Overcoming challenges to utilization of dormant forage in year-round grazing systems[1]

E. E. Grings*[2], N. Zampaligre†, and A.Ayantunde‡

*United States Agency for International Development, Washington DC;
†Institut de l'Environnement et de Recherches Agricoles (INERA), Ouagadougou, Burkina Faso;
and ‡International Livestock Research Institute, Ouagadougou, Burkina Faso

ABSTRACT: Livestock managers dealing with inter- and intra-annual forage quality dynamics use a variety of adaptive systems to cope. In higher rainfall areas, managers may have the ability to manipulate forage quantity and quality through forage management tactics such as grazing management, fertilization and use of seeded forages. In more semiarid and arid areas, forage dynamics are more heavily controlled by climatic factors. In these regions, adaption of animal management systems, such as by adjusting the match-up between seasonal nutrient demand and supply through manipulation of the animals' physiological state, or through the use of mobility, may be more appropriate. Understanding factors affecting forage dynamics and how managers develop systems to adjust is important to helping these managers to deal with future changes in climate and land use. This review describes livestock system adaptations used to deal with high and variable inter- and intra-annual forage dynamics primarily found in arid and semiarid production zones.

Key words: adaptation, forage quality, grazing, livestock systems, nutrition

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INTRODUCTION

Over 40% of the earth's surface is covered by grasslands, with resources usable for the production of meat, milk, and fiber through the grazing of ruminant livestock. Management systems for livestock vary dramatically across a wide range of grassland systems and climate zones. Forage quality dynamics in grazing lands are reflective of an area's climatic regime and soil composition, which impact types of plant species available for grazing. Climate and soils affect the composition of vegetative classes, such as grasses, forbs, trees and shrubs and also species within vegetation class, notably warm and cool season (temperate and tropical) species and annual and perennial species. Grasslands have been categorized by their complexity and response to management into systems that exhibit either equilibrium or non-equilibrium dynamics (Tainton et al., 1996; Vetter, 2005). Systems exhibiting equilibrium dynamics tend to exist in higher rainfall areas and can be manipulated by external factors such as grazing and fertilization. Forage management tactics can be used to partially overcome challenges associated with dormant season grazing. For example, forages may be planted rather than native and species can be selected to meet nutritional needs of grazing livestock. Non-equilibrium systems tend to be more climate-driven with impacts of grazing and other forage management tactics having lesser impact (Haferkamp et al., 1993). These non-equilibrium systems tend to be variable and less predictable, therefore requiring greater levels of adaptability in livestock management. This paper will focus primarily on non-equilibrium systems and the livestock system adaptations used to deal with high and variable inter- and intra-annual forage dynamics.

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[2]Corresponding author: elaine.ethel@hotmail.com, elainegrings@gmail.com

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Table 1. Examples of animal management strategies used in yearlong grazing programs to overcome challenges associated with dormant forages along with a rationale for its use, a trigger for the strategy and knowledge gaps to improve its use

Situation	Management strategy	Rationale	Trigger for the strategy	Knowledge gap
Variations in forage quality during the dormant season	Selection of livestock species, breeds and individuals that exploit different forages	Differences among species, breeds and individuals in diet selection patterns	Varied changes in forage quality of plant species	Understanding of drivers of variation among breeds and individuals in diet selection processes; effects of nutrition during the dormant season on offspring productivity
Shrublands available for dormant season grazing	Use of shrubs for winter feed	Shrubs contain greater nutritional quality than grasses during the dormant season	Need for improved forage quality for dormant season grazing	Diet selection strategies of different classes of livestock; winter use of shrublands on co-exisiting wildlife; impact of shrub characteristics on intake
Availability of crop residues	Graze standing crop residues during dormant season	Inexpensive feed resource; improve nutrient cycling in mixed crop-livestock system	Declining pasture availability and presence of crop residues	Improved information on nutrient cycling in mixed crop livestock systems
Late summer crop harvest	Plant and graze cover crops	Improve nutrient cycling in mixed crop-livestock system	Interest in improved nutrient management strategies	Value of varied cover crop blends; appropriate stocking rates and residue management; impacts on soil characteristics and subsequent crop yields
Limitation in forage quality and quantity	Use of individuals or breeds with lower milk yield potential; wean calves to remove nutritional demand of lactation	Decrease requirements for nutrients associated with milk production	Arid, semiarid climates; high and unpredictable variations in rainfall	Long-term impacts of climate change on amount and variations in rainfall; adaptive management strategies for situations of unpredictable rainfall
Winter grazing available	Summer calving	Match of minimum nutrient demand with minimum nutritional quality available	Areas of limited snowfall; ability to breed in late summer; limited predator risk during summer; summer pastures accessible to young livestock	Appropriate growing and finishing management for summer-born calves; impacts of summer calving on cow longevity
Drought	Early weaning	Decrease requirements for nutrients associated with milk production; need to provide young stock access to higher quality feed	Limited forage quantity; declining cow body condition	Decision-support tools for long term forage forecasting

DISCUSSION

Forage quality dynamics and forage management systems

In many year-round grazing systems, there is a period of time when forages are dormant and of low quality, generally below that needed to meet livestock nutritional requirements without some loss of body weight or productive function. This poses challenges to management of grazing livestock and a variety of tactics may be used to help deal with these periods of nutritional limitations. Genetic adaptability of breeds, timing of nutritionally relevant physiological events, availability of external inputs, and livestock mobility are all management tactics designed to deal with variability in forage dynamics (Table 1). Changes in forage quality and quantity associated with changing climate and land use are continuing challenges for ruminant systems globally. Understanding how ruminant livestock management systems are designed to deal with forage quality dynamics can help to strengthen adaptability and to develop new systems appropriate for responding to changes in forage quality and availability.

