Influence of native shrubs on nutritional status of goats: nitrogen retention

GREGORIO NUNEZ-HERNANDEZ, JERRY L. HOLECHEK, JOE D. WALLACE, MICHAEL L. GALYEAN, ACKIM TEMBO, RAUL VALDEZ, AND MANUEL CARDENAS

Abstract

In vivo digestibility trials were conducted to evaluate the influence of shrubs containing low and high levels of soluble phenolic/-tannins on digestibility and nitrogen retention by Angora goats. Each of 6 shrubs and alfalfa hay (*Medicago sativa* L.) were fed to goats at 30% (dry matter basis) of the diet in a barley straw-prairie hay mixture. The mixture was regulated so that all diets contained about 8% crude protein. High soluble phenolic shrubs used included big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*), gray oak (*Quercus grisea* Liebm.), true mountain mahogany (*Cercocarpus montanus* Raf.), and one-seed juniper (*Juniperus monosperma* [Engelm.] Sarg). Low-soluble phenolic species included common winterfat (*Ceratoides lanata* [Pursh.], J.T. Howell), fourwing saltbush (*Atriplex canescens* [Pursh.], Nutt.), and alfalfa. Nitrogen digestibilities of winterfat, gray oak, mountain mahogany and one-seed juniper diets were less ($P<.05$) than the alfalfa controls, but big sagebrush did not differ ($P>.05$) compared with the alfalfa control. Retained nitrogen (g/d) differed ($P<.05$) only among alfalfa, juniper, and mountain mahogany diets. Goats fed juniper had greater ($P<0.05$) retained nitrogen than the alfalfa control. Shrubs high in soluble phenolics, with the exception of big sagebrush, had elevated fecal nitrogen losses, but reduced urinary nitrogen losses compared with the alfalfa control. Forage organic matter intake (% body weight) and nitrogen intake (g/d) were correlated more highly with nitrogen retention than dietary crude protein (%) or digestible protein (%). Present data indicate that protein found in palatable native shrubs is assimilated with similar efficiency to that in alfalfa hay if these shrubs are consumed at moderate levels.

Key Words: browse, Angora goats, ruminants, forage

Historically, range management has emphasized grasses because of their ability to produce large quantities of forage for livestock. However, Holechek et al. (1989) reviewed several studies showing that shrubs are important components of range livestock diets on many ranges. Typically, cattle, sheep, and goats make heavier use of shrubs during periods when grasses and forbs are dormant, and low in nutritive value. During the dormant season, leaves of evergreen shrubs have greater crude protein than grass leaves or stems (Holechek et al. 1989). Evergreen shrub leaves also have less fiber and greater phosphorus concentrations than grass plant parts.

Some shrubs have high levels of soluble phenolics and tannins that can reduce protein digestibility and retention (Mould and Robbins 1981, Nastis and Malechek 1981, Robinson 1982). Hence, crude protein concentration may be misleading as an indicator of nutritive value of these species. Ruminants consuming shrub diets that are high in soluble phenolics and(or) tannins have elevated fecal nitrogen concentrations (Mould and Robbins 1981, Nastis and Malechek 1981, Wofford et al. 1985), but such increases can be compensated for by reduced urinary nitrogen losses (Nastis and Malechek 1981). Further, diets high in condensed tannins may have increased post-ruminal absorption of nitrogen (Barry and Manley 1984) and increased nitrogen retention (Barry et al. 1986). Comparative studies regarding absorption and retention in ruminants fed low phenolic shrubs, high phenolic shrubs, and commercial forages are limited. Our objectives were to evaluate nitrogen digestibility and retention by Angora goats when they were fed 7 isonitrogenous mixtures containing low phenolic shrubs, high phenolic shrubs, and a standard commercial forage.

Authors are graduate research assistant and professors Department of Animal and Range Sciences, New Mexico State University, Las Cruces, 88003; graduate research assistant and professor, Department of Fishery and Wildlife Sciences, New Mexico State University; and professor, Department of Experimental Statistics, New Mexico State University.

