

Co-grazing of sheep and goats: Benefits and constraints[☆]

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Abstract

Co-grazing of sheep and goats has been practiced throughout history and is commonplace around the world. However, its benefits may not be fully appreciated and means to maximize them have not been extensively studied. Advantages of co-grazing of sheep and goats are derived primarily from differences in preferences for particular plant species and parts, abilities or willingness to consume forages that are not highly preferred and would have greater adverse effects on the other species, and physical capabilities to gain access to specific types of vegetation. Hence, the degree to which total stocking rate or carrying capacity is greater for co- versus mono-species grazing increases with increasing vegetation diversity and, concomitantly, decreasing dietary overlap. Perhaps the most important management decision pertaining to co-grazing is appropriate stocking rates. A simple ‘baseline’ or ‘starting point’ method of estimating co-grazing stocking rates is: $(\text{number with mono-species grazing} \times (100 - \% \text{ overlap})/100) + (\text{number with mono-species grazing} \times (\% \text{ overlap} \times 0.5/100))$. The equation is applied to both sheep and goats, with values added to determine the total stocking rate. Botanical composition and available forage mass are important determinants of numbers of both sheep and goats with mono-species grazing, and factors affecting nutrient requirements such as body weight and production state, preference for or willingness to consume forages present, and desired length of grazing will have impact as well. Previous experience with the particular grazing and animal conditions will aid in projecting mono-species stocking rates. Estimates of dietary overlap when co-grazing should be based on the most accurate method available, which in many instances may be prior experience or visual observation at different times of the day and in various seasons. However, the equation noted above has limitations. It assumes that intake of forages potentially consumed by each animal species is equal, which obviously is not always true. Furthermore, interactions between stocking rates when the two species graze together versus alone are not considered. Nonetheless, because of its simplicity, the method may have value in field settings, and illustrates the importance of browse plant species in many grazing systems and why management practices are frequently employed to maintain or increase their prevalence and vegetation diversity. © 2008 Elsevier B.V. All rights reserved.

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1. Introduction

Grazing two or more species of livestock together or separately on the same land in a single growing season is known as common use, dual use, or multi-species

grazing (Byington, 1985). Multi- or mixed species grazing systems may be based on sequential grazing (i.e., grazing by one species following another at separate times) or co-grazing simultaneously of two or more species of livestock and/or game animals. These practices have greatest effect on efficiency of forage use with land containing a variety of vegetation types (Walker, 1994). In accordance, the degree of dietary overlap in consumption of specific plant species and parts is a major factor influencing benefits of multi-species grazing. A related attribute of co-grazing, though relatively more important with presence of cattle, is con-

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sumption by sheep and(or) goats of plants toxic to or avoided by another ruminant species present (Walker et al., 1994). Ruminant species also vary in the preference, tolerance, and(or) ability to graze lands with different topography and terrain. Seasonal nutrient and labor requirements differ among ruminant species as well, although patterns of breeding and management of sheep and goats in the U.S. are similar. Product diversification can be an attribute of multi- versus mono-species grazing. Greater biological efficiency, defined as product from a system on a continuing basis, for multi-species grazing enhances total income and enterprise sustainability.

Given the aforementioned potential favorable outcomes of co-grazing yet lack of widespread employment, there must be disadvantages or other constraining considerations. One is simply a lack of knowledge or appreciation of the attributes. Greater management skills and knowledge necessary for two or three species versus one can be an important factor, as well as additional production inputs for raising of small ruminants such as increased fencing requirements and protection from predation. Furthermore, there may be reductions in production efficiencies. An example is purchase of smaller lots of health management supplies at a higher cost with limited numbers of two or more co-grazing species compared with one in mono-species grazing. However, these issues seem of much lesser significance for co-grazing of sheep and goats than of cattle and one or two species of small ruminants.

The objectives of this paper are to review literature currently available regarding co-grazing of sheep and goats, focusing on nutrient requirements, selectivity, ingestive and grazing behaviors, and animal performance. Thereafter, practical considerations for assessing and achieving greatest benefits from co-grazing of small ruminants are addressed.

2. Nutrient requirements

Many factors influence how sheep and goats respond to grazing together versus alone, among which are nutrient requirements. Forbes and Provenza (2000) proposed that, when given the opportunity, ruminants consume different quantities of one or more feedstuffs to correct or limit nutrient deficiencies and minimize excesses to achieve low levels of ‘metabolic discomfort.’ Furthermore, ruminants continually ‘experiment’ in consumption of different levels of particular feedstuffs, and conceivably plant parts, in relation to changes in composition of available feedstuffs as well as shifting nutrient needs. Therefore, a brief overview of similarities and

dissimilarities in nutrient requirements between species is warranted.

2.1. Energy

The ME requirement for maintenance (ME_m) relative to body weight^{0.75} is less for sheep than for goats (NRC, 2007). NRC (2007) discussed literature supporting no or little differences among sheep breeds in ME_m . Conversely, there appear differences in ME_m among general types (i.e., biotypes) of goats selected for unique productive purposes (e.g., dairy > Boer and indigenous). ME_m is modified by many other factors, including level of previous or present feed intake, age, gender, body composition, grazing activity, and acclimatization. It is not known if influences of such factors differ between sheep and goats.

Though methods of describing energy requirements for growth by sheep and goats may differ (e.g., NRC, 2007), requirements per unit of gain appear similar if composition of tissue accretion is considered. In some instances the ratio of average daily gain (ADG) to DM intake (DMI) has been greater for sheep than for goats (Al Jassim et al., 1991; Mahgoub and Lodge, 1998). However, this might primarily involve relatively low growth potential of particular goats used or comparisons with dairy goat breeds that have higher ME_m than other genotypes (Urge et al., 2004; NRC, 2007). In support, Animut et al. (2006) observed similar ADG:DMI for Boer goats and Khatadin sheep consuming mixed forage-concentrate diets. As is true for energy needs for growth, requirements for other productive functions such as lactation, fiber growth, and pregnancy are thought to be comparable between sheep and goats relative to levels of production, milk composition, birth weight, etc.

2.2. Nitrogen

Factorial approaches are frequently used to estimate crude protein (CP) requirements for maintenance, with contributing losses of metabolic fecal (MFCP), endogenous urinary (EUCP), and scurf or dermal plus fiber CP (SFCP). The SFCP loss is small relative to MFCP and EUCP except for animals producing large amounts of fiber (i.e., wool-producing sheep and Angora goats). MFCP is usually based on DMI. MFCP per unit of DMI for sheep and goats proposed by NRC (2007) (i.e., 1.52 and 2.67% DMI for sheep and goats, respectively) differs, but with a lower assumed efficiency of protein use for sheep the metabolizable protein (MP) requirement for MFCP is not markedly dissimilar (2.25 and 2.67% DMI for sheep and goats, respectively). MP needed for

EUCP based on [NRC \(2007\)](#) recommendations also does not markedly vary between species (e.g., 7.2–18.2 g/day for sheep and 5.8–22.2 g/day for goats ranging from 10 to 60 kg BW). Hence, the protein requirement for tissue maintenance is similar between sheep and goats.

Efficiency of MP use in protein accretion for growth is assumed similar for sheep and goats ([NRC, 2007](#)). Hence, species comparisons of protein requirements depend on absolute rates of protein gain. However, due to limited data available, [NRC \(2007\)](#) MP requirements for tissue gain by goats are based simply on ADG, whereas those for sheep consider the proportion of mature size and body condition score (BCS). As was stated for energy, species differences in protein requirements for other functions (i.e., milk yield, fiber growth, pregnancy) primarily relate to levels of production. Higher energy and protein requirements for growing sheep versus goats and for lactating sheep with faster growing progeny than goats are largely functions of greater growth potential.

