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Supplementation and sustainable grazing systems[1]

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ABSTRACT: The purpose of this review is to emphasize rangeland and landscape attributes that effect animal grazing behavior while highlighting successful approaches that have utilized this knowledge to devise supplementation strategies that improve the sustainability of grazing systems through modification of grazing behavior and pasture distribution, irrespective of animal nutrient requirements. Consequently, supplementation strategies are no longer formulated with the sole objective of addressing animal nutrient requirements. One of the principle drivers for this change in management philosophy is rangelands have become valued for many ecological services beyond forage for livestock. The threat of litigation and/or legal mandates that require land managers to consider the ecological, social, and economic impact of management decisions has increased scrutiny of livestock grazing. This has resulted in a significant body of research evaluating the ability of supplementation strategies to maintain or improve rangeland health and ecological function in a way that is economically viable. Herein, we will review the use of supplementation practices to alter livestock grazing location and control invasive species. Also, we will discuss the use of complimentary forages to bridge periods of inadequate forage quality. Rangeland-based livestock producers utilizing extensive landscapes will continue to face management challenges including changes in public land policy, anthropogenic development, climatic variability, invasive weeds, wildfire, water quality, and threatened and endangered species concerns. As an industry and a discipline we must continue to improve or ability to manage for "designed" landscapes that improve the economics of livestock production while maintaining or enhancing rangeland health and ecological function, thereby improving the long-term sustainability of grazing systems.

Key words: grazing behavior, landscape, livestock, management, rangelands, supplementation

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INTRODUCTION

Historically, the objective of supplementation programs has been to address nutrient deficiencies based on the difference between animal nutrient requirements and nutrients provided by the forage, with emphasis on improving forage utilization and animal performance. Numerous scientific reviews have done an excellent job summarizing the available data on this aspect (Cook and Harris, 1968; Moore et al., 1999; DelCurto et al., 2000; Greene, 2000; Kunkle et al., 2000; Olson, 2007). However, recent land management challenges have resulted in another reason to use a supplementation program- modification of grazing behavior. When ruminants graze large, extensive pastures, specifically arid/semiarid rangelands with rough topography, they tend to prefer areas with gentle terrain and proximity to water while avoiding those areas more distant from water and with steeper slopes (Bailey et al., 1996; George et al., 2007; Bailey et al., 2015). This can concentrate grazing in certain locations, year-after-year, resulting in localized overgrazing while significant portions of the pasture are rarely visited and have abundant forage. This management challenge has resulted in research demonstrating that strategic supplementation can attract cattle to underutilized locations within a pasture (Bailey and Welling, 1999; Bailey et al., 2001; Bailey, 2004), minimize the

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time spent in and/or utilizing riparian areas (McDougald et al., 1989; George et al., 2008), modify grazing time and harvest efficiency (Krysl and Hess, 1993), and potentially lessen the severity of wildfires by reducing fine fuels on the landscape (Diamond et al., 2012; Schmelzer et al., 2014). Consequently, in this review we discuss the prospect of using strategic supplementation to modify grazing behavior, concentrating on the potential to improve pasture distribution while maintaining or enhancing rangeland health and ecological function, thereby improving the long-term sustainability of grazing systems.

COORDINATING ANIMAL MANAGEMENT WITH THE FORAGE RESOURCE

The primary challenge facing managers of grazing lands, especially those in the western U.S. where almost 100 million hectares of BLM and USFS lands are grazed (GAO, 2005), is the development of grazing systems that are economically viable while maintaining or improving the ecological function and social experience of the land resource. This is in contrast to historical practices that emphasized efficient livestock production with little concern for the ecological consequences. The passage of the Forest Reserve Act of 1891 and the Taylor Grazing Act of 1934 addressed the problem of unrestricted use of public grazing lands and focused management on sustainable practices that yielded long-term output of livestock products. However, with passage of the Classification and Multiple Use Act in 1964, National Environmental Policy Act in 1969, Endangered Species Act in 1973, and the Federal Land Policy and Management Act in 1976, management practices on public lands were regulated to consider potential impacts on the natural resource including wildlife, water quality, and recreation. Since 1970, the number of livestock that graze on public lands has decreased by approximately 30% (USDI, 2012).

