. Therefore, any management or environmental factor that affects grazing time or forage availability can potentially alter energy expenditure for maintenance. Senft et al. (1987) demonstrated that metabolizable energy intake of free-grazing heifers varied greatly with changes in season, and at times, metabolizable energy intake was poorly related to energy retained in the empty body. In fact, during August, the daily metabolizable energy intake was 236.2 kcal/kg metabolic body weight (the highest measured), whereas energy stored in the body was

only 3.4 kcal (one of the lowest measured; Senft et al., 1987).

In work evaluating maintenance requirements of beef cattle breeds across season, Laurenz et al. (1991) found that requirements were higher in Simmental than in Angus cattle (adjusted for metabolic body weight). Moreover, the maintenance requirement for weight equilibrium (kcal/kg of metabolic BW) was lower in winter for both Angus and Simmental breeds than in summer, spring, and fall. However, when these data (Laurenz et al., 1991) were expressed as maintenance requirements for energy equilibrium, Simmental cattle were observed to have the lowest maintenance requirement in the summer. Angus cows had the lowest maintenance requirement for energy equilibrium in the winter. These data should be independent of productive stage because cows were nonpregnant and nonlactating throughout the study year. Moreover, Simmental cows were found to have greater requirements for ME use throughout the year compared with Angus cows. Reasons for this are probably best explained by differing digestive and metabolic efficiencies (Grovm, 1986).

Although differing seasonal influences on maintenance requirements of cattle or differing breeds have been documented in cows of similar physiological state, it is unclear whether seasonal effects are independent of energy expended for grazing. Research in this area seems warranted.

Krysl and Hess (1993) reviewed data evaluating the influence of supplementation on grazing time. They concluded that increasing the level of supplemental grain (starch) decreased amount of time spent grazing. However, data evaluating distance traveled as influenced by supplementation was inconclusive. Krysl and Hess (1993) recognized that grazing behavior and energy expenditure could be closely related. Therefore, they calculated a "harvesting efficiency," which was determined to be grams of OM intake-kilogram of BW⁻¹·minute spent grazing⁻¹. These results demonstrated that grazing efficiency

Table 2. Daily energy expenditure of sheep confined or pastured (adapted from Osuji, 1974)

Activity	Total energy cost of activities, kcal/d	
	Housed	Grazed
Eating	31.0	202.5
Ruminating	12.0	12.0
Standing	6.0	36.0
Walking	29.5	180.0
Total energy cost of muscular work	78.5	430.5
Resting metabolic rate + heat increment	1,200.0	1,200.0
Total daily energy expenditure amount	1,278.5	1,630.5

was a relatively constant value across forage type and amount or type of supplement offered. Research comparing harvesting efficiency of differing breeds and season have not been reported.

Energy requirement associated with grazing cattle varies depending on production level and energetic expenditure related to the work of grazing. Season of year and breed can also affect requirement.

Supplementation of energy may alter energy requirements of grazing ruminants by altering grazing behavior or by influencing efficiency of nutrient use (Caton and Dhuyvetter, 1996). Data of Sarker and Holmes (1974) and Adams (1985) indicate that supplementing concentrates will decrease grazing time. If grazing time is decreased, energy demands from work associated with grazing should also decrease. Additionally, Adams (1985) indicated that degree of change in grazing time associated with supplementation depended on time of supplementation. Other work (DelCurto et al., 1990; Minson, 1990) indicated little change in grazing time in response to supplementation. These authors did not report data on efficiency of energy use. Efficiency of utilization of dietary ME for maintenance and gain is influenced by forage to concentrate ratio (NRC, 1984). As supplemental energy increases, the efficiency of energy use should increase. Energy from concentrates is used more efficiently for both maintenance and gain functions than is energy from forages (NRC, 1984).

Responses of Grazing Ruminants to Energy Supplements

Intake. Forage intake by grazing ruminants is a moving target that is currently inadequately defined. Intake of grazed forage has been reported to range from .91 to 4.3% of BW in cattle grazing native range throughout the year (Adams, 1985; Kirby and Parman, 1986; Krysl et al., 1987).