Forage quality from a grazing animal's perspective is a function of both the nutrient density of the forage and also the ability of an animal to consume an adequate quantity to meet daily nutritional needs. Forage quality tends to be a combination of the effect of plant part and plant age: young plant tissue is more nutritious that old tissue (green plants are more nutritious than brown ones) and leaves are higher in quality than stems. Quality also varies between warm- and cool-season forages, forbs, shrubs, and trees.

Very young growth of grasses that is primarily leaf with little stem tends to be quite high in CP, as much as 15 to 20% CP at the 2 to 3 leaf stage and to also have high digestibility. Quality declines as the plants age and green cool-season grass tends to contain about 10 to 12% CP, but CP of these forges can fall to about 4 to 7% when dormant (Heitschmidt et al., 1995). These relative differences in quality for live and dead plant tissue hold true for digestibility and some of the major minerals, such as phosphorus, magnesium, and potassium (Greene et al., 1987; Grings et al., 1996). Other minerals, such as copper and zinc, are not directly related to tissue age and color. The quality of a grazing animal's diet is, therefore, partially a function of the ability to select among plant tissues of different age.

Although drought decreases forage supply, its impact on forage quality depends on the severity of drought. Often, if there has been some moisture, quality of green forage can be higher than in non-drought years because plants may stay at less mature stages of growth with more leaf and less stem (Sheaffer et al., 1992). However, if conditions have been so dry that there is no new growth; quality can be very low, due to the older age of the plant tissue. While quality of mature forage from a given year's growth may range from 4 to 7% (Heitschmidt et al., 1995), mature grass left over from a previous year and carried through the winter, may contain only 2 to 5% CP. Additionally, in a normal rainfall year, forage growth may stop at first freeze and forage may only be dormant a few months during the non-growing season, and will be expected to be about 4 to 5% CP. In a year when the forage becomes dormant due to lack of moisture in mid-summer, the dormant forage is 3 mo older than in a normal year and will have protein concentrations lower than in a normal dormant season.

In addition to the nutrient density of forage consumed, the ability of livestock to consume enough food to maintain productive function is also important. Reportedly, up to 50% of the variation in digestible nutrient intake is associated with voluntary dry matter intake (Allen, 1996). Intake is a function of both forage quality and quantity. Dormant forages, which are generally high in fiber, can limit intake due to high ruminal fill and low digestibility, therefore, livestock grazing dormant forages can have nutrient intake shortfalls through both quality and intake limitations.

Characteristics of forage available for grazing during the dormant season will impact nutrient intake. Bite size is the major controlling factor to intake (Forbes, 1988), which can be somewhat compensated by grazing time (Erlinger et al., 1990). However, when grazing dormant forages, time required to chew coarse forages can negatively affect intake. Areas that have been previously grazed during the growing season may have more stem and less leaf available for grazing during dormancy and stem density (Benvenutti et al., 2006), length and proportion (Boval et al., 2007) can all impact short-term intake rates. Wide dispersal of forages in grazing areas also plays a role in intake when livestock have to spend time in searching and prehending food. When shrubs are used as a major feed resource in the dormant season, bite size can be affected by leaf size and thorn density (Sebata and Ndlovu, 2010). The combined impact of forage characteristic on intake often results in livestock consuming DM at less than 2% of their BW, compared to greater than 2% during the plant growing season.

Management systems can be designed to account for some loss of BW during plant dormancy, but this should be closely monitored. Additionally, current research is showing lifetime impacts on offspring due to periods of undernutrition during pregnancy (Funston and Summers, 2013). Further understanding of this process may results in future changes to livestock management systems.

Grazing livestock have the ability to select a diet that is of higher quality than the average of the forage being grazed. How much greater is dependent on the opportunity for selection. This is again related to the availability of different tissue classes. The difference between forage and diet quality can be greater in the growing season when there is greater variation in forage quality among plant species and plant parts compared with the dormant season when all species and plant parts may be of similar quality (Grings et al., 2001). Figure 1 shows the difference between diet and forage quality for beef cows grazing Northern Great Plains cool-season dominated rangelands in April through December averaged from 4 yr of data. The difference between diet and forage was about 3% in spring, but less than 1% in fall and winter.

