B-1450
August 1983

Integrated Brush Management Systems (IBMS): Concepts and Potential Technologies for Running Mesquite and Whitebrush

The Texas Agricultural Experiment Station/Neville P. Clarke, Director/The Texas A&M University System/College Station, Texas

CONTENTS

CONVERSION OF METRIC TO ENGLISH UNITS

Metric unit(s)	**English equivalent(s)**
Centimeter (cm)	0.394 Inch
(Degrees centigrade [°C]x9/5) + 32	Degrees Fahrenheit (°F)
Hectare (ha)	2.471 Acres
Kilogram per hectare (kg/ha)	0.892 Pound/acre
Kilometer (km)	0.621 Mile
Kilometer per hour (km/hr)	0.621 Mile/hour
Liter per hectare (liter/ha)	0.107 Gallon/acre
Meter (m)	3.28 Feet (ft)
Square meter (m^2)	10.758 Square feet

INTEGRATED BRUSH MANAGEMENT SYSTEMS (IBMS): CONCEPTS AND POTENTIAL TECHNOLOGIES FOR RUNNING MESQUITE AND WHITEBRUSH

C. J. Scifres
Thomas M. O'Connor Professor
The Texas Agricultural Experiment Station (Department of Range Science)

J. L. Mutz
Assistant Research Scientist
The Texas Agricultural Experiment Station (Corpus Christi)

G. A. Rasmussen
Research Associate
The Texas Agricultural Experiment Station (Department of Range Science)

R. P. Smith
Research Associate
The Texas Agricultural Experiment Station (Department of Range Science)

SUMMARY

Integrated Brush Management Systems (IBMS) use two or more brush management methods in an appropriate sequence to achieve specific resource management goals within an economic framework, with cognizance of critical needs for enhancement of environmental quality and improvement of wildlife habitat. This concept reduces dependency on single methods of brush control by developing a logical series of treatments for application over a defined planning horizon. IBMS minimize the weaknesses of each treatment while amplifying its unique strengths. This can help the resource manager capitalize on ecological and economic synergisms not possible with single-treatment approaches. Research on IBMS reported herein describes herbicide-fire based systems applied with decision-deferment grazing for improving South Texas rangeland supporting excessive covers of whitebrush or the running mesquite complex (a shrub type composed of a mixture of decumbent honey mesquite and screwbean).

Prescribed burning in the winter, approximately 31 months after aerial application of 1.1 kilograms per hectare (kg/ha) of 2,4,5-T + picloram in the spring, and burning again at about 57 months after spraying, maintained canopy reduction of running mesquite more effectively than spraying or prescribed burning alone. Grass standing crops were greater and a higher proportion of the grass stands were composed of species of good-to-excellent grazing value on plots sprayed and burned than on untreated areas (periodic grazing deferment only) or those treated with herbicide or burning alone.

Aerial application of tebuthiuron pellets at 2 kg/ha in the fall of 1975 effectively controlled heavy stands of whitebrush. Although the subsequent prescribed burn could not improve brush control, forage production was increased and botanical composition of the stands was improved compared to areas treated with herbicide only.

Herbicide-fire combinations appear promising for improving rangeland supporting excessive cover of running mesquite or whitebrush. Herbicide application initially reduces the brush cover and releases herbaceous vegetation to serve as fine fuel as well as increasing livestock carrying capacity. Prescribed burning expedites forage production, improves botanical composition of herbage stands, and suppresses brush regrowth and reinvasion by woody seedlings. This research indicates that such sites may be burned at 3- to 5-year intervals during periods of average rainfall.

INTEGRATED BRUSH MANAGEMENT SYSTEMS (IBMS): CONCEPTS AND POTENTIAL TECHNOLOGIES FOR RUNNING MESQUITE AND WHITEBRUSH

INTRODUCTION

Excessive cover of woody plants on rangeland is a primary constraint to livestock production in Texas and much of the Southwest. Although there are accounts of vast expanses of pristine grasslands in South Texas (Scifres, 1980), there is reason to guard against conjuring visions of early grasslands completely free of woody plants such as honey mesquite *(Prosopis glandulosa)* (Hester, 1980). Woody plants long have been components of range vegetation. Remains of honey mesquite from archeological digs along the Frio River have been dated to, 300 B.C. (Hester, 1980). The diaries of explorers and travelers through Texas in the 1700's often refer to presence of specific woody plants which are now considered to be serious management problems (Inglis, 1964).

Woody plants, by virtue of man's influences (reducing occurrence of fires, restricting movements of grazing animals, overgrazing and spreading of seeds) (Scifres, 1980, 1983), spread from the draws and waterways and increased in stature and density to form today's "brush problem" (Bogusch, 1952; Johnston, 1962; York and Dick-Peddie, 1969). Bray (1901) referred to the "pigmy" forests of "chaparral" on the South Texas Plains at the turn of the century as not yielding to mesophytic forests because of low rainfall. In rationalizing the general dominance of woody plants instead of grassland, he stated:

> The temperature conditions are of significance to vegetation in the province but only indirectly do they react upon the character of the grass formations. This indirect control consists chiefly in permitting the occurrence of woody species that require high annual temperatures (Mimoseae, for example), which, with certain artificial barriers removed, *the burning of grass notably,* [emphasis added], are capable of waging a successful struggle against grass vegetation. With respect to the relations of grass formations to woody formations in the Rio Grande Plain, the encroachment of the latter has been so vigorous as practically to destroy continuous areas of open grass formation. Much of the province is covered by impenetrable thickets of chaparral.

Presently, more than 80 percent of the 43 million hectares (ha) of rangeland in Texas is so heavily covered with brush that livestock production is reduced (Scifres, 1980).

Early workers, bent on ridding rangeland of brush, set out to develop methods to *eradicate* the brush—an optimistic, if not impossible, goal (Scifres, 1981). The term soon found a prominent place in the vocabularies of ranchers (Caird, 1947) and researchers (Fisher *et al.*, 1946). Early efforts were viewed as a "war" against an enemy which was felt to be progressively occupying all productive rangeland (Caird, 1947). However, there were workers during the same period who recognized some positive attributes of plants such as mesquite. Parker (1943) proposed that:

> [c]onsidering the advantages and disadvantages of mesquite, the problem appears to be one rather of control than elimination; that is, control of further encroachment into grass land areas and the use of practical methods of thinning out some of the present stands, allowing the remaining perennial grasses to spread.

The term "brush control," as a philosophical replacement for "brush eradication," rapidly gained popularity and was almost universally used by the mid-1950's. However, the goal of brush control, applied in the purest sense, still connotes the desire to kill 100 percent of the target woody plant stand. Development of brush control methods traditionally has emphasized use of single technologies. Each available method is characterized by certain weaknesses as well as unique strengths. Some weaknesses of standard methods (Scifres, 1981) include:

1. Incomplete control of the target population of brush resulting in rapid development of regrowth stands which negate treatment effectiveness, and which may be more difficult to control than the original growth form.
2. Partial or ineffective control of associated species resulting in release of "new" brush problems after controlling the primary species. This may be a particular problem in mixed stands where secondary species released are more difficult to control than the initial target population. An example is release of yaupon *(Ilex vomitoria)* and/or winged elm *(Ulmus alata)* after control of post oak *(Quercus stellata)* and blackjack oak *(Quercus marilandica)* in east-central Texas (Scifres, 1980).
3. Lack of economic acceptability because of high treatment costs and/or requirement for reapplication. Multiple applications with phenoxy herbicides are usually necessary for effective control of species such as the post-blackjack oak complex, Macartney rose *(Rose bracteata)*, and running mesquite *(Prosopis* spp.) stands.

4. Potential for damage to susceptible crops in adjacent areas by physical drift and/or volatility associated with herbicide sprays. This potential problem is magnified when multiple herbicide applications are required for brush control.

5. Damage to desirable species, as is the case with use of aerial sprays that control native legumes.

Combinations of methods have been investigated to develop complementary treatment sequences, especially use of low-cost measures to extend the effective treatment life of costly practices and to improve degree of efficacy. Some of these treatments, spraying and chaining of honey mesquite as one example (Scifres, 1973), have proven highly satisfactory, and provide the basis for pursuing development of brush management systems.