The future of livestock grazing in the Western US is dependent on the development of management strategies and tools that allow for economically efficient livestock production while maintaining/improving rangeland health and addressing wildlife habitat needs. One of these potential tools is strategic supplementation; however, to effectively design a supplementation program that modifies grazing behavior, managers need to understand the abiotic and biotic factors that affect grazing behavior and distribution, which in large, extensive pastures with rough topography, includes:

1 Differences in forage quality and quantity across the landscape/pasture (Bailey et al., 1989; Ganskopp and Bohnert, 2006; Ganskopp and Bohnert, 2009)
2. Seasonality of grazing preferences (Senft et al., 1985; Harris et al., 2002; Parsons et al., 2003)
3. Watering locations (Williams, 1954; Valentine, 1947; Ganskopp, 2001); riparian areas (Roath and Krueger, 1982a; George et al., 2008)
4. Thermal cover (Houseal and Olson, 1995; Bailey, 2005)
5. Terrain heterogeneity (Mueggler, 1965; Ganskopp and Vavra, 1987; Bailey et al., 2015)
6. Fire history (Bondini et al., 1999; Allred et al., 2011; Clark et al., 2014)
7. Animal trails (Weaver and Tomanek, 1951; Vallentine, 1974; Ganskopp et al., 2000)

A knowledge and understanding of these factors and their interactions is critical for the implementation and success of a supplementation program designed to influence grazing behavior and distribution on rangelands. If managed appropriately, this type of supplementation strategy can help maintain or improve landscape ecological function by limiting areas with excessive utilization and increasing grazing locations at underutilized areas, thereby more evenly spreading out the grazing impact by livestock. As a result, strategic supplementation can be used as a tool to benefit livestock production, wildlife habitat, and numerous other ecosystem services.

Factors affecting variability in forage quality/quantity

Plant phenological stage (Angell et al., 1990; Clark et al., 1998; Arzani et al., 2004), plant species (Ganskopp and Bohnert, 2001; 2003), quantity and timing of precipitation (Ganskopp and Bohnert, 2001; 2003), fire history (Hobbs and Spowart, 1984; Allred et al., 2011), grazing history (Ganskopp and Bohnert, 2006; Clark et al., 1998; 2000), and soil fertility (Oelberg, 1956; Krueger and Donart, 1974; Assefa and Ledin, 2001) are the primary factors known to influence forage nutritive quality. Managers of livestock and wildlife need to have a working knowledge and understanding of these factors and how they influence forage nutritional characteristics. This is important because grazing animals are attracted to vegetation of better nutritional quality (increased crude protein, digestibility, etc.; Senft et al., 1985; Ganskopp and Bohnert, 2006; 2009), often resulting in animal distribution and forage utilization patterns that are not consistent across a pasture/field.

Factors affecting animal distribution on the landscape

Disproportional use of rangelands by grazing livestock has been, and continues to be, a concern of land managers due to the potential for negative impacts on plant community composition, riparian function, or displacement of wildlife. Additionally, poor livestock distribution reduces harvest efficiency and livestock production. Consequently, a considerable quantity of research has attempted to determine the factors that affect grazing distribution on a landscape scale.

Water. Jardine and Anderson (1919) stated "the distribution of water may influence the distribution of cattle and the utilization of forage more than any other single factor", illustrating that water availability is a critical component of animal distribution on the landscape and has a direct effect on the carrying capacity of rangeland or pasture (Jardine and Anderson, 1919; Valentine, 1947; Ganskopp, 2001). Also, riparian areas often experience excessive utilization, especially in late season, due to animal water needs and increased nutritional quality of the riparian vegetation compared with the associated uplands (Parsons et al., 2003). In an eastern Oregon study, Roath and Krueger (1982b) reported that riparian areas accounted for only 1.9% of the land area, but provided 21% of the available forage and accounted for 81% of the total forage removed by cattle during the summer months.

Water availability can vary by year and season, especially in arid and semiarid regions, depending on the timing, amount, and type of precipitation. For example, the functionality of stock ponds, and the corresponding rangeland use, is dependent on runoff from rains and/or snow melt and may only be available for a short period of time due to animal use, evaporation, and/or leakage. Late-season snow can be used by adapted animals to replace some portion of traditional water intake, thereby potentially increasing pasture distribution and utilization by livestock. Adams et al. (1995) noted that only 65% of cattle in a winter grazing study drank water daily, 33% drank water every second or third day, and 2% never drank water while grazing snow-covered Montana rangeland.

