Peter F. Ffolliott
Gerald J. Gottfried
William H. Kruse

Vegetation Management Practices: Past and Present

Abstract: Improving management practices have been at the core of most research conducted in the semidesert grass-shrub vegetation on the Santa Rita Experimental Range. Much of this research has been directed to sustaining forage resources through proper livestock grazing and controlling the invasion of competing woody plants, primarily mesquite. Both research orientations require an understanding of the basic ecological requirements and dynamics of the plant species on the Experimental Range. Cattle grazing system based on seasonal grazing and periodic rest periods have been able to improve the production and diversity of native perennial grasses. Several methods have been successful in controlling the occurrence of mesquite and improving forage production, although there is a growing acknowledgment that mesquite has a place on the landscape. Research emphasis on the Santa Rita Experimental Range in the future is likely to be placed more on evaluating the effectiveness of ecosystem-based, multiple-use vegetation management practices that are ecologically sustainable and environmentally sound.

Keywords: semidesert rangelands, grass-shrub vegetation

Acknowledgments: The authors gratefully acknowledge the reviews of this paper by Warren P. Clary, Project Leader, USDA Forest Service (retired), Boise, ID, and Alejandro Castellanos, Professor, University of Sonora, Hermosillo, Sonora, Mexico.

Introduction

Semidesert grass-shrub vegetation is the characteristic plant cover of the Santa Rita Experimental Range. This vegetation is similar to that occupying extensive acreage in the Southwestern United States, although its actual coverage is difficult to quantify because of the historical and, to some extent, continuing invasion of woody vegetation onto adjacent grasslands. Semidesert grass-shrub vegetation is found between 3,000 and 5,000 ft (900 and 1,500 m) elevation within a strip 50 to 100 miles (80 to 160 km) wide along the southern boundaries of Arizona, New Mexico, and western Texas (Martin 1975). The vegetation below 3,000 ft (900 m) consists mainly of desert shrubs, while the vegetation above 5,000 ft (1,500 m) is chaparral, pinyon-juniper or oak woodlands, or (on occasion) grassland. Vegetation on the Santa Rita Experimental Range is largely a microcosm of that found on semidesert grass-shrub rangelands throughout the Southwestern United States.

Forage components on Southwestern semidesert grass-shrub vegetation have supported a livestock industry in the Southwest since 1850 (Herbel 1979; Martin 1975; McPherson 1997; Sayre 1999), while the small trees have historically been cut by local people for firewood, poles, posts, and corral rails (Conner and others 1990; Ffolliott 1999; Martin 1986,). However, the primary land-use concern on these rangelands is no longer to simply graze livestock or occasionally cut trees for local use. The emphasis in the future will likely be placed more on evaluating the effectiveness of ecosystem-based, multiple-use management practices that are ecologically sustainable and environmentally sound.

A review of past and present vegetation management practices on the Santa Rita Experimental Range and other semidesert grass-shrub rangelands in the Southwestern United States is presented in this paper to show how the management emphasis has changed through time and is likely to continue to change into the future. The literature forming the basis of this review is not intended to be all inclusive, but rather it is representative of the historical knowledge base obtained on the Santa Rita Experimental Range and other Southwestern semidesert grass-shrub rangelands.

Peter F. Ffolliott is Professor, School of Renewable Natural Resources, 325 Biological Sciences East, University of Arizona, Tucson, AZ 85721; e-mail: ffolpete@ag.arizona.edu. Gerald J. Gottfried is Research Forester, Rocky Mountain Research Station, USDA Forest Service, Phoenix, AZ. William H. Kruse is Range Scientist, Rocky Mountain Research Station, USDA Forest Service (retired), Flagstaff, AZ.

In: McClaran, Mitchel P.; Ffolliott, Peter F.; Edminster, Carleton B., tech. coords. Santa Rita Experimental Range: 100 years (1903 to 2003) of accomplishments and contributions; conference proceedings; 2003 October 30–November 1; Tucson, AZ. Proc. RMRS-P-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Vegetation Resources

The diversity of vegetation that is characteristic of semidesert grass-shrub rangelands is also found on the Santa Rita Experimental Range (Humphrey 1953; Humphrey and Mehrhoff 1958; Martin 1966, 1975, 1986a; Medina 1996; Severson and Medina 1981). Herbaceous plants include a variety of perennial grasses, forbs, and succulents. Annual plants spring forth following rainfall events that are favorable to their germination. Woody vegetation on these rangelands is dominated by small trees and medium to large shrubs that are often a detriment to sustaining vigorous stands of forage plants but can have value in themselves.

Herbaceous Vegetation

The composition and relative abundance of perennial grasses on the Santa Rita Experimental Range change with elevation and, therefore, temperature regimes and precipitation amounts. Tall threeawns (*Aristida hamulosa* and *A. ternipes*) are commonly found at all elevations. Santa Rita threeawn (*A. glabrata*) and Rothrock grama (*Bouteloua rothrockii*) are the major species in the middle and lower elevations but are comparatively minor species above 4,000 ft (1,200 m). Other species of grama including black (*B. eriopoda*), side oats (*B. curtipendula*), slender (*B. filiformis*), sprucetop (*B. chondrosioides*), and hairy (*B. hirsuta*) comprise about two-thirds of the perennial grass stands at the upper elevations. However, these latter species are comparatively scarce at the middle and lower elevations. Arizona cottontop (*Trichachne californica*) is a common grass throughout all of the elevations on the Experimental Range. Other species include, but are not limited to, tanglehead (*Heteropogon contortus*), bullgrass (*Muhlenbergia emersleyi*) and bush muhly (*M. porteri*), slim tridens (*Tridens muticus*) and fluffgrass (*T. pulchellus*), and curlymesquite (*Hilaria belangeri*).

Lehmann lovegrass (*Eragrostis lehmanniana*), an aggressive species that was introduced into the Southwestern United States from South Africa in 1913, is the dominant grass on about 40 percent of the Santa Rita Experimental Range. This plant is especially well adapted to the climatic patterns and edaphic conditions of southeastern Arizona (Cable 1971; Cox and Roundy 1986; Elmi 1981; Giner-Mendoza 1986; Martin 1986a; Nascimento 1988). It thrives at elevations where annual rainfall amounts vary from 10 to 15 inches (250 to 380 mm) and on sites with a dominance of sandy to sandy-loam soils (Ruyle and Cox 1985). Factors that have contributed to the spread of Lehmann lovegrass include fire, excessive livestock grazing, and drought conditions.

Among the forbs commonly found on the Santa Rita Experimental Range are alfileria (*Erodium cicutarium*), pink penstemon (*Penstemon parryi*), lupine (*Lupinus* spp.), bladderpod (*Lesquerella gordonii*), and goldpoppy (*Eschscholtzia* spp.). Succulents on the Experimental Range include cholla (*Opuntia fulgida*, *O. spinosior*, and *O. versicolor*) and prickly pear cactus (*O. engelmannii*).

Annual plants become most abundant on sites with light to moderate densities of perennial grasses and where native grasses are able to persist within a cover of Lehmann lovegrass (Medina 1988). Spring annuals dominated largely by a variety of legumes, crucifers, and borages are found in years when the cool-season rainfall is high. The most common summer annual grasses are needle grama (*B. aristidoides*) and six-week threeawn (*A. adscensionis*).

