B-1567
August 1987

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THE TEXAS AGRICULTURAL EXPERIMENT STATION/Neville P. Clarke, Director/The Texas A&M University System/College Station, Texas

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Improvement of Oak-Dominated Rangeland with Tebuthiuron and Prescribed Burning

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Summary

Excessive cover of post oak, blackjack oak, and associated woody species limit cattle production on about 4.5 million hectares in the eastern third of Texas. Aerial applications of tebuthiuron pellets at 2.2 or 4.4 kg/ha (active ingredient) control the oaks and several species of understory shrubs, and grass production may increase significantly within a growing season after tebuthiuron application. However, tebuthiuron-tolerant species, especially vines such as saw greenbrier, southern dewberry and peppervine, increase in abundance following control of the overstory trees and associated shrubs with tebuthiuron. In addition, the understory shrub American beautyberry may increase dramatically on sites after aerial application of tebuthiuron. The increase in tebuthiuron-tolerant vines, the spread of American beautyberry, and the invasion of other woody species may negate grass production within 3 years after release by herbicide treatment. Prescribed burning as headfires in late winter within two growing seasons after tebuthiuron application, and at regular intervals thereafter, suppresses the development of secondary woody plant stands. Prescribed burning has little effect on infiltration rates, sediment production, or nutrient loss in runoff on near level sandy loam sites. Forage production and cattle weight gains may not be increased until the growing season following tebuthiuron application, especially after treatment of heavy brush stands. Follow-up burns should extend animal performance into the fall when available nutrients are typically less than required for maintenance of growing and lactating cattle. Apparently, control of the forbs and browse in heavy brush canopies without increased production of grasses accounts for reduced cattle performance during the first growing season after tebuthiuron application. Tebuthiuron can be applied in strips or other suitable patterns to prevent negative alterations in habitat for white-tailed deer and sustain nutrient intake of cattle. Treated strips probably should be no wider than 325 meters (m) and alternate with untreated strips at least 80 m wide. Populations of small rodents, such as cotton rats and wood rats, are cyclic following tebuthiuron application in response to shifts in vegetal cover.

The Problem

The Texas Post Oak[1] Savanna, a land resource of about 3.2 million hectares[2] (ha), was originally open grassland dotted with stately, individual oak trees or with small scattered clusters of oaks (Gould 1975). Potential vegetation of these highly productive grasslands includes mid- and tall grasses such as little bluestem, indiangrass, Texas wintergrass, and purpletop. Species of *Chasmanthium* and low-growing *Panicums* occur in the heavily wooded areas, especially along the drainages and waterways. Heavy cover of post oak and blackjack oak in association with various other trees and shrubs also occurs on the Coastal Prairie and Cross Timbers regions, limiting production of livestock on about 4.5 million ha in the eastern third of Texas (Scifres and Haas 1974).

Restriction of naturally-occurring fires in conjunction with overgrazing by livestock, often continuous for prolonged periods, and periodic droughts of various durations are largely responsible for creation of dense thickets over much of the Post Oak Savanna (Scifres 1980). The densities of post and blackjack oaks have increased and the woody stands are further thickened by establishment of yaupon, winged elm, honeylocust, common persimmon, downy hawthorn, gum bumelia, tree huckleberry, eastern redcedar, buckbrush, willow baccharis, American beautyberry, Texas persimmon, and various other trees and shrubs. Vines, especially saw greenbrier, peppervine, and southern dewberry, grow with the shrubs to form impenetrable thickets on some sites. Dense woody cover has reduced the carrying capacity for cattle to 1 animal unit (AU)[3] per 14 to 16 ha (35 to 40 acres) on land that, in good range condition, could support 1 AU per 4 to 5 ha (10 to 12 acres). Invading grasses include red lovegrass, broomsedge bluestem, splitbeard bluestem, and smutgrass. Common broadleaf species include bullnettle, yankeeweed, and western ragweed.

Mechanical clearing of the brush (dozing, raking, stacking, and burning the stacks) and establishment of tame pastures with common bermudagrass, bahiagrass, or dallisgrass is commonly practiced in the region. Methods for conversion of the woodlands to native grasslands have included dozing, chaining, and application of herbicides. Prior to the early 1970's, the primary herbicide treatment was aerial application of 0.8 to 1.1 kilograms per hectare (kg/ha) of 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid] for two or three consecutive growing seasons (Darrow and McCully 1959).

The first herbicide application effectively removed the oak overstory. The second and third treatments were applied to control the understory shrubs. The application of a mixture containing equal parts of picloram (4-amino-3,5,6-trichloropicolinic acid) and 2,4,5-T at 1.1 kg/ha total herbicide was more effective than 2,4,5-T applied alone (Scifres and Haas 1974), but the proximity of herbicide susceptible crops and public concern about use of 2,4,5-T restricted spraying over much of the Post Oak Savanna. Further, cessation of production of 2,4,5-T for domestic use in 1984 necessitated development of alternative practices for improvement of range vegetation in the region.

Tebuthiuron N-[5-1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N-N-dimethylurea] was registered in 1979 by the Environmental Protection Agency for control of brush species including oaks on rangeland. It is formulated as an extruded pellet containing 20 percent active ingredient (ai). Tebuthiuron is readily absorbed by plant roots (Steinert and Stritzke 1977) and translocated to the foliage where it inhibits photosynthesis. Many species of oaks, including post oak and blackjack oak, are susceptible to the herbicide applied broadcast (Scifres et al. 1981a), in grids (Stritzke 1976), or subsurface in rows (Meyer et al. 1978).

Since tebuthiuron was introduced as a potential herbicide for brush management on rangeland, considerable research has been conducted to define appropriate dosages for brush control, forage and livestock responses to its application, and other factors affecting tebuthiuron use. This publication collates the available literature on tebuthiuron use for improvement of rangeland dominated by oak-mixed hardwoods and reports the results of long-term experiments with the herbicide in light of other research data.

Experiments were established on the Native Plant and Animal Conservancy, Texas A&M University campus, in 1977 and 1978 to (1) evaluate vegetation and cattle responses to tebuthiuron application and (2) provide a basis for designing long-term brush management systems for the Post Oak Savanna, giving due attention to wildlife. Preliminary data from these experiments have been reported (Scifres et al. 1981a, 1981b; Kirby and Stuth 1981). Additional data collected from 1981 through 1984 and general observations through 1986 are presented in light of the initial findings.

[1] Scientific names of plants and animals mentioned in text are given in Appendix A.

[2] Conversions of metric to English units are given in Appendix B.

[3] Animal unit (AU) is defined as 454 kg (1,000 lb) cow with calf or equivalent.

Materials and Methods

Study Site Description and Treatment Installation

Tebuthiuron pellets (20 percent active ingredient [ai]) were aerially applied at 2.2 kg/ha to two pastures of approximately 2 ha each on May 9, 1977. Woody plants were dozed into stacks in a second pair of pastures during May and June 1977. The mechanically-cleared pastures were shredded in June 1982. Pastures were randomly selected for treatment from among six, leaving two pastures untreated, so that the experiment was arranged as a randomized complete block with two replications.

Woody canopy cover at initiation of the research was composed of an overstory of post and blackjack oaks. The understory included yaupon, winged elm, gum bumelia, buckbrush, water oak, willow baccharis, downy hawthorn, saw greenbrier, American beautyberry, honey locust, common persimmon, cedar elm, Texas persimmon, and southern dewberry with occasional honey mesquite and eastern redcedar. The replicates were stratified to account for differences in topography with one on nearly level terrain and the other with slope varying from 2 to 7 percent. Soils, primarily sandy loam to fine sandy loam of the Lufkin-Axtell-Tabor series (Udertic Paleustalfs), contained 49 percent sand, 13 percent clay, and 1.3 percent organic matter with a pH of 5.5 to 5.6 in the surface 15 cm (Scifres et al. 1981a). Clay content increased with depth to 35 percent at 60 cm and sand content decreased to 28 percent.

In late February 1979, 1981, and 1984, the pastures treated with tebuthiuron in 1977 were burned with headfires. The mechanically-treated pastures were burned in the winter 1984. Immediately prior to burning, standing fine fuel was harvested and mulch collected from twenty-five to fifty 0.25-m^2 plots, equidistantly spaced down the center of each pasture. At the same time, 10 to 25 fine fuel samples and soil samples to 8 cm deep were collected for determination of water content. Soil and fuel samples were weighed wet, then oven-dried at 60 degrees centigrade (°C), and reweighed. Environmental variables monitored during the burns included air temperature, instantaneous wind speeds with a hand-held anemometer, and relative humidity with a psychrometer. Maximum fire temperatures were recorded at 10 to 25 selected points in 1979 and 1981 with heat-sensitive tablets and at 15 points with continuously recording thermocouples in 1984.

Tebuthiuron pellets (20 percent ai) were applied at 0, 2.2, or 4.4 kg/ha in a second experiment to duplicate, 3.2-ha plots on April 7, 1978. The study site was less than 5 kilometers (km) from the first, and the woody canopy cover averaged 60 percent. Species present were the same as for the experiment established in 1977 except that eastern redcedar commonly occurred in the woody plant stands and honey mesquite was rare. Topography was rolling with slope varying from 2 to 5 percent. Soils were primarily sandy loams of the Axtell-Tabor series with textural characteristics similar to those described for the 1977 study site.

The pastures treated in 1978 were subdivided into equal parts during the summer 1980. Prescribed burns were installed as headfires in February 1981 and 1984 to two of the four pastures receiving each of the treatments. Variables were monitored as described for burns applied to the 1977 study area.

Vegetation Evaluation

Changes in canopy cover, density, and frequency of live woody plants were evaluated in the fall using the point-centered-quarter method (Cottam and Curtis 1956) from 1977 through 1984. The distance to the nearest woody plant in each quadrant and reduction in its canopy were recorded at 25 to 50 points equally spaced down the center of each plot. In addition, canopy reduction of woody plants occurring in a 20-meter (m)-wide belt down the center of each plot was estimated by two workers. Canopy intercepts of 1-m-tall and shorter shrubs were recorded along ten 33-m lines in June 1984.

