Sphaeralcea angustifolia as a Substitute for Alfalfa for Growing Goats

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Abstract

Narrowleaf globemallow (*Sphaeralcea angustifolia* [Cav.] G. Don) occurs on millions of hectares of rangeland in the United States and Mexico, and it constitutes an important forage for herbivores. Forty 2-mo-old crossbred female goats (native × dairy goats; 9.4 ± 2.2 kg) were randomly allotted to five dietary groups (two] goats per pen, four replications per ration) to evaluate the effects of feeding different levels of *S. angustifolia* in a complete ration on growth performance and diet digestibility. The rations were a total mixed control ration containing 0% *S. angustifolia* (T0) and four rations in which *S. angustifolia* progressively replaced alfalfa (25% [T25], 50% [T50], 75% [T75], and 100% [T100]). Grains and forage made up 70% and 30% of the dietary dry matter (DM) in all rations. Differences ($P < 0.05$) were observed between treatments in average daily gain (ADG; range 88–124 g · d^{-1}) and DM intake (DMI; range 3.3–4.0% body weight). Feed conversion ratio (DMI/ADG; range 4.0–4.8) was similar ($P > 0.20$) among treatments. Goats fed diets with any of the *S. angustifolia* levels had similar apparent nitrogen (N) digestion (range 67.6–69.8%) as those fed only alfalfa, but N retention was greater ($P < 0.05$) in goats on T25 and T50 diets compared to other diets. The apparent digestibilities of DM, neutral detergent fiber, and acid detergent fiber were greater ($P < 0.05$) for T25 and T50 than for other diets. Results indicate that *S. angustifolia* at the flowering stage was a savory and nutritious roughage, which could fully replace alfalfa hay in diets of growing goats. Considering that *S. angustifolia* is readily consumed by foraging animals, it is abundant enough that it is a significant source of forage, and has a sufficient quality to nutritionally satisfy herbivores, this forb is a potentially useful forage for pen-fed goats.

Resumen

La hierba del negro (*Sphaeralcea angustifolia* [Cav.] G. Don) crece en millones de hectáreas de pastizales en los Estados Unidos y México, y constituye una fuente importante de alimento para los herbívoros. Cuarenta cabras de dos meses de edad de genotipo indefinido (9.4 ± 2.2 kg; cabras criollas x cabras lecheras) fueron distribuidas al azar en cinco grupos dietéticos (dos cabras por corral, cuatro replicas por ración) para evaluar los diferentes niveles de alimentación de la *S. angustifolia* en una ración completa, en el crecimiento y la digestibilidad de la dieta. Las raciones fueron: una mezcla completa de control con 0% de *S. angustifolia* (T0) y cuatro raciones en las cuales *S. angustifolia* remplazó progresivamente a la alfalfa (25% [T25], 50% [T50], 75% [T75] y 100% [T100]). Los granos y el forraje constituyeron el 70 y 30% del DM dietético en todas las raciones. Diferencias ($P < 0.05$) fueron observadas entre los tratamientos en la ganancia de peso promedio (ADG, el rango entre 88 y 124 g día^{-1}) y el consumo diario de alimento (DMI, rango entre 3.3 y 4.0% BW). La ración de conversión alimenticia (DMI/ADG; rango entre 4.0 y 4.8) fue similar ($P > 0.20$) entre los tratamientos. Las cabras que consumieron dietas con diferentes niveles de *S. angustifolia* tuvieron digestión de nitrógeno (N) aparente similares (rango entre 67.6 y 69.8%) a las que consumieron sólo alfalfa; sin embargo, la retención de nitrógeno fue mayor ($P < 0.05$) en las cabras de las dietas T25 y T50 comparadas con las otras dietas. Las digestibilidades aparentes de DM, NDF y ADF fueron mayores ($P < 0.05$) para T25 y T50 que en las otras dietas. Los resultados indican que *S. angustifolia* en estado de floración fue un forraje nutritivo y apetecible, que podría reemplazar por completo el heno de alfalfa en las dietas de las cabras en crecimiento. *S. angustifolia* es consumida fácilmente por los herbívoros, ésta es bastante abundante por lo que es una fuente significativa de forraje, y tiene una calidad suficiente para satisfacer nutricionalmente a los herbívoros. Esta herbácea es un alimento potencialmente útil para cabras alimentadas en corral.