It has been generalized that goats have a greater ability to survive and produce under harsh nutritional environments than other ruminant species ([Silanikove, 2000a](#)). In particular, goats are thought to have greater capacity for recycling N than cattle and sheep ([Silanikove, 2000b](#)). In accordance, [NRC \(2007\)](#) recommended a lower rumen degraded intake CP requirement (DIP) for goats versus sheep. In some cases this has been proposed to contribute to species differences in diet selection. This would seem more likely with diets fairly low in CP concentration when N recycling is important compared with diets adequate in CP.

2.3. Minerals and vitamins

Mineral and vitamin requirements of goats have not been studied as extensively as those of sheep, with in many instances recommendations for goats based on findings for other ruminant species. However, one notable difference in need of consideration for co-grazing is the greater requirement for Cu and higher dietary Cu level at which toxicity may occur for goats than for sheep ([NRC, 2007](#)).

2.4. Voluntary feed intake

Voluntary feed intake is an important consideration when addressing the comparison between small ruminant grazing species. For example, [Luo et al. \(2004\)](#) with a database of treatment mean observations from the literature to develop feed intake prediction equations for goats of different genotypes, genders, and stages and levels of production accounted for the influence of energy

requirements through an assumption of constant efficiency of whole body energy metabolism ([Tolkamp and Ketelaars, 1994](#)). [NRC \(2007\)](#) cited some of the studies in which feed intake by sheep and goats has been contrasted, reporting higher intake by goats, the opposite, or no difference. It was concluded, in part based on [SCA \(1990\)](#), that clear evidence is lacking to recommend generalized intake differences between sheep and goats. In this regard, there are numerous experimental conditions that influence such species comparisons, among which is genotype or biotype.

3. Ingestive behavior

Ruminant species are commonly classified into morphological feeding types of grass/roughage consumers or grazers, concentrate selectors, and ones with intermediate behaviors or mixed feeders ([NRC, 2007](#)). Cattle and sheep are categorized as grazers, and goats are usually placed in the intermediate group. Grazers have relatively short lips, broad muzzles, and a cornified tongue tip, designed for maximal intake of grass at low biomass ([Van Soest, 1994; NRC, 2007](#)). Goats have a fairly narrow but deep mouth opening and mobile lips and tongue that allow selective harvesting of particular plants and plant parts, such as leaves and twigs of woody plant species ([Hofmann, 1989; Van Soest, 1994; NRC, 2007](#)). Goats are quite agile compared with cattle and sheep, frequently using a bipedal stance and climbing to gain access to vegetation of interest ([Sanon et al., 2007; Figs. 1 and 2](#)).

Compared with grazers, intermediate feeders have greater salivary gland weight relative to BW ([Hofmann, 1989; Robbins et al., 1995](#)). These glands produce a



Fig. 1. Example of the agile nature of goats while browsing. These goats are climbing on wire panels leaning against trees and brush to gain access to tree leaves.



Fig. 2. Example of the bipedal stance used by goats. These goats are standing on hind legs in order to gain access to foliage of a juniper tree.

greater proportion of thin, proteinaceous serous saliva, which may play a role to help counter some plant defensive chemicals such as tannins (Hofmann, 1989; Robbins et al., 1995). Relatedly, intermediate feeders and concentrate selectors have a relatively large number of HCl-producing parietal cells and a thicker abomasal mucosa, which may be adaptations to plant secondary metabolites such as for thorough liberation of proteins bound to condensed tannins in the reticulo-rumen (Hofmann, 1989).

Relative to body size, intermediate feeders have a smaller reticulo-rumen and omasum and a lesser number of omasal lamina than grazers (Van Soest, 1994). The small size of the reticulo-rumen and a larger opening of the reticulo-omasal orifice relative to body size for intermediate feeders versus grazers yield potential for shorter ruminal retention time of particulates and a large size of particles exiting the rumen and appearing in feces, although such differences depend largely on the specific diets consumed (Hofmann, 1989).

Comparative chewing efficiency (CE) of sheep and goats was studied by Domingue et al. (1991). Ingestive CE was defined as the proportion of particles less than 1.0 mm in reticulo-ruminal boli present just after swallowing, and ruminative CE was termed as the proportion of particles greater than 1.0 mm in size following rumination. Ingestive CE was greater for goats than for sheep, whereas ruminative CE tended to be greater for sheep. Higher ingestive CE for goats could be due to more frequent chewing, a greater grinding surface area of teeth ($\text{mm}^2/\text{kg body weight}^{0.75}$), and/or differences in the structure of the skull and jawbones that determine forces applied during eating (Ulyatt et al., 1986). Of these factors, greater chewing frequency appears most important, since when Domingue et al. (1991) corrected

for chewing frequency both ingestive and ruminative CE were similar between sheep and goats.

Some of the differences noted above among species and morphological feeding types can influence ingestive behaviors of bite mass and rate of biting. The product of bite mass and rate of biting, intake rate, multiplied by grazing time yields daily intake. Bite mass is dictated by bite area and forage density in the prehension zone. The size and shape of the dental arcade is a determinant of the bite area and, thus, impacts intake rate (Illius and Gordon, 1987; Gordon et al., 1996). However, the practical importance of such properties depends on characteristics of the forage available. For example, with a vegetative sward sheep penetrated far down into the canopy with deep bites, but with tall, stemmy grasses in reproductive stages of growth penetration was less and only the leafy component was consumed (Gong et al., 1996b). Conversely, in the same study goats were less selective with the more mature grasses, consuming leaves but also available seedheads and stalk components. In this and related studies with grasses, bite mass and intake rate were greater for sheep versus goats except when grasses were in reproductive stages of growth (Gong et al., 1996a,b,c). Factors responsible for such differences are unclear, but greater ingestive CE with swallowing of larger proportions of small particles by goats than sheep may be involved (Domingue et al., 1990, 1991).

Botanical composition of the pasture or range affects ingestive behavior of sheep and goats. For example, Papachristou (1997) noted that goats had a greater biting rate compared with sheep when browse was the dominant forage available, and the opposite species difference existed when non-browse plant species were most prevalent. Biting rate for both species was greater for low versus high browse levels, with a considerably greater difference for sheep than for goats. This stronger negative relationship between shrub cover and biting rate for sheep than for goats reflects a greater flexibility or adaptability of ingestive behavior of goats to varied pasture conditions.

With declining bite mass, biting rate and grazing time increase up to certain levels to prevent or limit reductions in daily intake (Coleman et al., 1989). In accordance, though bite mass is often greater for sheep than for goats, in some cases greater rates of biting by goats have resulted in similar intake rate (Gordon et al., 1996). Nonetheless, a possible important performance effect of bite mass is through influence on grazing time, because of the strong positive relationship between the activity energy cost and grazing time (Osuji, 1974; Sahlu et al., 2004).

4. Forage preference/selectivity

4.1. Plant species

Hodgson (1979) defined preference as the discrimination exerted by animals for sward components and selection a function of preference modified by physical constraints, although often the terms are used interchangeably. Goats generally consume a wider array of plant species and exhibit preference for a more varied diet in terms of botanical composition than sheep (Wilson et al., 1975; Haenlein et al., 1992). Though goats have preferences and exhibit selectivity, their diets are more closely related to availability of sward components than diets of sheep (Papachristou, 1997; Bartolome et al., 1998).