CONCEPTUAL BASIS FOR INTEGRATED BRUSH MANAGEMENT SYSTEMS (IBMS)

The concept of brush management, "management and manipulation of stands of brush to achieve specific management objectives," considers the potential values of woody plants in the range ecosystem. The term *brush management* was used in the mid-1960's (Box and Powell, 1965) but has only recently been formalized (Scifres, 1980), and apparently is gaining acceptance. Appreciation of the concept was precipitated largely by the increasing values of rangeland for uses other than solely as grazing by domestic livestock, especially its importance as wildlife habitat. The emergency of wildlife as an economically viable resource provided impetus for managing the use of all range vegetation, not just the grass. "Although the concept of brush management on rangeland is not new, the time appears right for promoting its general acceptance" (Scifres, 1978).

Development of brush management systems requires consideration of all applicable brush control technologies. However, a brush management system, *a plan of procedure in which the application of the individual methods is coordinated by the manager in an orderly fashion,* is much more than simply a combination of brush control methods. "*Development of effective brush management systems necessitates that all processes required for designing, implementing, and maintaining range improvement—from the development of objectives for a given management unit to assessment of economic feasibility—be given appropriate consideration*" (Scifres, 1980). The systems are based on ecological potential of the land resource using principles of sound business and land management to achieve an economic result. IBMS are employed to optimize rangeland production considering all uses (livestock, wildlife, recreation) of the resource, not necessarily to maximize returns from any given use. Brush management is integrated with all other management inputs, especially grazing management, to achieve the appropriate result.

The IBMS concept reduces dependence on any given brush management method by emphasizing an appropriate sequencing of a series of alternatives. *The alternatives are selected such that the unique strengths of one compensate for any characteristic weaknesses of the other(s).*

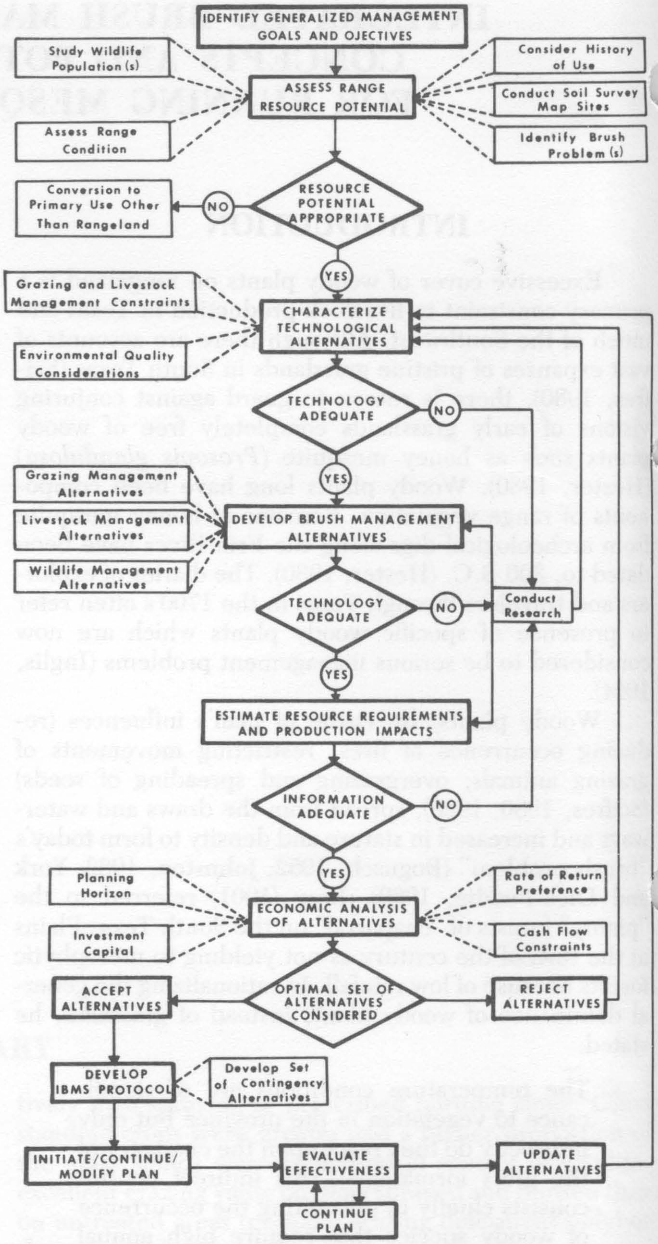

Figure 1. Processes and functions required for development of Integrated Brush Management Systems (IBMS) (from Scifres et al., 1983). Various persons contributed to development of the flow chart including R. E. Whitson, W. T. Hamilton, J. M. Inglis, and J. R. Conner.

It is beyond the scope of this paper to entertain in detail all steps involved in developing a specific IBMS (Figure 1). Present IBMS concepts represent an evolution of philosophies arising from experimentation since the early 1970's (Scifres, 1975, 1978, 1980). Scifres *et al.* (1983) discuss procedures for IBMS development. However, critical considerations, briefly stated, for developing an IBMS are:

1. *Management objectives*. The best use (relative to overall firm goals) of the management unit(s) targeted for brush management must be discerned, and reasonable production goals to be achieved in an appropriate time framework must be established. The objectives may usually be established to optimize economic returns from all potential uses rather than to maximize income from any single use.
2. *Natural resource potential*. Realistic management objectives cannot be established without a reliable estimate of production potential of the management unit. Present production level must be compared against potential production to assess economic feasibility.
3. *Grazing management*. Success from IBMS cannot be expected unless sound grazing management is an integral part of the system. Development of the most effective IBMS may necessitate some changes in grazing management strategies. IBMS may also be developed which take full advantage of present grazing management, or grazing management systems may be developed simultaneously with formulation of an IBMS.
4. *Available alternatives*. All available alternatives should be considered relative to such factors as their efficacy, characteristic weaknesses, expected treatment life, biological secondary effects (positive as well as negative), application requirements, and effects on wildlife habitat so that maximum flexibility of treatment choice is possible.
5. *Proportion of management unit to be treated*. Often there is management wisdom to applying the brush treatments in a pattern rather than treating the entire management unit. Key sites for wildlife habitat and areas for livestock shade and loafing must be considered. The pattern should be "tailor made" so as to best meet management objectives for the targeted management unit. This need has precipitated development of some rather novel treatment designs such as the "Variable Rate Pattern" (Scifres and Mutz, 1982).
6. *Economics*. A reasonable planning horizon, in light of management objectives, should be chosen. Management benefits and treatment costs must be projected, and alternative uses of capital considered. Sound, practical criteria must be selected for economic projections. These may range from projecting simple rates of return and payback periods on borrowed capital to more detailed approaches such as present-value analyses.

The primary purpose of this research was to investigate herbicide-prescribed fire combinations as potential components of IBMS for improvement of rangeland infested with running mesquite or whitebrush *(Aloysia lycioides)*. The research was stimulated by the effectiveness of herbicide/fire treatment sequences in systems for improving rangeland supporting excessive cover of difficult-to-manage species such as Macartney rose (Scifres, 1975).

THE RUNNING MESQUITE PROBLEM

There are 44 species of the genus *Prosopis* (mesquites) distributed in arid and semiarid areas of North and South America, northern Africa, and eastern Asia (Burkart and Simpson, 1977). The genus can be subdivided into the "mesquites" and the "screwbeans" based on legume (seed pod) characteristics (Bensen and Darrow, 1954). The legume of mesquite is slightly curved, creamish-tan (sometimes purple-tinged) at maturity, and generally resembles those of garden beans. The legume of screwbeans (also referred to as "tornillos") are tightly coiled spirals of uniform diameter (Bensen and Darrow, 1954) and bright yellow in some species.

Correll and Johnston (1970) list four species of *Prosopis* in Texas: *P. reptans* var. *cinerascens*, *P. pubescens*, *P. laevigata*, and *P. glandulosa*. Gould (1975) lists the same species as Correll and Johnston (1970), except that he includes three varieties of *P. glandulosa* (var. *glandulosa* [honey mesquite], var. *torreyana* [western honey mesquite], and var. *velutina* [velvet mesquite]). Honey mesquite *(P. glandulosa)* is the most cosmopolitan representative of the genera occurring in virtually every resource region of the state. Gould (1975) gives *P. reptans* var. *cinerascens* the common name "creeping mesquite" which also is locally referred to as running mesquite.