Key Words: digestibility, feed conversion ratio, feed intake, serum urea, weight gain

INTRODUCTION

Some range forbs are troublesome to domestic livestock because of their stiff hairs, thorns, or sharply pointed seeds, which may cause mechanical injury to the mouth, eyes, and digestive canal (Cook et al. 1954; Cooper and Owen-Smith 1986). Other forbs of the Chihuahuan desert present high levels of phytotoxins, which cause lower animal production or even death (Torell et al. 1988; Allen and Segarra 2001). However, not all forbs are "bad"; in fact, some of them constitute staple food for livestock and wild herbivores on rangeland. One such

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forage is narrowleaf globemallow (*Sphaeralcea angustifolia* [Cav.] G. Don), a plant abundant in the Mohave, Sonoran, and Chihuahuan deserts, which constitutes an important forage for goats (Mellado et al. 2004a), sheep (Mellado et al. 2005a), prairie dogs (Mellado et al. 2005b), and cattle (Mellado et al. 2005b) in the Chihuahuan Desert range throughout the year. Because of the preference of herbivores for this plant it is presumed that this forb does not provoke negative postingestive consequences and contains a high percentage of digestible nutrients. It is important to characterize this local forage for its chemical composition, its in vitro degradability, the suitable rate of incorporation in the ration of different animals, and the effect on intake and growth rate.

The literature appears devoid of feeding studies with any kind of animals involving *S. angustifolia*. The purpose of this study was to characterize the feeding value of *S. angustifolia*, a plant that is readily available to goat producers in the arid zones of Mexico, and to test the hypothesis that the nutritive value of this plant is equal to alfalfa. Thus, a trial was designed to evaluate *S. angustifolia* as replacement for alfalfa hay in rations for growing goats.

MATERIALS AND METHODS

Animals and Housing

This trial was carried out at the Universidad Autonoma Agraria Antonio Narro in northeastern Mexico (lat 25°22′N, long 101°00′W) during the fall of 2005. Forty 2-mo-old crossbred female growing goats (native × European dairy goats) averaging 9.4 kg (2.2 SD) were randomly allotted to five rations with ratios of alfalfa (*Medicago sativa* L.) to *S. angustifolia* hay of 100:0 (T0), 75:25 (T25), 50:50 (T50), 25:75 (T75), and 0:100 (T100). Eight weaned goats were used per treatment, with two goats per pen. Thus, the experimental units were the pens ($n = 4$).

Goats were mother-raised on rangeland; thus, they were exposed to *S. angustifolia* before the commencement of the confinement trial. Upon arrival to the pens, goats were ear-tagged, treated against internal parasites (Ivomec; Merck and Company, Rahway, NJ) and vaccinated for protection against various clostridia. Health status of the experimental animals was evaluated and recorded daily.

The pens (1.5 × 2 m) were constructed using metal tubes on four sides, with concrete floors without bedding. Goats had access to at least 0.3 m of feed bunk space. Each pen had a water bucket, so water was available at all times. Goats housed in this facility had direct exposure to the weather.

Feeding Trial

The duration of the feeding trial was 70 d, preceded by an adaptation period of 7 d. Animals were fed in pairs twice per day, at 0900 and 1600 hours.

Five experimental rations were prepared using the ingredients listed in Table 1. *S. angustifolia* (leaves, stems, and flowers) was collected in the range adjacent to the study site at 100% flower by hand-clipping. This forage was sun-dried to a constant humidity and passed through a forage chopper fitted with a 5-mm screen to reduce the staple length of the forage and minimize selection by goats of fractions of forage offered. Alfalfa hay (25% bloom) was obtained from a commercial source.

Table 1. Ingredient composition (% dry matter) of rations (treatments, T) containing various levels (0–100%) of *Sphaeralcea angustifolia*.

Ingredient	T0	T25	T50	T75	T100
Alfalfa hay	30	22.5	15	7.5	0
Sphaeralcea angustifolia	0	7.5	15	22.5	30
Ground corn grain	50	49.7	49.6	49.4	49.2
Soybean meal	6	6.5	6.7	6.9	7.1
Animal fat	1	0.5	0.5	0.5	0.5
Cane molasses	10	10	10	10	10
Bicarbonate	1	0.5	0.5	0.5	0.5
Mineral mix[1]	3	2.5	2.5	2.5	2.5
Common salt	0	0.25	0.25	0.25	0.25

[1]Macro- and microelements, monensin, and vitamins A, D, E (GANATEC-25; Técnicas Nutricionales S.A. de C.V., San Nicolás de los Garza, Mexico).