Nutritional indices. Livestock have the ability to remember not only where they have grazed, but they retain knowledge of forage availability, by location, for up to at least 24 h (Bailey et al., 1989). Also, Ganskopp and Bohnert (2006) demonstrated that grazing cattle preferentially selected areas of crested wheatgrass (Agropyron desertorum [Fisher ex Link] Schultz) pastures that had been grazed the previous year compared with areas with more senesced plant material that were not grazed (68% vs. 32% of grazing observations, respectively). They noted that the CP concentration (DM basis) of standing forage in the previously grazed areas was 11.3% compared with 6.5% for the non-grazed areas, implying a penchant for higher nutritional quality forage. Furthermore, in a subsequent study, Ganskopp and Bohnert (2009) were able to correlate nutritional quality across extensive rangeland pastures with cow distribution and grazing preference. They noted that free-ranging cattle preferred locations within pastures with greater forage CP and digestibility, and lower neutral detergent fiber (NDF), than pasture averages.

Timing of grazing can also influence animal distribution on a landscape. Parsons et al. (2003) evaluated time cattle spent in riparian areas and associated uplands in early season (mid-June to mid-July) compared with late season (mid-August to mid-September). They noted that during early season cattle were farther from riparian areas than late season. Also, utilization of riparian vegetation was lower, and use of upland vegetation greater, during early season than late season. This change in grazing distribution and utilization by season was partially described by increasing temperatures in late season and shifts in forage quantity and quality.

Topography. It has long been known that degree of slope influences use of a grazing area by livestock and wildlife in extensive environments with rough terrain (Mueggler, 1965; Ganskopp and Vavra, 1987; Bailey, 2005). Cattle typically will not utilize areas with slopes in excess of 30% (Gillen et al., 1984; Ganskopp and Vavra, 1987), while horses and deer have been shown to avoid slopes greater than 50 and 60%, respectively (Fig. 1).

Changes in season of use and climatic events can also change the way animals use pasture terrain, especially as it relates to slope, aspect, and cover. Animals will seek cover/protection to avoid temperature extremes to minimize the expenditure of energy required to maintain their body temperature when ambient temperature is outside their particular zone of thermoneutrality (NRC, 2000). Consequently, livestock have been shown to moderate the effects of climate by utilizing microclimates to escape high winds (Houseal and Olson, 1995), preferentially selecting use of warm slopes (south-facing) in winter but east-facing slopes in summer (Senft et al., 1985) and seeking trees for shade in the summer while avoiding them in the winter (Harris et al., 2002). Nevertheless, it should be noted that animals will seek cover, such as trees, during a winter storm event to minimize exposure and reduce short-term thermal stress (Rubio et al., 2008).

Another important driver of utilization on steep slopes is distance (vertical and horizontal) to water (Mueggler, 1965; Roath and Krueger, 1982a). Mueggler (1965) provided data demonstrating that as slope and vertical distance to water increased the relative time cattle spent in those locations was reduced. Likewise, Roath and Krueger (1982a) measured forage utilization versus elevation rise above water in a forested system and noted that utilization approached zero

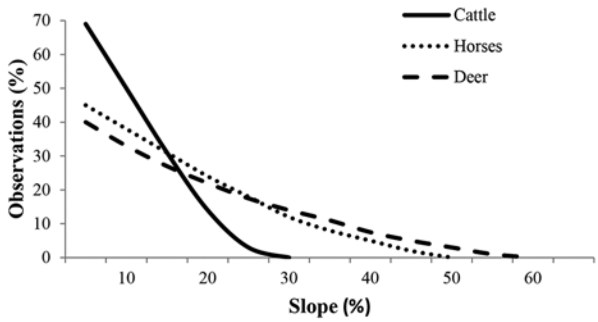

Figure 1. Slope use by cattle, horses, and deer. Adapted from Ganskopp and Vavra (1987).

when vertical distance above water was 80 m or more. Consequently, Bailey (2005) compiled this and other data to construct a nice prediction of the estimated effects of slope, horizontal distance to water, and vertical distance to water on grazing use.

When transitioning from feeding, watering, or resting sites, livestock move across the landscape using pathways that offer the least resistance or energy expenditure. This results in the establishment of a network of trails or "highways" that are used year-after-year for timely and efficient travel (Weaver and Tomanek, 1951; Ganskopp et al., 2000). Also, it has been suggested that cattle will use roads as travel venues; however, Roath and Krueger (1982a) noted that even though cattle used roads for loafing and travel in steep/rough terrain, roads were not a factor affecting animal distribution with gentle terrain.