Tactics that make use of diet selection strategies and the preference of livestock to consume high quality diets can be exploited to help livestock deal with periods of low quality dormant forage (Provenza and Balph, 1988). Sheep have been shown to be more accepting of lower quality forages when they have been previously exposed to those forages (Catanese et al., 2015). However, while grazing livestock will prefer to include higher quality feeds in their diets when available, they will consume a lower quality diet when the costs of seeking out the higher quality diet becomes too high (Illius et al., 1999). Individual dietary preferences may be inherited (Snowder et al., 2001) or learned from relatives or peers when animals are young (Howery et al., 1998). Selecting species, breeds and individuals with greater ability to select a higher quality diet may be useful in exploiting low quality forage resources. However, much of the research on this topic has been conducted in settings with clear differences in forage quality; during periods of plant dormancy, these preferences may not be expressed due to lack of choice or high foraging costs (Illius et al., 1999; Grings et al., 2001; Searle et al., 2010). Further research on whether there is ability to better exploit low quality forage resources through behavioral and genetic means may be useful.

Utilization of shrubs and shrublands are a means to improve diet quality in select seasons of the year. Desert ranges of the Intermountain west have his-

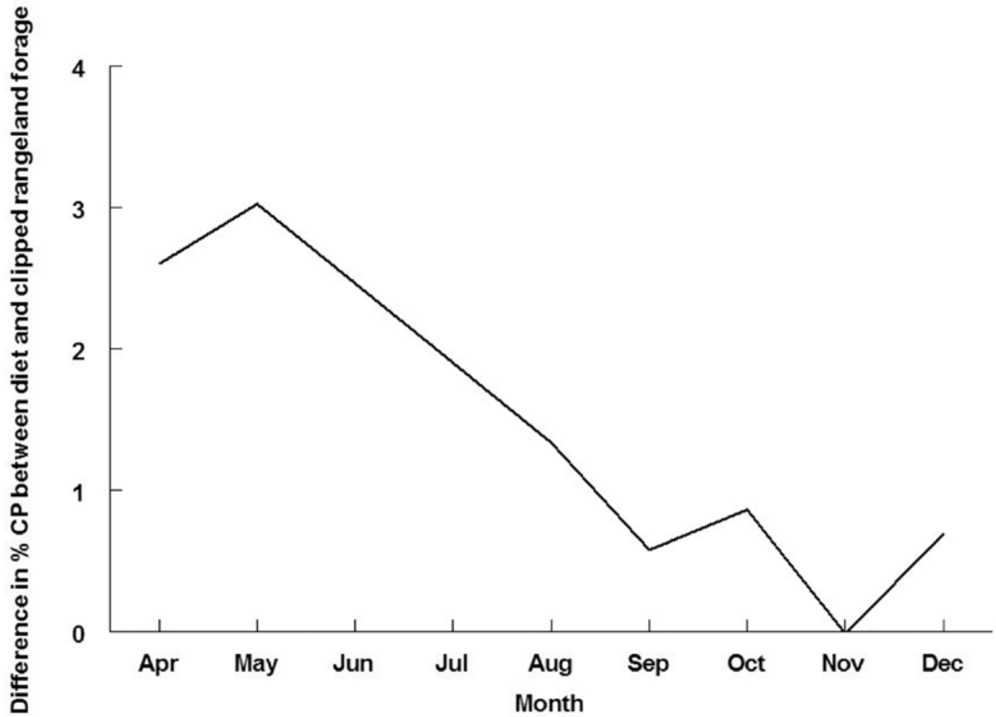

Figure 1. Difference in CP content of esophageal extrusa samples collected by grazing beef cattle and clipped forage on Northern Great Plains rangelands averaged over 4 yr.

torically been used for winter range for cattle and sheep. Early research showed cattle and sheep diets contained about 41 and 70% browse, respectively when grazing salt desert rangelands (Cook and Harris, 1968). Browse species averaged 5.3% higher in CP than grasses on the same rangelands in Utah during the winter. Using livestock that can best exploit the shrub forage resource is a reasonable adaptive strategy. Livestock systems using these desert ranges often have included mobility as part of the management strategy. Livestock were moved to higher elevation ranges for summer grazing on high quality meadow grasses followed by winter use of salt desert shrublands that were both more accessible due to limited snow cover and had higher quality winter feed.

While quality of shrubs can be high relative to grasses during the dormant season, physical characteristics of shrubs are quite important to the ability of livestock to use them. Sebata and Ndlovu (2010) studied bite rate and bite size of goats grazing shrubs in Zimbabwe and found bite size to be affected by both leaf size and shrub thorn density, while bite rate was affected by how the leaves were arranged on the stem as well as thorn density. Shrub resources are best used by livestock species with morphological characteristics that allow them deal with characteristics of specific shrub species.

In temperate areas with adequate rainfall, inclusion of legumes into pasture-based systems is used to increase forage yield and quality while also having the advantage of decreasing fertilizer inputs (Lüscher et al., 2014). Mixtures of grasses and legumes have shown increased yields when compared to either forage class grown alone (Finn et al., 2013). Most attempts to increase the proportion of legumes in semiarid rangelands have met with little success. One species of yellow-flowered alfalfa (*Medicago falcate*), has shown an ability to persist when planted in mixed grass prairie in Wyoming and South Dakota (Mortenson et al., 2005; Misar et al., 2015). Inclusion of this species in a mixed grass prairie increased above ground biomass along with the CP concentrations of native forages growing with it.

