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Potential for woody plant control by Spanish goats in the sagebrush steppe

B. Fajemisin [a], D. Ganskopp [b,*], R. Cruz [c], M. Vavra [d]

[a] *National Animal Production Research Institute, Ahmadu Bello University, Zaria, Nigeria*

[b] *USDA Agricultural Research Service, HC-71 4.51 Highway 205, Burns, OR 97720, USA*

[c] *Department of Rangeland Resources, Oregon State University, Corvallis, OR 97731, USA*

[d] *Eastern Oregon Agricultural Research Center, HC-71 4.51 Highway 205, Burns, OR 97720, USA*

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Abstract

The botanical composition of the diet of eight Spanish goats was studied on the Northern Great Basin Experimental Range during two stages of plant phenology (active growth in early July and cured forage in mid-August) to assess their potential for control of sagebrush (*Artemisia tridentata* subspp. *wyomingensis* Nutt.) and western juniper (*Juniperus occidentalis* Hook.) and the nutritional value of their diets on sagebrush steppe rangelands. Diets were quantified by documenting the number of visits to each species, the number of bites harvested and time expended grazing each forage over four consecutive days in each period. Forage chemical characteristics evaluated included: CP, NDF, ADF, ADL and IVDMD. Diet composition and forage quality indices varied significantly ($P<0.05$) with changes in plant phenology. Vegetation cover averaged 52% in the pasture and consisted of 36% grasses, 8% forbs, 7% shrubs and 0.6% trees. Available herbage (excluding woody plants) was 534 kg ha^{-1} during active growth trials and 572 kg ha^{-1} when forages had cured. When forages were green goats acquired 28% of their total bites from grasses, 71% from forbs, 0.3% from shrubs and 0.9% from juniper trees. After forages had cured values were 35% from grasses, 56% from forbs, 0.1% from shrubs and 8.8% from juniper. The browsing of juniper (both foliage and bark), after herbaceous forages had cured, was the only substantive use of woody plants. Sagebrush was only lightly used (0.2% of total bites) when herbaceous forages were actively growing. Available herbage was of relatively high quality during both trials. When forages were actively growing, CP of grasses ranged between 8.9–5.6%, forbs from 17.7–8.5%, sagebrush scored at 8.5%, juniper foliage at 8.1% and juniper bark at 3.2%. After herbaceous forages had cured, grass CPs ranged between 6.2 and 3.1%; forbs from 10.4 to 4.4%; shrubs were not sampled; and juniper foliage averaged 7.6%. Given the low levels of browsing exhibited by goats on sagebrush and juniper we see little opportunity for control of these woody plants when pastures provide a diverse ($n=25$ species) array of readily available (534–572 kg ha^{-1}) and nutritious forages and pastures are lightly stocked (0.63 goats ha^{-1} month^{-1}). We do need, however, to explore further their potential for control of these species under several other regimes. These include: extended trials on more deteriorated rangelands; trials during seasons or conditions where forage is limited and the animal's selective opportunity is restricted; and trials in high quality environments on newly established sagebrush and juniper seedlings.

Keywords: Biological control; Sagebrush; Juniper; Forage selection; Grazing behavior; Nutrition; Forage quality

* Corresponding author at: USDA Agricultural Research Service, HC 71 4.51 Hwy. 205, Burns, OR 97720, USA. Tel. 541-573-2064; Fax. 503-573-3042; E-mail. ganskopd@ccmail.orst.edu.

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1. Introduction

Due to a variety of factors, the Northern Great Basin sagebrush steppe is experiencing expansion of western juniper (*Juniperus occidentalis* Hook.) stands and increases in the density and cover of sagebrush (*Artemisia* spp.) on otherwise good condition rangelands (Miller et al., 1994). In both instances this is occurring at the expense of perennial grasses and forbs. Chemical controls are becoming prohibitively expensive and politically unpopular (Britton and Sneva, 1979 and Bastian et al., 1995), and biological efforts have shown little potential to date for control of these competitive plants (Richman et al., 1994). While severe defoliation can kill big sagebrush (Cook and Stoddart, 1960; Pringle, 1960 and Wright, 1970) the literature provides no information on seasons or intensities of defoliation required to affect western juniper. This being the case, many avenues for biological control of these woody plants remain largely unexplored, including use of the various breeds of goats.

