Mechanical Control and Fertilization as Brush Management Practices Affect Forage Production in South Texas[1]

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Highlight

Brush control methods involving a minimum of soil disturbance were the most reliable methods of improving successional stage and increasing forage production. Soil disturbance retarded plant succession and caused a large fluctuation in yearly forage production. Nitrogen fertilizer increased forage production, but adversely affected species composition unless applied in conjunction with mowing. Mowing, as a follow-up maintenance practice, improved range condition, increased forage production on all brush control plots, and greatly increased the beneficial effects of all fertilizer treatments.

Prevention of shrub reinvasion after brush control by grazing management alone is difficult. Follow-up practices should be designed to take advantage of any gain by forage plants after the initial treatment. This study reports the use of fertilizer application and mowing as maintenance treatments in retarding brush reinvasion after mechanical brush removal.

Brush composition in South Texas is complex. Often as many as eight to ten species make up the plant composition referred to as "chaparral" (Box, 1964). These brush species, although growing together in the same habitat, have different growth forms and different physiological responses to brush control treatments. Because many species differ in their physiological response to herbicides, chemical treatment is seldom completely successful (Allison and Rechenthin, 1956). Control of one species often releases another more noxious one. Therefore, this project was designed to study effects of mechanical brush control practices commonly used in South Texas and to develop methods of maintaining the desired effects after treatment.

The study was conducted on the Rob and Bessie Welder Wildlife Foundation Refuge, San Patricio County, Texas. The Refuge lies in the western Gulf Prairies and Marshes (Gould, Hoffman, and Rechenthin, 1960) and has been described in detail by Box and Chamrad (1966).

The climate is characterized by warm temperature and high humidity throughout most of the year. The annual rainfall pattern normally has two peaks, one in the late spring and early summer and one in early fall. Plant production is relatively high and corresponds rather closely to the rainfall pattern, with seasonal peaks in the spring and fall (Box, 1960).

The study area is located on Victoria clay in the chaparral-bristlegrass community. Victoria clay is a heavy, self-mulching grumusol with Gilgai relief, low bulk density, high moisture holding capacity, low permeability, and high fertility (Box, 1961).

Methods and Materials

Five mechanical brush control treatments were applied as 20-acre, randomized blocks at each of three locations in late June, 1963 (Fig. 1). Treatments and costs were shredding (1.50/acre), roller chopping ($5.00/acre), scalping with a KG blade ($10.00/acre), root plowing ($10.00/acre), and root plowing with raking ($16.00/acre) (Box and Powell, 1965). All locations were within a pasture grazed yearlong at the rate of one mature steer to 15 acres and one white-tailed deer to 7 acres.

Brush composition and canopy cover were measured at each location before treatment, immediately after treatment in 1963, one year later in 1964, and two years later in 1965 by a modification of the line intercept method (Canfield, 1942). Fifteen, 100-ft intercepts were located randomly on each treatment.

In June, 1964, five fertilizer treatments were applied in a split-plot design on each brush control plot. Treatments included 100 lb N/acre,

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300 lb N/acre, 100 lb N plus 100 lb P_2O_5/acre, 100 lb P_2O_5/acre, and no fertilizer on a check plot. Nitrogen was applied as ammonium sulfate. Phosphorus was applied as treble superphosphate. Fertilizer treatments were selected on the basis of soil chemical analysis (Box, 1961; Kovar, 1963). Fertilizer was broadcast with a drill-type fertilizer spreader on plots parallel to each other.

A rectangular area across the fertilizer plots on each brush control block was mowed to a three-inch stubble with a rotary blade mower in late June, 1964, at a cost of $1.50/acre. This split split-plot design gave each brush control plot all combinations of fertilized, mowed plots and fertilized, unmowed plots. A cattle exclosure protected each treatment after mowing. Each exclosure contained an unmowed, fertilized area and a mowed, fertilized area of equal size.

Herbage production was sampled by a modification of the ranked set method described by McIntyre (1952). Instead of clipping and weighing a sample from every set, herbage from one in every four sets of ranked samples was weighed. Herbage in the other three sets was estimated. Production was determined in late August, 1964 and 1965 by species on each subplot.

Species composition of herbaceous vegetation on each treatment subplot was used to calculate the percentage of climax grasses as an indication of range condition. Only herbaceous vegetation was used in the calculation since the weight sample of woody plants was not adequate. Herbaceous vegetation from each treatment was sampled to within 10% of the mean.

A composite grass sample, approximating the species composition of the grasses, was collected from each fertilizer plot in late August, 1964, and analyzed for percent crude protein (Assoc. Offic. Agr. Chemists, 1960). On April 1, 1965, samples of Texas wintergrass (*Stipa leucotrica* Trin. and Rupr.) were collected from each fertilizer plot at each of the three locations. These samples were analyzed for percent crude protein and phosphorus (A.O.A.C., 1960).

Differences between brush control treatments were determined by simple analysis of variance. Differences between subplot treatments and interaction between treatments were determined by a split split-plot analysis of variance (Snedecor, 1956). Differences within treatments were determined by Duncan's new multiple range test (Li, 1957).

