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Title: Influence of Protein Supplementation Frequency on Cows Consuming Low-quality Forage: Performance, Grazing Behavior, and Variation in Supplement Intake.

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Abstract approved:

David W. Bohnert

Our objective was to determine the influence of CP supplementation frequency (**SF**) on cow performance, grazing time, distance traveled, maximum distance from water, cow distribution, DMI, DM digestibility, harvest efficiency (**HE**), percentage of supplementation events frequented, and CV for supplement intake for cows grazing low-quality forage. One hundred-twenty pregnant (approx. 60 d) cows (467 ± 4 kg BW) were used in a 3 x 3 Latin square for one 84-d period in each of 3 yr. Cows were stratified by age, body condition score (**BCS**), and weight and assigned randomly to one of three 810-ha pastures. Treatments (**TRT**) included an unsupplemented control (**CON**) and supplementation every day (**D**; 0.91 kg; DM basis) or once every 6 d (**6D**; 5.46 kg; DM basis) with cottonseed meal (43% CP; DM basis). Four cows from each treatment (each year) were fitted with global positioning system collars to estimate grazing time (h/d), distance traveled (m/d), maximum distance from water (m/d), cow distribution (percentage of ha occupied•pasture^{-1}•yr^{-1}), and percentage of supplementation events frequented. Collared cows were dosed with intraruminal n-alkane controlled-release devices on d 28 for estimation of DMI (g•kg BW^{-1}•d^{-1}), DM digestibility (%), and HE (g DMI•kg BW^{-1}•min $grazing^{-1}$). Additionally, Cr_2O_3 was incorporated into CSM on d 36 at 3% of DM for use as a digesta flow marker to estimate the CV for supplement intake (%). Cow weight and BCS change were more positive ($P \leq 0.03$) for supplemented TRT compared with CON. No weight or BCS differences ($P \geq 0.14$) occurred between D and 6D. Grazing time was greater ($P = 0.04$) for CON compared with supplemented TRT with no difference ($P = 0.26$) because of SF. Distance traveled, maximum distance from water, cow distribution, DMI, DM digestibility, and HE were not affected ($P \geq 0.16$) by CP supplementation or SF. The percentage of supplementation events frequented and the CV for supplement intake were not affected ($P \geq 0.22$) by SF. Results suggest that providing CP daily or once every 6 d to cows grazing low-quality forage increases weight and BCS gain while decreasing grazing time. Additionally, cow distribution, DMI, and HE may not be affected by CP supplementation or SF.

Key words: Rangeland, Cattle, Sagebrush Steppe, Distribution

Influence of Protein Supplementation Frequency on Cows Consuming Low-quality Forage: Performance, Grazing Behavior, and Variation in Supplement Intake

by
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Christopher S. Schauer, Author

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CONTRIBUTION OF AUTHORS

In Chapter 2, D.C. Ganskopp provided global positioning collars, assisted with experimental design, assisted with data collection, and aided in interpretation of data. Additionally, C.J. Richards provided n-alkane analysis and aided in interpretation of dry matter intake data and S.J. Falck assisted with data collection.

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CHAPTER 1: LITERATURE REVIEW

Introduction

Many cattle in the western United States consume low-quality forage (< 6% crude protein; DM basis) from late summer through winter; consequently, supplementation with crude protein (**CP**; nitrogen % x 6.25) is necessary to maintain or increase cow body weight and condition score (Clanton and Zimmerman, 1970). Annual winter-feed and supplementation costs in the intermountain west often total $100 to 200 per cow, including the cost of labor and equipment associated with supplement delivery.

Decreasing the frequency of CP supplementation is a management practice that decreases labor costs. Melton and Riggs (1964) suggested that providing a supplement twice per week resulted in savings of approximately 60% in labor and travel compared with daily supplementation. Additionally, research has shown that CP supplements can be fed at infrequent intervals while maintaining acceptable levels of performance (McIlvain and Shoop, 1962; Huston et al., 1999b; Bohnert et al., 2002b). Bohnert et al. (2002b) suggested that the ability of ruminants to conserve N between infrequent supplementation events may be linked to changes in permeability of the gastrointestinal tract to urea-N and[or] renal regulation of urea excretion.

Grazing time has been reported to decrease by 1.5 h/d for supplemented compared with unsupplemented cows (Barton et al., 1992; Krysl and Hess, 1993). Additionally, Bailey et al. (2001) demonstrated that supplement placement can be used to modify livestock distribution. However, little research has evaluated the effects of infrequent supplementation of CP on cow grazing behavior and pasture distribution. Therefore, our objectives were to determine whether infrequent supplementation of CP to cows grazing low-quality forage affects cow performance, grazing time, distance traveled, maximum distance from water, within pasture distribution, percentage of supplementation events frequented, forage intake, harvest efficiency, and variation in supplement intake.

Crude Protein Supplementation

Protein Supplement Sources

Sources of supplemental protein can be broken down into degradable intake protein (**DIP**) and(or) undegradable intake protein (**UIP**). Degradable intake protein provides NH_3 for ruminal bacteria through the degradation of protein, peptides, amino acids, amides, urea, nitrates, and some other non-protein nitrogen compounds by ruminal microbes (NRC, 1985; 1996; 2001). Feedstuffs such as alfalfa, soybean meal, and cottonseed meal (88, 80, and 57 % DIP, respectively; CP basis; NRC, 1996) tend to contain high levels of DIP. Sources of UIP provide intact proteins, peptides, and amino acids to the small intestine for enzymatic degradation and absorption (Chalupa, 1975; NRC, 1996; 2001). Proteins of plant or animal origin that have been heat or chemically treated (Chalupa, 1975) tend to have increased levels of UIP compared to non-heat or chemically treated proteins. Examples of UIP include blood meal, corn gluten meal, and feather meal (75, 62, and 70% UIP, respectively; CP basis; NRC, 1996). Most forms of supplemental protein contain proportions of both DIP and UIP.

Non-protein nitrogen (**NPN**) is an inexpensive DIP source that can provide nitrogen (**N**) for use by rumen microbes. Helmer and Bartley (1971) noted that ruminant nutritionists have known since the late 1800's that ruminants can convert NPN to protein. Common sources of NPN include urea $[(NH_2)_2CO]$ and biuret $[(NH_2)_2(CO)_2NH]$. Because of its high N content (47%) and low cost per unit N, urea is an attractive supplemental N source, however, it is very soluble in water and rapidly hydrolyzes to NH_3 within the rumen. This can result in urea toxicity if too much urea is consumed in a short period of time, thereby exceeding the ability of ruminal microbes to assimilate NH_3 into microbial CP (Raleigh and Wallace, 1963; Helmer and Bartley, 1971; Bartley et al., 1976). Current suggestions for use of urea in ruminant diets include: 1) it should not constitute more than 3% of a concentrate mix; 2) it should be less than 1% of the total diet; 3) it should not provide more than one-third of the total CP in the diet (Chalupa, 1968). Additionally, Helmer and Bartley (1971) suggest daily urea intake should not exceed 0.30 g/kg BW. Biuret (41% N) is an alternative source of NPN that is not soluble in water and is degraded to NH_3 at a slower rate than urea (Fonnesbeck et al., 1975). Therefore, because biuret does not exhibit the toxic effects often observed with urea, it can be incorporated into supplements at a higher concentration than urea (Hatfield et al., 1959). Research suggests that biuret supplementation results in N efficiency and performance similar to urea (Hatfield et al., 1959; Fonnesbeck et al., 1975; Currier et al., 2003b), however, it is more expensive per unit N.

Performance

The first reported evidence that food N was an essential nutrient to animals occurred in 1816. Francois Magendie (1816) documented that dogs fed purified diets of sugar and fat were deficient in N. Since then, CP supplementation of ruminants consuming low-quality forage and(or) roughage deficient in N has been studied extensively. In 1917, a cooperative study to determine the CP requirements for cattle was undertaken by the National Research Council (**NRC**; Maynard, 1937) and results reported in two NRC bulletins (Armsby, 1921; Forbes, 1924). While the results were considered of limited scientific value (Maynard, 1937), they helped set the foundation for future studies in protein nutrition of cattle.

Recent research with ruminants consuming low-quality forage has focused on quantifying the body weight (**BW**) and body condition score (**BCS**; Herd and Sprott, 1986) change derived from CP supplementation. The benefits most often observed from CP supplementation are reduced BW and BCS losses compared with no supplementation (Appendix Table 1). DelCurto et al. (1990b) supplied isonitrogenous quantities of supplements with increasing levels of CP to cows grazing dormant tallgrass prairie and reported a linear decrease in cow BW loss as supplemental CP concentration increased during the 120 d prior to calving. Cows consuming 39% CP supplements lost less weight and BCS than cows provided 25% CP supplements, with both treatments losing less weight and BCS than cows receiving 13% CP supplements. Also, Horney et al. (1996) fed gestating cows tall fescue straw supplemented with either tall fescue hay or alfalfa hay on an isonitrogenous basis and noted supplemented cows gained more BW than nonsupplemented cows, with no difference between supplemented treatments. Similarly, Bohnert et al. (2002b) provided supplemental protein to cows consuming meadow hay (5% CP) and noted that pre- and post-calving weight and BCS change were greater for supplemented groups than for controls.

The positive changes in cow BW and BCS often observed with CP supplementation can lead to improvements in reproductive efficiency (Clanton and Zimmerman, 1970). Sasser et al. (1988) noted that reduced protein intake increased the postpartum interval to first estrus, first service, and conception, as well as decreasing the total number of cows showing estrus and conceiving.

Crude protein requirements for a 545 kg cow (moderate milking ability) during the first, second, and third trimester have been determined to be 8.6, 6.2, and 7.8% CP, respectively (12.1, 11.0, 11.0 kg/d dry matter intake, respectively; NRC, 1996). Favorable BW and BCS change can be expected with supplemental CP when the basal forage contains less than these concentrations (6 – 8% CP). Additionally, CP supplementation can increase forage intake and nutrient utilization.

Forage Intake and Nutrient Utilization

Forage Intake. Research in the 1960's focused on evaluating the effects of ruminal or post-ruminal infusion of urea or casein on forage intake (Appendix Table 2). Campling et al. (1962) noted that urea infused into the reticulo-rumen at 25, 75 or 150 g/d increased intake of low-quality straw (26, 40, and 40% above an unsupplemented control, respectively). Similarly, Egan (1965) and Egan and Moir

(1965) reported that infusion of casein or urea into the duodenum increased intake of low-quality forage; however, casein appeared to yield a more consistent response than urea. Since then, the effects of supplemental CP on forage intake have been reported with mixed results. Increased forage intake due to CP supplementation has been reported by multiple researchers (Appendix Table 2). McCollum and Galyean (1985) reported a 27% increase in prairie hay intake when cottonseed meal (**CSM**) was supplemented to steers. Similarly, Krysl et al. (1987) increased prairie hay intake 19% when ewes consuming low-quality forage were supplemented with CSM. Köster et al. (1996) ruminally infused increasing levels of DIP and reported an increase in forage organic matter intake (**OMI**) compared with an unsupplemented control. In a similar trial, Bandyk et al. (2001) noted an increase in hay OMI when supplemental DIP was provided ruminally or postruminally (62 and 28%, respectively) compared with an unsupplemented control. Supplement CP concentration may also affect forage intake. DelCurto et al. (1990a) provided supplements containing increasing levels of CP (provided on an isonitrogenous basis) to steers consuming dormant bluestem hay and increased forage dry matter intake (**DMI**) by 34% with CP supplementation. However, 41 and 28% CP supplements increased forage intake by 70 and 42%, respectively, compared with a 12% CP supplement (DelCurto et al., 1990a).

Researchers have also demonstrated that CP supplementation may have no affect on forage intake by ruminants consuming low-quality forage (Ferrell et al., 1999; Bohnert et al., 2002a, 2002b). Ferrell et al. (1999) reported no increase in forage DMI when urea, soybean meal (**SBM**), or blood meal/feather meal were provided to wethers consuming bromegrass hay. Similarly, Bohnert et al. (2002a, 2002b) noted no increase in low-quality forage intake by steers and lambs fed CP supplements. The difference in results concerning the affect of CP supplementation on forage DMI may be explained by differences in intake of total digestible nutrients (**TDN**), protein status of the animal, and(or) neutral detergent fiber (**NDF**) intake. Moore et al. (1999) reported in a review that supplements (either protein or energy) decreased voluntary forage intake (**VFI**) when supplemental TDN intake was > 0.7% of BW (high grain supplements), forage TDN:CP ratio was < 7 (adequate dietary CP), or forage OM intake was > 1.75% of BW. When forage TDN:CP ratio was > 7 (CP deficit diet) supplements increased VFI. In contrast, Mertens (1985, 1994) proposed that NDF intake may be the most important factor influencing forage intake of ruminants fed low-quality forage. He suggested that a forage intake response to CP supplementation could be expected when NDF intake is less than 12.5 g•kg BW^{-1}•d^{-1}. McCollum and Galyean (1985), DelCurto et al. (1990a), Köster et al. (1996), and Bandyk et al. (2001) reported NDF intake of unsupplemented controls was 11.4, 6.4, 5.1, and 8.2 and increased with CP supplementation to a maximum of 14.6, 14.3, 11.3, and 13.3 g•kg BW^{-1}•d^{-1}, respectively. In studies where CP supplementation had no affect on forage intake, NDF intake of unsupplemented controls was 13.0, 13.9, and 12.5 g•kg BW^{-1}•d^{-1} (Ferrell et al., 1999; Bohnert et al., 2002a, 2002b, respectively). Supporting these results, Mathis et al. (2000) evaluated low-, medium-, and high-quality forages (4.3, 5.9, and 8.2% CP, respectively) with ruminally infused sodium caseinate at 0, 0.41, 0.82, and 0.124% BW/d. Neutral detergent fiber intake for unsupplemented high- and medium-quality forage fed steers was 17.6 g•kg BW^{-1}•d^{-1}, with CP supplementation exhibiting no affect on forage intake. However, when low-quality forages were fed, NDF intake without supplementation was 10.4 g•kg BW^{-1}•d^{-1}; consequently, forage intake increased by 33% with CP supplementation. The results of these trials appear to indicate that NDF intake may be the most significant factor influencing the affect of CP supplementation on intake of low-quality forage. However, Owens et al. (1991) proposed that rumen fill and distension resulting from NDF intake may not be limiting forage intake. A theory proposed by Owens et al. (1991) is that increased N recycling during N deficiency affects forage intake. The affects of N recycling during N deficiency will be discussed further in the "Nitrogen Recycling" section. Regardless, the affects of CP supplementation on forage intake are complex and a more thorough discussion of nitrogen utilization, metabolic responses, and nutrient utilization is warranted.

Nitrogen Utilization. Protein ingested by ruminants can be divided into DIP and UIP. Degradable intake protein is that protein which is broken down by ruminal microorganisms and UIP is the remaining protein that passes through the rumen to the small intestine for enzymatic digestion and potential absorption (NRC, 1985; 1996; 2001). The N which enters the small intestine is a combination of microbial CP, UIP, and endogenous protein (which has been sloughed from the gastrointestinal tract). For ruminants consuming low-quality forage, microbial CP provides the majority of the N flowing to the small intestine (Hannah et al., 1991; Köster et al., 1996; Bohnert et al., 2002a).

The ability of ruminal microorganisms to grow and reproduce is largely a function of the availability of DIP (Hannah et al., 1991; Köster et al., 1996; Bohnert et al., 2002a). The principle N sources for growth and reproduction of ruminal microorganisms are supplemental DIP and(or) recycled urea (from digested and absorbed UIP, mobilized tissue protein, or digested and absorbed microbial protein; Allison, 1969; Tillman and Sidhu, 1969; Harmeyer and Martens, 1980). These N sources are degraded to NH_3 within the rumen. Mercer and Annison (1976) estimated that 50 to 80% of rumen microbial CP is derived from NH_3. Providing supplemental CP to ruminants consuming low-quality forage increases total N, bacterial N, and nonammonia-nonmicrobial N flow to the small intestine (Appendix Table 3). Additionally, intestinal N disappearance and total tract N digestibility is usually increased with supplemental CP (Köster et al., 1996; Bohnert et al., 2002b). When DIP and(or) recycled N are deficient, microbial CP production is limited and may not meet the N requirements of the host animal. Additionally, when DIP is limiting microbial growth, fiber digestibility may be depressed, which can decrease forage intake due to an increase in ruminal fill and(or) decreases in ruminal fluid and particulate passage rates (Kartchner, 1980; Köster et al., 1996).