Use of livestock in prescription grazing programs to control undesirable plants demands knowledge of the animal's innate dietary preferences and the composition and nutritive value of the forage resources. Both aspects must be integrated in biological control efforts to affect the target plant without impacting desirable components of the vegetation and to assure adequate livestock production. Among ruminants, the goat (*Capra hircus*) is well known for utilizing a broad array of forages which explains their ability to adapt to various environments, especially the arid areas (Morand-Fehr, 1988). Leclerc (1984) reported that browse constituted 75% to the diet of goats in the Corsican 'maquis' during winter but did not exceed 15% during spring. Similarly, Narjisse and El Bare (1986) found woody plants contributed most significantly to the diet (68%) when herbaceous forage was less available on the forest floor. Goats appear to be especially flexible in their food selection, and through their selective grazing habits can maintain a higher plain of nutrition than larger less selective foragers. The objectives of this study were: (1) to assess the potential of Spanish goats for woody plant control during both growing and dormant forage conditions on good condition sagebrush rangeland, and (2) to evaluate the nutritive value of the goats' dietary choices on northern Great Basin, sagebrush steppe vegetation. Direct observation techniques were used to quantify the relative amounts of plant species selected by goats as they freely grazed during two 4-day trials. One trial was conducted in early July, when all forages were actively growing and of high nutritional value. The second was conducted in mid-August when herbaceous vegetation had ceased growing and cured to marginal nutritional levels.

2. Materials and methods

The study was conducted in 1993 on the Northern Great Basin Experimental Range about 65 km southwest of Burns, Oregon. This semi-arid desert range (elevation 1370 m) lies in the northern edge of the Great Basin and receives mean annual precipitation of about 30 cm. Approximately 80% of the moisture falls between October and June with the majority occurring as snow. Growth of herbaceous forages is typically arrested by late July, as soil moisture is gradually depleted by evapo-transpiration during the growing season.

Tree, shrub, and herbaceous plant density and cover were sampled in a temporary, electrically fenced, 1.7 ha pasture prior to the July grazing trial. These pasture characteristics were not reassessed before the second trial because we expected only slight changes as forages entered dormancy. The pasture has a long history (50+ years) of brief summer use by cattle, and with the exception of increasing sagebrush and juniper, supported a very desirable and productive array of native grasses and forbs. Foliage cover of each species was measured along five 50 m line transects systematically arranged within the pasture. Frequency of occurrence and density of shrubs and herbaceous plants were sampled from 40 1-m^2 randomly distributed quadrats, and all western juniper trees in the pasture were counted. Available biomass of herbaceous plants was harvested from 25 1-m^2 quadrats prior to each of the two grazing trials and oven dried at 60°C for 3 days. Grasses were sorted by species in each quadrat while forbs were composited. Herbage production of trees and shrubs was not sampled. Prior to each trial samples of the most prominent forages were harvested, oven dried for 3 days at 60°C, ground to pass a 1 mm screen, and retained for later chemical analyses of forage quality.

Eight dry, non pregnant, adult female goats, weighing 26.3 kg (SE $\pm$ 1.2), were grazed to quantify plant

species selected over four consecutive days during each of two forage phases: actively growing (6–9 July) and dry, dormant forages (17–20 August). Although the animals were on station approximately 6 weeks before the trials, we elected to limit their exposure to native rangeland to the 24 h period immediately prior to sampling when they were confined in a temporary holding paddock in one corner of the pasture. The paddock supported sagebrush, juniper, several of the grasses common to the pasture, and a portion of the forb component. We followed this protocol because the goat industry is not well established in our region, and local land managers seeking to implement biological controls would typically be forced to import herds of naive animals from other areas.

Goats were released in a random sequence in the morning and dietary composition estimated by direct observation and talley of individual bites (Altmann, 1974; Holechek et al., 1984; Austin et al., 1994; Jones et al., 1994 and Richman et al., 1994). A technician equipped with a lap top computer recorded each bite harvested by pressing the space bar, and noted walking or transition between feeding stations by pressing the 'W' key. The subsequent data file consisted of a series of time entries (i.e. 09:32:17.6), each denoting an individual bite, and interjections where the 'W' key was pressed (i.e. W09:32:18.1 126) which referenced the time of movement to a new feeding station and the observation number (126) of the next plant to be grazed. A second technician concurrently recorded the species of each plant as it was grazed. Immediately upon entering the pasture, each goat was monitored as it foraged upon a series of 50 plants. Sampling typically occupied the entire morning, and the goats were allowed to remain in the pasture until evening when they were penned overnight to avoid potential coyote (*Canis latrans*) predation. This overnight confinement may have altered their subsequent feeding behavior to some degree.

