EFFECTS OF FIRE, ASH, AND LITTER ON TOBOSA PRODUCTION

by

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The effects of fire (litter removal, ash deposition, and direct heating) on soil factors (moisture, temperature, exchangeable ammonia, and nitrate) and tobosa production were studied in 1974 near Post, Texas in an effort to understand increases in tobosa yields following burning. In addition, tobosa community nitrogen levels were examined on five different ages of burns ranging from current to five years old for both convex and concave topographic sites near Colorado City, Texas in July of 1973 and 1974.

Of fire's effects, only litter removal affected the soil factors measured. Plots without litter were warmer slightly drier, and had higher soil nitrate levels than plots with litter. In years of normal or above normal precipitation, the higher soil temperatures stimulate tobosa growth and soil nitrate production on plots without litter compared to the cooler plots with litter. During dry years, however, the warmer temperatures on plots without litter increased moisture stress on plants which negated the beneficial effects of warmer soil temperatures and decreased tobosa yields on burned plots.

Fire consumes most of the litter and old growth originally present. Relatively large new growth yields the first two growing seasons following fire restores old growth-N to prefire levels by the end of the third growing season. Litter-N levels, however, are not restored until the end of the fifth growing season when stems produced during the first few seasons die and fall as litter. High inherent variation prevented the recognition of any meaningful trends in root or soil nitrogen levels. Concave sites tended to recover from fire more quickly than did convex sites.

It appears that concave sites may be burned at five year intervals without depleting community nitrogen reserves and endangering future tobosa yields. Convex sites should not be burned more frequently than once every 7 or 8 years.

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CHAPTER I

INTRODUCTION

Spring burning has proven useful in managing tobosa (*Hilaria mutica*, Benth.) communities in Texas. Wright's (1969, 1972) reports of increased tobosa production, removal of standing dead mesquite trees, and the killing of live mesquite trees by spring burning has greatly heightened interest in controlled burning of tobosa communities.

A recently completed study (Sharrow, 1973) indicates that higher tobosa yields following fire are accompanied by a reduction in the total amount of nitrogen stored in the soil, thus burning too frequently may deplete the soil nitrogen reserves and reduce future plant growth.

With the increasing use of prescribed burning in tobosa communities in recent years, an insight into fire's mode of action in stimulating tobosa production and an estimate of the longevity of its effects upon the community becomes increasingly important.

The objectives of this study were two-fold. First, the relative importance of the following effects of fire in stimulating herbage production were evaluated: litter removal, ash deposition, and direct heating. Second, the time required for re-establishment of the prefire levels of litter, standing old vegetation, current growth, and total soil nitrogen were obtained. It is hoped that these data will serve as a guide in determining the proper interval between prescribed burns in tobosa communities.

CHAPTER II

LITERATURE REVIEW

Plant Response to Spring Burning

The impact of spring burning on herbage production varies with climate and the species composition of the stand.

Several authors have noted increased bluestem (*Andropogon* spp.) production following spring burning on the Great Plains. In northwest Wisconsin, Vogl (1969) reported herbage yields of 865 and 2363 kg/ha on control and burned plots respectively. Hadley and Kieckhefer (1963) reported that annual burning of big bluestem (*Andropogon gerardii*) and Indian grass (*Sorghastrum nutans*) communities in Illinois maintained high shoot production compared to unburned communities. This production declined by over 50% following one year without fire. It was also noted that root biomass increased with increased fire frequency. Old (1969), working in east central Illinois, observed total herbage productions of 513 and 272 g/m^2 on a current year's burn and a four year old burn respectively. Increased flower stalk production accounted for most of the extra production on burned areas. In central Louisiana, Duvall and Whittaker (1964) reported increased plant production following spring burning of bluestem range.

In the drier portions of their range, bluestems do not benefit from annual fire. Owensby and Anderson (1967) found that early spring burning of bluestem range in the Kansas Flint Hills reduced herbage production while late spring burning had little effect upon production. McMurphy and Anderson (1965), also working in the Flint Hills, confirmed these results and noted reductions in water infiltration rates and soil moisture on burned areas relative to controls. It appears that in the more xeric portions of its range, little bluestem (Schizachyrium scoparium) requires above average precipitation or some litter on the soil surface to maintain adequate soil moisture.

Yearly variations in precipitation and other climatic parameters can greatly affect post fire herbage yields. Ehrenreich and Aikman (1963) reported that vegetation on burned areas initiated growth two to three weeks earlier than on unburned areas, but that in 1956, following a very dry year in 1955, growth on the burned areas stopped early in the summer due to inadequate soil moisture, while vegetation on the control areas continued to grow late into the summer. The net result was equal seasonal production for all treatments. In 1955, following a year of above average precipitation in 1954, all burned areas produced more herbage than controls even though the summer of 1955 was quite dry. It thus appears that the previous year's precipitation can greatly affect plant responses to burning in the spring.

In contrast to bluestems, some grasses do not respond favorably to fire. Dix (1960) noted decreased production of western wheatgrass (*Agropyron smithii*) and needle-and-thread (*Stipa comata*) the first year following fire. Cable (1967) found little difference in production of perennial grasses on burned and unburned areas in Arizona. Launchbaugh (1964) reported that spring burning during a dry year reduced the production of buffalograss (*Buchloe dactyloides*)- blue grama (*Bouteloua gracilis*) by 65%, western wheatgrass by 82%, and shortgrasses by 48% on an upland site near Hays, Kansas. Smith (1960) found little difference in production between control and burned plots in northern Australia; however, a definite shift in species composition of the burned stand was evident.

In the mixed prairie, Wright (1974) reported that vine mesquite (*Panicum obtusum*) and Arizona cottontop (*Digitaria californica*) were favored by fire during years of adequate moisture, while buffalograss, blue grama, and sand dropseed (*Sporobolus cryptandrus*) were unaffected by spring burning. Sideoats grama (*Bouteloua curtipendula*) was not harmed by fire in a wet year, while in a dry year, fire reduced its production by 40%. Tobosa grass responded to spring burning by increased growth in normal to wet years and by decreased growth during drought years. Wright (1972) observed that tobosa yields in Texas were 2396 vs. 1118 kg/ha during a normal year and were 897 vs. 1086 kg/ha during a dry year for spring burned and control areas, respectively. He noted that any increase in production following fire declined with increasing time, nevertheless, increased yields on burned areas were still discernable four years after burning.

Fire and Its Direct Effects

Fire can conveniently be divided into three active components: litter removal, deposition of ash, and direct heating effects.

Fire often removes large portions of the litter layer. Vogl (1969) reported removal of 91% of the litter and 78% of the dead standing vegetation present by a spring burn in northwest Wisconsin. Dix (1960) found that virtually all of the 2048 kg/ha of fresh mulch and 4795 out of 5443 kg/ha of humic mulch were removed by a spring burn in North Dakota. Dix and Butler (1954) observed almost complete consumption of the litter layer by a September burn on a dry, thin soiled prairie in Wisconsin. Sharrow (1973) reported virtually complete consumption of 5451 kg/ha of litter by a March burn in a tobosa community.

Removal of the litter layer often has profound effects upon soil moisture and temperature relations. Weaver and Rowland (1952) observed that a 14 to 16.6 cm thick layer of bluestem mulch absorbed 49 to 62% of a simulated 0.6 cm rain applied in 30 minutes. They also noted increased infiltration rates and reduced evaporational water loss on mulched soils compared to soils which were stripped of the litter layer. Hopkins (1954) found that a mulch cover reduced evaporation when the soil surface was moist, but had little effect once the soil surface had dried. Glendening (1942) reported increased soil moisture in the top inch of mulched soil relative to unmulched soil in Arizona. Beutner and Anderson (1943) recorded July to October runoffs of 57.4%, 31.0%, and 9.2% of observed precipitation on bare soil, rothrock's grama (Bouteloua rothrockii) cover without mulch, and rothrock's grama cover with mulch respectively.