In addition to N requirements, ruminal bacteria require energy for growth. The affect of CP supplementation on microbial efficiency (g microbial N/kg OM truly digested) has been variable (Appendix Table 4). Some results have indicated no affect of CP supplementation on microbial efficiency, with a range of 7.7 to 19.7 g microbial N/kg OM truly digested (Stokes et al., 1988; Krysl et al., 1989; Lintzenich et al., 1995). However, other researchers have demonstrated an increase in microbial efficiency due to CP supplementation (Köster et al., 1996; Bohnert et al., 2002a). Köster et al. (1996) reported that microbial efficiency increased from 12 to 20 g microbial N/kg OM truly digested when 0 and 720 g/d sodium caseinate were ruminally infused, respectively. Similarly, Bohnert et al. (2002a) increased microbial efficiency from 20 to a maximum of 32 g microbial N/kg OM truly digested when DIP supplements were provided. It is of interest to note the difference in values between trials. In the research by Bohnert et al. (2002a), microbial efficiency values are approximately 200% greater than those reported by Stokes et al. (1988), Krysl et al. (1989), Olson et al. (1994), Lintzenich et al. (1995), and Köster et al. (1996). A possible reason for this discrepancy is a difference in the procedures used in determining the purine content of ruminal bacteria and ruminal digesta. Bohnert et al. (2002a) utilized a modification (Makkar and Becker, 1999) of the Zinn and Owens (1986) procedure. The Makkar and Becker (1999) modification improves purine recovery by approximately 100% for samples containing matrices of cellulose, starch, NDF, and(or) undigested hay residue when compared to the original Zinn and Owens (1986) procedure. Because of this discrepancy, care should be taken when comparing results between trials, as data obtained using the non-modified Zinn and Owens (1986) procedure may under-estimate microbial efficiency by 50%. Additionally, the NRC (1996) was developed using microbial efficiencies based on the Zinn and Owens (1986) procedure. Therefore, it may under-estimate the ability of ruminants to utilize DIP when consuming low-quality forage.

Ruminal NH_3 and Volatile Fatty Acid Response. Crude protein supplementation of ruminants consuming low-quality forage consistently increases ruminal NH_3 concentration (Appendix Table 5). As discussed previously, the ability of ruminal microorganisms to grow and reproduce is largely dependant on the availability of ruminal NH_3. Maximum growth of ruminal microorganisms occurs when ruminal NH_3 is between 2.94 and 12.94 mM (Satter and Slyter, 1974; Mehrez et al., 1977; Slyter et al., 1979). When ruminal NH_3 is below this concentration, supplementation with CP should increase microbial growth, thereby increasing N flowing to the small intestine and, possibly, increasing forage digestibility.

In addition to ruminal NH_3 requirements for growth, the ability of celluloytic microorganisms to degrade fiber is also dependant on non-cellulolytic bacteria and their ability to produce volatile fatty acids (**VFA**; Yokoyama and Johnson, 1988). Some non-cellulolytic bacteria species produce branch-chain VFA (**BCVFA**) from the deamination of amino acids (valine, isoleucine, leucine, and proline; Leng, 1973). Theoretically, when bacteria are deficient in N, supplemental DIP should increase BCVFA and total VFA production. Hannah et al. (1991) increased total VFA when steers consuming bluestem range were provided CP supplements. Similarly, Lintzenich et al. (1995) and Köster et al. (1996) increased total VFA when low-quality forages were supplemented with CP. In addition to increasing total VFA, Mathis et al. (1999, 2000) increased the proportions of BCVFA when supplemental CP was provided to steers consuming prairie hay. However, other researchers have observed no increase in total and BCVFA production (McCollum and Galyean, 1985; Krysl et al., 1989). Differences in results may be attributable to increases in ruminal fluid dilution rate and liquid volume due to CP supplementation (Bohnert et al., 2002c).

Nutrient Digestibility. Crude protein supplementation of livestock consuming low-quality forages has generally increased OM and NDF disappearance from the stomach and total tract (Appendix Table 6). McCollum and Galyean (1985) reported that in vitro dry matter digestibility (**IVDMD**) of prairie hay increased after 6, 12, 18, and 24 h when rumen fluid from CSM supplemented steers was used as the inoculum compared with inolculum from unsupplemented steers. Similarly, Caton et al. (1988) supplemented CSM to steers grazing dormant blue grama rangeland and noted in vitro OM digestibility (**IVOMD**) and in situ NDF disappearance increased (6 and 19%, respectively) compared with unsupplemented controls. Beaty et al. (1994) increased total tract DM and NDF digestibility by steers consuming wheat straw and provided supplemental CP compared with those not provided supplemental CP. Similar results were reported by Mathis et al. (1999). They increased total tract OM and NDF digestibility with increasing quantities of supplemental CP compared to an unsupplemented control, however, increases in digestibility reached a plateau when supplemental SBM reached 0.33% BW/d (DM basis; Mathis et al., 1999). When supplemental CP was provided as DIP and(or) UIP, digestibility of DM, OM, and NDF increased in wethers and steers consuming meadow hay (Bohnert et al. 2002a, 2002b) . In contrast, research has also suggested that CP supplementation may have no affect on digestibility of low-quality forages (Spragg et al., 1986; Mathis et al., 2000). Spragg et al. (1986) supplemented CSM to heifers consuming alkali-treated oat straw and reported no affect on total tract OM digestibility. In research reported by Mathis et al. (2000), total tract digestion of OM and NDF was not affected by ruminal infusion of sodium caseinate when forage containing 8 or 6% CP was fed to steers, however, when forage quality decreased to 4% CP, total tract digestion of OM and NDF increased with sodium caseinate infusion. Results from Mathis et al. (2000) support Peterson (1987), who suggested that increases in digestibility of low-quality forages, and subsequently increases in forage intake, may largely be the result of improved N availability for the ruminal microflora.

Nitrogen Recycling

Ruminants have the ability to utilize endogenous urea-N as a source of supplemental DIP (NRC, 1985). This is the result of N recycling; the absorption of NH_3 from the rumen or small intestine into the portal blood, the conversion of NH_3 to urea-N in the liver, and the recycling of urea-N to the rumen and saliva for eventual use by rumen microorganisms.

Ammonia Absorption

In the rumen, ammonia is present either as ammonium (**NH_4^+**) or ammonia (**NH_3**), with the majority present as NH_4^+ (because normal ruminal pH is lower than the ammonium-ammonia pKa; 9.24). However, for the purpose of this discussion, I will refer to both forms as "ammonia". Much of the NH_3 present in the rumen is of feed (the result of CP hydrolysis by bacteria) or endogenous (degraded sloughed cells or urea-N recycled from the liver through the rumen epithelium or in saliva; Owens and Zinn, 1988) origin. Ammonia production in the rumen has been estimated at 17 to 84% of dietary N intake (Mercer and Annison, 1976). In the rumen, urea-N and protein/peptides are hydrolyzed by rumen bacteria into NH_4^+ and passively absorbed across the rumen or small intestine epithelium into the portal blood as NH_3, and protonated to re-form NH_4^+ in the portal blood (Huntington and Archibeque, 1999). Additionally, Parker et al. (1995) reported alternative methods of NH_3 absorption across the rumen wall, such as association with bicarbonate or VFA anions.

Huntington and Archibeque (1999) reported in a review that the amount of N absorbed as NH_3 is equivalent to 16 to 73% of N intake, with absorption from the small intestine accounting for 27 to 51% of net uptake of NH_3 into the portal vein (Cocimano and Leng, 1967; Parker et al., 1995). Following absorption, NH_3 is transported via the portal vein to the liver for conversion to urea-N (Tillman and Sidhu, 1969).

Urea Metabolism

The ability of ruminants to convert NH_3 into urea-N prevents NH_3 accumulation in the peripheral blood and, subsequently, NH_3 toxicity (Huntington and Archibeque, 1999). The majority of urea-N production occurs in the liver via the enzymes of the ornithine cycle (Krebs and Henseleit, 1932) and enzymes catalyzing transamination reactions (Katz, 1992), however, a minor pathway for production is present in the kidneys (Emmanuel, 1980). Harmeyer and Martens (1980) reported that approximately one half of urea-N production originates from free NH_3, with aspartate donating the remainder of N in the conversion of cirtulline to arginine. However, recent studies by Lobley et al. (1995, 1996) indicate that from 59 to 70% of urea-N is derived from NH_3. Lewis et al. (1957) found that the liver was able to quantitatively convert absorbed NH_3 to urea-N until the NH_3 concentration in the portal blood reached 0.8 mM. Recently, Huntington et al. (1996) reported that production of urea-N increased when greater amounts of concentrates were fed, suggesting an energy requirement for urea-N production. Additionally, Huntington et al. (1996) proposed that renal production of urea-N (to maintain osmotic gradients needed for reabsorptive function) may contribute to urea-N production and recycling, especially as the level of concentrate increases in the diet.

Urea Recycling

Urea-N enters the peripheral blood stream following urea-N production in the liver. Kennedy and Milligan (1978) estimated that 26 to 72% of plasma urea-N was derived from rumen NH_3, suggesting a strong relationship between concentrations of plasma urea-N and rumen NH_3 (Egan and Kellaway, 1971). In the peripheral blood, plasma urea-N has two possible destinations: excreted in the urine as urinary urea-N, or recycled through the peripheral blood to the rumen, post-rumen GIT, or saliva (Cocimano and Leng, 1967).

Read (1925) was the first to demonstrate net urea-N retention by fore-gut fermenters. He reported pregnant camels fed a low-protein diet had practically no urea-N in the urine. Huntington and Archibeque (1999) reported in their review that urinary urea-N excretion accounts for 25 to 60% of endogenous urea-N production in goats, sheep, beef heifers, and beef steers. Renal excretion of urea-N is increased when N intake is at or above an animal's requirements and is reduced when N intake is below requirements (Harmeyer and Martens, 1980). Also, Harmeyer and Martens (1980) reported that the quantity of urea-N excreted by the kidneys may be influenced by three factors: 1) changes of urea-N concentration in plasma and corresponding changes in filtered urea load; 2) changes in glomerular filtration rate; and 3) changes in tubular resorption of urea-N. Schmidt-Nielsen et al. (1957) and Schmidt-Nielsen and Osaki (1958) reported that in camels and sheep with adequate N intake, 40% of urea-N filtered by the glomeruli was excreted in the urine, however, when a N deficient diet was fed, excretion of urea-N fell to 1 to 2%. Additionally, Marini and Van Amburgh (2003) found that renal clearance of urea-N decreased with decreasing dietary N. These results indicate that during periods of N deficiency, ruminants have the ability to decrease renal excretion of urea-N, thereby maintaining N status and ruminal fermentation through increased N recycling to the gastrointestinal tract (**GIT**).

Recycling of urea-N, via saliva, to the rumen of sheep was first reported by McDonald (1948). Huntington and Archibeque (1999) reported in a review that between 15 and 94% of recycled urea-N may be recycled through the saliva. Salivary urea-N concentration is approximately 60% of plasma urea-N concentration (Bailey and Balch, 1961b), with salivary urea-N accounting for over 82% of the total N in saliva (Bailey and Balch, 1961a). Some research suggests that elevated ruminal NH_3 concentrations can depress salivary flow (Oltjen et al., 1969), however, Kennedy and Milligan (1980) suggest that salivary secretions are more likely related to intake and the amount of forage in the diet.

Houpt (1959) reported that urea-N diffused across the ruminal wall of goats. It is commonly thought that urea-N is diffused across the rumen wall from the blood (Bunting et al., 1989) and is subsequently hydrolyzed into NH_3 (Owens and Bergen, 1983). The free NH_3 is then trapped in the rumen by conversion to NH_4^+ (Owens and Bergen, 1983). However, recent research suggests that urea transporters may play a role in carrier mediated (facilitative type) transfer of urea-N across the rumen epithelium (Ritzhaupt et al., 1997; 1998; Marini and VanAmburgh, 2003), but the direction of transfer (into or out of the rumen) is not clear.

Kennedy and Milligan (1978) reported a negative relationship between the rate of plasma urea-N transfer to the rumen and ruminal NH_3 concentration, however, a positive relationship existed for the rate of plasma urea-N transfer to the rumen and plasma urea-N concentration and OM digestion in the rumen. Huntington (1989) reported that increasing the intake of readily fermentable carbohydrate, at the expense of N and fiber, increased the percentage of urea-N recycled to the GIT and focused recycling to the rumen (versus saliva and post-ruminal). Marini and Van Amburgh (2003) increased gastrointestinal clearance of urea-N (rate of transfer of urea-N to the GIT per unit of plasma urea-N concentration) by decreasing N in the diet. In addition to diffusion of plasma urea-N across the rumen wall, evidence exists that plasma urea-N can diffuse across the intestinal wall and be used by micro-organisms for post-ruminal growth (Cocimano and Leng, 1967). Following transfer of plasma urea-N into the GIT, NH_3 is available for assimilation by bacteria.

Ammonia Assimilation

The utility of the N recycling process (rumen $NH_3 \rightarrow$portal blood $NH_3 \rightarrow$blood urea-N$\rightarrow$rumen NH_3) is that ruminal microbes can incorporate recycled NH_3 into microbial CP, which is then available as a N source to the host animal. Ammonia assimilation by rumen microbes occurs through three possible pathways: 1) Glutamate dehydrogenase; 2) Glutamine synthetase/Glutamate synthase (**GS-GOGAT**); and 3) Asparagine synthetase (Allison, 1969). Glutamate dehydrogenase is the principle means of NH_3 assimilation and occurs when ruminal NH_3 concentrations are high (> 2 mM). When ruminal NH_3 concentrations are below 2 mM, GS-GOGAT becomes the primary method of NH_3 assimilation. Asparagine synthase is another minor pathway for NH_3 assimilation by bacteria. Mercer and Annison (1976) and Hristov and Broderick (1994) determined that 50 to 80% of microbial CP may be derived from NH_3. Marini and Van Amburgh (2003) found that the proportion of microbial CP derived from blood urea-N increased with decreasing dietary N. Following assimilation of NH_3 into microbial CP, microbial CP can pass down the digestive tract and be utilized as the principle source of protein for ruminants consuming low-quality forage (Hannah et al., 1991; Köster et al., 1996; Bohnert et al., 2002a).

Frequency of Crude Protein Supplementation

Performance

Research has shown that protein supplements can be fed at infrequent intervals (up to 6 d separating supplementation events) to ruminants consuming low-quality forage and still maintain acceptable levels of performance (Appendix Table 7). McIlvain and Shoop (1962) were the first to document that steers consuming dormant, winter range forage and supplemented with CSM three times or once per week had similar, positive weight gains compared to steers supplemented every day. Similarly, Melton and Riggs (1964) demonstrated that decreasing supplementation frequency (**SF**) of CSM to twice per week had no affect on cow weight gain, percent calf crop weaned, or calf weaning weight. Huston et al. (1999a, 1999b) and Bohnert et al. (2002b) demonstrated similar results. They noted that cows or ewes could be supplemented as infrequently as once per week and maintain performance similar to daily supplemented individuals. However, an interesting observation has been recorded regarding the variability in body weight change as affected by SF. Huston et al. (1999b) reported that body weight change was more variable within groups for once daily feeding than when supplemented less frequently. The possible reason for this discrepancy will be discussed further in another section.