The running mesquite type consists of low, spreading individuals, rarely exceeding 2 meters (m) tall (usually less than 1 m), and usually occurs on alkaline or gypsum soils of the South Texas Plains. The stands may be surrounded by mixed brush *(Prosopis-Acacia)* on the less saline soils, and may contain various proportions of species common to mixed-brush stands, especially pricklypear *(Opuntia* spp.). We and others have often used the scientific name, *P. reptans* var. *cinerascens*, as the species which typifies such stands. However, most authorities (Vines, 1960; Burkart and Simpson, 1977; Bensen and Darrow, 1954) describe this species as "screwbean," "dwarf screwbean," or "tornillo." Based on legume characteristics of individuals in the stand studied in the present experiment and on similar sites, it appears that the running mesquite type in South Texas is composed primarily of a decumbent form of *P. glandulosa* with scattered individuals of *P. reptans* var. *cinerascens*. Therefore, future reference to "running mesquite" herein refers to a kind of shrub stand rather than to a specific species. There are no reliable estimates as to the area of influence of the running mesquite brush type, but it occurs throughout the South Texas Plains and into northern Mexico, especially on saline clay sites.

Control of running mesquite with conventional sprays, as with several other problem species such as Macartney rose, requires multiple herbicide applications. Two or three successive annual applications of 0.8 kilograms per hectare (kg/ha) active ingredient (ai) each of 2,4,5-T (2,4,5,-trichlorophenoxy)acetic acid are usually required for effective control (Hoffman and Ragsdale, 1967). Scifres *et al.* (1976) reported that three successive annual applications of 2,4,5-T at 0.8 kg/ha killed 11 percent of the running mesquite and reduced the canopies by 99 percent. The effective life of such treatments is normally about 5 years and rarely exceeds 10 years.

THE WHITEBRUSH PROBLEM

Whitebrush, also called "beebrush," is a serious management problem on about 2.4 million ha of South Texas rangeland. Almost 250,000 ha of these stands have canopy covers of $\geq$20 percent (Smith and Rechenthin, 1964). Whitebrush may occur in mixed stands with more than 15 other species of woody plants or in almost pure, dense thickets. Plants rarely exceed 2 m tall and are characterized by groups of relatively small, brittle stems arising from the base. The greatest canopy covers usually occur on sites of relatively high production potential. Whitebrush stands greatly reduce forage production and utilization by livestock, and the plant is of little value as browse or cover for range animals.

Conventional sprays of phenoxy herbicides at rates commonly used for range improvement do not control whitebrush effectively. Prior to the advent of tebuthiuron (*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N*,*N*′-dimethylurea), only picloram (4-amino-3,5,6-trichloropicolinic acid) effectively controlled whitebrush (Meyer *et al.*, 1969; Scifres *et al.*, 1981). Applications of 1 to 2 kg/ha of tebuthiuron effectively control many whitebrush and associated species, except for honey mesquite and pricklypear (Scifres *et al.*, 1979).

RESEARCH OBJECTIVES

Specific objectives of this study were to determine if:

1. a single application of 1.1 kg/ha of 2,4,5-T + picloram (1:1) could be used to effectively control running mesquite when followed by appropriately applied prescribed burns, and
2. there are advantages of prescribed burning following application of tebuthiuron pellets at 2 kg/ha ai for improvement of whitebrush-infested rangeland.

The results of the specific experiments were then considered as potential technological elements for inclusion into IBMS.

MATERIALS AND METHODS

Running Mesquite Case Study

The running mesquite-dominated site was Maverick clay loam (fine montmorillonitic, hyperthermic family of Ustollic Cambothids). The brush stand on the study area was dominated (>90 percent of the canopy cover) by running mesquite with scattered blackbrush acacia *(Acacia rigidula)* and lotebush *(Ziziphus obtusifolia)* plants. Initial canopy cover was estimated as 50 to 60 percent.

The site, located between Cotulla and Freer on the South Texas Plains, was aerially sprayed with 1.1 kg/ha of 2,4,5-T + picloram (1:1) in 47 liters/ha of a diesel oil:water (1:4) emulsion on May 24, 1977. Grazing exclosures, 1 ha in size, were erected on the sprayed and on an adjacent unsprayed area the following December. On January 25, 1979, half of each exclosure was randomly selected for burning with a headfire when the air temperature was 24 degrees centigrade (°C), relative humidity was 52 to 58 percent, and wind speed was 10 to 12 kilometers per hour (km/hr) from the southwest. Immediately prior to burning, fine fuel load was harvested from 24 randomly placed, 0.25-meter-square (m^2) quadrats, dried at 60°C for 48 hours (hr), and weighed.

Half of each plot sprayed in 1977 and burned in 1979 was reburned on February 16, 1982, with headfires when the air temperature was 33°C, relative humidity was 17 percent, and wind speed was 7.5 km/hr from the southwest. The area had not been grazed since the previous September 15 to allow accumulation of fine fuel. Fine fuel was harvested to a 2-centimeter (cm) stubble height from 20, 0.25-m^2 areas equally spaced on a diagonal across each plot, dried at 60°C for 48 hr, and weighed. The 1982 burn resulted in five treatments in the demonstration: untreated; sprayed in 1977; burned in 1979; sprayed in 1977 and burned in 1979; and sprayed in 1977 and burned in 1979 and again in 1982.

Reduction in brush canopy cover on each plot was estimated in late August to mid-September each year from 1977 until 1982. Standing crops of herbaceous vegetation were evaluated by clipping 15 to 25, 0.25-m^2 quadrats to a 2-cm stubble height in September 1977; May and August 1978; January, May, and July 1979; June and September 1980; July 1981; and June 1982. Herbage was separated into grasses and forbs, dried at 60°C for 48 hr, and weighed. Means of treated areas were compared to those of untreated areas using t-test ($\alpha = .05$). At the same time that standing crops were harvested, botanical composition based on foliar cover was determined from 50 inclined, 10-point frame sampling units equidistantly spaced on a diagonal across each plot. Species were grouped by grazing value according to assessments by Gould and Box (1965), Hoffman *et al.* (1979), and the range site condition guide published by the Soil Conservation Service. Experimental area was grazed in mid-May and again in mid-September each year of study except the first growing season after spraying when it was deferred until September. Grazing animals were removed from the area when approximately 60 percent of the topgrowth of key species was removed.

Ten to 15 soil samples were recovered from 0 to 8, 8 to 15, and 15 to 30 cm deep on April 10, May 2, June 12, and October 15, 1979; on April 1 and June 23, 1980; and on July 26, 1981. Samples were dried at 105°C for 48 hr and percentage soil water calculated on a dry-weight basis.

Whitebrush Case Study

The study site, located about 16 km northeast of Tilden, Texas, is predominantly Clareville sandy loam (fine montmorillonitic, hyperthermic family of Pachic Arguistolls). The site was dominated by whitebrush (canopy cover of 24.5 percent) but the stand contained scattered honey mesquite, spiny hackberry *(Celtis pallida)*, blackbrush acacia, and lotebush.

Tebuthiuron pellets (20 percent ai) were aerially applied at 2 kg/ha (ai) to the whitebrush site on November 29, 1975. Herbicide was applied to duplicate 2.1-ha plots alternated with untreated plots of the same size. On January 24, 1979, half of each plot was burned with a headfire when the air temperature was 13°C, the relative humidity was 19 percent, and the wind speed was 3 to 8 km/hr from the southeast. Prior to burning, fine fuel load was harvested from 50 randomly-placed, 0.25-m^2 quadrats in each plot. The fuel samples were oven-dried at 60°C for 48 hr and weighed. Immediately following burning, basal diameter (ground line) of whitebrush stumps and standing stems intercepted by six equally spaced, 46-m lines were measured with a caliper.

Standing forage was harvested in 25, 0.25-m^2 areas equidistantly spaced through each plot and separated into grasses and forbs in July 1977, and in August and December 1978. Immediately following the burning in 1979, 10 exclosures were established on each plot. In April and late July 1979, June and September 1980, and August 1981, herbage was harvested from 0.25-m^2 quadrats inside each exclosure and at 1 m from the exclosures. Grazing animals were allowed access to the experimental area using the same schedule as described for running mesquite. Foliar cover, based on 50 to 100, 10-point frame samples equidistantly spaced on a diagonal across each plot, by herbaceous species, was recorded at each harvest date. Initial brush cover was based on 50 to 60 sampling locations per plot using the point-center quarter method. Posttreatment brush canopy reduction was estimated visually at each herbage harvest date.