Rations were formulated to meet the dietary nutrient requirements during the feeding periods (National Research Council 1981). All diets were fed as a total mixed ration.

The distributed and refused quantities of feed were weighed daily. Animals were weighed at the beginning and the end of the trial and every 14 d (prior to the morning meal) throughout the trial without withdrawal of feed or water. Both initial and final weights were determined using the average of weights taken on two consecutive days. Average daily gain (ADG), dry mater intake (DMI), and feed conversion ratio (FCR; defined as DMI/ADG) were determined for all goats.

Digestion Trial

At the end of the feeding trial, 10 goats (two animals chosen randomly per group) were allocated to the same diet offered during the feeding trial in a completely random design. Goats were housed in an open-air building in individual 1.2 × 0.7 m metabolism stalls with steel floors to allow collection of feces.

Animals were fed individually at 0800 and 1400 hours daily at 10% above the intake of the previous day. Fresh water was available constantly throughout the experiment. The trial consisted of 10-d period, with 5 d of adaptation. Collection of feces and urine was carried out during 5 d. Feed offered and total refused ration were sampled and collected daily. Total feces were collected and weighed, and a 10% aliquot was retained and stored at −20°C for subsequent analysis. All samples of feces were composited for each animal over the collection period.

The ration components were sampled daily and composited samples of rations were frozen at −20°C. For urine collection of goats, sterile Foley catheters (5-mL balloon, 14 Fr) were permanently placed into the bladder of all animals, and these catheters emptied into containers with sufficient 6 *N* HCl added to maintain a pH below 3.0, in order to prevent loss of ammonia.

The measurement of the total volume of urine was done each day, and a 5% aliquot of urine was retained daily and composited for each goat during the collection period. The cumulated sample was cooled to 4°C and analyzed for nitrogen (N) content (one sample per goat) using standard macro-Kjeldahl procedures (Association of Official Analytical Chemists [AOAC] 1990; method ID 954.01). The fecal and urinary N content was subtracted from the N intake to estimate N balance. Apparent digestibilities were calculated by difference of output and intake.

Chemical Analyses and In Vitro Gas Production

Three *S. angustifolia* clip samples were taken at random in representative areas of the range to estimate forage quality. Three samples of alfalfa hay were also used for assessing chemical composition. Combined dry samples of feed and feces (collected over 5 d for the digestion trial) were assembled and prepared for analysis (one sample per goat). These samples were ground with a Wiley mill to pass through a 1-mm screen. Chemical analyses were conducted in duplicate. Ash was determined by ignition of dried samples in a muffle furnace at 600°C for 3 h (AOAC 1990; ID 942.05). The crude protein (CP) content was determined by a Kjeldahl method (AOAC 1990; ID 954.01). Ash-free neutral detergent fiber (NDF) and ash-free acid detergent fiber (ADF) were determined using methods described by Van Soest et al. (1991). Condensed tannins were determined using the technique described by Terril et al. (1992) using quebracho tannins as standard.

In vitro gas production was determined as described by Menke and Steingass (1988). The in vitro ruminal incubation procedure consisted of placing 200 mg of air-dried forages sample, in triplicate, in 100-mL graduated glass syringes fitted with plungers in an anaerobic medium. Plungers were lubricated with a dose of syringe oil (Jupiter Vet Products, Harrisburg, PA) to ensure consistent plunger resistance and movement. Buffer and mineral solution were prepared and placed in a water bath at 39°C under continuous flushing with CO_2. Rumen fluid was collected after the morning feeding using a manually operated vacuum pump from two rumen-fistulated, nonlactating, nonpregnant Holstein cows fed a grass hay diet. The rumen fluid was placed in prewarmed thermos flasks, where it was mixed and filtered through four layers of cheesecloth and then flushed with CO_2. The CO_2-flushed rumen fluid was added to the buffered mineral solution (1:3 v/v), which was maintained in a water bath at 39°C, and mixed. Buffered rumen fluid (30 mL) was pipetted into each syringe containing the forage samples and the syringes were immediately placed into the water bath at 39°C. Three syringes with only buffered rumen fluid were incubated and considered as the blanks. The syringes were gently shaken every 2 h, and the incubation terminated after recording the 72-h gas volume. The gas production at 24 h was corrected for day-to-day variation in the activity of rumen liquor using the Hohenheim hay standard.