Fire. Fire can have a significant impact on grazing distribution patterns and resource selection by ruminants, with burned areas being strongly preferred over non-burned areas (Coppedge and Shaw, 1998; Vermeire et al., 2004; Clark et al., 2014). This has been attributed to removal of "old" forage and the consequent increase in forage quality (Sensenig et al., 2010; Allred et al., 2011). However, when evaluating the effects of fire in mesic sagebrush steppe, Clark et al. (2014) reported that grazing preferences attributed to fire lasted 2 to 3 yr longer than was expected based on fire-induced improvements in forage quality. This suggests, as proposed by Allred et al. (2011), that grazing behavior is influenced more by the fire-grazing interaction than what would be expected based on the individual effects of fire or grazing.

Grazing as a tool to reduce fire frequency and intensity

There has been a global increase in the frequency and intensity of wildfires (Krawchuk et al., 2009; Adams, 2013). This has resulted in significant costs to land managers. For example, the U.S. federal government has spent more than $1 billion annually since 2000 on wildfire suppression, with costs increasing in recent years and exceeding $1.5 billion in 2006, 2007, 2008, 2011, 2012, 2013, and 2014 (NIFC, 2015). The two primary factors believed to contribute to the noted increase in wildfire behavior are climate change and human management (allowing buildup of fine fuels and not implementing fuels reduction strategies; Adams, 2013). Consequently, land managers have begun to focus on presuppression management of fine fuels to help control the severity, extent, and cost of catastrophic wildfire (Snider et al., 2006).

Fine fuels. Prescribed grazing by livestock is one of the few tools available to land managers to reduce accumulation of fine fuels at large scales on rangelands (Davies et al., 2010; Leonard et al., 2010; Bates and Davies, 2014). More importantly, recent research has shown that grazing cannot only reduce the quantity of fine fuels but it can increase fuel moisture (Davies and Nafus, 2013; Davies et al., 2015; 2016), thereby decreasing wildfire size, intensity, and behavior (Davies et al., 2016).

Invasive Weeds. A management concern of many land and livestock managers is the prevalence and spread of invasive weeds, such as cheatgrass (*Bromus tectorum* L.), medusahead rye (*Taeniatherum caput-medusae* L.), and ventenata (*Ventenata dubia*), on rangelands. Also, the expansion of these invasive species has been considered to be part of the reason for the increase in frequency of wildfires (Wright and Bailey, 1982; Whisenant, 1990; Davies and Nafus, 2013).

Targeted grazing is the application of grazing animals at a defined season, duration, and intensity to accomplish a landscape or vegetation management objective (Launchbaugh and Walker, 2006). Recent research has suggested that targeted grazing can help control the expansion of these invasive species while also helping to sustain native plant communities. Davies et al. (2009) evaluated the effects of grazing and fire in a sagebrush-bunchgrass community in southeastern Oregon. They found areas that had not been grazed for almost 60 yr were more susceptible to cheatgrass invasion and had less perennial vegetation following fire compared with adjacent areas that had been moderately grazed during the same time period. Also, other research has noted that targeted grazing can be used to reduce cheatgrass biomass (fine fuels) and seed bank compared with not grazing (Diamond et al., 2012; Schmelzer et al., 2014), thereby helping shift the composition of the forage species from a community dominated by cheatgrass to one favoring more perennial bunchgrasses with an improved diversity of forage species. Likewise, Reiner and Craig (2011) reported that targeted livestock grazing reduced cover of medusahead in California blue oak woodlands. Consequently, there is a growing body of evidence suggesting that targeted livestock grazing is an economical tool for land managers to use in their battle against the spread of invasive weeds and frequency of catastrophic wildfire.