Data were subjected to one-way analysis of variance to evaluate treatment effect. Means were separated ($\alpha = .05$) using Student-Newman-Kuel's test (Steel and Torrie, 1980).

Ten to 15 soil samples each from 0 to 8, 8 to 15, and 15 to 30 cm deep were recovered from each plot on July 26, 1979, June 19, 1980, and July 23, 1981. Samples were dried at 105°C for 48 hr and percentage soil water calculated on a dry-weight basis. Rainfall data were obtained from the U.S. Weather Bureau recording station at Tilden.

RESULTS AND DISCUSSION

Running Mesquite Case Study

Canopy reduction of running mesquite exceeded 95 percent by August the year of application of 2,4,5-T + picloram (Figure 2). However, the woody plants recovered rapidly from the herbicide application. Canopy reduction averaged about 55 percent by fall 1979 following spraying in May 1977 (Figure 2). Although the spray killed about 25 percent of the plants, rapid regrowth of surviving brush had replaced nearly 90 percent of the original canopy cover by fall 1981.

Removal of the brush canopy by herbicide application, although temporary, improved botanical composition of the grass stand compared to stands on the untreated areas. For example, species of good-to-excellent grazing value accounted for nearly 50 percent (based on foliar cover) of the forage stand on the sprayed area by fall 1979, compared to less than 30 percent of stands on untreated areas (Figure 3). Rainfall in 1978 was greater than the longterm average, primarily the result of fall rains, but rainfall in 1979 was only 65 percent of average (Table 1). Species of good-to-excellent grazing value included common curlymesquite *(Hilaria belangeri)*, plains bristlegrass *(Setaria macrostachya)* and buffelgrass *(Cenchrus ciliaris)*. Primary species of fair grazing value were lovegrass tridens *(Tridens eragrostoides)*, sourgrass *(Digitaria insularis)*, pink pappusgrass *(Pappophorum bicolor)*, whiplash pappusgrass *(Pappophorum vaginatum)* and silky bluestem *(Dicanthium sericeum)*. Grasses of poor grazing value included whorled dropseed *(Sporobolus pyramidatus)*, purple threeawn *(Aristida purpurea)*, red grama *(Bouteloua trifida)* and tumble windmillgrass *(Chloris verticillata)*.

Improved botanical composition and grass release through the 1978 growing season following spraying in

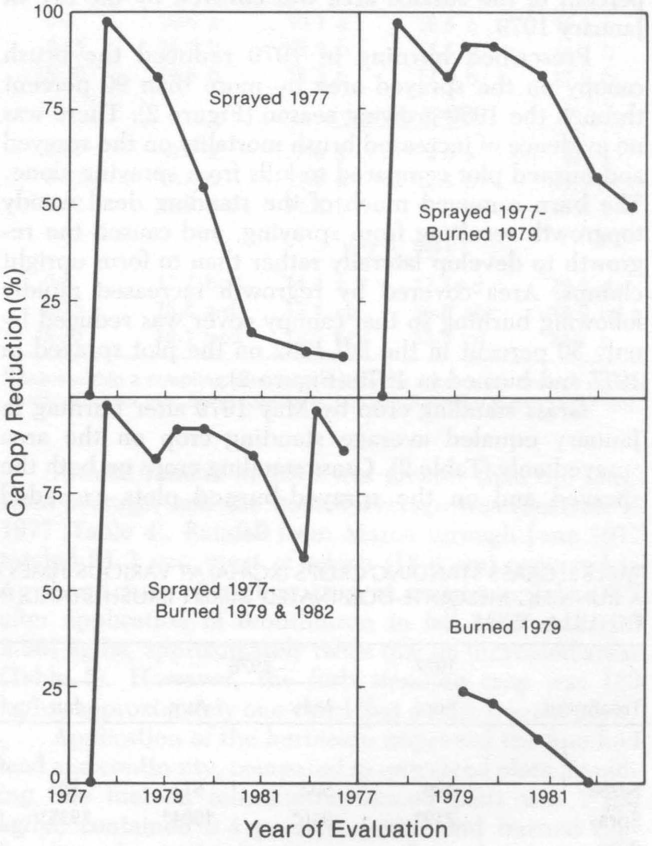

Figure 2. Canopy reduction (%) of running mesquite at various times after aerial application near Cotulla, Texas, of 2,4,5-T + picloram (1:1) at 1.1 kg/ha on May 24, 1977; spraying followed by prescribed burning on January 24, 1979; spraying followed by burning in 1979 and again in 1982; or burning in January 1979.

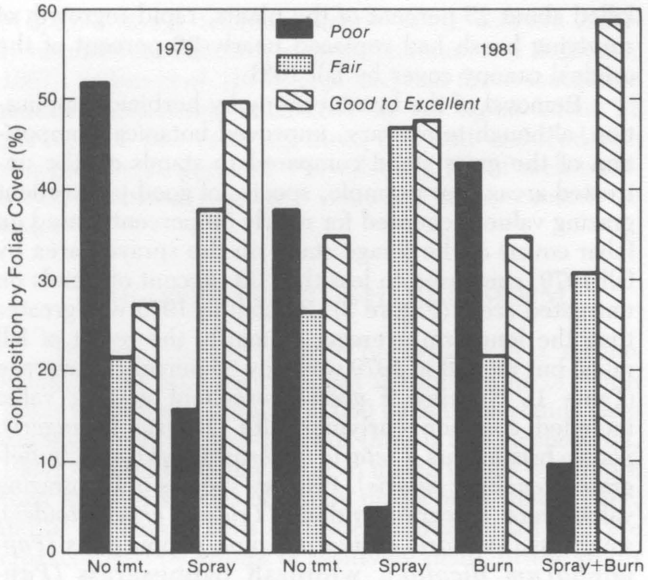

Figure 3. Composition (%) of grass stands based on grazing value of grasses near Cotulla, Texas, after aerial application of 2,4,5-T + picloram (1:1) at 1.1 kg/ha on May 24, 1977 and/or prescribed burning on January 24, 1979.

1977 (Table 2) improved fine fuel load (1,935 kg/ha) and continuity for prescribed burning. Consequently, 90 percent of the surface area was covered by the fire in January 1979.

Prescribed burning in 1979 reduced the brush canopy on the sprayed area by more than 90 percent through the 1980 growing season (Figure 2). There was no evidence of increased brush mortality on the sprayed and burned plot compared to kills from spraying alone. The burn removed much of the standing dead woody topgrowth resulting from spraying, and caused the regrowth to develop laterally rather than to form upright clumps. Area covered by regrowth increased rapidly following burning so that canopy cover was reduced by only 50 percent in the fall 1982 on the plot sprayed in 1977 and burned in 1979 (Figure 2).

Grass standing crop by May 1979 after burning in January equaled average standing crop on the area sprayed only (Table 2). Grass standing crops on both the sprayed and on the sprayed-burned plots exceeded standing crop on the untreated area during spring 1979. By the end of the second growing season following the burn (September 1980), standing crop on the area sprayed and burned exceeded ($\alpha = .05$) that on the plot which was sprayed only. Moreover, grass stands in the fall 1981 on areas sprayed in 1977 and burned in 1979 contained a greater proportion of species of good-to-excellent grazing value than those sprayed only (Figure 3). Improvement in botanical composition following burning resulted primarily from reduction in the proportion of the stands composed of species of fair grazing value, compared to stands on areas which were sprayed but not burned.