Woody Vegetation

Woody vegetation on the Santa Rita Experimental Range and other semidesert grass-shrub rangelands is dominated by stands of mesquite (*Prosopis velutina*). (While the taxonomy of *Prosopis* undergoes almost constant revision [Burkart 1976; Ffolliott and Thames 1983; Martin 1986b; Hocking 1993], it is not a purpose of this paper to clarify or update the classification on *Prosopis* species.) Mesquite occupies two general types of habitat in the Southwestern region (Conner and others 1990; Martin 1980, 1986b). Tree forms of mesquite tend to grow along riparian (streamside) corridors, while shrub forms typically occupy dry upland sites. Other frequently encountered woody species include acacia (*Acacia greggii* and *A. angustissima*), mimosa (*Mimosa biuncifera* and *M. dysocarpa*), false mesquite (*Calliandra eriophylla*), burroweed (*Haplopappus tenuisectus*), creosote bush (*Larrea tridentata*), and ocotillo (*Fouquieria splendens*). Scattered paloverde (*Cercidium microphyllum*) trees are found along drainages.

More complete listings of the herbaceous and woody plant species on the Santa Rita Experimental Range and other semidesert grass-shrub rangelands of the Southwestern region are found in Little (1962), Martin (1966, 1975), Kearney and Peebles (1969), Eyre (1980), Severson and Medina (1981), and Medina (1996).

Vegetation Site Complexes

Major vegetation site complexes on the Santa Rita Experimental Range are listed in table 1. The *Prosopis-Opuntia-Haplopappus* complex is the most extensive. It is known that changes in vegetative structure have occurred since the Experimental Range was established (Cable 1976; Humphrey and Mehrhoff 1958; Martin 1970, 1975, 1986a; Martin and Turner 1977; Medina 1996). For example, mesquite has invaded nearly 30,000 acres (12,150 ha) of previously shrub-free grassland on the Experimental Range in the past 100 years. However, while the information presented in table 1 represents a "snapshot" of the conditions 30 years ago, it is assumed to reflect the present situation largely because of the curtailment in large-scale mesquite removals.

Management of Herbaceous Vegetation

Depending on the inherent site conditions and prevailing rainfall patterns, annual herbage production (standing biomass) on semidesert grass-shrub rangelands, such as found on the Santa Rita Experimental Range can vary from less than 1,000 to over 1,500 pounds per acre (1,125 to over 1,675 kg per ha). However, the herbage production on a site can be reduced to significantly lesser amounts by overstories of woody plants that compete with the herbage for the often

Table 1—Major vegetation-site complexes on the Santa Rita Experimental Range[a].

Dominant shrubs	Annual rainfall	Elevation	Major grass genera	Major soil groups	Slope
	inches	*feet*			*percent*
None (*Prosopis* has been killed)	15 to 17	4,100 to 4,500	*Bouteloua*, *Aristida*, *Trichachne*	Whitehouse Caralampi Comoro	5 to 15 10 to 40 0 to 10
Prosopis, *Haplopappus*, *Opuntia*	10 to 13	2,900 to 3,500	*Aristida*, *Bouteloua*, *Trichachne*	Anthony Sonoita	0 to 5 1 to 8
	14 to 17	3,500 to 4,200	*Bouteloua*, *Aristida*, *Trichachne*, *Heteropogon*	Comoro Sonoita Whitehouse	0 to 3 1 to 8 10 to 35
Fouquieria, *Calliandra*	12 to 15	3,400 to 3,800	*Bouteloua*, *Aristida*, *Heteropogon*	Whitehouse	5 to 10
Larrea	12	3,100 to 3,300	*Muhlenbergia*, *Tridens*	Anthony	0 to 5
Acacia, *Opuntia*, *Fouquieria*	12 to 14	3,100 to 3,800	*Bouteloua*, *Hilaria*, *Aristida*, *Trindens*	Bernadina Hathaway	2 to 30 2 to 30

[a]Source: Martin and Reynolds (1973).

limiting soil water and essential nutrients. Competitive relationships between herbaceous and woody vegetation are generally characteristics of forest, woodland, and shrubland ecosystems (Bartlett and Betters 1983; Ffolliott and Clary 1982). That is, as one form of vegetation (woody plants) increases in its occurrence, the other form of vegetation (herbage) decreases. Such competitive relationships occur on the Santa Rita Experimental Range and other semidesert grass-shrub rangelands (Cable 1969; Cable and Martin 1964; Kincaid and others 1959; Martin 1963, 1970; Martin and Cable 1962; Parker and Martin 1952; Patten 1978; Reynolds and Tschirley 1963, 1975; Tiedemann and Klemmedson 1971, 1977). Knowledge of these relationships is necessary in estimating the amount of forage that might be available for livestock production on rangelands with woody vegetation.

Proper management of herbaceous (forage) vegetation is a crucial factor for sustaining livestock production on semidesert grass-shrub rangelands, which is often a primary management goal in the Southwestern region. Among the issues that a manager must confront in meeting this goal are selecting the type of livestock that are suitable to the conditions encountered, designating the proper stocking rates for the rangeland, and implementing the livestock grazing systems that will sustain the forage resources at the desired level of production while maintaining a "healthy" rangeland condition. Forage management practices that are often implemented to sustain or, where feasible, increase this limiting resource include the control of competing woody vegetation, elimination of undesirable herbaceous plants, and seeding of selected forage species. Other management activities that can lead to sustaining or enhancing forage resources (but will not be addressed in this paper) are fencing to control livestock movements, constructing stock tanks and developing other water sources, and placing salt or salt-meal blocks at strategic locations to attain better distributions of livestock on the rangeland (Heitschmidt and Stuth 1991; Holechek and others 2001; Jemison and Raish 2000; Stoddart and others 1975; Vallentine 2001).

Sustaining Forage Resources Through Livestock Grazing

Cattle are better suited to graze on semidesert grass-shrub rangelands than sheep or goats because they require less managerial effort (herding) than other kinds of livestock, and they compete less directly with indigenous wildlife for forage resources (Bohning and Martin 1956; Culley 1947; Gamougoun 1987; Herbel 1979; Martin 1966, 1975). Therefore, cattle have been and continue to be the primary type of livestock that graze on the Santa Rita Experimental Range.

A "rule of thumb" for specifying the stocking rate of cattle for a semidesert grass-shrub rangeland to maintain or, where possible, improve the rangeland condition is the number of cattle that will utilize about 40 percent of the perennial grasses produced in an "average" year. This stocking rate varies with the rangeland condition and must be adjusted up or down depending on the trend in rangeland condition. The estimated average yearlong stocking rates for cattle on the Santa Rita Experimental Range are shown in table 2. According to Martin (1975), the stocking rates that are presented in this table also apply to the entire spectrum of semidesert grass-shrub rangelands in the Southwestern region and the rangeland conditions encountered.

Yearlong grazing has historically been the most common grazing system on semidesert grass-shrub rangelands. Unfortunately, this grazing system can result in "excessive" forage consumption in areas where cattle concentrate, and

Table 2—Estimated average yearlong stocking rates of cattle by rangeland condition class for the Santa Rita Experimental Range and other semidesert grass-shrub rangelands in the Southwestern Region[a].

Elevation	Precipitation	Rangeland condition class: Very poor		Poor to fair		Good to excellent	
feet	*inches*	*animals per mi^2*	*acres per animal*	*animals per mi^2*	*acres per animal*	*animals per mi^2*	*acres per animal*
4,000 to 5,000	16+	<12	>50	15 to 18	35 to 45	28 to 25	25 to 35
3,300 to 4,000	12 to 16	<6	>100	6 to 12	50 to 100	12 to 16	40 to 50
<3,300	<12	<4	>160	4 to 6	100 to 160	6 to 10	60 to 100

[a]Source: Reynolds and Martin (1968).