Journal article 1410 of the New Mexico Agr. Exp. Sta., Las Cruces.
Manuscript accepted 31 October 1988.

Materials and Methods

Leaves from big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*), gray oak (*Quercus grisea* Liebm.), true mountain mahogany (*Cercocarpus montanus* Raf.), fourwing saltbush (*Atriplex canescens* [Pursh.] Nutt.), common winterfat (*Ceratoides lanata* [Pursh.] J.T. Howell), and one-seed juniper (*Juniperus monosperma* [Engelm.] Sarg.) were collected from various ranges in New Mexico. Big sagebrush and winterfat leaves were collected near Taos, New Mexico. Juniper and oak leaves were collected near Silver City, New Mexico. Plant materials from these 4 species were collected during the winter of 1985. Mountain mahogany leaves were collected at Aguirre Springs, New Mexico, in May 1986. Fourwing saltbush leaves were collected near Las Cruces, New Mexico, in June 1986. In all cases, plant collection consisted of current year's annual growth of leaves. Leaves were air-dried before use.

Table 1. Dry matter composition (%) of diets fed to goats in 3 digestion trials.

	Diets					
Trial	Control	%	High phenolic	%	Low phenolic	%
1	Alfalfa	30	Big sage	30	Winterfat	30
	Prairie hay	5	Prairie hay	30	Prairie hay	25
	Straw	65	Straw	40	Straw	45
2	Alfalfa	30	Oak	30	Saltbush	30
	Prairie hay	20	Prairie hay	50	Prairie hay	25
	Straw	50	Straw	20	Straw	45
3	Alfalfa	30	Juniper	30	M. mahogany	30
	Prairie hay	0	Prairie hay	55	Prairie hay	5
	Straw	70	Straw	15	Straw	65

Three digestion trials using male Angora goats were conducted in a temperature-controlled building at New Mexico State University during the summer of 1986. Each trial evaluated one high phenolic diet, one low phenolic diet, and an alfalfa (*Medicago sativa* L.) control diet. Diets provided the goats with about 8% crude protein on a dry matter basis (Tables 1 and 2). Each diet contained 30% of the various shrubs being tested. Barley straw (*Hordeum vulgare* L.) and prairie hay, primarily blue grama (*Bouteloua gracilis* [H.B.K.] Lag. Ex. Griffiths), comprised the other 70% of the diets. Amounts of barley straw and prairie hay

Table 2. Chemical composition on a dry matter basis, of the diets consumed by goats in 3 digestion trials[1].

Trial Diets[2]	N (%)	ADIN (%)	NDF (%)	ADF (%)	ADL (%)	EE (%)	T mgCE[3]/10 mg	PHE mg/g
1 Alfalfa	1.31	0.15	72.0	46.1	7.2	1.8	0.06	8.4
Big sagebrush	1.28	0.15	70.2	44.0	8.5	5.1	0.15	30.4
Winterfat	1.23	0.18	74.4	46.5	9.5	2.2	0.03	11.7
2 Alfalfa	1.50	0.13	70.7	45.5	6.4	2.0	0.04	8.9
Oak	1.41	0.21	70.6	43.8	9.0	2.7	0.14	38.8
Fourwing Saltbush	1.44	0.14	71.6	41.6	6.9	1.9	0.05	13.6
3 Alfalfa	1.37	0.19	69.2	42.5	7.5	2.3	0.03	7.9
Juniper	1.34	0.16	66.1	41.2	9.5	5.7	1.29	38.7
Mountain mahogany	1.20	0.26	74.6	47.0	12.4	2.9	0.90	29.5

[1]N = Total nitrogen, ADIN = Acid detergent insoluble nitrogen, NDF = Neutral detergent fiber, ADF = Acid detergent fiber, ADL = Acid detergent lignin, EE = Ether extract, PHE = Phenolics, T = Tannins.
[2]Alfalfa and browse plants were 30% of diets based on dry matter basis. The remainder was variable proportion of prairie hay and barley straw.
[3]CE = Catechin equivalents.

were regulated in each diet to obtain the desired crude protein concentration. Initially, true mountain mahogany was thought to be a low phenolic shrub but chemical analyses showed otherwise (Table 3). Forages were ground through a 2.5-cm screen and mixed manually to minimize selectivity.