Integration of bite-count files and the concurrently generated species lists allowed derivation of several variables for each animal. These included: the number of visits to each species, the total number of bites harvested from each, the mean number of bites per visit to each forage, and calculation of the mean time expended grazing each species (derived from the times of the first and last bites at each feeding station). Software for acquisition and integration of these data were generated in GWBasic by the second author.

Analyses of forage samples included: dry matter, organic matter, ash content, and Kjeldahl nitrogen (CP = Kjeldahl × 6.25) as determined by AOAC (1980) procedures. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were measured according to Goering and Van Soest (1970), and in vitro dry matter disappearance (IVDMD) was determined with Tilley and Terry (1963) techniques with liquor withdrawn from rumen cannulated goats.

With the exception of 'visits to plants', which is autocorrelated because the same number of observations occurred for each goat or block, variables describing grazing behavior of goats were analyzed using a split-split plot analyses of variance. Data indexing total bites harvested and total time expended grazing each species were converted to percentages for presentation after analyses. Individual goats ($n = 8$) functioned as replicates or blocks. Stages of phenology ($n = 2$) and days ($n = 4$) could not be randomized and served as whole plots and subplots, respectively, and plant species ($n = 25$) functioned as sub-subplots. Mean separations were accomplished with Fisher's protected LSD procedures ($P < 0.05$). Total number of observations in the two trials was 1600 (eight animals × two stages of phenology × 4 days × 25 species of forages).

3. Results and discussion

Herbaceous vegetation covered roughly 45% of the soil surface. Idaho fescue (*Festuca idahoensi* Elmer) ranked highest in cover and occurred with the greatest frequency, being present in 95% of the plots sampled (Table 1). Sandberg's bluegrass (*Poa sandbergii* Vasey), however, attained the highest density with roughly 4.5 plants m^{-2}. Among the forbs, bushy birdbeak (*Cordylanthus ramosus* Nutt.) ranked highest in cover (3.3%), density (3.4 m^{-2}), and frequency (80%). The shrub layer was dominated by Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis* Beetle), and western juniper characterized the overstory with a density of 169 trees ha^{-1}. Approximately 44% of the junipers were less than 2 m tall with the remaining being scored as mature trees. Because ground level branches are persistent on these trees,

Table 1
Characteristics of the sagebrush steppe vegetation grazed by Spanish goats on the Northern Great Basin Experimental Range in 1993. (–) indicates trace amounts or not encountered in sampling. Nomenclature according to Hitchcock and Cronquist (1973)

Species	% Cover (SE)	Density m^{-2}(SE)	% Frequency
Festuca idahoensis	15.7(1.9)	3.8(0.4)	95
Agropyron spicatum	7.6(1.5)	1.4(0.2)	63
Poa sandbergii	7.3(1.2)	4.5(0.5)	83
Koeleria cristata	4.2(1.8)	1.8(0.3)	70
Stipa thurberiana	0.9(1.8)	0.6(0.3)	20
Sitanion hystrix	0.3(0.1)	0.2(0.1)	13
Bromus tectorum	0.1(0.0)	0.2(0.1)	13
Total grasses	36.1	12.5	
Cordylanthus ramosus	3.3(0.9)	3.4(0.5)	80
Eriogonum spherocephalum	1.6(1.2)	0.1(0.1)	10
Erigeron lineraris	1.1(0.7)	1.0(0.2)	45
Erigeron filifolius	0.6(0.3)	0.3(0.1)	23
Phlox hoodii	0.5(0.2)	0.1(0.1)	28
Astragalus filipes	0.5(0.2)	0.5(0.1)	10
Lupinus caudatus	0.4(0.2)	–	35
Achillea millefolium	0.3(0.3)	0.2(0.1)	5
Crepis accuminata	0.1(0.0)	–	10
Penstemon speciosus	0.1(0.1)	0.2(0.2)	5
Total forbs	8.4	5.8	
Artemisia tridentata	6.2(0.3)	3.0(0.1)	
Chrysothamnus viscidiflorus	0.4(0.2)	–	
Total shrubs	6.5	3.0	
Juniperus occidentalis	0.6(0.4)	169.3/ha	
Total trees	0.6	169.3	

foliage of both juvenile and mature specimens is within easy reach of browsing goats.