Distance to the nearest American beautyberry plant, its height, and number of basal stems were recorded at 200 points equidistantly spaced down the center of each pasture in May-June 1983. The nearest overstory species within 2 m of the American beautyberry plant was also recorded. Mean values for canopy cover, stems/ha, and height of American beautyberry plants from treated areas were compared to those on untreated pastures, using least significant difference (LSD) ($P \leq 0.05$).

Within 30 days after application of tebuthiuron on each experiment, 20 to 25 circular grazing exclosures (1.3 m in diameter and 2 m tall) were equally spaced along a line down the center of each pasture. Standing herbaceous crops were harvested to a 2.5-cm stubble height in a 0.25 m^2 area from the center of each exclosure. The exclosures were then relocated 1 m away from the original points based on random selection of a cardinal direction. Standing crops were separated into grasses and forbs, dried at 60 °C for at least 48 hours and weighed. Data collected through the 1980 growing season are reported by Scifres et al. (1981a, 1981b). Subsequent evaluation dates for the area treated in 1977 were July 17 and November 26, 1981; July 15, August 30 and December 20, 1982; and November 20, 1983. Pastures treated in 1978 were evaluated on May 18 and November 8, 1981; May 31, August 30, and December 7, 1982; May 16 and November 3, 1983; and May 2, 1984. Standing crop data were subjected to analysis of variance and means were separated by Student-Newman-Keul's procedure ($P \leq 0.05$) (Steel and Torrie 1960).

Each time standing crop was harvested, basal cover of herbaceous species was recorded from fifty, inclined, 10-point-frame samples spaced equidistantly down the center of each pasture. Species cover was expressed as proportions represented by grazing value categories (good-to-excellent, fair, or poor) based on published assessments (Gould and Box 1965, Hoffman et al. 1970). Within each year of evaluation, cover values for little bluestem and brownseed paspalum were summed for the experiment initiated in 1978. The proportion of the sum represented by little bluestem was transformed ($\sqrt{X+0.5}$), and means of burned and unburned pastures not treated with tebuthiuron were contrasted using a t-test. The same comparisons were developed for burned and unburned pastures which had been treated with tebuthiuron.

Analysis of Wildlife Habitat Features

Changes in woody canopy and herbaceous productivity offer insights about the influence of manipulation of the brush stands on food and cover for wildlife. Senzota (1985) evaluated variation in habitat attributes and the influence on small mammals on the study site. In addition, differences in screening cover in September 1985 among pastures treated in 1978 were evaluated for this study. Screen closure was determined with a 2-m-tall, 15-cm-wide board with alternating black and white, 50-cm segments. Distance required to obscure 100 percent of the board was measured in two opposite directions from 50 equidistantly-spaced points down the center of each pasture. Data were subjected to analysis of variance and means separated by Student-Newman-Keul's test ($P \leq 0.05$).

Analysis of Cattle Diets and Performance

A simulated high-intensity, low frequency grazing scheme (7-pasture,1-herd, 20 to 21 days graze, 130 to 180 days rest) was implemented for all experiments. Pastures were grazed by eight, preconditioned steers weighing approximately 200 kg in 1977 and 1978. However, following burning in 1981 and 1984, 350 to 400 kg cows were used.

Grazing studies on pastures treated in 1977 and 1978 were initiated in the fall following herbicide application in the spring. Grazing was terminated in each trial when 50 percent utilization was observed on the key management species, which were brownseed paspalum the year of treatment and little bluestem in subsequent years.

Grazing was initiated during spring following the late winter burns in 1981 and 1984. Utilization did not exceed 50 percent in the 1981 study. A "complete graze-out" of herbaceous forage was enforced for purposes of the 1984 study.

Animal performance data were obtained by weighing new groups of steers before and after each season of each experiment. Data were expressed as average daily gains (ADG) (kg/steer/day), total daily gains (TDG) (kg/ha/day), and days of available grazing. Days of grazing is defined as the number of days a pasture supplied herbage for a given number of steers based on proper forage use, expressed herein as steer days/ha. Animal performance data were not collected in 1981 or 1984.

Four esophageally fistulated cows or steers were utilized in grazing trials during 1977, 1978, 1981, and 1984 to collect extrusa for botanical and nutritional analyses. Dietary samples were mixed, dried at 60 °C for 48 hours, and two subsamples removed. One subsample was ground to pass a 1-mm screen and subjected to crude protein (CP) analysis (AOAC 1970) and *in vitro* digestible organic matter (IVDOM) analyses (Tilley and Terry 1963, Van Soest and Wine 1967). The other subsample was subjected to macrofragment analysis to determine composition of diets selected by the animals (Lopes and Stuth 1984).

Results and Discussion

Rainfall Pattern

Rainfall at the study site during 1977 was 72 percent of the long-term average (Table 1). About 27 percent (19.5 cm) of the total annual rainfall was received in April 1977, the month prior to tebuthiuron application. However, rainfall during the 30-day period following tebuthiuron application apparently was adequate to solubilize the herbicide and move it into the soil profile. As a result, symptoms of tebuthiuron phytotoxicity were uniformly apparent on woody plants by midsummer.

Rainfall in 1978 was 81 percent of the long-term average (Table 1). Rainfall in May-June 1978 was slightly greater than it was during the previous year, and September-October rainfall exceeded 14 cm.

The winter-spring of 1979 was relatively wet with more than 10 cm/month received from January to April and with about 26 cm in May (Table 1). Rainfall in July, 17.9 cm, accounted for the summer (June-July-August) 1979 being the wettest (29.2 cm) during the years of study.

Rainfall during the spring (March-May) and fall (September-October) growing periods is critical to forage production. Spring rainfall varied from 17.6 cm in 1978 to 50.6 cm in 1979, and averaged 30.1 cm for 1977 through 1984 (Table 1). Fall rainfall ranged from 8.9 in 1977 to 34.1 cm in 1984, and averaged 21.1 cm for 1977 through 1984.

Rainfall during the study period was typical of the long-term pattern. Annual rainfall from 1977 through 1984 averaged 98 cm compared to the long-term average of 99.4 cm (Table 1). As is normal for the region, relatively dry years were bound by extremely wet years.

Woody Plant Responses to Brush Management Treatments

Prior to tebuthiuron application in 1977, the woody plant canopy cover was 43 percent, 22 percent oaks and about 7 percent yaupon. Initial canopy cover on the site treated in 1978 was 60 percent.

Tebuthiuron pellets at 2.2 kg/ha in both experiments and at 4.4 kg/ha applied in 1978 effectively controlled post oak, blackjack oak, water oak, winged elm, yaupon, downy hawthorn, gum bumelia, and willow baccharis (Scifres et al. 1981a). By the end of the second growing season after application, the canopies of these species were reduced by no less than 95 percent. On the average, tebuthiuron removed 90 percent of the overall woody canopy by the second growing season after application on both study areas.

Species not effectively controlled by tebuthiuron included honeylocust, saw greenbrier, common persimmon, American beautyberry, peppervine, and southern dewberry. These species accounted for a low proportion of woody cover so that initial overall reduction by the herbicide applications exceeded 85 percent. However, the abundance of American beautyberry and of

Table 1. Monthly rainfall received on the study pastures where tebuthiuron-prescribed burning systems for improvement of thicketed post oak savanna were evaluated from 1977 through 1984 near College Station, Texas

	Precipitation (cm)							
Month	1977	1978	1979	1980	1981	1982	1983	1984
January	4.9	9.5	10.3	8.2	7.4	2.2	10.3	4.0
February	8.4	7.2	10.6	4.4	3.6	3.7	7.9	2.4
March	4.8	6.5	12.2	15.4	4.3	8.4	14.1	8.8
April	19.5	5.3	12.7	4.6	2.8	11.0	1.2	0.2
May	2.0	5.8	25.7	13.3	12.9	14.3	28.9	11.6
June	7.8	6.4	4.9	0.2	26.3	5.3	6.0	13.1
July	0.2	1.3	17.9	0.5	7.4	5.6	6.0	1.0
August	4.1	1.5	6.4	0.9	9.3	4.8	12.8	7.1
September	4.4	13.5	10.5	11.2	9.3	4.0	18.6	1.3
October	4.5	0.9	3.7	5.1	21.8	16.9	10.3	32.8
November	6.9	15.6	7.8	9.3	4.0	7.6	7.3	6.1
December	5.4	7.3	7.5	0.6	0.8	8.8	4.1	9.1
Total	72.0	80.5	130.2	73.7	109.9	92.6	127.5	97.5
Deviation[1]	−27.4	−18.9	31.5	−25.8	10.3	−7.0	27.9	−1.9

[1]Deviation from average rainfall for 1950 through 1976.

Table 2. Canopy cover, stem densities, and heights of American beautyberry and overstory associates in May-June 1983 after aerial application of tebuthiuron pellets in May 1978 near College Station, Texas

Site	Tebuthiuron rate (kg/ha)	American beautyberry: Canopy cover (%)	Stems/ha	Height (m)	Frequency (%) of associated species: Oak	Yaupon	Yaupon-oak	Others
Upland	0	5	338	1.6	16	14	70	0
	2.2	94*	10,399*	1.2*	0	0	100	0
	4.4	95*	10,307*	1.2*	0	11	89	0
Lowland	0	6	331	1.9	6	17	74	3
	2.2	17*	1,833*	1.5*	7	24	70	0
	4.4	12*	1,267*	0.9*	10	36	48	6

*Significantly different (LSD=0.05) from means representing no herbicide treatment.

vines, especially saw greenbrier, increased dramatically by the third growing season after tebuthiuron application.