Fine fuel accumulation (3,290 kg/ha of standing fine fuel and 1,630 kg/ha of mulch) was adequate for installation of a second burn on the sprayed area during February 1982. At the time of the second burn, water content (dry-weight basis) of fine standing fuel averaged 7.4 percent. The heavy load of dry fuel, low relative humidity (17 percent), and relatively high air temperature (33°C) resulted in an intensely hot fire. Flame height was estimated to exceed 8 m during combustion

TABLE 1. MONTHLY RAINFALL (CM) FROM 1977 THROUGH 1981 ON THE EXPERIMENT IN WHICH HERBICIDE-PRESCRIBED FIRE WAS EVALUATED FOR IMPROVEMENT OF RANGELAND DOMINATED BY A STAND OF RUNNING MESQUITE NEAR COTULLA, TEXAS

	Year				
Month	1977	1978	1979	1980	1981
January	4.7	1.1	2.0	0.8	4.6
February	0.9	1.3	1.5	0.6	1.5
March	0.6	0.2	1.5	0.6	6.3
April	10.4	1.3	9.6	1.3	5.8
May	4.2	8.8	1.2	8.0	20.3
June	7.0	9.8	5.6	0	17.8
July	2.6	4.8	3.0	0.3	2.4
August	0.8	9.4	1.1	12.3	9.7
September	2.6	14.7	4.1	5.7	2.6
October	6.5	6.1	0	0.3	8.5
November	1.8	3.0	0.1	4.0	0
December	0.7	3.1	4.6	1.1	1.5
Total	42.8	63.6	34.3	35.0	81.1
% of avg	81	121	65	66	154

TABLE 2. GRASS STANDING CROPS (KG/HA) AT VARIOUS TIMES AFTER AERIALLY APPLYING 1.1 KG/HA OF 2,4,5-T + PICLORAM (1:1) TO A RUNNING MESQUITE-DOMINATED MIXED BRUSH STAND IN MAY 1977 AND/OR PRESCRIBED BURNING IN JANUARY 1979 NEAR COTULLA, TEXAS

	1977	1978		1979			1980		1981	1982
Treatment	Sept	May	Aug	Jan	May	July	June	Sept	July	June
					Grasses					
None	429	502	612	383	805	612	720	540	915	493
Spray	719*	916*	1004*	1935*	1629*	940*	1152*	2143*	2218*	1464*
Burn	—	—	—	—	533	552	691	997	1043	977*
Spray + burn	—	—	—	—	1557*	972*	2667*	3037**	3419*	1720*

*Significantly different from untreated area ($\alpha = .05$).

**Significantly different from untreated area and from area sprayed only ($\alpha = .05$).

on areas of heavier fuel loads. The second burn reduced woody plant canopy cover by 85 percent for the 1982 growing season (Figure 2). Grass standing was 1,653 kg/ha (data not shown) by June 1982 on plots sprayed in 1977 and burned in 1979 and 1982.

These results imply that prescribed burning may be used to prolong the canopy reduction achieved by herbicide treatment of running mesquite stands. Based on development rate of woody plant regrowth in this study, prescribed burning should be applied at about 3-year intervals to maintain brush suppression and improve production of herbaceous stands.

Prescribed burning was not effective as an initial treatment for reducing woody plant canopies. Prescribed burning of an unsprayed area in January 1979 reduced the brush canopy by only about 20 percent, based on evaluations in spring 1979 (Figure 2). The unsprayed plot supported only 383 kg/ha of fine fuel which occurred primarily in the spaces between brush plants. Consequently, only about 40 percent of the surface area was covered by the relatively cool burn. Grass standing crops on the area burned only did not statistically exceed those on the untreated plot, regardless of evaluation date, through July 1981 (Table 2). The apparent difference in grass standing crops of burned and unburned areas in June 1982 was attributed to random chance in sampling rather than to treatment effect.

Proportion of grasses of good-to-excellent grazing value had increased in 1981 compared to 1979, on the untreated area (Figure 3), apparently in response to the long deferments from grazing. There was little difference in the composition of herbaceous stands on the area burned once and the untreated area. Thus, the single prescribed burn of running mesquite stands did not result in substantial range improvement.

Development of luxuriant herbaceous growth on burned areas may reduce soil water contents in the upper 13 cm soil layer (Wright and Bailey, 1982). However, soil water contents to 30 cm deep from untreated plots and those burned only were generally less than from sprayed plots, whether burned or not, during April and May 1979 (Table 3). Since the most herbaceous vegetation occurred on the sprayed plot and the area sprayed and burned, the usual trend relative to soil water depletion did not occur on this site.

By mid-June, the growing season after burning, there was little difference in soil-water contents, regardless of treatment or sampling depth. Soil water contents varied little among treatments by fall 1979. Thus, prescribed burning alone or following spraying did not appear to accelerate soil-water depletion rates.

Whitebrush Case Study

Control of whitebrush by fall 1976 exceeded 90 percent after aerial application of tebuthiuron at 2 kg/ha the previous fall. Based on evaluations on January 20 and August 9, 1978, the herbicide had completely controlled the whitebrush. Whitebrush canopy cover on untreated plots on these dates averaged 32 percent.

TABLE 3. SOIL WATER CONTENTS (%) AT THREE DEPTHS AT VARIOUS TIMES AFTER AERIALLY SPRAYING RUNNING MESQUITE-DOMINATED MIXED BRUSH WITH 2,4,5-T + PICLORAM (1:1) AT 1.1 KG/HA ON MAY 25, 1977; BURNING ON JANUARY 25, 1979; OR SPRAYING FOLLOWING BURNING NEAR COTULLA, TEXAS

Soil depth (cm)	Treatment[1] None	Spray	Burn	Spray/burn
		April 10, 1979		
0-8	14.4 ab	20.2 bcd	12.8 a	16.6 abc
8-15	15.0 ab	21.4 cd	14.9 ab	19.0 bcd
15-30	15.6 ab	22.8 d	16.1 abc	20.4 bcd
		May 2, 1979		
0-8	15.4 a	19.2 b	16.5 ab	17.0 ab
8-15	17.4 ab	22.0 c	18.6 b	22.6 c
15-30	19.1 b	22.4 c	18.8 b	23.9 c
		June 12, 1979		
0-8	16.4 a	19.4 ab	18.8 ab	17.8 ab
8-15	19.2 ab	22.2b	21.5 b	21.4 b
15-30	18.9 ab	20.4 ab	20.9 b	21.1 b
		October 15, 1979		
0-8	7.3 ab	6.7 a	8.2 b	7.0 a
8-15	10.3 c	10.5 c	10.8 c	10.9 c
15-30	12.4 d	13.4 de	13.2 de	13.8 e
		April 1, 1980		
0-8	10.6 a	10.1 a	10.5 a	10.3 a
8-15	14.1 b	13.9 b	13.5 b	14.2 b
15-30	14.6 b	15.3 b	13.8 b	15.0 b
		June 23, 1980		
0-8	8.9 a	7.0 a	9.0 a	8.0 a
8-15	12.2 b	11.2 b	12.1 b	11.5 b
15-30	13.7 b	12.2 b	13.8 b	11.8 b
		July 6, 1981		
0-8	17.7 bcd	14.4 a	17.1a-d	20.1 de
8-15	16.8 a-d	15.1 ab	16.0 abc	18.9 cd
15-30	18.1 bcd	17.5 bcd	18.5 cd	22.1 e

[1]Means within a sampling date followed by the same letter are not significantly different ($\alpha = .05$) according to Student-Newman-Kuel's range test.

Annual rainfall in 1976 was greater than the long-term average, and the annual average was received in 1977 (Table 4). Rainfall from March through June 1977 totaled 21.3 cm, most of which (18.4 cm) occurred in April and June. Standing crop of grasses in July 1977 after application of tebuthiuron in fall 1975 averaged 2,561 kg/ha, approximately twice that on untreated areas (Table 5). However, the forb standing crop was 120 kg/ha, approximately one-third that on the treated plots.

Application of the herbicide improved the fine fuel load and continuity, compared to untreated plots. Standing fine fuel on tebuthiuron-treated plots was 1,750 kg/ha, contained 9.4 percent water, and burned uniformly and completely. Maximum flame height was 10 m, and the fire front moved at 46 to 60 m/minute. However, untreated plots did not burn because of the marginal fine fuel load (940 kg/ha with 10 percent water) which was not uniformly distributed.