When plants are actively growing, soil moisture is utilized to support plant growth. Increased plant production on some burned areas results in decreased soil moisture in the root zone. Several authors have observed decreased soil moisture on burned areas (Ehrenreich and Aikman, 1963; Hopkins, 1954; Anderson, 1965). Old (1969), however, noticed no difference in soil moisture attributable to burning treatments. Sharrow (1973) reported yearly average soil moisture means of 13.8%, 8.1%, and 9.2% of oven dry weight for soils from control, burned, and clipped (litter removed) plots respectively.

Higher soil temperatures following litter removal are often credited for the observed earlier and more prolific plant growth on burned areas. Ehrenreich and Aikman (1963) attributed a 2 to 3 week earlier initiation of growth on burned areas to a 5.5°C higher soil temperature at the 1.3 cm soil depth. MacKinney (1929) observed that a litter layer lowered soil temperature in the spring-summer period and raised it in the fall-winter period. Weaver and Rowland (1952) noticed that May soil temperatures at the 0 to 1.3 cm depth were 10.2 to 10.3°C colder under a layer of mulch than where the mulch had been removed. This difference disappeared later in the season due to shading by the dense vegetative canopy on the mulchless plots. Hopkins (1954) observed that soil temperature varied proportionally to the amount of litter present, with increased litter causing decreased soil temperatures. Ehrenreich (1959) confirmed Hopkin's results and described a strong correlation between rising soil temperature in the spring and increasing rate of plant growth. Old (1969) found that the presence of mulch in the spring reduced vegetative production and flowering proportional to the length of time it was in place.

The time required for regeneration of the litter layer following fire is a function of the completeness of combustion and the productivity of the community. Vogl (1965) reported a pronounced accumulation of litter on burned areas the second growing season after controlled burning of brush prairie savanna in Wisconsin. Dix and Butler (1954), also working in Wisconsin, postulated a four to five year recovery period for litter in a little bluestem - Indian grass community. They noted that about 1/4 (1.7 cm) of the depth of the litter layer was replaced during the first growing season following the fire. Duvall (1962) observed similar litter layers on burned and control areas three years after burning paintbrush bluestem (*Andropogon tenarius*)- slender bluestem (*A. divergens*) communities. Hadley and Kiechkhefer (1963), working in the Trelease Prairie, found that litter biomass was the same for unburned and two year old burned plots under big bluestem, while under Indian grass, it was higher on burned plots one year and the same for both two-year-old burns and controls another year. In Texas, Wright (1972) reported rapid accumulation of standing tobosa grass litter on burned areas the first three seasons following spring burning. Extrapolation of litter recovery data indicated that full recovery of the litter layer may be attained in five years.

Ash deposition by fire is often credited with providing nutrients for soil microorganisms and for plant growth. Reports on fire's effects on soil properties commonly include increased soil nitrogen availability (Vlamis and Gowans, 1961; Vlamis et al, 1955; Mayland, 1967) and increased magnesium (Owensby and Wyrill, 1973), sodium, potassium, calcium, and pH near the soil surface (Marshall and Averill, 1928; Jasson, 1951; Perry, 1951; Metz et al, 1961). Some authors have noted increased available phosphorus (Vlamis and Gowans, 1961; Ehrenreich and Aikman, 1963); others however, found reduced phosphorus availability following fire (Isaac and Hopkins, 1937; Tarrant, 1956; Beaton, 1959).

Increased nutrient availability and higher soil temperature following fire may indirectly increase soil nitrogen availability by stimulation of organic decay, nitrogen mineralization, and nitrification (Fowles and Stephenson, 1934; Hesselman, 1918; Burns, 1952).

The deposition of basic salts in ash raises soil pH, thus favoring bacterial over fungal populations. Neal et al. (1965) noted an increase in bacteria relative to fungi throughout an entire year following a slash fire. Fuller et al. (1955) reported that fire caused an initial decline in soil bacteria followed by a rise to an abnormally high population reaching a peak three weeks after the fire.

The population then leveled off at prefire levels. Heyward and Tissot (1936) reported that soil microfauna of Southeastern forests were reduced by fire.

Broadbent and Nakashima (1971) maintain that the addition of inorganic salts of potassium, calcium, and aluminum increase soil nitrogen mineralization by increasing the availability of soil organic matter to microorganisms.

Hopkins (1937) asserted that increased calcium availability on burned areas favored Azotobacter, an important nitrogen fixing genera.

Many of the inorganic salts in ash are highly soluble, and if they are not quickly used by plants or soil organisms, leaching losses will occur (Perry and Coover, 1933; Finn, 1934; Miller et al., 1955; Neal et al., 1965; Smith, 1970).

Although little information is available concerning the direct effects of fire's heat upon plant production, any effect on soil chemistry is confined to the top 8 cm of the mineral soil (Isaac and Hopkins, 1937; Austin and Baisinger, 1955; Beaton, 1959; Smith, 1970).

Overview

The major effects of fire on plant production are due to litter removal with a smaller secondary fertilization effect from ash deposition. Grelen and Epps (1967) concluded,

> Yield and nutrient content of herbage on burned plots differed little from that on plots that were closely mowed and raked. Thus, the beneficial effects of burning were attributed mainly to litter removal.

Curtis and Partch (1950) ascertained that the increased flowering of big bluestem on burned areas was mainly due to litter removal with a small effect of heat and ash. Old (1969) noted that clipping, burning, or nitrogen fertilization increased flower stalk production, while the addition of ash to unclipped plots had no effect. Wolters (1971) observed that litter removal by burning influenced plant production more than did the addition of ash. Hulbert (1969) concluded that the major effect of fire on plant production is due to litter removal rather than to fertilization or direct heat effects. Wright (1969) ascribed increased production in spring burned tobosa communities primarily to litter removal; a small fertilizing effect of ash was also evident. Sharrow (1973) reported tobosa yields of 838, 1571, and 2652 kg/ha for control, clipped (no litter), and burned plots, respectively. In this case, litter removal alone accounted for less than 50% of the increased production on burned areas.

Conclusions

Increased herbage production on burned bluestem range is predominantly due to litter removal which favors plant growth by raising soil temperatures in the spring (Greene, 1935; Curtis and Partch, 1950; Weaver and Rowland, 1952; Ehrenreich, 1959; Ehrenreich and Aikman, 1963; Duvall and Whittaker, 1964; Vogl, 1965; Grelen and Epps, 1967; Hulbert, 1969; Old, 1969). Likewise, in more xeric areas and during dry years, reductions in plant growth on annually burned areas are attributable to litter removal and its detrimental effects upon soil moisture.

In tobosa grass communities, the mechanism of fire's stimulation of herbage production is less clear. Wright (1972) reported that tobosa communities produced more herbage in wet years and less herbage in dry years following spring burning. Most of this increase in plant growth following burning was attributed to litter removal, however, increased soil fertility following burning was also a factor (Wright, 1969). Sharrow (1973) found that litter removal alone accounted for less than 50% of the increased yield on burned areas, thus indicating that other factors (factor) were responsible for over 50% of the increase.

CHAPTER III

METHODS AND PROCEDURES

This study was conducted in two parts. The first study was initiated in 1973 and continued in 1974 to determine the long-term effects of fire on total nitrogen in the ecosystem of tobosa communities. It was conducted on convex (1-3% slope) and concave (0% slope) sites with Stamford soils 15 miles south of Colorado City, Texas. Plant and soil samples were collected from areas burned in 1970, 1971, 1972, 1973, and 1974. The tobosa was dense on all plots. The mesquite (*Prosopis glandulosa* var. *glandulosa*) had been top killed with 2,4,5-T in 1966 before burning. Elevation is 633 m and the annual precipitation is approximately 48 cm.

The second study was initiated in 1974 to separate the effects of heat, ash, and litter on inorganic nitrogen and herbage yields. It was conducted on a Typic Chromustert soil (Stamford series) 10 miles south of Post, Texas. Vegetation consisted of a moderately dense stand of tobosa with an open overstory of living mesquite. Elevation is 724 m and the annual precipitation is approximately 48 cm.

