Journal of Arid Environments (2000) **44:** 123–131
Article No. jare.1999.0571
Available online at http://www.idealibrary.com on IDEAL®

The effect of feeding ewe lambs a 15% tarbush (*Flourensia cernua* DC) pellet pre- and post-weaning on the subsequent diet selection of tarbush

E. L. Fredrickson*‡, R. E. Estell*, K. M. Havstad*, W. L. Shupe* & L. W. Murray†

**USDA-ARS, Jornada Experimental Range, P.O. Box 30003, MSC 3 JER, New Mexico State University, Las Cruces NM 88003, U.S.A.*
† Department of Experimental Statistics, New Mexico State University, Las Cruces, NM 88003, U.S.A.

(Received 10 June 1998, accepted 15 July 1999)

The shrub *Flourensia cernua* (tarbush) has rapidly increased in dominance within Chihuahuan Desert grasslands, and is comparable to alfalfa in nutrient content. Increasing tarbush in livestock diets may improve diet quality, but reduces tarbush dominance. We examined dietary selection for tarbush by sheep, and the effect of previous exposure on selection. Thirty-eight ewe lambs received either tarbush or alfalfa in a sorghum-based pellet 120 days postparturition, after which dietary selection was assessed. Previous exposure to tarbush deterred lambs from tarbush consumption. Lambs without previous exposure maintained greater intakes initially, but this declined with time, which corresponds with the onset of tarbush toxicosis.

Keywords: arid land remediation; learning; diet selection; sheep; biological control

Introduction

The Chihuahuan Desert is the largest of the North American deserts that, until recently, largely consisted of desert grasslands. During the last 120 years, these grasslands have undergone transition from desert grassland to land dominated by shrubs. This process, commonly termed desertification, has negative affects on water quality and availability, air quality, and species diversity and abundance, with possible influences on global climatic patterns (Schlesinger *et al.*, 1990). Desertification is also associated with a concomitant loss in agricultural productivity of both grazing and arable lands which produce basic food supplies. Consequently, such a transition influences the quality of life in these areas, and eventually human demographic patterns. For example, within the Chihuahuan Desert human populations are declining in rural areas while dramatically increasing in already overcrowded urban areas around the Mexican–U.S. border (Wilson, 1993).

‡Author to whom correspondence should be addressed.

0140-1963/00/010123 + 09 $35.00/0

Emerging ecological models suggest a transition back to grassland will not occur without external inputs, or corrective measures (Friedel, 1991). So far, efforts to control or abate shrub expansion into grasslands have largely involved applications of herbicides or an array of energy-intensive mechanical methods that are expensive and only moderately successful. The short-term effects of these treatments, coupled with large treatment costs, generally prevent investment outlays from being recovered under most economic situations found within the Chihuahuan Desert region (Sherwood, 1994; Herbel & Gould, 1995). It is increasingly apparent that other methods of shrub control that are economically viable, yet environmentally beneficial, are needed.

The use of domestic livestock to control undesirable shrubby species, while decreasing reliance on chemical or other energy intensive remedial technologies, has been successful in more temperate environments (see for example Olson & Lacey, 1994; Sharrow, 1994). However, in arid conditions, most shrubs that are increasing in dominance appear to reduce herbivory, including herbivory by domestic herbivores, by synthesizing chemical deterrents. Herbivory on plants producing deterrents is effectively reduced, or eliminated, while herbivore pressure on plant species not protected chemically or physically is increased (i.e. by thorns etc.; Pollard, 1992). This selection process generally decreases the vigor and eventually the presence of non-protected plants from the ecosystem. Consequently, plants that are chemically defended have a competitive advantage for water and limiting nutrients. Diet training techniques suggested by Provenza & Balph (1988) demonstrate animal forage preferences can be manipulated. Theory leading to diet training suggests that exposing ruminants to plants typically not preferred at critical learning periods early in life, will enhance the animal's preference for the same plant later in life. In conjunction with other grazing techniques, altering diet selection to encourage increased shrub intake should lessen the competitive advantage of shrubs and promote the growth of competing grasses.