Not all year-long grazing systems rely solely on non-cropped vegetation. Many systems exist in which livestock graze standing crop residues or seasonally available forage crops as a complement to other forage resources. Grazing of standing corn stalks in the Corn Belt (Klopfenstein et al., 2013), grazing of wheat pasture in the Southern Plans (Horn, 2006) and grazing of cover crops planted after cereal harvest (McCartney et al., 2009) are all examples from North America. Grazing of cereal stovers is also a dormant season management strategy in many other areas of the world, although uses vary with farmers' preferences: crop production levels, access to alternative biomass resources, and biomass demand relative to other uses such as mulch (Valbuena et al., 2015). Grazing of corn stubble in the U.S., where the grain is mechanically harvested leaving grain and husk in the field for grazing (Klopfenstein et al., 2013) may provide a different level of nutrition than those areas where grains may be hand harvested and all that remains in the field is primarily stock and leaf. In the Sahel zone of West Africa, herders traditionally moved herds of mixed livestock south to cropping zones to make use of standing cereal stovers. Contracts were made with farmers to utilize stubble in return for manure applied by the grazing livestock (Powell and Williams, 1993; Ayantunde et al., 2000). However, changing agricultural systems in these regions has resulted in less cereal residues available for pastoral herds as crop farmers begin raising their own animals and making use of use the crop residues in cut and carry systems.

Cover crops used in rotational cropping systems to improve soil tilth and soil nutrient cycling (Gardner and Faulkner, 1991) can also be utilized by livestock as high quality forage to fill nutrient gaps for livestock production (Koch et al., 2002; McCartney et al., 2009; Stackhouse et al., 2015). Cover crops planted after late summer grain harvest potentially provide a high quality feed resource for fall grazing during a period when both quantity and quality of pasture resources have declined, while also decreasing pressure on traditional pastures. For example, Smart and Pruitt (2006) used turnips or rye cover crops planted in late July after small grain harvest in South Dakota for replacement heifers for 63 d of fall grazing, potentially sparing pasture forage. In Nebraska, where conditions allowed for planting of cover crops in March, Titlow et al. (2014) sowed oats, peas and turnips for grazing in June, which spared pasture for grazing at an alternative time. Additional research on optimal management of cover crops, species blends, stocking rates and appropriate residue management for soil health benefits is still needed.

Livestock management strategies to adjust to forage dynamics

Many of the above listed tactics attempt to make use of alternative forage sources for grazing during periods of grass dormancy. In addition to finding alternative feed resources to fill nutritional gaps, animal management can be altered to manipulate nutrient requirements during the dormant period. Nutrient requirements of livestock are driven by productive function, with nutrient needs affected by age and physiological state, such as pregnancy and lactation. Milk production puts high nutritional demands on lactating females and manipulating milk production timing and levels is a valid means of matching nutrient supply and demand in grazed systems. Milk production can be altered genetically, by selecting females that produce milk at levels consistent with the nutrient supply available. Higher milk producing breeds can be used in more temperate regions with a more consistent supply of nutrient dense forage and lower milk producing breeds are more appropriate for more semiarid and arid environments where changes in nutrient quality are more varied throughout the year.

Nutrient demand for beef cows is greatest at the time of peak milk production, generally considered to be about 50–60 d after calving followed by decreasing demands as milk yield declines (NRC, 2000). Nutrient requirements increase again in late pregnancy as the fetus begins to grow rapidly. Season of parturition affects how nutrient demands match varied forage qualities due to the shifting of time of milk peak yield and fetal growth relative to periods when forge quality can supply high levels of nutrients.

In the Central Plains of the U.S., forage quality and quantity are maximized during periods of higher rainfall and temperatures appropriate for the primary grass species (cool-season dominant in the north and warm-season dominant in the south). For beef cattle, various calving times have been proposed to optimize use of non-harvested feed resources in systems relying on primarily native grasses in these environments.

Several studies on calving seasons for rangeland-based beef production systems have been conducted within the Great Plains (Pang et al., 1998; Adams et al., 2001; Grings et al., 2005; Reisenauer Leesburg et al., 2007; Funston et al., 2016). Time of peak forage quality differs for rangelands dominated by either warm- or cool-season forages, making this a major consideration for selecting a calving season. Cool season forages will contain their greatest nutritional value during spring followed by a decline during mid- to late-summer. In contrast, warm-season forages are of highest quality in the warm summer months. This difference in forage type may result in an altered preferred time of calving, with early spring being preferred on cool-season rangelands compared with a late spring calving time in warm-season forage dominated areas.

Another option for designing a livestock production system is to match periods of periods of lowest nutritional demand with periods of lowest forage quality. For beef cattle, this might be accomplished by using a calving system that utilizes dormant forages for non-lactating cows in midgestation (the period of lowest nutritional demand). Even in situations where harvested feeds are used in the dormant season, a lower quality (and presumably less expensive) feed source can be used to support the herd through the dormant period.