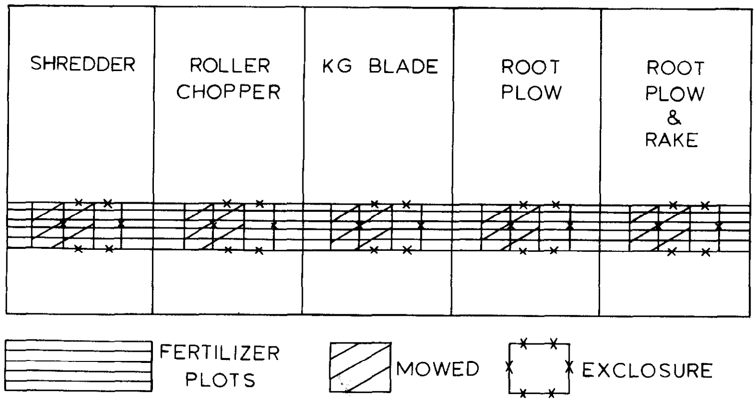

Fig. 1. Plot design of mechanical brush control, mowing, and fertilizer treatments.

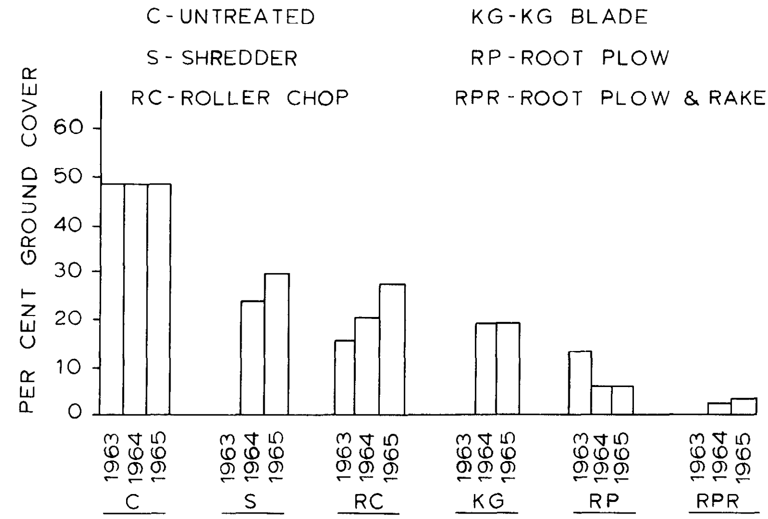

Fig. 2. Average per cent ground cover of woody species on brush control plots on the Welder Wildlife Refuge 1963, 1964, 1965.

Results and Discussion

Brush Control Treatments

Woody Vegetation.—Brush in the untreated, chaparral-bristlegrass community had a total ground cover of 48.6%. Many species of brush, such as blackbrush acacia (*Acacia rigidula* Benth.), agarito (*Berberis trifoliolata* Moric.), granjeno (*Celtis pallida* Torr.), lime prickly ash (*Zanthoxylum fagara* (L.) Sarg.), and *Condalia* spp., were found mixed together in brush "mottes." Huisache acacia (*Acacia farnesiana* (L.) Willd.) and honey mesquite (*Prosopis glandulosa* Torr.) were found more often as solitary plants.

Brush cover was reduced more than 50% by all brush control treatments (Fig. 2). Shredding, scalping with a KG blade, and root plowing with raking removed all brush cover in 1963. Immediately after treatment in 1963, brush cover was 15.9% on roller-chopped areas and 13.7% on root-plowed areas. Many plants on root-plowed areas which appeared to be alive immediately after treatment died later causing a decrease in brush cover between 1963 and 1964.

Between 1963 and 1964, many of the brush plants on top-removal treatments sprouted pro-

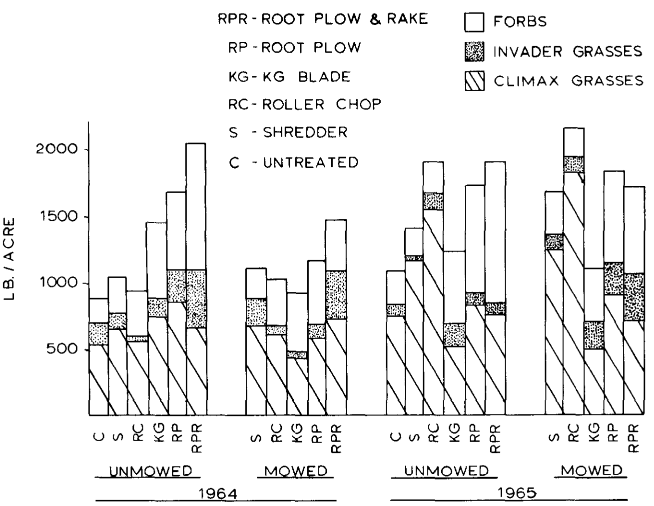

Fig. 3. Oven dry weight of herbage on brush control plots on the Welder Wildlife Refuge 1964, 1965.

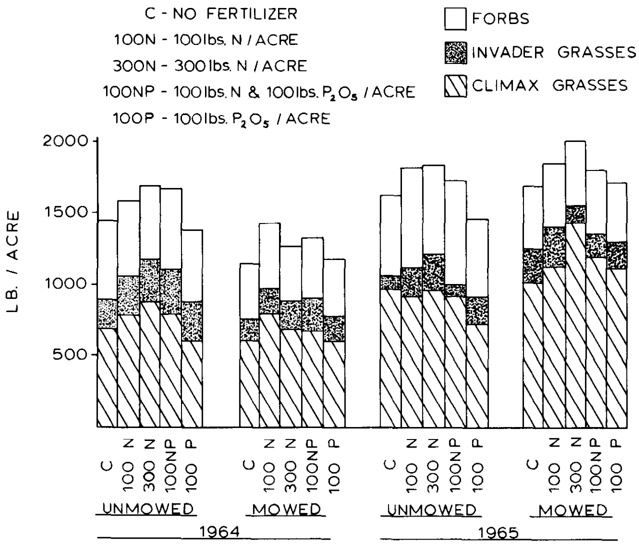

Fig. 4. Oven dry weight of herbage produced on fertilized and mowed plots on the Welder Wildlife Refuge 1964, 1965.

fusely, forming a low, dense brush canopy of succulent regrowth. Brush plants on roller-chopped areas were slightly taller than those on shredded or scalped areas. Brush on scalped areas resembled that on shredded areas except for a lower total brush cover on scalped areas.