Effects of Heat, Ash, and Litter

Effects of the individual active agents of fire (heat, ash, and litter removal) on inorganic soil nitrogen and tobosa production were studied using a 2^3 factorial arrangement of treatments in a completely randomized design. Twenty four 2 m^2 plots were located within a 0.2 hectare area. The plots were numbered and three replications of the following treatments were randomly assigned by means of a random numbers table: (1) control, (2) control + ash, (3) clip (litter removed), (4) clip (litter removed) + ash, (5) burn, (6) burn - ash, (7) burn + litter, and (8) burn - ash + litter.

Before application of treatments, twelve 5 X 8 cm long steel pipes were inserted into the soil flush with the mineral soil surface on each plot in March, 1974 to provide soil samples free of root activity for nitrate and ammonia analysis. Also, before treatment, all plots received 4 cm of water on April 5, 1974. Water was applied as a mist spray from a pickup-mounted fire pump. Little water was lost as runoff.

From the clipped plots, all vegetation and litter were removed by hand down to mineral soil and spread over the + litter plots on April 9 & 10, 1974. Burned plots were burned on April 8, 1974, using a 2 m^2 X 1 m high 16 ga steel box to contain the fire (Fig. 1). Ash and charred material was vacuumed up from the burn - ash plots, hand sorted into ash and charred material, weighed separately, and then combined and spread over + ash plots (Fig. 2).

Fig. 1. Burning tobosa grass plots using a steel box to contain the fire.

Fig. 2. Burned plot (center) and burn-ash plot (foreground) in a tobosa grass stand near Post, Texas.

Iron-constantan thermocouples were placed into the soil at 1, 8, and 36 cm soil depths. They were installed by digging a hole with a soil auger and then inserting the thermocouples into the soil 5 cm from the edge of the hole. Soil temperatures were read weekly from April 23, 1974 through July 30, 1974. Additional readings were taken on September 6 and November 2, 1974.

Samples for soil nitrate and exchangeable ammonia analyses were taken on each plot from 3 steel pipes on April 21, May 7, May 22, and July 3, 1974. Soil removed from each pipe was placed in a separate covered can and immediately frozen using chipped dry ice before transporting them to the lab. All samples were stored at - 5°C until analyzed as recommended by Nelson and Bremner (1972).

Soil nitrate and exchangeable ammonia levels were determined by the following procedure: (1) frozen soil samples were pulverized using a mortar and pestile, (2) samples were weighed and an equal weight of 2 M KCl for NH_4^+ samples or distilled water for NO_3^- samples was added, (3) the samples were thawed in a 25°C water bath, (4) soil and extractant were thoroughly mixed, (5) 0.1 ml of 50% NaOH was added to ammonia samples and the resulting ammonia gas detected with an Orion ammonia gas sensing electrode. Nitrate ions were detected in nitrate samples using an Orion nitrate ion specific electrode. Gravimetric soil moisture, determined for each sample, was used to convert both exchangeable ammonia and nitrate measurements to a ppm over (100°C) dry weight basis.

From July 8 to 11, 1974, six 0.09 m^2 quadrats were clipped on each plot to estimate herbage yields. Similarly, after fall rains, the plots were clipped again on November 1, 1974 to estimate the combined spring and fall growth. Current years tobosa growth was separated from past years growth by hand where appropriate.

Long-Term Effects of Fire on Total Nitrogen

Two replications of five different aged burns on Stamford soils, one on an convex site and one on a concave topographic site, ranging from current year to four years old were sampled for total nitrogen in July, 1973 and again in July, 1974 on the Spade Ranch near Colorado City, Texas. A five-year-old burn was also sampled in 1974 only. Total nitrogen of current growth, standing old growth, litter, roots, and soil on these burns was compared to an unburned area sampled at the same time to determine the length of time required for re-establishment of prefire total nitrogen levels.

Plant material was collected down to mineral soil with twenty 0.09 m^2 rectangular quadrats. This material was hand-sorted into current tobosa growth, past years' standing old growth, and litter. The sorted material was oven dried (65°C oven), weighed, and then ground in a Wiley mill to pass a #40 screen.

Five soil nitrogen samples and forty root nitrogen samples were taken on each area to a depth of 5 cm by inserting a 5 X 7.5 cm soil can into the soil and then extracting the sample contained within the can. Soil samples (including fine roots) were oven dried, weighed, and then ground with a mortar and pestle to pass a 1 mm sieve.

All soil was washed off the roots for root nitrogen samples. Roots were then oven dried (65°C oven), weighed, and then ground in a Wiley mill to pass a #40 screen.

Total nitrogen was determined for every soil, plant, and root sample using a Coleman nitrogen analyzer.

The amount of nitrogen in current growth, past years' standing old growth, litter, and roots was separately calculated by multiplication of their standing biomass by their percent (oven dry weight) nitrogen content.

Soil nitrogen was converted from percent oven dry weight to kg/ha by multiplication of %N, soil bulk density, and the appropriate conversion constant (cc/ha for a 5 cm soil depth).

The effectiveness of all treatments was determined statistically by means of Snedecor's F-test. Means of effective treatments were separated using Duncan's multiple range test. The critical region for all tests was at the 0.05 level of probability.

CHAPTER IV

RESULTS AND DISCUSSION

Precipitation during 1973 was about 46% above average in Colorado City, Texas with 34 cm falling during the winter-spring period (January 1 to July 1) and 36 cm falling during the summer-fall period (July 1 to December 31). However, precipitation during the period of most rapid growth in May and June was less than 50% of normal. This limited the growth of plants to a near normal rate. In contrast, precipitation in 1974 was 54% below average at Colorado City, and 48% below average at Post, Texas until August 1, with 11 to 13 cm falling during the winter-spring period and 40 to 42 cm falling during the summer-fall period. Thus, in determining the long-term effects of fire on plant and soil nitrogen in mesquite-tobosa communities, a somewhat wet year is contrasted with a dry year.

Heat, ash, and litter effects on available soil nitrogen (nitrate and exchangeable ammonia) were measured under root-free conditions at Post, Texas following application of 4 cm of water prior to burning on April 8, 1974. Following this watering, soil water was not limiting root-free soil nitrogen dynamics until after June 1 (Table 1). These measurements compliment those for soil containing active roots reported by Sharrow (1973).

Moreover, the plant yields during this dry year contrast those for a wet year (1972), also reported by Sharrow (1973).

TABLE 1

GRAVIMETRIC SOIL WATER (PERCENT OVEN DRY WEIGHT, ROOT FREE SOIL) IN THE 0 TO 8 CM SOIL DEPTH FOR FOUR DATES AND EIGHT TREATMENTS[1/]

Treatment	Date			
	April 21	May 7	May 28	July 3
Control	20.4^{b}	24.8^{abc}	23.1^{b}	5.50^{a}
Control + ash	18.0^{ab}	25.5^{bc}	23.4^{b}	6.4^{a}
Clip	19.0^{ab}	22.5^{ab}	21.9^{ab}	4.2^{a}
Clip + ash	16.4^{a}	21.8^{a}	20.6^{ab}	4.5^{a}
Burn - ash + litter	19.5^{ab}	25.9^{c}	21.6^{ab}	5.2^{a}
Burn + litter	17.9^{ab}	24.1^{abc}	22.8^{b}	5.7^{a}
Burn - ash	17.5^{ab}	22.4^{ab}	18.9^{a}	4.7^{a}
Burn	20.2^{b}	22.0^{a}	20.1^{ab}	4.5^{a}

[1/]All means in a column not sharing a common letter are statistically different at P = 0.05. Error mean square was 3.23.