Precipitation during the preceding September to June period is correlated strongly with annual yield of herbaceous forage in the region (Sneva, 1982) and was 167% of the long term mean (255 mm) for the 1993 forage year. As a result, forage availability was greater than average. Among the grasses Idaho fescue and bluebunch wheatgrass (*Agropyron spicatum* Scribn. and Smith) ranked highest in biomass (Table 2). Availability of grasses decreased approximately 14% between the active growth and cured forage sampling periods, while the later maturing forbs increased in availability from 41.2 to 151.2 kg ha^{-1} in the same period. The increase in forb biomass more than offset the decrease in grasses, and total available herbaceous material increased from 534 to 572 kg ha^{-1} between the green and dormant stages of growth. This difference was not statistically significant ($P > 0.05$), however.

Although we did not sample shrub and tree biomass, Richman (1993) quantified sagebrush production in a similar environment in 1990 and 1991. Richman (1993) estimated sagebrush cover at 4.3% and twig and leaf biomass at 340 kg ha^{-1}. Given our measure of 6.2% sagebrush cover and more precipitation than Richman's 1990–1991 sampling period, we estimate our sagebrush biomass at least equalled or exceeded 486 kg ha^{-1}. We have no means of estimating availability of juniper foliage.

In our analyses of foraging activities, variation among goats or blocks was not significant ($P > 0.05$), suggesting that the animals exhibited a high degree of similarity in their grazing behavior. Forage species and species × phenology effects were consistently significant ($P < 0.01$) for all variables, while days and interactions with days were not. Consequently, data are presented for each stage of phenology (Table 3). Forbs were the most prominent dietary constituent during both stages of phenology. Grasses ranked second, while shrubs and trees were of minor importance.

When forages were actively growing, forbs and grasses constituted 64.0 and 33.7% , respectively, of the total plants visited (Table 3). The mean number of bites monitored per goat in a daily grazing session was 169 with roughly 64% harvested from forbs and 34% selected from grasses. Shrubs and trees were

Table 2
Available herbage of sagebrush steppe vegetation grazed by Spanish goats on the Northern Great Basin Experimental Range during active growth and cured forage stages of phenology in 1993

Species	Active growth — July (kg ha^{-1}; SE)	Cured forage — August (kg ha^{-1}; SE)
Festuca idahoensis	131.6(23.2)	122.8(20.1)
Agropyron spicatum	111.6(30.2)	141.6(38.5)
Poa sandbergii	123.8(21.5)	58.8(8.1)
Koeleria cristata	67.8(7.6)	66.4(13.3)
Stipa thurberiana	22.6(11.8)	21.6(9.0)
Sitanion hystrix	19.6(10.4)	6.0(3.5)
Bromus tectorum	16.0(6.7)	4.4(2.1)
Total grasses	493.0	421.6
Total forbs	41.2(14.7)	151.2(31.5)

Table 3
Percent of total visits, total bites harvested, and total grazing time expended on each forage species by Spanish goats grazing sagebrush steppe vegetation for 4 day periods during two stages of phenology on the Northern Great Basin Experimental Range in 1993. Means in columns sharing a common letter do not differ significantly ($P > 0.05$)