"wasted" forage resources on sites where cattle seldom graze (Cable and Martin 1975; Herbel 1979; Martin 1972, 1975; Martin and Ward 1976; Reynolds 1959). Yearlong grazing can also lead to the inequitable use of forage species among the available forage species, with "favorite species" grazed more closely and more often than those species that are less palatable. Because of these and other drawbacks, the sustainability of the forage resources is difficult to attain on many semidesert, grass-shrub rangelands when yearlong grazing is practiced. As a consequence, several alternatives to yearlong grazing have been proposed, tested, and implemented in attempting to better sustain the forage resources on these rangelands. These alternatives include seasonal (spring) grazing systems, rest-rotational systems, high-intensity short-duration grazing systems, and variations and combinations of these systems.

The so-called "Santa Rita three-pasture" system of cattle grazing has evolved on the Experimental Range. Each unit of the three-pasture system is rested from March through October (spring-summer) in 2 out of 3 years (Martin 1973, 1975, 1978; Martin and Severson 1988; Rivers and Martin 1980). Winter grazing (November to February) takes place between two successive March-to-October rest periods. Trampling by cattle in the winter helps to plant seeds in the soil, and grazing of the older forage allows seedlings of intolerant forage species a better chance of becoming established. The system's grazing schedule provides 12 months of rest immediately before each period of spring-summer grazing and, as a consequence, the system is planned to reduce the intensity of grazing and regrazing of "favorite forage plants" in the spring. The Santa Rita three-pasture system is more flexible in its implementation and management than other grazing systems tested on the Experimental Range because departures from the pre-established livestock grazing schedule are permitted if it becomes necessary to sustain the forage resource. Cattle are normally moved twice (November 1 and March 1), although they can be moved to the next pasture ahead of the scheduled time if the forage resource on the grazed pasture is inadequate. Therefore, a forage shortage tends to speed up the grazing cycle, although the "normal schedule" is resumed as soon as possible thereafter. A forage surplus can allow an extra rest period to be scheduled.

A comprehensive paper on grazing systems and livestock production on the Santa Rita Experimental Range and other semidesert grass-shrub rangelands in the Southwestern United States is found elsewhere in these proceedings.

Control of Competing Woody Vegetation

Several factors have been identified by researchers as being responsible for the invasion of mesquite and other unwanted woody vegetation onto the Santa Rita Experimental Range and other semidesert grass-shrub rangelands in the past 100 years (Fisher and others 1973; Herbel 1979; Martin 1975; McPherson 1997). The consensus of these researchers is that grazing cattle have likely been the most dominant of these factors. Grazing cattle can spread the seeds of these woody plants by consuming them with many seeds, and then passing them through their digestive tract and depositing them on the ground as they graze. Cattle have further contributed to this invasion by "weakening" stands of native grasses by their past overgrazing patterns, which in turn fostered the spread of woody vegetation. Excessive overgrazing practices of the past also contributed to the invasion of woody plants by reducing the buildup of fuels necessary for the occurrence of rangeland fires that helped to control this invasion.

Semidesert grass-shrub rangelands infested with mesquite and other woody plants can often be restored to a comparatively high level of forage productivity if the competing woody overstory is removed. Among the methods that have been tested and, on occasional, operationally implemented for this purpose are controlled burning treatments (Cable 1967; Reynolds and Bohning 1956); applications of herbicides (Cable 1971, 1972b, 1976; Cable and Martin 1975; Cable and Tschirley 1961; Martin 1968; Martin and Cable 1974); hand grubbing, root plowing, cabling or chaining, or other mechanical treatments (Martin 1975; Reynolds and Tschirley 1963); and varying applications of fire, herbicides, and mechanical control methods in combination (Martin 1975; Martin and others 1974; Medina 1996). The environmental concerns of the public and regulations of rangeland management agencies are restricting or, in some case, prohibiting the use of some of these control methods, especially those involving applications of herbicides.

Followup treatments have often been necessary with some of these control methods to sustain the observed increase in production of forage vegetation. For example, the removal of mesquite trees with a power saw with control of post-treatment sprouting by handsawing has recently been attempted with some success (Pease and others 2000).

Elimination of Undesirable Herbaceous Plants

There have been a few "exploratory investigations" of methods that can lead to the elimination of undesirable (noxious) herbaceous plants to favor the establishment and increase the production of "more favored" forage plants. Artificial shade has been shown to favor the development of Arizona cottontop, bush muhly, plains bristlegrass (*Setaria macrostachya*), and other forage species that are adapted to shade (Tiedemann and others 1971). Limited tests have indicated that pre-emergence winter applications of herbicides (dicamba, glyphosate, and picloram) to eliminate undesirable annual plants are largely ineffective. On the other hand, summer herbicidal treatments (atrazine, dicamba, and tebuthiuron) can be effective in eliminating some species of competing annuals (Al-Mashhdany 1978). The removal of competing herbaceous plants by clipping their previous summer's biomass has resulted in increased production of sideoats grama (de Andrade 1979). However, most of the methods that might eliminate undesirable or competing herbaceous plants have not been applied on a large-scale basis because of economic and environmental considerations.

Seeding of Forage Species

Forage production has been improved on the Santa Rita Experimental Range by the seeding of selected forage species, with the seeding of perennial grasses preferred to seeding of other plants in most instances. The results of early, often small-scale investigations of seeding experiments were summarized by Glendening (1937a,b,c, 1939a,b, 1942) and other researchers. Later studies considered the respective roles of site quality, rainfall amount and timing, and other factors that might affect seeding success in more detail (Anderson and others 1957; Medina 1996). Level sites with deep, fertile, medium-textured soils that are able to maintain moisture levels conducive to plant survival have been determined to be the best candidates for seeding. Other research efforts examined the relative successes of alternative seeding methods (Cox and Martin-R 1984; Cox and others 1986), varying site preparation techniques (Slayback and Cable 1970), and applications of fertilizers to alleviate nutrient deficiencies (Holt and Wilson 1961; Martin 1975). It has been generally concluded that successful seeding of forage species requires continual control of the competing vegetation and that cattle grazing be closely controlled or excluded from the seeded rangeland.

A more detailed paper on seeding techniques and their comparative successes and other revegetation practices that have been tested on the Santa Rita Experimental Range to improve forage production is presented elsewhere in these proceedings.

Impacts of Fire

The historical impact of fire on the vegetation of semidesert grass-shrub rangelands is unclear. Early photographs of the Santa Rita Experimental Range show extensive grassland communities free of trees and shrubs that are currently dominated by woody overstories with perennial grasses and other herbaceous plants in the understories. According to researchers, this change has likely come about because of a lack of naturally occurring wildfire to burn freely in the more recent years. Wright (1980, 1990) and others believe that occasional fires in combination with cycles of drought played a significant role in controlling the establishment of small trees and shrubs and, therefore, kept the rangelands as predominately grassland ecosystems. This situation changed with enforcement of the fire suppression policies established by the Southwestern Region's management agencies in the 1900s. The wildfire frequencies of 5 to 10 years that were commonly encountered before 1900 have lengthened to 25 years and longer (Kaib and others 1999; Swetnam and Baisan 1996), with this change attributed largely to the implementation of these fire suppression policies and changes in land-use practices in the region.