The rate and extent of gas production were calculated by the exponential equation of Brody: $GAS = GAST \cdot 1 - b \cdot \exp^{-c \cdot time}$), where GAS (mL) denotes the cumulative gas production at time t, GAST is asymptotic gas production, c (mL $\cdot$ h^{-1}) is rate of gas accumulation, and b is a scale parameter.

Volume of gas (mL $\cdot$ g^{-1} DM) produced after 24 h of incubation (G24) was used as an index of digestibility and energy feed value.

Organic matter digestibility (OMD; g $\cdot$ kg^{-1} DM) and metabolizable energy (ME) content were calculated by the following relationships:

$$OMD = 14.88 + 0.889 \cdot GV24 + 0.45 \cdot CP + 0.0651 \cdot XA \quad [1]$$

$$ME(MJ \cdot kg^{-1} \cdot DM) = 2.2 + 0.136 \cdot GV24 + 0.057 \cdot CP + 0.0029CP^2 \quad [2]$$

where XA denotes ash g $\cdot$ kg^{-1} DM, and GV24 denotes cumulative gas production in mL at 24 h of incubation.

Blood Parameters

In order to assess the impact of diets on nutritional status of goats and possible effects of *S. angustifolia* on the integrity of liver and kidneys, blood samples were collected by jugular venipuncture from all goats at the end of the feeding trial. The blood sample was allowed to coagulate and, after centrifugation, the serum was decanted and stored at −20°C until analyzed for various metabolites and minerals of blood. Serum total protein concentration was determined with a kit based on the bicinchoninic acid reagent with bovine serum albumin as a protein standard (Pierce Chemical, Rockford, IL). Glucose was assayed with kit 115-A based on glucose oxidase, and urea was quantified using kit 640-A based on urease (Sigma-Aldrich Co., St. Louis, MO). Creatinine was measured in serum using the QuantiChromTM Creatinine Assay Kit (DICT-500; BioAssay Systems, Hayward, CA). Albumin was determined with the albumin fluorescence assay kit (Sigma-Aldrich Co.). Except for phosphorus (P), serum minerals (calcium, copper, and zinc) were determined by atomic absorption spectrophotometry (Perkin Elmer Instruments model 2380; Perkin Elmer, Waltham, MA). P was determined by the method of Fiske and Subbarow (1925).

Statistical Analysis

Forage composition data were analyzed statistically using Student's paired t test (SAS 1990), taking the $P < 0.05$ level as significant. The model contained the effects due to forage, and samples ($n = 3$) served as the experimental unit. For the performance data, statistical analyses were performed using the GLM procedure of SAS (1990) for a complete randomized design, using the initial body weight of goats as covariate. The model contained the effect of level of *S. angustifolia*. Pens served as the experimental unit for ADG, DMI, and FCR. If the main effect from treatment was significant ($P < 0.05$), treatment means were compared with the LSD statement of SAS (1990).

Digestion trial results were subjected to analysis of variance (SAS 1990) to statistically compare treatments, with animals as the experimental units and diet as the only class variable. Because goats selected for the digestion trial continued on the same diet, it was not necessary to incorporate the effect of previous diet for the statistical analysis.

RESULTS AND DISCUSSION

Chemical Composition of Forages

The chemical compositions of *S. angustifolia* and alfalfa hay are shown in Table 2. Clipped forage samples of *S. angustifolia* had higher ($P < 0.01$) ash and fat content than alfalfa hay. CP levels were similar between *S. angustifolia* and alfalfa.

Alfalfa had higher ($P < 0.01$) ADF but lower NDF than *S. angustifolia*. The proportion of NDF in *S. angustifolia* was far below the concentration of 600 g $\cdot$ kg^{-1}, which is considered a limit for acceptable intakes of forage (Meissner et al. 1991). The ADF fraction for *S. angustifolia* was about 50% of the NDF, which is indicative of high levels of hemicellulose. The low ADF content of *S. angustifolia* is indicative of a low cell wall content of this plant, a characteristic of high-quality forages. Higher absolute values of ADF have also been reported in different species of the Chihuanan Desert range (Holechek et

Table 2. Chemical composition and tannin concentration (g · kg^{-1} dry matter) of *Sphaeralcea angustifolia* and alfalfa hay.[1]