Table 1 provides brief summaries of conditions and findings of studies in which preference and/or selectivity was compared between these species. Based on this table, inclusive of a wide variety of experimental settings, it is difficult to present conclusions without exceptions. But, it is apparent that, when available, goats select a greater quantity and dietary proportion of browse and shrubs than sheep (Migongo-Bake and Hansen, 1987; Kronberg and Malechek, 1997; Sanon et al., 2007). As an example, Walker et al. (1994) noted that diets of sheep, cattle, and goats were 50, 70, and 30% grass, 30, 15, and 10% forbs, and 20, 15, and 60% browse, respectively. Thus, usually there is greater dietary overlap between cattle and sheep versus cattle and goats. However, with limited availability of other types of plants, sheep can be very efficient browsers as well (Valderrabano et al., 1996), although this generalization does not consider a greater tolerance of many anti-nutritional factors by goats (Salem et al., 2006) and willingness to consume some plants avoided by sheep (Walker et al., 1994; Bartolome et al., 1998). Likewise, browse can make considerable contributions to intake by cattle in some settings and seasons (Brosh et al., 2006).

Differences between sheep and goats in dietary preference/selectivity with grass–legume mixtures have been inconsistent. In some cases sheep have had higher preference for legumes than goats (Collins and Nicol, 1987; Gurung et al., 1994; Penning et al., 1997), but with a tropical grass–legume pasture Norton et al. (1990b) noted the reverse. Similarly, with a variety of forbs and multiple species of grasses, Animut et al. (2005b) observed greater preference of goats versus sheep for forbs and greater preference of sheep for grasses. A sward characteristic that may contribute to such varied findings is the vertical distribution of different plant species in relation to most natural or perhaps preferred methods of harvest-

ing. That is, sheep appear to desire and strive to graze in the lower stratum or deep in the sward horizon (Collins and Nicol, 1986; Gong et al., 1996a,b,c). Conversely, goats generally have a shallower depth of biting and prehend from the top of the sward or horizon down, with biting and head movements horizontally or from side to side. In support, DM intake by goats decreases with decreasing pasture height more rapidly than intake by sheep (McCall and Lambert, 1987; Penning et al., 1997). Therefore, differences in preference/selectivity between species may be related to vertical distribution of various plant species and plant parts rather than being attributed simply to plant species presence.

An alternate way of considering the more varied botanical composition of diets consumed by goats than sheep is simply because of greater flexibility. For example, Grant et al. (1984) found that selectivity of goats for rushes (*Juncus effusus*) in a mixture with various grasses decreased as their proportion decreased. Likewise, the botanical composition of goat diets varies in accordance with seasonal availability. In this regard, diets of feral goats were 90% browse, 4% forbs, and 6% grass in winter when browse availability was high and 8% browse, 18% forbs, and 74% grass in the summer when growth of grasses and forbs was rapid (Coblentz, 1977). Sheep also can modify consumption of different plant species in relation to changing seasonal availability but to a lesser extent than goats (Kronberg and Malechek, 1997; Papachristou, 1997).

Stocking rate is an obvious factor affecting available forage mass, but which has not been extensively studied in regards to co-grazing of sheep and goats. Animut et al. (2005b) observed that, although preference values for forbs differed between goats and sheep, as stocking rate increased and forage mass decreased preference values of both species for the most prevalent forb, ragweed (*Ambrosia artemisiifolia*), increased. The preference value for more preferred forbs decreased and for grasses was unchanged.

Genotypic variation can also influence preference and selectivity (Bryant et al., 1979; Warren et al., 1984). Angora goats have a disadvantage in browsing of dense brush because of their low height and presence of mohair fiber that can limit access (Taylor, 1985). As a result, the botanical composition of diets of Angora goats resembles that of sheep more than of Spanish goats (Bryant et al., 1979; Warren et al., 1984). Region of origin can impact diet selection as well (Fedele et al., 1993). Furthermore, consumption of some plants with anti-nutritional factors, such as junipers and sagebrush, is heritable and thus can be modified by selective breeding (Warren et al., 1983; Fraker-Marble et al., 2007).

Table 1
Comparisons of diet composition of sheep and goats

Source	Conditions	Results
Grasses vs. legumes or mixed grass/forb pastures		
Norton et al. (1990b)	Two different tropical grass–legume pastures, one with signal grass (<i>Brachiara decumbens</i>) and the other with paspalum (<i>Paspalum plicatulum</i>). Both pastures were oversown mainly with siratro (<i>Macroptilium atropurpureum</i>), axillaris (<i>Macrotyloma axillaris</i>), and greenleaf desmodium (<i>Desmodium intortum</i>)	Sheep selected less legume and more grass leaf compared with goats. There were no major differences between species in proportions of grass stem consumed
Gurung et al. (1994)	Annual pastures containing wimmera rye (<i>Lolium rigidum</i>), barley grass (<i>Hordeum leporinum</i>), silver grass (<i>Vulpia bromoides</i>), and subterranean clover (<i>Trifolium subterraneum</i>)	Sheep selected more green clover and less green grass and dry herbage than goats. Goats consistently preferred green grass while sheep prefer green clover
Del Pozo et al. (1996)	Perennial ryegrass (<i>Lolium perenne</i>)/white clover (<i>Trifolium repens</i>) pastures.	Swards grazed by goats had a higher proportion of white clover than those grazed by sheep.
Penning et al. (1996)	Perennial ryegrass (<i>Lolium perenne</i>)/white clover (<i>Trifolium repens</i>) pasture	Swards grazed by goats had a greater clover mass compared with ones grazed by sheep
Penning et al. (1997)	Monocultures of perennial ryegrass (<i>Lolium perenne</i>) adjacent to monocultures of white clover (<i>Trifolium repens</i>), as well as pastures with 20 or 80% clover by area	Sheep exhibited 70% and goats 52% preference for clover
Animut et al. (2005b)	Pastures contained a mixture of grasses, predominantly bermudagrass (<i>Cynodon dactylon</i>) and johnsongrass (<i>Sorghum halepense</i>), and forbs, primarily ragweed (<i>Ambrosia artemisiifolia</i>), <i>Lespedeza cuneata</i> , and nightshade (<i>Solanum</i> spp.)	Goats had a greater preference for forbs compared with sheep, and sheep had a higher preference for grass compared with goats
Browse vs. grasses and forbs		
Wilson et al. (1975)	Semi-arid woodland in western New South Wales	Goat diets consisted mainly of browse. Sheep exhibited preferences for herbaceous species, mainly spear grass (<i>Stipa variabilis</i>) and copper burrs (<i>Bassia</i> spp.). When these plants were unavailable, the dietary proportion of browse increased
Bryant et al. (1979)	Excellent range condition with grasses, forbs, and browse plant species	Sheep diets were dominated by grasses and goat diets consisted of similar grass and browse levels
Squires (1982)	Semi-arid poplar box (<i>Eucalyptus populnea</i>) woodland, with a dense understory of shrubs, grasses, and forbs	Sheep selected more green grass than did goats, and goats selected more shrubs and trees than did sheep
Warren et al. (1984)	Different breeds of sheep and goats grazing on three selected range types	Grasses were preferred by sheep and Angora goats. Forbs were equally selected by all breeds of sheep and goats. Breeds of both species varied in the amount of browse consumed. Spanish goats and to a lesser extent Angora goats depended more heavily on browse compared with sheep breeds
Pfister and Malecheck (1986a)	Deciduous woodland vegetation	During the wet season, sheep mainly selected grasses and forbs, while goats rapidly shifted among grass, forbs, and browse. In the dry season both species selected similar diets
Migongo-Bake and Hansen (1987)	Semi-arid range containing various species of grasses, shrubs, and trees	Sheep consumed more grasses than did goats and goats selected more browse than did sheep. But, browse contributed more than 30% to the diet of sheep
Kronberg and Malechek (1997)	Deciduous woodland vegetation, composed of a variety of trees, annual grasses, and forbs	Goats selected more browse than sheep. Grasses and forbs were important parts of the diet of sheep in wet and early dry periods. During the dry period many browse species were equally important for both sheep and goats