At initiation of the research, canopy cover of American beautyberry varied from 5 to 7 percent. Although the tebuthiuron applications defoliated the plants, most of the American beautyberries survived the treatment. By early summer 1983, American beautyberry canopy cover was 2- to 3-fold greater on treated than on untreated lowlands (Table 2). American beautyberry stem densities exceeded 10,000/ha in 1983 on uplands treated with tebuthiuron in 1978, roughly 30 times the stem density on untreated upland sites. In most cases, American beautyberry was growing beneath yaupon plants, oaks, or a mixture of oaks and yaupon. Control of overstory woody plants with tebuthiuron apparently released American beautyberry to form continuous canopy cover on the upland sites. On the average, the American beautyberry plants were shorter on treated than on untreated pastures in 1983, indicating that a large proportion of the increase was the result of seedling establishment, apparently shortly after tebuthiuron application. The height difference was particularly pronounced on lowland sites.

The abundance of vines, especially southern dewberry, peppervine, and saw greenbrier, also increased following tebuthiuron applications. For example, the proportion of woody plant cover attributed to southern dewberry in the fall 1983, after aerial application of tebuthiuron pellets in 1978, ranged from 6.6 to 9.2 percent compared to less than 1 percent on untreated pastures (Table 3). Prescribed burning of the herbicide-treated pastures had no effect on the southern dewberry canopy cover. Although vines were not included in measurements in summer 1984, it was estimated that saw greenbrier, peppervine, southern dewberry, and poison ivy accounted for more than 20 percent of the woody plant cover on tebuthiuron-treated plots, regardless of burning treatment. Saw greenbrier alone accounted for 10 to 12 percent of the cover in 1984 on pastures treated with tebuthiuron in 1978.

Not considering the influence of vines, canopy cover of woody plants in late summer 1985 averaged about 52 percent and 25 percent on plots treated with 2.2 and 4.4 kg/ha of tebuthiuron, respectively, in 1978 (Table 4). Cover on tebuthiuron-treated pastures which were not burned was dominated by American beautyberry. Values in Table 4 represent the weighted average of lowland and upland areas. American beautyberry canopy cover averaged less than 2 percent on untreated pastures, about 37 percent on pastures treated with 2.2 kg/ha of tebuthiuron, and 27 percent on pastures treated in 1978 with the higher application rate.

In contrast, American beautyberry canopy cover averaged 6 and 4 percent, respectively, on pastures treated with 2.2 and 4.4 kg/ha of the herbicide and then burned in the winters of 1981 and 1984. Prescribed burning also removed most of the eastern redcedar less than 4 m tall. As a result, total woody cover, not considering vines, averaged about 13 and 5 percent, respectively, where 2.2 and 4.4 kg/ha of the tebuthiuron pellets were applied in 1978 and pastures were burned in the winters of 1981 and 1984. Woody species with canopy cover less than 0.1 percent were not included in the summary (Table 4). These minor species included honey mesquite, black locust, pricklypear, and chinese tallow, which were most common in plots treated with 2.2 kg/ha of tebuthiuron but not burned.

Table 3. Proportion (%) of foliar cover as southern dewberry in September 1983 after aerial application of tebuthiuron pellets in May 1978 and prescribed burning in February 1981 near College Station, Texas

Burned	Tebuthiuron rate (kg/ha): 0	2.2	4.4
No	0.1	9.2*	6.6*
Yes	0.2	8.9*	9.4*

*Significantly different (LSD=0.05) from means representing no herbicide treatment.

Herbaceous Vegetation Responses to Brush Management Treatments

Tebuthiuron at 2.2 kg/ha in 1977 did not alter average grass standing crop during the growing season of treatment (Scifres et al.

1981b). However, grass standing crop on treated pastures was approximately four times that of untreated plots at 1 year after herbicide application, and the increase in forage production was maintained through the second and third years after treatment.

Grass standing crop in July 1981 on pastures aerially treated with tebuthiuron at 2.2 kg/ha in 1977, followed by burning in the winters of 1979 and 1981, was roughly twice that of areas that were untreated or mechanically cleared in 1977 (Table 5). Pretreatment woody cover on these pastures averaged about 40 percent. Grass standing crops were maintained on the chemically-treated pastures into the fall and were greater than those on the untreated or on adjacent mechanically-treated pastures. The same general pattern occurred in mid-summer 1982, except that the grass standing crops on the mechanically-treated pastures were no different from those on pastures treated with tebuthiuron.

Enhanced grass response on the mechanically-treated pastures was attributed to the influence of shredding the previous spring. However, grass standing crops on mechanically-treated and untreated pastures were no different by late August 1982. Suppression of grass standing crop by the end of the growing season after shredding indicates the extremely rapid topgrowth replacement by woody plants in this region. By fall 1983, grass standing crop averaged 4,262 kg/ha on the herbicide-treated areas providing ample fine fuel for prescribed burning the following winter. Standing fine fuel loads on mechanically-treated pastures was about half that on pastures treated with tebuthiuron.

Forb standing crops were unaffected by tebuthiuron application during the first growing season but were greatly reduced during the second and third growing season after treatment in 1977 (Scifres et al. 1981b). Forb standing crops did not differ among treatments at 3 years after tebuthiuron application in 1977.

Forb standing crops on pastures which had been treated with tebuthiuron in 1977 were consistently greater than standing crops on untreated pastures, regardless

Table 4. Canopy cover (%) of major woody species in June-July 1985 following aerial application of tebuthiuron pellets at 2.2 or 4.4 kg/ha on May 11, 1978, and prescribed burning in late February 1981 and 1984 of thicketed post oak savanna near College Station, Texas

	Tebuthiuron rate (kg/ha)					
	No burn			Burn		
Species	0	2.2	4.4	0	2.2	4.4
Post Oak	7.5	0.2	0	14.7	0.1	0
Blackjack oak	3.0	0	0	5.4	0	0
Water oak	1.8	0	0	1.5	0	0
American beautyberry	1.7	36.8	26.6	1.8	6.4	3.6
Black willow	0	0	0	0.1	0	0
Buckbrush	0.3	0	0.1	0.8	0	0
Chinaberry	0	0	0.9	0.3	0	0
Chinese elm	1.2	0	0	1.1	<0.1	0
Common persimmon	0.3	1.1	0.7	1.1	0	0
Eastern redcedar	2.1	8.1	4.2	3.1	3.1	1.2
Farkleberry	0.3	0	0	0.3	0	0
Gum bumelia	0.3	0.2	0.1	0.5	0	0
Honeylocust	0.3	0.4	0.5	0.3	0	0
Possumhaw	0.6	0	0	2.1	<0.1	0
Sugar hackberry	0.3	0	0	0.3	0	0
Willow baccharis	1.8	2.9	1.4	2.6	2.3	0.2
Winged elm	0.4	0	0	1.5	0	<0.1
Yaupon	27.7	2.5	0.5	14.4	0.6	<0.1
Total cover (%)	59.7	52.2	25.2	51.6	12.7	5.1

Table 5. Oven-dry herbaceous standing crops (kg/ha) at various dates after aerial application of tebuthiuron at 2.2 kg/ha in May 1977 followed by prescribed burning in February 1979 and 1981 compared to pastures with brush removed by dozing in June-July 1977 and shredded in March-April 1982, near College Station, Texas

	Standing crops[1]						
	1981		1982			1983	
Treatments(s)	July 17	Nov. 26	July 15	Aug. 30	Dec. 20	May 8	Nov. 10
				Grasses			
None	1,076 a	832 a	990 a	750 a	820 a	600 a	1,690 a
Tebuthiuron-burn	2,596 b	3,268 c	1,984 b	2,412 b	2,800 b	2,812 c	4,262 b
Doze, stack-shred	1,323 a	1,462 b	1,508 b	830 a	1,170 a	1,413 b	2,150 a
				Forbs			
None	472 a	149 a	52 a	40 a	34 a	76 a	46 a
Tebuthiuron-burn	648 ab	415 b	90 a	586 c	84 a	112 a	196 b
Doze, stack-shred	984 b	491 b	252 b	120 b	68 a	82 a	161 b

[1] Means within a growth form and date of evaluation followed by the same letter are not significantly different (P≤0.05) according to Student-Newman-Keul's test.

of season of evaluation from 1981 through 1983 (Table 5). Except for the spring following the shredding, forb standing crops were the same or greater on the herbicide-treated and burned pastures than on those treated mechanically.

There was no difference in grass standing crops among treatments at 4 months after application of tebuthiuron pellets at 2.2 or 4.4 kg/ha in 1978 (Scifres et al. 1981b). Grass standing crops at 13 months after treatment were increased, compared to untreated pastures, where the herbicide was applied at 2.2 kg/ha. However, grass production was not increased on pastures treated with 4.4 kg/ha, compared to that on untreated pastures. The lack of difference was attributed to suppression of grass production in localized areas on pastures treated with the higher herbicide dosage. Furthermore, grass production was highly variable within pastures treated with 4.4 kg/ha of tebuthiuron. Large bare spots occurred near robust individuals of grasses which were tolerant of the herbicide. However, by the end of the second growing season, grass standing crop was greater on pastures treated with 4.4 kg/ha than on those treated with the lower herbicide rate and was greater on treated than untreated pastures. This difference among treatments also occurred at 30 months after herbicide application (Scifres et al. 1981b).

There were no differences in grass standing crops in May or November 1981 on pastures treated with 2.2 or 4.4 kg/ha of tebuthiuron in 1978, and standing crops on treated pastures were about 10-fold greater than those on untreated pastures (Table 6). Forb standing crops were greater on herbicide-treated than on untreated pastures in both spring and fall 1981. Prescribed burning of previously untreated pastures in February 1981 did not alter grass standing crops the following growing season, compared to unburned, brush-dominated pastures. Standing fine fuel loads were inadequate and the fuel too discontinuous to carry an effective fire. Thus, the fires were restricted almost solely to surface fuels, primarily leaf litter, and were "cool" and spotty.

Grass standing crops were reduced in May 1982 following the burns in the winter 1981 on herbicide-treated plots, compared to those pastures treated with tebuthiuron and not burned (Table 6). Grass standing crops had recovered by August 1982 on pastures that had been treated with tebuthiuron in 1978 and burned in the winter 1981. Increased grass standing crops on the burned pastures were maintained until December 1982 and were especially evident on pastures that had been treated with 4.4 kg/ha of tebuthiuron.