Energy supplementation is often practiced during summer dormancy and in winter months to maintain desired production levels or minimize losses. Providing additional energy in the form of supplement has often produced reductions in intake of grazed forage. Chase and Hibberd (1987) fed incremental levels of corn to cows consuming low-quality forage and reported linear decreases in forage OM intake. These results support observations from earlier work on energy supplementation (Lusby and Wagner, 1986). More recently, Pordomingo et al. (1991) reported that cattle supplemented with corn while grazing summer pasture in New Mexico had reduced forage intakes. These reports above agree with other data from tropical and temperate forages (Minson, 1990).

Working with sheep, Henning et al. (1980) reported that low levels of corn supplementation (7.8% of DM intake) actually increased forage intake. However, with higher levels of corn supplementation

Table 3. Influence of barley supplementation on forage and total intake by beef steers fed grass hay (from Westvig, 1992)

Component	Intake g/d		SEM
	Control	2.7 kg barley	
Forage	6,821 ^a	5,510 ^b	556.5
Total ^c	7,453	8,137	546.5

^{a,b}Means within a row having differing superscripts differ ($P < .05$).

^cSoybean meal was used to equalize protein intake between control and barley treatments.

(greater than 23% of DM intake) forage intake was reduced compared with that of control sheep. Others have reported that low levels of energy supplementation to sheep consuming forage-based diets have increased intake (Matejovsky and Sanson, 1995). In general, as level of energy supplement provided increases, intake usually decreases. Reports that low levels of energy supplementation increase forage intake seem to occur much more frequently in studies with sheep than in those with cattle.

Reductions in forage intake associated with corn supplementation have been attributed to starch. Sanson et al. (1990) demonstrated that increasing levels of cornstarch supplementation decreased forage intake in steers. These reductions have been attributed to either depressions in ruminal pH or a carbohydrate effect (Mould et al., 1983). Declining ruminal pH associated with increasing dietary starch should affect the ruminal bacteria toward greater amyolytic and lower cellulolytic population. Resulting bacterial shifts are thought to reduce fiber digestion and negatively affect intake of grazed forage. Conversely, Mould and Ørskov (1983), working with penned sheep fed high levels of concentrate, demonstrated that artificially raising ruminal pH with bicarbonate infusions failed to return in situ DM digestion to the level of forage-fed controls.

Data evaluating barley supplementation (Westvig, 1992) suggest that providing 2.7 kg of barley/steer daily decreases forage intake by 1.3 kg/head daily (Table 3). In this study, total diet digestions of DM and NDF were unaffected, whereas in situ DM and NDF digestion were both reduced by barley treatment after 36 h of ruminal incubation. Additional work from our laboratory with incremental increases of barley as a supplement (Table 4) fed to steers consuming a 10% CP grass hay diet showed that forage intake was reduced but total intake was unaffected as level of barley increased. In these two studies CP levels were equalized with soybean meal and, therefore, responses should be due to additional energy supplied by barley supplements. Digestible OM intake in this study was increased ($P < .10$) by all levels of supplementation compared to controls. However, no differences in

Table 4. Influence of level of barley supplementation on forage intake in steers fed medium-quality hay (from Ulmer et al., 1990)

Intake, kg/day	Control	Barley supplement			SEM
		.9 kg	1.8 kg	2.7 kg	
Forage	4.89 ^a	4.84 ^a	4.30 ^b	3.78 ^c	.13
Total	5.73 ^a	6.24 ^b	6.25 ^b	6.29 ^b	.13
Digestible OM	3.76 ^a	4.25 ^b	4.24 ^b	4.45 ^b	.08

^{a,b,c}Means having differing superscripts differ ($P < .10$).