Systems designed to rely heavily on a fixed grazable forage base result in a smaller herd size than systems utilizing harvested feed inputs. Evaluation of late winter, early spring or late spring calving systems in the Northern Great Plains, showed that, when calves were weaned a similar ages, herd size based on expected forage intake was approximately 11% smaller for a late spring than early spring system using the same fixed forage base (Kruse et al., 2008). In a simulated evaluation of calving seasons, also for the Northern Great Plains, herd size was 2% greater for summer calving compared to spring calving (Reisenauer Leesburg et al., 2007). If calves were weaned on October 31 instead of December 15, herd size for a summer calving system could be increased by 10% over the spring calving herd. The difference in expected herd size between the 2 studies was a consequence of winter feed management decisions, with higher estimated harvested feed inputs used during winter dormancy for summer calving in the study of Reisenauer Leesburg et al. (2007) than for that of late spring calving in the study of Kruse et al. (2008). In both studies the goal was to have cows in moderate body condition at calving. In the study of Reisenauer Leesburg et al. (2007) this was done by maintaining simulated body condition throughout winter through the use of harvested feedstuffs, whereas in the study of Kruse et al. (2008) cows were allowed to lose some body condition in winter with the assumption that condition would be gained during spring grazing before calving.

Economic evaluation of late winter, early spring, and late spring calving in the Northern Great Plains, an area where the primary forages are cool-season grasses, was conducted using the data from work conducted at USDA-ARS, Miles City (Kruse et al., 2008). When calves were sold at weaning, no differences in ranch gross margins were observed; due, in part, to high variability in winter feed costs as a result of varied weather conditions among years of the study. However, gross margins were greater for the late spring system if steer calves were retained through backgrounding or finishing. Similarly, Stockton et al. (2007) reported that net returns were greater in a June- compared to March-calving system in the Sandhills of Nebraska, an area dominated by warm-season forages. In contrast, Reisenauer Leesburg et al. (2007) reported lower ranch gross margins for summer compared to spring calving in the Northern Great Plains when summer calving cows were fed to maintain body condition throughout the period of forage dormancy. Decisions regarding feed management relative to livestock nutrient requirements in the dormant season were a key factor in determining economic value of the systems.

Throughout the U.S., research with beef cattle has shown advantage of manipulating weaning times as a means to respond to yearly variations in forage quality dynamics. Research has been conducted on both early (Waterman et al., 2012) and delayed weaning strategies (Short et al., 1996) to cope with environmental variation. Removal of suckling offspring can have dramatic impacts on the nutrient intake requirements of the dam, resulting from both decreased needs in nutrient concentration as well as dry matter intake. The NRC (2000) beef cattle requirement tables suggest that a non-lactating cow eats as much as 25% less than a lactating cow (depending on stage and level of milk production) and protein and energy requirements are also decreased. A study on early weaning of beef calves conduced in western South Dakota found a 36% reduction in forage disappearance between August and November in pastures used by cows whose calves had been weaned in August compared to those with calves weaned 90 d later in November (Johnson et al., 2015). By measuring forage disappearance, this study accounted for additional forage losses due to trampling or fouling that might not be accounted for by measuring intake alone.

Calving season and weaning date have been shown to interact, thereby affecting the nutrient supply for both the cow and the calf. Data from a study conducted in the Northern Great Plains (Grings et al., 2005) showed that calves born in late spring and weaned at 190 d of age (December) were lighter at weaning than those born in early spring and weaned at the same age (October). This was due to lower quality forage between October and December, which provided fewer nutrients both to the dam for milk production and directly to the calf through consumed forage. Colder temperatures and decreased forage availability may have also affected calf gains in the October to December time frame.

Genetic potential and animal class

A major consideration for livestock production systems that require animals to utilize dormant forages is how well the genetic makeup of the animal matches the nutrient resource available. Many factors such as body size, milk yield, heat and cold tolerance, and grazing behavior are influenced by animal class, breed choice and genetic selection. Under conditions of low feed availability, systems using livestock of smaller body size and lower milk yield can be most appropriate. The ability to store energy for use in periods of nutrient deficiencies is also critical and may require a trade off in high lean yield (BIF, 2010).

Feed resources should be considered in terms of both amount and quality. Milk production requires both high nutrient quality and quantity. Some environments may have adequate amounts of feed available, but if quality is low, high genetic potential for milk can still put a nutritional stress on the lactating female, resulting in poor reproductive performance. The increased need for feed resources for greater body size may be more a need for greater dry matter intake, with less need for greater concentrations of specific nutrients compared to the impacts of increasing milk yield (NRC, 2000). Inappropriate matching of genetics to the environment increases production risk and the degree and skill of management needed. For U.S. beef cattle, guidelines have been developed for appropriate matching of forage resources with milk yield, cow size, lean yield, calving ease, ability to store energy and resistance to stress (BIF, 2010).

