Effects of Fire, Ash, and Litter on Soil Nitrate, Temperature, Moisture and Tobosagrass Production in the Rolling Plains

STEVEN H. SHARROW AND HENRY A. WRIGHT

Removal of litter by burning or clipping in tobosagrass communities increased soil temperature and the rate of nitrogen mineralization. Ash had no effect on either of these soil properties in 1972, but did appear to stimulate production in 1974. With adequate soil moisture, the higher soil temperatures on burned or clipped plots stimulated plant growth and concomitantly reduced soil moisture and nitrates. By contrast, suboptimal soil temperatures on control plots limited plant growth, even though soil nitrate and moisture were ample. During dry years, soil moisture is the limiting plant growth factor and burning has no beneficial effects.

Prescribed burning has proven useful in managing tobosagrass (*Hilaria mutica*, Benth.) communities. When properly applied, spring burning kills some mesquite trees, removes dead trees, and increases production and potential utilization of tobosagrass (Wright 1969, 1972; Heirman and Wright 1973). As prescribed burning becomes more widely used, an understanding of the effect of fire on soil nitrogen, as well as how the various factors associated with fire affect plant growth in semiarid climates, becomes increasingly important.

Fire largely consumes litter and, depending upon the completeness of combustion (Finn 1934), this can be a major mechanism for nitrogen loss (Burns 1952; Austin and Baisinger 1955; De Bell and Ralston 1970). Remaining nutrients are concentrated in the ash and unconsumed litter (Isaac and Hopkins 1937). Many nutrients are leached into the soil where they are available for plant growth. If these nutrients are not quickly taken up by plants and soil organisms, appreciable losses due to leaching may occur (Finn 1934; Neal et al. 1965).

Increased total and available soil nitrogen is often observed following fire (Heyward and Barnette 1934; Mayland 1967; Vlamis et al. 1965). Some possible explanations for these increases are: stimulation of legumes (Mayland 1967), washing of charred surface material into the soil by rain (Metz et al. 1961) and the deposition of nutrient-rich ash, which stimulates the growth of nitrifying (Burns 1952; Fowells and Stephenson 1934) and nitrogen-fixing (Isaac and Hopkins 1937) micro-organisms. However, decreases in total soil nitrogen after fi have also been reported (Austin and Baisinger 1955).

In the true prairie, the major effect of fire upon plant growth i due to litter removal, which favors plant yields by raising so temperatures in the spring (Weaver and Rowland 1952; Kucer and Ehrenreich 1962). Ash had little effect on plant growt (Hulbert 1969; Old 1969; Wolters 1971). Similarly, increase tobosagrass yields following burning appear to be primaril due to litter removal by fire; however, Wright (1969) hа speculated that heat or ash may have some influence.

Objectives of this study were (1) to measure changes i nitrate, exchangeable ammonium, total soil nitrogen, so moisture, and soil temperatures following spring burning, an (2) to determine the extent to which each of these soil facto increased growth of tobosagrass following fire.

Methods

In 1972, a pilot study was conducted on the Spade Ranch ne Colorado City, Texas, (elevation 633 m; annual precipitation 48 cm to examine soil temperature, moisture, nitrate, and total nitrogen *i situ* as possible explanations for increased tobosagrass yields follow ing fire. As a result of this study, a second, more intensive study wa conducted in 1974 near Post, Texas, (elevation 724 m; annual precip tation 48 cm) to evaluate the relative importance of litter removal, as deposition, and direct heating by fire in stimulating tobosagras yields. Responses of soil nitrate and soil moisture under root-fre conditions as well as soil temperature *in situ* were measured. Th results of these two studies are reported here.

Both the Colorado City and Post sites supported dense stands o tobosagrass with fairly open overstories of honey mesquite (*Prosop glandulosa* var. *glandulosa* Torr.). The soils (Stamford clay) at bot sites were fine textured with well developed vertic (shrinking swelling) properties. The Stamford Soil Series is a member of the fin montmorillonitic, thermic family of the Typic Chromustest. Bot sites had been stocked moderately with cattle during the past 10 year However, because of its coarseness, tobosagrass is rarely grazed mo than 10 or 20% in its untreated condition.