Much of the controlled burning that has occurred on the Santa Rita Experimental Range since its establishment had been prescribed to kill or control the woody vegetation that was competing with forage vegetation for the limited soil moisture available for plant growth. Both early-season and late-season burning treatments have been tested for this purpose with varying results. Small trees and shrubs appear to be susceptible to early-season burning. Herbaceous species such as Lehmann lovegrass and Santa Rita threeawn seem to survive early-season burning very well; Arizona cottontop, Rothrock grama, and tanglehead survives intermediately well; and black grama and tall threeawns are easily damaged by fire (Cable 1965, 1967, 1972a; Glendening and Paulsen 1955; Martin, 1975; Reynolds and Bohning 1956; White 1969). Late-season burning has also resulted in the killing of smaller mesquite trees, many other woody plant species, and cacti. Lehmann lovegrass often eventually increases following a late-season fire with most of the other perennial grass species not greatly affected (Humphrey and Everson 1951; Martin 1983; Humphrey 1963, 1969).

The "immediate effects" of prescribed burning treatments on herbaceous (forage) vegetation of semidesert grass-shrub rangelands can be relatively short lived. The postfire status of perennial grasses often lasts 1 or 2 years, while small trees and shrubs might be easily topkilled by burning but come back quickly unless they are also rootkilled by the fire (Cable 1967; Cave and Patten 1984; Martin 1975; McLaughlin and Bowers 1982; Robinett 1994; Robinett and Barker 1996; Rogers and Vint 1987; Ruyle and others 1988; Sumrall and others 1990). Most burning treatments favor plant species that can survive the fire or quickly reproduce themselves from seed or sprouts after the fire. Selective prescribed burning treatments at specified intensities and suitable intervals that are scheduled in combination with other rangeland improvement methods are generally necessary to achieve the desired results (Wright 1980, 1990).

The effects of fire on the vegetation of semidesert grass-shrub rangelands are species specific, season specific, and site specific. Many fire-adapted species, both herbaceous and woody, have achieved dominance on these rangelands because of mechanisms that enable them to survive burning (table 3). However, the traits that might enhance a plant's success for survival in the presence of fire can also enhance the plant's success in the presence of other stressful environmental factors (McPherson 1995). Therefore, caution must be exercised in interpreting the stimulus for these adaptive

Table 3—Mechanism of plants at different life stages that enable them to survive fire[a].

Life stage	General response	Mechanisms
Seeds	Avoidance	Burial
	Resistance	Insulative seed coat; protective tissue around fruit
	Stimulus	Increased germination; mortality of established neighbors
Juveniles	Avoidance	Rapid growth to resistance (protected) size
	Resistance	Aboveground buds protected by insulative plant tissue; belowground buds protected by soil
	Stimulus	Rapid growth of resprouts
Adults	Avoidance	Life cycle shorter than fire-return interval; flowing and fruiting phenology out of phase with fire season; suppression of understory fine fuel production
	Resistance	Thick, platy, corky, fissured bark; aboveground buds protected by insulative plant tissue; belowground buds protected by soil
	Stimulus	Rapid growth of resprouts; fire-obligate flowering; increase flowering (?)

[a]Source: Steuter and McPherson (1995).

traits. Plant species are usually most susceptible to fire damage when they are actively growing and tolerant of fire when they are dormant.

Management of Woody Vegetation

This discussion centers largely on the management (or lack thereof) of mesquite trees and shrubs because of the dominance of this species in the woody overstory on the Santa Rita Experiment Range. Mesquite is a plant of often conflicting values. Mesquite is often associated with nitrogen-fixing *Rhizobia* bacteria, which results in higher nitrogen levels in the soil beneath the tree canopies (Geesing and others 2000; Wilson and others 2001). It has been and continues to be a source of wood, chemicals and, on occasion, feed for ruminants. It also provides shade for people and their livestock on sites where there is little other shade available. But, as already mentioned in this paper, many ranchers view mesquite as a threat to livestock production because of its aggressive spreading onto otherwise productive semidesert grass-shrub rangelands (Glendening 1952; Herbel 1979; Martin 1975, 1986a; McPherson 1997; Parker and Martin 1952; Tschirley 1959). In spite of the efforts made to control this spread, the invasion of mesquite remains a problem of significant proportions on some rangelands. Compounding this problem is the need to also accommodate other benefits of semidesert grass-shrub rangelands in the Southwestern Region, including watershed protection, wildlife habitats, and recreation, in planning for mesquite control or harvesting activities.

Stand, Stocking, and Growth Characteristics

Mesquite trees up to diameters of 12 to 30 inches (30 to 76 cm) and heights of 20 to 50 ft (6 to 15 m) can form nearly pure even- or uneven-aged stands in habitats of favorable soil moisture conditions. Although mesquite is designated a "forest type" by the Society of American Foresters (Martin 1980), per-acre values of stand, stocking, and growth characteristics that are commonly used to characterize a forest or woodland type have little meaning because of the high variability in these characteristics in stands of mesquite trees. Investigators in one study on the Santa Rita Experimental Range reported an average of about 85 mesquite trees per acre (about 200 mesquite per ha), but only about 60 percent of the sample plots in the study were stocked with mesquite trees (DeBano and others 1996).

Most of the volume of mesquite trees is contained in the large and mostly scattered single-stem trees along drainages, with less volume in the smaller mesquite trees and shrubs occupying the upland sites. Growth of mesquite trees is slow, with annual growth rates averaging less than 0.5 percent of the standing volume in most stands (Chojnacky 1991; Ffolliott 1999). Assuming that the dominant woody plants are mesquite trees, and using this species as a "proxy" for all of the trees growing on a site, the annual growth rate of the assemblage of trees found on semidesert grass-shrub rangelands can vary from less than 0.5 to 1.5 ft^3 per acre (0.35 to 1 m^3 per ha). Natural mortality of these trees prior to their decadence is also comparatively low.

Wood Production

The wood of mesquite trees has been historically used for a variety of purposes by people of the Southwest. Many of these uses originated with the American Indian, passed onto the Mexican, and then the American pioneers from the Eastern United States. Exploring the potentials of mesquite trees as a wood source for future uses continue. Mesquite wood inherently has a high calorific value (Ffolliott 1999; Hocking 1993; National Academy of Science 1980), making it a valuable firewood resource. It also makes excellent charcoal. Wood of mesquite is physically strong and durable and, as a consequence, has been and continues to be utilized locally for poles, posts, and corral rails (Ffolliott 1999). Mesquite wood is hard and has a beauty of grain and color that also makes it suitable for processing into furniture, parquet flooring, and miscellaneous novelties.

Efficiently harvesting mesquite trees is one of the main problems that has limited its more widespread use for timber, firewood, and chemical products. The type of harvesting equipment that is available for felling, grappling, and hauling larger trees of more "commercial value" is not always economically or environmentally suitable for harvesting the relatively small and characteristically multi- and crooked-stemmed mesquite trees. Nevertheless, there are a few small wood processing industries in the Southwestern United States that are dependent on harvesting mesquite trees as a primary wood source in their operations.

Management Practices

Management of mesquite trees for sustainable wood production has not been a main focus of the past or present management activities on the Santa Rita Experimental Range or other semidesert grass-shrub rangelands in the Southwestern Region. However, mesquite trees continue to gain attention for crafting woodworking and a product for grilling gourmet food, and, therefore, could represent a valuable resource in the future. As a consequence, there is a need to better "manage" rather than "mine" the mesquite resources in the region. Appropriate management guidelines for this purpose have been generally lacking in the past, although this situation is changing.