Effects of Heat, Ash, and Litter

Heat and ash:

Neither heat nor ash had any effect on soil temperature, soil moisture, accumulative soil nitrate, or exchangeable soil ammonia (Tables 2 & 3). Heating of soil by tobosa

TABLE 2

RESPONSE OF SOIL FACTORS TO HEAT FROM FIRE FOR APRIL 8 TO JULY 3, 1974 NEAR POST, TEXAS[1/]

Factor Measured	Treatment No Heat	Treatment Heat
Soil temperature at 8 cm (°C)	28.1[a]	29.0[a]
Soil moisture at 0 to 8 cm (%)	17.4[a]	17.0[a]
Accumulative soil nitrate at 0 to 8 cm (ppm)	21.2[a]	21.1[a]
Accumulative exchangeable soil ammonia at 0 to 8 cm (ppm)	0.7[a]	0.7[a]

[1/]Means in a row followed by the same letter are not significantly different at P = 0.05.

TABLE 3

RESPONSE OF SOIL FACTORS TO ASH FROM FIRE FOR APRIL 8 TO JULY 3, 1974 NEAR POST, TEXAS[1/]

Factor Measured	Treatment No ash	Treatment Ash
Soil temperature at 8 cm (°C)	28.8[a]	28.3[a]
Soil moisture at 0 to 8 cm (%)	17.3[a]	17.1[a]
Accumulative soil nitrate at 0 to 8 cm (ppm)	21.1[a]	21.2[a]
Accumulative exchangeable soil ammonia at 0 to 8 cm (ppm)	0.7[a]	0.7[a]

[1/]Means in a row followed by the same letter are not statistically different at P = 0.05.

grass fires can be intense at the soil surface, but it is of short duration (Stinson and Wright, 1969) and temperatures drop off rapidly with soil depth (Whittaker, 1961). Thus, it is not reasonable for heating of soil by fire to have anything but a very temporary effect such as the slight increase in exchangeable soil ammonia recorded in Appendix D.

Heated plots had almost twice as much exchangeable soil ammonia in the 0-8 cm soil depth as did unheated plots on April 21, 1974. Thereafter, no effect of heat was discernible. The mechanism by which fire's heat initially increases exchangeable soil ammonia is unclear. Prolonged heating of soil can increase soil ammonium without affecting soil nitrate levels (Singh, 1968), however, heating from grass fires is too short lived to produce this effect even at the soil surface. Oxygen consumption by fire could produce an anaerobic zone favorable to ammonia production near the soil surface. Such a zone could explain the very small increase in ammonia observed on heated plots.

Eighty three percent of the 6,800 kg/ha of standing tobosa old growth and litter initially present was consumed by fire, leaving 890 kg/ha of ash and 207 kg/ha of charred material. In theory, salts from the ash should release previously unavailable soil organic matter in a soluble form which is readily available to soil microbes (Broadbent and Nakashima, 1971; Singh et al., 1969). If this effect occurred to any appreciable extent, soil nitrate and/or ammonia levels should be higher on plots with ash than on plots without ash. No effect of ash on either soil nitrate or exchangeable ammonia levels was observed, suggesting that either small amounts of salts were deposited or salts were not limiting for bacterial growth.

Litter:

Litter had a significant effect on soil temperature, soil moisture, and accumulative soil nitrate (Table 4). The litter-free plots averaged 4°C warmer than plots with litter for the spring and early summer growing period at the 8 cm soil depth. This agrees with the 5.5°C warmer soil temperature measured on clipped (no litter) plots at the 7.5 cm depth by Sharrow (1973).

Energy exchange at the soil - air interface is greatly affected by litter layers. First, the relatively still air within the litter layer and the low thermal conductivity of the litter itself form a thick boundary layer which reduces thermal exchange and moisture diffusion at the soil - air interface.

Secondly, removal of the light gray litter, exposing the dark brown soil surface probably decreases the albedo of the surface exposed to solar radiation. If this is true,

TABLE 4

RESPONSE OF SOIL FACTORS TO LITTER REMOVAL FOR APRIL 8 TO JULY 3, 1974 NEAR POST, TEXAS[1/]

Factor Measured	Treatment No Litter	Litter
Soil temperature at 8 cm (^{o}C)	30.5^{a}	26.6^{b}
Soil moisture at 0 to 8 cm (%)	16.3^{a}	18.1^{b}
Accumulative soil nitrate at 0 to 8 cm (ppm)	24.2^{a}	18.1^{b}
Accumulative exchangeable soil ammonia at 0 to 8 cm (ppm)	0.8^{a}	0.6^{a}

[1/]Means in a row followed by the same letter are not significantly different at P = 0.05.

surface reflectivity would allow more efficient capture of incoming radiation, thus increasing the surface heat load during the day. The increased heat load would promote evaporational and transpirational water use and increase soil temperatures on litter-free plots.

Litter removal reduced soil water by about 2% compared to plots with litter. Since the soil sampled was free of active plant roots, reduced soil water on litter-free plots resulted from increased evaporational rather than transpirational water use on these plots compared to litter plots. In soil containing active roots, water in the upper 5 cm of soil was 6% lower on clipped (no-litter) than on control plots (9.9% vs 16.3% moisture, respectively) in 1972 (Sharrow, 1973). Since the climatic conditions during this study were much more conducive to evaporational water use than were the conditions during 1972, somewhat less than 2% of the observed 6% reduction in soil water on clipped plots in 1972 was due to increased evaporation from the exposed soil surface. The remaining 4+% or over 2/3 of the total water reduction on clipped plots was thus due to increased transpirational water use on these more highly producing litter-free plots.

Litter removal increased nitrate but did not affect exchangeable soil ammonia levels in the upper 8 cm of soil (Table 4). Higher soil temperatures on litter-free plots were probably the major factor in stimulating nitrate production on these plots compared to the cooler litter plots. Black (1957) estimated the optimum soil temperature for nitrate production and its uptake by plants to be 35 to 45°C. Ecotypic adaptation to prevailing soil temperatures by soil microbial populations should place West Texas microbes in the warmer portion of this range (Anderson et al., 1971). The 10°C difference in soil temperatures observed between litter and litter-free plots (35 vs 45°C, respectively) at the 1 cm soil depth during the April 23 to July 23, 1973 period was certainly large enough to account for the observed moderate difference (6ppm) in soil nitrate (Table 4). Since no difference in exchangeable soil ammonia was observed between litter and litter-free plots, increased soil temperatures on litter-free plots must have stimulated nitrogen mineralization to the same extent as it did nitrification. Reductions in total soil nitrogen (Appendix K) and soil nitrate levels (Appendix L) on clipped (no-litter) compared to control plots reported by Sharrow (1973) supports the contention that litter removal stimulates the conversion of soil nitrogen from organic to inorganic forms and demonstrates the high availability of the inorganic nitrogen to rapidly growing plants.

Tobosa Production

Drought conditions during the spring growing period in 1974 (Apr-l 5 to July 28) minimized treatment effects and reduced tobosa yields to a maximum of 824 kg/ha (Table 5) from the 1,300 to 2,400 kg/ha which would be expected on similar range sites during years of normal precipitation (Wright, 1972). Warmer spring soil temperatures on litter-free plots relative to controls, generally an important factor in stimulating increased plant growth on burned plots (Ehrenreich, 1959; Ehrenreich and Aikman, 1963; Old, 1969; Sharrow, 1973), was ineffective here due to inadequate soil water for plant growth.

TABLE 5

TOBOSA GRASS PRODUCTION (Kg/ha) AT TWO DATES FOR EIGHT TREATMENTS[1/]

Treatment	Date July 7, 1974	Date Nov. 1, 1974
Control	824[a]	2066[a]
Control + ash	782[a]	1897[a]
Clip	707[a]	2149[a]
Clip + ash	745[a]	2294[a]
Burn - ash + litter	790[a]	2223[a]
Burn + litter	831[a]	2297[a]
Burn - ash	700[a]	2261[a]
Burn	721[a]	2109[a]

[1/]Means in a column not sharing a common letter are significantly different at P = 0.05. Error mean squares were 10.85 and 32.86 for the July 7 and November 1 dates, respectively.