Mixed species herds are used in some areas to make use of varied forage resources that may be available through niche selection and to provide a buffer to both variable markets and forage conditions (Accatino et al., 2014). Multi-species grazing takes advantage of the preferred diet selection patterns of differing species, where cattle may prefer diets of predominately grass, goats selecting diets of a majority of browse when accessible, and sheep falling somewhere in between (Walker, 1994). This can be especially important at times when grass forage is dormant and of relatively low quality while browse has maintained higher quality. Browse may also be more resilient to drought conditions, providing some high quality forage during a period when grass growth is limited (Accatino et al., 2014). Multi-species grazing also allows for exploitation of physiological differences between species. Camels, for example, can go for longer periods without water, allowing use of sites not accessible to other types of livestock, and also have a relatively long lactation period (12–18 mo) that can prolong access to milk, including that for human consumption, during extended dry periods (Thurow et al., 1989).

Systems relying on livestock mobility

Various types of 'grazing systems' have been employed to allow livestock to take advantage of variations in forage quality throughout the year. These have included systems that rotate animals through paddocks to effectively exploit rapid changes in forage quality where climate permits rapid regrowth and systems of extensive movement of livestock across vegetation zones allowing the use of different forage resources though out the year. An example of the latter includes sheep management systems in the Western U.S where flocks were moved to high elevation rangelands for summer grazing and then moved to low elevation salt desert shrublands when snow cover prevented mountain grazing and shrubs provided high quality feed at a time when grasses were at their lowest quality. Examples from outside the U.S. include long-distance movement of livestock herds in areas of the world where forage resources are affected by highly variable climates and were environmental conditions affect the ability to utilize forage resources during certain times of the year, such as water limited environments of the Sahel in West Africa or snow driven movements as in the mountain areas of Nepal and the grasslands of Mongolia.

In traditional transhumant systems, movement generally occurs along predetermined pathways or 'corridors' (Ayantunde et al., 2014; Kitchell et al., 2014). Timing of movement is adaptive to local conditions, such as rainfall to produce new forage growth or snowfall levels to drive herders to lower elevations. Timing of livestock movement in some areas, such as the western U.S., may be regulated by grazing permits, which affect the functional adaptability of these systems.

In the arid and semiarid areas of West Africa livestock production depends largely on grazing resources which vary both spatially and temporally (Hiernaux et al., 2009). In this region, year-round grazing systems also vary depending on agro-ecological zones (Table 2). In the arid area, the year-round grazing systems are characterized by continuous grazing of communal rangelands in the wet season and southward movement of the animals to the sub-humid and humid zones in the dry season in search of forage and water. The year-round grazing systems in the semiarid area are similar except that the animals also graze crop residues in the early part of the dry season (October to December) before moving southward in search of grazing resources in the dry season. In the sub-humid and humid zone with higher rainfall and high biomass, ruminants graze communal rangelands in the wet season and crop fields after the harvest but return to graze the rangelands when the crop residues are exhausted. Rationale for the selection of the various systems is included in Table 3 along with identification of some knowledge gaps where additional research would be informative to improving system management.

The demographic pressure in the West African region has led to the expansion of cropping areas into grazing land, particularly in the semiarid zone. Associated with diminishing grazing areas is decline in available forage and the growing importance of crop residues as animal feed in the zone. For example, a recent study on assessment of feed resources in Yatenga province in Burkina Faso, a semiarid area, showed that 50% of the livestock feed came from crop residues (Amole and Ayantunde, 2015). Another effect of the expansion of cropping areas into grazing land is a change in the florisitic composition of the herbaceous vegetation as land with greater soil fertility is cultivated leaving less fertile land as grazing area. This favors the establishment of species that thrive well on poor soil such as *Sida cordifolia*, which are often less palatable to animals. Change in floristic composition of the herbaceous species may affect the properties of graz-

Table 2. Features of year-round grazing systems in different agro-ecological zones of West Africa

Agro-ecological zone	Dominant livestock system	Feature	Year-round grazing system
Arid	-Pastoral -Agro-pastoral	-Dominant species: camel, sheep, goat, cattle -Large frame zebu breeds and small ruminants -Extensive production systems -Highly mobile (seasonal movements to sub-humid zone, i.e. transhumance) -Mainly dependent on grazing resources -Ecologically friendly but highly vulnerable to drought -Livestock the main source of livelihood	-Continuous grazing of communal rangeland only in wet season -Southward movement to sub-humid zone in dry season to graze crop residues and pastures
Semiarid	-Agro-pastoral -Mixed crop-livestock	-Dominant species: Cattles, sheep, goat -Large frame zebu breeds -Market opportunities, especially sale of live animals -Extensive production systems -Feed resources are natural pastures and crop residues -Seasonal mobility to sub-humid zone for forage and water	-Continuous grazing of communal rangeland only in wet season -Grazing of crop residues in early dry season (October to December) - Southward movement to sub-humid zone in dry season to graze crop residues and pastures
Sub-humid/humid	-Mixed crop-livestock	-Dominant species: Sheep, goat, cattle -Small frame *Bos taurus* trypanotolerant breeds (dwarf) of cattle and small ruminants -Mainly sedentary production systems as household herd size is generally small -High disease burden such as the vector borne diseases e.g. ticks, trypanosomiasis -High feed biomass but often of low quality -Contribution of livestock to livelihood is low as crop farming is the main source of livelihood -Host to transhumant herds from arid/semiarid zones and associated cases of conflict between farmers and herders	-Grazing of natural pastures in wet season around homestead -Grazing of crop residues in the early dry season -Grazing of communal pastures in the dry season after the crop residues have been exhausted -Host to high number of transhumant herds grazing in the grazing areas and crop field in the dry season