More accurate estimates of the volume of mesquite trees that are potentially available for wood products are being obtained (Andrews 1988; Chojnacky 1988; O'Brien 2002) to provide a better basis to prescribe management practices and, where appropriate, harvesting schedules to balance volume removals and growing-stock levels. Whole-stand growth and volume simulation (prediction) models depicting the difference of stand volumes at two selected points in time to estimate growth are also available (Chojnacky 1991). While regeneration and other ingrowth components of mesquite stands are still largely missing in these models, simulations of mesquite growth rates for alternative management practices can be made for selected 10-year planning periods. Culmination of mean (average) annual growth increments of mesquite trees on the Santa Rita Experimental Range suggests a "biological" rotation age of about 45 to 50 years. However, the profits (returns less costs) obtained from harvesting mesquite trees for primary wood products are likely to be maximized earlier.

Silvicultural Prescriptions

Silvicultural prescriptions for mesquite stands are incomplete. But, because of its ability to regrow (sprout) following cutting, silvicultural treatments based on coppicing (which is the regeneration of stump sprouts or root suckers) might be feasible on sites supporting mesquite stands such as those on the Santa Rita Experimental Range. Therefore, the reproduction of mesquite trees based on vegetative strategies could be possible (Ffolliott 1999; Ffolliott and others 1995). Artificial propagation depending on seeding or seedling establishment is more difficult and probably not economically or environmentally feasible for mesquite on most semidesert grass-shrub rangelands.

Felker (1998) recommended that mesquite trees on Southwestern rangelands be managed for the production of high quality wood within a silvopastorial (trees and livestock) agroforestry system that retains a number of selected crop trees within a pasture. A spacing of 30 to 35 ft (10 to 10.5 m) between the crop trees should result in optimal yields (Felker and others 1990).

Impacts of Fire

Fire has played a historical role in determining the status of mesquite trees and shrubs on the Santa Rita Experimental Range and other semidesert grass-shrub rangelands (Blydenstein 1957; Cable 1965; McLaughlin and Bowers 1982; McPherson 1997; Reynolds and Bohning 1956; Rogers and Steele 1980; Womack 2000; Wright and others 1976). The mostly lightning-ignited and often uncontrolled fire of the past helped to slow the invasion of mesquite onto semidesert, grass-shrub rangelands. However, the slowing of mesquite invasion by occurrences of wildfire largely ended with the initiation of aggressive fire suppression policies by management agencies in the early 1900s. Many of these policies remain in effect, although there is increasing interest by managers, ranchers, and other stakeholders in reintroducing fire into Southwestern ecosystems.

Mesquite can also be adapted to fire depending on the fire's intensity. For example, it was found that an illegally set fire (of unknown burning intensity) on the Santa Rita Experimental Range only killed 30 percent of the mature mesquite trees and reduced residual stocking by only 10 percent because over 70 percent of the trees initially damaged by the fire resprouted by 18 months after the fire (DeBano and others 1996).

Prescribed burning treatments that are planned to be low in intensity and limited in extent are rarely successful in effectively controlling the establishment of dense stands of mesquite on semidesert grass-shrub rangelands because of the frequent lack of sufficient fuel loads to carry the fire (Ffolliott 1999; Martin 1973, 1975). Furthermore, a fire that is "hot" enough to kill mesquite is likely to also kill the understory grasses and other forage species.

Other Woody Species

The use of other tree species on the Santa Rita Experimental Range and other semidesert grass-shrub rangelands for wood production has not often been a planned management activity. One occasional exception to this situation has been when the trees have been mechanically uprooted or killed by herbicides in conversion treatments to improve forage production and are then "salvaged" for firewood by local people (Ffolliott and others 1979, 1980).

Vegetation Management for Other Purposes

The vegetation on the Santa Rita Experimental Range and other semidesert grass-shrub rangelands in the Southwestern region has values other than livestock forage or wood production (Ffolliott 1999; Germano and others 1983; Martin 1986b; McPherson 1997). This vegetation furnishes needed food and protective cover for a variety of mammals, avifauna, and herpetofauna. Many of these wildlife species are indigenous to semidesert grass-shrub rangelands, others are transitory, and some are threatened, endangered, or sensitive.

Ethnobotanists are continually locating indigenous plant species that had been used by historic peoples, which are then studied, developed, and when they have proven value, incorporated into "modern" food and fiber products of value to people. Organic agriculture enterprises often develop with these native plants furnishing a basis.

Overland flows of surface runoff, when they occur, are lower in velocity and, therefore, are less erosive when these rangelands have a "good protective cover" of perennial grasses and other herbaceous plants than on rangelands with a sparse vegetative cover. As a result, maintaining a protective cover of vegetation helps to mitigate the losses of soil to the erosive actions of water and wind on sites susceptible to these losses. Therefore, good rangeland management is also good watershed management.

Semi-desert grass-shrub rangelands are important to hunters, hikers, and birdwatchers. They possess unique landscapes of vegetation and topography that appeal to local residents and visitors alike.

Summary

Southwestern semidesert grass-shrub rangeland vegetation has historically supported a livestock industry and been a source of limited wood for a variety of mostly local uses. However, the review of past and present vegetation management practices tested on the Santa Rita Experimental Range and implemented on other semidesert grass-shrub rangelands presented in this paper suggests that the diversity of vegetation on these rangelands has values other than only forage or wood production. This vegetation furnishes food and protective cover for a variety of desert-dwelling wildlife species; provides a protective cover to mitigate the losses of soil resources; and is a valuable backdrop to hikers, campers, and other recreationists. Future management emphasis for this vegetation, therefore, is likely to be placed more on evaluating the effectiveness of ecosystem-based, multiple-use management practices that are ecologically sustainable and environmentally sound. A presentation on the future of the Santa Rita Experimental Range and other semidesert grass-shrub rangelands in the Southwestern United States is found elsewhere in these proceedings.

References

Anderson, D.; Hamilton, L. P.; Reynolds, H. G.; Humphrey, R. R. 1957. Reseeding desert ranges in southern Arizona. Bull. 249. Tucson: University of Arizona, Agricultural Experiment Station. 31 p.

Andrews, S. A. 1988. Volume estimation and multi-purpose management of *Prosopis velutina* in southern Arizona. Tucson: University of Arizona. 67 p. Thesis.

Al-Mashhdany, S. A. 1978. Chemical control of the annual weeds of southern Arizona rangeland. Tucson: University of Arizona. 55 p. Thesis.

Bartlett, E. T.; Betters, D. R., eds. 1983. Overstory-understory relationships in Western forests. West. Reg. Res. Publ. 1. Fort Collins: Colorado State University, Colorado State University Experiment Station. 37 p

Blydenstein, J. 1957. The survival of velvet mesquite (*Prosopis juliflora* var. *velutina*) after fire. Journal of Range Management. 10: 221–223.

Bohning, J. W.; Martin, S. C. 1956. One rancher's experience—in the grassland range of southern Arizona. Journal of Range Management. 9: 258–260.

Burkart, A. 1976. A monograph of the genus *Prosopis* (Mimosoideae). Journal of the Arnold Arboretum. 57: 219–249, 450–525.

Cable, D. R. 1965. Damage to mesquite, Lehmann lovegrass and black grama by a hot June fire. Journal of Range Management. 18: 326–329.

Cable, D. R. 1967. Fire effects on semidesert grasses and shrubs. Journal of Range Management. 20: 170–176.