Table 1 (Continued)

Source	Conditions	Results
Papachristou (1997)	Cleared, slashed, and undisturbed kermes oak (<i>Quercus coccifera</i>) shrublands containing a mixture of woody species, grasses, and forbs	Grasses and forbs constituted about 70 and 30% of sheep and goat diets, respectively, while browse contributed about 30% to sheep and 51–90% to goat diets
Bartolome et al. (1998)	Mediterranean heath-woodland range	Goats tended to avoid grasses. Sheep avoided the tree <i>Quercus ilex</i> , while goats selected for it. There was substantial dietary overlap between sheep and goats in other plant species
Ngwa et al. (2000)	Sahelian rangeland of Cameroon, dominated by thorny shrubs	Goats and sheep spent 75 and 25% of time browsing, respectively, with remaining time consuming grass
Browse alone and noxious plants		
Walker et al. (1994)	Leafy spurge (<i>Euphorbia esula</i> L.)-infested rangeland (50% of standing crop)	Goats and sheep took 64 and 20% of bites from leafy spurge, respectively. Goats consumed less grass than sheep, but forb consumption was similar between species
Valderrabano et al. (1996)	Sheep and goats browsed pastures containing an identical number of saltbush (<i>Atriplex halimus</i>) plants	The level of saltbush utilization, including DM intake and BW gain supported, was similar between animal species. The mean volume reduction of bushes and diameter of twigs consumed was greater for goats compared with sheep
Holst et al. (2004a)	Replicate plots of perennial pasture infested with nodding thistle (<i>Carduus nutans</i>). Major pasture species were fescue (<i>Festuca arundinacea</i>), ryegrass (<i>Lolium perenne</i>), white clover (<i>Trifolium repens</i>), and subterranean clover (<i>Trifolium subterraneum</i>) grazed by sheep or goats	Goats consumed more thistle than did sheep. Sheep consumed the thistle only when pasture was limiting
Holst et al. (2004b)	1.6-ha paddocks containing scotch broom (<i>Cytisus scoparius</i>) at 4–10% ground cover, grazed by goats or sheep	The level of defoliation of broom by sheep and goats was similar with 10% broom ground cover. As broom cover decreased the level of defoliation by goats was higher than by sheep. Goats stripped bark of broom and, hence, were more effective than sheep in controlling broom

4.2. Plant parts

Both sheep and goats generally select for live or green forage and against dead plant parts (Hamilton et al., 1973; Gurung et al., 1994). Norton et al. (1990b) did not observe major differences between sheep and goats in the proportion of dead material in the diet, whereas Collins and Nicol (1987) reported less dead material intake by goats.

In most cases leaves are higher in nutritive value than stems, and often leaves of legumes are of higher quality than of grasses. However, nutritional value of different plant parts is not the only factor affecting selection. In a tropical grass–legume pasture, goats had a high preference for legume leaves and discriminated against both grass and legume stems (Norton et al., 1990b). In this same study, sheep had a relatively high preference for grass leaves and selected against legume and

grass stems. These species differences were presumably associated with spatial distribution of different plants and their parts in the sward. Conversely, Collins and Nicol (1987) noted that goats preferred green stem to green leaf. In oat–ryegrass pastures, Norton et al. (1990a) reported a higher yield of residual grass stems in paddocks grazed by goats, suggesting low preference and selection, whereas sheep selected for both grass leaf and stem. Pfister and Malecheck (1986a), with a woodland grazing area, observed a low leaf to stem ratio during the dry season for both sheep and goats and inconsistent animal species differences throughout the grazing season.

Goats are known for their consumption of seeds and reproductive stems and the ability to decrease spread of some undesirable plant species. Mature seeds may be viable after passage through the gastrointestinal tract, but immature seeds frequently consumed by goats do not

germinate. Allan and Holst (1996) observed that goats reduced the seed bank of thistles and Mayo (2000) noted decreased seed production when goats were used to control *Sericea lespedeza*. Goats are also adept at prehending fruits through the use of a bipedal stance, and in some seasons fruits are more important in diets of goats than sheep (Pfister and Malecheck, 1986a). Ngwa et al. (2000) noted that blossoms, fruits, and pods contributed to diets of both sheep and goats and to a greater extent in the dry than wet season.

4.3. Chemical composition

Both sheep and goats select diets higher in digestible organic matter and CP than the average of all available forage (Gurung et al., 1994; Papachristou, 1997; Hadjigeorgiou et al., 2003). Species differences in chemical composition of selected diets are inconsistent, which may not be surprising given the significant impact of specific plant species available on selection. Also, species differences in dietary nutritive value are not necessarily associated with corresponding performance differences because of the importance of level of feed intake and how quantities of nutrients consumed relate to requirements (Wilson et al., 1975; Gurung et al., 1994).

In some instances the dietary CP content has been greater for sheep versus goats (Gurung et al., 1994; Animut et al., 2005a), whereas the opposite has been noted in other studies (Wilson et al., 1975; Pfister and Malecheck, 1986b). With grass–clover pastures (Hughes et al., 1984; Gurung et al., 1994) and woodland grazing conditions (Wilson et al., 1975; Pfister and Malecheck, 1986b), diet digestibility was similar for sheep and goats. Sheep selected diets of higher in vitro digestibility than goats with tropical grass–legume pasture (Norton et al., 1990b) and semi-arid woodlands (Squires, 1982), whereas Papachristou (1997) found greater dietary in vitro digestibility for goats versus sheep. When browse plant species are available, dietary nutritive value has been greater for goats versus sheep because of greater preference and more efficient harvesting by goats (Wilson et al., 1975; Bartolome et al., 1998; Pfister and Malecheck, 1986b) and generally high nutritive value of browse that varies less with time or season compared with grasses and forbs (Fadel Elseed et al., 2002).

Season can have a large impact on the nutritional value of both sheep and goat diets. Normally the dietary CP content is greater in wet versus dry seasons (Pfister and Malecheck, 1986b; Kronberg and Malecheck, 1997). Browse availability has a major impact on dietary CP levels, particularly in the dry season, and resultant differences between sheep and goats depend on avail-

ability of other plant species and the nature of specific browse plants available in regards to species differences in preference and physical capabilities of harvesting.

5. Grazing behavior

5.1. Distance traveled

Distance traveled is thought to be a determinant of energy expended by ruminants in activity (ME_a) and is included in many factorial systems of prediction (e.g., AFRC, 1993, 1998; SCA, 1990; NRC, 2000, 2001, 2007). Some systems also consider additional costs for vertical movement. Effects of co-grazing on distance traveled by sheep and goats have not been extensively studied, with available estimates in Table 2. There is a wide range in values due to differences in conditions as well as methods of measurement. Relatively low estimates of Gipson et al. (2003) are based on fixes of GPS collars taken every 30 min and, thus, are underestimates. Similar low values of Animut et al. (2005a, 2007) were determined in small paddocks and calculated from the number of foreleg steps and an assumed constant step length regardless of activities (e.g., grazing, moving between grazing bout sites, and walking without grazing).