While the above mentioned research primarily used CSM as the supplemental CP source, researchers have also demonstrated that other sources of CP can be fed at infrequent intervals (Appendix Table 7). Thomas and Armitage (1972) fed SBM, urea, or biuret daily or every other day to steers consuming grass hay and found no difference because of CP source or SF on weight gain. Similarly, Beaty et al. (1994) reported no difference in weight and BCS change at weaning for cows consuming wheat straw and provided a mixture of SBM and sorghum grain once or three times per week. Currier et al. (2003a) found no difference in weight and BCS gain of cows supplemented with urea or biuret daily or every other day. Additionally, palatability of supplement may play a role in an animal's ability to consume all of an infrequently offered supplement, which can affect livestock performance (Farmer et al., 2002).

Forage Intake and Nutrient Utilization

Forage Intake. While the effects of CP supplementation on forage intake have been documented extensively (Appendix Table 2), little research has addressed the effects of protein SF on forage intake (Appendix Table 8). Multiple researchers have demonstrated no affect of SF on forage and total DM intake (Coleman and Wyatt, 1982; Krehbiel et al., 1998; Huston et al., 1999a). Coleman and Wyatt (1982) reported that steers fed range hay and supplemented with CSM every other day or once every fourth day had similar DM intake to daily supplemented individuals.

Additionally, researchers have reported no difference in forage intake for ewes supplemented infrequently compared with daily supplementation (Krehbiel et al., 1998; Huston et al., 1999a). However, other researchers have demonstrated a decrease in forage intake as SF decreased (Beaty et al., 1994; Huston et al., 1999b; Bohnert et al., 2002b). Beaty et al. (1994) reported that steers consuming wheat straw and supplemented three times per week consumed 17% less straw than daily supplemented individuals. Similarly, Huston et al. (1999b) reported a decrease in forage intake of 38 and 27% for supplementation 3d/wk and once per week, respectively, compared to daily supplementation. Bohnert et al. (2002b) noted a linear decrease in hay intake (13%) as SF decreased for lambs consuming low-quality meadow hay. Huston et al. (1999b) and Bohnert et al. (2002b) suggested that decreased forage intake may be the result of a substitution of supplement DM for forage DM by infrequently supplemented individuals, especially on the day of a supplementation event. While the results of SF on forage intake have been variable, most research suggests a substitution effect of supplement for forage which causes a concomitant decrease in forage intake. For individuals supplemented only once per week this can be substantial; however, because of the higher nutrient density of the supplement, total nutrient intake may not be affected as negatively as forage intake.

Nitrogen Utilization. Research with urea-N recycling has demonstrated that renal clearance of urea-N decreases with decreasing dietary N (Marini and Van Amburgh, 2003), suggesting that, during periods of N deficiency, ruminants have the ability to return urea-N to the plasma instead of excreting it as urinary urea-N. Nitrogen balance trials evaluating SF suggest that this may occur during the period between supplementation events (Appendix Table 9). Coleman and Wyatt (1982) noted that protein supplementation as infrequently as once every 4 d had no effect on N retention compared to daily supplementation of steers consuming low-quality forage. Similar results are reported by Bohnert et al. (2001b), who noted that protein supplementation as infrequently as once every 6 d to lambs consuming low-quality forage resulted in daily digested N retained similar to daily supplemented individuals, however, a decrease in N balance was also reported (likely caused by decreased forage intake as SF decreased, causing total N intake to also decline). Krehbiel et al. (1998) suggested that infrequent supplementation may affect the pattern of N absorption but not the net absorption of N from the GIT. Huston et al. (1999a) and Bohnert et al. (2002b) reported that plasma urea-N concentration increased on the day of supplementation for infrequently supplemented individuals, but then returned to control levels between supplementation events. Also, Bohnert et al. (2002b) reported that plasma urea-N, when reported as a 6-d mean, was lower for infrequently supplemented individuals than daily supplemented individuals. Results by Bohnert et al. (2002b) can largely be explained by a decrease in N intake as SF decreased. Krehbiel et al. (1998) provided further evidence of improved urea-N recycling by ruminants consuming low-quality forage and supplemented infrequently with CP. They noted portal drained viscera removal of urea-N increased from 12% of N intake on the day supplement was provided to 74% during the 2 d between supplementation events (Krehbiel et al., 1998). The results of these trials indicate that nutritional regulation of N recycling and urinary excretion of urea-N is an important factor contributing to maintenance of body weight and body condition during periods between supplementation events.

Ruminal NH_3 and Volatile Fatty Acid Response. Ruminal NH_3 concentration is largely the result of the amount of DIP provided in the diet (Appendix Table 5). Therefore, on the day of supplementation for infrequently supplemented individuals, ruminal NH_3 concentration can be expected to be elevated compared to daily supplemented individuals (Appendix Table 10). Farmer et al. (2001) and Bohnert et al. (2002c) reported that ruminal NH_3 concentration increased 24 h following supplementation for infrequently supplemented individuals and then declined between supplementation events. However, on the days when no supplement was provided, Bohnert et al. (2002c) noted that ruminal NH_3 concentration of infrequently supplemented steers remained higher than unsupplemented controls. This suggests that N recycling may have provided sufficient supplemental DIP to maintain ruminal fermentation between supplementation events. This was supported in a companion study in which bacterial N synthesis and daily bacterial N flow at the duodenum were not affected by SF, suggesting that recycled urea-N maintained microbial CP production between supplementation events (Bohnert et al., 2002a).

Similar responses to decreased SF have been reported for ruminal VFA (Appendix Table 10). Farmer et al. (2001) and Bohnert et al. (2002c) reported increased total VFA on the day of supplementation as SF decreased, followed by decreased total VFA during periods when no supplement was offered. However, between supplementation events total VFA concentration was similar to daily supplementation. These data suggest that the ability of ruminants to recycle N between supplementation events provides ruminal microbes with the N necessary to maintain rumen fermentation and forage digestibility.

Nutritient Digestibility. Researchers have documented that infrequent supplementation does not have large negative affects on DM, OM, and(or) NDF digestibility (Appendix Table 11). Coleman and Wyatt (1982), Hunt et al. (1989), and Bohnert et al. (2002a) reported no affect of SF on digestibility of nutrients. Coleman and Wyatt (1982) supplemented CSM infrequently to steers consuming low-quality hay and found no affect on DM digestibility compared to daily supplemented individuals. Similarly, Hunt et al. (1989) reported no difference in NDF and ADF in situ disappearance in steers supplemented CSM infrequently while consuming low-quality fescue hay. Bohnert et al. (2002a) provided the only data to date which evaluated ruminal, post-ruminal, and total tract OM disappearance of forage as affected by SF. Decreasing SF did not affect ruminal, intestinal, or total tract OM disappearance in steers fed low-quality meadow hay and supplemented once, three times, or six times per week. However, variable results in total tract disappearance of nutrients have been observed (Appendix Table 11). Beaty et al. (1994) reported that reducing SF increased DM and NDF digestion of steers consuming wheat straw and supplemented once or three times per week. In contrast, Farmer et al. (2001) demonstrated that steers consuming tallgrass prairie and supplemented as infrequently as twice per week had decreased total tract OM disappearance as SF decreased. However, the magnitude of change in OM disappearance was small (5%), therefore, the biological relevance of the reduction in OM disappearance may be questionable. Nevertheless, Farmer et al. (2001) proposed that this effect may have been due to altered rumen fermentation by infrequently supplemented individuals, which was supported by a quadratic decrease in ruminal liquid dilution rate as SF decreased. In comparison, Bohnert et al. (2002b) and Currier et al. (2003a) found no difference in total tract DM, OM, or NDF digestibility in lambs consuming low-quality forage and supplemented with CP infrequently.

Variability in Supplement Intake

A managerial concern of supplementing grazing livestock is variability in supplement intake between animals and the subsequent affect on livestock performance (Appendix Table 12). As alluded to previously, Huston et al. (1999b) reported that cow body weight change was more variable for once daily feeding compared with cows supplemented less frequently (every 3 d or once per week). All cows were present at each supplementation event, therefore, each had an equal opportunity to consume supplement. However, cows supplemented three times or once per week exhibited approximately 33% less variability in supplement intake than daily supplemented individuals (Huston et al., 1999). These results suggest that competition between animals for supplement during daily supplementation events may prevent less aggressive animals from consuming supplement. During less frequent supplementation, passive animals may be able to consume supplement without having to compete against more aggressive, dominant animals. This is most likely because of the increased quantity of supplement offered with less frequent supplementation (Appendix Table 12). Foot and Russel (1973) demonstrated that the coefficient of variation (CV) for supplement intake decreased from 36 to 13% when supplement offered to ewes was increased from 100 to 453 g/d. Additionally, Kahn (1994) found that the CV for supplement intake by sheep decreased by 10% when supplement offered was increased from 55 to 110 g/d. Infrequent supplementation increases the amount of supplement offered per supplementation event, thereby potentially allowing individual animals more opportunity to consume supplement.

However, research has documented that infrequent supplementation can result in some animals not receiving any supplement (McIlvain and Shoop, 1962; Melton and Riggs, 1964). McIlvain and Shoop (1962) reported that cattle fed once per week often had to be driven to supplement while cattle supplemented every other day or daily could easily be called to a supplementation event. Similarly, Melton and Riggs (1964) documented that cows fed twice per week required an audio cue to entice them to appear at a supplementation event while cattle supplemented daily followed a pickup and were readily present at the time of supplementation. These results suggest that infrequent supplementation of cattle in extensive rangeland conditions may require additional management to assure consistent supplement intake (audio cue, herding, taking supplement to cattle, etc.).

Other factors can affect variation in supplement intake, such as supplement type, cow age, and bunk space (Appendix Table 12). In a review of relevant literature, Bowman and Sowell (1997) reported that the percentage of non-feeders for molasses blocks, dry supplements, and liquid supplements was 14, 15, and 24%, respectively; the CV of individual supplement intake was 79, 41, and 60% for molasses blocks, dry supplement, and liquid supplements, respectively. Similarly, Nolan et al. (1975) reported that 49% of sheep given access to a liquid urea-molasses supplement did not consume any supplement, with a range of supplement intake for the sheep that did consume supplement of 5 to 550 ml/d. However, Dixon et al. (2001) noted that a loose mineral mix had a CV for supplement intake of 52 to 103% while concentrate or molasses-based supplements had CV's for supplement intake of 23 to 43%, respectively. The CV's for supplement intake were considerably lower than the variability observed by Nolan et al. (1975). Evidence of cow age on variability in supplement intake, possibly due to cow aggressiveness, has been reported (Bowman et al., 1999). Two-yr-old cows visited a liquid molasses supplement less frequently, spent less time at the supplement, and consumed less total supplement than 3-yr-old cows (Bowman et al., 1999). Wagnon et al. (1966) reported that when 91 cm of trough space was provided per cow, less fighting and dominant/submissive behavior was observed during supplementation events than when 180 cm per cow was provided. Proper management can alleviate much of the variation in supplement intake associated with supplemental CP source, cow age, and bunk space.

Livestock Distribution and Behavior

Water and Salt

Water has long been known to have a major impact on livestock distribution. In arid regions of the world, water location determines the availability of forage for livestock across a rangeland. Cattle will generally travel up to 1 mile from water to consume forage, less during periods of extreme heat or when the terrain is steep or rough, and more when the terrain is flat or rolling hills (Valentine, 1989). Modification of livestock distribution through the use of salt has been reported as early as 1926 (Chapline and Talbot, 1926). Ares (1936) reported that feeding salt away from water reduced the length of time cattle gathered around water, increased the area of the range receiving proper use, and decreased the percentages of heavy and light use on level, rock-free range in southern New Mexico. Similarly, Ares (1953) found that feeding a CSM-salt mix (4:1 ratio) away from water resulted in a larger, properly used area and smaller area of heavy and light use than did feeding CSM-salt at water. Holechek et al. (1995) estimated that placement of salt away from water in mountainous range can increase grazing capacity by up to 20%. However, other researchers have demonstrated no difference in cattle distribution due to salt placement (Appendix Table 13). Martin and Ward (1973) found that the placement of salt or a meal-salt mix (3:1 ratio) did not significantly affect pasture utilization or livestock distribution on a semidesert grass-shrub range. Similarly, Bailey and Welling (1999) found that salt placement did not have an effect on cattle distribution or grazing behavior on Montana foothills.

Other researchers have evaluated the combination of salt and water placement and their affects on livestock distribution (Appendix Table 13). Cook (1966) evaluated factors affecting livestock distribution on mountain range in northern Utah and found that water and salt placement significantly affected distribution of cows; however, when up to 21 factors believed to affect livestock distribution were included in their model, they could account for only 37 to 55% of the variability in pasture utilization. Ganskopp (2001) evaluated water and salt as a means to modify livestock distribution in the northern Great Basin. Movement of watering points was the most effective tool for altering cattle distribution, while movement of salting stations was ineffective at redistributing livestock distribution (Ganskopp, 2001). Distance traveled daily (5.78 m), grazing time (11.0 h/d), resting time (10.1 h/d), and the area (325 ha) of minimum convex polygons (livestock distribution) were unaffected by water and salt treatments (Ganskopp, 2001). However, Porath et al. (2002) found that cow distribution and grazing behavior in the foothill mountains of northeastern Oregon was influenced by offstream water and salt placement. Results from these studies indicate that water and salt placement can affect the distribution patterns of grazing livestock, however, many other factors influence livestock distribution and must be accounted for when designing management plans for rangelands.

Supplement

Distance traveled. The use of free-choice protein supplements to alter livestock distribution usually includes the use of salt as an intake limiter (Ares, 1953; Martin and Ward, 1973). However, recent research has addressed the use of supplements, without salt, to modify livestock distribution (Appendix Table 13). Wagnon (1963) demonstrated that supplemented cows traveled further than unsupplemented cows. Similarly, Adams (1985) found that steers supplemented with corn traveled 0.5 km/d further than unsupplemented steers. However, Barton et al. (1992) demonstrated that steers supplemented with CSM spent the same amount of time walking as unsupplemented steers. Results from these trials suggest that supplementation of grazing ruminants can affect the distance livestock travel/day. Adams (1985) stated that the affects of supplementation on livestock distribution and distance traveled may affect grazing activity and, consequently, forage intake.

Grazing time. The ability of researchers to evaluate grazing time gives insight into performance responses elicited from infrequent supplementation (Appendix Table

14). Wagnon (1963) was the first researcher to document the affects of supplementation on livestock grazing behavior, noting that supplemented cattle spent 5% less time grazing than unsupplemented cattle. Similarly, Yelich et al. (1988) found that cows supplemented with alfalfa decreased grazing time by 10% compared to unsupplemented individuals. Hess et al. (1992), Krysl and Hess (1993), and Barton et al. (1992) reported that protein supplementation affected time spent grazing; unsupplemented cattle grazed approximately 1.5 h/d more than supplemented cattle. Also, other research has suggested that type of supplemental CP and time of daily feeding does not alter time spent grazing (DelCurto et al., 1990c; Brandyberry et al., 1992; Krysl and Hess, 1993). Similarly, Adams (1985) found no difference in grazing time when steers were supplemented with corn, however, he did report that the pattern of grazing was affected; supplemented steers did not graze for 2 to 4 h following supplemention, which was different than unsupplemented controls. Additionaly, Brandyberry et al. (1991) found no differences in grazing behavior among steers self-fed a salt-limited supplement or steers hand-fed daily (SBM:grain sorghum mix). While there are some discrepancies between studies, protein supplementation appears to decrease grazing time by approximately 1.5 h/d. This response, however, does not directly answer whether or not forage intake is affected.

Harvest efficiency. Grazing time does not directly address forage intake, therefore, a measure of forage intake in relation to time spent grazing is useful in determining the efficiency of CP supplementation (Appendix Table 15). Brandyberry et al. (1991) found no difference in forage intake or harvest efficiency (**HE**; grams of forage intake·kilogram BW^{-1}·minute spent $grazing^{-1}$) when steers were supplemented with SBM:sorghum grain. Hess et al. (1992) noted that forage intake was not altered by CP supplementation or CP source, but HE was greater for alfalfa and CSM supplemented cattle (0.036 and 0.037, respectively) compared to corn gluten feed supplemented and control cattle (0.03 and 0.027, respectively). Similarly, Barton et al. (1992) found that forage intake of grazing steers was not affected by CP supplementation, but HE increased from 0.037 to 0.050. However, supplement type (energy vs protein) may have an affect on HE (Adams, 1985; Bodine and Purvis, 2003). Adams (1985) reported that forage intake decreased by 11% when corn was supplemented to grazing steers, with a decrease in HE from 0.0620 to 0.0565. Similar results reported by Bodine and Purvis (2003) suggest that corn supplementation decreases grazing time, grazing intensity, and HE compared with SBM or cottonseed hull supplementation. A possible reason for the decrease in HE is a decrease in forage digestibility due to negative associative affects often observed with supplementation of low-quality forage with non-structural carbohydrates (Caton and Dhuyvetter, 1997). In summary, Krysl and Hess (1993) reviewed relevant literature and reported that CP supplementation increased HE from 8 to 60% compared with no supplementation.