ing land by altering plant cover. Floristic composition changes have also occurred in East Africa rangelands. For example, brush encroachment by *Prosopis juliflora*, a non-native shrub, has altered rangeland forage availability in lowland areas of Ethiopia (Kebede and Coppock, 2015). Additionally, the ability to move to areas previously relied on for seasonal grazing have been limited by increased use of land for cropping (Nyariki et al., 2009; Dong et al., 2011).

Table 3. Rationale for using various management strategies in West Africa to manage livestock in systems relying on yearlong grazing, its associated trigger for use and knowledge gaps to improve their use

Situation	Management strategy	Rationale	Trigger for the strategy	Knowledge gap
Wet season high quantity and quality of rangeland forage	Continuous grazing of communal rangeland	High quality and quantity for animal nutrition and productivity; Only feed resources available	Rain creates forage green up	Information on how climate change affects spatial and temporal availability of forage
Wet season high quantity and quality pastures around the homestead	Rotational grazing of natural pasture around homestead	To avoid damage to growing crops by the animals. They are then confined or often tethered on pastures around the homestead	Germination of crops in the crop field	The effect of restricted access to grazing in the wet season through confinement on the animal performance and vegetation dynamics
High quantity and good quality crop residues immediately after the grain harvest in early dry season	Continuous grazing of crop residues	Significant decline in quantity and quality of available natural pastures; Availability of good quality crop residues after grain harvest; Collection and storage of crop residues for late dry season use at homestead	Harvest of grains from the crop field; Opening of the crop field for grazing by the animals	Constraints to adoption of techniques to conserve and or improve the quality of the crop residues; Nutrient cycling within mixed crop-livestock systems
Availability of forage resources and water in the destination areas in the sub-humid zone in the dry season	Continuous grazing of natural pastures; Controlled grazing of crop residues	Difficulty in meeting the nutritional needs of the animals due to significant decline in available pasture and crop residues in the community	Lack of feed resources in the communal rangeland and exhaustion of the crop residues on the crop field; Conflicts with other land uses may affect distance and/or locations	The effect of long distance movement on animal performance and herd dynamics; Cost and benefit of long distance movement; Effects of long distance livestock movements on nutrition within the household; Effects of land tenure policies on livestock mobility patterns

Table 4. Main herbaceous species richness and percentage of ground cover per vegetation patch in the classified forest of Dinderesso in the Sudanian savannah zone of Burkina Faso

	Richness (number of species)			Percentage of cover		
Grass type	Dense woodland	Open woodland	Grassland	Dense woodland	Open woodland	Grassland
Annual	6	9	10	9.1	39.4	41.2
Perennial	8	8	8	79.3	47.8	35.5
Legumes	6	2	3	5	0.2	1.1
Forbs	10	11	8	6.6	12.6	22.2
Total	30	30	29	100	100	100

Alterations in land use toward increased and more intensified cropping systems and potential for land use conflicts with crop farmers, therefore, have increasing influence on decisions regarding mobility. In a survey of mobile livestock herders in West Africa (Turner et al., 2014) disadvantages to moving livestock more than 40 km from the main household were the potential loss of milk for home consumption and increased risk of conflicts with crop farmers. In areas where pasture exists far from cropland in the more northern grazing areas, the ability to avoid conflicts was viewed as an advantage to mobility.

West Africa Case Study

To better understand livestock management strategies being used by local herders in an area of West Africa, a case study of year-round grazing management was conducted in the Sudanian zone of Burkina Faso around protected areas in the National park of Po and the classified forest of Dinderesso. The main vegetation types in the 2 sites are gallery forest, dense and open woodlands, and grasslands. Tree density and richness are higher in the woodlands (Table 4), including palatable browse species such *Afzelia africana, Pterocarpus erinaceus, Piliostigma thoningui and P. reticulatum*. For the herbaceous layer, the main species are *Andropogon gayanus, A. ascinoides, A. spceudapricus, Diheteropogon hagerupii,* and *Schizachyrium sanguineum*. In terms of life growth forms, annual and perennial grasses are dominant species in the different vegetation patches (Table 4). In general, there is a high inter-annual variation of aboveground biomass production in Sudanian zones. Preliminary results provide insights on the year-round grazing arrangement, underlying a potential benefit of including livestock grazing in forest management strategy, which can ensure vegetation diversity while providing valuable pasture resources for livestock. For example, livestock removal during the grazing period (from June to January) can contribute in reducing the bushfire damage to the vegetation as fuel load is consequently reduced by livestock at the end of rainy season.