^dControl treatments were provided soybean meal to equalize protein intake.

digestible OM intake were noted with increasing levels of supplementation. Although these data and the work of others (Chase and Hibberd, 1987) suggest that increasing levels of barley or corn supplementation have little effect on digestible OM intake, these data do not consider possible changes in efficiency of energy use. The NRC (1984) indicates that as concentrate increases in the diet, efficiency of energy use for both maintenance and gain increases. Thus, reductions in forage intake and marginal changes in total digestible OM intake could be partially compensated for by changing efficiencies of ME use. Matejovsky and Sanson (1995) indicated that corn supplementation levels of less than .25% of BW resulted in no adverse effects on forage utilization. In work from our laboratory (Table 4) it was suggested that barley supplementation of 1.8 kg/steer daily would only marginally affect forage intake and digestibility. This supplementation level represents .8% of BW. These results are consistent with recommendations of Horn and McCollum (1987), who suggested an energy supplementation level that would minimally affect forage utilization of 30 g/kg of BW^{.75}, which represents approximately .7% of BW.

Studies evaluating readily degradable fiber sources as energy supplements for grazing and forage-fed ruminants have yielded different responses than research with grains. Martin and Hibberd (1990) indicated that feeding soybean hulls results in only small decreases in forage intake when fed up to 3 kg per cow daily. These findings are supported by the work of others (Grigsby et al., 1992). Other sources of readily degraded fiber such as wheat midds, beet pulp, and corn gluten feed have generally not decreased forage intake as much as grain-based supplements. Carey et al. (1993) compared beet pulp, corn, and barley supplemented at 1.3 kg/steer daily and found that intake of a 10% CP forage was reduced by all three treatments when compared to control supplement steers. Differences between this study and others may be partially explained by the fact that energy supplements contained soybean meal to equalize supplemented protein intakes across treatments.

Reductions in forage intake in response to energy supplementation depend to some degree on basal

Table 5. Substitution coefficients as influenced by forage protein level (adapted from Minson, 1990)

Forage CP, %	No. of studies	Average substitution coefficient	Average forage CP, %
0 to 7	13	.27	4.4
7 to 14	9	.44	10.3
>14	10	.51	17.5

forage quality. Work with wethers (Henning et al., 1980) fed either straw or hay and supplemented with increasing levels of corn has shown that reductions in hay intake were greater than reductions in straw intake. Matejovsky and Sanson (1995) supplemented lambs with incremental levels of corn and provided basal forages containing 5.2, 10.2, or 14.2% CP. In this study, additional CP was provided in the form of soybean meal to equalize protein. Results of their work indicated that lambs consuming 10.2 and 14.2% CP forages had linear decreases in basal forage intake, probably resulting from higher substitution rates. Conversely, lambs fed straw and supplemented with corn had increased intake at lower levels of supplementation. Responses of lambs fed straw-based diets in this study could be partially explained by added supplemental protein.

In general, energy supplementation reduces grazed forage intake in ruminants (Horn and McCollum, 1987; Paterson et al., 1994). In some cases, especially with sheep, forage intake is stimulated by lower levels of supplemental grain. Providing supplemental energy as readily digestible fiber usually has a less negative effect on forage intake than starch-based supplements and can result in increases in total intake. While providing supplemental energy in the form of grain increases efficiency of energy use (NRC, 1984), the impact of readily digestible fiber sources on these efficiencies is less well-defined.

Reductions in forage intake by grazing and pen-fed ruminants due to energy supplementation has been termed substitution. Amounts of basal forage exchanged for supplemented nutrients have been assigned values termed substitution coefficients (amount of decrease in basal forage divided by amount of supplement provided). Recent reviews have covered substitution effects and coefficients in considerable detail (Horn and McCollum, 1987; Minson, 1990) and readers are referred to these authors for more extensive reviews.