Tarbush (*Flourensia cernua* DC) is a common shrub found throughout the Chihuahuan Desert that readily establishes and eventually dominates many productive grassland sites. In time, dominance of tarbush diminishes as it is replaced by creosotebush (*Larrea tridentata* (DC) Cov.), a long lived shrub that is protected by a complex chemistry which deters all but a few specialized herbivores (Rhoades, 1977). This transition occurs even in areas where mechanical and chemical shrub controls were actively pursued or livestock excluded. Tarbush has a nutrient composition similar to alfalfa (Estell *et al.*, 1996). Therefore, increasing tarbush dietary intake may enhance animal production, in addition to decreasing the competitiveness of tarbush. This is an important consideration for regional population subsisting on animal agriculture.

Our study was conducted to evaluate the effects of previous dietary exposure of ewe lambs to tarbush in a pelleted ration, on their subsequent dietary selection for tarbush in field conditions. We hypothesize that early exposure to pelletted tarbush will increase ovine selection for tarbush later in life.

Methods

Thirty-eight (10/treatment) ewe lambs of Polypay × Rambouillet breeding were randomly assigned at birth to receive either tarbush or alfalfa in a sorghum-based, pelleted growing ration. The ration dry matter consisted of 53% grain sorghum, 25% cottonseed meal, 5% molasses, 0·5% trace mineral salt, and 1·5% calcium carbonate. The remaining 15% was either tarbush or alfalfa. Tarbush was collected in August, from within a singular 3 ha location on the Jornada Experimental Range located in the northern Chihuahuan Desert. No flowers or fruits were present on tarbush plants during collections. Shrubs were harvested at the base and air-dried for 96 hours. Leaves were then separated from the stems by threshing and winnowing. A local mill (Valley Feed Mills, Clint, TX) pelleted (6·4 mm pellets) each diet. Northeast DHIA Forage Analysis Lab

Table 1. *Dry matter composition of pelleted rations containing either 15% tarbush or 15% alfalfa and fed to growing ewe lambs*

Item	15% Tarbush	15% Alfalfa
Dry matter (g $100g^{-1}$ as fed)	92·7	92·8
Crude protein (N × 6·25) (g $100g^{-1}$)	20·7	23·0
Available protein (g $100g^{-1}$)	19·4	21·5
Neutral detergent fiber (g $100g^{-1}$)	13·3	19·2
Acid detergent fiber (g $100g^{-1}$)	8·0	11·5
Total digestible nutrients (g $100g^{-1}$)	78·0	76·0
Calcium (g $100g^{-1}$)	0·87	0·36
Phosphorus (g $100g^{-1}$)	0·52	0·54
Magnesium (g $100g^{-1}$)	0·35	0·32
Potassium (g $100g^{-1}$)	1·21	1·23
Sodium (g $100g^{-1}$)	0·391	0·111
Iron (mg kg^{-1})	432	178
Zinc (mg kg^{-1})	104	44
Copper (mg kg^{-1})	34	10
Manganese (mg kg^{-1})	63	25
Molybdenum (mg kg^{-1})	1·7	1·5

(Ithaca, NY) completed nutritive analyses of the pellets using conventional procedures. Results are listed in Table 1.

Lambs were fed *ab libitum* the above diets from birth for 60 days until weaning and for 60 days post-weaning. During the pre-weaning period, barriers were constructed that restricted the lamb's access to solid feed other than their respective experimental feeds. Similarly, dams were prevented from consuming pellets intended for lambs. Water and trace mineralized salt blocks (Acco Feeds, Amarillo, TX) were available at all times. No differences existed between treatments in feed consumption during either the pre- or post-weaning periods.

After 120 days, each lamb was placed in one of two adjacent 45 m^2 paddocks dominated by tarbush and burrograss (*Scleropogon brevifolius* Phil.). An assessment of individual diet selection was determined visually from a platform elevated 7 m above the ground. A trained observer located each animal based on numbers (16 cm high) painted over the rump and loins. Immediately after identification, the observer then examined the feeding activity of the animal with the aid of binoculars (7 × 35) to determine the plant being selected. This procedure was repeated for each animal every 3 minutes for 4 hours following sunrise. On the second day, lambs were placed in the opposite paddock and the procedure repeated. This set of observations was repeated every 30 days until tarbush dormancy (November). Between each observation period, lambs were pastured in 10 ha paddocks with a plant species composition similar to the study paddocks.

Cover of plant species within each paddock was determined using a 0·25 m^2 Daubenmire frame (Daubenmire, 1959). Twenty-five frames were read for each of 20 randomly selected transects within each paddock. Canopy cover estimates were obtained at the beginning, middle, and end of the experiment.