Species	Active growth — July			Cured forage — August		
	Percent visits	Percent bites	Percent time	Percent visits	Percent bites	Percent time
Agropyron spicatum	12.3	8.9d	8.8abcd	17.3	11.6ef	10.3cde
Agropyron desertorum	7.7	8.1d	9.0bcd	8.8	7.9cde	8.2cd
Festuca idahoensis	7.9	5.0bcd	4.1abc	7.2	4.2bc	7.7c
Elymus cinereus	0.8	2.6ab	3.9abc	0.9	2.2ab	2.2ab
Poa sandbergii	3.1	2.5ab	2.4abc	0.9	0.6ab	0.4a
Sitanion hystrix	0.4	0.2a	0.2a	1.2	0.5ab	0.4a
Koeleria cristata	0.6	0.5a	0.4ab	8.7	7.6cd	5.9bc
Bromus tectorum	0.8	0.4a	0.4ab	0.0	0.0a	0.0a
Stipa thurberiana	0.1	0.0a	0.0a	0.3	0.1a	0.2a
Total grasses	33.7	28.2	29.2	45.3	34.7	35.3
Astragalus filipes	14.4	22.1f	21.8e	19.1	24.7g	23.3f
Achillea millefolium	15.6	16.8e	14.5de	12.9	11.8f	9.1cde
Lepidium perfoliatum	11.6	8.8d	8.5abcd	1.8	1.3ab	1.3a
Crepis accuminata	6.6	6.6cd	6.5abcd	1.7	1.3ab	1.0a
Erigeron filifolius	3.2	2.3ab	2.3abc	1.9	1.5ab	1.2a
Eriogonum spherocephalum	4.6	3.4abc	2.9abc	1.1	0.6ab	0.6a
Sisymbrium altissimum	1.6	1.4ab	1.5abc	0.3	0.1a	0.1a
Lithospermum ruderale	5.2	8.2d	9.8cd	6.6	11.9f	12.2de
Lupinus caudatus	0.4	0.3a	0.5ab	0.4	0.2a	0.1a
Penstemon speciosus	0.4	0.5a	0.6ab	3.8	2.3ab	1.9ab
Phlox hoodii	0.4	0.4a	0.3ab	0.1	0.1a	0.1a
Cordylanthus ramosus	0.0	0.0a	0.0a	0.9	0.6ab	0.7a
Total forbs	64.0	70.8	69.2	50.6	56.4	51.7
Artemisia tridentata	0.6	0.2a	0.2a	0.1	0.0a	0.0a
Chrysothamnus viscidiflorus	0.1	0.1a	0.4ab	0.1	0.1a	0.3a
Tetradymia canescens	0.1	0.0a	0.0a	0.0	0.0a	0.0a
Total shrubs	0.8	0.3	0.6	0.2	0.1	0.3
Juniperus occidentalis	1.5	0.9a	1.0ab	3.9	8.8def	12.6e
Total trees	1.5	0.9	1.0	3.9	8.8	12.6

minor dietary components. Mean foraging time measured for each goat averaged 5.7 min per session with approximately 69% and 29% devoted to forbs and grasses, respectively. Since time involved in travel and scrutiny of forages was not included in this measure, actual periods of observation were considerably greater in duration.

During the dormant stage of phenology, visits to forbs still dominated (50.6%), but they were less prominent than when forages were green. Visits to grasses increased roughly 12% over the earlier sampling period, and the number of bites harvested from grasses increased by slightly over 6%. On average, each goat was monitored for 200 bites and roughly 5.3 min of actual foraging time per day. Again, shrubs were of minor importance, but bites harvested from juniper trees did increase to nearly 9% of the total.

These observations mirror those of several others. Fedele et al. (1988) and Pizzillo et al. (1988) found the spring diets of goats were primarily grasses (65–75%), followed by other non-grass and non-legume families (22–25%) and legume families (3–10%). Grasses diminished in the diet during summer (55–60%), forbs increased (40–45%) and the legume component tended to disappear (Fedele et al., 1988 and Pizzillo et al., 1988).

Shrubs appeared to be the least preferred class of plants to goats during both trials as indicated by low

Table 4
Percent dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), in-vitro dry matter disappearance (IVDMD), and ash content of forages constituting greater than 5% of the diet of Spanish goats as determined from bite count data on the Northern Great Basin Experimental Range during two stages of phenology in 1993. Upper and lower positions of numerical pairs depict data during active growth and cured forage stages of phenology, respectively. (–) indicates species or component not sampled