In Minson's (1990) review, the average substitution coefficient was .69. This mean value, representing many studies over a wide range of grazing situations, is higher than values obtained with barley supplementation from our laboratory. These coefficients have ranged from .40 (Westvig, 1992) to .48 (Ulmer et al., 1990). Differences in these estimates may be due to experimental conditions. In our studies, animals were

fed in pen settings, whereas Minson's mean value derives from a considerable amount of data from grazing situations. Conversely, work with penned beef cows fed harvested native hay and supplemented with corn (Chase and Hibberd, 1987) has yielded substitution coefficients of .83. Moreover, work with stanchioned steers by Carey et al. (1993) provided an average substitution coefficient of .53 resulting from barley, beet pulp, and corn supplementation.

Substitution coefficients seem to be responsive to forage quality. Data adapted from Minson (1990; Table 5) indicate that, as forage CP increases, substitution coefficients increase. These data are supported by the work of Lamb and Eadie (1974), Paterson et al. (1994), and Matejovsky and Sanson (1995).

Digestibility. Results of research on the effects of energy supplementation on dietary digestibility in ruminants consuming forage-based diets in grazing and pen-fed situations have been varied. When considering these data it is important to differentiate between effects of basal forage digestibility and that of total diet because production management objectives may favor one situation over another.

In situ OM digestibility of summer range forage was reduced by corn supplementation at .4 or .6% of steer BW and increased when corn was supplemented at .2% of BW (Pordomingo et al., 1991). Branine and Galyean (1995), working with steers grazing winter wheat pasture, reported an increased forage digestibility in response to .5 kg of grain-based supplement provided during the early vegetative plant stage of growth. When steers grazing blue grama rangeland were supplemented with .5 kg of sorghum grain daily (Krysl et al., 1989), no effects were observed in in situ forage digestion whereas grain supplementation increased total tract OM digestion. Lake et al. (1974) supplemented beef calves grazing irrigated pasture with .45 or 1.36 kg of corn/calf daily and found that higher levels increased total tract DM digestion but that no effects were noted at lower levels of supplementation.

In general, rate of digestion (%/h) has not been affected by supplementation. Caton et al. (1988) and Freeman et al. (1992) reported that both protein and energy supplementation had little influence on rate of NDF digestion in cattle grazing blue grama rangeland or fed prairie hay. These data agree with research evaluating rate of digestion as influenced by supplementation in cattle grazing wheat pasture (Branine and Galyean, 1995), native range (Krysl et al., 1989; Pordomingo et al., 1991), or fed grass hays (Cordes et al., 1988; Carey et al., 1993; Ulmer et al., 1990). Notable exceptions to above data are the work of Westvig (1992) and Leventini et al. (1990). Westvig (1992) reported decreases in rate of DM (but not NDF) digestion due to barley supplementation in steers fed low-quality grass hay. Leventini et al.

(1990) fed 10, 30, and 50% barley-based diets and noted linear declines in DM and NDF rates of digestion. Differences noted by Leventini et al. (1990) were to be expected, considering the high levels of barley. Reasons for the decline in rate of DM digestion (Westvig, 1992) associated with 2.7 kg of added barley to steer diets of grass hay are less clear. Other data (Ulmer et al., 1990) have demonstrated that feeding 2.7 kg of barley to steers provided grass hay similar to that used by Westvig (1992) has no effect on rate of digestion.

Several studies have found that grain supplementation has reduced total tract DM and OM digestibilities (Hannah et al., 1989; Zorrilla-Rios et al., 1989; Vanzant et al., 1990). Others have noted increased or no effect on total tract digestibility in response to grain supplementation (Kartchner, 1981; Krysl et al., 1989; DelCurto et al., 1990; Freeman et al., 1992; Matejovsky and Sanson, 1995; Branine and Galyean, 1995; Table 6). Differences in the above reports may be partially explained by the level of protein provided. Digestibility responsiveness to energy supplementation may be dependent on protein level. In situations in which CP is limiting, energy supplementation alone theoretically could worsen the CP deficiency and result in reduced intake, digestibility, and performance (Sanson et al., 1990).