TABLE 4. MONTHLY RAINFALL (CM) FROM 1975 THROUGH 1981 NEAR TILDEN, TEXAS WHERE A COMBINATION OF AERIALLY APPLIED TEBUTHIURON AND PRESCRIBED BURNING WAS EVALUATED FOR IMPROVEMENT OF RANGELAND DOMINATED BY WHITEBRUSH

	Year						
Month	1975	1976	1977	1978	1979	1980	1981
January	0.9	1.2	5.7	1.3	4.6	4.0	4.7
February	2.1	T	2.0	1.6	3.5	1.7	1.9
March	1.6	0.9	1.8	T	2.3	3.0	4.5
April	5.6	11.2	8.8	2.3	9.1	0.9	6.6
May	14.6	11.3	1.1	5.3	2.5	16.0	21.6
June	5.0	0.3	9.6	13.8	8.9	0	19.7
July	8.0	32.4	4.1	1.4	3.1	0.2	4.9
August	3.9	1.0	0.2	11.7	6.0	19.1	10.5
September	8.8	8.6	4.5	15.9	4.3	5.5	3.2
October	3.8	17.7	6.0	1.5	0.1	0.2	10.1
November	0	7.5	7.1	4.7	0.8	10.1	0
December	2.0	5.3	0.1	4.3	0.9	1.5	1.6
Total	57.2	97.3	51.0	63.8	46.1	62.2	89.3
% of avg	102	174	91	114	82	111	159

The fire burned down all whitebrush stems, 0.63 cm in diameter or smaller, on the area treated with tebuthiuron (Figure 4). Percentage burndown decreased as stem diameter increased with only 13 percent of the stems 1.9 cm in diameter being removed. Overall, the fire reduced the density of standing dead stems by 60 percent.

Grass standing crops in April 1979 after burning in January 1979 did not differ between burned and unburned areas which were treated with tebuthiuron (Table 5). Average standing crop on burned areas (3,988 kg/ha) was greater by July 1979 than that on plots treated with tebuthiuron but not burned. However, the increase in grass standing crop attributable to burning did not occur in 1980 or 1981. Increased grass standing crop for only the growing season following burning was expected because of the high degree of effectiveness of tebuthiuron in controlling the whitebrush.

Primary species of good-to-excellent grazing value were multiflowered false rhodesgrass *(Chloris pluriflora)*, common buffelgrass, buffalograss *(Buchloe dactyloides)*, pink pappusgrass, Arizona cottontop *(Digitaria californica)* and vine mesquite *(Panicum obtusum)*. Grasses of fair grazing value were represented primarily by hooded windmillgrass *(Chloris cucullata)*, sand dropseed *(Sporobolus cryptandrus)*, lovegrass tridens and filly panicum *(Panicum hallii* var. *filipes)*. Grasses of poor grazing value included oldfield threeawn *(Aristida oligantha)*, common sandbur *(Cenchrus incertus)*, tumble windmillgrass, gummy lovegrass *(Eragrostis curtipedicillata)* and red lovegrass *(Eragrostis secundiflora)*. Other grasses included Bell rhodesgrass *(Chloris gayana)*, common Bermudagrass *(Cynodon dactylon)*, common curlymesquite, southwestern bristlegrass *(Setaria scheelei)*, red threeawn *(Aristida longiseta)*, red grama, fall witchgrass *(Leptoloma cognatum)*, and whorled dropseed.

Application of tebuthiuron and lengthy deferments from grazing allowed proportion of grasses of good-to-excellent grazing value to essentially double, compared to stands on untreated areas, by 1978 (Table 6). Much of the increase in proportion of the more desirable grasses was attributed to dramatic increases in multiflowered false rhodesgrass. This species further responded positively to prescribed burning, accounting for the increase in the proportion of grasses of good-to-excellent value on plots treated with herbicide and burned, compared to that on plots burned only.

Prescribed burning increased utilization of the grasses, especially multiflowered false rhodesgrass, which may rapidly develop rank growth. The experimental area was grazed in a manner to prevent damage to burned

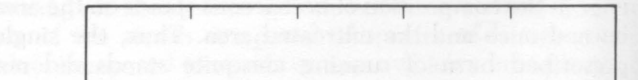

Figure 4. Burndown (% based on density) of whitebrush stems of various sizes on January 24, 1979 after aerial application of tebuthiuron pellets at 2 kg/ha on November 29, 1975 near Tilden, Texas.

TABLE 5. STANDING CROPS OF FORBS AND GRASSES AT VARIOUS TIMES AFTER APPLICATION OF TEBUTHIURON PELLETS AT 2 KG/HA IN NOVEMBER 1975 AND BURNING IN JANUARY 1979 NEAR TILDEN, TEXAS

	1977[1]	1978		1979		1980	1981
Treatment	July	Aug	Dec	April	July	June	Aug
				Grasses[2]			
None	1298 a	1232 a	842 a	524 a	996 a	452 a	1872 a
Tebuthiuron	2561 b	2504 b	1750 b	1208 b	1892 b	1738 b	3624 b
Tebuthiuron + burn	—	—	—	1288 b	3988 c	1960 b	3960 b
				Forbs[2]			
None	381 a	400 a	389 a	306 a	560 a	260 a	280 a
Tebuthiuron	120 b	100 b	180 b	332 a	320 a	180 a	240 a
Tebuthiuron + burn	—	—	—	796 b	940 b	220 a	758 b

[1]Taken from Scifres and Mutz, 1982.
[2]Means within a date followed by the same letter are not significantly different ($\alpha = .05$).

plots the growing season following burning. For example, cattle were excluded in late July 1979 after removing 49 percent of the standing crop on the burned plots (use of multiflowered false rhodesgrass was estimated at 55 to 60 percent). During the same period, they removed 18 percent of the grass standing crop on plots treated with tebuthiuron but not burned, and a negligible amount from the untreated plots. However, differences in utilization between burned and unburned areas were not apparent in 1980, the second growing season following prescribed burning. The cattle were allowed to remove 70 percent of the standing crop in mid-June 1980 from plots treated with tebuthiuron in 1975 and burned in 1979. They removed essentially the same amount (64 percent) from areas treated with tebuthiuron but not burned, but removed only 8 percent of the standing crop from untreated areas. The same trend was apparent after a grazing period in late July 1981 when the cattle removed 33 percent of the standing crops from plots treated with tebuthiuron and burned, 36 percent from plots treated with tebuthiuron only, and 15 percent from untreated plots.

No difference in soil-water contents occurred among treatments, regardless of depth, in late July 1979 (Table 7). However, average water contents were reduced, compared to that of untreated areas, to 15 cm deep on tebuthiuron-treated plots, both burned and unburned, on June 19, 1980. Variation in water contents of the surface soil was attributed to differences in amount of herbaceous standing crop among treatments during the dry period (no rainfall was received in June, rainfall in May came as a single early storm, and March-April precipitation totaled only 3.9 cm [Table 4]). The increased herbaceous cover apparently increased the water demand on the surface 15 cm of soil during this dry period (Table 7).

TABLE 6. PROPORTION OF HERBAGE STANDS COMPOSED OF GRASSES BY GRAZING VALUE AT VARIOUS TIMES AFTER AERIAL APPLICATION OF TEBUTHIURON PELLETS AT 2 KG/HA IN NOVEMBER 1975 AND PRESCRIBED BURNING OF TEBUTHIURON-TREATED AREAS IN JANUARY 1979 NEAR TILDEN, TEXAS

Grazing value	None	Tebuthiuron	Tebuthiuron + burn
		August 9, 1978	
Good-to-excellent	20.3	46.3	—
Fair	65.9	47.0	
Poor	13.8	6.7	
		April 25, 1979	
Good-to-excellent	26.0	51.0	66.7
Fair	50.0	36.7	18.2
Poor	24.0	12.2	15.1
		June 19, 1980	
Good-to-excellent	21.6	57.2	65.5
Fair	58.3	30.8	28.3
Poor	20.0	21.0	6.2

TABLE 7. SOIL WATER CONTENTS (%) AT VARIOUS TIMES AFTER AERIAL APPLICATION OF TEBUTHIURON PELLETS AT 2 KG/HA IN NOVEMBER 1975 AND BURNING IN JANUARY 1979 NEAR TILDEN, TEXAS

	Treatment[1]		
Soil depth (cm)	None	Tebuthiuron	Tebuthiuron + burn
		July 26, 1979	
0-8	13.8 b-d	12.7 d	11.7 d
8-15	17.8 ab	16.0 ad	16.2 a-d
15-30	17.3 ac	18.0 ab	16.2 a-d
		June 19, 1980	
0-8	6.4 ef	5.5 e-g	3.1 g
8-15	11.1 a-c	8.2 c-e	5.7 d-g
15-30	13.6 a	11.7 ab	11.0 a-c
		July 23, 1981	
0-8	7.0 cd	5.1 de	6.0 cd
8-15	8.6 bc	8.8 bc	9.1 bc
15-30	12.0 a	11.2 ab	9.7 a-c

[1]Means within a date followed by the same letter are not significantly different ($\alpha = .05$) according to Student-Newman-Kuels range test.