Frequency of Supplementation

Little research has addressed the issue of frequency of supplementation and its effects on livestock distribution and grazing behavior (Appendix Table 16). McIlvain and Shoop (1962) documented that as SF decreased cattle were present at a supplementation event less often. Similar anecdotal responses were noted by Melton and Riggs (1964) who reported that cows supplemented twice/week tended to graze more widely over the pasture than those fed more frequently. Box et al. (1965) found that unsupplemented cattle walked over twice as far as cattle supplemented with CSM on alternate days, however, they did not differ in time spent grazing. Unfortunately, Box et al. (1965) did not supplement every day in order to provide a positive control. One of the few studies that evaluated grazing behavior in relation to SF was reported by Brandyberry et al. (1992). Supplemental CP was fed daily or alternate days to grazing cows. Distance traveled (9.92 km/d) and time spent grazing (5.93 h/d) were not affected by SF. However, cows did graze less on days in which all animals received supplement (5.66 vs. 6.30 hr/d) because of the time required to consume supplement.

Conclusion

Research has shown that CP supplements can be fed at infrequent intervals and still maintain acceptable levels of performance; however, data is limited comparing the effects of SF on harvest efficiency, animal dispersal across pasture, pasture utilization, DM intake, and individual variation in supplement intake. Therefore, the following research was designed to evaluate the influence of CP supplementation frequency on cow performance, grazing time, distance traveled, maximum distance from water, cow distribution, percentage of supplementation events frequented, DM intake, harvest efficiency, and variation in supplement intake when consuming low-quality forage.

CHAPTER 2: INFLUENCE OF PROTEIN SUPPLEMENTION FREQUENCY ON COWS CONSUMING LOW-QUALITY FORAGE: PERFORMANCE, GRAZING BEHAVIOR, AND VARIATION IN SUPPLEMENT INTAKE

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Abstract

Our objective was to determine the influence of CP supplementation frequency (**SF**) on cow performance, grazing time, distance traveled, maximum distance from water, cow distribution, DMI, DM digestibility, harvest efficiency (**HE**), percentage of supplementation events frequented, and CV for supplement intake for cows grazing low-quality forage. One hundred-twenty pregnant (approx. 60 d) cows (467 ± 4 kg BW) were used in a 3 x 3 Latin square for one 84-d period in each of 3 yr. Cows were stratified by age, body condition score (**BCS**), and weight and assigned randomly to one of three 810-ha pastures. Treatments (**TRT**) included an unsupplemented control (**CON**) and supplementation every day (**D**; 0.91 kg; DM basis) or once every 6 d (**6D**; 5.46 kg; DM basis) with cottonseed meal (43% CP; DM basis). Four cows from each treatment (each year) were fitted with global positioning system collars to estimate grazing time (h/d), distance traveled (m/d), maximum distance from water (m/d), cow distribution (percentage of ha occupied•pasture^{-1}•yr^{-1}), and percentage of supplementation events frequented. Collared cows were dosed with intraruminal n-alkane controlled-release devices on d 28 for estimation of DMI (g•kg BW^{-1}•d^{-1}), DM digestibility (%), and HE (g DMI•kg BW^{-1}•min grazing^{-1}). Additionally, Cr_2O_3 was incorporated into CSM on d 36 at 3% of DM for use as a digesta flow marker to estimate the CV for supplement intake (%). Cow weight and BCS change were more positive ($P \leq 0.03$) for supplemented TRT compared with CON. No weight or BCS differences ($P \geq 0.14$) occurred between D and 6D. Grazing time was greater ($P = 0.04$) for CON compared with supplemented TRT with no difference ($P = 0.26$) because of SF. Distance traveled, maximum distance from water, cow distribution, DMI, DM digestibility, and HE were not affected ($P \geq 0.16$) by CP supplementation or SF. The percentage of supplementation events frequented and the CV for supplement intake were not affected ($P \geq 0.22$) by SF. Results suggest that providing CP daily or once every 6 d to cows grazing low-quality forage increases weight and BCS gain while decreasing grazing time. Additionally, cow distribution, DMI, and HE may not be affected by CP supplementation or SF.

Key words: Rangeland, Cattle, Sagebrush Steppe, Distribution

Introduction

Many cattle in the western United States consume low-quality forage (< 6% CP; DM basis) from late summer through winter; therefore, supplementation with CP is necessary to maintain or increase cow weight gain and body condition score (Clanton and Zimmerman, 1970; Rusche et al., 1993). Crude protein supplementation can be expensive; however, decreasing the frequency of supplementation is one management practice that decreases labor costs. Melton and Riggs (1964) suggested that providing a supplement twice per week resulted in savings of approximately 60% in labor and travel when compared with daily supplementation. Research has shown

CP supplements can be fed at infrequent intervals to ruminants while maintaining acceptable levels of performance (McIlvain and Shoop, 1962; Huston et al., 1999b; Bohnert et al., 2002b). Bohnert et al. (2002b) suggested that the ability of the ruminant to conserve N between infrequent supplementation events may be linked to changes in the permeability of the gastrointestinal tract to urea-N and[or] renal regulation of urea excretion.

Grazing time has been reported to decrease by 1.5 h/d for supplemented compared with unsupplemented cows (Krysl and Hess, 1993). However, little research has addressed the affects of supplementation frequency (**SF**) on livestock distribution and grazing behavior. Therefore, our null hypothesis was that infrequent supplementation of CP to cows grazing low-quality forage will not affect cow performance, distribution, DMI, harvest efficiency (**HE**), and CV for supplement intake compared with daily supplementation. Our objectives to test this null hypothesis were to determine whether infrequent supplementation of CP to cows grazing low-quality forage affects cow performance, grazing time, distance traveled, maximum distance from water, cow distribution, DMI, DM digestibility, HE, percentage of supplementation events frequented, and CV for supplement intake for cows grazing low-quality forage.

Materials and Methods

Experimental Site

Research was conducted at the Northern Great Basin Experimental Range (**NGBER**; 119°43'W, 43°29'N; elevation 1425 m), 72 km west-southwest of Burns, OR. Ganskopp (2001) characterized the vegetation as a dispersed western juniper (*Juniperus occidentalis* Hook.) overstory and a shrub layer dominated by either low sagebrush (*Artemisia arbuscula* Nutt.), wyoming big sagebrush (*A. tridentata* subsp. *wyomingensis* beetle) or mountain big sagebrush (*A. tridentata* subsp. *vaseyana* (Rydb.) beetle). Dominant herbaceous plants included bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. and Smith), Idaho fescue (*Festuca idahoensis* Elmer), and Sandberg's bluegrass (*Poa sandbergii* Vasey).

Experimental Design

One hundred-twenty pregnant (approx. 60 d) cows (467 ± 4 kg BW) were used in a 3 x 3 Latin square with one 84-d period in each of 3 yr (2000, 2001, and 2002) to evaluate the influence of SF on cow performance, grazing time, distance traveled, maximum distance from water, distribution within pasture, DMI, DM digestibility, HE, percentage of supplementation events frequented, and CV for supplement intake. The experimental protocol was approved by the Institutional Animal Care and Use Committee at Oregon State University. Cows were stratified by age, body condition score (**BCS**; 1=emaciated, 9=obese; Herd and Sprott, 1986), and weight and assigned randomly to one of three pastures (810 ha/pasture). The same cows were used throughout the study; however, if an animal had to be removed from the study (death or not pregnant at weaning), an individual of similar age and genetic background replaced it. Cows were not rotated through the pastures; each cow group remained in the same pasture for all 3 yr. However, during the approximately 9 mo between experimental periods all cows were grouped into one herd and managed according to NGBER and Eastern Oregon Agriculture Research Center management practices.

Treatments (**TRT**) included an unsupplemented control (**CON**) and supplementation every day (**D**; 0.91 kg; DM basis) or once every 6 d (**6D**; 5.46 kg; DM basis) with cottonseed meal (**CSM**; 43% CP; DM basis). Cottonseed meal was provided 10 min after an audio cue (Signal Horn, Tempo Products Co., Solon, OH) at approximately 0800 for each supplementation event. Approximately 75-cm of trough space was provided per cow. A trace mineralized salt mix was available free choice (7.3% Ca, 7.2% P, 27.8% Na, 23.1% Cl, 1.5% K, 1.7 % Mg, .5% S, 2307 ppm Mn, 3034 ppm Fe, 1340 ppm Cu, 3202 ppm Zn, 32 ppm Co, 78 ppm I, 85 ppm Se, 79 IU/kg vitamin E, and 397 kIU/kg vitamin A). Water, mineral/salt, and supplement placement within each pasture was maintained in the same location throughout the study.

Experimental periods were 84 d, beginning about August 9 (2 wk following weaning) and concluding about November 1 of each year. Cow weight and BCS were measured on d 0 and 84. All weights were obtained following an overnight shrink (16 h). Supplement samples were collected weekly, dried at 55°C for 48 h, ground through a Wiley mill (1-mm screen), and composited by period for analysis of DM and OM (AOAC, 1990) and N (CN-2000, LECO Corp, St. Joseph, MI).

Forage Nutritive Value

Rumen cannulated steers were used to estimate forage nutritive value in each pasture using three 2-ha fenced enclosures (one in each pasture) on d 1-3, 43-45, and 80-82, except for in yr 1 during which data was not collected for d 1-3. One enclosure was collected each day. Steers were caught at 0730, transported to an enclosure, and rumen evacuated (not previously withheld from grazing) as described by Lesperance et al. (1960), except that the ruminal wall was washed with a wet sponge, and steers were allowed to graze for approximately 1 h. The newly grazed masticate was removed and the initial ruminal contents replaced. The masticate was immediately frozen (-20°C), lyophilized, and ground with a Wiley mill (1-mm screen) for determination of DM and OM (AOAC, 1990), N (CN-2000, LECO Corp, St. Joseph, MI), and NDF (Robertson and Van Soest, 1981) and ADF (Goering and Van Soest, 1970) using procedures modified for an Ankom 200 Fiber Analyzer (Ankom Co., Fairport, NY).

Standing Forage

Available standing forage in each pasture was measured at the beginning and conclusion of each experimental period (d 0 and 84, respectively) by clipping 10 randomly placed 1-m^2 quadrats from predetermined range sites in each pasture. Range sites were selected based on known soils and associated vegetation within each pasture (Lentz and Simonson, 1986). Also, available forage in each 2-ha exclosure was estimated by clipping (as described previously) immediately before and after each fecal collection period (described in DM and supplement intake section). Clipped forage samples were dried at 55°C for 48 h and weighed for determination of available standing forage.

Animal Distribution and Behavior

Four cows from each TRT (each year) were fitted with global positioning system (**GPS**) collars (Lotek GPS_2000 Collars; Lotek, 115 Pony Drive, Newmarket, Ontario, Canada, L3Y7B5) to obtain data related to animal distribution and behavior. Collars were placed on the same cows each year; however, if an animal was removed from the study (death or not pregnant at weaning), an individual of similar age and genetic background replaced it the following year. Collars were equipped with head forward/backward and left/right movement sensors, a temperature sensor, and a GPS unit. Collars were programmed to take position readings at 10-min intervals for three 6-d periods evenly distributed across the 84-d period (in each of 3 yr) to estimate grazing time (h/d), distance traveled (m/d), maximum distance from water (m/d), cow distribution (percentage of ha occupied•pasture^{-1}•yr^{-1}), and percentage of supplementation events frequented. The 6-d periods were designed to include a complete supplementation schedule for the 6D TRT. Collar data was retrieved following each 6-d period, downloaded to a computer, and converted from latitude/longitude to Universal Transverse Mercator as described by Ganskopp (2001). Grazing time was determined through generation of prediction modes from observation data. Briefly, each collared cow was visually observed for 8-12 h per year. Activities monitored included: grazing, resting (lying down), walking, standing, drinking, and consuming mineral or supplement. Prediction models for estimating grazing time were developed via stepwise regression analysis (SLENTRY=0.25; SLSTAY=0.15) for each cow/year (SAS; SAS Inst. Inc., Cary, NY). The dependent variable was grazing time (min) and the independent variables from GPS collar data included: head forward/backward and left/right movement sensor counts, sum of forward/backward and left/right movement counts, and the distance traveled (m) by the cow within each 10-min interval. Grazing models were determined for each individual cow, TRT x year, year, and for the entire data set (n = 35, 9, 3, and 1,

Table 1. Actual and predicted grazing time (minutes percentage of total time observed) and associated correlation coefficients.

		Model Type					
Item	Actual	Individual	TRT x year	Year	Total	SEM[a]	*P*-value[b]
Grazing, min[c]	152	155	154	155	154	7	0.999
Correlation[d]	---	0.9953	0.7605	0.6641	0.5528	---	---
Grazing, %[e]	30	30	30	30	30	2	0.999
Correlation[d]	---	0.9972	0.8385	0.7702	0.7000	---	---

[a]n = 35.
[b]*P*-value for affect of model type on predicted grazing.
[c]Minutes grazing of total time observed.
[d]Correlation for actual grazing vs. predicted grazing (by model).
[e]Percentage grazing of total timed observed.

respectively). Individual models were used to determine grazing time because of a higher correlation coefficient than all other model types (Table 1). Distance traveled (used for determining grazing time and distance traveled/d) is underestimated because straight-line pathways were assumed between successive coordinates. Cow distribution within pasture was determined with Geographical Information Systems software (Idrisi32 For Windows, Clark Univ., Worcester, MA) using 1-ha grid cells within each pasture (Table 2). The percentage of supplementation events frequented was determined as the percentage of collared cows within 50 m of supplement within 20 min of a supplementation event.

Dry Matter and Supplement Intake

Each GPS collared cow was dosed with an intraruminal n-alkane controlled-release device (IACRD; Captec Ltd., Auckland, NZ) containing dotriacontane (C32) and hexatriacontane (C36) on d 28. Dotriacontane and tritriacontane (C33) were used as digesta flow markers to estimate diet intake and digestibility as described by Dove and Mayes (1996). Additionally, chromic oxide was incorporated into CSM on d 36 (day of supplementation for D and 6D TRT) at 3% of DM for use as a digesta flow marker to estimate supplement intake. A sub-sample of the Cr-CSM mixture was collected for later analysis of Cr. All 40 cows per TRT were herded to supplement bunks and allowed the opportunity to consume chromic oxide dosed supplement. After all supplement was consumed on d 36, IACRD dosed cows were placed in the 2-ha enclosures used for determining forage nutritive value to facilitate fecal collection. Fecal grab samples (approximately 300 g) were obtained

Table 2. Calculations and units used to define cow distribution within pasture, DMI, DM digestibility, fecal output, harvest efficiency, supplement intake, and CV for supplement intake

Item	Units	Calculation
Distribution	% ha occupied•pasture^{-1}•yr^{-1}	ha occupied / ha in pasture
DMI	g•kg BW^{-1}•d^{-1}	((fecal$_{C33}$ / fecal$_{C32}$) * dosed$_{C32}$) / (herbage$_{C33}$ - ((fecal$_{C33}$ / fecal$_{C32}$) * herbage$_{C32}$))[ab]
DM digestibility	%	1 – (herbage$_{C33}$ / fecal$_{C33}$)[ab]
Fecal output	kg/d	(DMI, kg/d) * (indigestibility,% / 100)
Supplement intake	g/d	((fecal output * 1000) * peak fecal Cr conc.[c], mg/g) / supplement Cr concentration (mg/g)
CV for supplement intake	%	(treatment SD / mean) * 100
Harvest efficiency	g•kg BW^{-1}•min grazing^{-1}	g DMI•kg BW^{-1}•min grazing^{-1}

[a]Dove and Mayes, 1996.