Ruminal pH. Ruminal pH has received considerable attention as a mechanism explaining reductions in intake and forage digestibility resulting from energy supplementation. Moreover, Ulmer et al. (1990) demonstrated linear declines in 16- and 48-h in situ NDF digestion resulting from increasing barley supplementation. Work by Burgwald-Balstad et al. (1995), comparing concentrate- (80%) and forage- (100%) based diets offered for ad libitum consumption, reported considerable reductions and diurnal variations in ruminal pH associated with concentrate feeding and confirmed traditional thought based on data from the 1950s and early 1960s.

Mertens (1977) suggested that forage fiber digestion declined when ruminal pH fell below 6.7. Later, Ørskov (1982) and Mould et al. (1983) indicated that ruminal pH below 6.2 would reduce the activity of cellulolytic bacteria and digestion of straw, respectively. These researchers indicated that depressions in ruminal pH could be responsible for reductions in forage fiber digestibility associated with grain supplementation. Church (1979) suggested that ruminants consuming forage-based diets maintained ruminal pH between 6.2 and 6.8 whereas those consuming concentrates ranged from 5.8 to 6.6. Russell et al. (1979) and Russell and Dombrowski (1980) indicated that populations of cellulolytic bacteria diminish when pH ranges from 5.7 to 6.2, whereas soluble carbohydrate fermenting bacteria persist until ruminal pH ranges from 4.6 to 4.9. Sensitivity of ruminal bacteria to pH and shifting

Table 6. Influence of energy supplementation on digestibility

Animal	Digestibility			Author
	Supplement and amount	Basal diet	Total diet	
Beef steers	Corn; 0, .2, .4, and .6% BW	Summer Range		Pordomingo et al., 1991
Beef steers	Soybean hulls; 0, 15, 30, 45, and 60% of diet	Low-quality	96 h extent increased by .2% and decreased by .4 and .6% of BW	Grigsby et al., 1992
Beef steers	Soyhulls and corn; 12.5, 25, and 50% of DMI	Corn stalklage	Increased DMD, OMD, and NDFD	Anderson et al., 1988
Beef steers	Barley; 10, 30, and 50% of diet	Brome hay	Increased DMD, decreased NDFD	Leventini et al., 1990
Sheep	Corn; 0, 10, and 20 g/75 kg of diet daily	Wheat straw	Decreased DMD, decreased NDFD	Zorrilla-Rios et al., 1989
Beef steers and heifers	Corn 0, 5, and 10 g/75 kg of diet	Wheat straw	No effect on NDFD	Zorrilla-Rios et al., 1989
	Corn or corn gluten feed; 1% BW	Fescue pasture	Corn decreased OMD but corn gluten feed did not	Hannah et al., 1989
Beef steers	0, .5, or 1.0 kg grain based supplement daily	Winter wheat pasture	No effect	Branine and Galyean, 1995
Beef cows	.7 kg cracked barley daily	Native winter	No effect	Kartchner, 1981
	Corn; .25, .50, and .75% of BW	Low, medium, and high quality hay	Linearly increased DMD in all forages linearly, decreased NDFD in lambs fed low and medium hays	Matejovsky and Sanson, 1995
Beef steers	Alfalfa; .23, .47, .70 and .94% of BW daily	Tallgrass prairie hay	No effect DMD, NDF decreased	Vanzant and Cochran, 1994
Beef steers	Sorghum grain; 0, .17, .32, and .66%	Early growing Bluestem range	Decreased DMD, no effect on NDFD	Vanzant et al., 1990
Beef cattle	Corn grain and corn gluten feed	Grass hay diets	Both corn and corn gluten increased OM	Cordes et al., 1988
Beef steers	22.5 and 45% of ME requirement	Low-quality hay	Increased DMD by higher energy	DeCurto et al., 1990
Beef steers	.5 kg steam-flaked sorghum	Blue grama rangeland	Increased OMD digestion	Krysl et al., 1989
Beef calves	.45 or 1.36 kg corn	Irrigated pasture	Increased by 1.36 kg; no effect by .45 kg	Lake et al., 1974
Beef cows	Soybean hulls; 0, 1, 2, and 3 kg	Low-quality native hay	Increased OMD, ADFD; no effect on NDFD	Martin and Hibberd, 1990
Steers	Soybean hulls; 0, 15, 30, 45, and 60% of diet	Grass hay	Increased DMD, OMD, NDF	Grigsby et al., 1991
Steers	Beet pulp, barley, corn; 1.3 kg/hd daily	Grass hay	Pulp increased DMD, OMD; Corn; increased DMD, OMD and decreased NDGD, Barley decreased NDFD, ADFD	Carey et al., 1993
Cows	Corn; 1, 2, and 3 kg/d	Low-quality grass hay	Increased DMD, OMD while decreasing NDFD, ADFD	Chase and Hibberd, 1987
Cows	Corn; 1% BW	Tall fescue, pasture	No effect total DMD digestion	Hannah et al., 1989
Steers	Barley; .9, 1.8, and 2.7 kg/d	Grass hay	Increased DMD, OMD	Ulmer et al., 1990
Steers	Barley; 2.7 kg	Grass hay	No effect	Westvig, 1992