Based on available direct comparisons, it is not possible to generalize about differences in distance traveled between goats and sheep when co-grazing. Values in some studies are similar between species but in other cases are higher or lower for sheep versus goats. However, disparate findings are not unexpected considering presumed interactions between specific grazing conditions and animal characteristics. For example, distance traveled was negatively correlated with temperature, humidity, and hours of daylight to a lesser extent for goats than for sheep (Swain et al., 1986), reflecting greater adaptability to hotter environments of goats (Silanikove, 2000b).

5.2. Spatial distribution

Spatial distributions of livestock are very important in grazing systems (Holecek et al., 2004). Distributions of livestock on pastoral or rangeland areas are consequences of countless factors, most not well understood. Land topography and the quantity and quality of forage available in different grazing areas obviously have impact, as well as environmental conditions including use of micro-climatic conditions in specific areas to avoid temperature–humidity extremes. Generally both sheep and goats seek and utilize areas with amounts of forage

Table 2
Grazing behavior of co-grazing sheep and goats

Source/species	Distance traveled (km/day)	EE ^a	Time spent (h)				Grazing conditions
			Grazing	Ruminating	Idle	Lying	
Taylor (1985)							
Sheep	6.1	–	–	–	–	–	230-ha pasture with a mixture of forage species (grasses, forbs, and browse)
Goat	9.7	–	–	–	–	–	
Swain et al. (1986)							
Sheep	14.3	–	–	–	–	–	Semi-arid natural range
Goats	10.0	–	–	–	–	–	
Kronberg and Malechek (1997)							
Sheep ^b	–	–	6.3	7.7	10.0	–	Deciduous woodland vegetation, composed of a variety of trees, annual grasses, and forbs, with tree leaf litter supplying 70% of available herbage during the dry season
Goat ^b	–	–	5.6	8.3	10.0	–	
Penning et al. (1997)							
Sheep ^c	–	–	8.1	–	–	–	Grass–clover pastures
Goat ^c	–	–	6.7	–	–	–	
Sheep ^d	–	–	11.1	3.9	9.1	–	
Goat ^d	–	–	8.7	3.5	11.9	–	
Gipson et al. (2003)							
Sheep	1.32	–	–	–	–	–	Pastureland dominated by smooth sumac (<i>Rhus glabra</i>), sand plum (<i>Prunus angustifolia</i>), and lovegrass (<i>Eragrostis curvula</i>)
Goats	1.29	–	–	–	–	–	
Animut et al. (2005a)							
Sheep ^e	–	–	7.8	3.4	2.3	4.7	Mixed grass/forb pastures at three stocking rates
Goats ^e	–	–	7.6	2.3	3.2	4.5	
Sheep ^d	1.30 ^h	578	9.0	7.3	7.7	10.0	
Goats ^d	1.26 ^h	539	7.9	7.6	8.4	10.1	
Schlecht et al. (2006)							
Sheep ^f	9.3	–	5.0	–	1.1	–	298-km ² area consisting of rangelands, fallow lands, and settlements
Goats ^f	8.6	–	5.0	–	1.2	–	
Animut et al. (2007)							
Sheep ^e	–	–	7.0	3.7	2.6	5.5	Mixed grass/forb pastures with or without alley-cropped mimosa (<i>Albizia julibrisin</i>)
Goats ^e	–	–	7.6	2.0	3.7	4.6	
Sheep ^d	1.24 ^h	608	8.4	7.5	8.2	11.4	
Goats ^d	1.24 ^h	529	7.7	7.4	9.0	10.9	
Sanon et al. (2007)							
Sheep ^g	–	–	7.2	0.8	1.3	–	Natural pasture containing grasses, herbs, and many browse species
Goats ^g	–	–	7.3	0.8	1.2	–	

^a EE = energy expenditure (kJ/kg BW^{0.75}).

^b Measured in a 24-h period, but daytime observation was for 10 h and animals were confined at night.

^c Measured over a 16-h daylight period.

^d Measured over a 24-h period.

^e Measured over a 13.5-h daylight period.

^f Measured over a 8.4-h daylight period.

^g Measured over a 9.25-h daylight period.

^h Calculated as number of total foreleg steps × 0.25 m/step (Rook et al., 2004).

greater than the average of the entire area (Schlecht et al., 2006). Preferential use of areas with most desired vegetation has also been observed. In an Oklahoma pasture with some areas high in lovegrass (*Eragrostis curvula*) and others rich in browse plant species such as smooth sumac (*Rhus glabra*) and sand plum (*Prunus angustifolia*), sheep spent most time in locations with abundant grass though distinct areas of preference for goats were

not observed (Gipson et al., 2003). In wooded rangelands of northeastern New South Wales, the number of animals per unit area was greater for goats versus sheep; goats preferred areas with shrubs and trees and sheep density was positively related to availability of non-browse plant species (Landsberg and Stol, 1996). Likewise, Gipson et al. (2003) noted shorter distances between goats than between sheep when grazing, but speculated this to be a

function of the social nature of goats besides a result of the density and(or) spatial distribution of most preferred plant species. Similarly, in some situations goats may spend more time than sheep on eroded land, preventing or slowing vegetation regeneration, which relates to greater numbers of goats present simultaneously in such areas compared with sheep (Greaves and Wedderburn, 1995).

The importance of social behaviors to spatial distribution of co-grazing sheep and goats has not received a great deal of research attention. Although, Gipson et al. (2003) noted that co-grazing sheep and goats behaved or interacted as two separate groups rather than as one unit. Forage preferences could have impacted location where sheep and goats spent relatively long periods of time and distance between species while grazing. But, it seems reasonable to assume that social considerations contributed to a greater distance between sheep and goats at night than between animals within each species group. However, these particular groups of sheep and goats had not been exposed to each other or to other animals of the different species before the grazing period.

5.3. Time spent in different behaviors

Based on values for co-grazing sheep and goats in Table 2, it appears that in some but not all instances grazing time is greater for sheep. With the variable conditions of the listed studies, it is not possible to discern why grazing time did or did not differ between species. Body weight, stage of maturity, and growth potential might be involved; in support, Penning et al. (1997) noted that scaling eating time by body weight^{0.75} removed species differences.

Ruminants display diurnal patterns in time spent grazing and in other activities such as ruminating, idle, and lying (Fierro and Bryant, 1990; Sharma et al., 1998). Research is not available to suggest appreciable differences between sheep and goats in diurnal patterns of grazing activities. However, differences would be anticipated in accordance with specific environmental conditions and adaptation of particular genotypes being studied. For example, a goat genotype adapted to hot climates might be expected to graze relatively more during the day with high temperature than a sheep breed more appropriate for temperate climates, such as one selected for wool production.

Season has profound effects on grazing behavior of sheep and goats. Kronberg and Malechek (1997) noted longer grazing time in the dry than wet season, whereas Sanon et al. (2007) observed the opposite. In the study of Kronberg and Malechek (1997), time spent foraging by sheep was longer than for goats in the wet season, but

length in the dry season was similar. It was proposed that similar grazing and rumination times in the dry season were consequences of reliance of both animal species on browse plant species. Conversely, browse consumption during the wet season was relatively greater for goats. Schlecht et al. (2006) found that distance traveled by both sheep and goats in the dry season was shorter than in the rainy season.