Forage class and species	Forage constituent						
	%DM	%CP	%NDF	%ADF	%ADL	%IVDMD	%Ash
Grasses							
Festuca idahoensis	53.3	6.1	58.9	44.3	5.3	60.3	17.1
	61.1	3.1	71.1	52.4	5.8	44.6	19.3
Agropyron spicatum	55.3	5.6	62.1	42.5	6.5	55.4	8.8
	59.6	4.4	63.9	48.8	6.3	48.1	14.3
Koeleria cristata	–	–	–	–	–	–	–
	56.8	5.9	58.1	53.2	5.3	63.4	18.8
Agropyron desertorum	44.8	8.9	66.9	40.9	8.4	56.8	5.9
	61.7	6.2	69.2	43.8	7.2	50.8	8.3
Forbs							
Astragalus filipes	33.4	17.7	52.5	42.4	8.5	54.8	4.8
	45.1	7.3	60.1	47.7	10.1	50.7	5.3
Achillea millefolium	35.1	8.6	33.0	23.1	4.8	80.5	12.6
	51.3	10.4	49.2	36.1	7.1	74.6	16.9
Crepis accuminata	28.1	8.5	30.9	26.8	3.9	81.8	8.2
	45.0	4.4	42.9	36.4	7.7	65.1	9.9
Lepidium perfoliatum	53.0	9.9	51.8	41.1	8.5	54.8	5.2
	86.5	3.9	67.1	57.0	8.8	44.1	7.2
Lithospermum ruderale	31.6	10.5	30.2	25.3	4.3	73.5	23.8
	38.1	7.8	34.6	27.6	4.7	67.5	28.4
Shrubs							
Artemisia tridentata	45.0	8.5	40.3	30.1	6.2	61.3	4.4
	–	–	–	–	–	–	–
Trees							
Juniperus occidentalis	58.7	8.1	40.5	29.3	14.2	49.6	3.9
(foliage)	61.6	7.6	43.3	34.8	21.4	43.1	4.2
Juniperus occidentalis	60.1	3.2	49.7	48.1	25.3	31.1	7.1
(bark)	–	–	–	–	–	–	–

values for visits to plants (0.2–0.8%) and percent of total bites (range of 0.1–0.3%). Although not presented in our data summaries, the highest number of bites per visit (8.6–10.8) and time per visit (16.0–29.8 s) were recorded for *Elymus cinereus*. This was a large stature grass (> 2 m high), and was the only graminoid from which the goats foraged by stripping individual leaves from the plant. *Astragalus filipes* and *Achillea millefolium* were the most visited forbs. Among the forbs the greatest number of bites per visit (5.3–6.2) occurred with *Lithospermum ruderale* which was quite rare and remained succulent throughout both trials. While the patterns of visits to and bite counts on individual plants did not generally change much between trials, there was considerable variation among the forage classes.

Chemical composition and in vitro organic matter disappearance for plants grazed by goats varied considerably between the green and dormant stages of phenology. Levels of various plant nutrients, constituting 5% or more of the total bites at either stage of growth, are listed in Table 4. Collectively, the forages in Table 4 accounted for roughly 86 and 91% of the total bites harvested during the active growth and dormant stages of phenology, respectively. Crude protein and IVDMD values were consistently higher for forages in the first period than in the second, and generally, the reverse occurred for DM, NDF, ADF, ADL and ash

values. Weighting of CP values of forages by the proportion of total bites taken from each species (Schwartz et al., 1977) yielded CP estimates of the goats diet of 10.7% during active growth and 6.7% when forages were cured. These values are most certainly negatively biased, however, because grazers typically harvest diets of higher quality than our best hand compounded efforts.

Studies of seasonal composition of goat diets by Malechek and Provenza, 1981 and Rubino et al. (1988) have shown that the ration, especially on arid rangelands, undergoes considerable modification depending on climate and year. Among grasses *Agropyron desertorum* had the highest crude protein content (8.9–6.2%) and *Agropyron spicatum* the lowest at 5.6–4.4%. NDF values for grasses ranged between 58.1 and 71.1%, ADF's from 40.9–53.2%, and ADL's between 5.3 and 4.45%. Among forbs, *Astragalus filipes* had highest CP value of 17.7–7.3%, and *Crepis accuminata* the lowest at 8.5–4.4%. Across forbs NDF's ranged from 25.3–67.4%, ADF's from 26.8–57.0% and ADL's between 4.3 and 10.1%. IVDMD ranges varied from 44.6–63.4% for grasses to 44.1–81.8% for forbs.