Top-removal treatments, such as shredding, scalping, and roller chopping, caused resprouting of many of the same brush species that were cut or chopped. Only honey mesquite, tasajillo (*Opuntia leptocaulis* DC.), and pricklypear (*O. lindheimeri* Engelm.) decreased in percentage composition on those plots subjected to top-removal treatments. Huisache acacia, blackbrush acacia, agarito, granjeno, lime prickly ash, and *Condalia* spp. each had less canopy cover, but all increased in percentage composition as compared to untreated areas.

Root-plowed areas had a brush cover of 6.2% in 1964. Although the soil was root plowed to a depth of 10 to 14 inches, some of the brush plants reestablished root systems while others remained as standing litter. Reestablishment of root systems was especially true for cacti. Ground cover of pricklypear increased 365%, and tasajillo 20% on root-plowed areas. Ground cover of all other woody species decreased on root-plowed areas. Root-plowed and raked areas had a brush cover of 2.0% in 1964, most of which was due to seedlings. Ground cover of all woody species decreased on root plowed and raked areas.

Total brush cover increased to 30.2% on shredded areas and 28.2% on roller-chopped areas as compared to brush covers of 24.5% and 20.7% on these areas in 1964. There was little change in brush cover between 1964 and 1965 on areas which were scalped, root plowed, or root plowed and raked.

Herbage Production.—In 1964 total grass production was significantly ($P<0.05$) greater on root-plowed and root-plowed and raked areas than on the other four brush-treated areas (Fig. 3). However, there was no significant difference in climax grass production between any of the six brush-treated areas. In 1965 both total and climax grass production were significantly ($P<0.05$) greater on shredded and roller-chopped areas than on the other four brush-treated areas. Forb production was significantly ($P<0.05$) greater on scalped, root-plowed, and root-plowed and raked areas than on the other three areas in 1964 and 1965.

Brush cover was negatively correlated with grass production ($P<0.10$) and forb production ($P<0.05$) in 1964. Correlation coefficients between percent brush cover and grass and forb production were -0.796 and -0.843, respectively. Reduction of brush cover allowed more sunlight on areas previously shaded by brush mottes. In 1965 forb production was negatively correlated ($P<0.05$) with percent brush cover, but grass production was not affected by ground cover. Correlation coefficients between percent brush cover and forb and grass production were -0.877 and -0.276, respectively.

Between 1964 and 1965, total herbage increased on untreated, shredded, roller-chopped and root-plowed areas and decreased on scalped and root-plowed and raked areas. Grass increased on untreated, shredded, and roller-chopped areas and decreased on other areas. Forbs increased on untreated, root-plowed, and root-plowed and raked areas and decreased on other areas.

The amount of grass produced

increased most on treatments with least soil disturbance. The percentage of herbage produced by grass increased on shredded and roller-chopped areas and decreased on all other areas. Roller-chopped areas had the greatest increase in grass production (172.0%) and the greatest increase in percentage of herbage produced by grass (26.3%). Root-plowed areas had the greatest increase in forbs, 38.0%, and the greatest decrease in percentage of herbage produced by grass (10.7%).

Species Composition.—Most of the herbaceous vegetation in the untreated, chaparral-bristlegrass community was found in open areas between brush mottes. Grass grew well around edges of brush mottes and in rather open mottes, but few herbaceous species grew under mottes which had 100% canopy cover. In 1964 grass made up 79.2% of the herbage on untreated areas (Table 1).

As on untreated areas, a large percentage of the herbage on shredded areas was produced by grass. Spike bristlegrass (*Setaria leucopila* (Scribn. and Merr.) K. Schum.) was the most abundant grass and produced more than three times as much herbage as any other grass or forb on shredded areas. Grass composition on shredded areas was much like that on untreated areas except for an increase in spike bristlegrass. Most of the increased spike bristlegrass production occurred on those areas formerly covered by dense brush mottes. Of all grasses, spike bristlegrass responded the most vigorously after brush mottes were opened to sunlight. The herbage on shredded areas contained a relatively low percentage of forbs and a high percentage of desirable grasses.

Buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) was the most abundant grass on roller-chopped areas in 1964 and was more abundant on roller-chopped areas than on any other area. Relative abundance of stoloniferous grasses was increased by roller chopping. Sod-formers were not harmed as much as bunchgrasses but the cutting action of the chopper blades.

The release of spike bristlegrass on shredded mottes was not observed on roller chopped mottes. Shading by the taller brush plants on roller-chopped mottes was enough to maintain suppression of spike bristlegrass plants under the brush. Also, brush cover was present at all times on roller-chopped mottes, whereas there was no brush cover on shredded mottes immediately after treatment.

Nearly all of the grasses on scalped, root-plowed, and root-plowed and raked areas were invaders or "weedy" increasers or those grasses which grow best on disturbed soil and under moist conditions. Because most of the climax grasses on these areas

Table 1. Percentage composition of herbaceous vegetation on brush control plots on Welder Wildlife Refuge.