Colorado City site, 1972

A two-hectare grazing exclosure was established at the Colorad City site in 1971. Three 0.4 hectare plots for (1) burned, (2) clippe and (3) control tobosagrass treatments were located within th exclosure in 1972. Plot 1 was burned on March 10, 1972, under th following weather conditions: air temperature, 28°C; relative humid ty 37%; wind, south 13 to 26 km/hour. The clipped treatment consiste of removing all vegetation and litter by hand from 15 randoml

Authors are assistant professor of range science, Department of Animal Science, Oregon State University, Corvallis 97331, and professor of range management, Department of Range and Wildlife Management, Texas Tech University, Lubbock 79409.

This report is a contribution of the College of Agricultural Sciences, Texas Tech University, Publication Number T-9-162.

Manuscript received June 10, 1976.

Fig. 1. *Burning tobosagrass plots using a 16 ga steel box to contain the fire.*

selected 2-m diameter quadrats on March 12 to 19, 1972, leaving the mineral soil surface bare but relatively undisturbed.

Twenty 0.22-m^2 randomly located quadrats were clipped from each 0.4-hectare plot before treatments were applied on March, 1972, and again at the end of the primary growing season in July, 1972, to estimate standing crop of vegetation and litter. Current year's growth in July, 1972, was separated from old growth by hand. Samples were oven-dried at 60°C for 36 hours before weighing. This drying temperature was used to minimize the volatilization of nitrogen.

Four samples of dormant tobosagrass and litter were collected at random from the burned plot before application of treatments in March and analyzed for total nitrogen (performed on a Coleman model 29 A nitrogen analyzer using a platinum catalyst) to estimate the nitrogen content of plant material. After the fire, ash was collected down to mineral soil within 36 rectangular 0.22 m^2 quadrats. These samples were oven dried at 60°C for 36 hours, weighed, ground (1-mm mesh), and then analyzed for nitrate and total nitrogen. Nitrate was measured with the Orion nitrate ion specific electrode using distilled water as an extractant for nitrate. The loss of nitrogen caused by burning was assumed to be the difference between nitrogen content of all plant material before the burn and nitrogen content of ash after the burn.

Soil cores from four randomly selected, permanently-marked sites within each treatment were collected monthly at 0–2.5, 2.5–5.0, and 5.0–12.5 cm depths from April 1, 1972, to March 1, 1973. Soil moisture was determined gravimetrically (60°C for 36 hours). Samples were then ground (1-mm mesh) and analyzed for nitrate and total nitrogen.

Soil temperatures at 2.5 and 7.5 cm were measured monthly at three locations for each treatment using standard mercury thermometers.

Post site, 1974

In 1974 the effects of fire (heat, ash, and litter removal) on inorganic soil nitrogen and moisture in root-free soil and tobosa production were studied at the Post site using a 2^3 factorial arrangement of treatments in a completely randomized design. Twenty-four 2 × 2-m plots were located within a fenced 0.2-hectare exclosure. Three replications of the following treatments were applied in April, 1974: (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, 12 steel pipes, 8 cm long × 5 cm in diameter, were driven into the soil, flush with the soil surface on each plot to provide soil samples free of living roots for nitrate, ammonium, and moisture data. 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.

All vegetation and litter was removed by hand down to mineral soil from the clipped plots and spread over the "+ litter" plots after they were burned. The appropriate plots were burned using a 2 × 2 × 1-m high, 16-ga steel box to contain the fire (Fig. 1). Ash and charred material were vacuumed up from the burn − ash plots, hand sorted into ash and charred material, weighed separately, and then combined and spread over + ash plots.