Twelve male Angora wether goats ($\bar{x}$ 41 ± 4 kg) reared on shrubland range in southcentral New Mexico were used in each trial. Treatments were assigned randomly to goats in each trial. Goats were weighed before and after each trial with all weights taken after a 14-hour fast. Each trial consisted of a 10-d adjustment period followed by 4 d of total fecal collection. Goats were placed in digestion crates at the beginning of the adjustment period, and diets were provided ad libitum with feed offered twice daily (0800 and 1600 h). Orts were weighed daily during the fecal collection period. Total fecal collection was used to determine apparent digestibility coefficients. Feed, orts, feces and urine samples were obtained daily during each fecal collection period for chemical analyses. Total fecal output and urine volume were recorded daily and subsamples (10% aliquot) were frozen. Volatilization of ammonia from urine samples was prevented by adding 10 ml of 50% HCl to the collection vessel. Fecal samples were dried partially at 60° C for 48 h before grinding. Feed, orts, and feces were ground through a 1-mm screen in a Wiley mill.

Chemical analyses were performed on samples of feed, orts, feces, and urine composited across days for each animal. Dry matter, organic matter, ether extract, and total N were determined by standard procedures (AOAC 1984). Acid detergent fiber, neutral detergent fiber, acid detergent lignin, and acid detergent insoluble nitrogen analyses were performed by nonsequential procedures of Goering and Van Soest (1970). Tannin content of feeds was determined by the vanillin/HCl procedure (Burns 1971) as modified by Price et al. (1978). Total phenolic content was measured according to the Folin-Denis procedure (AOAC 1984). Chemical composition of the diet consumed was estimated from the chemical composition and amount of feed offered and chemical composition and amount of orts.

Differences in intake, in vivo digestibility, digestible protein, and nitrogen balance among treatments within trials were determined using a completely random design. One goat was removed from treatment 2 in trial 1, treatment 1 in trial 2, treatment 1 in trial 3 and treatment 3 in trial 3 because of refusal to consume study diets. Thus, an analysis of variance with unequal replication was performed in all trials. If a significant treatment F test was observed, means were separated by the least significant difference method (Steel and Torrie 1980). Relationships among fecal nitrogen, urinary nitrogen, digestible protein, nitrogen balance, crude protein, unavailable nitrogen, nitrogen intake, phenolic content, and tannin content of diets were evaluated using correlation and regression analysis (Draper and Smith 1966). More details on experimental procedures are provided by Nunez-Hernandez (1987).

Results and Discussion

Nitrogen Retention

Nitrogen retention (g/d) by goats showed no consistent difference among high-phenolic, low-phenolic and alfalfa diets (Table 4). Nitrogen retention differences occurred only in Trial 3, where goats fed one-seed juniper had greater ($P<.05$) nitrogen retention than those fed true mountain mahogany and alfalfa diets. Based on these data, it appears that phenolics and tannins have a limited influence on nitrogen status of goats when forages containing high

Table 3. Chemical composition of forages fed to goats in the three digestion trials.[1]

Forages	N[2] (%)	ADIN (%)	NDF (%)	ADF (%)	ADL (%)	EE (%)	T mg CE[3]/10 mg	PHE mg/g
Alfalfa	3.4	0.24	45.2	30.9	7.3	2.6	0.07	12.0
Big sagebrush	1.9	0.26	44.3	31.3	12.8	15.2	0.34	61.0
Common winterfat	1.7	0.24	69.2	41.9	12.7	2.6	0.07	13.0
Gray oak	1.6	0.34	53.2	38.2	16.0	3.8	0.69	79.0
Fourwing saltbush	2.5	0.24	54.4	27.2	8.6	2.9	0.01	23.3
One-seed juniper	1.0	0.33	41.2	31.1	16.3	12.8	1.36	80.3
True mountain mahogany	2.0	0.59	57.1	44.7	20.1	4.6	0.74	64.7
Prairie hay	1.8	0.26	72.1	42.4	6.2	3.6	0.04	12.4
Barley straw	0.9	0.17	71.9	47.7	5.6	2.4	0.03	7.9