The second burn in February 1984 of the area treated in 1978 did not alter grass standing crops on brush-dominated pastures (Table 6). Fire behavior during the second burn was the same as with the burn in 1981. These data indicated the necessity of removing the woody plant canopy to release fine fuel for most effective burning post oak-mixed hardwoods. The burns in 1984 were more effective than those in 1981 when applied to pastures treated with tebuthiuron in 1978. Grass standing crops in May 1985 were greater on pastures treated with tebuthiuron and burned, and there was no difference attributable to application rate of tebuthiuron. Standing crops in the fall were greatest where 4.4 kg/ha of tebuthiuron were followed by prescribed burning but did not differ among the other herbicide-burning treatments.

Table 6. Oven-dry standing crops of grasses and forbs at various dates after aerial application of tebuthiuron pellets at 2.2 or 4.4 kg/ha on May 11, 1978, and prescribed burning in late February 1981 and 1984 of post oak-mixed hardwoods near College Station, Texas

	Standing crops[1]							
	1981		1982			1983		1984
Treatment	May 18	Nov. 8	May 31	Aug. 30	Dec. 7	May 16	Nov. 3	May 2
				Grasses				
None	96 a	231 a	134 a	184 a	182 a	94 a	206 a	88 a
Prescribed burn	—	—	112 a	266 a	226 a	116 a	217 a	89 a
Tebuthiuron (2.2 kg/ha)	1,136 b	2,000 b	848 bc	1,162 b	1,162 b	1,006 b	2,650 bc	2,047 b
Tebuthiuron (2.2 kg/ha)-burn	—	—	544 ab	1,404 c	1,412 b	1,812 c	2,823 c	1,355 b
Tebuthiuron (4.4 kg/ha)	1,192 b	2,965 b	1,268 c	1,376 c	2,076 c	1,127 b	2,375 b	2,417 d
Tebuthiuron (4.4 kg/ha)-burn	—	—	694 abc	1,816 d	2,786 d	2,103 c	3,516 d	1,317 b
				Forbs				
None	50 a	47 a	34 a	24 a	150 b	54 a	36 a	16 a
Prescribed burn	—	—	30 a	35 a	322 e	57 a	48 a	24 a
Tebuthiuron (2.2 kg/ha)	358 b	865 c	164 b	198 b	56 b	167 bc	270 b	150 b
Tebuthiuron (2.2 kg/ha)-burn	—	—	258 d	579 c	96 c	184 c	298 b	363 c
Tebuthiuron (4.4 kg/ha)	312 b	375 b	204 c	193 b	6 a	115 b	262 b	149 b
Tebuthiuron (4.4 kg/ha)-burn	—	—	326 e	534 c	10 a	213 e	270 b	441 c

[1] Means within a forage category and within a date of evaluation followed by the same letter are not significantly different ($P<0.05$) according to Student-Newman-Keul's range test.

Forb standing crops were reduced the growing season after application of 4.4 kg/ha of tebuthiuron in 1978 (Scifres et al. 1981b). Forb standing crops did not differ among treatments at 25 months after herbicide application but were greater on herbicide-treated than on untreated pastures after 30 months.

Forb standing crops following burning in 1981 of pastures treated with tebuthiuron in 1978 showed the same trends as grasses (Table 6). Burning of brush-dominated plots had no effect on forb standing crops in May or August 1982. Burning of tebuthiuron-treated pastures increased forb standing crops at both the spring and fall samplings, compared to untreated pastures. However, standing crops of forbs in the winter 1982 were uniformly low on tebuthiuron-treated plots, regardless of herbicide rate or burning treatment. This reduction was attributed to the increased standing crop of grasses on the treated pastures.

Proportion of the grass stand as species of good-to-excellent grazing value varied little on untreated pastures, accounting for 2 to 4 percent of the total cover each year (Table 7). The proportion of species of fair grazing value accounted for 55 to 68 percent of the total foliar cover. Burning in the winter 1980 caused a relatively rapid increase in the proportion of species highly desirable for grazing, primarily by promoting vegetative growth of little bluestem. However, the proportion of species of good-to-excellent grazing value in 1982 and 1983 was no different on burned and unburned pastures that had not been treated with the herbicide.

The proportion of species of good-to-excellent grazing value on pastures treated with tebuthiuron in 1978 and not burned averaged 26 to 29 percent in 1981 but only 8 percent in 1984 (Table 7). In comparison, pastures treated with tebuthiuron in 1978 and burned in 1981 contained grass stands with 16 percent of the foliar cover provided by species of good-to-excellent grazing value.

Much of the variation in the proportion of species of good-to-excellent grazing value caused by treatment can be explained by the shifting ratio of little bluestem to brownseed paspalum foliar cover. Since this ratio was not influenced by herbicide rate (i.e. 2.2 compared to 4.4 kg/ha), pastures receiving 2.2 kg/ha are compared to untreated pastures (Table 8). Data represented that proportion of the sum of the cover of the two species that was represented by little bluestem. The proportion of little bluestem in relation to brownseed paspalum in untreated pastures increased from 1981 through 1984 (Table 8). This was attributed to managed grazing which included rest periods to reduce selective grazing pressure on the little bluestem.

Although absolute grass cover was greater where tebuthiuron was applied but not followed by prescribed burning, amounts of little bluestem relative to cover of brownseed paspalum complex differed little from that of untreated pastures. The ratio of little bluestem to brownseed paspalum cover was greater for three growing seasons after burning pastures which had not been chemically treated. The proportion of little bluestem was increased in all years of evaluation from 1981 through

Table 7. Estimated proportion of grasses by grazing value based on percentage foliar cover from 1981 through 1984 after aerial application of tebuthiuron pellets in May 1978 and prescribed burning in late February 1981 and 1984 near College Station, Texas

	Tebuthiuron rate (kg/ha)					
Forage category	0	2.2	4.4	0	2.2	4.4
	Unburned			Burned		
			1981			
Good-to-excellent	2	26	29	16	24	22
Fair	55	50	56	69	54	75
Poor	43	24	15	15	22	3
			1982			
Good-to-excellent	4	7	13	4	15	13
Fair	63	70	62	90	66	63
Poor	34	23	25	6	19	24
			1983			
Good-to-excellent	3	6	6	2	14	15
Fair	68	74	76	93	81	78
Poor	29	20	18	5	5	7
			1984			
Good-to-excellent	4	8	8	5	16	16
Fair	58	72	80	61	68	74
Poor	38	20	12	33	16	10

Table 8. Percentage of the total foliar cover of little bluestem plus brownseed paspalum contributed by little bluestem in the fall (September-October) 1981 through 1984 following tebuthiuron application at 2.2 kg/ha in 1978 and prescribed burning in late February 1981 and 1984 near College Station, Texas

	No herbicide		Tebuthiuron (2.2 kg/ha)	
Year	Unburned	Burned	Unburned	Burned
1981	4	12*	12	17*
1982	11	29*	8	30*
1983	12	17*	11	12
1984	12	16	13	21*

*Significantly different (P≤0.05) from mean of unburned pasture within the respective treatment based on t-test.

1984, except in 1983 where pastures treated with 2.2 kg/ha of tebuthiuron were burned in 1981, compared to chemically-treated but unburned pastures. These data indicate that prescribed burning can be used to increase the presence of little bluestem on these sites.

Cattle Performance and Diets Following Tebuthiuron Application

Forage response differences were expressed in livestock performance, using weight gains of steers as the criterion (Scifres et al. 1981b), following tebuthiuron application in 1977 and 1978. By the first fall after application of tebuthiuron in 1977, average daily steer gains, total daily steer gains, and days available grazing were increased on pastures treated with 2.2 kg/ha of tebuthiuron, compared to untreated pastures (Table 9). This improvement was maintained through the first 3 years after tebuthiuron application when the measurements were discontinued.

In contrast, average daily steer gains and total daily steer gains were negative and less on treated than on untreated pastures during the fall after tebuthiuron application at 2.2 kg/ha in the spring 1978 (Table 10). Application of 4.4 kg/ha of the herbicide extended the negative effects on livestock performance through the second growing season after treatment. However, animal performance responded positively during the second growing season.

The favorable response to tebuthiuron application in 1977 can be linked to several important characteristics of the oak woodland. First, the woodland had a younger age structure of trees compared to the 1978 study site. Fall standing crops from untreated pastures were five to seven times greater on the younger woodland site treated in 1977 than on the mature woodland treated in 1978. Therefore, there was a good stand of residual herbage which responded quickly to herbicide treatment compared to the mature woodland.

Improved performance of steers grazing tebuthiuron-treated pastures in the younger oak woodland can be related to greater stability of the grass stand when subjected to grazing pressure. The steers were able to select diets higher in crude protein the fall and summer following tebuthiuron application than on the untreated pastures. Animals grazing the untreated pastures were unable to select diets having crude protein content above maintenance requirements during the fall after treatment and subsequently lost weight.

The greater steer-day/ha capacity was attributed primarily to greater herbaceous standing crop and more reliance on browse to sustain nutrient requirements. Browse comprised 26 to 45 percent and 4 to 23 percent of the cattle diets at the end of the seasonal grazing trials in the untreated and treated pastures, respectively. This resulted in a general trend for reduced caloric (IVDOM) value of the diet and probably reduced forage intake on untreated pastures when compared to treated pastures. Enhanced individual animal performance of steers grazing tebuthiuron-treated pastures can be attributed to higher *ad libitum* diet quality and greater nutritional stability furnished by the pastures. Steer-days/ha capacity of the pastures was primarily a function of initial standing crop and growth rate of herbage as mediated by browse consumption.