	1964						1965					
Species	C	S	RC	KG	RP	RPR	C	S	RG	KG	RP	RPR
FORBS	20.8	21.3	39.0	36.7	35.8	45.8	29.1	15.7	12.7	42.5	46.5	56.1
GRASSES												
Andropogon saccharoides	5.3	4.5	5.5	1.0	—	—	3.9	9.9	3.6	T	1.2	—
Aristida roemeriana	5.9	4.0	1.0	1.6	—	—	T	2.0	3.9	—	T	—
Bouteloua rigidiseta	1.0	—	—	—	—	—	—	—	—	—	—	—
Buchloe dactyloides	9.8	8.0	15.0	1.6	T	T	19.8	25.4	21.9	8.5	8.8	1.6
Chloris spp.	1.2	3.0	1.0	7.0	3.1	1.4	—	—	2.0	—	2.3	T
Cynodon dactylon	—	—	T	T	—	1.4	—	—	—	—	—	6.8
Digitaria insularis	—	—	—	—	—	—	—	—	T	—	—	1.3
Eragrostis lugens	T	—	—	—	4.0	T	5.3	2.3	6.6	6.1	3.2	2.1
Eriochloa contracta	4.9	3.0	—	—	4.3	14.7	—	—	—	—	T	T
Eriochloa sericea	—	1.5	—	T	—	—	2.3	5.3	—	—	—	—
Hilaria belangeri	1.8	3.0	1.0	—	—	—	1.4	—	4.2	—	—	—
Leersia monandra	—	4.5	T	—	—	—	T	1.6	1.1	—	—	—
Leptochloa nealleyi	—	2.5	—	3.6	—	1.3	1.5	—	—	15.6	—	3.1
Panicum filipes	8.3	5.6	7.5	11.7	T	9.0	3.2	4.9	5.7	7.4	—	3.1
Panicum obtusum	—	3.0	6.0	T	T	4.7	2.8	T	5.7	—	1.2	3.4
Paspalum pubiflorum	11.2	—	2.5	—	—	—	5.0	2.3	4.4	2.0	—	3.4
Setaria geniculata	3.5	—	2.5	13.5	5.5	14.5	2.7	—	2.0	7.4	2.7	2.7
Setaria leucopila	11.8	28.7	9.0	20.7	39.0	2.6	13.1	22.4	19.1	8.2	25.7	10.4
Sporobolus pyramidatus	4.7	3.5	—	—	5.9	—	T	—	—	—	2.1	—
Sporobolus asper	—	—	—	—	—	—	3.5	T	T	—	1.7	—
Stipa leucotricha	7.1	2.9	8.0	2.6	1.2	T	4.5	6.3	4.8	3.2	1.7	3.8
Tridens albescens	—	—	—	—	1.2	T	1.9	T	T	—	2.1	T
Tridens congestus	2.3	1.0	1.0	T	—	—	—	—	—	—	—	—

C, Untreated; S, Shredded; RC, Roller Chopper; T, Less than 1.0%; KG, KG Blade; RP, Root Plow; RPR, Root Plow and Rake; —, Not present.

were increasers, range condition calculated from percent of climax grasses indicated a lower condition than on plots with less soil disturbance.

Spike bristlegrass was the most abundant grass on scalped and root-plowed areas and produced 62.0% of the total grass production on root-plowed areas. Robust spike bristlegrass plants occurred on scalped microhighs where brush mottes had been sheared clean of vegetation by the KG blade. On root-plowed areas spike bristlegrass grew most vigorously on microhighs around prickleypear and woody plants.

Root plowing with raking destroyed most of the desirable grasses and caused the greatest increase in forbs and invader grasses. Forbs produced nearly half of the herbage, and invader grasses produced almost one-fourth. The percentage of climax grasses on root-plowed and raked areas was lowest for all treated or untreated areas.

Raking after root plowing reduced spike bristlegrass considerably. Root plowing alone did not remove the uprooted brush plants, and the plowing resulted in a rough, uneven surface with microhighs. However, raking removed brush litter, leveled microhighs, and destroyed favorable microsites for spike bristlegrass plants. Good drainage on the microhighs appears to be a significant factor in the distribution of spike bristlegrass and other bunchgrasses.

Most of the surface on scalped, root-plowed, and root-plowed and raked areas remained as bare ground immediately after the brush control treatments in 1963. In 1964 these areas had more, but less desirable, forage than the other brush control plots. The percentage of annual and weedy perennial grasses and invader forbs was greatest on those plots which had the greatest soil disturbance. In general, annual and weedy perennial species were closely associated with soil disturbance.

In 1965 the most abundant grasses on untreated, shredded, and roller-chopped areas were buffalograss and spike bristlegrass. Buffalograss increased considerably on all brush control plots between 1964 and 1965. The percentage of climax grasses remained greater for shredded areas than for any other area.

The greatest increase in climax grasses occurred on roller chopped areas. This large increase was mainly due to a 62.0% decrease in forbs with a subsequent increase in perennial grasses. The percentage of climax grasses on roller-chopped areas in 1965 was only slightly less than for shredded areas.

Both the number of grass species and the percentage of desirable grasses decreased on scalped areas between 1964 and 1965. Both weedy and desirable grasses decreased on scalped areas, and forbs increased. Nealley sprangletop (*Leptochloa nealleyi* Vasey) was the only annual grass which produced much herbage on any brush-control plot in 1965, and most of it occurred on scalped areas.

Forbs produced about half of the herbage on root-plowed and root-plowed and raked plots in 1965. Invader grasses decreased greatly on those plots, while desirable grasses decreased on root-plowed plots and increased only slightly on root-plowed and raked plots. Percentage of climax grasses remained lower for root-plowed and raked areas than for any other area.