[1]Percentages are on a dry matter basis.
[2]N = Total nitrogen, ADIN = Acid detergent insoluble nitrogen, NDF = Neutral detergent fiber, ADF = Acid detergent fiber, ADL = Acid detergent lignin, EE = Ether extract, T = Tannins, PHE = Phenolics.
[3]CE = catechin equivalents.

Table 4. Organic matter intake, in vivo organic matter digestibility and nitrogen utilization by Angora goats fed diets containing low and high phenolic shrubs.

	Trial 1[1]			Trial 2[1]			Trial 3[1]		
	Alfalfa[2]	Big sagebrush	Winterfat	Alfalfa	Oak	Fourwing saltbush	Alfalfa	Juniper	Mountain mahogany
Organic matter intake, %BW[3]	1.5[a]	0.9[b]	1.4[a]	2.0[a]	2.0[a]	1.8[a]	1.5[b]	2.0[a]	1.7[ab]
Apparent organic matter digestibility, %	57.3[a]	59.1[a]	57.1[a]	54.3[a]	45.6[b]	54.1[a]	53.7[b]	58.2[a]	51.8[b]
Nitrogen intake, g/d	8.8[a]	5.0[c]	7.7[b]	13.7[b]	14.4[a]	13.3[b]	10.5[b]	12.4[a]	10.0[b]
Fecal nitrogen, g/d	3.2[a]	1.7[b]	3.0[a]	4.8[b]	7.3[a]	4.4[b]	3.7[c]	5.9[a]	4.6[b]
% of N intake	36.4[a]	34.0[a]	38.9[a]	35.0[b]	50.7[a]	33.1[b]	35.2[b]	47.6[a]	46.0[a]
g/100 g organic matter intake	0.5[a]	0.5[a]	0.5[a]	0.6[b]	0.9[a]	0.6[b]	0.5[c]	0.7[a]	0.6[b]
Urinary nitrogen, g/d	7.0[a]	6.0[a]	5.4[a]	6.9[a]	5.2[b]	5.8[b]	5.4[a]	2.6[b]	3.2[b]
% of N intake	79.5[ab]	120.0[a]	70.1[b]	50.3[a]	36.1[c]	43.6[b]	51.4[a]	20.9[c]	32.0[b]
g/kg $BW^{.75}$	0.4[a]	0.4[a]	0.3[a]	0.4[a]	0.3[b]	0.4[a]	0.3[a]	0.2[b]	0.2[b]
Crude protein, % of diet	8.2[a]	8.0[a]	7.7[b]	9.4[a]	8.8[a]	9.0[a]	8.6[a]	8.4[a]	7.5[b]
Apparent digestible protein, % of diet	5.2[a]	5.3[a]	4.7[b]	6.1[a]	4.3[b]	6.0[a]	5.5[a]	4.4[b]	4.0[b]
Apparent retained nitrogen, g/d	−1.4[a]	−2.7[a]	−0.7[a]	2.0[a]	1.9[a]	3.1[a]	1.4[b]	3.9[a]	2.2[b]
Apparent retained nitrogen, % of nitrogen intake	0.0	0.0	0.0	14.6[b]	12.8[b]	22.5[a]	13.5[b]	31.4[a]	21.7[b]

[1]Row means within trials that have not letters in common differ ($P<0.05$).
[2]Alfalfa and browse plants were 30% of diets mixed with prairie hay and barley straw on a dry matter basis.
[3]BW = Live body weight (kg).

levels of these substances are fed at moderate amounts in the diet (30%). Nastis and Malechek (1981) found goats fed diets containing 40% and 80% mature Gambel oak (*Quercus gambelii* Nutt.) with alfalfa hay had small reductions in nitrogen retention compared with all alfalfa hay diets. However, when goats were fed diets containing 80% immature oak, nitrogen retention was depressed severely. Similarly, Sidahmed et al. (1981) fed goats 3 diets, each containing 35% of a shrub high in soluble phenolics and tannins. Nitrogen retention in 2 of the diets was depressed compared with the control. A fourth diet, containing 100% shrubs high in soluble phenolics and tannins, showed drastically depressed nitrogen retention compared with other diets and the control. These studies indicate that stage of maturity, percentage of the diet, and shrub species can influence nitrogen retention when goat diets contain high levels of soluble phenolics/tannins.