SUPPLEMENTATION AS A TOOL TO MODIFY GRAZING BEHAVIOR AND IMPROVE RANGELAND FUNCTION

Supplementation research has been considered important by the organizers of past Grazing Livestock Nutrition Conferences (Judkins et al., 1987; Petersen et al., 1991; Judkins and McCollum, 1996; Waterman et al., 2010), especially the 1987 and 1996 conferences. There have been great reviews of research associated with supplement type (e.g., non-protein nitrogen vs. natural protein, energy vs. protein, starch vs. fiber, degradable intake protein vs. undegradable intake protein, organic vs. inorganic minerals, gluconeogenic precursors, fat sources), supplementation practices (e.g., frequency and timing of supplementation, self-fed vs. hand-fed; cool-season vs. warm-season forages), animal performance (e.g., gain, pregnancy rate, calf vigor/health), and/or economics of supplementation strategies that addressed nutrient deficiencies of grazing ruminants. This review will not revisit those aspects of supplementation, rather we will provide an overview of the current literature related to supplementation practices with the primary objective of modifying grazing behavior.

Supplementation practices to alter livestock grazing location

Historically, livestock managers have attempted to increase livestock densities to improve grazing uniformity by reducing pasture size; however, this often only increases the intensity of grazing on preferred areas while areas farther from water, or on steeper slopes, continue to receive little use (Irving et al., 1995; Bailey and Brown, 2011). Building fences to reduce livestock use of riparian areas can be a viable option, but building fences in areas with rough topography and limited water infrastructure often make this option economically and logistically impractical. Furthermore, disruption of wildlife movement/migration often makes building fences undesirable on public rangelands (Stevens et al., 2012). In contrast, using knowledge of the principles affecting grazing distribution and behavior outlined earlier, livestock and land managers have been able to achieve some success using strategically placed supplements as a tool to improve grazing distribution and reduce localized overgrazing without high infrastructure input.

Salt. Placement of salt away from water locations is often recommended as a tool to influence livestock grazing distribution (Williams, 1954); however, results are mixed in the efficacy of salt to improve livestock distribution. Bailey and Welling (1999) found no increase in utilization of upland areas within 200 m of salt placement compared to similar sites with no salt placement in the late fall on northern Montana rangelands. In southeastern Oregon, Ganskopp (2001) indicated that strategic salt locations did not correct distribution problems on sagebrush/bunchgrass rangeland. Salt and meal-salt placement in southern Arizona increased utilization of perennial grasses in areas 0.6 to 4.0 km from water that usually only received light utilization, but salt or salt-meal placement away from water did not reduce high utilization levels on vegetation near water sources (Martin and Ward, 1973). These results indicate that salt alone may have limited use as a tool to decrease localized overgrazing near water or riparian areas. However, salt is typically fed to cattle on rangelands, encourages some cattle to move to underutilized areas, and can often be placed away from water just as easily as near water. Consequently, placing salt in underutilized areas greater than 0.5 miles (0.8 km) from water is a sound practice to encourage better livestock distribution.

Protein. Protein supplements are an effective method of manipulating livestock grazing distribution in large, topographically diverse pastures in the western United States (Bailey, 2004). They provide a nutritional incentive for cattle to travel to areas of the pasture that are farther from water, on steeper slopes, have less palatable vegetation, or are at higher elevations. Strategic placement of protein supplements can typically provide added grazing distribution from the late-summer through the winter months when vegetation is dormant and forage quality is not meeting the animals' nutrient requirements. If adequate protein is available in the forage, protein supplements have minimal effect on altering grazing distribution or improving utilization in strategic areas (George et al., 2008; Stephenson, 2014). Protein supplements can be fed in a variety of feedstuffs and in many different delivery forms (i.e., alfalfa hay, pressed blocks, low-moisture blocks, liquid feeds, range cake, etc.). While efforts should be made to feed all protein supplements on underutilized areas of extensive rangelands to improve grazing utilization, some feedstuffs may be more effective than others at altering livestock distribution.

Low-moisture block protein supplements (LMB) have been evaluated extensively for their ability to influence livestock grazing locations (Bailey and Welling, 1999; Bailey et al., 2001; Bailey et al., 2008a; George et al., 2008). Low-moisture blocks are molasses-based, self-regulating protein supplements that entice cattle to return regularly to consume the supplement. As a result, cattle tend to remain in and graze near areas where the supplement is located. Low-moisture blocks have generally been more effective at altering grazing distribution and increasing cattle utilization on uplands when compared to other supplementation methods such as dry mineral mixes (Bailey and Welling, 2007) or range cake (Bailey and Jensen, 2008). Bailey et al. (2008a) found that cattle used higher elevations, areas farther from water, and traveled greater daily distances with strategic LMB placement compared to placing only salt in the same locations on northern Montana rangelands in the fall. Utilization on upland areas surrounding LMB can be increased in areas up to 600 m from the supplement (Fig. 2; Bailey and Welling, 1999; Bailey et al., 2001; George et al., 2008). However, topography affects the efficacy of LMB to influence cattle distribution with greater utilization of uplands with moderate terrain compared to areas with rough terrain (Fig. 3; Bailey and Welling, 1999).