HERBICIDE APPLICATION/ PRESCRIBED BURNING AS POTENTIAL IBMS TECHNOLOGIES

Based on results of this research, herbicide application and prescribed burning combinations have potential as components of Integrated Brush Management Systems (IBMS) for rangeland supporting excessive cover of running mesquite stands or whitebrush. Success from such systems hinges largely on initial control of the woody species by herbicide applications.

Running Mesquite Complex

Based on results of the demonstration near Cotulla, prescribed burning following aerial application of 2,4,5-T + picloram (1:1) at 1.1 kg/ha maintained the reduction in woody canopy more effectively than where spraying alone was used for range improvement. However, burning alone was not effective as an initial treatment. Thus, effective performance of prescribed burning depended on initial effectiveness of the herbicide application. Strict attention must be given to applying the herbicide under the optimum environmental conditions and when the brush is in the appropriate stage of development (Scifres, 1980). Given those conditions, herbicide application reduces the brush canopy cover, thins the density of live plants, and releases herbaceous vegetation for grazing as well as fuel for prescribed burning (Figure 5).

Results of this study confirm earlier conclusions that single applications of foliar-active herbicides result in only short-term suppression of running mesquite. However, prescribed burning was effectively substituted for subsequent herbicide treatments, at least for the 6-year investigation period.

Perpetuation of brush suppression with prescribed burning was reflected by greater standing crops and grass stands composed of a higher proportion of species of good-to-excellent grazing value than those on untreated areas. A single burn of unsprayed areas did not generally increase forage yields compared to untreated areas. Ineffectiveness of burning alone was attributed to the extremely light load and discontinuity of fine fuel. Thus, the spray application increased amount and continuity of fine fuel.

The study on running mesquite was conducted on level to gently rolling topography, and burning plans and expected results will vary with topography. However, the failure of unsprayed brush to burn effectively in this study gives us reason to believe that the desired pattern

	PHASE I HERBICIDE APPLICATION	PHASE II IMPROVE HERBACEOUS STANDS	PHASE III FINE FUEL DEVELOPMENT/ BURN PREPARATION	PHASE IV PRESCRIBED BURNING	PHASE V MAINTENANCE OF RANGE IMPROVEMENT
OBJECTIVES	Reduce canopy cover and density of running mesquite and associated brush to release forage.	Use graze:rest periods to allow increase in proportion of desirable perennial herbs in stand.	Build continuous load of fine fuel adequate to ensure hot, uniform fire.	Maintain brush suppression; expedite increased proportion of desirable grasses and forbs.	Perpetuate desired level of productivity with minimal financial input.
ACTIVITY	Aerially apply 1.1 kg/ha of 2,4,5-T + picloram (1:1) or equivalent in the spring.	Defer from grazing for 60-90 days to allow for grass release; increase stocking rate in accordance with response of key species.	Defer grazing for 90-120 days in fall to build fuel; prepare fire plan and install fire guards.	Install prescribed burn according to sound fire plan; defer grazing to allow recovery of key species; then allow removal of no more than 60-65% of topgrowth before next deferment.	Schedule prescribed burns as needed (approximately 3- to 5-year intervals).
CONSIDERATION(S)	Apply in appropriate pattern for game management; usually treat no more than 80% of management unit; treatments will likely be extremely damaging to several preferred browse species.	First flush (first season) of grasses usually short-term opportunists released from shading etc; deferment designed to allow vigorous development of key species.	Deferment period must be adjusted to rainfall conditions; under drought conditions, utilize proper amount of accumulated fuel and delay burn.	Late winter when wind speed 16-19 km/hr, RH $< 60\%$, fine fuel water content $< 20\%$, backfire 30-45 m before headfiring: if RH $< 20\%$, fuel water $\leq 10\%$, wind speed of steady 8-11 km/hr will effectively burn.	Grazing deferment to build adequate fine fuel and post burn to allow grass recovery.
RESULTS	Brush defoliation $>90\%$ for first growing season; then 50% original cover replaced third growing season if not burned; grass released by spray may more than double that on unsprayed areas first growing season; forbs will be controlled by spray for at least 1 growing season.	Proportion of grass stand of good-to-excellent grazing dramatically increases by second growing season.	Accumulate 2,500-3,000 kg/ha of fine fuel with only minor discontinuities.	Fire covers $>90\%$ of area; brush stem ≤ 1.5 cm diam. consumed or dropped; warm-season perennials increased; brush regrowth killed to ground line; forb population restored.	Continual suppression of brush sprouts; remove rough vegetation, improve grazing distribution and range condition, etc.

Figure 5. Potential aerial spray-prescribed burning applications as components of Integrated Brush Management Systems (IBMS) for improvement of running mesquite-dominated rangeland.

for game management can be installed with the herbicide sprays, and be maintained with burning without undue risk of removing too much brush. This opinion, however, does not diminish the need for involving sound fire control measures within the fire plan. Under proper conditions, fire might be used to enlarge or reduce the area of brush suppression. Our data indicate that prescribed burning may be applied at 3-year intervals on previously sprayed sites with positive results, except as restricted by periodic drought.

Differential carrying capacities of the treatments applied to running mesquite were evaluated in late summer 1980. Based on available forage, it was estimated that 32 ha would be required to support an animal unit (AU) yearlong on the untreated rangeland. In comparison, estimated carrying capacities were 8 ha/AU for sprayed sites, and 6 ha/AU for areas which were sprayed and then burned.

Whitebrush

Primary objectives for prescribed burning following tebuthiuron application were to suppress species not affected by the herbicide (e.g., honey mesquite); remove standing woody debris; improve botanical composition of the forage stands; and improve grazing distribution and use of species which tend to develop rank growth after short periods of protection from grazing (e.g., multiflowered false rhodesgrass).

Prescribed burning in January 1979 following application of 2kg/ha of tebuthiuron in November 1975 increased forage standing crops only during the growing season following the burn. Lack of difference in subsequent years was attributed to the highly effective control of the whitebrush by the tebuthiuron. However, burning tended to improve the proportion of the herbaceous stand composed of grasses of good-to-excellent grazing value, and improved grazing distribution. Moreover, the prescribed burn removed standing whitebrush stems with basal diameters ≤1.0 cm and top-killed honey mesquite less than 1.5 m tall, but did not kill the large (4 to 6 m tall) honey mesquite trees (Figure 6). As a result the treated strips assumed a parklike appearance.

Based on forage production and using the technique of Whitson *et al.* (1979), the whitebrush-infested rangeland was capable of supporting 1 AU/14 to 16 ha yearlong. Carrying capacity at 18 months after herbicide application was estimated to be 1 AU/8 to 9 ha. However, it is important to note that carrying capacity for livestock was essentially unchanged during the growing season of herbicide application. This is to be expected because of the time required for tebuthiuron to complete its activity (Scifres *et al.*, 1979). Range improve-

	PHASE I HERBICIDE APPLICATION	PHASE II FINE FUEL DEVELOPMENT/ BURN PREPARATION	PHASE III PRESCRIBED BURNING	PHASE IV MAINTENANCE OF RANGE IMPROVEMENT
ACTIVITY	Aerially apply tebuthiuron pellets at 2 kg/ha (a.i.) in fall (Sept.-Oct.) or late winter (Feb.).	Defer grazing during fall for 90-120 days; prepare fire plan and install fire guards.	Install prescribed burn according to sound fire plan; defer grazing until late April-May or until reserve soil moisture adequate for rapid growth; defer after 60-65% of top growth removal by grazing.	Schedule prescribed burns as needed (approximately 3-year intervals).
CONSIDERATION	Apply in strips for game management (ex: 190-200 m treated alternated with 30-45 m untreated to improve 80-85% of area) will control spiny hackberry and several other associated species but not mesquite.	Deferment period must be adjusted to rainfall conditions; under drought conditions utilize proper amount of accumulated fuel and delay burn until next year.	When wind speed 16-19 km/hr, RH <60%, fine fuel moisture content <25%, backfire 30 to 45 m; if RH <20%, fine fuel moisture ≤10%, wind speed of steady 8-11 km/hr will effectively burn.	Grazing deferment to build adequate fuel and post burn to allow grass recovery.
RESULTS	Whitebrush defoliation greater than 90% by end of first growing season under average rainfall; ultimate kill usually exceeds 90%, grass release evident by end of first growing season; fall deferment expedites grass release; forb production greatly reduced.	Accumulate 2,500 to 3,000 kg/ha acre of standing fine fuel of relatively uniform distribution. (Fuel load on research area varied from about 1,000 to <2,500 kg/ha [oven-dry basis] but without major discontinuities).	Dead brush stems ≤1 cm in diam. consumed or dropped, grass released to uniform stand; warm season perennials increased, annuals decreased; forb population restored (wet springs stimulate forb production); fires usually do not carry through heavy brush covers on untreated strips.	Suppress brush sprouts, remove rough vegetation, improve grazing distribution, improve range condition, etc.