Soil temperature was determined weekly from April 23 to July 30, 1974, using iron-constantan thermocouples placed at depths of 1, 8, and 36 cm. Additional temperature readings were taken on September 6 and November 2, 1974.

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

Soil samples for nitrate and exchangeable ammonium analyses were taken on each plot from three steel pipes on April 21, May 7, May 22, and July 3, 1974. Soil removal from each pipe was placed in a separate covered can and immediately frozen using chipped dry ice before transporting it to the lab. All samples were stored at −5°C in the moist condition until analyzed as recommended by Nelson and Bremmer (1972). They were thawed just prior to analysis and corrected for soil moisture.

Nitrate ion and exchangeable ammonium content of soil samples were measured with the Orion nitrate ion specific electrode using distilled water as an extractant for nitrate ion and the Orion ammonia gas sensing electrode using 2 m KCl as an extractant for exchangeable soil ammonium (NH_4^+). All measurements were converted to ppm (60°C oven-dry weight basis).

Results and Discussion

Precipitation during 1972 was about 20% above average in Colorado City, Texas, with 16 cm falling during the winter-spring period (January to July) and 40 cm falling during the summer-fall period (July to December). In contrast, precipitation in 1974 was 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 effects of fire on plant growth in mesquite-tobosa communities, a somewhat wet year is contrasted with a dry year on Stamford clay soils.

Fire consumed virtually all of the 5,451 kg/ha of litter and old growth at the Colorado City site, leaving behind 1,030 kg/ha of ash. The net loss of nitrogen was 36.4 kg/ha; 5.6 kg/ha remained on the soil after the fire. At the Post site, 97% of the 6,800 kg/ha of standing old growth and litter initially present was consumed by fire, leaving behind 890 kg/ha of ash and 207 kg/ha of charred material. These values for litter removal by fire in tobosagrass communities agree well with those reported for other grassland communities (Dix and Butler 1954; Dix 1960; and Vogl 1965) where fire removed from 91 to 100% of the litter layer.

Effect of Fire on Soil Properties

Soil temperature was increased at the 7.5 to 8 cm soil depths by clipping and burning compared to control plots on both the Colorado City and Post sites (Figs. 2 and 3). The clipped and the burned plots were 4 to 5°C warmer than control plots after May 1 and stayed warmer throughout late spring and summer. Thus, soil temperatures of plots with litter lagged behind those without litter from 15 to 45 days during the latter half of the spring-early summer growing season.

The similarity of temperatures between burned and clipped plots suggests that increased soil temperature on burned soils is

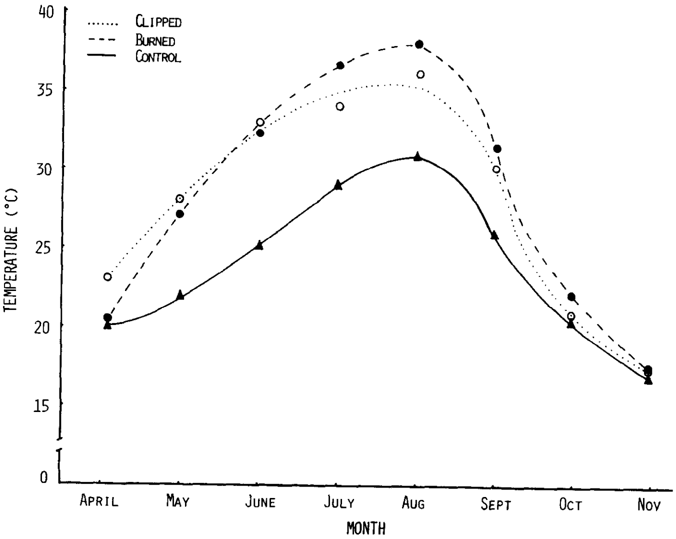

Fig. 2. *Soil temperatures at a depth of 7.5 cm for burned, clipped, and control plots in 1972 at Colorado City, Texas.*