The percentage of each time lamb grazed, ate tarbush, and ate other (cheifly burrograss) forages were calculated for each day of observation. Two analyses of variance were conducted on all response variables. The first analysis used a split-plot in time as a design (month and day within month), with a completely-randomized design as the whole plot design. The whole plot treatment factor was the tarbush/alfalfa feeding treatments and individual sheep was the experimental unit. Because of significant month by treatment interactions, the data were also analysed by month, with day as the split-plot factor in time. Means and standard errors were calculated for each response. All calculations were performed using SAS PROC GLM (SAS Institute, 1989).

Results and discussion

Percentage of plant cover by species did not differ between the two paddocks used in this study, therefore, cover data were pooled across the paddocks and are presented in Table 2. These data reflect both tarbush dominance and the low vegetative cover characteristic of grassland sites now dominated by tarbush. By comparison, localized areas near this site, where shrubs are absent or recently established, tobosa grass (*Pleuraphis mutica* Buckly) and burrograss are the dominant species and provide approximately 50% vegetative cover. By summing the cover for each species, the vegetative cover estimate is inflated since most plants on these sites are growing under tarbush plants where soil nutrient concentration tends be greater (Charley & West, 1982). Ground cover from dead plant material (litter) is absent in the interspaces between shrubs. The resulting lack of ground cover on the study site means that more than 70 to 75% of the soil surface is subject to erosional forces resulting from wind and rain.

Plants contributing greater than trace amounts to the vegetative cover include crucifixion thorn (*Koeberlinia spinosa* Zucc.), wrinkled globemallow (*Sphaeralcea subhasta* Coult.), and hog potato (*Hoffmanseggia glauca* (Ort.) Eifert). Crucifixion thorn is leafless, consisting of woody photosynthetic stems and thorns. Due to the severity of the thorns, this plant is rarely grazed. Wrinkled globemallow is highly preferred by sheep and beef cattle, and was removed early during all periods. Hog potato often grows within burrograss clumps, making it difficult to distinguish from burrograss during grazing observations. Because of the dominance of tarbush and burrograss, dietary selection of only these two species will be presented.

With the exception of July, ewe lambs grazed for at least 40% of the 4-hour observation periods (Fig. 1). In July, grazing time for both treatments was low, with lambs that were fed 15% tarbush pellets and 15% alfalfa pellets grazing for only 48

Table 2. *Percent vegetative cover by species (standard deviation)*

Species*	Sampling Date		
	June 19	August 19	October 11
Tarbush (*Flourensia cernua*)	17·5 (26·0)	17·0 (24·3)	12·3 (19·1)
Burrograss (*Scleropogon brevifolius*)	6·7 (10·0)	10·0 (14·9)	8·1 (13·0)
Hog potato (*Hoffmanseggia densiflora*)	0·4 (1·1)	0·1 (0·5)	T
Desert Holly (*Perezia nana*)	T†	T	T
Wrinkled globemallow (*Sphaeralcea subhasta*)	0·9 (3·7)	0·3 (1·6)	0·1 (0·6)
All-thorn (*Koeberlinia spinosa*)	0·2 (2·3)	0·3 (4·1)	0·5 (4·3)
Bush muhly (*Muhlenbergia porteri*)	T	T	T
Ear muhly (*Muhlenbergia arenacea*)	0·1 (1·5)	T	T
Red threeawn (*Aristida purpurea* var. *longisita*)	T	T	T
Hairyseed bahia (*Bahia absinthi folia*)	T	0	0
Opuntia Sp.	0	T	T
Sum of species cover	26·0	28·8	21·0

*Species nomenclature follows Allred (1993) for grasses and Allred (1988) for forbs and shrubs.
†T = trace.