Figure 6. Potential tebuthiuron-prescribed burning applications as components of Integrated Brush Management Systems (IBMS) for improvement of whitebrush-dominated rangeland.

ment was initiated during the second growing season and under complete protection from grazing.

Estimated carrying capacity was 1 AU/5 to 6 ha by the growing season following application of the burns. Untreated ("brushy") areas protected from grazing for the same times were judged to be capable of supporting 1 AU/12 ha. These results and time-lapse between treatments will undoubtedly vary with rainfall conditions.

As with the running mesquite sites, the tebuthiuron-treated whitebrush sites may be effectively burned at 3-year interals, depending on rainfall. The treatment sequence in this study has left a minimal amount of brush residuum in the treated strips. This suggests the need for careful analysis of game requirements when developing a treatment pattern and determining percentage of the management unit to be treated.

ACKNOWLEDGMENTS

The authors gratefully acknowledge P. H. Welder and Dick Horton for providing land for this research. The efforts of Julia Scifres in manuscript typing and preparation are appreciated. The aid of numerous graduate students who helped with treatment installation and data collection from these studies is acknowledged, and the help of B. H. Koerth in data collection is appreciated.

LITERATURE CITED

Bensen, L., and R. A. Darrow. 1954. The Trees and Shrubs of the Southwestern Deserts. Univ. Arizona Press, Tucson. 437 pp.

Bogusch, E. R. 1952. Brush invasion in the Rio Grande Plains of Texas. Texas J. Sci. 4:85-91.

Box, T. W., and J. Powell. 1965. Brush management techniques for improved forage values in south Texas. Trans. North Amer. Wildl. and Nat. Resour. Contr. 38:285-294.

Bray, W. L. 1901. The ecological relations of the vegetation of western Texas. Bot. Gaz. 32:99-123, 195-207, 262-291.

Burkart, A., and B. B. Simpson. 1977. The genus *Prosopis* and annotated key to the species of the world. p. 201-215 *in* Simpson, B. B. (Ed.) Mesquite. Its Biology in Two Desert Ecosystems. US/IBP Synthesis Ser. 4; Dowden, Hutchinson and Ross, Inc., Stroudsburg, PA. 250 pp.

Caird, R. W. 1947. Eradicating mesquite. The Cattleman (Jan.):17-19.

Correll, D. S., and M. C. Johnston. 1970. Manual of the Vascular Plants of Texas. Texas Res. Found., Renner, TX. 1,881 pp.

Fisher, C. E., J. L. Fultz, and H. Hopp. 1946. Factors affecting action of oils and water soluble chemicals in mesquite eradication. Ecol. Monogr. 16:109-126.

Gould, F. W. 1975. Texas Plants. A checklist and ecological summary. Texas Agr. Exp. Sta. Misc. Pub. 585 (Rev.):121 pp.

Gould, F. W., and T. W. Box. 1965. Grasses of the Texas Coastal Bend. Texas A&M Univ. Press, College Station. 186 pp.

Hester, T. R. 1980. Digging into South Texas Prehistory. Corona Press, San Antonio, TX. 201 pp.

Hoffman, G. O., and B. J. Ragsdale. 1967. Chemical brush control. Broadcast aerial application. Texas Agr. Ext. Ser. L-415. 1 p.

Hoffman, G. O., J. D. Rogers, B. J. Ragsdale, and R. V. Miller. 1979. Know your grasses. Tex. Agr. Ext. Ser. B-182. 47 pp.

Inglis, J. M. 1964. A history of the vegetation on the Rio Grande Plains. Texas Parks and Wildlife Dept. Bull. 45. 122 pp.

Johnston, M. C. 1962. Past and present grasslands of southern Texas and northern Mexico. Ecology 44:456-466.

Meyer, R. E., T. E. Riley, H. L. Morton, and M. G. Merkle. 1969. Control of whitebrush and associated species with herbicides in Texas. Texas Agr. Exp. Sta. MP-390:18 pp.

Parker, K. W. 1943. Control of mesquite on southwestern ranges. U.S. Dep. Agr. Leaflet. No. 234:8 pp.

Scifres, C. J. (Ed.). 1973. Mesquite. Distribution ecology, uses, control, economics. Texas Agr. Exp. Sta. Res. Monogr. 1. 84 pp.

Scifres, C. J. 1975. Systems for improving Macartney rose-infested coastal prairie rangeland. Texas Agr. Exp. Sta. Misc. Pub. 1224. 12 pp.

Scifres, C. J. 1978. Range vegetation management with herbicides and alternate methods: An overview and perspective. Symp. Use of Herbicides in Forestry, U.S. Dep. Agr.-U.S. Environ. Prot. Agency, Arlington, VA (Feb. 21-22):151-165.

Scifres, C. J. 1980. Brush Management. Principles and practices for Texas and the Southwest. Texas A&M Univ. Press, College Station. 360 pp.

Scifres, C. J. 1981. Integrated brush management (IBMS) for rangeland: Concepts and applications. Internat. Stockmen's School. Beef Cattle Sci. Handbk. 18:74-79.

Scifres, C. J. 1983. Integrated brush management system (IBMS): Applications to the northern Tamaulipan Biotic Province. Proc. Symp. Tamaulipan Biotic Prov. (Oct. 28-30), Corpus Christi, TX. (In press).

Scifres, C. J., D. L. Embry, and J. L. Mutz. 1981. Whitebrush response to tebuthiuron and picloram pellets. Texas Agr. Exp. Sta. B-1356. 10 pp.

Scifres, C. J., W. T. Hamilton, J. M. Inglis, and J. R. Conner. 1983. Development of integrated brush management systems (IBMS): Decision-making processes. Brush Manage. Symp. Proc., Soc. Range Manage. (In press).

Scifres, C. J., G. O. Hoffman, and H. G. McCall. 1976. Carrier volume comparisons for multiple 2,4,5-T applications to South Texas mixed brush. Proc. So. Weed Sci. Soc. 29:245-252.

Scifres, C. J., and J. L. Mutz. 1982. Integrated brush management (IBMS): Concepts and case studies with whitebrush and running mesquite. Texas Agr. Exp. Sta. Prog. Rep. 4104. *in* Brush Manage. and Range Improve. Res. 1980-81:145-151.

Scifres, C. J., J. L. Mutz, and W. T. Hamilton. 1979. Control of mixed brush with tebuthiuron. J. Range Manage. 32:155-158.

Smith, H. N., and C. A. Rechenthin. Grassland restoration: The Texas brush problem. Unnumbered Bull., U.S. Dep. Agr., Soil Conserv. Serv., Temple, Texas. 17 pp.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and Procedures of Statistics. (2nd ed.). McGraw-Hill Book Co., New York. 633 pp.

Vines, R. A. 1960. Trees, Shrubs and Woody Vines of the Southwest. Univ. of Texas Press, Austin. 1,104 pp.

Whitson R. E., W. T. Hamilton, and C. J. Scifres. 1979. Techniques and considerations for economic analysis of brush control alternatives. Tex. Agr. Exp. Sta. Dep. Range Sci. Tech. Rep. No. 79-1. 30 pp.

Wright, H. A., and A. W. Bailey. 1982. Fire Ecology. John Wiley and Sons, New York. 501 pp.

York, J. C., and W. A. Dick-Peddie. 1969. Vegetation changes in southern New Mexico during the past 100 years. *In* Arid Lands in Perspective. Univ. Arizona Press, Tucson. 166 pp.

[Blank Page in Original Bulletin]

2M—8/83