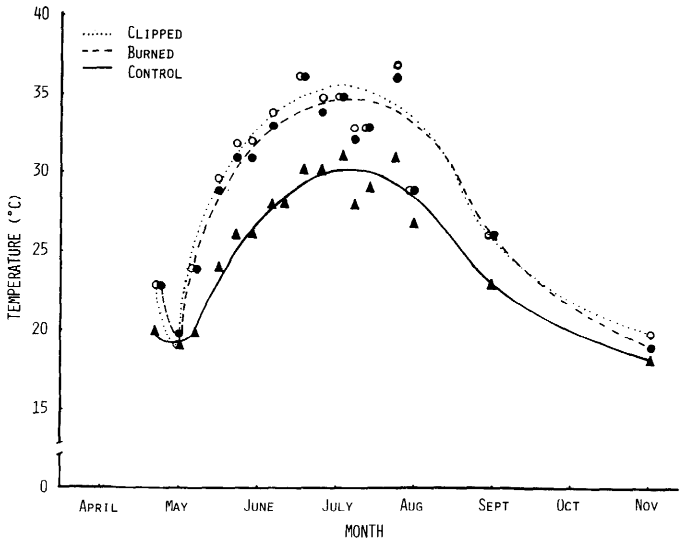

Fig. 3. *Soil temperatures at a depth of 8.0 cm for burned, clipped, and control plots in 1974 at Post, Texas.*

primarily due to exposure of the soil surface by litter removal (Table 1), not the absorptivity of black ash (Table 2).

Soil moisture, the factor generally limiting plant growth during dry years, was reduced in the 0 to 8 cm depth following litter removal on soil with active roots at the Colorado City site (Table 3). Where roots were excluded on the Post site, neither clipping nor burning lowered soil moisture levels during an exceptionally dry year. These data were taken during two different years at different locations, but the soils are both Stamford clays and evaporative losses were measured under the most extreme conditions. Thus, reduced soil moisture on burned areas is primarily due to increased transpirational water use by the rapidly growing plants rather than evaporation of water from bare soil surface.

Where roots were excluded, litter removal by clipping or burning resulted in increased nitrate levels in the 0 to 8 cm soil depth (Table 1). Warmer soil temperatures on the litter-free plots are probably responsible for the higher nitrate levels observed on these plots compared to the cooler control plots. Black (1968) estimates that the optimum soil temperature for nitrate production and its uptake by plants is 35 to 45°C. Thus, rapid warmup of soils on burned or clipped areas (Figs 2 and 3) in the spring increased maximum soil temperatures from the 28–32°C range on control plots to the 32–38°C range on litter-free plots. This increase in soil temperature should substantially increase nitrate production on clipped or burned plots. Where roots were active, however, as on the Colorado City site in 1972, soil nitrate levels were lower on clipped or burned plots than on control plots (Table 4). Rapid uptake of nitrate ions by the vigorously growing plants on the clipped or burned plots probably accounts for the lower nitrate levels on these plots. Thus, it appears that nitrate ions are rapidly produced by bacteria and rapidly used by plants when soil temperatures are optimal for the growth of both of them.

Table 1. Response of soil factors to litter removal in root-free soil from April 8 to July 3, 1974, near Post, Texas.

Factor measured	Treatment	
	No litter	Litter
Soil temperature at 8 cm (°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 within a row followed by the same letter are not significantly different ($P < 0.05$).

Table 2. Response of soil factors to ash in root-free soil from April 8 to July 3, 1974, near Post, Texas.

Factor measured	Treatment	
	No ash	Ash
Soil temperature at 8 cm (°C)	28.8[a]	28.3[a]
Soil tmoisture 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 within a row followed by the same letter are not statistically different ($P < 0.05$).

Table 3. Average gravimetric soil moisture (percent dry weight) on Stamford clay soils during the growing season (April to July) for soil with and without active plant roots.