Negative nitrogen retention values were observed in all goats in Trial 1 (Table 4). Goats in this trial consumed less nitrogen than goats in Trials 2 and 3. Sidahmed et al. (1981) reported that spanish goats consuming shrub diets were in positive nitrogen balance when they consumed .42 g N/kg BW daily or more. Similar data for Angora goats consuming shrub containing diets has not been reported. Our data indicate Angora goats were in a positive nitrogen balance when nitrogen consumption exceeds .24 g N/kg BW daily. However, it is widely recognized that nitrogen balance trials are not necessarily the best approach for determining ruminant nitrogen requirements.

An experimental limitation of the present study is that dried forage was used in the mixed diets. Drying might have caused some changes in the chemical properties of the phenolic/tannin compounds, particularly in that such compounds may have been less extractable, and thus less harmful, to the animal (Price et al. 1979). However, research by Robbins et al. (1987) indicates that a sub-

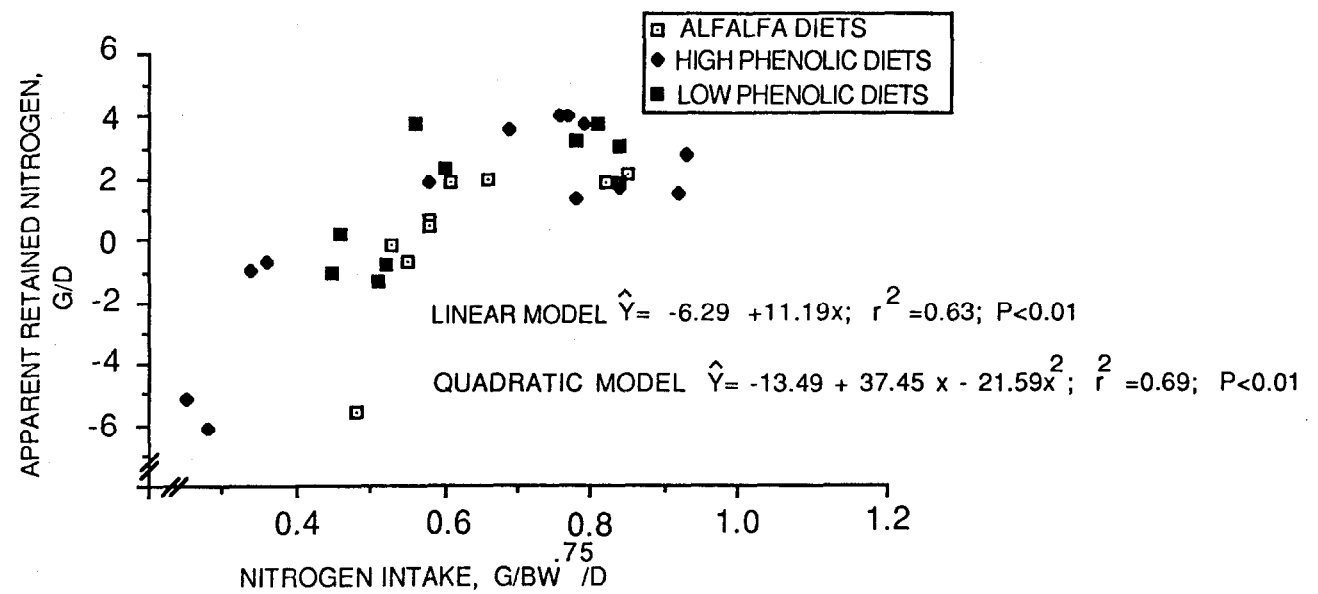

Fig. 1. *Relationship between nitrogen intake and apparent retained nitrogen in Angora goats fed diets containing alfalfa or native shrubs.*

stantial fraction of these compounds remains soluble after drying and relative differences in protein digestion among forages are not changed greatly by drying.