Cable, D. R. 1969. Competition in the semidesert grass-shrub type as influenced by root systems, growth habits, and soil moisture extraction. Ecology. 50: 28–38.

Cable, D. R. 1971. Lehmann lovegrass on the Santa Rita Experimental Range. Journal of Range Management. 24: 17–21.

Cable, D. R. 1972a. Fire effects in Southwestern semidesert grass-shrub communities. Tall Timbers Fire Ecology Conference. 12: 109–127.

Cable, D. R. 1972b. Fourwing saltbush revegetation trials in southern Arizona. Journal of Range Management. 25: 150–153.

Cable, D. R. 1975. Influence of precipitation on perennial grass production in the semidesert Southwest. Ecology. 56: 981–986.

Cable, D. R. 1976. Twenty years of changes in grass-reduction following mesquite control and reseeding. Journal of Range Management. 29: 286–289.

Cable, D. R.; Martin, S. C. 1964. Forage production and stocking rates on southern Arizona ranges can be improved. Res. Note RM-30. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 11 p.

Cable, D. R.; Martin, S. C. 1975. Vegetation responses to grazing, rainfall, site condition, and mesquite control on semidesert range. Res. Pap. RM-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 24 p.

Cable, D. R.; Tschirley, F. H. 1961. Responses of native and introduced grasses following aerial spraying of velvet mesquite in southern Arizona. Journal of Range Management. 14: 155–159.

Cave, G. H.; Patten, D. T. 1984. Short-term vegetation responses to fire in the upper Sonoran Desert. Journal of Range Management. 37: 491–496.

Chojnacky, D. C. 1988. Juniper, pinyon, oak, and mesquite volume equations for Arizona. Res. Pap. INT-391. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Chojnacky, D. C. 1991. Growth prediction for Arizona's mesquite (*Prosopis velutina*) woodlands. Forest Ecology and Management. 42: 292–310.

Conner, R. C.; Born, J. D.; Green, A. W.; O'Brien, R. A. 1990. Forest resources of Arizona. Resour. Bull. INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 92 p

Cox, J. R.; Martin-R., M. H. 1984. Effects of planting depth and soil texture on the emergence of four lovegrasses. Journal of Range Management. 37: 204–205.

Cox, J. R.; Martin-R., M. H.; Ibarra-F., F. A.; Morton, H. L. 1986. Establishment of range grasses on various seedbeds at creosotebush (*Larrea tridentata*) sites in Arizona, U.S.A., and Chihuahua, Mexico. Journal of Range Management. 39: 540–546.

Cox, J. R.; Roundy, G. B. 1986. Influence of climatic and edaphic factors on the distribution of *Eragrostis lehmanniana* in Arizona, U.S.A. Journal of the Grassland Society of South Africa. 3: 25–29.

Culley, M. 1948. Modern business methods in handling cattle. Arizona Stockman. 14(4): 13, 26–27.

de Andrade, I. F. 1979. Growth response of sideoats grama to seasonal herbage removal and competition from adjacent vegetation. Tucson: University of Arizona. 90 p. Dissertation.

DeBano, L. F.; Gottfried, G. J.; Villanueva-Diaz, J.; Ffolliott, P. F.; Valdez-Zamudio, D. 1996. Initial assessment of fire-damaged mesquite trees following an illegal burn. In: Ffolliott, P. F.; DeBano, L. F.; Baker, M. B., Jr.; Gottfried, G. J.; Solis-Garza, G.; Edminster, C. B.; Neary, D. G.; Allen, L. S.; Hamre, R. H., tech. coords. Effects of fire on Madrean Province ecosystems: a symposium proceedings. Gen. Tech. Rep. RM-GTR-289. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 226–228.

Elmi, A. A. 1981. Phenology, root growth and root carbohydrates of Lehmann lovegrass (*Eragrostis lehmanniana*) in response to grazing. Tucson: University of Arizona. 58 p. Thesis.

Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 148 p.