bacterial populations in response to reduced pH have been suggested as reasons for reduced intake and forage digestion by ruminants fed forage-based diets (Horn and McCollum, 1987). Although this may be the case in many instances, evidence exists for additional mechanisms. Table 7 includes several more recent data sets indicating that ruminal pH is not always reduced by grain supplementation.

When reviewing current data (Table 7) we find that cattle grazing summer range and supplemented with increasing levels of corn demonstrate no reduction in ruminal pH (Pordomingo et al., 1991). In fact, these researchers reported that ruminal pH averaged between 6.3 and 6.4, well above reported values that reduce intake and digestion of fiber components (Ørskov, 1982). Likewise, other researchers (Henning et al., 1980; Van der Linden et al., 1984) could not relate reductions in fiber digestibilities to reductions in the amount of time ruminal pH was below 6.0 and 6.5, respectively. Stockdale et al. (1987), working with dairy cows consuming pasture grass and supplemented with 0 to 10 kg of a high-energy pellet, also reported no reductions in ruminal pH. Conversely, with beef steers grazing early bluestem rangeland and supplemented with increasing levels of sorghum grain (0, .17, .32, and .66% of BW) linear reductions in ruminal pH have been reported (Vanzant et al., 1990). However, in that study, ruminal pH never fell below 6.4. Therefore, it is unlikely that decreases in ruminal pH could be solely responsible for reductions in DM digestibility reported, unless the data of Mertens and Loften (1980) were applicable to the data of Vanzant et al. (1990), suggesting that ruminal pH of less than below 6.7 could reduce fiber digestion. Moreover, in work on blue grama rangeland in northern New Mexico, Krysl et al. (1989) reported that supplementing steers with .5 kg of sorghum grain resulted in no effect on ruminal pH. However, in the study of Krysl et al. (1989) no differences were noted in OM digestion.

Work with penned ruminants fed various forages and supplemented with energy sources have yielded mixed results with regard to ruminal pH. Westvig (1992) fed steers medium-quality grass hay and supplemented with either 0 or 2.7 kg of barley and found that ruminal pH was below 6.0 for approximately 9 h. Although this certainly seems to indicate that ruminal function could be altered, other work from our laboratory has suggested little or no effect of increasing level of barley supplementation (0, .9, 1.8, and 2.7 kg/steer) daily on ruminal pH (Sime et al., 1990, 350-kg steers; Ulmer et al., 1990, 195-kg steers). Additionally, Carey et al. (1993) reported that ruminal pH patterns were the same in control or corn-supplemented (1.3 kg/steer daily) steers; however, in this study barley supplementation resulted in lower ruminal pH responses compared with controls.

Additional work with penned ruminants supplemented with barley (Zorrilla-Rios et al., 1989) and corn (Chase and Hibberd, 1987) has demonstrated reductions in ruminal pH in response to supplementation. However, in both of these studies ruminal pH never fell below 6.2, indicating that ruminal environment should not be detrimental to cellulolytic bacteria (Ørskov, 1982). However, if the more conservative threshold pH levels suggested by Mertens (1977) are correct, then microbial populations may have been affected by supplementation levels in the above studies.