Item	*Sphaeralcea angustifolia*	Alfalfa hay
Dry matter	951 ± 4.5a	821 ± 3.7b
Ash	131 ± 2.7a	79 ± 2.2b
Crude fat	39 ± 1.5a	33 ± 1.6b
Crude fiber	241 ± 3.4a	231 ± 1.5b
Crude protein (total nitrogen × 6.25)	170 ± 3.2a	170 ± 2.8a
Nitrogen-free extract	419 ± 3.8a	486 ± 4.6b
Acid detergent fiber	237 ± 4.3a	283 ± 2.9b
Neutral detergent fiber	414 ± 7.7a	379 ± 2.8b
Condensed tannins (soluble)	15	—
Condensed tannins (insoluble)	99	—

[1]Means within a row with different lowercase letters differ ($P < 0.01$).

Table 3. Parameters estimated from the in vitro gas production for *Sphaeralcea angustifolia* and alfalfa.[1]

Item[2]	*Sphaeralcea angustifolia*	Alfalfa
Potential gas production (mL · g^{-1} DM)	0.96 ± 0.40a	1.60 ± 0.12b
Rate gas accumulation (mL · h^{-1})	0.08 ± 0.02a	0.11 ± 0.03a
Total gas production (mL · g^{-1} DM)	154 ± 4.7a	223 ± 4.8b
In vitro OM degradability (g · kg^{-1})	523 ± 7.1a	637 ± 6.8b
ME (MJ · kg^{-1} DM)	8.18 ± 0.11a	9.72 ± 0.10b

[1]Means within a row with different lowercase letters differ ($P < 0.01$).
[2]DM indicates dry matter; OM, organic matter; and ME, metabolizable energy.

al. 1989). Condensed tannin levels were above the 20–40 g · kg^{-1} DM concentration considered ideal for forage legumes (Aerts et al. 1999).

Considering the high CP and low fiber of this forb, as well as the high preference of this forage by grazing goats (Mellado et al. 2004b), it can be typified as "good-quality" forage at the flowering stage. The CP level of *S. angustifolia* reported in this study is similar to levels reported for various other forbs in this type of landscape (Box et al. 1967; Schweitzer et al. 1993). The high ash content of *S. angustifolia* could be because of the abundance of soluble salts in the arid soils of this region. We are not aware of other published data on the nutrient levels in *S. angustifolia* or how such levels may change with season.

The gas production kinetics, OMD, and ME content of feedstuffs studied are presented in Table 3. Both cumulative gas released at 72 h and fractional rate of in vitro gas production (gamma) was higher ($P < 0.01$) for alfalfa compared to *S. angustifolia*. Both the OMD and ME values were lower ($P < 0.01$) in *S. angustifolia* than in alfalfa. The higher NDF fraction in *S. angustifolia* compared to alfalfa seems to explain these differences, because degradability of forages is highly correlated with NDF (Getachew et al. 2004). The high tannin content of *S. angustifolia* could be an additional cause of the reduced OMD of *S. angustifolia*. Although concentrations of condensed tannins considered to be optimal for intake, digestion efficiency, and general animal performance are not universally established, the ideal concentration of condensed tannins in forage legumes generally ranges from 20 g · kg^{-1} to 40 g · kg^{-1} DM, at which level they may bind with the dietary proteins during mastication and protect the protein from microbial attack in the rumen (Aerts et al. 1999). If they occur at concentrations above 60 g catechin equivalents · kg^{-1} DM, condensed tannins reduce voluntary feed intake and depress digestion efficiency (Barry and Manley 1986) and inhibit microbial enzymes involved in fiber degradation and produce an astringent taste (Kumar and Singh 1984).

The lower gas production of *S. angustifolia* was reflected in a lower ($P < 0.01$) OMD value compared to alfalfa. This premise is supported by the results of Apori et al. (1998), who also reported a positive correlation between gas production and digestibility with browse leaves. Other researchers have also documented the relationship of gas production parameters with digestibility and degradation characteristic of forages and concentrate feedstuffs (Khazaal et al. 1993; Sommart et al. 2000).