In addition to increasing utilization of uplands, LMB protein supplements can reduce grazing pressure on sensitive, preferred areas of pastures (George et al., 2008; Bailey et al., 2008b). Time cattle were observed grazing in riparian areas was reduced from 37% to 14.5% of the time cattle were in pastures with upland placement of LMB on California rangelands during the summer (George et al., 2008). Bailey et al. (2008b) used a combination of herding and LMB supplementation to reduce overutilization of riparian areas during the late growing season on Montana rangelands. In this study, grasses around LMB locations were utilized more and stubble heights along streams were greater on pastures where cattle were regularly herded to LMB locations compared to control pastures where cattle were allowed to roam freely. Additionally, studies using a combination of herding and strategic LMB placement in the southwest USA decreased time cattle spent at water tanks and increased utilization on targeted areas surrounding LMB during the late-fall and winter (Stephenson, 2014; Bruegger et al., 2016).

Liquid protein supplements also may effectively attract cattle to, and increase utilization at, strategic locations. On rangelands in northern Nevada, cattle utilized dormant cheatgrass (*Bromus tectorum*) in the late-fall on areas surrounding strategically placed liquid protein tanks at distances up to 4 km from water (Stephenson, unpublished data). On average, GPS-tracked cattle remained within 250 m of supplement locations for nearly 3 $h \cdot d^{-1}$ and reduced standing crop of cheatgrass by nearly 80%.

Understanding the costs of different protein supplement delivery methods is an important consideration when determining which type of supplement is most appropriate for a given situation. Low-moisture block supplements are typically more expensive than other forms of protein supplementation when compared on a crude protein basis (Olson, 2015). However, less frequent delivery requirements in areas with rough terrain and increased grazing distribution may offset some of the extra cost. Tanaka et al. (2007) indicated that strategic placement of LMB supplements was a profitable practice to lengthen the grazing season on northeastern Oregon rangelands. In this situation, providing LMB supplements in the fall increased the length of the grazing season for cattle by improving grazing efficiency and increasing forage intake of cattle on underutilized areas. Increasing the length of time cattle remained on rangelands reduced the amount of harvested feed required by cattle during the winter feeding period, thereby, reducing total yearly feed costs.

With knowledge of the factors affecting resource selection on the landscape, research has demonstrated that grazing distribution and forage utilization can be altered with strategic supplementation. This is a powerful tool that livestock and land managers can use to help address management objectives.

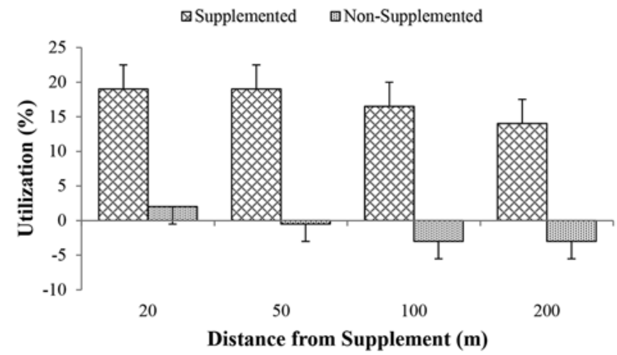

Figure 2. Grass utilization in relation to supplement placement. Adapted from Bailey and Welling (1999).

Supplementation to control invasive species

Proper supplementation can aid in maintaining acceptable livestock production while accomplish-

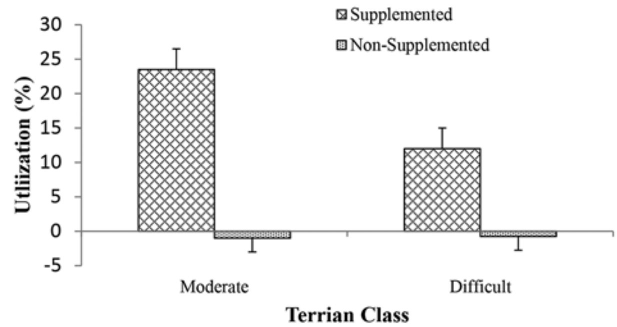

Figure 3. Change in grass utilization in moderate and difficult terrain with and without strategic supplement placement. Adapted from Bailey and Welling (1999).

ing targeted grazing control and use of invasive species. Additionally, supplementation offers flexibility to livestock producers, and often an associated increase in efficiency of animals utilizing the target species, when applying targeted grazing at different times of the year.