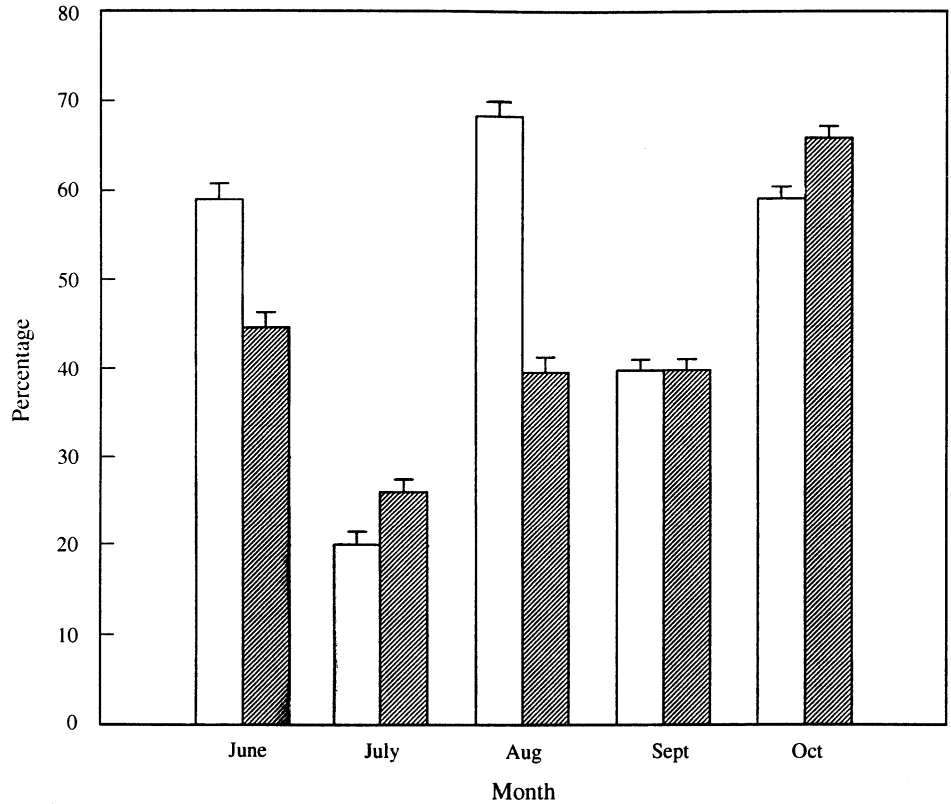

Figure 1. Percentage of observations that ewe lambs were foraging during five, 2-day observation periods, for lambs previously fed either pellets containing 15% tarbush (▨) or 15% alfalfa (□) from birth to 60 days post-weaning (120 days).

and 63 minutes, respectively. During this time, temperatures approached 37°C with wind gusts of up to 98 km h^{-1}. In response, the lambs bedded down, grazing only plants in close proximity. This atypical situation undoubtedly explains the treatment × month interaction ($p < 0{\cdot}05$; see Figs 1 & 2). Excluding July, ewe lambs previously fed 15% tarbush pellets spend more time grazing ($p > 0{\cdot}01$) during observations in June and August, with grazing time being similar ($p > 0{\cdot}05$) for both treatments in September. In October, ewe lambs previously fed pellets containing 15% alfalfa grazed 20 minutes longer ($p < 0{\cdot}05$) than ewe lambs previously fed 15% tarbush pellets.

Interestingly, feeding 15% tarbush pellets to lambs early in life averted sheep from eating tarbush (Fig. 2). This result did not agree with our hypothesis that previous experience would increase tarbush intake. With the exception of July, between 25 and 30% of the bites observed of ewe lambs previously exposed to tarbush were from tarbush. Initially, 55% of the bites observed by lambs without prior exposure to tarbush were from tarbush. In August, this proportion (52%) was similar ($p > 0{\cdot}05$) to the proportion observed in June. However, by September, the proportion of tarbush bites declined ($p < 0{\cdot}05$) by nearly half (28%) to proportions similar ($p > 0{\cdot}05$) to those of ewe lambs with prior exposure to tarbush. In October, both treatments selected tarbush at the same low level (30 and 25% for tarbush and alfalfa treatments, respectively; $p > 0{\cdot}05$).

A companion study examining the potential toxicosis from long-term tarbush consumption (Fredrickson *et al.*, 1994) appears to offer the best explanation for the