Increased soil temperatures, available soil nitrogen, and the release of nutrients other than nitrogen from ash increased tobosa production from the 838 kg/ha on control plots to the 2652 kg/ha observed on burned plots (Sharrow, 1973) when soil water was not limiting plant growth. However, increased evaporational water use following litter removal negates the beneficial effects of fire when soil moisture is inadequate, and often causes a net reduction in tobosa yields on burned relative to unburned plots during dry years (Wright, 1974).

With the return of favorable moisture conditions in the fall growing period (July 28 to November 1, 1974), warm soil temperatures and adequate soil water favored rapid tobosa growth on all plots. Again, as in the spring, no treatment affected tobosa yields (Table 5).

The failure of ash to increase tobosa production during the fall period when soil water was adequate is somewhat perplexing. In a previous study (Sharrow, 1973), burned and clipped (no-litter) plots produced 2652 and 1571 kg/ha of tobosa grass respectively. This difference in yield was attributed to a fertilization effect of nutrients other than nitrogen which were present in the ash. Unusually high tobosa production in the fall of 1971 prior to spring treatment application in 1972 may have tied up a larger portion of the soil nutrients in the previous study than did the scanty growth prior to this study. Reduced available soil nutrient levels resulting from this tie-up may have made the nutrients present in ash much more important for growth in the previous study than in this study and the one by Wright (1969).

Flowering

Litter removal alone did not affect flowering. However, litter removal in combination with ash deposition increased flower production (Table 6).

TABLE 6

NUMBER OF FLOWERING TOBOSA GRASS CULMS ON NOVEMBER 1, 1974 FOR EIGHT TREATMENTS NEAR POST, TEXAS[1/]

Treatment	Flowering culms/0.09 m^2
Control	12.3^{bc}
Control + ash	6.3^{a}
Clip	9.6^{ab}
Clip + ash	16.1^{cd}
Burn - ash + litter	12.1^{bc}
Burn + litter	10.9^{ab}
Burn - ash	9.0^{ab}
Burn	20.3^{d}

[1/]Means not sharing a common letter are significantly different at P = 0.05. Error mean square was 90.16.

Increased flowering of big bluestem on burned compared to unburned plots was attributed to reduced shading of new growth by litter and standing old growth, thus establishing more favorable carbohydrate levels in plants on burned areas during the period of inflorescence primordia development (Curtis and Partch, 1950; Old, 1969). This explanation appears equally as plausable for tobosa grass as it does for big bluestem. Spring growth in untreated tobosa plants is mainly initiated from axillary buds high up onthe vegetative canopy. Thus, the actual effect of shading is minimal.

However, removal of old living stems, which are net energy consumers, may produce increased plant carbohydrate levels much as does a reduction in shading. In addition to low plant carbohydrate levels, some nutrient contained in ash must be limiting flower production. Thus, both litter removal and the presence of ash are required for increased flower production.

Increased available soil nitrate levels resulting from more favorable conditions for microbial activity on the warmer burned plots may also play a role in increasing flowering on burned compared to the cooler unburned plots (Old, 1969).

Long-Term Effects of Fire On Tobosa Community Nitrogen

The long-term effects of fire on tobosa community nitrogen were studied as five separate units: (1) current growth, (2) past year's standing old growth, (3) litter, (4) soil (includes fine roots), and (5) coarse roots. All aerial plant parts produced during the current spring and early summer through July) growing season were included in new growth. Old growth consisted of all dead standing vegetation produced prior to the current growing season. Material lying at or near the soil surface was considered litter if it was easily recognized to be of plant origin. Soil included both mineral soil and organic matter which was too decomposed to be easily recognized as a plant organ. In addition, soil included fibrous grass roots less than 1 mm in diameter. Roots included both the large rhizomes and the coarse fibrous roots (greater than 1 mm in diameter) of tobosa grass.

The standing crop of nitrogen contained in new growth is very much a function of plant productivity. When soil water is adequate, as in 1973, increased herbage production on burned relative to unburned plots the first growing season following fire produces a higher new growth - N crop. However, during dry years, such as 1974, removal of the insulating litter layer by fire tends to reduce soil moisture on burned relative to unburned plots. This lower soil moisture drastically reduces both tobosa growth and new growth-N on burned plots the first growing season (Fig. 3 and 4). Regardless of the initial response to fire, new growth-N usually returns to pre-fire levels by the end of the third growing season.

Litter and old growth play an important role in tobosa communitiies. Together, they form an insulating layer which effectively reduces the rates of spring soil warm up, fall soil cooling, evaporative water loss from the soil surface, and which protects the soil surface from erosion. In addition, they serve as an important nitrogen reserve which can become available for future

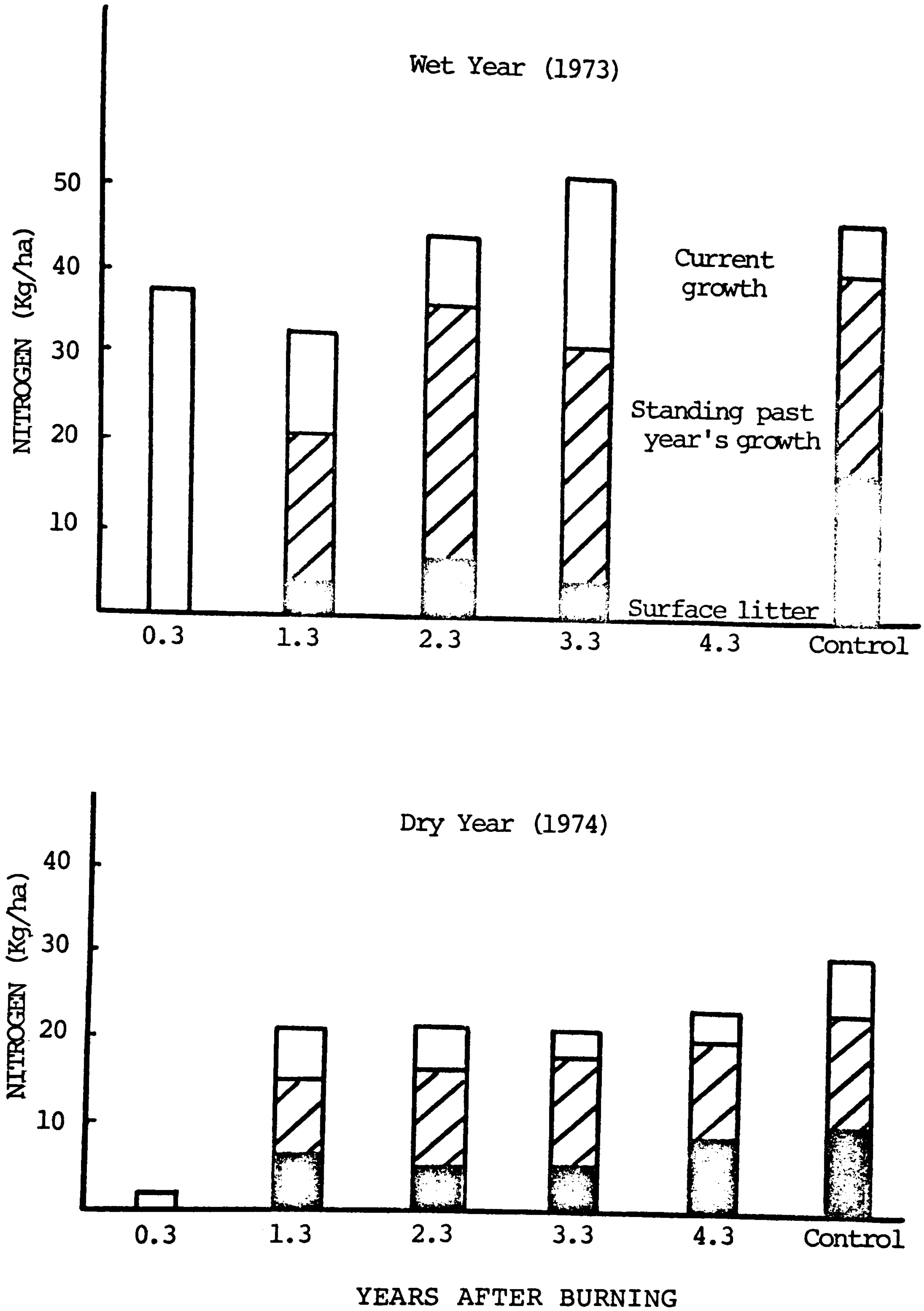

Fig. 3. Nitrogen content of tobosa material in July, 1973 and 1974 on convex topographic sites for five different ages of burns and an unburned control near Colorado City, Texas.