[b]C32 = dotriacontane ($C_{32}H_{66}$); C33 = tritriacontane ($C_{33}H_{68}$).

[c]Determined with 5 parameter Weibull distribution within peak function of Sigma Plot.

from IACRD dosed cows on d 36 through 40 at 0800 h to determine n-alkane concentration for estimation of DM intake and digestibility. Also, fecal grab samples from D and 6D IACRD dosed cows were collected at 0, 12, 24, 28, 32, 40, 48, 54, 60, 72, 84, and 96 h following supplementation to derive a dose response curve for fecal Cr concentration. Fecal samples were dried at 55°C for 96 h and ground in a Wiley mill to pass through a 1-mm screen. The fecal samples obtained from IACRD dosed cows at 0800 on d 36 through 40 were composited by cow and year for analysis of n-alkanes while the serially collected D and 6D fecal samples were analyzed individually for Cr.

Masticate samples from cannulated steers and cow fecal samples were analyzed for n-alkanes by the following procedure. Forage and fecal samples were weighed into 50-ml glass screw-cap tubes with Teflon-lined caps (1.5 and 1.0 g, respectively). One ml of internal standard (0.25 mg/ml tetratriacontane; **C34**) was placed in each tube, followed by 15 ml of 1M ethanolic KOH per tube. Samples were mixed and heated in a shaking water bath at 90°C for 8 h, vortexing at least 4 times during the incubation. After tubes cooled to 60°C or less, 14 ml n-heptane and 4 ml distilled water were added and tubes capped and placed in a 60°C shaking water bath for 2 h. Tubes were then shaken vigorously on a shaker at room temperature for 18 h followed by centrifugation at 500 x g for 15 min (4°C). The top layer (n-heptane layer) was then transferred using a glass Pasteur pipette into a 16 x 125 Pyrex tube (Corning No. 9820) and placed into a CentriVap® centrifugal concentrator (Labconco, Kansas City, MO) at 75°C until completely evaporated. Residual material in the centrifuge tube was subjected to a second n-heptane extraction as above with the n-heptane layer added to the CentriVap® tube containing the evaporated material from the 1st extraction. The sample was again evaporated as above. The sample was reconstituted by adding 3.5 ml of n-heptane and vortexing until dissolved. A solid phase separation was conducted by pouring the reconstituted sample onto the top of a chromatograph column packed with 5 ml of Porasil® Silica (125 Å, 55-105 μm; Waters, Corp., Milford, MS). The column was rinsed three times with 3.5 ml of n-heptane and the combined eluatants collected. Samples were evaporated to dryness as previously noted. Fecal samples were reconstituted with 0.5 ml n-heptane, transferred to gas chromatograph (**GC**) vials using glass Pasteur pipettes, caped, and sealed. Samples were analyzed by GC on a HP 5890 (Agilent Technologies, Palo Alto, CA) with a Supelco SPB-1 wide bore capillary column (30 m length x 0.75 mm ID x 1 um film thickness).

The IACRD release rates of C32 and C36 alkanes were validated using steers consuming low-quality forage (< 6% CP; DM basis). Total intake, ort, and fecal collections were conducted on 5 consecutive days (d 10 to 14 following dosing). Steers were fed meadow hay ad libitum at 120% of the previous 5 d average intake. Validated release rates for C32 and C36 alkanes were 240 ± 3 and 242 ± 11 mg/d, respectively, which were 60 ± 1% and 61 ± 3% of the predicted release rate, respectively. These release rates are consistent with other trials conducted with low-quality forage (E.S. Vanzant, University of Kentucky, personal communication). Fecal recovery of naturally occurring C33 and C35 were 98 ± 6 and 79 ± 2%, respectively. Dry matter intake was determined through the ratio of dosed C32 and naturally occurring C33 concentrations (Dove and Mayes, 1996) while DM digestibility was determined using the ratio of herbage and fecal C33 concentrations (Table 2). Fecal output was calculated from intake and digestibility data determined from n-alkane analysis (Table 2).

Supplement and fecal samples were prepared as described by Williams et al. (1962) for analysis of Cr using atomic absorption spectroscopy (air/acetylene flame; Model 351 AA/AE Spectrophotometer, Instrumentation Laboratory, Inc., Wilmington, MA). Supplement and peak fecal Cr concentration were used in conjunction with fecal output to estimate supplement intake (Table 2). Peak Cr concentration in the feces was determined using the five parameter peak function with a Weibull distribution in Sigma Plot (SPSS Inc., Chicago, IL; $R^2 = 97 \pm 0.7\%$). The CV for supplement intake was determined from estimated supplement intake (Table 2). Harvest efficiency was calculated as grams DMI•kg BW^{-1}•min spent $grazing^{-1}$ (Table 2). Dry matter intake from the IACRD dosed cows was used to calculate HE for all GPS collection periods.

Statistics

Forage nutritive value, available standing forage, cow weight and BCS change, distribution within pasture, DMI, DM digestibility, HE, percentage of supplementation events frequented, and CV for supplement intake were analyzed as a 3 × 3 Latin square using the GLM procedure of SAS. The model included TRT, year, and pasture (Krysl et al., 1989). Orthogonal contrasts, CON vs supplemented TRT and D vs 6D TRT, were used to partition specific TRT effects. Grazing time, distance traveled, and maximum distance from water, determined for each day of the three 6-d GPS data collection periods, were averaged by day and year and analyzed using the REPEATED statement with the MIXED procedure of SAS. The model included pasture, year, TRT, day, and TRT x day. Pasture x year x TRT was used to specify variation between experimental units (using the RANDOM statement). Pasture x year x TRT was used as the SUBJECT and autoregression used as the covariance structure. The same orthogonal contrasts noted above were used to partition TRT sums of squares.

Results and Discussion

Standing Forage and Nutritive Value

Initial standing forage in pastures was not affected ($P \geq 0.11$) by TRT, pasture, or year (299 ± 27 kg/ha; data not shown). However, end of period standing forage tended to decrease ($P = 0.06$) from yr 1 through 3 (266, 170, and 164 ± 15 kg/ha, respectively), with no affect ($P \geq 0.11$) of TRT or pasture. Initial standing forage was not affected ($P \geq 0.30$) by TRT, pasture, or year (251 ± 72 kg/ha; data not shown) in the fecal collection exclosures. However, similar to overall final standing forage in pastures, final standing forage in nutrition exclosures decreased ($P = 0.04$) from yr 1 through 3 (288, 171, and 122 kg/ha, respectively) with no difference ($P \geq 0.10$) because of TRT or pasture. Precipitation for the crop year was 86, 72, and 42% of the 65 yr average (WRCC, 2003) for yr 1, 2, and 3, respectively, which explains the decrease in quantity of standing forage as the trial progressed. Forage nutritive value did not differ by TRT ($P \geq 0.16$); therefore, results are reported by year and pasture (Table 3). Masticate CP concentrations were below requirements (NRC; 1996) for this type of cow at the end of the first trimester of pregnancy, but higher than those reported by Turner and DelCurto (1991; < 5% CP) for similar forage at a comparable time period at the NGBER.

Table 3. Effect of year and pasture on forage nutritive value of diets selected by steers grazing native range in the northern Great Basin

	Year			
Masticate	1	2	3	SEM[a]
OM, % DM				
Pasture 1	80	76	78	0.7
Pasture 2	81	84	82	0.7
Pasture 3	80	78	79	0.7
CP, % DM				
Pasture 1	8.6	5.6	6.8	0.61
Pasture 2	9.2	5.5	7.3	0.61
Pasture 3	9.3	6.1	7.9	0.61
NDF, % DM				
Pasture 1	62	63	60	1.3
Pasture 2	62	64	58	1.3
Pasture 3	61	62	59	1.3
ADF, % DM				
Pasture 1	39	40	37	0.9
Pasture 2	38	38	36	0.9
Pasture 3	38	37	37	0.9
C32, mg/kg DM[b]				
Pasture 1	23	35	33	---
Pasture 2	30	36	33	---
Pasture 3	27	33	35	---
C33, mg/kg DM[b]				
Pasture 1	66	53	60	---
Pasture 2	72	55	74	---
Pasture 3	55	54	66	---

[a]n = 3, except for year 1 where n = 2; therefore, the largest SEM is presented.
[b]C32 = dotriacontane ($C_{32}H_{66}$); C33 = tritriacontane ($C_{33}H_{68}$).

Performance

Cow weight and BCS change were greater ($P \leq 0.03$) for supplemented TRT compared with CON (Table 4). No change in weight or BCS ($P \geq 0.14$) was noted because of SF. Ruminants consuming low-quality forage and supplemented as infrequently as once per week have consistently demonstrated similar weight and BCS change compared with daily supplemented individuals (McIlvain and Shoop, 1962; Huston et al., 1999b; Bohnert et al., 2002b). McIlvain and Shoop (1962) supplemented cows 7d/wk, every-third-day, or 1d/wk with CSM and noted similar, positive weight gains between supplementation regimes. Similarly, Huston et al. (1999b) supplemented CSM to beef cows consuming low-quality native range in western Texas either 7d/wk, 3d/wk, or 1d/wk. They reported CP supplementation decreased body weight loss by 67 to 83%, with no difference because of SF. In a study by Bohnert et al. (2002b), cows were supplemented with degradable intake protein or undegradable intake protein daily, once every 3 d, or once every 6 d. They noted SF did not affect cow weight or BCS gain. In contrast to these results, other researchers (Beaty et al., 1994; Farmer et al, 2001) have reported that infrequent supplementation increased cow weight and BCS score loss compared with daily supplementation. Beaty et al. (1994) fed a mixture of soybean meal (**SBM**) and sorghum grain daily or three times per week to cows consuming wheat straw. They reported pre-calving weight change was 16% less negative for daily supplementation than infrequent supplementation, but not different for cow weight and BCS change at weaning. Similarly, Farmer et al. (2001) fed a 43% CP supplement 7d/wk, 5d/wk, 3d/wk, or 2d/wk to cows grazing tallgrass prairie. They reported infrequent

Table 4. Effect of CP supplementation frequency on performance, behavior, DMI, DM digestibility, harvest efficiency, and supplement intake variability of cows grazing native range in the northern Great Basin

	Treatment[a]				*P*-value[c]	
Item	CON	D	6D	SEM[b]	Con vs Supp.	D vs 6D
Initial weight, kg	470	465	468	---	---	---
Weight change, kg	17	51	43	2	0.01	0.14
Initial body condition score	4.67	4.63	4.67	---	---	---
Body condition score change	0.01	0.45	0.32	0.06	0.03	0.24
Grazing time, h/d	9.57	7.08	7.87	0.36	0.04	0.26
Distance traveled, m/d	5917	5823	5903	160	0.81	0.76
Maximum distance from water, m/d	1912	1919	1760	105	0.63	0.40
Distribution, %[d]	70	69	67	2	0.42	0.40
DMI, g•kg BW^{-1}•d^{-1}	24.9	21.6	18.6	1.8	0.16	0.36
DM digestibility, %	50.7	49.4	45.3	3.7	0.53	0.51
Harvest efficiency, g•kg BW^{-1}•min $grazing^{-1}$	0.045	0.053	0.042	0.006	0.75	0.32
Supplementation events frequented, %	---	66	70	12	---	0.82
CV for supplement intake, %	---	36	21	7	---	0.22

[a]CON = control; D = supplementation every day; 6D = supplementation every sixth day.

[b]n = 3.

[c]Con vs Supp = control vs supplemented treatments; D vs 6D = daily supplementation vs every sixth day supplementation.

[d]Distribution = percentage of ha occupied•$pasture^{-1}$•yr^{-1}.

supplementation linearly increased cow BW loss from December 7 until calving. However, BCS change was not affected by SF during the same period. It is important to note than in both the aforementioned trials, magnitude of the cow BCS and/or weight difference attributed to SF tended to be relatively small and was not consistent throughout the trial.

An explanation for the ability of ruminants to maintain weight and BCS as CP SF decreases is provided by Bohnert et al. (2002b). They noted lambs fed supplemental protein as infrequently as once every 6 d had similar digested N retained to daily supplementation, suggesting N efficiency was maintained as SF decreased. Possible mechanisms for this response include: increased urea-N removal from the blood by the portal-drained viscera as SF decreases, increased permeability of the gastrointestinal tract to urea-N as the N content of the diet decreases between supplementation events, and changes in renal regulation that decrease urinary excretion of N as the N content of the diet decreases between supplementation events (Krehbiel et al., 1998; Marini and Van Amburgh, 2003). Changes in renal regulation of urea-N excretion in ruminants fed low-quality forage and supplemented infrequently may assist in maintaining N status and ruminal fermentation through increased recycling of N to the gastrointestinal tract.

Animal Behavior and Distribution

Grazing time prediction models are presented in Table 5. Treatment x day interactions were not present ($P = 0.61$) for grazing time; therefore, overall TRT means are presented. Grazing time was greater ($P = 0.04$) for CON compared with supplemented TRT with no difference ($P = 0.26$) because of SF (7.5 h/d; Table 4).

Table 5. Individual models for predicting grazing time

Treatment[a]	Grazing Model[b]	R^2	Actual[c]	Predicted[c]
	Year 1			
CON				
Cow 1	0.05218 * act1 - 0.72554	0.76	213	213
Cow 2	0.04139 * act1 - 0.02029 * act2-0.01224 * travel + 0.64248	0.62	199	202
Cow 3	0.03383 * act1 + 0.20768	0.67	202	202
Cow 4	0.037 * act1 - 0.84095	0.69	208	216
D				
Cow 5	0.02823 * act1 - 0.39466	0.50	114	119
Cow 6	0.03125 * act1 - 0.14842	0.65	139	142
Cow 7	0.02736 * act1 - 0.71422	0.45	126	133
Cow 8	0.03787 * act1 + 0.75428	0.50	173	173
6D				
Cow 9	0.10521 * act1 + 0.0153 * travel - 0.06619 * sum + 0.80007	0.78	173	190
Cow 10	0.03611 * act1 - 0.01591 * act2 - 0.32976	0.54	203	205
Cow 11	0.03834 * act1 - 0.04348 * act2 + 0.65766	0.45	142	142
Cow 12	0.03019 * act1 + 0.00598	0.54	149	149
	Year 2			
CON				
Cow 5	0.039 * sum + 0.45036	0.78	261	257
Cow 6	0.05061 * act1 - 0.02204 * travel + 1.17354	0.56	257	254
Cow 7	0.03467 * sum - 0.01683 * travel - 0.13108	0.57	149	151
Cow 8	-0.01375 * travel + 0.04205 * act1 - 0.26827	0.80	183	188
D				
Cow 9	0.03855 * act1 - 0.09109	0.79	159	160
Cow 10	0.02785 * act1 - 0.18510	0.50	61	65
Cow 11	0.0379 * act1 - 0.29034	0.71	136	140
Cow 12	0.04165 * act1 - 0.06751 * act2 + 0.01007 * travel + 0.1281	0.88	153	159
6D				
Cow 1	0.03446 * act1 + 0.32726	0.49	107	107
Cow 2	0.04552 * travel + 0.00958 * sum - 0.29681	0.60	62	64
Cow 3	0.02463 * act1 - 0.05136 * act2 + 0.02004 * travel + 0.6979	0.41	76	84
Cow 4	0.05541 * act1+0.01458 * travel-0.02767 * sum + 0.49995	0.43	76	85
	Year 3			
CON				
Cow 9	0.04269 * act1 - 0.19339	0.94	146	149
Cow 10	0.04478 * act1 - 0.40103	0.88	159	166
Cow 11	-0.08321 * act2 + 0.04996 * travel + 0.03598 * sum + 0.65359	0.66	180	180
Cow 12	0.04189 * act1 - 0.02288 * act2 - 0.10469	0.90	147	148
D				
Cow 1	0.02621 * act1 - 0.044848 * travel + 1.46694	0.16	129	131
Cow 2	-0.06529 * act1 + 0.04144 * travel + 0.05547 * sum - 0.1959	0.93	129	125
Cow 3	0.15617 * act1 + 0.05739 * travel - 0.13144 * sum - 0.18054	0.32	155	163
Cow 4	0.03018 * act1 + 0.01997 * travel - 0.2864	0.81	162	162
6D				
Cow 5	0.04297 * act1 - 0.67051	0.75	122	129
Cow 6	0.04702 * act1 + 0.01699 * travel - 0.4403	0.60	121	124
Cow 7	0.03007 * act1 + 0.67205	0.42	136	136
Cow 8	0.03626 * act1 + 0.04589	0.63	123	123

[a]CON = control; D = supplementation every day; 6D = supplementation every sixth day.