Much of the change in species composition and herbage production on brush control plots between 1964 and 1965 was due to a difference in rainfall distribution for the two years (Table 2). During 1963 and the first half of 1964, rainfall on the study area was 40.5% below average. On July 19, 1964, the study area received 6.75 inches of rain. Annuals and weedy perennials responded vigorously to the moisture and produced much of the herbage on plots which had undergone a soil disturbance due to plowing or scalping. During the winter quarter in 1964, rainfall was 21.0% below average. Spring rainfall in 1965 was about average, but the 1965 summer rainfall was considerably less than average.

Near average spring rainfall in 1965 helped to increase production of a high percentage of perennial grasses on shredded, roller-chopped, and untreated areas. Perennial grasses continued to produce green forage throughout the relatively dry 1965 summer, whereas many of the annual and weedy grasses died. The lack of response from annuals and weedy increasers in 1965 resulted in an increase in invader forbs and a sharp decrease in forage production on many of the disturbed areas.

Most of the high forb production on scalped, root-plowed, and root-plowed and raked plots in

Table 2. Average quarterly rainfall on the study area between 1956 and 1963 and between January, 1963, and September, 1965.

Year	Quarter	Rainfall (Inches)
1956-1963	Jan.-March	5.19
	April-June	9.27
	July-Sept.	7.78
	Oct.-Dec.	8.34
	Total	30.58
1963	Jan.-March	1.92
	April-June	3.82
	July-Sept.	5.68
	Oct.-Dec.	6.18
	Total	17.60
1964	Jan.-March	4.30
	April-June	4.91
	July-Sept.	12.63
	Oct.-Dec.	6.46
	Total	28.30
1965	Jan.-March	3.91
	April-June	8.34
	July-Sept.	5.19

1965 was due to the increased production of western ragweed (*Ambrosia psilostachya* DC.) and Texas broomweed (*Xanthocephalum texanum* (DC.) Shinners). Pure stands of these forbs were observed in 1965 on many disturbed areas which were formerly occupied by annual and weedy perennial grasses in 1964.

Forage production fluctuated more widely on disturbed areas than on relatively undisturbed areas in relation to the amount and distribution of the annual rainfall. Methods requiring the least soil disturbance give a more stable yearly yield in areas subect to fluctuating climatic conditions.

Fertilizer Treatments

Herbage Production and Species Composition.—Nitrogen fertilizer significantly ($P<0.01$) increased grass production in 1964 (Fig. 4). There was no significant difference between the three nitrogen treatments. In both 1964 and 1965 grass production was greatest on plots which received the heaviest rate of nitrogen. In 1964 grass production on 300 lb N/acre plots was 32.0% greater than that on check plots. In 1965 grass production on 300 lb N/acre plots was 14.0% greater than that on check plots, but the difference was not significant ($P<0.05$). Grass production, in 1965, was significantly ($P<0.05$) greater on 300 lb N/acre plots than on 100 lb N plus 100 lb P_2O_5/acre and 100 lb P_2O_5/acre plots.

Forb production on fertilizer plots was not significantly different in either 1964 or 1965, and no single forb species appeared to be affected by any fertilizer treatment.

Annual and weedy, perennial, invader grasses responded more vigorously to all fertilizer treatments in 1964 than did climax grasses (Table 3). Invader grasses increased considerably on both nitrogen and phosphorus plots, while climax grasses increased slightly on nitrogen plots and decreased on phosphorus plots.

The relative abundance of forbs decreased on check plots and increased on all fertilized plots between 1964 and 1965. The greatest increase of forbs occurred on the plots which had the greatest decrease of invader grasses. The change in relative abundance of invader grasses, climax grasses, and forbs on each fertilizer plot indicates that forbs, in 1965, were more aggressive than climax grasses on fertilized plots and less aggressive than climax grasses on unfertilized plots.

In general, grasses which responded most vigorously to fertilizer treatments were the annuals and weedy perennials which increased most under conditions of soil disturbance and excess moisture. Rapid growth during the period of readily available soil moisture allowed weedy grasses to utilize more of the fertilizer nutrients than were utilized by the later maturing, climax grasses.

Percent Crude Protein.—Percent crude protein was significantly ($P<0.01$) greater in grass samples from all fertilized plots than in samples from check plots (Table 4). Percent crude protein was greater in grass samples

Table 3. Percentage composition of herbaceous vegetation on fertilizer plots on Welder Wildlife Refuge.