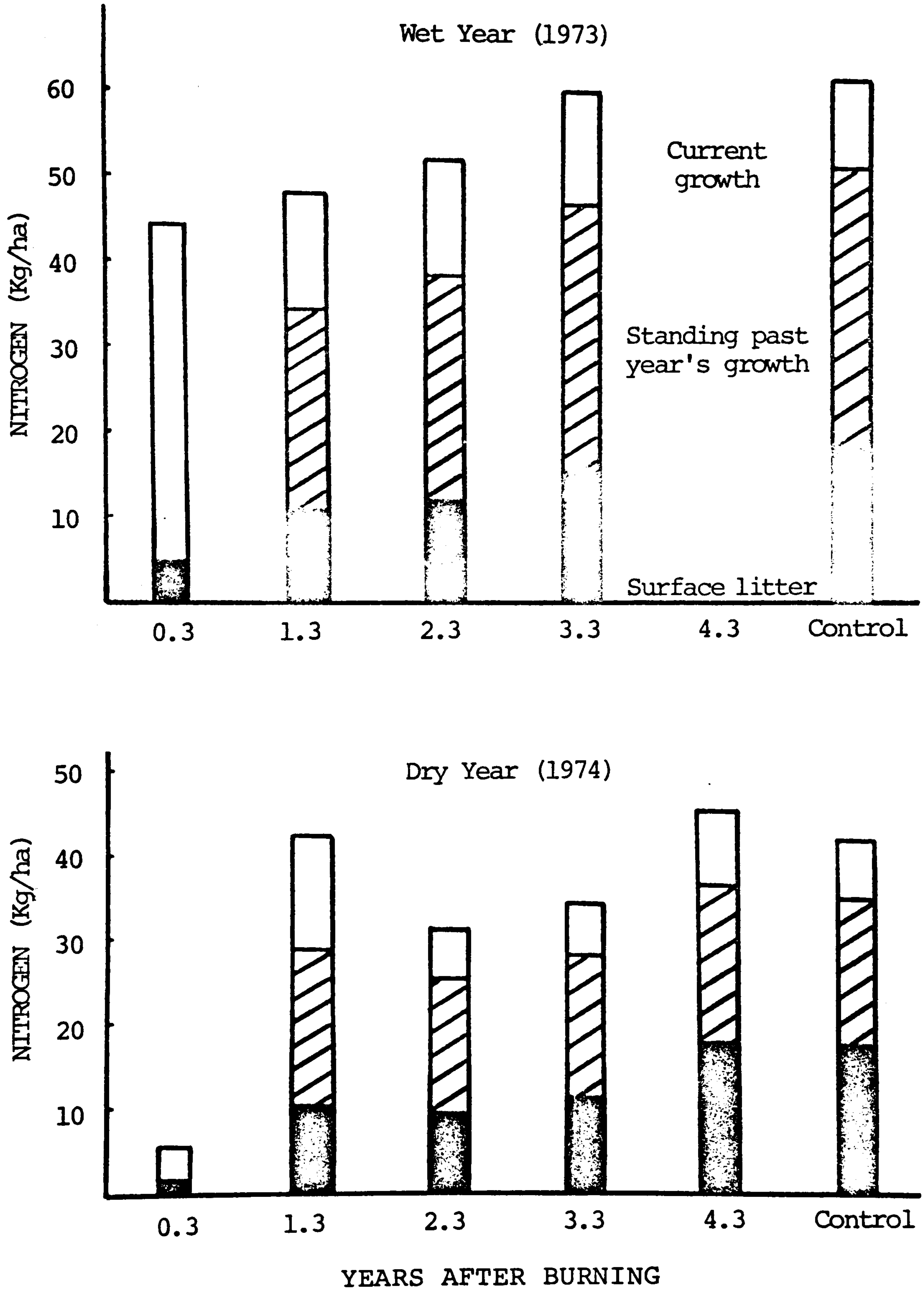

Fig. 4. Nitrogen content of tobosa material in July, 1973 and 1974 on concave topographic sites for five different ages of burns and an unburned control near Colorado City, Texas.

plant growth through the processes of organic decay, nitrogen mineralization, and nitrification.

Fire removes litter and old growth, leaving behind a litter-like layer of ash and charred material, thus reducing old growth-N to zero the first growing season following fire. Relatively high new growth-N produced the first two growing seasons after a fire contributes substantially to old growth-N measured in succeeding years (Fig. 3 and 4). Increased plant productivity following fire restores old growth-N to pre-fire levels by the end of the third growing season. Similarities between the time required for both new growth-N and old growth-N to recover from fire support the contention that old growth plays a role in regulating tobosa productivity. Fire removed a large portion of the accumulated litter-N originally present. Litter-N then gradually accumulated during the first four growing seasons. During the fifth growing season, litter-N abruptly increased to pre-fire levels on concave sites, but will take longer to reach equilibrium on convex sites (Fig. 3 and 4). The longevity of tobosa stems most likely produces this pattern of litter accumulation. Stems produced following a fire will live for several years before they die, break off, and contribute to the litter layer. Thus, during the first four growing seasons following fire, few dead stems are available and litter fall consists predominantly of dead leaf blades. By the end of the fourth and fifth growing seasons many stems have died and are sufficiently decomposed to fall as litter. Establishment of litter-N comparable to controls appears to be the best indicator of recovery following fire.

Soil and tobosa root nitrogen contents in the upper 5 cm of soil are presented in Tables 7 and 8. Sharrow (1973) reported decreased soil nitrogen levels during an entire year on burned compared to unburned tobosa plots (Appendix K). Here, however, no soil-N or root-N differences were observable because of the high inherent variation between the areas sampled and the relatively large amount of nitrogen stored in the soil.

The foregoing observations suggest that tobosa communities can be burned at five year intervals without depleting the community nitrogen reserves on concave sites. Convex sites probably should not be burned more frequently than once every 7 or 8 years. More frequent fires may induce a decline in soil nitrogen reserves and in nitrogen available for plant growth, although this aspect remains unclear.

TABLE 7

NITROGEN (Kg/ha) CONTENT OF TOBOSA ROOTS IN THE TOP FIVE CENTIMETERS OF SOIL IN JULY, 1974 MEASURED ON FIVE DIFFERENT AGES OF BURNS AND AN UNBURNED AREA, NEAR COLORADO CITY, TEXAS[1/]

Year Burned	Topographic	
	Convex Site	Concave Site
1974	22.3[a]	23.2[a]
1973	26.3[a]	21.5[a]
1972	17.9[a]	42.1[c]
1971	21.6[a]	26.4[ab]
1970	19.0[a]	36.7[bc]
Unburned	19.0[a]	21.5[a]

[1/]Means in a column not sharing a common letter are statistically different at P = 0.05. Error mean squares were 3.87 and 5.00 for convex and concave sites, respectively.