Several studies have shown a reduction in ruminal pH resulting from energy supplementation. Leventini et al. (1990) demonstrated a reduced ruminal pH (below 6.0 for 9 h) with increasing levels of barley supplementation (10, 30, and 50% of DMI). Differences in these results compared with others cited above may be explained by level of supplement provided. The work of Leventini et al. (1990) contained levels of barley supplementation that resulted in diets that could be described as a 50% concentrate. One would expect these levels of grain to reduce ruminal pH. Horn and McCollum (1987) suggested that intakes of grain supplements of levels of less than 30 g/kg metabolic body weight would not greatly alter forage intake or, presumably, ruminal function.

Supplementation with a readily degradable fiber source has been suggested as an option for maintaining ruminal stability in regard to fiber digestion (Horn and McCollum, 1987), ruminal pH, and minimizing intake reductions associated with grain supplementation. In the work of Carey et al. (1993), beet pulp was also included as a supplement (1.3 kg/steer daily). Their results suggest that ruminal pH patterns associated with beet pulp supplementation more closely resemble those of barley supplementation than those of control steers (196 kg). Other work with soybean hulls (Anderson et al., 1988; Martin and Hibberd, 1990; Grigsby et al., 1992) has suggested that at higher levels of supplementation, ruminal pH can be reduced.

It seems that energy supplementation from grains can reduce ruminal pH levels (Sanson et al., 1990). However, current data clearly suggest that responses are not consistent and that at times ruminal pH is not greatly affected by grain supplementation, especially at moderate to low levels of supplementation. Use of readily degradable fiber sources as energy feeds has yielded production responses similar to those to grain supplements (Anderson et al., 1988). Their impact on ruminal pH is less defined and seems to be related to level of supplementation. In the case in which energy supplements, regardless of source, begin to substitute for large amounts of basal forage, reductions in ruminal pH and, hence changes in ruminal environment, often occur. At lower levels of supplementation, responses are much less predictable. It seems that some of the data indicate that decreases in forage

Table 7. Influence of energy supplementation on ruminal pH

Animal	Supplement	Basal diet	Influence on ruminal pH	Author
Beef steers	Corn: .2, .4, and .6% BW	Summer range	No effect, averaged 6.3 to 6.4	Pordomingo et al., 1991
Beef steers	Soybean hulls: 0, 15, 30, 45, and 60% of diet	Low-quality bromo	Linear decline, none below 6.1	Grigsby et al., 1992
Beef steers	Soybean hulls and corn	Corn stalklage	Rapid decline with corn; gradual decline with soy hulls	Anderson et al., 1988
Beef steers	Barley: 10, 30, and 60% of DMI	Bromo hay	Decreased pH 6 hours below 6.0	Leventini et al., 1990
Sheep	Whole corn: 0, 10, and 20 g/.75 kg diet	Straw	Decreased linearly at 4 & 12 h post feeding. Never below 6.2	Zorrilla-Rios et al., 1989
Dairy cows	0-10 kg high energy pellet; wheat or barley	Pasture grass	No effect	Stockdale et al., 1987
Beef steers	0, .5, and 1.0 kg of grain based equipment	Winter wheat pasture	No effect, ranged 5.3 to 6.5	Branine and Galyean, 1995
Beef steers	Sorghum grain: 0, .17, .32, and .66% BW	Early growing Bluestem range	Linear decrease. Lowest 6.45	Vanzant et al., 1990
Beef steers	Increasing levels of corn: 0, 2, and 4 g of starch/kg of BW	Grass hay	Reduced pH, below 6.0 for 8 h	Sanson et al., 1990
Beef cows	Corn grain: 0, 1, 2, and 3 kg/hd daily	Low-quality grass hay	2 and 3 kg reduced pH for 9 h; however never below 6.2	Chase and Hibberd, 1987
Beef cattle	Corn grass or corn gluten feed	Grass hay	No effect	Cordes et al., 1988
Beef steers	22.5 and 45% of ME requirement	Low-quality hay	High level reduced pH, lowest 6.4	DeCurto et al., 1990
Beef steers	Steamed-flaked sorghum: .5 kg	Blue grama rangeland	No effect	Krysl et al., 1989
Beef cows	Soybean hulls: 0, 1, 2, and 3 kg	Low-quality native hay	Reduce pH at high levels. Never below 6.2	Martin and Hibberd, 1990