	1964					1965				
Species	C	100N	300N	100NP	100P	C	100N	300N	100NP	100P
FORBS	37.7	32.5	30.5	33.7	36.7	35.2	39.0	34.0	42.0	37.5
GRASSES										
Andropogon saccharoides	1.6	T	T	T	T	2.8	4.1	4.6	4.0	2.9
Aristida roemeriana	1.0	T	T	T	T	1.3	1.8	1.4	T	2.5
Buchloe dactyloides	3.8	7.4	5.3	4.2	4.1	11.1	8.8	8.1	9.3	7.2
Chloris spp.	3.2	1.0	2.3	2.3	2.6	1.1	1.2	2.2	1.5	1.6
Cynodon dactylon	T	T	T	3.6	1.8	1.6	1.7	T	1.1	T
Eragrostis lugens	1.0	T	T	T	1.4	3.6	3.6	1.8	3.4	6.6
Eriochloa contracta	5.7	3.2	5.4	13.2	8.2	T	T	T	T	T
Hilaria belangeri	T	1.0	1.0	T	T	T	1.8	T	T	2.2
Leptochloa nealleyi	1.4	7.8	5.0	1.5	1.4	3.1	5.7	6.5	2.2	2.2
Panicum filipes	7.1	5.9	7.2	6.7	7.1	4.1	4.9	3.3	6.6	5.1
Panicum obtusum	3.0	2.4	2.0	2.5	1.0	3.4	2.9	3.0	2.8	4.2
Panicum reptans	T	T	T	1.4	1.6	—	—	—	—	—
Paspalum pubiflorum	T	1.2	1.6	1.0	2.1	2.5	1.7	1.4	1.1	T
Setaria geniculata	8.6	11.0	10.6	8.1	8.8	2.6	1.3	2.3	2.1	2.9
Setaria leucopila	19.1	16.1	16.5	16.6	14.0	17.3	15.6	19.2	13.3	15.0
Sporobolus asper	—	—	—	—	—	T	1.3	3.3	1.2	1.3
Sporobolus pyramidatus	1.8	2.0	4.0	3.1	3.3	T	1.1	T	T	T
Stipa leucotricha	2.5	2.2	2.7	2.0	2.5	3.6	5.3	3.6	4.9	4.1
Tridens albescens	T	T	1.6	T	T	T	T	2.3	T	1.0
Tridens congestus	T	1.3	T	—	T	T	T	—	T	—

C—No fertilizer; 100N—100 lb nitrogen/acre; 300N—300 lb nitrogen/acre; 100NP—100 lb nitrogen plus 100 lb P_2O_5/acre; 100P—100 lb P_2O_5/acre; — Not present; T—Less than 1.0%.

from plots fertilized with nitrogen than in samples from plots fertilized with phosphorus or with nitrogen and phosphorus together.

Percent crude protein in grass from roller chopped and scalped plots was lower than in grass from shredded, root-plowed, and root-plowed and raked plots (Table 4). Most of the difference in protein in grass from brush-control plots may be attributed to a difference in species composition on different plots. Per cent crude protein in each species was not determined, but it may be assumed that percent protein was not equal in all grasses on the study area. Apparently, the species which made up the bulk of the grass on roller-chopped and scalped areas were not as high in crude protein as the species on shredded, root-plowed, and root-plowed and raked areas.

That all grasses did not respond to different fertilizer treatments in the same manner or to the same degree is also shown by a significant ($P<0.01$) interaction between brush control and fertilizer treatments. Percent crude protein was generally highest in grass samples from 300 lb N/acre plots and lowest in grass samples from check plots. However, this was not consistent on each brush-control plot, and protein in grass samples from any one brush-control plot did not rank consistently high or low for all fertilizer treatments.

Percent crude protein in Texas wintergrass was significantly ($P<0.01$) lower on phosphorus plots and higher on 300 lb N/acre plots than on other fertilizer plots (Table 5). Protein in grass from 100 lb N/acre and 100 lb N plus 100 lb P_2O_5/acre plots was only slightly higher than that in grass from check plots. The higher protein in Texas wintergrass on 300 lb N/acre plots indicates a nitrogen carry-over from 1964 to 1965.

Table 4. Average percent crude protein in composite grass samples from fertilizer and brush control plots in August, 1964.

Brush Control Treatments	Fertilizer Treatments: C	100N	300N	100NP	100P	Avg.[1]
Shredder	9.10	11.09	11.36	10.27	10.20	10.41[a]
Roller Chop	7.29	9.33	9.20	8.00	7.87	8.33[b]
KG Blade	9.22	9.67	9.92	9.94	8.55	9.46[b]
Root Plow	8.99	10.55	11.74	10.03	9.39	10.13[a]
Root Plow & Rake	9.83	10.54	10.34	9.09	10.56	10.07[a]
Average	8.88[a]	10.24[b]	10.51[b]	9.46[c]	9.31[c]	

[1] Those averages followed by the same letter are not significantly different; those followed by a different letter are significantly different.

Table 5. Average percent crude protein and percent phosphorus in Texas wintergrass from fertilizer plots in April, 1965.[1]

Percent	C	100N	300N	100NP	100P
Crude Protein	10.88[a]	10.91[a]	14.12[b]	11.25[a]	9.69[c]
Phosphorus	0.20[a]	0.20[a]	0.20[a]	0.34[b]	0.36[c]

[1] Those averages followed by the same letter are not significantly different; those followed by a different letter are significantly different.

A significantly higher percent phosphorus in Texas wintergrass from phosphorus plots indicates a phosphorus carry-over also. Phosphorus was 70.0% and 80.0% higher in grass from 100 lb N plus 100 lb P_2O_5/acre and 100 lb P_2O_5/acre plots, respectively, than in grass from plots not fertilized with phosphorus (Table 5).

Mowing Treatments

Mowing-Brush Control Treatments. — The 1964 data reflect first-year response to mowing treatments. All 1965 data pertaining to mowing treatments were collected 14 months after plots were mowed, and reflect the conditions the second year after mowing.

Mowing significantly decreased grass production ($P<0.01$), forb production ($P<0.05$), and brush production ($P<0.01$) in 1964. Averaged over all unfertilized, brush-control treatments, mowing decreased grass production 11.8%, forb production 21.5%, and brush production 64.7%.