Particularly important is the greater overall performance of the steers in the untreated pastures during the spring trial on the area treated in 1977. Individual animal performance was essentially the same, yet caloric content was lower and crude protein content was higher in diets of steers grazing

Table 9. Dietary composition, quality, animal performance, and forage supply for three seasonal grazing trials after aerial application of tebuthiuron pellets at 2.2 kg/ha to Post Oak Savanna on May 9, 1977, near College Station, Texas

	Fall 1977				Summer 1978				Spring 1979			
	Untreated		Tebuthiuron		Untreated		Tebuthiuron		Untreated		Tebuthiuron	
Variable	Begin[1]	End	Begin	End	Begin	End	Begin	End	Begin	End	Begin	End
Diet composition (%)												
Grass	83	54	90	76	81	61	99	79	74	46	91	53
Forb	10	1	4	1	10	12	0	16	22	28	8	43
Browse	7	45	6	23	9	27	1	5	4	26	1	4
Diet quality (%)												
IVDOM[2]	54	47	53	46	60	49	63	52	57	58	63	64
Crude protein	7.9	6.8	10.0	7.2	8.0	7.2	10.0	7.8	11.3	9.8	10.0	7.8
Animal performance (kg)												
Avg. daily gain	−.01		.35		.35		.60		.63		.58	
Gain/ha/day	−.21		1.51		1.80		2.76		3.12		2.32	
Forage supply												
Initial standing crop	1,400		1,150		1,100		2,750		350		400	
Steer-days/ha	89		61		81		132		59		44	

[1]Refers to beginning and end of trials which generally lasted 10 days.

[2]*In vitro* digestible organic matter content.

Table 10. Dietary composition, quality, animal performance, and forage supply for three seasonal grazing trials after aerial application of tebuthiuron pellets at 0, 2.2 or 4.4 kg/ha to Post Oak Savanna on May 7, 1978, near College Station, Texas

Variable	Fall 1978						Summer 1979						Spring 1980					
	0		2.2		4.4		0		2.2		4.4		0		2.2		4.4	
	Begin	End	Begin	End	Begin	End	Begin	End	Begin	End	Begin	End	Begin	End	Begin	End	Begin	End
Diet compostion (%)																		
Grass	95	—	88	—	88	—	87	61	96	91	92	83	85	24	88	86	94	83
Forb	4	—	7	—	3	—	4	11	2	4	7	7	11	28	10	7	5	13
Browse	1	—	5	—	9	—	9	28	2	5	1	10	4	48	2	7	1	4
Diet quality (%)																		
IVDOM	59	—	55	—	55	—	61	53	63	55	65	54	62	48	61	58	61	57
Crude protein	9.8	—	11.1	—	12.3	—	10.5	7.4	12.4	10.4	13.5	10.4	13.4	10.4	14.5	11.2	15.9	13.0
Animal performance (kg)																		
Avg. daily gain (ADG)	−.01		−.34		−.99		.25		.19		−.11		.37		.32		.34	
Gain/ha/day	−.04		−.57		−1.55		.38		.29		−.07		.65		.54		.55	
Forage supply (kg/ha)																		
Initial standing crop	221		149		183		224		485		141		473		1,191		1,363	
Steer-days/ha	29		24		19		36		36		28		53		82		85	

untreated pastures. The only logical explanation for this difference relates to the potential dietary role of browse during spring allowing animals to selectively maintain nutrient intake when herbaceous standing crops are low.

Oaks and yaupon, the principal browse species in the pastures, have average *in vitro* (IVDOM) and crude protein values of 60 to 69 percent and 12 to 16 percent in April, respectively (Tables 11 and 12). These data indicate that complete treatment of a pasture would reduce the animal's degree of flexibility in selecting forage species to facilitate stability of nutrient intake. Therefore, the need for patterning brush treatments for wildlife habitat should be extended to the need for enhancing livestock selectivity of nutrients on landscapes.

Animal performance data from the mature oak woodland indicated that the acute effects of tebuthiuron application were largely caused by reduced standing crop of herbaceous forage and elimination of alternative browse species needed to sustain nutrient intake of the animals. Initial herbaceous standing crops in the fall following treatment in the spring were similar between untreated and tebuthiuron-treated pastures. However, caloric value of diets for animals grazing the tebuthiuron-treated pastures was lower than for animals on untreated pastures. Apparently the steers had to move onto residual browse much quicker in the tebuthiuron-treated pastures which drastically reduced their caloric intake.

Only herbicide-resistant woody species with average IVDOM and crude protein contents of 46 to 53 percent and 7.5 to 10 percent, respectively, were available during fall after treatment (Tables 11 and 12). The decline in steer-days/ha of grazing with increasing rate of tebuthiuron application indicated that the animals were depleting the herbage supply more rapidly and depending on lower quality residual browse in fall than on "brush" pastures.

Animal performance was similar in the fall trials of 1977 and 1978 and, depending on age structure of the woodland, positive animal performance, or acute weight loss, can be extended based on characteristics of the brush stand treated with tebuthiuron. Animal performance was depressed during the summer 1979 following application of tebuthiuron in spring of 1978, with acute weight loss by steers grazing pastures treated with 4 kg/ha. Analysis of diet composition and quality did not explain the weight losses. However, available herbage apparently was still suppressed in pastures treated with 4 kg/ha of the herbicide causing animals to seek a severely reduced browse reserve.

Diet quality data indicated that those animals in pastures treated with 4 kg/ha of tebuthiuron could select alternative diets and sustain nutrient concentration in summer but because of restricted supply could not sustain daily intake. This supports the need to provide cattle with access to untreated areas to buffer against loss of browse as a nutritional reserve.

Animal performance differences between treated and untreated pastures were minimal by spring 1980 in the mature oak woodland. Individual animal performance and gain/ha-day were 50 and 20 percent less on spring grazed mature oak woodlands treated with tebuthiuron, compared to younger woodland sites which had been treated. This indicated that expected benefits are delayed approximately 2 years on mature compared to young oak woodlands treated with tebuthiuron. The more rapid positive response in animal performance during the summer 1979 on pastures treated with 2 kg/ha of tebuthiuron provided further evidence of the need to maintain a residual browse supply.

Cattle preferred to graze native grassland dominated by little bluestem and brownseed paspalum and treated with 0.5, 1, or 2 kg/ha of tebuthiuron over adjacent untreated plots (Scifres et al. 1983). Moreover, cattle usually grazed on plots treated with 1 or 2 kg/ha of tebuthiuron longer and more often than on plots treated with the same rates of 2,4-D [(2,4-dichlorophenoxy) acetic acid] or picloram sprays. The apparent preference was observed in summer and fall after herbicide application in spring, but was not observed the following growing season. These

Table 11. *In vitro* digestible organic matter (%) content of available terminal 10 cm current year's leaves and stems of major browse sprouts growing on a mechanically cleared Tabor fine sandy loam soil of Post Oak Savanna near College Station, Texas, in 1977 and 1978 (each value represents 20 grab samples from 10 plants of each species)

		Sampling date (1977-78)					
Species	Plant part	12/22	2/26	4/8	6/18	8/21	10/7
Post oak	Leaf	46	—	60	55	45	46
	Stem	31	35	58	43	29	31
Blackjack oak	Leaf	48	—	60	44	38	41
	Stem	29	35	51	40	30	22
Water oak	Leaf	45	49	46	47	44	42
	Stem	32	33	38	40	30	29
Winged elm	Leaf	—	—	56	56	54	53
	Stem	26	30	40	35	33	25
Yaupon	Leaf	53	59	69	54	48	53
	Stem	29	32	38	38	25	30
Gum bumelia	Leaf	—	—	56	48	49	44
	Stem	29	26	46	47	29	24
Willow baccharis	Leaf	62	69	64	57	54	50
	Stem	48	52	51	46	44	45
Sparkleberry	Leaf	44	50	48	43	63	44
	Stem	19	26	34	25	28	20
Buckbrush	Leaf	56	—	63	66	64	44
	Stem	23	24	45	25	29	25

Table 12. Crude protein (%) content of available terminal 10 cm current year's leaves and stems of major browse sprouts growing on a mechanically cleared Tabor fine sandy loam soil of the Post Oak Savanna near College Station, Texas, in 1977 and 1978 (each value represents 20 grab samples from 10 plants of each species)

		Sampling date (1977-78)					
Species	Plant part	12/22	2/26	4/8	6/18	8/21	10/7
Post oak	Leaf	7.5	—	16.7	10.8	8.8	8.5
	Stem	5.2	5.2	11.4	7.2	4.0	3.0
Blackjack oak	Leaf	5.3	—	16.8	8.6	7.8	8.3
	Stem	4.0	3.3	9.3	9.4	3.5	3.2
Water oak	Leaf	10.5	11.4	16.3	10.2	8.1	10.3
	Stem	5.2	4.6	8.0	5.0	3.6	3.5
Winged elm	Leaf	—	—	17.5	9.8	8.6	9.2
	Stem	6.0	5.5	6.9	3.4	4.2	5.0
Yaupon	Leaf	14.1	8.6	12.7	8.0	6.6	7.5
	Stem	1.7	3.8	4.4	5.6	3.9	3.8
Gum bumelia	Leaf	—	—	16.8	8.6	7.8	8.3
	Stem	5.4	6.2	11.6	9.4	5.6	5.6
Willow baccharis	Leaf	11.5	10.5	15.2	8.8	8.6	11.0
	Stem	5.2	5.0	6.7	5.0	4.3	5.6
Sparkleberry	Leaf	8.8	7.1	15.1	7.8	8.7	10.0
	Stem	4.1	3.7	8.3	3.9	4.0	8.3
Buckbrush	Leaf	13.3	—	16.4	7.0	6.5	14.9
	Stem	3.6	3.7	5.5	2.5	3.6	4.5

observations were later confirmed when tillers of brownseed paspalum were permanently marked in pastures receiving partial treatment with tebuthiuron at 2 kg/ha.

Tiller height reduction was monitored before and after grazing on a treated and untreated grassland community within a pasture of a 15-pasture, 1-herd short duration grazing system. Cows removed 5.2 to 9.2 cm more height from tillers growing in treated than untreated grasslands from August through November (Table 13). There were no observable differences in tiller use during winter. Approximately 25 percent of the marked tillers in the study overwintered in the untreated grasslands while no tillers survived the extremely cold winter on the sites treated with tebuthiuron. This appears to be related to loss of insular properties by the grass bunches and reduced fall tiller production by heavily grazed plants.