Fecal and Urinary Nitrogen Losses

Except for big sagebrush, diets with high phenolic shrubs had elevated fecal nitrogen losses but reduced urinary nitrogen losses (Table 4) compared with the alfalfa control diet. Correlation analyses using all data revealed that urinary nitrogen loss (g/d) was associated negatively ($P<.05$) with dietary tannin ($r = -.55$, n = 32) and phenolic contents ($r = -.50$, n = 32). However, fecal nitrogen loss (g/d) was associated positively ($P<.05$) with dietary tannin ($r = .37$, n = 32) and phenolic contents ($r = .50$, n = 32). Our data are consistent with Nastis and Malechek (1981) and Barry et al. (1986) in showing an apparent sparing of urinary nitrogen excretion, but elevated fecal nitrogen excretion, when ruminants are fed diets containing forages that are high in soluble phenolics/tannins. Barry et al. (1986) fed sheep trefoil (*Lotus pedunculatus* Cav.) that was high in condensed tannins, and the same forage treated with polyethylene glycol to reduce the tannin content. Urinary nitrogen excretion was 8.1 g/d for untreated and 13.3 g/d for treated trefoil. Sheep had the same nitrogen and metabolizable energy intakes with both treatments.

Fecal and urinary losses were expressed as percentages of nitrogen intake to adjust for the influence of differences in nitrogen intakes on nitrogen losses (Table 4). With the exception of big sagebrush, data expressed in this manner showed elevated fecal nitrogen losses and reduced urinary nitrogen losses of the high phenolic/tannin plants compared with the alfalfa control.

Soluble phenolic and tannin compounds can react directly with dietary proteins, forming complexes resistant to ruminal degradation (Hatfield 1970, Chalupa 1975). This could reduce nitrogen available for ruminal microbes. However, Barry et al. (1986) found that rumen ammonia concentration and pool size declined only slightly when sheep were fed a diet high in condensed tannins.

Lower urinary nitrogen losses for the high phenolic/tannin diets in our study may indicate an increase in recycled nitrogen to the rumen. Nitrogen influx into the rumen has been associated commonly with a decreased renal nitrogen excretion (Harmeyer and Martens 1980). Bunting et al. (1987) fed a low crude protein (8.7%) diet and a high crude protein (15.4%) diet to lambs. A greater percentage of urea produced in the body was degraded in the digestive tract with the low protein diet, resulting in a lower percentage of nitrogen being excreted in the urine.

Soluble phenolic/tannin-protein complexes that escape degradation in the rumen can be assimilated in the lower digestive tract (Chalupa 1975). Provided that protein quality is superior to microbial protein, these "protected proteins" can improve ruminant nitrogen retention and performance because protein is made directly available to the lower digestive tract without undergoing microbial degradation (Owens and Isaacson 1977).

Evaluation of Nitrogen Status

Our study shows that both dietary percentage crude protein and digestible protein are inconsistent measures of protein status when ruminants are consuming diets with moderate and varying levels of phenolic/tannin compounds. Organic matter intake (percentage body weight) and nitrogen intake showed much better associations with nitrogen retention than either crude protein or digestible protein content (Fig. 1, Table 5). Crude protein percentage was better associated with nitrogen retention than digestible protein percentage, which is explained by the fact that digestible protein reflects elevated fecal nitrogen losses, but not reduced urinary nitrogen losses when diets are high in phenolic/tannin compounds. Based on our data, nitrogen intake is a better indicator of ruminant protein status than crude protein or digestible protein contents when ruminants consume moderate and variable quantities of browse.

Table 5. Simple correlation coefficients relating dietary characteristics to apparent nitrogen retention of Angora goats consuming low and high phenolic diets.