Cheatgrass and medusahead are examples of introduced invasive annual grasses that have altered ecosystem function on millions of hectares of sagebrush steppe rangelands (Whisenant, 1990; D'Antonio and Vitousek, 1992; Brooks et al., 2004). Because of their growth habits, these species create large amounts of fine fuel and increase wild fire frequencies to levels that native perennial vegetation often cannot survive (Davies et al., 2009).

Heavy grazing in the spring, when cheatgrass is growing and high in quality, is an effective management tool to reduce the risk of wildfire in cheatgrass infested areas (Diamond et al., 2009). However, planning for grazing on cheatgrass infested areas in the spring is often difficult because of large year-to-year climatic differences in temperature and precipitation and, consequently, cheatgrass forage production. Grazing dormant cheatgrass in the fall may help producers better manage planning because growth of plants is finished and forage production is known. Grazing cheatgrass in the late-fall also can reduce the amount of carryover biomass and decreases the risk of overgrazing on perennial grasses. Schmelzer et al. (2014) found that cattle grazing poor-quality, dormant cheatgrass-perennial grass range in the late-fall increased or maintained body condition score and body weight when provided with a 14% CP liquid protein supplement. In addition to adequately maintaining cattle body condition, heavy grazing (60 to 80% utilization) on cheatgrass in the late-fall reduced cheatgrass biomass, reduced cheatgrass in the seed bank, and increased perennial grass production after 3 yr of treatment. Targeted grazing of cheatgrass may be our best tool available to manage these rangelands at a large scale.

Sheep grazing medusahead increased thatch intake when supplemented with energy and protein compared to non-supplemented animals; however, supplementation had limited effects on intake of medusahead hay (Hamilton et al., 2015). Villalba and Burritt (2015) found no differences in the amount of medusahead consumed by energy supplemented and non-supplemented sheep, but concluded that greater gains by supplemented animals could increase feasibility of targeted grazing as an option to control medusahead without sacrificing livestock performance.

Browsing for control of juniper species (*Juniperus spp*.) can also be influenced by supplementation strategies. In a pen setting, one-seed juniper (*Juniperus monosperma*) intake by sheep and goats was 2 times greater when animals received a protein supplementation (Utsumi et al., 2009). However, season of use affected juniper intake and effectiveness of protein supplementation strategy. The lowest amount of juniper was consumed in the fall when plant secondary metabolites were highest. In the Edwards Plateau region of Texas, Campbell et al. (2007) reported increased intake of red-berry juniper (*Juniperus pinchotii*) by goats when provided alfalfa and cottonseed meal supplements compared to those receiving no supplement or an energy-based supplement (i.e., corn). In another experiment reported by the authors, diet composition of red-berry juniper in free-ranging goats was 4.6% points greater for goats supplemented with soybean meal compared to non-supplemented animals (Campbell et al., 2007).

The use of invasive plants as a supplement in ruminant diets has the benefit of reducing the need for traditional feedstuffs while also assisting in the control and management of the invasive plant. Russian knapweed (*Acroptilon repens*), a highly invasive forb found throughout the western United States and Great Plains regions, has been evaluated as a possible feedstuff. Bohnert et al. (2014) found no difference in weight gain or body condition score of mid-gestation cattle fed either alfalfa hay or harvested knapweed as a supplement to a hard fescue straw diet. Harvesting and feeding juniper has also been suggested as an option to provide feed for livestock while managing juniper infestations on rangelands. Whitney et al. (2011) replaced cottonseed hulls with juniper leaves and found no differences in several carcass characteristics of lambs. Other research has indicated that whole juniper trees could be ground and added to sheep diets as a partial replacement of other low-quality roughages (Stewart et al., 2015).

The use of supplementation to help control the expansion of invasive plants can assist in addressing 2 major production challenges; managing the spread of invasive plants and providing a feedstuff that reduces an impediment (nutrient deficiency, cost, etc.) in livestock production systems.