Feeding Trial

No adverse health effects in goats were observed due to the consumption of *S. angustifolia*. Both ADG and DMI were influenced ($P < 0.05$) by levels of *S. angustifolia* (Table 4). The highest ADG and DMI were observed in T50, but these parameters did not differ between T0 and T100, which suggests a positive associative effect of partial replacement of alfalfa with *S. angustifolia* in high-concentrate diets for growing goats. The high content of tannins of *S. angustifolia* could have increased its feeding value when mixed 50:50 with alfalfa, because goats fed condensed tannin–containing forages present a reduction in methane gas production (Frutos et al. 2004; Puchala et al. 2005) and reduced protein degradation in the rumen, with the subsequent increased bypass protein flow to the small intestine (Min et al. 2003; Frutos et al. 2004). On the

Table 4. Performance for growing goats fed rations (treatments, T) containing five levels (0–100%) of *Sphaeralcea angustifolia.* Values are means ± SD.[1]

Item[2]	T0	T25	T50	T75	T100
Initial live weight, kg	10.0 ± 2.2	9.3 ± 1.5	9.8 ± 1.8	7.2 ± 0.9	8.9 ± 3.5
Final live weight, kg	17.3 ± 2.5	17.8 ± 2.0	18.5 ± 1.9	14.3 ± 1.8	15.1 ± 5.4
Average daily gain, g	105 ± 18bc	121 ± 16ab	124 ± 16a	101 ± 180c	88 ± 21c
Daily DMI, g	450 ± 36ab	454 ± 45ab	478 ± 24a	430 ± 26b	417 ± 66b
Daily DMI, % BW[3]	3.3	3.3	3.4	4.0	3.5
FCR (DMI/ADG)	4.5 ± 0.7a	4.0 ± 0.9a	4.0 ± 1.0a	4.4 ± 0.8a	4.8 ± 1.8a

[1]Means within a row with different lowercase letters differ ($P < 0.05$).
[2]DMI indicates dry matter intake; BW, body weight; FCR, feed conversion ratio; and ADG, average daily gain.
[3](Daily DMI ÷ [(initial live weight + final live weight) ÷ 2]) · 100.

Table 5. Digestibility coefficients of dry matter (DM), neutral detergent fiber (NDF), and acid detergent fiber (ADF) in mixed-breed goats as influenced by the dietary level (0–100%) of *Sphaeralcea angustifolia*. Values are means ± SD.[1]

Apparent digest, %	T0	T25	T50	T75	T100
DM	68.8 ± 0.5bc	72.1 ± 1.3a	71.0 ± 0.1ab	69.2 ± 1.2bc	67.6 ± 0.4c
NDF	71.6 ± 0.6a	70.6 ± 0.9ab	68.0 ± 0.1c	69.7 ± 1.1bc	63.6 ± 0.7c
ADF	32.2 ± 1.1b	42.2 ± 1.9a	42.6 ± 0.2a	38.9 ± 4.7a	29.2 ± 1.1b

[1]Means within a row with different lowercase letters differ ($P < 0.05$).

other hand, the similar DMI between goats offered T0 and T100 indicates that condensed tannins of *S. angustifolia* did not appear to be a limiting factor for ingestion of this roughage. Jansen et al. (2007) observed that tannin minimization was not the best explanation for diet selection by goats.

Lack of *S. angustifolia* effects on DMI with total replacement of alfalfa is similar to other results observed with fodder tree species such as *Leucaena leucocephala* and *Calliandra calothyrsus* (Phiri et al. 1992), *Atriplex numularia* (Azócar et al. 1996), *Leucaena leucocephala* (Nantoumé et al. 2001), and prickly pear (*Opuntia ficus-indica*; Azócar et al. 1996; McMillan et al. 2002) when replacing alfalfa in goat diets.

FCR was not different ($P > 0.05$) between treatments, suggesting no negative impacts on performance due to physical or chemical defenses of *S. angustifolia*. Despite the fact that inclusion of *S. angustifolia* to diets did not modify FCR, it was numerically 37% higher in T100 compared to T0. This difference could lead to practical important differences in feed conversion efficiency with total substitution of alfalfa by *S. angustifolia*. The similar goat performance between T0 and T100 suggests that, under the conditions of this experiment, *S. angustifolia* provides nearly the same nutrients as alfalfa, at a comparable maturity in diets for growing goats. These results are consistent with other studies (Box et al. 1967; Schweitzer et al. 1993) in showing that some native forbs of the Chiuahuan Desert range can be nutritious forage for livestock.