Masters and Scifres (1984) investigated the potential influence of tebuthiuron applications on nutritional attributes of several grasses. The *in vitro* digestible organic matter concentrations of leaves of little bluestem, bahiagrass, Bell rhodesgrass, or green sprangletop were not altered by applications of 1.1 or 2.2 kg/ha (active ingredient) of tebuthiuron. Leaf water concentrations of bahiagrass, green sprangletop, or little bluestem were not consistently altered by application of tebuthiuron. However, application of 1.1 or 2.2 kg/ha of tebuthiuron to seeded stands or to native little bluestem increased foliar crude protein concentrations. Applications of 0.125, 0.188, or 0.25 parts per million of tebuthiuron in aqueous solutions to pots containing grasses in the greenhouse significantly increased foliar crude protein concentrations, compared to untreated plants. Crude protein concentrations were increased only during the growing season of application in the native stand of little bluestem. These results suggested application of tebuthiuron for brush control may enhance crude protein concentrations while not affecting *in vitro* digestible organic matter.

Post-burn Diet Selection by Cattle

Diet quality and quantity of steers grazing during the spring and fall following burning were contrasted in 1981 on the oak woodland site treated with tebuthiuron in 1978 to determine livestock responses to maintenance burns (Table 14). Surprisingly, burning did not enhance diet quality during late spring 90 days following burning. Diet crude protein was lower for steers on the burned pastures in spring. There was a trend for diet IVDOM to be higher on burned pastures in spring and fall following burning.

During spring the steers selected diets similar in species composition (Table 15). However, amount of live leaf tissue was higher and live stem and seedhead consumption was lower in diets from the burned pastures. Brownseed paspalum was the primary seed contributor to the diets. Apparently, greater seed consumption increased relative crude protein levels in the diets of steers grazing unburned pastures. Greater leaf blade consumption probably explains the trend for higher IVDOM in diets selected from the burned pastures during spring.

Burning resulted in greater grass and less forb consumption during the fall after burning (Table 15). This probably explains the higher crude protein and lower IVDOM contents of steer diets from the unburned than from burned pastures. Diets of cattle grazing burned pastures in the fall contained more live leaf tissue and a lower proportion of seedheads than cattle grazing the unburned pastures.

Winter burning may not improve livestock performance in the spring but would allow steers or lactating cows to select diets that exceed maintenance requirements in fall. Thus, producers could capture gains in steers over a longer

Table 13. Height reduction brownseed paspalum tillers in untreated and tebuthiuron-treated grassland communities of a pasture six months post-treatment in a 15-pasture, 1-herd (16 pregnant cows) rotational grazing system, August 1984 to January 1985 near College Station, Texas

Grazing period	Treatment[1]	Height reduction cm	%
Aug. 24-30	Tebuthiuron	12.6	52
	None	5.0*	35
Sept. 26-Oct. 4	Tebuthiuron	15.7	70
	None	4.5*	27
Nov. 15-22	Tebuthiuron	6.6	46
	None	1.4*	12
Dec. 26-Jan. 6	Tebuthiuron	1.9	18
	None	2.3	21

[1]Tebuthiuron aerially applied at 2.2 kg/ha in May 1977.
*Significant difference between treatments (P≤.05)

Table 14. Crude protein (CP) and *in vitro* digestible organic matter (IVDOM) of esophageally fistulated steers grazing tebuthiuron-treated pastures in the Post Oak Savanna near College Station, Texas, during spring and fall following a late winter burn in February 1981

Treatment	Nutritent content (%) CP (Mean ± S.E.)[1]	IVDOM (Mean ± S.E.)
	Spring 1981	
Unburned	10.8 ± .54	56.3 ± 1.20
Burned	8.2 ± .45*	58.0 ± 1.08
	Fall 1981	
Unburned	8.4 ± .37	52.6 ± 1.00
Burned	7.7 ± .27	57.4 ± 1.00*

[1]Average values and associated standard errors.
*Significantly different from unburned (P≤0.05).

period and wean heavier spring calves or increase conception of fall calving cows. Probably, it would be wise to provide a protein supplement (e.g. low cost molasses/urea source) during late summer and into fall if precipitation does not stimulate fall forb production following burning.

A part of this research was directed toward determining how tebuthiuron shapes the plant community and interacts with burning to affect nutritional stability of the pasture. Specifically, the question becomes: how does the presence of browse interact with burning to affect how an animal can sustain nutrient intake?

A series of graze-out trials were conducted in May, August, and January after burning in February 1984 on the pastures treated with tebuthiuron in 1977. The tebuthiuron-treated pastures provided an excellent stand of grass with little available browse, while adjacent bulldozed pastures had abundant resprouts of shrubs, mature trees, and relatively good herbaceous stands.

Dietary IVDOM of cattle was not affected by plant stand composition differences a year after burning if grazing pressure was not heavy (Table 16). However, when grazing pressure was increased, animals switched to browse in the bulldozed pastures and maintained nutrient concentration at a higher level than in tebuthiuron-treated pastures, except in the hot dry part of summer. Browse in summer is very low in IVDOM (Table 11). Interestingly, the same can be said for crude protein content of cattle diets except under moderate grazing. Cattle selected diets higher in crude protein during August on burned pastures previously treated with tebuthiuron compared to bulldozed and burned pastures. This is attributed to higher browse consumption on tebuthiuron-treated versus bulldozed pastures during the hot dry period of the year (Figure 1), primarily because of greater consumption of willow baccharis and water oak.

When subjected to excessive grazing pressures, the burned pastures previously treated with tebuthiuron offered fewer opportunities for the steers to select alternative diets. This resulted in less nutritional stability of cattle diets from tebuthiuron-treated pastures. Again, it is apparent that maintaining diverse habitats through patterning of treatments is critical for stabilizing seasonal nutrient intake of cattle.

Influence on Wildlife Habitat Attributes

Based on measurements in August 1985, tebuthiuron application alone did not significantly alter average distance to screening closure (Table 17). Development of the understory shrub cover essentially replaced the screen provided by

Table 15. Composition of diets of esophageally fistulated steers grazing pastures treated with tebuthiuron in 1977 during the spring following a late winter burn in 1981 near College Station, Texas

	Food group					
	Grass		Forb		Browse	
Plant part	Unburned	Burned	Unburned	Burned	Unburned	Burned
			Spring 1981			
Live leaf	30.8	54.0*	6.2	6.3	0	0
Dead leaf	4.8	3.8	—	—	1.2	2.0
Live stem	33.5	18.3*	1.0	1.0	0	0
Dead stem	1.2	0.8	0.3	0.8	0	0
Reproductive	18.3	10.3*	3.0	2.5	0	0
Total	88.3	87.4	10.5	10.6	1.2	2.0
			Fall 1981			
Live leaf	23.8	53.1*	2.3	0.5	0.5	0.6
Dead leaf	18.9	12.9	1.4	0	0.3	0
Live stem	16.2	15.1	2.6	1.8	0.1	0
Dead stem	5.4	2.9	1.8	0.3	0	0
Reproductive	19.0	11.0*	5.5	1.7*	0	0
Total	84.2	95.1*	13.6	4.3*	2.2	0.6

*Significant differences exist between treatments by food group and plant part (P≤.05).

Table 16. *In vitro* digestible organic matter (IVDOM) and crude protein (CP) content as percentages of diets selected by cattle subjected to a graze-out regime on pastures treated with 2.2 kg/ha of tebuthiuron in 1977 or bulldozed the growing season following burning in February 1984 near College Station, Texas

	Nutrient (%) by grazing pressure					
	IVDOM			CP		
Treatment	Moderate	Heavy	Severe	Moderate	Heavy	Severe
			May			
Tebuthiuron/burn	56	51*	56*	8.9	10.3*	10.1*
Bulldoze/burn	56	58	54	9.5	13.1	11.5
			August			
Tebuthiuron/burn	57	44	44*	9.1*	5.5*	5.6*
Bulldoze/burn	57	46	41	7.8	6.6	7.9
			January			
Tebuthiuron/burn	46	46	44*	6.7	5.4	5.7
Bulldoze/burn	45	50	47	6.9	6.1	6.6

*Significant differences exist between treatments by food group and plant part (P≤.05).