Mowing did not decrease production by the same percentage on all brush control plots ($P<0.01$ interaction). In 1964 mowing significantly ($P<0.05$) increased grass production on plots with high percentages of desirable perennials and decreased grass production on disturbed plots with high percentages of undesirable forbs and weedy grasses. Perennial grasses, particularly buffalograss, appeared to withstand mowing better than annual and weedy, perennial grasses did. However, any comparison which might be made about the relative resistance of climax and weedy grasses to mowing was somewhat obscured by abnormally high summer rainfall after mowing. Many weedy grass plants, not present at the time of mowing, germinated and grew rapidly after the heavy rainfall of July 19, 1964.

In August, 1965, grass production averaged 16.8% greater on mowed plots than on unmowed plots, while forb and brush production averaged 22.0% and 53.8% lower, respectively, on mowed plots. The fact that grass production was greater on mowed plots one year after mowing indicates that grass production might have been greater on mowed plots in 1964 if there had been a longer growing period between mowing and sampling dates.

Between 1964 and 1965, grass increased on all mowed plots, but decreased on the unmowed, disturbed plots. The decrease in grass on the unmowed, disturbed plots was due to the sharp reduction in the production of drought-intolerant annual and weedy grasses during the dry 1965 summer. Mowing increased the percentage of perennial grasses, and grass production increased on mowed, disturbed plots between 1964 and 1965.

Mowing reduced brush cover on all plots from a low of 55.6% on scalped plots to a high of 90.0% on root plowed plots. Huisache was relatively abundant on scalped areas and resprouted rapidly after mowing. Cacti were abundant on root-plowed areas and were severely reduced by mowing. Cacti made up 94.0% of the brush on root-plowed areas and 64.0% on root-plowed and raked areas. Mowing decreased cacti 86.0% on root-plowed areas and almost 100% on root-plowed and raked areas.

Mower blades shredded cactus plants, and very few of the shredded pads formed new plants. Cactus pads, whether shredded or not, formed fewer new plants on grass-covered ground than on bare ground. Mowing appears to be an efficient and relatively inexpensive method of reducing cacti.

Mowing-Fertilizer Treatments. In 1964, grass and total herbage production were lower on all mowed, fertilizer plots than on unmowed, fertilizer plots. This may not be meaningful because of the short growing period between mowing and sampling dates. In 1965, after an equal growing period for both mowed and unmowed areas, grass production was greater on all mowed, fertilizer plots than on unmowed, fertilizer plots.

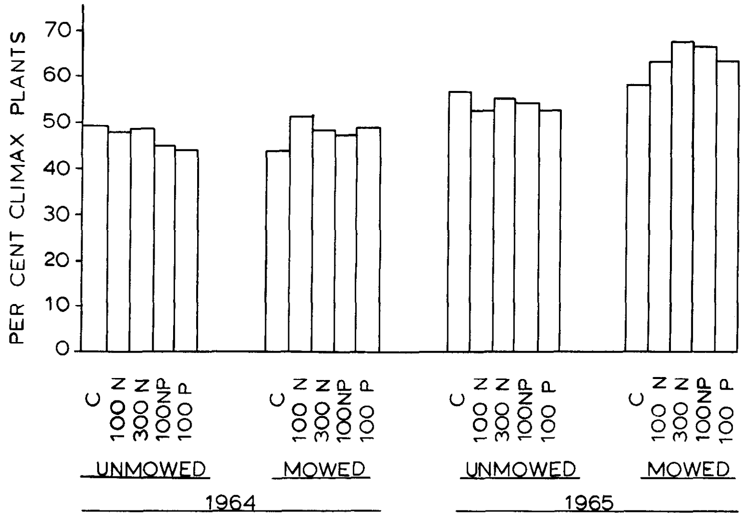

FIG. 5. Per cent of climax grasses on fertilized and mowed plots on the Welder Wildlife Refuge 1964, 1965.

Grass generally responded to fertilizer treatments in the same manner on mowed plots as on unmowed plots. Grass production was greater on mowed and unmowed, nitrogen plots than on mowed and unmowed, phosphorus and check plots. Mowing reduced differences in grass response to fertilizer treatments and masked differences in fertilizer uptake by different grass species. In general, weedy grasses responded readily to phosphorus and heavy rates of nitrogen on unmowed plots, but not on mowed plots.

In 1964 mowing and fertilizer treatments caused a greater reduction in grass on mowed, 300 lb N/acre plots than on other mowed, fertilizer plots ($P<0.05$ interaction). The difference in percent reduction was largely due to a differential response of invader and climax grasses to fertilizer and mowing treatments. The relatively large increase of invader grasses due to the 300 lb N/acre treatment was nullified because mowing reduced invader grasses more than climax grasses. The relative abundance of invader grasses was lower on unmowed check plots than on unmowed fertilized plots and generally greater on mowed check plots than on mowed fertilized plots.

All treatments with fertilizer on unmowed areas decreased the percentage of climax grasses (Fig. 5). In 1964 and 1965 there were more climax grasses on unmowed unfertilizer plots than on unmowed fertilized plots. By increasing the relative abundance of invaders and weedy increasers, fertilizer caused the fertilized areas to be in a lower successional stage than were the unfertilized areas. However, mowing and fertilizer treatments together caused greater climax grass production on all mowed fertilized plots than on mowed unfertilized plots. Mowing reduced invader competition on both fertilized and unfertilized plots. Reduced invader competition allowed more of the fertilizer nutrients to be utilized by climax grasses, and both percentage of climax grasses and grass production increased appreciably on mowed fertilized plots by 1965.

Mowing reduced forb and brush production about the same amount on all fertilizer plots. Neither forb nor brush production was significantly affected by fertilizer treatments on either mowed or unmowed plots in 1964 or 1965.