Digestion Trial and Blood Metabolites

Apparent digestibility of DM of diets with various levels of *S. angustifolia* was above 68%, with significant treatment effects ($P < 0.05$; Table 5). Apparent digestibility of DM for T25 and T50 was higher ($P < 0.05$) than that of T0 and T100. The cell wall components (NDF) were highly digestible, as the digestibility of this fraction exceeded 64%. Apparent digestibility of NDF was 7% lower ($P < 0.05$) in T100 compared to T0. Apparent digestibility of ADF for T25, T50, and T75 was greater ($P > 0.05$) than that of T0 and T100. The lower digestibility of ADF with the maximum amount of *S. angustifolia* is consistent with that observed with other shrubs of arid zones offered in high quantities (Boutouba et al. 1990). The decreased DM digestibility of diets containing more *S. angustifolia* was primarily due to linear decreases in digestibility of NDF.

Apparent digestibility coefficients indicated associative effects between alfalfa hay and low-to-moderate levels of *S. angustifolia* in the diets for ADF and DM, for which digestibility coefficients were higher ($P < 0.05$) than those predicted by a linear substitutive effect between feedstuffs. This positive associative effect of alfalfa on fiber digestion of nonleguminous forages has been previously documented by Grigsby et al. (1991), Hunt et al. (1985), and Ndlovu and Buchanan-Smith (1985). The associative effect observed with the inclusion of *S. angustifolia* could be also explained by the nutritional value added by the condensed tannins present in this forage, as limited condensed tannins enable protein to bypass degradation in the rumen (Barry 1987; Min et al. 2003) and undergo enzymatic hydrolysis in the abomasum (Jones and Mangan 1977).

The associative effect of the combination of both forages on fiber digestibility in the present trial corroborates results of Haddad (2000), who observed positive associative effects of supplementing barley straw–based diets to lambs with different levels of alfalfa in terms of feed degradability. Positive associative effects for the digestibility of alfalfa–fescue combinations have also been reported by Hunt et al. (1985).

Goats fed diets where *S. angustifolia* replaced 25% and 50% alfalfa had N intake higher ($P < 0.05$) than the goats fed diets containing 0%, 75%, or 100% of this forage (Table 6). Data from the feeding trial indicate that DMI was stimulated in T25 and T50 diets, thus, this seems to explain the higher N intake in diets with intermediate levels of *S. angustifolia*, despite the similar N content of diets.

Animals fed T25 and T50 diets had also greater ($P < 0.05$) fecal N than did those fed T0, T75, and T100, although apparent digestibility of N did not differ among diets, which indicated that dietary inclusion of *S. angustifolia* had no adverse effect on N utilization. These results differ from those reported by other authors, who found that the association of alfalfa with other low-quality forages have showed a general improvement in digestibility of CP (Franci et al. 1997) or N retention (Bowman and Asplund 1998) in small ruminants. In the present study goats receiving T25 and T50 diets showed more N loss in the urine and

Table 6. Nitrogen (N) metabolism in goats fed rations (treatments, T) varying in *Sphaeralcea angustifolia* levels (0–100%). Values are means ± SD.[1]

Item	T0	T25	T50	T75	T100
N intake, $g \cdot d^{-1}$	11.0 ± 0.3a	14.9 ± 0.7b	15.7 ± 0.7b	10.1 ± 0.7a	12.1 ± 1.4a
Fecal N, $g \cdot d^{-1}$	3.6 ± 0.4a	4.7 ± 0.1b	4.8 ± 0.2b	2.8 ± 0.3c	3.6 ± 0.4a
Apparent N digest, %	67.6 ± 3.2a	68.6 ± 1.0a	68.1 ± 1.1a	69.3 ± 3.6a	69.8 ± 0.3a
Urinary N, $g \cdot d^{-1}$	3.7 ± 0.4a	4.3 ± 0.8a	4.8 ± 0.4a	3.7 ± 0.3a	4.2 ± 0.9a
N retention, $g \cdot d^{-1}$	3.7 ± 0.6a	5.9 ± 0.2b	6.1 ± 0.5b	3.6 ± 0.7a	4.2 ± 0.1a
% of N intake	33.9 ± 6.1a	39.9 ± 33a	38.6 ± 1.2a	35.6 ± 4.7a	34.9 ± 4.0a
% of N digested	50.0 ± 6.7a	58.2 ± 5.8a	56.9 ± 3.0a	51.3 ± 4.1a	50.1 ± 6.1a

[1]Means within a row with different lowercase letters differ ($P < 0.05$).