The only substantial grazing that occurred on woody plants involved juniper during the dormant stage of phenology (Table 3) when the goats consumed nearly equal proportions of foliage and bark. Crude protein content of juniper foliage was 7.6% at this time, and an earlier sampling of juniper bark revealed an even lower CP content of 3.2% (Table 4). Juniper bark scored the lowest in IVDMD at 31.1%.

Pronounced selective feeding behavior of goats has been observed for legumes (Giger et al., 1987; Morand-Fehr et al., 1987;) and was also seen in the case of pasture hay and straw (Masson et al., 1989). Degree of selection by goats depends on the plant species offered and the forage's stage of growth. Most often the nutritive value of the forage actually ingested is substantially higher than the forage on offer (Morand-Fehr et al., 1980). In natural pastures, there is a high degree of variability in the chemical composition of the ration taken by goats throughout the year (Fedele et al., 1988; Pizzillo et al., 1988). Their selective grazing behavior, however, buffers to a large degree the annual variation in the chemical composition of the pastures.

Goat production in rangeland settings is increasing and resulting in well adapted grazing management techniques. Goats have been utilized in management schemes to keep woody plants at tolerable levels by controlling regrowth subsequent to other brush control measures in the southern California chaparral (Green et al., 1978 and Sidahmed et al., 1981). Goats also assist in woody plant control in Tanzania's Massailand (Martin and Huss, 1981) and in the northern and central rangelands of Mexico (L.C. Fierro, F. Gomez and M.H. Gonzalez, personal communication, 1980); in reducing Gambel oak (*Quercus gambielii*) sprouts in Colorado (Davis et al., 1975); for woody plant control in western Texas where Spanish goats are used in conjunction with prescribed burning during the growing season (Ueckert, 1980); and in biological control efforts in Australia and New Zealand (Holmst, 1980; Gray, 1984; and Radcliffe, 1985). All of these systems, however, require an understanding of feeding behavior, grazing effects on the subsequent growth and forage values of plants, and the dynamic relationship between the animal and the vegetation. The primary advantage of goats over other ruminants lies in their multipurpose-utility (meat, fiber, and milk) and dietary adaptability.

In this study, dietary preference shifted with changes in plant phenology. With our high levels of available forage (530–572 kg ha^{-1}), diverse array of species ($n=25$), relatively high forage quality and low stocking rates, we observed little potential for control of established Wyoming big sagebrush or western juniper. Our animals secured approximately 99% and 91% of their total bites from the herbaceous component of the vegetation during active growth and dormant phases of plant growth, respectively. Richman et al. (1994) attempted to precondition Angora goats to Wyoming big sagebrush to stimulate later consumption of the shrub in a similar environment. Their sampling occurred principally in 1991, which received roughly 90% of annual precipitation, and about 81% of the selected diet was derived from grasses. Prior exposure to sagebrush had little effect, with no substantial differences between exposed and naive animals, and their goats consumed on average about 1.23 g h^{-1} of sagebrush in a 15 month trial. About 80% of the sagebrush consumed by their animals consisted of dead material (Richman et al., 1994), which would have little if any impact on subsequent shrub vigor.

In biological control efforts we ideally wish to affect target plants without undue impact on the more desirable crop or forage (Vallentine, 1974). This is especially desirable on federally owned rangelands in the

United States where managing agencies typically allow removal of only 40–50% of the available herbage, and there is a strong desire to perpetuate the native flora. Some exemptions to this may be allowed, however, where weed infestations are severe. Whether goats would graze sagebrush or juniper on severely depleted rangelands where selective opportunity is more restricted, or on pastures where forage availability is decreased by snow cover is still to be investigated. Likewise, we should research the potential of goats for control of sagebrush and juniper during their early stages of establishment. In general, long-term trials are still necessary to develop land management strategies with goats in the arid regions of Pacific Northwest. There is also a need to determine plant responses to various intensities and seasons of grazing, particularly within the little investigated forb component that is not heavily utilized by cattle or horses (McInnis and Vavra, 1987). In closing, however, we find that Spanish goats have little potential for control of established *Artemisia* and juniper in good condition sagebrush steppe pastures supporting a diverse array of readily available and nutritious forages. Further study is needed, however, to examine their possibilities under an array of conditions where selective grazing opportunities are more restricted or in areas where sagebrush and juniper are in the initial stages of establishment.

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