The probability of improving range condition by mowing, without fertilizer, appears more likely than by using fertilizer, without mowing. Mowing and fertilizer together improved range condition much faster than either mowing or fertilizer alone. The combination of mowing and fertilizer is an excellent means of speeding up succession while increasing forage production.

Summary and Conclusions

Between June, 1963, and August, 1965, the effects of different brush control, fertilizer, and mowing treatments were studied on the Welder Wildlife Refuge in South Texas. Five mechanical brush-control treatments including shredding, roller chopping, scalping with a KG blade, root plowing, and root plowing with raking were applied in June, 1963. Five fertilizer treatments and two mowing treatments were applied one year later on the brush-control plots in a split-split-plot design. Fertilizer treatments included no fertilizer, 100 lb N/acre, 300 lb N/acre, 100 lb N/acre plus 100 lb P_2O_5/acre and 100 lb P_2O_5/acre. Mowing treatments included mowing and no mowing.

Brush cover was reduced more than 50% by all brush-control treatments. Root plowing and raking caused the greatest brush cover reduction. Top-removal treatments caused vigorous regrowth of brush sprouts. Root plowing more than doubled cacti ground cover.

Production of total herbage was higher on all brush-treated areas except mowed scalped areas than on untreated areas. Grass and forb production were greater on disturbed areas than on relatively undisturbed areas in 1964. High summer rainfall and soil disturbance caused an increase in forbs and weedy grasses and a decrease in climax grasses. Because of the abundance of weedy grasses and forbs, areas disturbed by scalping and plowing were in lower successional stages than the relatively undisturbed shredded, roller-chopped, and untreated areas.

Low summer rainfall in 1965 attributed to a large reduction in annual and weedy grasses. Total grass production decreased on all disturbed plots between 1964 and 1965 because of the high percentage of drought-intolerant weedy grasses on these plots in 1964. Forbs, particularly invaders, replaced much of the weedy grass production on disturbed areas. Grass increased on undisturbed areas where climax grasses were relatively abundant.

Grass production was increased by nitrogen fertilizer and decreased by phosphorus fertilizer. Forb and brush production were not significantly affected by fertilizer treatments. All fertilizer treatments increased the relative abundance of invader and weedy grasses. Fertilizer was more readily utilized by weedy grasses than by climax grasses on unmowed areas.

All fertilizer treatments increased per cent crude protein in composite grass samples. The greatest increase occurred in grass fertilized with the heaviest rate of nitrogen. Percent crude protein in grass from different brush control plots was also significantly different. Much of the difference in protein in grass was due to differences in species composition on different brush control and fertilizer plots as well as the effect of different fertilizer treatments on a particular species.

Percent crude protein in Texas wintergrass was increased by heavy rates of nitrogen and decreased by phosphorus. Percent phosphorus was increased by phosphate fertilizer whether applied as straight phosphate or together with nitrogen fertilizer.

Mowing increased grass production and decreased forb and brush production. Mowing decreased invader grasses and improved range condition on all mowed brush-control plots. Cactus density and ground cover were effectively reduced by mowing. Fertilizer and mowing together improved range condition and increased grass production faster than either mowing or fertilizer alone.

Complete eradication of brush on South Texas rangeland appears to be impossible. Brush control may best be thought of as a maintenance problem similar to fence repair. A systematic, brush maintenance or "brush management" program appears more likely to succeed in continually improving forage quality and increasing forage production than many of the "eradication" methods.

LITERATURE CITED

Allison, D. V., and C. A. Rechenthin. 1956. Root plowing proved best method of brush control in South Texas. J. Range Manage. 9: 130-134.

Assoc. Offic. Agr. Chemists. 1960. Official methods of analysis. A.O.A.C. Washington, D. C. 9th Ed. 823 p.

Box, T. W. 1960. Herbage production in four range plant communities in South Texas. J. Range Manage. 13: 72-76.

Box, T. W. 1961. Relationships between plants and soils of four plant communities in South Texas. Ecology 42: 794-810.

Box, T. W. 1964. Changes in wildlife habitat composition following brush control practices in South Texas. Trans. N. Am. Wildl. and Nat. Res. Conf. 29: 432-438.

Box, T. W., and A. D. Chamrad. 1966. Plant communities of the Welder Wildlife Refuge. Contrib. No. 5, Ser. B, Welder Wildlife Foundation, Sinton, Texas. 28 p.

Box, T. W., and J. Powell. 1965. Brush management techniques for improved forage values in South Texas. Trans. N. Am. Wildl. and Nat. Res. Conf. 30: 285-296.

Canfield, R. H. 1942. Application of the line intercept method in sampling range vegetation. J. Forestry 39: 388-394.

Gould, F. W., and G. O. Hoffman, and C. A. Rechenthin. 1960. Vegetational areas of Texas. Tex. Agr. Ext. Serv. Publ. L-492. 4 p.

Kovar, J. A. 1963. Physical, chemical, and mineralogical properties of some soils of the Welder Wildlife

Foundation. M. S. Thesis. A & M College of Texas. 88 p.

Li, J. C. R. 1957. Introduction to statistical inference. Edwards Brothers, Inc., Ann Arbor, Michigan. 568 p.

McIntyre, G. A. 1952. A method for unbiased selective sampling, using ranked sets. Austral. J. Agr. Res. 3:385-390.

Powell, J., and T. W. Box. 1966. Brush management influences preference values of South Texas woody species for deer and cattle. J. Range Manage. 19:212-214.

Snedecor, G. W. 1956. Statistical methods. 5th Ed. The Iowa State Univ. Press, Ames, Iowa. 534 p.