Felker, P. 1998. The value of mesquite for the rural Southwest: fine lumber and soil improvement. Journal of Forestry. 96(1): 16–20.
Felker, P.; Meyer, J. M.; Gronski, S. J. 1990. Application of self-thinning in mesquite (*Prosopis glandulosa* var. *glandulosa*) to range management and lumber production. Forest Ecology and Management. 31: 225–232.
Ffolliott, P. F. 1999. Mesquite ecosystems in the Southwestern United States. In: Ffolliott, P. F.; Ortega-Rubio, A., eds. Ecology and management of forests, woodlands, and shrublands in the dryland regions of the United States and Mexico. La Paz, Mexico: University of Arizona, Centro de Investigaciones Biologicas del Noroeste, U.S. Department of Agriculture, Forest Service: 95–106.
Ffolliott, P. F.; Clary, W. P. 1982. Understory-overstory vegetation relationships: an annotated bibliography. Gen. Tech. Rep. INT-136. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 39 p.
Ffolliott, P. F.; Thames, J. L. 1983. Handbook on the taxonomy of *Prosopis* in Mexico, Peru, and Chile. Rome, Italy: Food and Agriculture Organization (FAO) of the United Nations. 45 p.
Ffolliott, P. F.; Rasmussen, W. O.; Patterson, J. G. 1980. Biomass energy: potentials in Arizona. Biosources Digest. 2: 240–247.
Ffolliott, P. F.; Brooks, K. N.; Gregersen, H. M.; Lundgren, A. L. 1995. Dryland forestry: planning and management. New York: John Wiley & Sons, Inc. 453 p.
Ffolliott, P. F.; Rasmussen, W. O.; Warfield, T. K.; Borland, D. S. 1979. Supply, demand, and economics of fuelwood markets in selected population centers of Arizona. Arizona Land Marks. 9: 1–74.
Fisher, C. E.; Hoffman, G. O.; Scrifres, C. J. 1973. The mesquite problem. In: Mesquite growth and development, management, economics, and use. Res. Monog. 1. College Station: Texas A&M University, Texas Agricultural Experiment Station: 5–9.
Gamougoun, N. D. 1987. Cattle grazing behavior and range plant dynamics in southern Arizona. Tucson: University of Arizona. 235 p. Thesis.
Geesing, D.; Felker, P.; Bingham, R. L. 2000. Influence of mesquite (*Prosopis glandulosa*) on soil nitrogen and carbon development: implications for global carbon sequestration. Journal of Arid Environments. 36: 157–180.
Germano, D. J.; Hungerford, R.; Martin, S. C. 1983. Responses of selected wildlife species to the removal of mesquite from desert grasslands. Journal of Range Management. 36: 309-311.
Giner-Mendoza, M. 1986. Effect of clipping on photosynthesis, respiration and production of *Eragrostis lehmanniana* Ness and *Digitaria californica* (Benth.) Henr. Tucson: University of Arizona. 54 p. Thesis.
Glendening, G. E. 1937a. A method of revegetating small key plots on eroded areas. Res. Note 8. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Forest and Range Experiment Station. 2 p.
Glendening, G. E. 1937b. Litter aids germination of grass seeds and establishment of seedlings. Res. Note 7. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Forest and Range Experiment Station. 2 p.
Glendening, G. E. 1937c. Reseeding on denuded “adobe flats.” Res. Note 19. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Forest and Range Experiment Station. 2 p.
Glendening, G. E. 1939a. Comparison of the effects of various kinds of artificial litter upon the germination of grass seeds. Res. Note 61. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Forest and Range Experiment Station. 2 p.
Glendening, G. E. 1939b. How to establish black grama on depleted semidesert ranges. Res. Note 52. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Forest and Range Experiment Station. 4 p.
Glendening, G. E. 1942. Germination and emergence of some native grasses in relation to litter cover and soil moisture. Journal of the American Society of Agronomy. 34: 794–804.
Glendening, G. E. 1952. Some quantitative data on the increase of mesquite and cactus on a desert grassland range in southern Arizona. Ecology. 33: 319–328.
Glendening, G. E.; Paulsen, H. A., Jr. 1955. Reproduction and establishment of velvet mesquite as related to invasion of semi-desert grasslands. Tech. Bull. 1127. Washington, DC: U.S. Department of Agriculture. 50 p.
Heitschmidt, R. K.; Stuth, J. W. 1991. Grazing management: an ecological perspective. Portland, OR: Timber Press. 259 p.
Herbel, C. H. 1979. Utilization of grass- and shrublands of the south-western United States. In: Walker, B. H., ed. Management of semi-arid ecosystems. Amsterdam, The Netherlands: Elsevier Scientific Publishing Company: 161–203.
Hocking, D. 1993. Trees for drylands. New York: International Science Publishers. 370 p.
Holechek, J.; Pieper, R. D.; Herbel, C. H. 2001. Range management: principles and practices. Upper Saddle River, NJ: Prentice Hall. 587 p.
Holt, G. A.; Wilson, D. G. 1961. The effect of commercial fertilizers on forage production and utilization on a desert grassland site. Journal of Range Management. 14: 252–256.
Humphrey, R. R. 1953. The desert grassland, past and present. Journal of Range Management. 6: 159–164.
Humphrey, R. R. 1963. The role of fire in the desert grasslands of Arizona. Tall Timbers Fire Ecology Conference. 2: 45–62.
Humphrey, R. R. 1969. The past role of fire in range management in the Southwest and some future possibilities. In: Wagle, R. F., ed. Fire ecology and control and use of fire in wildland management: proceedings of a symposium. Tucson: Arizona Academy of Science, Society of American Foresters, Southwestern Interagency Fire Committee: 52–56.
Humphrey, R. R.; Everson, A. C. 1951. Effect of fire on mixed grass-shrub range in southern Arizona. Journal of Range Management. 4: 264–266.
Humphrey, R. R.; Mehrhoff. 1958. Vegetation changes on a southern Arizona grassland. Ecology. 39: 720–726.
Jemison, R.; Raish, C., eds. 2000. Livestock management in the American Southwest: ecology, society, and economics. Amsterdam, The Netherlands: Elsevier. 597 p.
Kaib, M.; Swetnam, T. W.; Baisan, C. H. 1999. Fire history in canyon pine-oak forests, intervening desert grasslands, and higher-elevation mixed conifer forests of the Southwest Borderlands. In: Gottfried, G. J.; Eskew, L. G.; Curtin, C. G.; Edminster, C. B., comps. Toward integrated research, land management, and ecosystem protection in the Malpai Borderlands: conference summary. Proc. RMRS-P-10. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 57–64.
Kearney, T. H.; Peebles, R. H. 1969. Arizona flora. Berkeley: University of California Press. 1,085 p.
Kincaid, D. R.; Holt, G. A.; Dalton, P. D.; Tixier, J. S. 1959. The spread of Lehmann lovegrass as affected by mesquite and native grasses. Ecology. 40: 738–742.
Little, E. L., Jr. 1962. Southwestern trees: a guide to the native species of New Mexico and Arizona. Agric. Handb. 9. Washington, DC: U.S. Department of Agriculture, Forest Service. 109 p.
Martin, S. C. 1963. Grow more grass by controlling mesquite. Progressive Agriculture in Arizona. 15(4): 15–16.
Martin, S. C. 1966. The Santa Rita Experimental Range. Res. Pap. RM-22. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 24 p.
Martin, S. C. 1968. Improving semidesert ranges in southern Arizona, USA, by grazing management and shrub control. Annals of Arid Zone. 7: 235–242.
Martin, S. C. 1970. Vegetation changes on semidesert range during 10 years of summer, winter, and year-long grazing by cattle. Eleventh International Grassland Congress Proceedings: 23–26.
Martin, S. C. 1972. Some effects of continuous grazing on forage production. Arizona Cattelog. 28(10): 17–18, 23–25.
Martin, S. C. 1973. A grazing system for semidesert ranges based on responses to seasonal rest. In: Abstracts of papers: 26th annual meeting of the Society for Range Management. Denver, CO: Society for Range Management: 21.
Martin, S. C. 1975. Ecology and management of Southwestern semidesert grass-shrub ranges: the status of our knowledge. Res. Pap. RM-156. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 38 p.
Martin, S. C. 1978. The Santa Rita grazing system. In: Nyder, D., ed. Proceedings of the First International Rangeland Congress. Denver, CO: Society for Range Management: 573–575.
Martin, S. C. 1980. Mesquite. In: Eyre, F. H., ed. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters: 118.