	All diets (n = 32)	Low phenolic diets (n = 18)	High phenolic diets (= 14)
Organic matter intake, % body weight	0.81**	0.68**	0.88**
Crude protein[1], %	0.41*	0.66**	0.27
Digestible protein, %	0.04	0.72**	–0.49
Acid detergent insoluble nitrogen[2], %	0.02	–0.38	0.21
Nitrogen intake, g/$w^{.75}$/d	0.79**	0.78**	0.81**
Phenolics contents, mg/g	0.19	0.26	0.58*
Tannins content, mg CE[3]/10 mg	0.40*	–0.31	0.55*
Ether extract[1], %	0.11	0.04	–0.03

[1]Dry matter basis.
[2]Percentage of total N.
[3]Catechin equivalents.
*$P<0.05$.
**$P<0.01$.

Intake and Apparent Digestibility

Organic matter intake and apparent organic matter digestibility did not differ ($P>0.05$) between low-phenolic and control diets while differences existed between high-phenolic and control diets (Table 4). A very low intake was recorded for goats fed big sagebrush in the diet, while a low apparent organic matter digestibility was observed for the oak-containing diet. Our data support the general opinion that big sagebrush is an undesirable forage for livestock because of its low palatability (Smith et al. 1966, Striby et al. 1983). Our data also is consistent with Nastis and Malechek (1981) in showing negative influences of oak on apparent dry matter digestibility. Goats fed the juniper diet had greater intake than the control ($P<0.05$), which may have resulted from low palatability of the control diet because of a high proportion of barley straw.

Management Implications

The value of leaves from shrubs as protein supplement for range livestock consuming mature grass diets is widely recognized. However, the actual availability of the nitrogen in browse leaves has been a concern because soluble phenolics, condensed tannins, and lignin are generally greater in shrub leaves than in those from forbs and grasses. These compounds have been thought to reduce availability of protein in shrub leaves and make them less valuable as protein sources than their crude protein concentrations would imply. Our study with Angora goats indicates that nitrogen retention of many high and low phenolic/tannin containing shrubs fed at moderate levels (30%) in the diet is similar to that for alfalfa hay fed at the same level.

Common winterfat, fourwing saltbush, and true mountain mahogany are shrubs used heavily by livestock and big game animals in the western US. Mixtures containing these shrubs supported both intake and nitrogen retention values equal or superior to that of alfalfa hay. We conclude that these shrubs are excellent protein sources for range livestock and big game animals. Gray oak receives moderate use by big game animals and livestock in the southwestern US (Boeker et al. 1972, Short et al. 1977, Manzanares 1986). Angora goats in our study had similar intake and

nitrogen retention values when fed diets containing either gray oak or alfalfa hay. One-seed juniper is a companion species with gray oak on many southern New Mexico ranges. Cattle reject this plant (Manzanares 1986) and it receives only limited use by mule deer (Boeker et al. 1972). Based on our data, Angora goats may have potential to improve efficiency of use of one-seed juniper ranges. This, however, needs to be studied under range conditions before any conclusions can be drawn. The big sagebrush diet had reduced intake ($P<.05$) compared with alfalfa and common winterfat diets. The low palatability of this plant to cattle and sheep is well documented. Our data indicate little potential to improve use of big sagebrush by grazing Angora goats.

Literature Cited

AOAC. 1984. Official methods of analyses (14th ed.). Association of Agricultural Chemists, Washington, D.C.

Barry, T.N., and T.R. Manley. 1984. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep. 2. Quantitative digestion of carbohydrates and proteins. Brit. J. Nutr. 55:123-137.

Barry, T.N., T.R. Manley, and S.J. Duncan. 1986. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep. 4. Sites of carbohydrate and protein digestion as influenced by dietary reactive tannin concentration. Brit. J. Nutr. 55:123-137.

Boeker, E.L., V.E. Scott, H.G. Reynolds, and B.A. Donaldson. 1972. Seasonal food habits of mule deer in southwestern New Mexico. J. Wildl. Manage. 36:56-68.