Table 7. Serum metabolites and minerals for mixed-breed growing goats fed different levels (treatments, T; 0–100%) of *Sphaeralcea angustifolia*. Values are means ± SD.[1]

Parameters	T0	T25	T50	T75	T100
Glucose (mg · dL^{-1})	74.0 ± 11.7a	77.8 ± 11.7a	82.7 ± 15.4a	72.8 ± 8.9a	73.5 ± 13.4a
Urea N (mg · dL^{-1})	21.1 ± 4.7a	23.3 ± 2.6a	22.9 ± 4.1a	24.8 ± 2.2a	24.8 ± 2.5a
Creatinine (mg · dL^{-1})	1.9 ± 0.4a	2.1 ± 0.4a	1.9 ± 0.2a	2.4 ± 0.2a	2.0 ± 0.5a
Total proteins, (mg · dL^{-1})	6.7 ± 0.6a	6.6 ± 1.9a	5.7 ± 1.0a	6.2 ± 1.0a	7.4 ± 2.1a
Cholesterol (mg · dL^{-1})	94 ± 25n	82 ± 25a	83 ± 30b	84 ± 27b	78 ± 10ab
Calcium (mg · dL^{-1})	11.0 ± 0.4a	10.8 ± 0.6a	11.0 ± 0.7a	10.5 ± 1.3a	11.6 ± 2.5a
Phosphorus (mg · dL^{-1})	9.0 ± 0.8a	8.4 ± 0.6ab	8.3 ± 0.9ab	8.9 ± 1.0a	7.6 ± 1.0b
Magnesium (mg · dL^{-1})	3.2 ± 0.3a	3.3 ± 0.5a	3.6 ± 0.5a	3.0 ± 0.7a	3.4 ± 0.5a
Copper (mg · kg^{-1})	1.7 ± 1.0a	2.1 ± 1.1a	3.0 ± 0.4a	2.5 ± 0.4a	3.0 ± 2.0a
Zinc (mg · kg^{-1})	1.3 ± 0.6a	1.2 ± 0.4a	0.8 ± 0.5a	1.4 ± 0.5a	1.5 ± 0.6a

[1]Means within a row with different lowercase letters differ ($P < 0.05$).

less in the feces as a percentage of N intake compared to other diets. This suggests that low-to-medium levels of *S. angustifolia* could have positively affected the efficiency of ruminal microbial protein synthesis, because ruminant urinary N losses relative to fecal N losses increase when dietary CP concentrations exceed 9% (OM basis; Van Soest 1982).

Except for serum P, there were no differences among treatments for certain goat serum metabolites and minerals (Table 7). Blood serum analyses revealed no toxicosis from any of the treatments. All values in Table 7 are within the normal range for goats (Cole 1986).

Serum P tended ($P = 0.06$) to be less with the greatest proportion of *S. angustifolia* in the diet. Possibly a component of this plant interferes with P absorption or utilization, as this has been observed with other Chihuahuan desert shrubs (Mellado et al. 2006).

Blood urea N and ruminal ammonia N concentrations increased with N intake (Davidson et al. 2003; Gabler and Heinrichs 2003). Hence, similar serum urea N in goats fed diets with different levels of *S. angustifolia* may have resulted from similar ruminal ammonia N concentrations. In other studies blood urea N have been found low in goats offered a lespedeza-based diet compared to an alfalfa-based diet (Turner et al. 2005), which suggests that *S. angustifolia* in the present study supplied enough protein as to maintain high blood urea levels.

MANAGEMENT IMPLICATIONS

Cutting *S. angustifolia* from the range at the flowering stage produces a nutritionally acceptable hay for pen-fed goats. In general, nutrient composition of *S. angustifolia* was close to alfalfa, although its in vitro OMD was 11% lower than alfalfa. Associative effects between *S. angustifolia* and alfalfa were demonstrated clearly in terms of ADG and nitrogen retention. Moreover, replacing all of the alfalfa of mixed rations with this forage did not affect ADG and DMI, which indicates that *S. angustifolia* could serve as an economical forage source for growing goats fed in confinement. Thus, if this plant is domesticated and incorporated into a crop production system, in arid zones it would be more ecologically desirable to use this available and accessible perennial forage in goat diets instead of alfalfa crop.

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