[b]act1 = forward/backward movement; act2 = left/right head movement; sum = sum of act1 and act2; travel = distance traveled between successive points.

[c]Actual and predicted minutes grazing for observational time period.

Variable results have been reported regarding the effect of supplementation on grazing time. Yelich et al. (1988) reported that cows grazing dormant tallgrass prairie and supplemented with alfalfa decreased grazing time by 10% compared to unsupplemented individuals. Similarly, Barton et al. (1992) demonstrated that providing CSM to steers grazing intermediate wheatgrass decreased time spent grazing by 1.5 h/d. In a review of relevant literature, Krysl and Hess (1993) reported that supplementation appeared to decrease grazing time of cattle by 1.5 h/d. However, Bodine and Purvis (2003) noted that steers fed SBM 5 d/wk while grazing dormant, native tallgrass prairie exhibited no difference in grazing time compared with unsupplemented controls (8.6 and 9.1 h/d, respectively). Results from our trial indicate that CP supplementation decreased grazing time by approximately 2 h/d, which is in agreement with the majority of literature. Differences between our trial and Bodine and Purvis (2003) may be due to pasture size (810 ha vs. 130 ha), which may have affected herd dynamics and group behavior.

Distance traveled and maximum distance from water did not exhibit TRT x day interactions ($P \geq 0.06$); therefore, overall TRT means are presented. Distance traveled (5881 ± 160 m/d) and maximum distance from water (1864 ± 105 m/d) were not affected ($P \geq 0.40$) by CP supplementation or SF (Table 3). Additionally, cow distribution (69 ± 2% ha occupied•pasture^{-1}•yr^{-1}) was not affected by CP supplementation or SF ($P \geq 0.40$; Table 4).

Strategic placement of a CP supplement can affect livestock distribution (Bailey et al., 2001); however, little research has evaluated the effects of CP supplementation and SF on livestock distribution. Adams (1985) reported that steers grazing Russian wild ryegrass and supplemented with corn traveled 0.5 km/d further than unsupplemented steers. In contrast, Barton et al. (1992) noted that steers supplemented with CSM did not spend any more time walking than unsupplemented steers grazing intermediate wheatgrass pasture, which is similar to results reported in our trial. Differences between trials for livestock distribution may be may be attributed to differences in grazing behavior because of supplement type (DelCurto et al., 1990b) as well as differences between trial locations in forage quantity and quality (native vs. introduced pastures). In research conducted at the NGBER, Brandyberry et al. (1992) reported that cows grazing native range and supplemented with alfalfa hay or alfalfa pellets daily or every-other-day did not differ in distance traveled (9.92 km/d). However, Melton and Riggs (1964) observed that cows supplemented infrequently with cottonseed cake grazed more widely over winter range than cows supplemented daily. Our results agree with those reported by Brandyberry et al. (1992), suggesting that SF does not affect distance traveled, maximum distance from water, or cow distribution in the northern Great Basin. Differences in results between our trial and Melton and Riggs (1964) may be attributed to differences in location (Southwest United States vs. northern Great Basin), supplement placement within pasture, pasture topography, and(or) herd age. Additionally, behavior data reported by Melton and Riggs (1964) are anecdotal in nature, while our trial was designed to evaluate distribution affects.

Dry Matter Intake and Digestibility

Dry matter intake (21.7 ± 1.8 g•kg BW^{-1}•d^{-1}) was not affected ($P \geq 0.16$) by CP supplementation or SF (Table 4). Multiple researchers suggest that CP supplementation may increase DMI (McCollum and Galyean, 1985; DelCurto et al., 1990a; Köster et al., 1996; and Bandyk et al., 2001); however, our results are in contrast to these. A possible explanation for our results could be related to NDF intake. Mertens (1985, 1994) proposed that NDF intake may be the most important factor influencing forage intake of ruminants fed low-quality forage, suggesting that a forage intake response to CP supplementation may be expected when NDF intake is less than 12.5 g•kg BW^{-1}•d^{-1}. In our trial, calculated NDF intake of control cows was 15 g•kg BW^{-1}•d^{-1} based on an average DMI of 24.9 g•kg BW^{-1}•d^{-1} (Table 4) and an average masticate NDF of 61% (Table 3). Therefore, we did not expect an affect of supplementation on DMI.

Multiple researchers have demonstrated no affect of SF on DMI (Coleman and Wyatt, 1982; Krehbiel et al., 1998; Huston et al., 1999a). Coleman and Wyatt (1982) noted that steers fed range hay and supplemented with CSM every-other-day or once every 4 d had similar DMI to daily supplemented individuals. Additionally, Krehbiel et al. (1988) and Huston et al. (1999a) reported no difference in forage intake for ewes supplemented infrequently compared with daily supplementation. However, other researchers have demonstrated a decrease in forage intake as SF decreased (Beaty et al., 1994; Huston et al., 1999b; Bohnert et al., 2002b). Beaty et al. (1994) reported that steers consuming wheat straw and supplemented three times per week consumed 17% less straw than daily supplemented individuals. Similarly, Huston et al. (1999b) noted a decrease in forage intake of 38 and 27% for supplementation 3d/wk and once per week, respectively, compared to daily supplementation. Bohnert et al. (2002b) reported a linear decrease in hay intake (13%) as SF decreased for lambs consuming low-quality meadow hay. Huston et al. (1999b) and Bohnert et al. (2002b) suggested that decreased forage intake may be the result of a substitution of supplement DM for forage DM by infrequently supplemented individuals, especially on the day of a supplementation event.

Dry matter digestibility (48 ± 4 %) was not affected ($P \geq 0.51$) by CP supplementation or SF (Table 4). While some researchers have demonstrated an increase in DM digestibility of low-quality forage when ruminants are supplemented with CP (McCollum and Galyean, 1985; Caton et al., 1988; Bohnert et al., 2002a, 2002b), the majority of these responses are evident when forage CP is below 6%. Peterson (1987) suggests that increases in digestibility of low-quality forage due to CP supplementation may largely be the result of improved N availability for the ruminal microflora. Research conducted by Mathis et al. (2000) demonstrated that when steers were infused ruminally with sodium caseinate, total tract digestion of OM and NDF was not affected when basal forage CP was 8 to 6%. However, when basal forage CP decreased to 4%, total tract digestion of OM and NDF increased with sodium caseinate infusion. In our trial, forage CP averaged 7.4%, which could have been sufficient to maintain ruminal fermentation and digestion. The lack of an affect of CP supplementation on DM digestibility could also explain our lack of an affect on DMI.

Research has demonstrated no affect of SF on DM digestibility (Coleman and Wyatt, 1982; Hunt et al., 1989; Bohnert et al., 2002a). Coleman and Wyatt (1982) supplemented CSM infrequently to steers consuming low-quality hay and found no affect on DM digestibility compared to daily supplementation. Similarly, Hunt et al. (1989) found no difference in NDF and ADF in situ disappearance in steers supplemented CSM infrequently while consuming low-quality fescue hay. Bohnert et al. (2002a) provided the only data to date which evaluated ruminal, post-ruminal, and total tract OM disappearance of forage as affected by SF. Decreasing SF did not affect ruminal, intestinal, or total tract OM disappearance in steers fed low-quality meadow hay and supplemented once, three times, or six times per week. However, variable results in total tract disappearance of nutrients have been observed (Beaty et al., 1994; Farmer et al., 2001). Beaty et al. (1994) reported that reducing SF increased DM and NDF digestion by steers consuming wheat straw and supplemented once or three times per week. In contrast, Farmer et al. (2001) noted that steers consuming tallgrass prairie and supplemented as infrequently as once per week had decreased total tract OM disappearance as SF decreased. However, the magnitude of change in OM disappearance was small (5%), therefore, the biological relevance of the reduction in OM disappearance may be questionable. Nevertheless, Farmer et al. (2001) proposed that this effect may have been due to altered rumen fermentation by infrequent supplementation, which was supported by a quadratic decrease in ruminal liquid dilution rate as SF decreased. Our results are similar to those of Bohnert et al. (2002b), who noted no difference in total tract DM, OM, or NDF digestibility in lambs consuming low-quality forage and supplemented with CP infrequently.

Harvest efficiency (0.047 ± 0.006 g DMI•kg BW^{-1}•min $grazing^{-1}$) was not affected ($P \geq 0.32$) by CP supplementation of SF (Table 4). No research has evaluated the affects of SF on HE; however, Krysl and Hess (1993) reported in a review that CP supplementation increases HE from 8 to 60% compared with no supplementation. Because we noted a decrease in grazing time and no affect on DMI, we were surprised to find no affect of CP supplementation on HE. A possible reason for this observation could be because of the numerical decrease in DMI as SF decreased in conjunction with the decrease in grazing time. Additionally, due to logistical constraints, DMI and grazing time estimates were not evaluated at the same time, which may have limited our ability to detect differences in HE.

Variability in Supplement Intake

The percentage of supplementation events frequented (68 ± 12%) was not affected by SF ($P = 0.82$; Table 4). In contrast, McIlvain and Shoop (1962) and Melton and Riggs (1964) reported anecdotal observations that more frequently supplemented cows seemed to anticipate supplementation events more consistently than those supplemented less frequently. Similarly, Beaty et al. (1994) reported that as SF decreased, cow proximity to the feeding area before a supplementation event decreased. Differences between trials may be attributed to our ability to monitor individual animals, in comparison to case studies or observational data for an entire herd. Additionally, we provided an audio cue to entice cows to a supplementation event, which was not provided in most of the previously mentioned studies.

The CV for supplement intake was not different ($P = 0.22$) between D and 6D TRT (36 and 21%, respectively), however, it is important to note the reduction in CV by 42% for 6D vs. D (Table 4). Numerically, our data was similar to Huston et al. (1999b), who reported that cows supplemented infrequently (three times weekly or once weekly) exhibited approximately 33% less variation in supplement intake compared with daily supplemented cows. The reason we were unable to detect a significant difference in CV for supplement intake was due to one cow in the 6D TRT consuming a disproportionate amount of supplement in one year. In fact, if we remove this outlier from the data set, we find that she accounted for 73% of the total MSE (160.55 vs. 43.23, respectively) and the CV for supplement intake decreased from 21 to 15% for the 6D TRT (D vs 6D; $P = 0.02$). While not statistically different, we believe there is a strong numerical trend for a decrease in variation in supplement intake as SF decreases. The decrease in the CV for supplement intake is most likely the result of the increased quantity of supplement offered with less frequent supplementation. Foot and Russel (1973) demonstrated that the CV for supplement intake decreased from 36 to 13% when supplement offered to ewes was increased from 100 to 453 g/d. Additionally, Kahn (1994) found that the CV for supplement intake by sheep decreased by 10% when supplement offered was increased from 55 to 110 g/d. Infrequent supplementation increases the amount of supplement offered per supplementation event, thereby potentially allowing individual animals more opportunity to consume supplement.

Implications

Infrequent supplementation of crude protein to cows grazing low-quality forage results in animal performance and grazing behavior similar to that of daily supplemented individuals. Variation in supplement intake may decrease with decreasing supplementation frequency, however, dominant cows may have the ability to consume disproportionate amounts of supplement regardless of supplementation frequency. Infrequent supplementation is a management alternative that can help lower costs associated with protein supplementation of cows grazing native range in the northern Great Basin.

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APPENDIX

Table 1: Evaluation of protein supplements fed to ruminants: Performance

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Grass hay or pasture	Low and high protein or energy	Heifers: High = 0.45 kg ADG L = 60-82% of high Cows: to maintain production	Reported digestible protein requirements for heifers and cows to begin estrus cycling and sustain pregnancy	Clanton and Zimmerman, 1970
Blue grass straw (2.27 % CP)	SBM (48% CP); adequate or deficient CP	Adequate = 1.68 kg/d SBM; Deficient = 0 kg/d SBM	Reduced protein intake increased postpartum interval to first estrus, first service, and conception and decreased the number of animals showing estrus and conceiving	Sasser et al., 1988
Dormant tallgrass prairie vegetation	13, 25, and 39% CP provided by SBM and dry-rolled grain	0.5% BW of supplement	Linear decrease in BW loss	DelCurto et al., 1990b
Tall fescue straw (4% CP)	Tall fescue hay (12% CP) or alfalfa hay (19% CP)	Tall fescue hay = 0.61% BW Alfalfa hay = 0.4% BW	BW gain increased: control vs supplementation and tall fescue vs alfalfa	Horney et al., 1996

Table 1. Evaluation of protein supplements fed to ruminants: Performance (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Low-quality prairie forage (3% CP)	SBM (54% CP)	0.08, 0.12, 0.16, 0.20, 0.24, 0.32, 0.40, or 0.48 % BW/d of SBM	BW and BCS loss decreased with supplementation, reaching a plateau at 0.32% BW	Mathis et al., 1999
Meadow hay (5% CP)	DIP (55% CP) or UIP (63% CP)	0.08% BW/d of CP	Pre- and postcalving cow weight and BCS change were more positive for supplemented groups than for controls	Bohnert et al., 2002b

Table 2. Evaluation of protein supplements fed to ruminants: Forage intake

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Oat straw (3% CP)	Urea infused into reticulo-rumen	0, 25, 75, or 150 g/d urea	Exp. 1 and 2: 75 or 150 g/d urea increased straw intake by 40% Exp. 2: 25 g/d urea increased straw intake by 26%	Campling et al., 1962
Chaffed oaten hay (3.9 – 4.4% CP)	Casein or urea infused into duodenum	Casein – 70g/d; Urea – 21.5g/d	Exp. 1: Increased hay intake for casein and urea Exp. 2: Increased hay intake for casein	Egan and Moir, 1965
Exp. 1 – oaten chaff (3.4% CP) Exp. 2 – wheat straw (2.3% CP) and 3% urea	Casein or urea infused into duodenum	Casein – 4.6g/d N; Urea – 4.5g/d N	Exp. 1: Increased hay intake for casein (42%) and urea (12%) Exp. 2: Increase hay intake for casein (11%)	Egan, 1965
Prairie hay (6% CP)	CSM (38% CP)	0 or 800 g CSM •head^{-1}•d^{-1}	Hay intake increased by 27% because of supplementation	McCollum and Galyean, 1985
Prairie hay (6.3% CP)	CSM (41% CP)	80 g CSM/d	Prairie hay intake increased by 19%	Krysl et al., 1987
Dormant bluestem hay (3% CP)	SBM and dry-rolled grain: 0, 12 (L), 28 (M), and 41 (H)% CP	0.4% BW	Supplementation increased forage intake (34%) and M and H TRT increased forage DMI by 70% and 42% compared with L TRT, respectively	DelCurto et al., 1990a

Table 2. Evaluation of protein supplements fed to ruminants: Forage intake (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Prairie hay (2% CP)	Intraruminally infused sodium caseinate (90% CP)	0, 180, 360, 540, and 720 g/d sodium caseinate	Increase in forage OMI compared to control, up to 720 g/d supplemental DIP (DOM intake = 11% DIP)	Köster et al., 1996
Bromegrass hay (4.3% CP)	Urea, SBM, Blood meal and Feather meal; 34, 30, and 34% CP, respectively	Urea = 0.3% BW/d; SBM and Blood/Feather meal = 0.33% BW/d	No affect of CP supplementation on hay DM intake	Ferrell et al., 1999
Bermudagrass (Exp. 1; 8% CP), bromegrass (Exp. 2; 6% CP), or forage sorghum (Exp. 3; 4% CP)	Ruminally infused sodium caseinate (90% CP)	0, 0.41, 0.82, and 0.124 % BW/d	Exp. 1: No affect on forage intake Exp. 2: No affect on forage intake Exp. 3: Forage intake increased	Mathis et al., 2000
Tallgrass-prairie hay (3.4% CP)	Ruminal and postruminal infused sodium caseinate (90% CP)	400 g/d sodium caseinate	Increased hay OMI for ruminal and postruminal infusion compared to control (28 and 62%, respectively)	Bandyk et al., 2001
Meadow hay (5.3% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.10% BW/d of CP	No affect of CP supplementation on hay DM or OM intake	Bohnert et al., 2002a