Table 8. Influence of energy supplementation on livestock production

Animal	Supplement	Basal diet	Response	Author
Beef cows	3.9 kg barley/hd daily	Summer range	No effect	Bellows and Thomas, 1976
Dairy cows	High-starch vs high-fiber	Ryegrass pasture	High-fiber supplement increased forage intake and milk production	Meijs, 1986
Beef steers and heifers	Soybean hulls or corn	Bromo and corn residue	Both supplements increased daily gains	Anderson et al., 1988
Stocker cattle	Soyhulls and wheat midds vs corn .75 to 1% BW	Wheat pasture	Gains increased by soy hulls and midds	Horn et al., 1991
Calves	Corn	Ryegrass	Increased gain	Grigsby et al., 1991
Beef cows	Alfalfa at .48, .72 or .96% of BW daily	Big Bluestem	Reduced wt loss, reduced condition loss, heavier calves, shorter interval to conception	Vanzant and Cochran, 1994
Beef cows	Corn vs protein	Sandhulls range	Corn-supplemented cows lost more wt; no effect on reproduction performance	Sanson et al., 1990
Pregnant cows	10, 20, 40% required DE	Native range	Reduced BW loss, reduced body condition loss, increased calf weaning wt	Huston et al., 1993
Steers	.5% BW corn	Bermudagrass	Increased ADG	Goetsch et al., 1991
Cows	To provide 9.4 Mcal ME/d	Winter range	Decreased BW loss, decreased BCS change	Heldt et al., 1995
Heifers	.5, .75, and 1.0 kg corn/heifer daily	Native flow meadow	No response	Angell et al., 1995
Heifers	.77, 1.53, and 2.31 kg corn/heifer daily	Alfalfa cubes	Increased BW gain and ADG	Paisley et al., 1995

digestibility associated with energy supplementation can occur independent of suppression of ruminal pH. Research in this area seems warranted.

Livestock Production. Most reports evaluating production characteristics have demonstrated improvements resulting from energy supplementation, regardless of source of energy (Meijs, 1986; Anderson et al., 1988; Horn et al., 1991; Grigsby et al., 1991; Vanzant and Cochran, 1994). These improvements are most often in the form of reduced weight loss, reduced body condition score loss, and(or) increased gains. At moderate levels of supplementation, improved reproductive performance has been difficult to achieve (Table 8). However, Vanzant and Cochran (1994) reported shorter interval to conception in cows grazing bluestem range and supplemented with alfalfa. In addition, Sanson et al. (1990) reported that corn supplementation of cows grazing sandhills rangeland resulted in greater weight loss than protein supplementation. The majority of the data suggests that energy supplementation either has no effect on production or reduces weight and body condition score loss in cows. In growing cattle, weight gains are often improved by energy supplementation.

Implications

Providing supplemental energy to grazing ruminants often improves production when measured as weight or body condition score change. Work defining energy requirements for grazing livestock needs to be conducted. Application of values generated in pen feeding situations to a grazing environment can present theoretical and practical concerns. Forage intake and digestibility are often affected by energy supplementation. Usually these effects are reduced intake and digestibility; however, in certain situations low levels of energy supplementation may increase forage intake and digestibility. Although it seems logical to conclude that reductions in ruminal pH associated with grain supplementation should explain reductions in forage digestibility and intake, only a portion of the data support this theory. Additional work in this area seems warranted.

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