Percent Browse Found in Diet

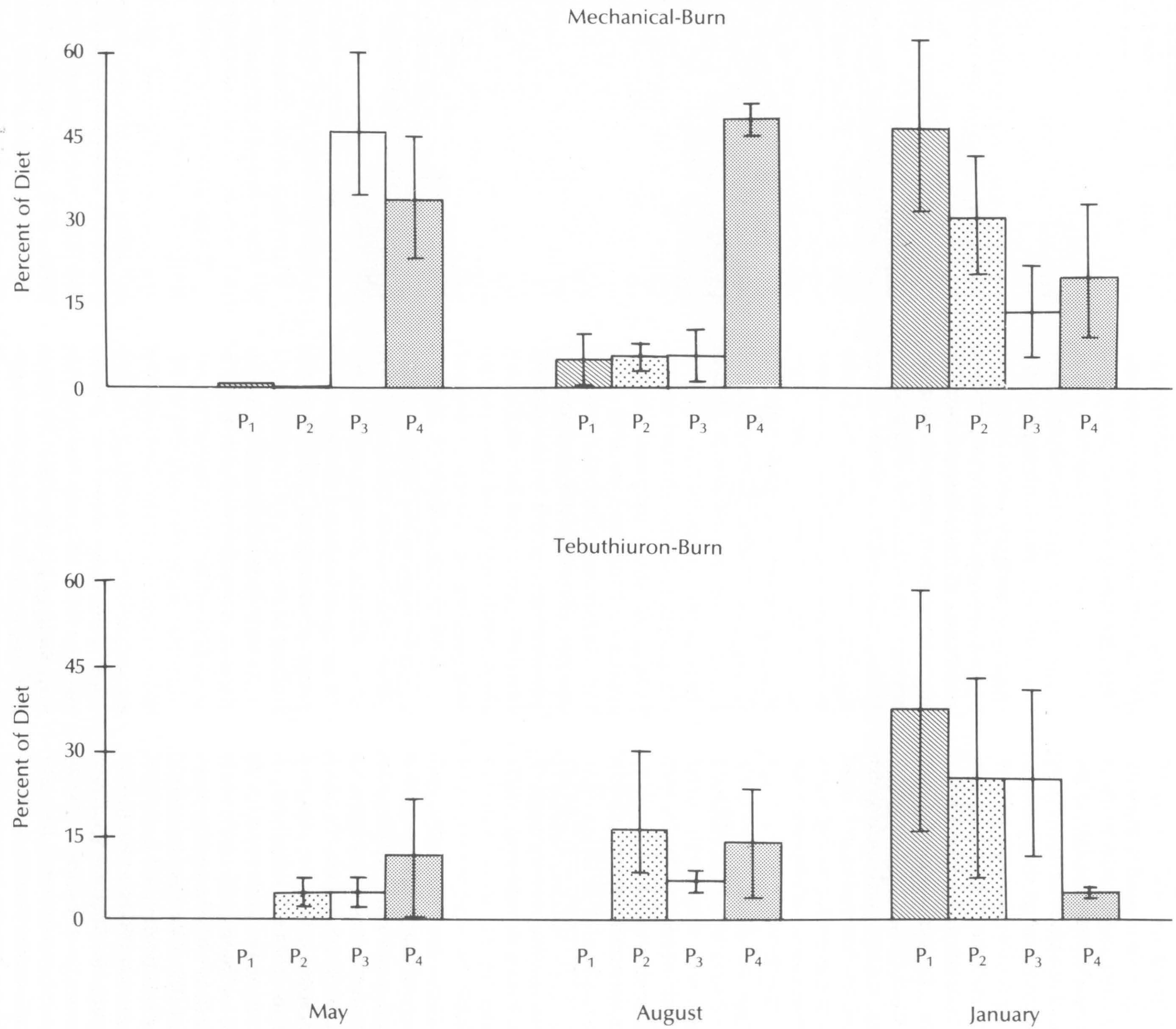

Figure 1. Percent browse in diets of cattle subjected to a series of graze-out trials the year following burning in the winter 1984 of pastures bulldozed or aerially treated with tebuthiuron at 2.2 kg/ha in May 1977.

the original woody cover. Prescribed burning following tebuthiuron application increased the distance to screening closure by reducing canopy cover and density of species such as American beautyberry. However, the greatest distance to screening closure was only 21 m. Subsequent burns likely would increase the distance to screening closure by continuing to diminish understory shrub cover. Thus, width of treated strips should be considered in treatment design.

Table 17. Average distance (m) to screening closure in August 1985 after application of tebuthiuron in May 1978 or where herbicide treatment was followed by prescribed burning in the late winters of 1981 and 1984 near College Station, Texas

Tebuthiuron rate (kg/ha)	Burned[1]	
	Yes	No
0	12 a	13 ab
2.2	11 a	17 bc
4.4	14 ab	21 c

[1] Means followed by the same letter are not significantly different (P≤0.05) according to Student-Newman-Keul's test.

Tebuthiuron had little direct effect on forb production by the third growing season after application (Table 5), and subsequent burning in the winter can promote forb standing crops. Therefore, there is no indication that the tebuthiuron-burning sequence reduces quality of habitat for deer if the treatments are applied in an appropriate pattern. In addition, several beneficial attributes can be derived from herbicide-burn sequences. Brush removal opens thick cover that hinders hunters in pursuit of game. Game can be seen more easily, thereby possibly increasing the marketability of hunting leases. Also, subsequent burning of grasslands can increase availability of seeds and insects to granivorous and insectivorous species such as bobwhite quail (Koerth et al. 1986).

These experiments were designed so that untreated strips were alternated with treated strips. Given the rolling terrain over much of the Post Oak Savanna, strip treatment provides an acceptable alternative for most brush management programs. It is suggested that treated strips be alternated with untreated strips to remove some of the woody canopy cover to increase herbaceous production while still allowing deer easy access to brushy areas for browsing and/or escape and thermal cover. Treated strips no more than 325 m wide should not limit use of the entire clearing by deer. Untreated strips, at least 80 m wide, should allow deer to find adequate screening cover even when deciduous species are defoliated. Such a pattern would result in no more than 80 percent of a pasture being treated with herbicide. Untreated strips also should be left along drainageways, around watering facilities, and adjacent to cultivated fields to allow maximum use of these areas by wildlife.

Senzota (1985) evaluated the response of small mammals to the treatments initiated in 1978 from fall 1982 to fall 1983. At least six species of small mammals were present during the study period, but only cotton rats and wood rats occurred in numbers adequate for evaluating their responses to treatment. Reduction of shrub canopy cover by burning was followed by a sharp reduction in the abundance of wood rats. Reduction of herbaceous cover reduced cotton rats for most of the year following the burns.

As the grass-dominated herbaceous cover was restored, the cotton rat population returned to preburn densities (Senzota 1985). Because significant shrub cover was not established during the year following burning, wood rats did not use the burned areas for the year following treatment. Senzota (1985) concluded that annual burning would drastically reduce wood rat populations. However, frequent burning would likely induce cyclic use patterns of treated areas by cotton rats. He further hypothesized that a prescribed burning frequency that promoted grass cover would encourage an increase in cotton rat populations.

Influence of Tebuthiuron/ Prescribed Burning on Watershed Attributes

Terminal infiltration rates and sediment production 3 years after aerial application of tebuthiuron at 2.2 kg/ha differed little from values for untreated (wooded) areas (Lloyd-Reilley et al. 1984). Prescribed burning in the winter (December-February) temporarily decreased infiltration rates and increased sediment production. Infiltration rates equilibrated among brush management treatments with reinstatement of the herbaceous cover within 6 months after burning.

Sediment production was generally greater from burned than unburned plots after 5.5 months, but the absolute amount of sediment produced on the near-level (1-3 percent slope) fine sandy loam sites was not great, regardless of treatment. Moreover, sediment production from burned sites was not significantly different from that of untreated sites 1 year after burning. The brush management treatments had no effect on nitrate concentrations in runoff. However, in one of two experiments, total unfiltered nitrogen and phosphorus contents in runoff were slightly greater during the growing season following burning than from unburned sites.

Integration of Prescribed Burning with Tebuthiuron Applications

Tebuthiuron effectively controlled many of the major woody species on rangeland dominated by oaks and mixed hardwoods. However, several species of shrubs tolerated the treatment and increased in abundance after the overstory of oaks was removed. The increase in abundance of vines was spectacular following tebuthiuron application. For example, saw greenbrier rapidly grew up and into the aerial portions of many of the dead oak trees. This growth was so extensive that it essentially replaced the original oak canopies until the trees deteriorated.

Compared to responses of herbaceous vegetation following application of foliar sprays for woody plant control, vegetation changes following application of tebuthiuron lag for approximately one growing season, depending on rainfall. For example, application of foliar sprays for brush management may remove the woody canopies within 30 days (Scifres 1980), which allows the cover and standing crop of the herbaceous understory to increase by fall of the first growing season. In contrast, maximum herbaceous production may not occur until the second growing season after tebuthiuron application. As a consequence, fine fuel (herbaceous plants) of adequate load for prescribed burning is not accumulated until the fall of the second year following tebuthiuron application.

Fuel continuity may not be adequate to carry an effective fire until the third fall following application of the herbicide. By that time, vines and shrubs that tolerated the herbicide treatment may have become the limiting factor to herbage production. During this period, post and blackjack oak trees killed by the herbicide progressively deteriorate. Wind storms may remove essentially all except the primary branches from the trees, adding a considerable amount of coarse fuel to the herbaceous layer. Therefore, the data suggested that it is critical to plan the first burn for the winter in the third year following tebuthiuron application.

Pastures were burned when the air temperature was greater than 16 °C, relative humidity less than 50 percent, and the wind speed was 13 to 20 kilometers per hour (kph). Under these conditions, standing fine fuel water content was normally less than 20 percent. However, the logs and large branches on the soil surface were wet on the underside, and water content often averaged 60 percent for pieces 10 cm or larger in diameter.

The first burn may be relatively cool and spotty because of the presence of surviving brush plants and the relatively wet, fallen wood from dead oak trees that litter the surface. Little of this wood, limited primarily to those pieces 5 cm or smaller in diameter, may be removed by the first burn, except where accumulated piles ignite. Accumulations of the fallen wood restrict fine fuel development and provide discontinuities that may prevent their ignition. Ignition of the piles results in hot local fires that delay subsequent development of herbaceous stands.

Given annual average rainfall, a second burn may be best timed for application during the second or third winter following the first prescribed burn. The first prescribed burn in this research reduced the stature of surviving woody plants, removed some of the fallen debris, and generally promoted fuel continuity. The second burn removed as much as 50 percent of the remaining debris, removed the tops of many of the surviving woody plants, and removed vines such as saw greenbrier to ground line. Botanical composition following the second burn was characterized by relatively large proportions of little bluestem and other species favored by burning. Prescribed burns may be applied at 3-year intervals following the second burning and the grass sward progressively improved.

Development of a fine fuel load of adequate continuity to carry an effective burn necessitated deferment from grazing in this study. Cattle usually were removed in late August-early September (depending primarily on August rainfall) to allow herbage growth in the fall. In most years, this deferment allowed accumulation of 3,000 kg/ha or more fine fuel, depending on the shrub cover. Burns were applied in February and pastures were not grazed in most years until mid-April when the desirable grasses were of relatively high vigor.

Economic Comparison of Brush Management Treatments

Scifres (1987) projected the economic performance of tebuthiuron alone and tebuthiuron followed by prescribed burning on pastures initially treated in 1977 (hereafter referred to as moderate brush cover) and in 1978 (heavy brush cover) with 2.2 kg/ha of tebuthiuron. The herbicide application was assumed to cover the entire management unit (i.e. not patterned). Carrying capacities were projected over the expected lives of the treatments based on trends in vegetation change from 1977-78 through 1986.