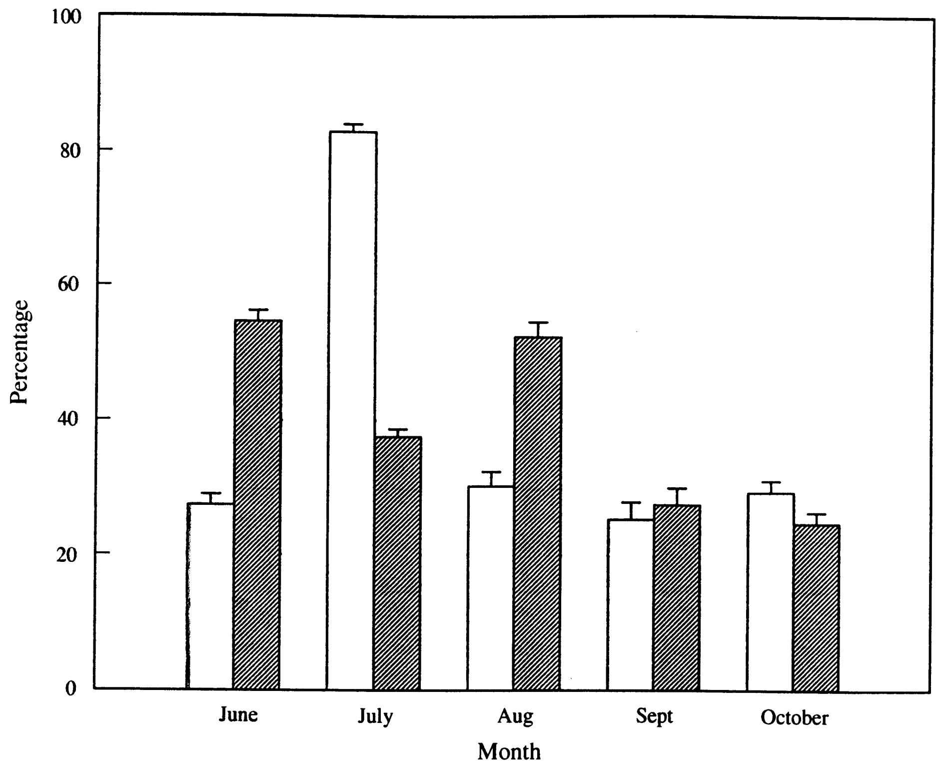

Figure 2. Percentage of observations that ewe lambs were browsing tarbush during five, 2-day observation periods, for lambs previously fed either pellets containing 15% tarbush (□) or 15% alfalfa (▨) from birth to 60 days postweaning (120 days).

initial difference in selection between treatments. In the toxicosis study, ewe lambs were fed the same pellets as used in this study. Symptoms of toxicosis, followed by the death of three lambs, were observed 115 to 120 days after lambs were first offered the tarbush pellets. Clinical observations and necropsies of five animals revealed liver damage and possible muscle damage due to chronic ingestion of tarbush. Current paradigms used to explain mammalian dietary preferences suggest toxicosis, including visceral damage, provides negative feedback on animal preferences for dietary components responsible for the toxicosis (see Provenza, 1995 for a review of this hypothesis). Furthermore, herbivores reduce ingestion of potential plant toxins and maintain intakes of toxicants that do not cause toxicosis (Launchbaugh *et al.*, 1993). Sight and smell provide pre-ingestive mechanisms by which animals are likely to recognize foodstuffs containing the offending toxicants. In our study, ewe lambs probably experienced some degree of toxicosis when fed pellets containing tarbush for 120 days. When allowed to choose between tarbush and burrograss, the lambs consumed tarbush at levels that failed to elicit a toxic response; thus, exhibiting a lower preference, or selection, for tarbush compared to controls. Prior to June observations, these animals only experienced tarbush in pelleted form and were never exposed to whole tarbush leaves or other plant parts. Therefore, olfaction is the most probable mechanism by which the lambs associated tarbush pellets (and its toxicity) with tarbush plants, thereby limiting the intake of tarbush leaves to avoid toxicity. Tarbush leaves are aromatic, with the volatile components of the leaves known to affect dietary selection of tarbush by sheep (Estell *et al.*, 1994*a*). The smell of tarbush is often described as hop-like (O'Laughlin, 1975), which is probably due to the presence of α-humulene and β-caryophyllene on the leaf surface waxes (Estell *et al.*, 1994*b*), since these terpenes are a major component of the essential oils in hops (*Humulus lupulus*; Langezaal *et al.*, 1990). We further hypothesize that ewe lambs previously fed alfalfa pellets were not averted to tarbush when first exposed to the plant during the June observation period, therefore their initial intake of tarbush remained relatively high. However, after exposure to tarbush for 90 days these ewes probably suffered some degree of toxicosis, which in turn reduced their intake of tarbush to non-toxic levels. This level of tarbush dietary intake was similar to the level maintained throughout the 4 month period by lambs previously fed tarbush pellets for 120 days. Studies by Provenza and his students (Provenza *et al.*, 1994; Provenza, 1995; Phy & Provenza, 1998) have demonstrated the post-ingestive effects of toxicants on the avoidance of foods. However, few studies have demonstrated a delay of this duration between introduction of a novel feed and negative post-ingestive feedback on dietary selection in domestic livestock.