Stocking rate can affect grazing behavior in a manner similar to differences between wet and dry seasons, although generalizations are again difficult because of the scarcity of available data and the number of influencing factors. In one particular co-grazing study with pastures containing a variety of grasses and forbs (Animut et al., 2005a,b), available forage mass and nutritive value decreased as stocking rate increased. These changes elicited increased distance traveled and time spent grazing and standing and decreased time spent lying, ruminating, and idle by both sheep and goats.

5.4. Energy expenditure for activity

The magnitude and importance of ME_a to performance of small ruminants and the most likely determinants or highly related factors have been recently addressed by Lachica and Aguilera (2003, 2005), Sahu et al. (2004), and NRC (2007). However, due largely to the difficulty in measuring energy expenditure, effects of co-grazing sheep and goats on ME_a have not received considerable attention. Animut et al. (2005a, 2007) noted greater energy expenditure by co-grazing sheep versus goats on grass-forb pastures, but differences could be largely explained by the greater growth rate of sheep. It can be postulated that co-grazing versus mono-species grazing would not have large impact on ME_a unless it had a marked effect on preferred forage species and plant parts available for harvesting. In such instances a decrease in grazing time or increase in nutrient intake with constant grazing time might be expected, both which would decrease the magnitude of ME_a relative to energy intake and(or) animal performance. However, when significant overlap exists between plant material consumed by the two species, with appreciable competition, opposite effects seem likely.

6. Animal performance and economic returns

6.1. Animal performance

Performance effects of co-grazing of small ruminants can be viewed on animal or land area bases. Co-grazing does not increase performance per animal unless specific

conditions exist. Stocking rate for each species must minimize dietary overlap and competition for particular plant species and plant parts, and forage removal by one animal species should promote growth of forage preferred by and/or of high nutritional value to the other species. Although, such effects might only be realized in the latter part of the grazing season or subsequent ones. In this regard, Taylor (1985) summarized 20 years of data from the Texas Agricultural Experiment Station with land consisting of various grasses, forbs, and browse plant species and found that co-grazing of cattle, wool-producing sheep, and Angora goats increased performance of sheep (ADG, wool production, and lamb crop percentage) but did not affect cattle or goat performance (ADG and mohair production for goats). Similarly, Walker (1994) concluded that with large vegetation diversity, many forage species of potentially high nutritive value will not be exploited unless animal species with varied preferences are present. Furthermore, complementary use of forage resources by more than one species with different dietary preferences and foraging behavior increases performance per animal by at least one and often each of the co-grazing species. However, these generalizations are primarily related to co-grazing of cattle and small ruminants rather than of sheep and goats without cattle. Nonetheless, it is recognized that the magnitude of increase in production per unit of land area rises with an increasing diversity of plant species. Vegetation diversity should include, in addition to preference for individual plant species, tolerance or willingness to consume particular plants or plant parts.

Another important consideration pertinent to effects of co-grazing on performance is potential levels of animal production. A relatively high level of productivity by one species is not likely to be realized when competition for forage is high because of high dietary overlap and limited available forage mass (Kronberg and Malechek, 1997) or when only plant species/parts not highly preferred are present (Valderrabano et al., 1996). However, Animut et al. (2005b) noted a similar adverse effect of increasing stocking rate on ADG by sheep and goats despite greater growth potential of sheep, which most likely was because neither forage availability nor quality was extremely low even with the highest stocking rate.

In many instances conditions are not conducive to increased performance per animal in response to co-grazing. As an example, with oat (*Avena sativa*)–ryegrass (*Lolium rigidum*) pastures Norton et al. (1990a) reported similar ADG by sheep and goats grazing together and separately. In rare cases co-grazing has depressed performance of a species. In the review of Walker et al. (1994), mixed grazing of sheep and cattle

had greatest positive effects on performance of sheep and in some cases decreased performance of cattle, which led to a conclusion that with limited available forage sheep were more competitive than cattle in forage consumption. In addition, with grass–clover pastures co-grazing of sheep and goats improved performance of sheep but not goats compared with performance when grazed separately (Radcliffe et al., 1991). A factor possibly involved in such findings with non-browse forages might be a greater internal parasite burden in goats when co-grazing with sheep than when grazing alone, due to particular plant materials selected and perhaps a lesser ability to avoid areas high in excreta of sheep versus goats (Jallow et al., 1994). In this regard, adverse performance effects of co-grazing seem due to inappropriate conditions for the practice, such as greater than optimal numbers of one or more species and/or a poor species choice, with ensuing high levels of dietary overlap and forage competition. Relatedly, goats are often blamed for grazing land degradation. This misconception is largely because of the ability of goats to survive and produce under harsh grazing conditions, typically too adverse for other ruminant species that have previously died or been removed. Hence, with very high stocking rates and extremely low availability and/or quality of forage, performance per animal should be greater for goats than for sheep when co-grazing (Kronberg and Malechek, 1997).

Many considerations and principles of different types of multi-species grazing are shared. The intent of sequential or lead grazing is for favorable impact of grazing by the first animal species on preference for and nutritive value of forage available to the second or subsequent species. For example, with grass–clover pastures lamb growth rate was improved by prior or lead grazing of goats because of an increased level of clover in the sward presented to sheep (Del Pozo et al., 1996). Del Pozo et al. (1998) reported greater ewe and lamb performance when grazing sequentially after goats rather than simultaneously. Factors responsible for such findings are unclear but might relate to the pattern of change in forage conditions. With sequential grazing, sheep would be immediately exposed to the sward altered by prior grazing of goats, perhaps involving removal of grass or plant parts near the top of the grazing horizon for greater clover access in the lower portions, compared with gradual change when sheep and goats continuously co-graze.

6.2. Economic returns

Economic considerations are of obvious paramount importance to decisions regarding the employment and methods of multi-species grazing, although biological

aspects have received most research attention. Land is a very expensive input in some areas; therefore, forage/livestock systems must yield a sufficiently high level of production per unit land for adequate return on the capital investment. When optimal co-grazing systems are employed, carrying capacity and total production are increased. Glimp (1985) stated that enhanced use of feed resources with mixed species grazing (cattle and sheep) increased offtake per unit land by 15–20% as a result of a corresponding increase in carrying capacity. Meyer and Harvey (1985) noted that in New Zealand, multi-species grazing elevates economic returns compared with mono-species grazing even though one species may be considerably less profitable than another.

Evaluations of economic returns from multi-species grazing should include not only short term benefits of increased net income and income diversity and steadiness within and between years, but also potential long term improvements in botanical composition, control of noxious weeds, range efficiency and health, and sustainability of livestock production (Ospina, 1985; Schuster, 1985). There are greater inputs required for multi-species grazing to be factored in as well, but they are relatively more important when considering co-grazing of small ruminants with cattle than mixed grazing of sheep and goats. That is, management practices and systems for sheep and goats are more similar than for small ruminants and cattle. Fencing requirements for goats are comparable to those for sheep, and both sheep and goats need protection from predation.