Estimated costs of treatment were $110.25/ha for tebuthiuron application, $10/ha for the first prescribed burn, and $5/ha for subsequent burns. Purchase prices were $650 for cows and $1,250 for bulls (assumed ratio of 1 bull/19 cows). Variable costs for annual maintenance was $100/AU for pastures with heavy initial brush cover and $80/AU for the pastures with moderate cover. Selling price of calves over the analysis period was $1.45/kg. No interest charges were associated with the investment capital. The brush management projects were considered as potential alternative investments to placing capital in interest accruing accounts.

Economic comparisons were based on estimated cash flows, internal rates of return, and net present values (Scifres 1987). A 10 percent discount rate was arbitrarily selected for comparing alternatives. When the net present value of treatment is 0, the project has paid all costs and generated a 10 percent return on the investment.

Application of 2.2 kg/ha of tebuthiuron to the moderate brush cover was projected to have a 16-year treatment life and to yield 9 kg/ha more beef each year of the expected treatment life than on adjacent untreated pastures (Scifres 1987). The herbicide application was projected to generate a 8.2 percent internal rate of return. In contrast, the internal rate of return following application of tebuthiuron to the mature oak woodland (1978 site) was negative over the expected 12-year treatment life. Accumulated cash was estimated at $-14.13/ha following treatment of the heavy brush cover compared to $147.02/ha after tebuthiuron application to the moderate woody cover. The difference in economic performance was attributed to (1) the reduced performance of livestock the year after treatment of the heavy brush cover and (2) the rapid dominance of the treated pastures by previously subordinate vines and shrubs.

The application of prescribed burns at 2, 4, and 7 years after application of tebuthiuron to the moderate brush cover increased the internal rate of return by 2.7 percent to 10.9 percent, compared to application of the herbicide but with no prescribed burning (Scifres 1987). Prescribed burning extended the effective treatment life to 20 years, compared to 16 years without burning, and increased the estimated additional beef produced to 13.9 kg/ha/year.

Prescribed burning at 3 and 6 years after application of tebuthiuron at 2.2 kg/ha to the heavy brush cover resulted in an estimated 6.6 percent internal rate of return, compared to a negative internal rate of return where herbicide application was not followed by burning (Scifres 1987). The prescribed burns extended the expected treatment life from 12 to 17 years. The positive influence of prescribed burning following tebuthiuron application to the heavy brush cover was attributed to suppression of vines and shrubs released by the herbicide treatment.

Observations in 1986, 10 growing seasons after application of the tebuthiuron, indicated that prescribed burning at approximately 3-year intervals will likely perpetuate the positive benefits of herbicide treatment for an additional 10 years. However, the understory shrubs rapidly thickened following the burn in 1984 where tebuthiuron had been applied to the heavy brush cover in 1978. The increase in shrub cover and associated reductions in amount and continuity of fine fuel mean that prescribed burning will no longer be effective. Thus, chemical or mechanical brush management to reduce the cover of shrubs will likely be required to reinstate forage production on the pastures.

Ecological, Economic, and Management Implications

Experiments monitored continuously for 9 to 10 growing seasons allow several conclusions about the use of tebuthiuron for management of oak-mixed hardwood stands. These conclusions apply to late winter-early spring applications of the herbicide.

1. Tebuthiuron pellets aerially applied at 2.2 kg/ha (active ingredient) effectively control post oak, blackjack oak, water oak, and associated hard-to-kill species such as yaupon and winged elm. Control, expressed as canopy reduction and killing of plants, is usually not fully expressed until the second growing season following herbicide application in the spring.
2. Vines and shrubs not controlled by the herbicide may increase dramatically on some sites, becoming a management problem by the third growing season after tebuthiuron application. In addition, species not occurring prior to tebuthiuron application or present in small amounts may also increase in importance. These secondary woody stands may be suppressed by prescribed burning with headfires during late winter; burning a second time within 2 or 3 years of the first burn will likely be required for most sites to maintain shrub suppression.
3. Grass production usually is not increased the growing season following application of 2.2 kg/ha of tebuthiuron pellets. This lag in grass response is related to the time required for maximum brush control to occur. Application of 4.4 kg/ha of the herbicide may suppress grass production in localized areas through the second growing season after application. Prescribed burning during the winter after the second or third growing season following tebuthiuron application will increase grass production, compared to areas treated with the herbicide and not burned.
4. Control of woody plants with tebuthiuron increases the proportion of grasses of good-to-excellent value for grazing. This may be largely attributed to the increase the amount of species such as little bluestem in the grass stands. Prescribed burning amplifies and accelerates this shift in species composition.
5. Forb standing crops may not be affected during the first growing season following application of tebuthiuron pellets at 2.2 kg/ha but may be reduced during the second and third growing seasons. Prescribed burning during the winter will enhance reinstatement of forb populations.
6. Steer gains may be reduced for the first growing season following application of tebuthiuron to heavy brush cover. This is attributed to the slow response of grasses to

treatment and the reduction of available browse. The negative effect on animal performance may not occur following treatment of moderate brush cover where some grass production occurs even though brush control is delayed. Maintenance of habitat diversity (patterns, rates of treatments, timing of treatments, etc.) is critical for cattle to stabilize nutrient intake.

7. Tebuthiuron application may cause grasses to be preferred for grazing by cattle during the growing season following application. Special attention should be given to this possibility where the herbicide is applied in a pattern, such as for wildlife habitat. Reasons for the preference have not been discerned, but crude protein content of grass leaves may be increased for the growing season following tebuthiuron application. These effects are not detectable during the second growing season following application of the herbicide.

8. Where white-tailed deer management is a land-use objective, tebuthiuron should be applied in strips, probably no more than 325 m in width, and alternated with untreated strips to treat no more than 80 percent of the landscape. This pattern allows deer easy access to brush areas for browsing and/or escape and thermal cover.

9. Application of tebuthiuron followed by burning of near level sandy loam sites only temporarily influenced infiltration rates and sediment production. However, the potential negative effects of burning should be considered in management planning for areas with slopes greater than 3 percent.

10. Estimated internal rates of return from investment in tebuthiuron applications were greater on sites not invaded by previously subordinate shrubs. Prescribed burning may be used to suppress the negative influence of the shrubs and vines and increase internal rate of return associated with treatment.

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Acknowledgments

The initial phase of this study was conducted cooperatively with Dr. R. W. Bovey. Dr. L. F. Bouse is gratefully acknowledged for aerial application of the herbicide which was supplied by Lilly Research Labs. Those who aided in plot installation, evaluation, and maintenance include Al Rasmussen, Mike Foster, Andy Crane, Rob Flinn, John Lloyd-Reilley, Ken Parker, David McKown, Ray Angel, and Hugh Aljoe. The efforts of Julia Scifres in manuscript preparation are appreciated.

Appendix A

Scientific Names of Plants and Animals Mentioned in Text

Common Name	Scientific Name
Plants	
American beautyberry	*Callicarpa americana*
Bahiagrass	*Paspalum notatum*
Bell rhodesgrass	*Chloris gayana*
Black locust	*Robinia pseudo-acacia*
Blackjack oak	*Quercus marilandica*
Black willow	*Salix nigra*
Broomsedge bluestem	*Andropogon virginicus*
Brownseed paspalum	*Paspalum plicatulum*
Buckbrush	*Symphoriocarpos orbiculatus*
Bullnettle	*Cnidoscolus texanus*
Cedar elm	*Ulmus crassifolia*
Chinese elm	*Ulmus pumila*
Chinese tallow	*Sapium sebiferum*
Chinaberry	*Melia azedarach*
Common bermudagrass	*Cynodon dactylon*
Common honeylocust	*Gleditsia triacanthos*
Common persimmon	*Diospyros virginiania*
Coralberry	(see buckbrush)
Dallisgrass	*Paspalum dilatatum*
Downy hawthorn	*Crataegus mollis*
Eastern redcedar	*Juniperus virginiana*
Farkleberry	*Vaccinium arboreum*
Green sprangletop	*Leptochloa dubia*
Gum bumelia	*Bumelia lanuginosa*
Honeylocust	*Gleditsia triacanthos*
Honey mesquite	*Prosopis glandulosa* var. *glandulosa*
Indiangrass	*Sorghastrum nutans*
Little bluestem	*Schizachyrium scoparium*
Plants (Continued)	
Peppervine	*Ampelopsis arborea*
Poison ivy	*Rhus toxicodendron*
Post oak	*Quercus stellata* var. *stellata*
Possumhaw	*Ilex decidua*
Pricklypear	*Opuntia* spp.
Purpletop	*Tridens flavus*
Red lovegrass	*Eragrostis secundiflora*
Saw greenbrier	*Smilax bona-nox*
Smutgrass	*Sporobolus indicus*
Southern dewberry	*Rubus trivialis*
Sparkleberry	(see farkleberry)
Splitbeard bluestem	*Andropogon ternarius*
Sugar hackberry	*Celtis laevigata*
Texas persimmon	*Diospyros texana*
Texas wintergrass	*Stipa leucotricha*
Tree huckleberry	*Vaccinium arboreum*
Water oak	*Quercus nigra*
Western ragweed	*Ambrosia psilostachya*
Willow baccharis	*Baccharis salicina*
Winged elm	*Ulmus alata*
Yankeeweed	*Eupatorium compositifolium*
Yaupon	*Ilex vomitoria*
Animals	
Bobwhite quail	*Colinus virginianus*
Cotton rat	*Sigmodon hispidus*
White-tailed deer	*Odocoileus virginianus*
Wood rat	*Neotoma floridana*

Appendix B

Conversion of Metric to English Units[1]

Metric	English Equivalent
1 pound per acre (lb/A)	1.1 kilograms per hectare (kg/ha)
1 hectare (ha)	2.471 acres
1 kilogram (kg)	2.205 pounds
1 kilometer (km)	0.621 mile
1 meter (m)	3.28 feet
1 centimeter (cm)	0.394 inch

[1]Temperature in degrees centigrade (°C) may be converted to degrees Farenheit (°F) using the relationship (°C × 9/5) + 32 = °F.

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