Does tarbush toxicity and its probable effect on tarbush consumption eliminate the use of sheep as a potential biological control of tarbush? Can tarbush be viewed as forage? The answer is probably best sought in the words of the Swiss physician, Paracelsus, during the 16th century. In his treatise *Von der Besucht*, he said, 'All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy' (Paracelsus, 1567; as cited by Gallo & Doull, 1991). This is the first principle of modern toxicology and it correctly describes tarbush. In a 28-day study, feeding tarbush leaves to sheep to replace 30% of a low quality grass diet did not produce toxicosis (King *et al.*, 1996), suggesting subchronic to chronic exposure to tarbush is necessary for toxicosis to occur. In this study, periodic removal of ewes from pastures containing tarbush for periods long enough to allow for metabolic clearance of tarbush toxicants may prevent sheep from becoming averted to tarbush. For a strategy of this type to be effective, future research efforts must be directed to identify tarbush toxicant(s), environmental and plant factors affecting plant production and storage of toxicant(s), and variation in animal response to these toxicant(s). In short, it appears dose must be researched and controlled.

Like most perennial desert plant species, tarbush has a complex chemistry which is believed to enhance the plants ability to survive harsh desert environments. Within the waxy layer of the leaf surface, we have observed numerous unidentified (mostly terpenoid) compounds (Estell *et al.*, 1994*b*). Of those terpenes positively identified, there is ascribed a diverse array of biological activities, including; analgesic, herbicidal, insecticidal, nematocidal, antimicrobial, antidiuretic, acetylcholinesterase inhibitor, prostaglandin inhibitor, fungicidal, drug accelerant, antineoplastic, and carcinogenic effects. Others have isolated benzofurans and benzopyrans in tarbush which can damage red blood cells (Aregullin-Gallardo, 1985), and cytotoxic flavonoids (Rao *et al.*, 1970; Dillon *et al.*, 1976). At present it is unknown which compound's are responsible for the toxicosis we observed.

Plant chemistry affecting herbivory is likely to vary substantially with plant genotype, environmental conditions, and genotype × environmental interactions (see Kennedy & Barbour, 1992, and associated reviews). Leaf surface compounds of tarbush vary with both plant location in the environment and stage of seasonal plant development, with plant developmental stage appearing to be more variable than plant location (Estell *et al.*, 1994*a*). Plant compounds interior to the leaf surface also vary significantly across both years and seasons (Estell *et al.*, 1996). Changes in specific phenolic compounds with time have yet to be examined. Furthermore, we have not explored changes in tarbush chemistry that might occur due to herbivory. Induction of plant chemical defenses by herbivores can affect the production of chemical deterrents (Coleman & Jones, 1991) and plant nutritional quality (Bryant *et al.*, 1991).

Important differences exist among livestock species in dietary selection (Schwartz & Ellis, 1981) and capacity to detoxify toxicants (Sipes & Gandolfi, 1991). Differences in dietary preferences (Herbel & Nelson, 1966; Fedele *et al.*, 1993) and detoxification capabilities (Sipes & Grandolfi, 1991) also exist among breeds, or strains, suggesting these differences are heritable. Further, this suggests that different species of potential economic value or animals within current livestock classes can be selected based upon foraging preference and ability to detoxify plant toxicants. Researchers have also demonstrated success in selecting ruminal microbes that detoxify plant toxins (Pratchett *et al.*, 1991). If toxicosis negatively affects plant preference, then detoxification of phytotoxins by ruminal microbes should lessen or abrogate their effects on plant preference. These types of technologies may provide economically viable methods of biological control of plants currently viewed as detrimental. At the same time, these methods could decrease our present reliance on energy intensive arid land remediation techniques while improving the nutritional regimen of important food and fiber producing animals.

References

Allred, K.W. (1988). *A Field Guide to the Flora of the Jornada Plain.* Agricultural Experiment Station Bulletin 739, Las Cruces, NM: New Mexico State University.

Allred, K.W. (1993). *A Field Guide to the Grasses of New Mexico.* Las Cruces, NM: New Mexico State University.