Table 2. Evaluation of protein supplements fed to ruminants: Forage intake (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Meadow hay (5.2% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.19% BW/d of CP	No affect of CP supplementation on hay DM or OM intake	Bohnert et al., 2002b

Table 3. Evaluation of protein supplements fed to ruminants: Nitrogen utilization

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Alkali-treated oat straw (11.3% CP)	CSM (46% CP)	700 g/d CSM	Total N and bacterial N flow at abomasum was higher for control than CSM TRT	Spragg et al., 1986
Bluestem-range (2.3% CP)	SBM and sorghum grain (L and M) or dehydrated alfalfa pellets	12.8 (L), 27.1 (M), and 17.5 (Dehy)% CP	Duodenal N flow was greater for M and dehy vs L and control; apparent ruminal N digestibility increased with supplementation	Hannah et al., 1991
Dormant bluestem-range (2.8% CP)	Dehydrated alfalfa pellets, longstem alfalfa hay, or sun-cured alfalfa pellets (approximately 20% CP)	0.5% BW	Increased total N, microbial N, and nonammonia-nonmicrobial N flows to the duodenum	Lintzenich et al., 1995
Tallgrass-prairie (2% CP)	Intraruminally infused sodium caseinate (90% CP)	0, 180, 360, 540, and 720 g/d	Total duodenal N flow maximized at 540 g/d DIP and total tract N digestibility increased with supplemental DIP	Köster et al., 1996
Bromegrass hay (4.3% CP)	Urea, SBM, Blood meal and Feather meal; 34, 30, and 34% CP, respectively	Urea = 0.3% BW/d; SBM and Blood/Feather meal = 0.33% BW/d	Apparent N digestibility increased with supplementation; supplementation increased arterial, and portal and hepatic vein ammonia N and urea N concentration	Ferrell et al., 1999

Table 3. Evaluation of protein supplements fed to ruminants: Nitrogen utilization (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Meadow hay (5% CP)	DIP (53% CP) or UIP (60% CP)	0.10% BW/d of CP	Supplemental CP increased duodenal N and nonbacterial N flow, intestinal N disappearance, and total tract N digestibility	Bohnert et al., 2002a
Meadow hay (5% CP)	DIP (53% CP) and UIP (60% CP)	0.19% BW/d of CP	Supplemental CP increased N retention, N digestibility, digested N retained, and plasma urea-N	Bohnert et al., 2002b

Table 4. Evaluation of protein supplements fed to ruminants: Microbial efficiency (g microbial N/kg OM truly digested)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Microbial Efficiency	Reference
Prairie hay (4.8% CP)	SBM (48% CP)	0, 0.12, 0.24% BW SBM	8.3, 7.7, and 8.7 (no affect of CP supplementation)	Stokes et al., 1988
Blue grama rangeland (9 – 13% CP)	SBM or steam-flaked sorghum grain	0 or 0.5 kg SBM or grain/d	19.7, 18.5, and 16.8 (no affect of CP supplementation)	Krysl et al., 1989
Mixed-grass prairie (9-10% CP)	Yeast culture and advancing season	0 or 28.4g/d yeast culture	17 and 16.4 (no affect of yeast supplementation, but increased as CP of forage decreased)	Olson et al., 1994
Bluestem-range (3% CP)	Alfalfa hay (21% CP)	0 or 0.5% BW/d	12.3, 13.3, 13.9, and 14.5 (no affect of CP supplementation)	Lintzenich et al., 1995
Tall-grass prairie forage (2% CP)	Intraruminal infusion of sodium caseinate (90% CP)	0, 180, 360, 540, and 720 g/d	12.2, 15.2, 17, 19.1, and 20 (increased efficiency with CP supplementation)	Köster et al., 1996
Low-quality forage (5%CP)	DIP or UIP supplements	0.1% BW/d of CP	20, 28.9, 29, 32, 23.2, 28.8, and 24 (increased efficiency with CP supplementation; Con vs DIP D, 3D, 6D, and UIP D, 3D, and 6D, respectively)	Bohnert et al., 2002a
Low-quality forage (4% CP)	Urea or Biuret	0.04% BW/d of CP	24.1, 20.8, 24.2, 26.2, and 26.9 (no affect of CP supplementation; Control vs Urea D, 2D, and Biuret D, and 2D)	Currier et al., 2003b

Table 5. Evaluation of protein supplements fed to ruminants: Ruminal NH_3 and volatile fatty acid responses

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Prairie hay (6% CP)	CSM (38% CP)	800 g/d CSM	Supplementation increased ruminal NH_3 and acetate and propionate concentrations, but not total VFA	McCollum and Galyean, 1985
Alkali-treated oat straw (11.3% CP)	CSM (46% CP)	700 g/d CSM	Rumen NH_3 and plasma urea N were higher for control than CSM TRT	Spragg et al., 1986
Prairie hay (6.3% CP)	CSM (41% CP)	80 g CSM/d	Ruminal pH, total VFA, and molar proportions of VFA were not affected by supplementation	Krysl et al., 1987
Dormant blue grama rangeland (Exp. 1 = 8% CP; Exp. 2 = 7 – 9% CP)	CSM (45.5% CP)	0.83 kg/d	Molar proportions of acetate and propionate were not affected, but butyrate and ruminal NH_3 increased due to supplementation	Caton et al., 1988
Blue grama rangeland (9 – 13 % CP; OM basis)	SBM	0.5 kg/d SBM	Supplementation increased ruminal NH_3 and valerate but had not affect on total VFA or isobutyrate and isovalerate	Krysl et al., 1989
Bluestem-range (2.3% CP)	SBM and sorghum grain (L and M) or dehydrated alfalfa pellets	12.8 (L), 27.1 (M), and 17.5 (Dehy)% CP	Ruminal NH_3 and total VFA increased with supplementation and for M and Dehy compared to L	Hannah et al., 1991

Table 5. Evaluation of protein supplements fed to ruminants: Ruminal NH_3 and volatile fatty acid responses (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Dormant bluestem-range (2.8% CP)	Dehydrated alfalfa pellets, longstem alfalfa hay, or sun-cured alfalfa pellets (approximately 20% CP)	0.5% BW	No affect on ruminal pH, but increased ruminal total VFA, butyrate and valerate, and NH_3 concentrations	Lintzenich et al., 1995
Tall fescue straw (4% CP)	Tall fescue hay (12% CP) or alfalfa hay (19% CP)	Tall fescue hay = 0.61% BW Alfalfa hay = 0.4% BW	Ruminal NH_3 was higher for supplemented than unsupplemented steers	Horney et al., 1996
Tallgrass-prairie (2% CP)	Intraruminally infused sodium caseinate (90% CP)	0, 180, 360, 540, and 720 g/d	Total ruminal VFA and NH_3 concentrations increased and pH decreased with supplemental DIP	Köster et al., 1996
Prairie hay (5.3% CP)	SBM (53% CP)	0.08, 0.16, 0.33, and 0.50% BS/d SBM	Ruminal pH tended to decrease and ruminal NH_3 and total VFA concentration increased with increasing levels of supplementation; molar proportions of BCVFA increased linearly	Mathis et al., 1999

Table 5. Evaluation of protein supplements fed to ruminants: Ruminal NH_3 and volatile fatty acid responses (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Prairie hay (6% CP)	SBM (49% CP)	0, 33, 66, or 100% of supplemental SBM necessary to meet DIP requirements	Supplementation did not affect BCVFA	Bodine et al., 2000
Bermudagrass (Exp. 1; 8% CP), bromegrass (Exp. 2; 6% CP), or forage sorghum (Exp. 3; 4% CP)	Ruminally infused sodium caseinate (90% CP)	0, 0.41, 0.82, and 0.124 % BW/d	Exp. 1: Ruminal pH was not affected but ruminal NH_3 and total and BCVFA increased Exp. 2: Ruminal pH was not affected but ruminal NH_3 increased linearly and total VFA increased quadratically; molar proportions of BCVFA increased linearly Exp. 3: Ruminal pH decreased as supplemental DIP increased and ruminal NH_3 and total and BCVFA increased	Mathis et al., 2000
Tallgrass-prairie hay (3.4% CP)	Ruminally or intraruminally infused sodium caseinate (90% CP)	400 g/d sodium caseinate	No affect of infused DIP on ruminal pH or total VFA concentrations; ammonia N and plasma urea N concentration increased with DIP supplementation	Bandyk et al., 2001

Table 5. Evaluation of protein supplements fed to ruminants: Ruminal NH_3 and volatile fatty acid responses (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Meadow hay (5% CP)	DIP (53% CP) or UIP (60% CP)	0.10% BW/d of CP	CP supplementation decreased ruminal pH and increased ruminal NH_3, propionate, isobutyrate, and valerate	Bohnert et al., 2002c

Table 6. Evaluation of protein supplements fed to ruminants: Nutrient digestibility

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Native fall-winter range (Exp. 1 = 5 – 7% CP; Exp. 2 = 6.5 – 9.4% CP)	Exp. 1 = CSM Exp. 2 = SBM	Exp. 1 = 0.75kg/d CSM Exp. 2 = 0.70 kg/d SBM	Exp. 1 = Total DMD was not affected by crude protein supplementation Exp. 2 = Total DMD increased by 14%	Kartchner, 1980
Prairie hay (6% CP)	CSM (38% CP)	800 g/d CSM	IVDMD increased at 6, 12, 18, and 24 h postfeeding	McCollum and Galyean, 1985
Alkali-treated oat straw (11.3% CP)	CSM (46% CP)	700 g/d CSM	Apparent OM digestibility from stomach decreased with supplementation (75 to 67%), but saw no affect on total tract OM digestibility;	Spragg et al., 1986
Prairie hay (6.3% CP)	CSM (41% CP)	80 g CSM/d	Rumen particulate retention time did not differ, but intestinal transit time was faster for supplemented TRT	Krysl et al., 1987
Dormant blue grama rangeland (Exp. 1 = 8% CP; Exp. 2 = 7 – 9% CP)	CSM (45.5% CP)	0.83 kg/d	In vitro OM and in situ NDF disappearance (36 h) increased with supplementation (6 and 19%, respectively)	Caton et al., 1988

Table 6. Evaluation of protein supplements fed to ruminants: Nutrient digestibility (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Dormant bluestem hay (2.9% CP)	12 (LP), 28 (MP), and 41 (HP)% CP supplements provided as SBM and dry-rolled grain	0.4% BW	Ruminal DM and indigestible ADF fill at 4 h postfeeding were greater for MP and HP TRT than control and LP TRT; Total tract DMD increased with supplementation (36 vs 47% for control and supplemented TRT, respectively)	DelCurto et al., 1990a
Bluestem-range (2.3% CP)	SBM and sorghum grain (L and M) or dehydrated alfalfa pellets	12.8 (L), 27.1 (M), and 17.5 (Dehy)% CP	Ruminal OMD increased by 39% for M and Dehy compared to L and control; Total tract OMD was greatest for M	Hannah et al., 1991
Wheat straw (3% CP)	Sorghum grain and SBM	12, 20, 30, and 39% CP	Total DM and NDF digestibility increased	Beaty et al., 1994
Dormant bluestem-range (2.8% CP)	Dehydrated alfalfa pellets, longstem alfalfa hay, or sun-cured alfalfa pellets (approximately 20% CP)	0.5% BW	Increased true ruminal OM and total tract OM digestibility	Lintzenich et al., 1995

Table 6. Evaluation of protein supplements fed to ruminants: Nutrient digestibility (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Tall fescue straw (4% CP)	Tall fescue hay (12% CP) or alfalfa hay (19% CP)	Tall fescue hay = 0.61% BW Alfalfa hay = 0.4% BW	DMD was greater for supplemented steers than for nonsupplemented steers.	Horney et al., 1996
Tallgrass-prairie (2% CP)	Intraruminally infused sodium caseinate (90% CP)	0, 180, 360, 540, and 720 g/d sodium caseinate	True ruminal OM and NDF digestion increased with the addition of 180 g/d DIP; total tract OM disappearance tended to increase with supplemental DIP, but no affect on NDF disappearance	Köster et al., 1996
Bromegrass hay (4.3% CP)	Urea, SBM, Blood meal and Feather meal; 34, 30, and 34% CP, respectively	Urea = 0.3% BW/d; SBM and Blood/Feather meal = 0.33% BW/d	Apparent digestibility of DM and OM increased with supplementation	Ferrell et al., 1999
Prairie hay (5.3% CP)	SBM (53% CP)	0.08, 0.16, 0.33, and 0.50% BW/d SBM	Total tract OM and NDF digestibility increased linearly with linear increases in supplementation, but reached a plateau at 0.33% BW/d	Mathis et al., 1999

Table 6. Evaluation of protein supplements fed to ruminants: Nutrient digestibility (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Bermudagrass (Exp. 1; 8% CP), bromegrass (Exp. 2; 6% CP), or forage sorghum (Exp. 3; 4% CP)	Ruminally infused sodium caseinate (90% CP)	0, 0.41, 0.82, and 0.124 % BW/d	Exp. 1: Total tract digestion of OM and NDF was not affected Exp. 2: Total tract digestion of OM and NDF was not affected Exp. 3: Total tract digestion of OM and NDF increased	Mathis et al., 2000
Tallgrass-prairie hay (3.4% CP)	Ruminally or intraruminally infused sodium caseinate (90% CP)	400 g/d sodium caseinate	Total tract OM digestibility increased with supplemental infused DIP, with no affect on NDF digestibility	Bandyk et al., 2001
Meadow hay (5% CP)	DIP (53% CP) or UIP (60% CP)	0.10% BW/d of CP	Supplemental CP increased total tract OMD but had no affect on ruminal OM and NDF disappearance	Bohnert et al., 2002a
Meadow hay (5% CP)	DIP (53% CP) and UIP (60% CP)	0.19% BW/d of CP	Supplemental CP increased DM, OM, and NDF digestibility	Bohnert et al., 2002b

Table 7. Evaluation of frequency of crude protein supplementation in ruminants: Performance

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Dormant, winter range	CSM (41% CP)	0.5 – 0.7 kg/d; 1x, every-3d, or 7x weekly	D, every 3d, and every 7d had similar, positive weight gains	McIlvain and Shoop, 1962
Dormant range	CSM	0.91 kg/d; 7x, 2x, or 3x weekly	No affect on percent calf crop weaned, weaning weight, or weaned calf weight produced; no difference in cow weight gain; 101 (twice) and 95% (thrice) weight gain of daily	Melton and Riggs, 1964
Meadow fescue grass hay (6.6% CP)	CSM (44% CP)	850 g/d; every 0, 12, 24, or 48 h	Improved ADG with supplementation (27%), but no difference between 12 and 48 h	Hunt et al., 1989
Wheat straw (3.1% CP)	Mixture of SBM and sorghum grain; 12, 20, 30 or 39% CP	1.98 kg/d; 1x or 3x weekly	Pre-calving weight change was less negative for daily supplementation (16%); no difference for weight and BCS change at weaning	Beaty et al., 1994
Low-quality forage	CSM (41% CP)	0, 1x, 4x, or 7x weekly	No difference due to SF in sheep body weight gain/loss	Huston et al., 1999a
Low-quality forage	CSM (41% CP)	0 or 0.91 kg/d; 1x, 3x, or 7x weekly	Supplementation decreased body weight loss (67 - 83%); no difference due to SF	Huston et al., 1999b
Tallgrass prairie (4% CP)	43% CP supplement	2x, 3x, 5x, or 7x weekly	No difference in BCS loss, but a decrease in BW loss with increasing SF	Farmer et al., 2001