Former Sahelian pastoralists have been settled for decades in the area surrounding the protected areas in Sudanian zones of West Africa, and have adopted cereal cropping in combination with livestock husbandry (Fournier et al., 2009). In the study sites, pastures in the protected areas and in the fallows and crop residues are the main forage resources for the livestock year around (Kiéma, 2007). The livestock feeding system is based on daily grazing and transhumance practices to make opportunistic use of pasture resources which vary in availability and quality according to land use types, soils and climate conditions. For example, livestock herds monitored using GPS devices and herd observations (Zampaligré, 2012) showed a daily distance traveled of 5 to 17 km and the total time spent on pasture ranged from 7 to 10 h. Cattle herds traveled longer distance and spent more time on pasture than the other livestock species and the highest time and distance traveled were recorded during the dry season.

The different vegetation patches and land use/cover types used by pasturing herds changed according to season. Livestock foraging activities such as feeding (grazing on herbaceous and browse species) significantly varied according to season and livestock species (Table 5). In the case of classified forest of Dinderesso, a *community based grazing system* has been implemented as a forest management tools since 2006 (Nacro, 2007). This grazing system allows livestock of settled pastoralists to graze daily into a unit of the forest (about 2000 ha) every year from June to January. In addition to settled pastoralist herds, many transhumant herds also use the protected area vegetation in the Sudanian zones as dry season pastures (Kiéma and Fournier, 2009. The *controlled grazing system* of Dinderesso forest showed the possible benefits of integrating livestock grazing as management tool for protected areas but a good monitoring system of the forest vegetation dynamics along with respect of the grazing agreements by the stakeholders involved is a key to safeguarding the forest resources against overgrazing and vegetation degradation.

Many traditional year-long grazing systems employing livestock mobility as a strategy have been

Table 5. Foraging behavior of cattle, sheep and goat herds and grazing itineraries characteristic of year round systems in the Sudanian savannah zone of Burkina Faso (from Zampaligré, 2012)

Herd monitored	Seasons	Duration (h)	Distance (km)	Resting	Feeding	Walking
Cattle	Wet season	8	8.5	37.6	40.0	22.4
	Early dry season	9	14.3	30.5	32.6	36.9
	Late dry season	10	17.4	22.0	37.8	40.1
Goat	Wet season	6	5.8	52.7	29.2	18.1
	Early dry season	8	7.7	40.8	42.8	16.4
	Late dry season	8	6.1	54.9	35.0	10.1
Sheep	Wet season	7	9.7	32.6	37.8	29.6
	Early dry season	8	12.0	26.2	32.6	41.2
	Late dry season	8	11.9	38.4	26.3	35.4
SEM		*0.28*	*1.26*	*5.44*	*2.83*	*4.52*
Variables	df	———	———	*P*-value	———	———
Season	2	< 0.001	< 0.001	0.001	0.163	< 0.001
Species	2	< 0.001	0.005	0.194	0.399	0.134
Season*Species	4	0.603	0.062	0.218	0.006	0.140

shown to be adaptive (Moritz et al., 2014) with movements adjusted to yearly alterations in forage conditions. However, the ability of system users to adapt to yearly variations has been affected by changes occurring in land and resource availability that have come with changes in land use, such as increased cropping or mining activities, altered water use that fragment traditional grazing lands; land tenure; and changing climate that impact forage and water availability (Dongmo et al., 2012). The impacts of climate change on forage availability and quality include changes in herbage growth, floristic composition of vegetation, herbage quality, and the importance of crop residues as animal feed (Thornton et al., 2009). The impacts of climate change on herbage growth will depend on the plant species as increases in future CO_2 levels may favor different grass species than are currently found, while the opposite is expected under associated temperature increases.

Previously, many pastoralist systems have used community-based adaptive management to deal with changing forages resource (Reid et al., 2014), and these management strategies need to be understood when developing land tenure and grazing policies. Without the ability to exercise these adaptive strategies for changing conditions, pastoralist populations can become more vulnerable to the effects of climate fluctuations on forage resources and disease management.

Mobile systems may rely heavily on both shared labor and shared information to provide inputs to decision processes. Therefore, social institutions can be key to success or failure of these systems and need to be considered as part of the decision process (Turner et al., 2014) along with biophysical data such as forage quality and water availability. Consideration of social institutions as part of grazing management strategies is in line with current strategies in the U.S. to understand the social factors driving the high adoption of rotational grazing systems when research based on short-term biophysical data (plant and animal response) do not support the perceived advantage to these systems (Briske et al., 2011).

LOOKING FORWARD

Success of livestock systems employing yearlong grazing often require adaptive approaches. However, formal indicators of adaptive management are often vegetation-based rather than livestock-based, leaving livestock managers in a position of making decoupled decisions. Lessons might be learned from the study of traditional mobile livestock systems as to how to link vegetation and livestock indicators to help inform the complex decision-making process involved in managing yearling grazing systems. Animal management systems, such as those using alterations in parturition and weaning times and selection of appropriate genetics to match animal and forage resources, allow land resources users to develop effective yearlong grazing management strategies that minimize harvested feed inputs.

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