Aregullin-Gallardo, M. (1985). Chemical and biological significance of benzofurans and benzopyrans in th Asteraceae. Ph.D. thesis, University of California Irvine. 204 pp.

Bryant, J.P., Danell, K., Provenza, F., Reichardt, P.B., Clausen, T.A. & Werner, R.A. (1991). Effects of mammal browsing on the chemistry of deciduous woody plants. In: Tallamy, D.W. & Raupp, M.J. (Eds), *Phytochemical Induction by Herbivores*, pp. 135–154. New York: John Wiley & Sons, Inc.

Charley, J.L. & West, N.E. (1982). Plant induced soil chemical patterns in some shrub-dominated semi-desert ecosystems of Utah. *Journal of Ecology*, **63**: 945–964.

Coleman, J.S. & Jones, C.G. (1991). A phytocentric perspective of phytochemical induction by herbivores. In: Tallamy, D.W. & Raupp, M.J. (Eds), *Phytochemical Induction by Herbivores*, pp. 3–45. New York: John Wiley & Sons, Inc.

Daubenmire, R. (1959). A canopy-coverage method of vegetational analysis. *Northwest Science*, **33**: 43–64.

Dillon, M.O., Mabry, T.J., Beeson, E., Bouillant, M.L. & Chopin, J. (1976). New flavinoids from *Flourensia cernua. Phytochemistry*, **15**: 1086–1087.

Elakovich, S.D. & Stevens, K.L. (1985). Phytotoxic properties of nordihydroguiairetic acid, a lignin of *Larrea tridentata* (creosote bush). *Journal of Chemical Ecology*, **11**: 27–33.

Estell, R.E., Fredrickson, E.L., Anderson, D.M., Mueller, W.F. & Remmenga, M.D. (1994*a*). Relationship of tarbush leaf surface secondary chemistry to livestock herbivory. *Journal of Range Management*, **47**: 424–428.

Estell, R.E., Havstad, K.M., Fredrickson, E.L. & Gardea-Torresday, J.L. (1994*b*). Secondary chemistry of the leaf surface of *Flourensia cernua. Biochemical Systematics and Ecology*, **22**: 73–77.

Estell, R.E., Fredrickson, E.L. & Havstad, K.M. (1996). Chemical composition of *Flourensia cernua* at four growth stages. *Grass and Forage Science*, **51**: 434–441.

Fedele, V., Pizzillo, M., Claps, S., Morand-Feh, P. & Rubino, R. (1993). Grazing behavior and diet selection of goats on native pasture in southern Italy. *Small Ruminant Research*, **11**: 305–322.

Fredrickson, E., Thilsted, J., Estell, R. & Havstad, K. (1994). Effects of chronic ingestion of tarbush (*Flourensia cernua*) on ewe lambs. *Veterinary and Human Toxicology*, **36**: 409–415.

Friedel, M.H. (1991) Range condition assessment and the concept of thresholds: a viewpoint. *Journal of Range Management*, **44**: 422–426.

Gallo, M.A. & Doull, J. (1991). History and scope of toxicology. In: Amdur, M.O., Doull, J. & Klassen, C.D. (Eds), *Casarett and Doull's Toxicology* (4th Edn), pp. 3–11. New York: Pergamon Press.

Herbel, C.H. & Gould, W.L. (1995). *Management of mesquite, cerosote and tarbush with herbicides in the northern Chihuahuan Desert.* New Mexico Agricultural Experiment Station Bulletin 775, Las Cruces.

Herbel, C.H. & Nelson, A.B. (1966). Species preference of Hereford and Santa Gertrudis cattle on a southern New Mexico range. *Journal of Range Management*, **19**: 177–181.

Kennedy, G.G. & Barbour, J.D. (1992). Resistance variation in natural and managed systems. In: Fritz, R.S. & Simms, E.L. (Eds), *Plant Resistance to Herbivores and Pathogens Ecology, Evolution and Genetics*, pp. 13–43. Chicago: University of Chicago Press.

King, D.W., Estell, R.E., Fredrickson, E.L., Havstad, K.M., Wallace, J.D. & Murray, L.W. (1996). Effects of tarbush (*Flourensia cernua* DC) ingestion on intake, digesta kinetics, in situ digestion and ruminal fermentation of sheep consuming low quality tobosa grass diets. *Journal of Range Management*, **49**: 325–330.