Complimentary forages to bridge periods of inadequate forage quality

Forage kochia (*Kochia prostrata*) is a perennial semi-shrub that is native to central Eurasia, but has been planted extensively in the western United States for its drought tolerance, ability to grow in saline soils, and ability to compete with invasive grasses like cheatgrass and halogeten (*Halogeten glomeratus*; Waldron et al., 2010). Forage kochia also provides high quality forage for livestock and wildlife and its nutritional profile compliments native forage in the Great Basin (Schauer et al., 2004). The CP content of forage kochia can typically meet the requirements for gestating cattle in the late-fall and winter. Waldron et al. (2006) reported CP content in forage kochia at 7.3 to 12.6% (DM basis) in the late-fall and early-winter on Utah rangelands. In this study, beef cows increased body weight and body condition score from early-November to late-January while grazing crested wheatgrass (*Agropyron desertorum*) pastures that had been interseeded with forage kochia. This type of management provided adequate nutrition and was a less costly option to feeding alfalfa in a drylot situation (Waldron et al., 2006); however, caution should be taken if cattle are not adapted to forage kochia or have limited access to other forage. Instances of frothy bloat in cattle have been reported when large amounts of forage kochia are consumed (B. Perryman; personal communication). In semiarid regions of the northern Great Plains, dryland alfalfa is another species that is often planted into grass stands to increase forage quality and production (White and Wight, 1984).

Rangelands in the western United States with a winterfat (*Krascheninnikovia lanata*) and/or fourwing saltbush (*Atriplex canescens*) component have long been valued for winter grazing (Cook et al., 1953; Cook and Harris, 1968; Shoop et al., 1985). These native shrubs provide excellent quality forage that is highly selected by livestock. Crude protein concentrations during the winter can range from 14% to 24% for fourwing saltbush (Otsyina et al., 1982; Garza and Fulbright, 1988; Kronberg 2015) and 10% to 15% for winterfat (Otsyina et al., 1982; Kronberg, 2015). On the Red Desert in Wyoming, winterfat made up only 3 to 4% of the available forage, but accounted for nearly 20% of horse and cattle diets in early winter (Krysl et al., 1984). Likewise, Shoop et al. (1985) noted that the diets of cattle contained as much as 55% fourwing saltbush during the late-winter on shortgrass prairie.

Designing grazing systems that utilize rangelands with complimentary forage species provides a less expensive, and practical, protein supplementation source for animals grazing low-quality, dormant forages.

FUTURE DIRECTION

Supplementation to address nutrient deficiencies will always be an important aspect of the livestock production enterprise; however, because rangelands are valued for many features and services other than just providing forage for livestock and wildlife, the ability of rangeland-based livestock producers to remain competitive when utilizing extensive landscapes will depend on the development of management practices that use ecologically-based principles of land management. Some specific challenges that livestock producers will face include: changes in public land policy, anthropogenic development, climatic variability, invasive weeds, wildfire, water quality, and threatened and endangered species concerns. These challenges are becoming increasingly complex and will require a multidisciplinary approach that looks beyond any single discipline or issue.

Strategic supplementation is an attractive tool, and in some cases one of the only tools, for land and livestock managers to address a multitude of animal and natural resource concerns because of its potential to economically alter grazing behavior and distribution. Some areas that we feel could benefit from additional research include:

1. The ability to modify grazing distribution at the landscape scale to address pre- and post-wildfire management concerns.
2. The ability to manage livestock distribution at the landscape scale to minimize conflicts with temporal wildlife activities and habitat needs
3. The potential to improve the success of rangeland restoration practices following disturbance
4. Improvement in our understanding of the relationship between supplementation, performance, grazing behavior, topography, and genetics of livestock.
5. Development of economic prediction models that include not only the production benefits of supplementation but the consequences on ecosystem services such as biodiversity, ecological resiliency, wildlife habitat, water quality, recreation, carbon sequestration, and rural economies.

Livestock grazing practices face increasing scrutiny, mostly because of the tendency for livestock to concentrate in specific areas and disproportionally use the vegetation to a degree that negatively impacts long-term ecological function (DelCurto et al., 2005). We have provided some evidence of how proper grazing management and strategic supplementation can be used to address natural resource concerns. If we can continue to improve our ability to control the behavior and distribution of grazing livestock, we can improve the sustainability of grazing systems by managing for "designed" landscapes that improve the economics of livestock production while maintaining or enhancing rangeland health and ecological function.

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