TABLE 8

NITROGEN (Kg/ha) CONTENT OF THE UPPER FIVE CENTIMETERS OF SOIL IN JULY OF 1973 AND 1974 MEASURED ON TWO TOPOGRAPHIC SITES FOR FIVE DIFFERENT AGES OF BURNS AND AN UNBURNED AREA, NEAR COLORADO CITY, TEXAS[1/]

Year Burned	Year Sampled/Site			
	1974 Convex Site	1974 Concave Site	1973 Convex Site	1973 Concave Site
1974	655^{a}	1036^{ab}		
1973	964^{b}	1112^{abc}	624^{a}	802^{b}
1972	1045^{b}	916^{a}	1005^{a}	857^{b}
1971	869^{ab}	934^{a}	692^{a}	527^{a}
1970	1045^{b}	1334^{bc}	819^{a}	1185^{c}
Unburned	874^{ab}	1174^{bc}	704^{a}	1237^{c}

[1/]Means in a column not sharing a common letter are statistically different at P = 0.05. All data have been adjusted to a common bulk density. Error mean squares were 9835 and 33376 for 1974 and 1973, respectively.

CHAPTER V

SUMMARY

The results obtained in this study when combined with those of Sharrow (1973) suggest the following conclusions:

1) Litter removal by fire increases the rapidity of spring soil warm up, thus stimulating earlier and more prolific tobosa growth on litter-free plots relative to controls during periods of adequate water. Increased transpiration by rapidly growing plants and to a lesser extent evaporation on litter-free plots reduces soil water compared to control plots. Burning during a dry year increases water stress and decreases plant production. In any event, tobosa yield returns to pre-fire levels by the end of the third growing season following fire.

2) Warmer soil temperatures on litter-free plots stimulate organic decay and nitrate production. Thus, burning reduces total soil nitrogen and increases soil nitrate levels. Rapid plant uptake of nitrate ion on high producing burned areas reduces observable soil nitrate levels relative to control areas in spite of increased nitrate production on burned areas.

3) A minimum of five years is required for the tobosa community nitrogen content to recover from fire. Burning more frequently than once every 5 years on concave sites

or more than once every 7 or 8 years on convex sites may deplete the community nitrogen reserves and lower future community productivity.

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APPENDIX

A. Soil temperature means (°C) over two time periods for eight treatments in relation to two soil depths.

B. Soil nitrate under root free conditions at the 0 to 8 cm soil depth for four dates and eight treatments.

C. Exchangeable soil ammonia (parts per million oven dry weight) under root free conditions at the 0 to 8 cm soil depth for four dates and eight treatments.

D. Exchangeable soil ammonia at the 0 to 8 soil depth on heat and no heat plots for four dates (ammonia in parts per million, oven dry weight, under root free conditions).

E. Nitrogen (kg/ha) content of current year's tobosa growth in July of 1973 and 1974 measured on two topographic sites for five different ages of burns and an unburned area, near Colorado City, Texas.

F. Nitrogen (kg/ha) content of standing past year's tobosa growth in July of 1973 and 1974 measured on two topographic sites for five different ages of burns and an unburned area, near Colorado City, Texas.

G. Nitrogen (kg/ha) content of tobosa litter in July of 1973 and 1974 measured on two topographic sites for five different ages of burns and an unburned area, near Colorado City, Texas.

H. Tobosa new growth (kg/ha) in July of 1973 and 1974 measured on two topographic sites for five different ages of burns and an unburned area, near Colorado City, Texas.

I. Tobosa old growth (kg/ha) in July of 1973 and 1974 measured on two topographic sites for five different ages of burns and an unburned area, near Colorado City, Texas.

J. Tobosa litter (kg/ha) in July of 1973 and 1974 measured on two topographic sites for five different ages of burns and an unburned area, near Colorado City, Texas.

K. Average percent soil nitrogen (April 1, 1972 to March 1, 1973) at three soil depths for three treatments applied in March, 1972.

L. Average soil nitrate (ppm) from April 1, 1972 to March 1, 1973 at three soil depths following application of three treatments in March, 1972.

APPENDIX A: SOIL TEMPERATURE MEANS (°C) OVER TWO TIME PERIODS FOR EIGHT TREATMENTS IN RELATION TO TWO SOIL DEPTHS.[1/]

	April 23 to July 23, 1974		July 23 to Nov. 2, 1974	
Plot	Soil Depth		Soil Depth	
	8 cm	30 cm	8 cm	30 cm
Control	26.3^{b}	23.3^{b}	23.0^{ab}	22.2^{ab}
Control+ash	25.3^{a}	23.0^{a}	22.6^{a}	22.1^{a}
Clip	31.2^{f}	24.5^{f}	25.0^{d}	22.4^{ab}
Clip+ash	29.7^{d}	24.2^{e}	24.7^{cd}	22.5^{ab}
Burn-ash+litter	27.6^{c}	23.9^{cd}	23.7^{abcd}	22.5^{b}
Burn+litter	27.4^{c}	23.8^{c}	23.5^{abc}	22.2^{a}
Burn-ash	30.30^{de}	24.1^{de}	24.2^{bcd}	22.5^{ab}
Burn	30.92^{ef}	24.4^{ef}	24.6^{cd}	22.3^{ab}

[1/]Mean within a column followed by the same letter are not significantly ($P < 0.05$) different. Error mean squares were 6.84, and 1.22 for the 8 cm and 30 cm depths during April 23 to July 23 and were 5.98 and 0.32 for the 8 cm and 30 cm depths during July 23 to November 2, 1974, respectively.

APPENDIX B: SOIL NITRATE UNDER ROOT FREE CONDITIONS AT THE 0 TO 8 CM SOIL DEPTH FOR FOUR DATES AND EIGHT TREATMENTS (Nitrate in parts per million oven dry weight).1/

Treatment	Date			
	April 21	May 7	May 28	July 3
Control	24.6^{a}	8.6^{a}	8.6^{a}	22.2^{abc}
Control+ash	27.4^{a}	10.8^{a}	12.3^{a}	16.0^{a}
Clip	22.8^{a}	7.0^{a}	11.1^{a}	18.8^{ab}
Clip+ash	24.1^{a}	9.5^{a}	13.3^{a}	27.9^{c}
Burn-ash+litter	24.1^{a}	5.6^{a}	9.3^{a}	18.1^{ab}
Burn+litter	22.8^{a}	8.7^{a}	11.4^{a}	16.1^{a}
Burn-ash	24.6^{a}	9.4^{a}	17.5^{a}	25.3^{bc}
Burn	25.8^{a}	8.8^{a}	15.5^{a}	24.9^{abc}

1/All means in a column not sharing a common letter are statistically different at P = 0.05. Error mean square was 24.24.

APPENDIX C: EXCHANGEABLE SOIL AMMONIA (Parts Per Million Oven Dry Weight) UNDER ROOT FREE CONDITIONS AT THE 0 TO 8 CM SOIL DEPTH FOR FOUR DATES AND EIGHT TREATMENTS.[1/]

Treatment	Date			
	April 21	May 7	May 28	July 3
Control	1.0^{a}	1.2^{a}	0.7^{a}	0.7^{a}
Control+ash	1.4^{ab}	1.5^{a}	0.7^{a}	0.5^{a}
Clip	1.3^{ab}	1.4^{a}	0.7^{a}	0.9^{a}
Clip+ash	1.2^{a}	1.1^{a}	0.6^{a}	0.9^{a}
Burn-ash+litter	2.3^{c}	1.3^{a}	0.7^{a}	0.6^{a}
Burn-litter	1.6^{ab}	1.6^{a}	0.9^{a}	0.5^{a}
Burn-ash	2.4^{c}	1.6^{a}	0.6^{a}	0.8^{a}
Burn	2.0^{bc}	1.1^{a}	0.8^{a}	0.8^{a}

[1/]All means in a column not sharing a common letter are significantly different at $P = 0.05$. Error mean square was 0.19.

APPENDIX D: EXCHANGEABLE SOIL AMMONIA AT THE 0 TO 8 CM SOIL DEPTH ON HEAT AND NO HEAT PLOTS FOR FOUR DATES (Ammonia in Parts Per Million, Oven Dry Weight, Under Root Free Conditions).[1/]

Date	Plot	
	Heat	No Heat
April 21, 1974	2.1[b]	1.2[a]
May 7, 1974	1.4[a]	1.3[a]
May 28, 1974	0.7[a]	0.7[a]
July 3, 1974	0.7[a]	0.7[a]

[1/]All means in a row not sharing a common letter are statistically different at P = 0.05. Error mean square was 0.19.