Langezaal, C.R., Chandra, A., Katsiotis, S.T., Scheffer, J.J.C. & de Haan, A.B. (1990). Analysis of supercritical carbon dioxide extracts from cones and leaves of a *Humulus lupulus* L cultivar. *Elsevier Applied Science*, **53**: 455–463.

Launchbaugh, K.L., Provenza, F.D. & Burritt, E.A. (1993). How herbivores track variable environments: response to variability to phytotoxins. *Journal of Chemical Ecology*, **19**: 1047–1056.

O'laughlin, T.C. (1975). The distribution and productivity of *Flourensia cernua* D.C. (Tarbush) in southern New Mexico. M.Sc. thesis, New Mexico State University, Las Cruces. 74 pp.

Olson, B.E. & Lacey, J.R. (1994). Sheep: a method of controlling rangeland weeds. *Sheep Research Journal*, Special Issue: 105–112.

Paracelsus (Theophrastus ex Hohenheim Eremita) (1567) Von der Besucht. Dillingen.

Phy, T.S. & Provenza, F.D. (1998). Eating barley too frequently or in excess decreases lamb's preference for barely but sodium bicarbonate and Lasalocid attenuate the response. *Journal of Animal Science*, **76**: 1578.

Pollard, J.A. (1992). The importance of deterrence: responses of grazing animals to plant variation. In: Fritz, R.S. & Simms, E.L. (Eds), *Plant Resistance to Herbivores and Pathogens: Ecology, Evolution and Genetics*, pp. 216–239. Chicago: University of Chicago Press.

Pratchett, D., Jones, R.J. & Syrch, F.X. (1991). Use of UDP-degrading rumen bacteria to overcome toxicity in cattle grazing irrigated leucaena pasture. *Tropical Grasslands*, **25**: 268–274.

Provenza, F.D. (1995). Postingestive feedback as an elementary determinant of food preference and intake in ruminants. *Journal of Range Management*, **48**: 2–17.

Provenza, F.D. & Balph, D.F. (1988). Development of dietary choice in livestock on rangelands and its implications for management. *Journal of Animal Science*, **66**: 2356–2368.

Provenza, F.D., Ortega-Reyes, L., Scott, C.B., Lynch, J.J. & Burritt, E.A. (1994). Antiemetic drugs attenuate food aversions in sheep. *Journal of Animal Science*, 72: 1989.

Rhoades, D.F. (1977). The antiherbivore chemistry of Larrea. In: Mabry, T.J., Hunziker, J.H. & DiFeo, D.R. Jr (Eds), *Creosote Bush. Biology and Chemistry in New World Deserts*, pp. 135–175. Stroudsburg, PA: Dowden, Hutchinson & Ross, Inc.

Rao, M.M., Kingston, D.G.I. & Splitter, T.D. (1970). Flavinoids from *Fourensia cernua. Phytochemistry*, **9**: 227–228.

SAS Institute (1989). *SAS/STAT® User's Guide*, Version 6, (4th Edn) Vol. 1. Cary, NC: Statistical Analysis System Institute, Inc. 943 pp.

Schlesinger, W.H., Reynolds, J.F., Cuuningham, G.L., Huenneke, L.F., Jarrell, W.M., Virginia, R.A. & Whitford, W.G. (1990). Biological feedbacks in global desertification. *Science*, **247**: 1043–1048.

Schwartz, C.C. & Ellis, J.E. (1981). Feeding ecology and niche separation in some native and domestic ungulates on the shortage prairie. *Journal of Applied Ecology*, **18**: 343–353.

Sharrow, S.H. (1994). Sheep as a silvicultural management tool in temperate conifer forest. *Sheep Research Journal*, Special Issue: 97–104.

Sherwood, R.D. (1994). Economic and environmental factors affecting the success of rangeland seeding. M.Sc. thesis, Texas Tech University, Lubbock.

Sipes, I.G. & Gandolfi, A.J. (1991). Biotransformation of toxicants. In: Amdur, M.O., Doull, J. & Klassen, C.D. (Eds), *Casarett and Doull's Toxicology* (4th Edn), pp. 88–126. New York: Pergamon Press.

Wilson, T.D. (1993). We seek work where we can: A comparison of patterns of transitional outmigration from a rancho in Jalisco and of internal migration into a Mexicali squatter settlement. *Journal of Borderlands Studies*, **8**: 33–58.