Bunting, L.D., J.A. Boling, C.T. Mackown, and R.B. Muntifering. 1987. Effect of dietary protein level on nitrogen metabolism in lambs: Studies using ^{15}N-Nitrogen. J. Anim. Sci. 64:855-867.

Burns, R.E. 1971. Method for estimation of tannin and grain sorghum. Agron. J. 63:511-512.

Chalupa, W. 1975. Rumen bypass and protection of proteins and amino acids. J. Dairy Sci. 58:1198-1203.

Draper, N.R., and H. Smith. 1966. Applied regression analysis. John Wiley and Sons, Inc., New York.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analyses (apparatus reagents, procedures and some applications). USDA-ARS Handbook No. 379.

Harmeyer, J., and H. Martens. 1980. Aspects of urea metabolism in ruminants with reference to the goat. J. Dairy Sci. 63:1707-1728.

Hatfield, E.E. 1970. Achieving the potential of high quality dietary protein for ruminants. Feedstuffs 42:23-28.

Holechek, J.L., R.D. Pieper, and C.H. Herbel. 1989. Range management principles and practices. Prentice-Hall Publ. Co., Englewood Cliffs, N.J.

Manzanares, D.M. 1986. Botanical composition of cattle diets on riparian and adjacent upland range in southwestern New Mexico. M.S. Thesis, New Mexico State University, Las Cruces.

Mould, E.D., and C.T. Robbins. 1981. Nitrogen metabolism in elk. J. Wildl. Manage. 45:323-332.

Nastis, A.S., and J.C. Malechek. 1981. Digestion and utilization of nutrients in oak browse by goats. J. Anim. Sci. 53:283-289.

Nunez-Hernandez, G. 1987. Effect of low and high phenolic browse plants on nutritive value of Angora goat diets. M.S. Thesis, New Mexico State Univ., Las Cruces.

Owens, F.N., and H.R. Isaacson. 1977. Ruminal microbial yields: Factors influencing synthesis and bypass. Federation Proc. 36:198-202.

Price, J.L., A.M. Stromberg, and L.G. Butler. 1979. Tannin content as a function of grain maturity and drying conditions in several varieties of *Sorghum bicolor*. J. Agr. Food Chem. 57:1270-1274.

Price, J.L., S. Van Scoyoc, and L.G. Butler. 1978. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. J. Agr. Food Chem. 26:1214-1218.

Robbins, C.T., T.A. Hanley, A.E. Hagerman, O. Hjelford, D.L. Baker, C.C. Schwartz, and W.W. Mantz. 1987. Role of tannins in defending plants against ruminants: Reduction in protein availability. Ecology 68:98-107.

Robinson, K.N. 1982. An evaluation of the relationships between fecal nitrogen and digestibility, crude protein and dry matter intake of forages. M.S. Thesis. Texas A&M Univ., College Station.

Short, H.L., W. Evans, and E.L. Boeker. 1977. Natural and modified pinyon-juniper woodlands as deer and elk habitat. J. Wildl. Manage. 4:43-48.

Sidahmed, A.E., J.G. Morris, L.J. Koong, and S.R. Radosevich. 1981. Contribution of mixtures of three chaparral shrubs to the protein and energy requirements of Spanish goats. J. Anim. Sci. 53:1391-1396.

Smith, G.E., D.C. Church, J.E. Oldfield, and W.C. Lightfoot. 1966. Effect of sagebrush on forage digestibility by lambs. p. 373-378. *In:* Proc. West. Sec. Amer. Soc. Anim. Sci.

Striby, K.D., R.G. Kelsey, and B.R. Moss. 1983. Big sagebrush in livestock rations, p. 25-28. *In:* Animal and range research highlights. Anim. and Range Sci. Dep. Montana State Univ. Res. Rep. 213.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd Ed. McGraw-Hill Book Co., Inc., New York.

Wofford, H., J.L. Holechek, M.L. Galyean, J.D. Wallace, and M. Cardenas. 1985. Evaluation of fecal indices to predict cattle diet quality. J. Range Manage. 38:450-454.