7. Practical considerations

7.1. Vegetation management

One of the primary reasons for and benefits from co-grazing of different ruminant species is management of and improvements in vegetation conditions. Goats are commonly used to clear or control trees, brush, and undesirable weeds that are competitive with plant species preferably grazed by sheep or cattle (Terrill and Price, 1985; Walker et al., 1994; Pompay and Field, 1996). Both goats and sheep have been used to control undesirable plants that are either unpalatable or poisonous to other grazing animals or invasive (Walker et al., 1994; Dabaan et al., 1997; Celaya et al., 2006). For instance, many plants toxic to cattle do not harm sheep, such as larkspur (*Delphinium* spp.; Ralphs et al., 1991), leafy spurge (*Euphorbia esula*; Walker et al., 1992), tansy ragwort (*Senecio jacobaea*; Craig et al., 1992), and ponderosa pine needles (*Pinus ponderosa*; Short et al., 1992).

The use of grazing livestock in the control of brush or invasive plant species is not only important for the long term ecological balance but also for increased herbaceous species biomass in the short term (Dabaan et al., 1997; Holst et al., 2004a,b; Celaya et al., 2007). For instance, Clark et al. (1982) with co-grazing sheep and goats on scrub pasture hill country of New Zealand noted consumption of gorse and thistles by goats with an increased amount of white clover available to sheep that avoided thistles and gorse. Similarly, Holst et al. (2004a,b) grazed sheep and goats separately on perennial pastures infested with nodding thistle (*Carduus nutans*) and found consumption of more thistle by goats than sheep and an increased level of clover in goat pastures. Celaya et al. (2007) reported that goats reduced accumulation of woody phytomass in healthier-gorse shrublands, resulting in enhanced forage quality in the resultant converted grassland. Magadlela et al. (1995) conducted research with hill land pasture in the Appalachians of the U.S. that initially had brush cover of 45%. Mono-grazing of goats more quickly decreased brush cover than sheep grazing alone. In addition, though the comparison was to mono-species grazing of sheep without determination of botanical composition of the diet, grazing sheep for a few days before goats appeared an effective means of minimizing dietary overlap and increasing reliance of goats on browse, presumably because of prior extensive removal by sheep of grasses and forbs.

Present and preferred vegetation conditions, inclusive of the desired speed of change, and differences between animal species in profitability of production, determine potential benefits from co-grazing of sheep and goats and appropriate stocking rates and periods of grazing. For an example, it can be assumed that vegetation conditions are not markedly dissimilar from targets, with a low level of browse and high levels of grasses and forbs, and potential net income from production of sheep and goats is similar. With this scenario, co-grazing might entail a high ratio of sheep to goats for little or no change in browse level, resulting in low to moderate dietary overlap and increased profit associated with a greater total stocking rate compared with mono-species grazing. Conversely, if possible profit from goats is much higher than from sheep, a low ratio of sheep to goats is a consideration. But, if this practice was maintained or continued, the associated rapid decrease in browse level would result in high dietary overlap and a lower total stocking rate than in the previous scenario. A second example quite different from the first pertains to many areas of the world where some grazing lands have become severely overgrown or encroached with undesirable trees and shrubs with resulting decreased prevalence of grasses

and forbs. Here vegetation management or rehabilitation is the primary goal. In this scenario, even with less potential profit from goats than sheep, temporary mono-species grazing of goats could be the preferred vegetation management intervention. Later, when presence of non-browse plant species has risen, co-grazing should be advantageous because of an increased total stocking rate and elevated economic returns. The subsequent optimal ratio of animal species and stocking rates would depend on differences in potential net income and desired final vegetation conditions and length of time for their attainment.

7.2. Stocking rates and carrying capacity

Determining appropriate stocking rates for co-grazing encompasses a large number of complex and interacting factors, most of which cannot be measured in practical, field settings as is typical of research scenarios. Botanical composition of the grazing area must be assessed, which should be in accordance with plants that will be consumed without human intervention and excluding others that will not be ingested, such as spiny cactus. Dietary overlap is also essential for determining co-grazing stocking rates. Van Dyne et al. (1980) summarized literature available at that time and concluded that year-long dietary overlap of sheep and goats averages 60%. However, dietary overlap fluctuates widely because of factors including season, grazing pressure, and plant community diversity (Squires, 1982). The relationship between plant species diversity and dietary overlap for sheep and goats appears consistently negative (Squires, 1982; Norton et al., 1990b).

Dietary overlap as a concept is not complex but is difficult to characterize in a manner useful in a variety of production settings. For example, though goats may have preferences ranking browse > forbs > grass, when only grasses are present dietary overlap between sheep and goats will be very high, perhaps 100% if one grass species consumed by both animal species is predominant. Hence, dietary overlap values are meaningful only in the specific setting of application. Also, it may be unrealistically simplistic to categorize plants as being consumed or not consumed by individual animal species, and perhaps dietary overlap should be estimated based on some minimum dietary contribution. The most practical method of determining dietary overlap in field settings is by visual appraisal. However, observations should be made at various times of the day and certainly in different seasons and within seasons as availability of specific plants change. Agreil and Meuret (2004) described a very detailed observation method for quantifying intake rate

and ingestive behavior of small ruminants for research purposes, components of which could be useful in field, production settings.

Available forage mass is of paramount importance, along with botanical composition, in projecting stocking rates of sheep and goats with mono-species grazing and, concomitantly, when co-grazing. It is desirable to determine mass of different types of forages, but for practical applications one average estimate of available forage mass coupled with botanical composition may be adequate. Relatedly, simple means to quantify browse mass are not available.

Nutrient requirements are very important to mono-species stocking rates and vary with body weight, previous nutritional plane, production state, etc. In some settings one sheep might be equivalent to one goat in terms of forage intake, whereas in others consumption might be greater for sheep or goats. There should be consideration of botanical composition relative to preferences for consumption by sheep and goats, including willingness to consume plants that are not highly preferred such as ones containing anti-nutritional factors (i.e., plant secondary metabolites). Forage stage of maturity and the spatial distribution of different plant species can also be important.

Currently there are no simple means of projecting co-grazing stocking rates or carrying capacity. With only two species a 'baseline' or 'starting point' method is given below, which is based on stocking rates for mono-species grazing and dietary overlap. The equation is applied to each species, with values for sheep and goats added to determine total stocking rate or carrying capacity.

$$\left(\text{number with mono-species grazing} \times \frac{(100 - \% \text{ overlap})}{100} \right) + \left(\text{number with mono-species grazing} \times \left(\frac{\% \text{ overlap} \times 0.5}{100} \right) \right) \quad (1)$$

The equation assumes that intake of forages potentially consumed by each species is equal, which obviously may not be true in all cases. Rather than equal consumption, different levels of consumption could be employed (e.g., 67% consumption by one species and 33% by the other), although this would be difficult to address with multiple overlapping forage plant species. Hence, a significant limitation is the use of one average dietary overlap value applied for all plant species and parts present, when in reality levels of particular plants consumed by the two species can vary markedly.

Table 3 provides a number of example scenarios of application of this equation to project stocking rates of

Table 3
Examples of a simple method of determining stocking rates of co-grazing sheep and goats

Example	Botanical composition (%) ^a			Available forage mass ^b	Dietary overlap (%) ^c	Mono-species (number/ha) ^d		Co-grazing (number/ha) ^e		
	Grasses	Forbs	Browse			Sheep	Goats	Sheep	Goats	Total
1	60	20	20	Moderate	50	15.2	12.7	11.4	9.5	20.9
2	100	0	0	Low	100	7.6	7.6	3.8	3.8	7.6
3	0	0	100	Moderate	100	5.1	7.6	2.6	3.8	6.4
4	0	100	0	High	100	15.2	17.8	7.6	8.9	16.5
5	80	20	0	Low	85	7.6	7.6	4.4	4.4	8.8
6	30	20	50	High	35	10.1	15.2	8.3	12.5	20.8
7a	20	20	60	Moderate	40	10.1	15.2	2.5	17.8	20.3
7b	45	25	30	Moderate	60	12.7	12.7	2.6	15.2	17.8
7c	70	30	0	Moderate	80	15.2	12.7	9.1	7.6	16.7

^a Botanical composition should be based on the most accurate method available. Although, in some cases the only possible means of assessment may be visual appraisal.