Martin, S. C. 1983. Response to semidesert grasses and shrubs to fall burning. Journal of Range Management. 36: 504–610.
Martin, S. C. 1986a. Eighty years of vegetation changes on a semidesert range in southern Arizona, U.S.A., and evaluation of causes. In: Ross, P. J.; Lynch, P. W.; Williams, O. B., eds. Rangelands: a resource under siege. Proceedings of the Second International Rangeland Congress, Canberra, Australia: Cambridge University Press: 53.
Martin, S. C. 1986b. Values and uses for mesquite. In: Patton, D. R.; Gonzales V., C. E.; Medina, A. L.; Segura T., L. A.; Hamre, R. H., tech. coords. Management and utilization of arid and semi-arid plants: symposium proceedings. Gen. Tech. Rep. RM-135. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 91–96.
Martin, S. C.; Cable, D. R. 1962. Grass production high 14 years after mesquite control. Arizona Cattlelog. 18(12): 48–61.
Martin, S. C.; Cable, D. R. 1974. Managing semidesert grass-shrub ranges: vegetation responses to precipitation, grazing, soil texture, and mesquite control. Tech. Bull. 1480. Washington, DC: U.S. Department of Agriculture. 45 p.
Martin, S. C.; Reynolds, H. G. 1973. The Santa Rita Experimental Range: your facility for research on semidesert ecosystems. Journal of the Arizona Academy of Science. 8: 56–67.
Martin, S. C.; Severson, K. E. 1988. Vegetation response to the Santa Rita grazing system. Journal of Range Management. 41: 291–295.
Martin, S. C.; Turner, R. M. 1977. Vegetation changes in the Sonoran Desert region, Arizona and Sonora. Journal of the Arizona Academy of Science. 12: 59–69.
Martin, S. C.; Ward, D. E. 1976. Perennial grasses respond inconsistently to alternate year seasonal rest. Journal of Range Management. 29: 346.
Martin, S. C.; Thames, J. L.; Fish, E. B. 1974. Changes in cactus numbers and herbage production after chaining and mesquite control. Progressive Agriculture in Arizona. 26(6): 3–6.
McLaughlin, S. P.; Bowers, J. E. 1982. Effects of wildfire on a Sonoran desert plant community. Ecology. 63: 246–248.
McPherson, G. R. 1995. The role of fire in desert grasslands. In: McClaran, M. P.; Van Devender, T. R., ed. The desert grassland. Tucson: University of Arizona Press: 130–151.
McPherson, G. R. 1997. Ecology and management of North American savannas. Tucson: University of Arizona Press. 208 p.
Medina, A. L. 1988. Diets of scaled quail in southern Arizona. Journal of Wildlife Management. 52: 753–757.
Medina, A. L. 1996. The Santa Rita Experimental Range: history and annotated bibliography (1903–1988). Gen. Tech. Rep. RM-GTR-276. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 67 p.
Nascimento, H. T. S. 1988. Pattern of utilization and response of Lehmann lovegrass (*Eragrostis lehmanniana* Nees) grazed by cattle. Tucson: University of Arizona. 195 p. Dissertation.
National Academy of Science. 1980. Firewood crops: shrub and tree species for energy production. Washington, DC: National Academy of Science. 237 p.
O'Brien, R. A. 2002. Arizona's forest resources, 1999. Resour. Bull. RMRS-RB-2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 116 p.
Parker, K. W.; Martin, S. C. 1952. The mesquite problem on southern Arizona ranges. Circ. 98. Washington, DC: U.S. Department of Agriculture. 70 p.
Patten, D. T. 1978. Productivity and production efficiency of an upper Sonoran Desert ephemeral community. American Journal of Botany. 65: 891–895.
Pease, S.; Ffolliott, P. F.; DeBano, L. F.; Gottfried, G. J. 2000. Effects of mesquite control and mulching treatments on herbage production on semiarid shrub-grasslands. In: Ffolliott, P. F.; Baker, M. B., Jr.; Edminster, C. B.; Dillion, M. C.; Mora, K. L., tech. coords. Land stewardship in the 21st century: the contributions of watershed management. Proc. P-RMRS-13. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 265–267.
Reynolds, H. G. 1959. Managing grass-shrub cattle ranges in the Southwest. Agric. Handb. 162. Washington, DC: U.S. Department of Agriculture. 40 p.
Reynolds, H. G.; Bohning, J. W. 1956. Effects of burning on desert grass-shrub range in southern Arizona. Ecology. 37: 769–777.
Reynolds, H. G.; Martin, S. C. 1968. Managing grass-shrub cattle ranges in the Southwest. Handb. 163. Washington, DC: U.S. Department of Agriculture. 44 p.
Reynolds, H. G.; Tschirley, F. H. 1963. Mesquite control in the Southwest. Leaflet 421. Washington, DC: U.S. Department of Agriculture. 8 p.
Rivers, W. J.; Martin, S. C. 1980. Perennial grass improves with moderate stocking. Rangelands. 2: 105–106.
Robinett, D. 1994. Fire effects on southeastern Arizona plains grasslands. Rangelands. 16: 143–148.
Robinett, D.; Barker, S. 1996. Fire effects on Sonoran grasslands. In: Ffolliott, P. F.; DeBano, L. F.; Baker, M. B., Jr.; Gottfried, G. J.; Solis-Garza, G.; Edminster, C. B.; Neary, D. G.; Allen, L. S.; Hamre, R. H., tech. coords. Effect of fire on Madrean Province ecosystems: a symposium proceedings. Gen. Tech. Rep. RM-GTR-289. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 64–68
Rogers, G. F.; Steele, J. 1980. Sonoran Desert fire ecology. In: Stokes, M. A.; Dieterich, J. H., tech. coords. Fire ecology workshop: proceedings of a technical conference. Gen. Tech. Rep. RM-81. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 15–18.
Rogers, G. F.; Vint, M. K. 1987. Winter precipitation and fire in the Sonoran Desert. Journal of Arid Environments. 13: 47–52.
Ruyle, G. B.; Cox, J. 1985. Lehmann lovegrass—a naturalized citizen. Arizona Farmer Stockman. 51(4): 26.
Ruyle, G. B.; Roundy, B. A.; Cox, J. R. 1988. Effects of burning on germinability of Lehmann lovegrass. Journal of Range Management. 41: 404–406.
Sayre, N. 1999. The cattle boom in southern Arizona: towards a critical political ecology. Journal of the Southwest. 41: 239–271.
Severson, K. E.; Medina, A. L. 1981. The Santa Rita Experimental Range. In: Patton, D. P.; de la Puente-E., J. M.; Ffolliott, P. F.; Gallina, S.; Bartlett, E. T., tech. coords. Wildlife and range research needs in Northern Mexico and Southwestern United States. Gen. Tech. Rep. WO-36. Washington, DC: U.S. Department of Agriculture, Forest Service: 56-59.
Slayback, R. D.; Cable, D. R. 1970. Larger pits aid reseeding of semidesert rangeland. Journal of Range Management. 23: 333–335.
Steuter, A. A.; McPherson, G. R. 1995. Fire as a physical stress. In: Bedunah, D. J.; Sosebee, eds. Physiological ecology and developmental morphology. Denver, CO: Society for Range Management: 550–579.
Stoddart, L. A.; Smith, A. D.; Box, T. W. 1975. Range management. New York: McGraw-Hill Book Company. 532 p.
Sumrall, L. F.; Roundy, B. A.; Cox, J. R.; Winkel, V. K. 1990. Seedbed ecology of Lehmann lovegrass in relation to fire. In: Krammes, J. S., tech. coord. Effects of fire management of Southwestern natural resources. Gen. Tech. Rep. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 186–189.
Swetnam, T. W.; Baisan, C. H. 1996. Historical fire regime patterns in the Southwestern United States since AD 1700. In: Allen, C. D., tech. coords. Fire effects in Southwestern forests: proceedings of the 2nd La Mesa fire symposium. Gen. Tech. Rep. RM-GTR-286. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 11–32.
Tiedemann, A. R.; Klemmedson, J. O. 1971. Effect of mesquite (*Prosopis juliflora*) trees on vegetation and soils in the desert grassland. In: Abstracts: 24th annual meeting. Reno, NV: Society for Range Management: 15–16.
Tiedemann, A. R.; Klemmedson, J. O. 1977. Effect of mesquite trees on vegetation and soils in the desert grassland. Journal of Range Management. 30: 361–367.
Tiedemann, A. R.; Klemmedson, J. O.; Ogden, P. R. 1971. Response of four perennial Southwestern grasses to shade. Journal of Range Management. 24: 442–447.
Tschirley, F. H. 1959. Effect of mesquite on range productivity. In: Your range—its management. Spec. Rep. 2. Tucson: Arizona Agricultural Experiment Station, University of Arizona: 17.

Vallentine, J. F. 2001. Grazing management. San Diego, CA: Academic Press. 659 p.

White, L. D. 1969. Effects of a wildfire on several desert grassland shrub species. Journal of Range Management. 22: 284–285.

Wilson, T. B.; Webb, R. H.; Thompson, T. L. 2001. Mechanisms of range expansion and removal of mesquite in desert grasslands of the Southwestern United States. Gen. Tech. Rep. RMRS-GTR-81. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 23 p.

Womack, J. D. 2000. Mortality and sprouting vigor of burned and cut velvet mesquite *(Prosopis velutina* Wooten): the role of basal diameter and number of stems. Tucson: University of Arizona. 61 p. Thesis.

Wright, H. A. 1980. The role and use of fire in the semidesert grass-shrub type. Gen. Tech. Rep. INT-85. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 23 p.

Wright, H. A. 1990. Role of fire in the management of Southwestern ecosystems. In: Krammes, J. S., tech. coord. Effects of fire management of Southwestern natural resources. Gen. Tech. Rep. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 1–5.

Wright, H. A.; Bunting, S. C.; Neuenschwander, L. F. 1976. Effect of fire on honey mesquite. Journal of Range Management. 29: 467–471.