Table 7. Evaluation of frequency of crude protein supplementation in ruminants: Performance (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Meadow hay (5.2% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.08% BW/d of CP; 1x, 3x, or 6x weekly	No affect of SF on cow weight and BCS gain, or calf birth date/weight	Bohnert et al., 2002b
Grass hay	20% CP; SBM, urea, or biuret	7x weekly or every other day	No affect of SF or CP source on weight gain	Thomas and Armitage, 1972
Dormant hay (6% CP)	CSM, urea, or biuret	7x weekly or every other day	No difference between SF or CP source	Oltjen et al., 1974 (Trial 4)
Dormant tall-grass prairie (4% CP)	40% CP; urea providing 0, 15, 30, or 45% of supplemental DIP	1.82 kg/d; 3x or 7x weekly	Cows fed 45% urea TRT 3x weekly had decreased supplement intake, cow weight, and BCS	Farmer et al., 2002
Hard fescue straw (4% CP)	29% CP; urea or biuret providing a portion of the supplemental DIP	0.04% BW/d of CP; 7x weekly or every other day	No affect of SF or urea vs biuret on cow weight or BCS	Currier et al., 2003a

Table 8. Evaluation of frequency of crude protein supplementation in ruminants: Forage intake

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Range hay (8% CP)	CSM	0.45kg/d; 7x weekly, every 4th, or every other day	No affect of SF on DM intake	Coleman and Wyatt, 1982
Meadow fescue grass hay (6.6% CP)	CSM (44% CP)	850 g/d; every 0, 12, 24, or 48 h	Dry matter and NDF intake was not affected by SF	Hunt et al., 1989
Wheat straw (3.1% CP)	Mixture of SBM and sorghum grain; 12, 20, 30 or 39% CP	1.98 kg/d; 1x or 3x weekly	3x weekly consumed 17% less straw DM than 7x weekly	Beaty et al., 1994
Bromegrass hay (7.5% CP)	SBM	80 g/d CP; every 24- or 72-h	No difference in forage and total intake between 24- and 72-h supplemented ewes	Krehbiel et al., 1998
Low-quality forage	CSM (41% CP)	0, 1x, once every 4 d, or 7x weekly	Forage intake was not affected by SF in sheep	Huston et al., 1999a
Low-quality forage	CSM (41% CP)	0 or 0.91 kg/d; 1x, 3x, or 7x weekly	Forage intake tended to decrease in proportion to supplement intake (38 and 27% for 3x and 7x TRT, respectively)	Huston et al., 1999b
Tallgrass prairie (5% CP)	43% CP supplement	2x, 3x, 5x, or 7x weekly	Forage and total OM intake decreased linearly as SF decreased	Farmer et al., 2001

Table 8. Evaluation of frequency of crude protein supplementation in ruminants: Forage intake (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Meadow hay (5.3% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.10% BW/d of CP; 1x, 3x, or 6x weekly	Hay and total DM and OM decreased for 6x weekly TRT, due to substitution affect (steers)	Bohnert et al., 2002a
Meadow hay (5.2% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.19% BW/d of CP; 1x, 3x, or 6x weekly	Hay and total DM, OM, N, and NDF intake decreased as SF decreased (13%) (lambs)	Bohnert et al., 2002b

Table 9. Evaluation of frequency of crude protein supplementation in ruminants: Nitrogen utilization

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Range hay (8% CP)	CSM	0.45kg/d; 7x weekly, every 4th, or every other day	SF did not affect N retained	Coleman and Wyatt, 1982
Bromegrass hay (7.5% CP)	SBM	80 g/d CP; every 24- or 72-h	SF may affect the pattern of N absorption, but does not affect net absorption of N	Krehbiel et al., 1998
Low-quality forage	CSM (41% CP)	0, 1x, every other day, or 7x weekly	SUN exhibited a significant increase on day of feeding for infrequently supplemented ewes, but declined to control levels between supplementation events	Huston et al., 1999a
Low-quality forage	CSM (41% CP)	0 or 0.91 kg/d; 1x, 3x, or 7x weekly	SUN increased at 24 and 96 h post-feeding for 7x compared to 1x; no difference between 1x and the mean of 3x and 7x	Huston et al., 1999b
Meadow hay (5.2% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.19% BW/d of CP; 1x, 3x, or 6x weekly	Nitrogen balance and plasma urea-N decreased linearly as SF decreased; digested N retained not affected by SF (lambs)	Bohnert et al., 2002b
Meadow hay (5.3% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.10% BW/d of CP; 1x, 3x, or 6x weekly	Duodenal N flow responded quadratically, with the highest value for the 3x TRT; no difference for SF on intestinal N disappearance	Bohnert et al., 2002a

Table 10. Evaluation of frequency of crude protein supplementation in ruminants: Ruminal NH_3 and volatile fatty acid responses

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Meadow fescue grass hay (6.6% CP)	CSM (44% CP)	850 g/d; every 0, 12, 24, or 48 h	Ruminal VFA concentration was not affected by SF	Hunt et al., 1989
Tallgrass prairie (5% CP)	43% CP supplement	2x, 3x, 5x, or 7x weekly	Ruminal NH_3 remained higher than other TRT for 6, 9, and 12 h post-prandial; supplementation 5x weekly had the highest ruminal NH_3; a similar trend was observed for total VFA concentration; increase in liquid passage rate as SF decreased	Farmer et al., 2001
Meadow hay (5.3% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.10% BW/d of CP; 1x, 3x, or 6x weekly	Ruminal NH_3 increased at a greater rate for DIP than UIP TRT as SF decreased on the d of supplementation; total VFA concentration increased as SF decreased on the d of supplementation; ruminal liquid volume increased as SF decreased for DIP, with a minimal effect for UIP on the d of supplementation; ruminal liquid dilution rate was greatest for 3x for DIP, and decreased with decreasing SF for UIP	Bohnert et al., 2002c

Table 11. Evaluation of frequency of crude protein supplementation in ruminants: Nutrient digestibility

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Range hay (8% CP)	CSM	0.45 kg/d; 7x weekly, every 4th, or every other day	SF did not affect total tract DM digestibility	Coleman and Wyatt, 1982
Meadow fescue grass hay (6.6% CP)	CSM (44% CP)	850 g/d; every 0, 12, 24, or 48 h	NDF and ADF in situ disappearance were not affected by SF	Hunt et al., 1989
Wheat straw (3.1% CP)	Mixture of SBM and sorghum grain; 12, 20, 30 or 39% CP	1.98 kg/d; 1x or 3x weekly	Reducing SF increased total tract DM and NDF digestion, but no affect on rumen particulate passage rate	Beaty et al., 1994
Tallgrass prairie (5% CP)	43% CP supplement	2x, 3x, 5x, or 7x weekly	Decreasing SF decreased total tract OM and NDF digestion by up to 5%	Farmer et al., 2001
Meadow hay (5.3% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.10% BW/d of CP; 1x, 3x, or 6x weekly	SF did not affect ruminal, intestinal, or total tract OM disappearance (steers)	Bohnert et al., 2002a
Meadow hay (5.2% CP)	SBM (53% CP) or soyPLUS (60% CP)	0.19% BW/d of CP; 1x, 3x, or 6x weekly	SF did not affect total tract DM, OM, or NDF digestibility (lambs)	Bohnert et al., 2002b

Table 11. Evaluation of frequency of crude protein supplementation in ruminants: Nutrient digestibility (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Hard fescue straw (4% CP)	Urea (29% CP) or Biuret (29% CP)	0.04% BW/d of CP; every d or every-other d	No affect of SF on OM or NDF disappearance from the stomach (steers)	Currier et al., 2003b
Hard fescue straw (4.3% CP)	Urea (29% CP) or Biuret (29% CP)	0.10% BW/d of CP; every d or every-other d	SF did not affect total tract DM, OM, NDF, or ADF digestibility (lambs)	Currier et al., 2003a

Table 12. Evaluation of crude protein supplements fed to ruminants: Variability in supplement intake

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Low-quality forage	Oats	100 or 453 g/d	CV for supplement intake decreased from 36 to 13% for ewes supplemented 100 or 453 g/d, respectively	Foot et al., 1973
Pasture	CSM	55 or 110 g/d	As supplement offered increased, low consumers decreased by 10%	Kahn, 1994
Low-quality forage	CSM (41% CP)	0 or 0.91 kg/d; 1x, 3x, or 7x weekly	Cows supplemented 3x or 7x per week exhibited 33% less variability in supplement intake	Huston et al., 1999b
Winter native pasture in New South Wales	Molasses-urea liquid	Ad-lib	17% of pregnant heifers did not consume measurable quantities of supplement; intake ranged from 0.3 to 2.4 l/d	Nolan et al., 1974
Barley straw	Cubed barley-SBM or molasses-urea blocks	Ad-lib blocks, 0.61 kg/d concentrate	CV for supplement intake decreased from 57 to 31% when dry supplement was offered	Kendall et al., 1980
Moderate-quality hay	Barley-SBM pellets or molasses-urea blocks	Ad-lib blocks, concentrate at the level of block intake	CV for supplement intake was higher for blocks (56%) than trough-fed concentrates (39%) at equal average daily DM intakes	Kendall et al., 1983
Native range	Regulated or unregulated liquid molasses (29% CP)	Regulated ad-lib or ad-lib	2-yr-old cows visited the feeders less frequently and spent less time at the feeders than 3-yr-old cows	Sowell et al., 1995

Table 12. Evaluation of crude protein supplements fed to ruminants: Variability in supplement intake (continued)

Basal Diet	Supplemental CP Source	Supplement Feeding Level	Response	Reference
Native range	Regulated or unregulated liquid molasses (29% CP)	Regulated at-lib or ad-lib	2-yr-old cows consumed less supplement than 3-yr-old cows	Bowman et al., 1999

Table 13. Evaluation of supplements fed to ruminants: Livestock distribution

Basal Diet	Supplement Source	Supplement Feeding Level	Response	Reference
			Supplemented cows traveled further than unsupplemented cows	Wagnon, 1963
Northern Utah range	Salt		Salt and water affected cow distribution	Cook, 1966
Russian wild ryegrass (6.6% CP)	Corn fed at 0730 or 1330 h	0.3 kg/100 kg BW	Steers supplemented with corn traveled 0.5 km/d further than unsupplemented steers	Adams, 1985
Dormant native range (5.5% CP)	Alfalfa hay or alfalfa pellets (20 and 18% CP)	2 kg/d or 4 kg/alternate day	No difference in distance traveled due to supplemental protein source	Brandyberry et al.,1992
Intermediate wheatgrass	CSM fed at 0600 or 1200 h	0.25% BW (47% available CP)	Steers supplemented with CSM did not spend any more time walking than unsupplemented steers	Barton et al., 1992
Semidesert grass-shrub range	Salt or meal-salt (3:1)		No affect of salt or meal-salt on pasture utilization or cow distribution	Martin and Ward, 1973
Montana foothill range	Salt		No affect on cattle distribution or grazing behavior	Bailey and Welling, 1999
Northern Great Basin range	Salt		Movement of salting stations did not affect livestock distribution	Ganskopp, 2001
Oregon foothill range	Salt		Cow distribution and grazing behavior affected by offstream salt and water placement	Porath et al., 2002

Table 14. Evaluation of supplements fed to ruminants: Livestock grazing time

Basal Diet	Supplement Source	Supplement Feeding Level	Response	Reference
			Supplemented cattle spent 5% less of their time grazing than unsupplemented cattle	Wagnon, 1963
Russian wild ryegrass (6.6% CP)	Corn fed at 0730 or 1330 h	0.3 kg/100 kg BW	No difference in grazing time/d	Adams, 1985
Dormant tallgrass prairie	Alfalfa hay fed at 0800 or 1600 h	3.2 kg/d	Cows supplemented with alfalfa decreased their grazing time by 10% compared to unsupplemented individuals	Yelich et al., 1988
Dormant tallgrass-prairie forage (2.7% CP)	SBM:sorghum grain mixture, alfalfa hay, or dehydrated alfalfa (25, 17, and 17% CP, respectively)	69% of CP requirement and 36% of ME requirement	Alfalfa TRT grazed less during February period, but no difference during the January period	DelCurto et al., 1990c
Bluestem range (7% CP)	SBM:sorghum grain mixture (28% CP)	Self-fed with walt, hand-fed with salt, or hand-fed without salt	No differences in grazing behavior	Brandyberry et al., 1991
Dormant intermediate wheatgrass	Alfalfa hay, CSM, or corn gluten feed	0.52, 0.22, or 0.36 % BW, respectively	Unsupplemented cattle grazed approximately 1.5 h/d more than supplemented cattle	Hess et al., 1992

Table 14. Evaluation of supplements fed to ruminants: Livestock grazing time (continued)

Basal Diet	Supplement Source	Supplement Feeding Level	Response	Reference
Dormant native range (5.5% CP)	Alfalfa hay or alfalfa pellets (20 and 18% CP)	2 kg/d or 4 kg/alternate day	Type of supplemental protein did not affect grazing behavior	Brandyberry et al.,1992
Intermediate wheatgrass	CSM fed at 0600 or 1200 h	0.25% BW (47% available CP)	Unsupplemented cattle grazed approximately 1.5 h/d more than supplemented cattle	Barton et al., 1992

Table 15. Evaluation of supplements fed to ruminants: Forage harvest efficiency

Basal Diet	Supplement Source	Supplement Feeding Level	Response	Reference
Russian wild ryegrass (6.6% CP)	Corn fed at 0730 or 1330 h	0.3 kg/100 kg BW	FI decreased by 11% when corn was supplemented to grazing steers, with a decrease in HE from 0.062 to 0.0565	Adams, 1985
Bluestem range (7% CP)	SBM:sorghum grain mixture (28% CP)	Self-fed with walt, hand-fed with salt, or hand-fed without salt	No difference in FI or harvest efficiency	Brandyberry et al., 1991
Dormant intermediate wheatgrass	Alfalfa hay, CSM, or corn gluten feed	0.52, 0.22, or 0.36 % BW, respectively	FI was not altered by CP supplementation or CP source, but HE was greater for alfalfa and CSM supplemented cattle (0.036 and 0.037, respectively) compared to corn gluten feed supplemented and control cattle (0.03 and 0.027, respectively)	Hess et al., 1992
Dormant native tallgrass prairie	Corn and SBM, corn and soybean hulls, SBM, or cottonseed hulls	13.6, 13.6, or 4.2 g DM/kg BW or 178 g DM, respectively	Corn supplementation decreased grazing time and intensity and HE when compared to SBM or cottonseed hull supplementation	Bodine and Purvis, 2003
Intermediate wheatgrass	CSM fed at 0600 or 1200 h	0.25% BW (47% available CP)	FI of grazing steers was not affected by supplementation, but HE increased from 0.037 to 0.05	Barton et al., 1992

Table 16. Evaluation of frequency of crude protein supplementation in ruminants: Distribution, behavior, and grazing time

Basal Diet	Supplement Source	Supplement Feeding Level	Response	Reference
Winter range	Cottonseed pellets (41% CP)	Approx. 1.5 lb/d; daily, every other day, or once per week	Daily cattle were at the feed troughs at feeding time, every other day less frequently, and once per week least frequently	McIlvain and Shoop, 1962
Winter range	Cottonseed cake	14 lb /week; daily, 2x or 3x per week	Grazing behavior was different on supplementation days than on unsupplemented days; twice weekly fed cows grazed more widely over the pasture	Melton and Riggs, 1964
Dormant mixed prairie range	Cottonseed cake (41% CP)	1.5 lb on alternate days	Unsupplemented cattle spent more time walking and walked over twice as far as supplemented cattle (4.1 vs. 1.9 mi./d)	Box et al., 1965
Dormant native range (5.5% CP)	Alfalfa hay or alfalfa pellets (20 and 18% CP)	2 kg/d or 4 kg/alternate day	Type of supplemental protein did not affect distance traveled or grazing behavior	Brandyberry et al.,1992