^b Available forage mass is a gross categorization used in projecting appropriate stocking rates for sheep and goats with mono-species grazing. This assessment should consider the planned length of grazing or segment to which the calculated co-grazing stocking rates will be applied.

^c Dietary overlap should be based on the most accurate method available. In many instances, however, dietary overlap may be estimated based on prior experience and visual observation.

^d Botanical composition and available forage mass are important determinants of numbers of sheep and goats with mono-species grazing. Factors affecting nutrient requirements such as BW and production state, preference for or willingness to consume forages present, and length of the grazing period should be considered. Previous experience with the particular grazing and animal conditions will in many cases be useful in projecting mono-species stocking rates.

^e Numbers of sheep and goats and the total when co-grazing for Examples 1, 2, 3, 4, 5, 6, and 7c are based on the following equation:

$$\left(\text{number with mono-species grazing} \times \frac{(100 - \% \text{ overlap})}{100} \right) + \left(\text{number with mono-species grazing} \times \left(\frac{\% \text{ overlap} \times 0.5}{100} \right) \right)$$

The total number of animals for Examples 7a and 7b was also based on this equation. However, for these examples the number of goats was not based on the equation, rather set higher to elicit desired changes in botanical composition. The number of sheep was based on the difference between the total derived from the equation and the number of goats.

co-grazing sheep and goats. In Example 1, grass, forb, and browse plant species are available in an overall moderate quantity or mass, with dietary overlap of 50%. Based on these conditions and the specific characteristics of the sheep and goats present, a slightly greater number of sheep than goats per unit of land area is projected. With 50% dietary overlap, the total number of animals or carrying capacity when co-grazing is 50% greater than the average of the mono-species stocking rates. In such a scenario, much greater economic return would be expected from co- versus mono-species grazing, unless profit from one of the species is considerably greater than from the other.

In Examples 2, 3, and 4 (Table 3), grazing land consists only of grass, forbs, or browse plant species. Assumed dietary overlap is 100%, although in reality overlap would probably be slightly lower because of differences among plant species within these categorizations. Nonetheless, with 100% overlap there is no advantage in carrying capacity with co- versus mono-species grazing. Example 5 is fairly similar to Examples 2, 3, and 4, in that with high dietary overlap there is little

improvement in carrying capacity with co-grazing. Conversely, in Example 6 there is a marked improvement in carrying capacity because of relatively low dietary overlap of 35%. Fig. 3 depicts how carrying capacity predicted with Eq. (1) increases with decreasing dietary overlap.

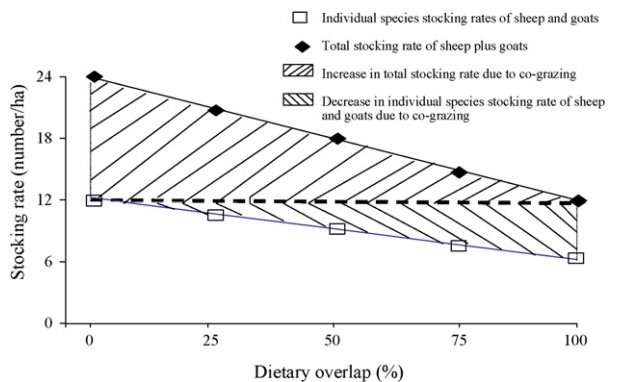


Fig. 3. The relationship between stocking rates and dietary overlap. The assumed mono-species stocking rate for sheep and goats was equal at 12/ha.



Fig. 4. An example of decreased browse plant species prevalence and increased grass growth in response to one summer season of grazing by goats at moderate to low stocking rate. The picture on the left was taken in the first season of grazing and that to the right in the second season.

Although Eq. (1) should be useful in the field because of simplicity, it assumes no interactions between stocking rates when the two animal species graze together versus alone. In this regard, as has been mentioned before, the presence of one animal species can influence the availability of plants with high or low preference by the other animal species, although such effects may be most prominent late in the grazing season or in subsequent ones. Relatedly, a common reason for deviating from projections of co-grazing stocking rates derived with Eq. (1) is desire to markedly alter forage conditions. In Example 7a the browse level is high, with the stocking rate of goats elevated to decrease the level of browse and increase that of grasses. The stocking rate of sheep is determined as the difference between the total number of sheep and goats based on Eq. (1) and the set number of goats. After a period of grazing, possibly a whole season or segment, conditions are reevaluated. Levels of grasses and forbs now have increased and that of browse has declined, resulting in an increase in dietary overlap from 40 (Example 7a) to 60% (Example 7b). Hence, the

number of goats is decreased but is still set at a level above that indicated by Eq. (1) in order to incur further decreases in the level of browse. The carrying capacity with these conditions is less than before (Example 7b versus 7a) because of the increase in dietary overlap, resulting in essentially no change in the stocking rate of sheep. After desired forage conditions have been reached (Example 7c), which in this particular setting is elimination of browse, dietary overlap is quite high, carrying capacity is less than when browse was present (Examples 7a and 7b), and numbers of sheep and goats are based on Eq. (1). Figs. 4–6 provide examples of changing forage conditions in response to grazing by goats that are pertinent to Examples 7a, 7b, and 7c.

In the discussion pertaining to use of a relatively high stocking rate of goats to decrease the browse level (Examples 7a, 7b, and 7c), the method of estimating the stocking rate of sheep was unrealistically simplistic. It essentially ignored dietary overlap, assuming the number of sheep present to be adequate for consumption of ‘non-overlapping’ plants consumed only by sheep. In the



Fig. 5. An example of decreased browse plant species prevalence and increased forb and grass growth in response to one summer season of grazing by goats at moderate stocking rate. The pasture on the right had been grazed by goats in the previous and current summer and that on the left had not.

scenario above this may not be a serious concern and, in fact, the error could be advantageous. That is, with Example 7b it is reasonable to suppose that a large proportion of the non-overlapping plant species consumed by sheep consisted of grasses, and the intent was to increase the level of grasses. Although, given the relatively high dietary flexibility of goats, it is likely that the high stocking rate of goats would have to some extent increased dietary overlap and elicited greater grass and forb consumption by goats. Conversely, because of lower dietary flexibility of sheep versus goats, it is expected that the rise in consumption of browse by sheep and elevated dietary overlap resulting from a relatively high stocking rate of sheep would be smaller compared with elevated goat numbers.



Fig. 6. An example of use of a high stocking rate of goats to eliminate browse plant species. The pasture on the right had been grazed by goats in the previous and current summer and that on the left had not.

8. Summary

Sheep and goats vary in many characteristics that influence how they graze. The species have different preferences and abilities to consume particular plant species and parts and tolerance or willingness to ingest generally less preferred forages. Advantages of these differences can be taken through co-grazing for increased production per unit land area under many vegetation conditions, most notably presence of a diverse array of plant species. But, because of the complexity of study and the multitude of possible production scenarios, successful field application of co-grazing will require careful consideration and contemplation by experienced advisors, including input from producers, both at the onset and continually throughout grazing seasons.

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