APPENDIX E: NITROGEN (Kg/ha) CONTENT OF CURRENT YEAR'S TOBOSA GROWTH IN JULY OF 1973 AND 1974 MEASURED ON TWO TOPOGRAPHIC SITES FOR FIVE DIFFERENT AGES OF BURNS AND AN UNBURNED AREA, NEAR COLORADO CITY, TEXAS.[1/]

Year Burned	Year Sampled/Site			
	1974 Convex Site	1974 Concave Site	1973 Convex Site	1973 Concave Site
1974	1.29[a]	4.33[a]		
1973	6.29[e]	13.13[d]	37.45[d]	39.02[c]
1972	4.38[cd]	6.41[ab]	12.66[b]	12.84[ab]
1971	2.54[ab]	6.55[b]	8.71[ab]	12.84[ab]
1970	3.35[bc]	9.17[c]	18.83[c]	12.73[ab]
Unburned	5.67[de]	7.01[bc]	5.88[a]	10.95[a]

[1/]Means in a column not sharing a common letter are statistically different at $P = 0.05$. Error mean squares were 3.17, 5.77, 41.51, and 28.22 for 1974 convex, 1974 concave, 1973 convex, and 1973 concave sites, respectively.

APPENDIX F: NITROGEN (Kg/ha) CONTENT OF STANDING PAST YEAR'S TOBOSA GROWTH IN JULY OF 1973 AND 1974 MEASURED ON TWO TOPOGRAPHIC SITES FOR FIVE DIFFERENT AGES OF BURNS AND AN UNBURNED AREA, NEAR COLORADO CITY, TEXAS.[1/]

Year Burned	Year Sampled/Site			
	1974 Convex Site	1974 Concave Site	1973 Convex Site	1973 Concave Site
1974	0^{a}	0^{a}		
1973	8.23^{b}	18.06^{b}	0^{a}	0^{a}
1972	11.72^{c}	15.88^{b}	17.13^{b}	24.45^{b}
1971	13.00^{c}	16.76^{b}	29.18^{d}	26.78^{bc}
1970	11.37^{c}	18.43^{b}	28.12^{cd}	30.90^{cd}
Unburned	13.33^{c}	17.99^{b}	24.21^{cd}	33.41^{d}

[1/]Means in a column not sharing a common letter are statistically different at P = 0.05. Error mean squares were 7.34, 13.46, 46.72 and 79.23 for 1974 convex, 1974 concave, 1973 convex, and 1973 concave sites, respectively.

APPENDIX G: NITROGEN (Kg/ha) CONTENT OF TOBOSA LITTER IN JULY OF 1973 AND 1974 MEASURED ON TWO TOPOGRAPHIC SITES FOR FIVE DIFFERENT AGES OF BURNS AND AN UNBURNED AREA, NEAR COLORADO CITY, TEXAS.[1/]

Year Burned	Year Sampled/Site			
	1974 Convex Site	1974 Concave Site	1973 Convex Site	1973 Concave Site
1974	0^{a}	1.62^{a}		
1973	6.36^{b}	10.53^{bc}	0^{a}	4.59^{a}
1972	4.90^{b}	8.75^{b}	3.57^{b}	10.31^{b}
1971	5.06^{b}	10.77^{bc}	6.58^{c}	11.87^{bc}
1970	8.62^{c}	18.18^{d}	3.95^{b}	15.62^{c}
Unburned	10.25^{c}	16.72^{d}	16.44^{d}	18.01^{c}

[1/]Means in a column not sharing a common letter are statistically different at P = 0.05. Error mean squares were 5.60, 10.61, 10.21, and 65.94 for 1974 convex, 1974 concave, 1973 convex, and 1973 concave sites, respectively.

APPENDIX H: TOBOSA NEW GROWTH (Kg/ha) IN JULY OF 1973 AND 1974 MEASURED ON TWO TOPOGRAPHIC SITES FOR FIVE DIFFERENT AGES OF BURNS AND AN UNBURNED AREA, NEAR COLORADO CITY, TEXAS.[1/]

Year Burned	Year Sampled/Site			
	1974 Convex Site	1974 Concave Site	1973 Convex Site	1973 Concave Site
1974	101^{a}	269^{a}		
1973	416^{cd}	655^{c}	3018^{e}	2805^{d}
1972	323^{bc}	455^{b}	1167^{c}	1394^{c}
1971	198^{ab}	482^{b}	759^{b}	1319^{c}
1970	258^{b}	586^{bc}	1574^{d}	1042^{b}
Unburned	479^{d}	518^{bc}	323^{a}	924^{b}

[1/]Means in a column not sharing a common letter are statistically different at P = 0.05. Error mean squares were 18,503; 23,352; 244,416; and 193,152 for 1974 convex, 1974 concave, 1973 convex, and 1973 concave sites, respectively.

APPENDIX I: TOBOSA OLD GROWTH (Kg/ha) IN JULY OF 1973 AND 1974 MEASURED ON TWO TOPOGRAPHIC SITES FOR FIVE DIFFERENT AGES OF BURNS AND AN UNBURNED AREA, NEAR COLORADO CITY, TEXAS.[1/]

Year Burned	Year Sampled/Site			
	1974 Convex Site	1974 Concave Site	1973 Convex Site	1973 Concave Site
1974	0^{a}	0^{a}		
1973	1229^{b}	2361^{b}	0^{a}	0^{a}
1972	2104^{cd}	2515^{b}	2559^{b}	4301^{b}
1971	1857^{c}	3059^{c}	3441^{c}	4784^{bc}
1970	2188^{cd}	3118^{c}	4070^{d}	4803^{bc}
Unburned	2735^{e}	3230^{c}	3424^{c}	5484^{c}

[1/]Means in a column not sharing a common letter are statistically different at P = 0.05. Error mean squares were 248,789; 354,493; 842,304; and 1,453,696 for 1974 convex, 1974 concave, 1973 convex, and 1973 concave sites, respectively.

APPENDIX J: TOBOSA LITTER (Kg/ha) IN JULY OF 1973 AND 1974 MEASURED ON TWO TOPOGRAPHIC SITES FOR FIVE DIFFERENT AGES OF BURNS AND AN UNBURNED AREA, NEAR COLORADO CITY, TEXAS.[1/]

Year Burned	Year Sampled/Site			
	1974 Convex Site	1974 Concave Site	1973 Convex Site	1973 Concave Site
1974	96[a]	162[a]		
1973	642[b]	943[b]	0[a]	459[a]
1972	658[b]	924[b]	329[b]	985[b]
1971	658[b]	1134[b]	606[c]	1088[b]
1970	1536[d]	1780[c]	420[b]	1446[bc]
Unburned	1167[c]	2039[c]	1625[e]	1753[c]

[1/]Means in a column not sharing a common letter are statistically different at P = 0.05. Error mean squares were 83,493; 166,962; 85,056; and 631,296 for 1974 convex, 1974 concave, 1973 convex, and 1973 concave sites, respectively.

APPENDIX K: AVERAGE PERCENT SOIL NITROGEN (APRIL 1, 1972 TO MARCH 1, 1973) AT THREE SOIL DEPTHS FOR THREE TREATMENTS APPLIED IN MARCH, 1972.[1/]

Treatment	Soil Depth (cm)		
	0-2.5	2.5-5.0	5.0-12.5
Control	0.236[a]	0.138[a]	0.097[a]
Clipped	0.186[b]	0.108[b]	0.092[a]
Burned	0.212[a]	0.095[c]	0.081[b]

[1/]Means within a column followed by the same letter are not significantly (P = 0.05) different. Data were taken from Sharrow (1973).