Treatment	Soil with roots[2]	Soil without roots[3]
Control	15.7 a[1]	18.4 a
Clipped	11.0 b	17.9 a
Burned	9.5 b	16.7 a

[1] Means within a column followed by the same letter are not significantly different ($P < 0.05$).
[2] Means of monthly observations on the Colorado City site from April 1 to July 31, 1972.
[3] Means of four sample dates (April 21, May 7, May 28, and July 3) on the Post site in 1974

Table 4. Average soil nitrate (ppm dry weight) at three depths during the spring growing period (April through July, 1972) at the Colorado City site.

Treatment	Soil depth (cm)		
	0–2.5	2.5–5.0	5.0–12.5
Control	94 a	37 a	25 a
Clipped	50 b	21 b	14 b
Burned	47 b	25 b	17 b

[1] Means within a column followed by the same letter are not significantly different ($P < 0.05$).

The deposition of basic salts, especially calcium, contained in ash stimulates nitrification in forest soils (Hesselman 1918, Fowells and Stephenson 1934). Grassland soils, however, tend to be naturally rich in calcium and other nutrients. Thus, nitrification in grassland soils does not respond as markedly to nutrients from ash (Table 2) as it does in the more nutrient poor forest soils.

Neither heat from fire nor ash deposition had any significant effect on soil temperature, soil moisture, or nitrate level on plots at the Post site. Burned plots had almost twice as much unchangeable soil ammonium in the 0 to 8 cm soil depth as did unburned plots on April 21, 1974 (2.1 and 1.2 ppm for heated and unheated plots, respectively). Thereafter, no effect of heat was discernable. Although heating of soil by tobosagrass fires can be intense at the soil surface, 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 grass fires to have anything but a very temporary effect such as the slight increase in exchangeable soil ammonium recorded in this study.

Burning lowered total soil nitrogen levels at the 2.5 to 5.0 and 5.0 to 12.5 cm soil depths (Table 5). However, clipping reduced nitrogen markedly only at the 0 to 5.0 cm depth. No effect of clipping was discernable at the 5.0 to 12.5 cm depth. This differential response between burning and clipping demonstrates that the effects of fire on soil nitrogen content are not due entirely to litter removal. The charred material from fire adds nitrogen to the upper soil layer (Metz et al. 1961), and warmer soil temperatures stimulate some nitrogen depletion from lower layers by active organic decay.

Table 5. Total soil nitrogen (%) in relation to treatment on the Spade site (April, 1972 to March, 1973).

Treatment	Soil depth (cm) 0–2.5	2.5–5.0	5.0–12.5
Control	0.236 a[1]	0.138 a	0.097 a
Burned	0.212 a	0.095 c	0.081 b
Clipped	0.186 b	0.108 b	0.092 a

[1] Means within a column followed by the same letter are not significantly different ($P < 0.05$).

Tobosagrass Yields

Tobosagrass on burned plots produced over three times as much new growth as the control and almost one and one-half as much as the clipped plots (Table 6) during a wet spring on the Colorado City site in 1972. Since soil nitrate and soil moisture levels were higher on the control than on the burned plots, the lower production of tobosagrass on the control plots could not be attributed to a lack of nitrate or moisture.

Higher soil temperatures in the spring were probably the major factor favoring tobosagrass growth on burned compared to the cooler control plots. Soil temperature could not, however, explain the difference in production at Colorado city between burned and clipped plots since their temperatures were similar. This yield difference was an unusual response compared to past work in tobosagrass communities (Wright 1969) and other studies (Hulbert 1969; Wolters 1971). Unusually high tobosagrass growth in the late fall of 1971 prior to spring treatment application in 1972 may have tied up a large portion of the normal supply of available soil nutrients, that, in this case, were released by the burn. Thus, nutrients contained in the deposited ash may have been more important than usual in stimulating tobosagrass growth during this particular year.

Table 6. Tobosagrass yields (kg/ha) on control, clipped, and burned plots at the Colorado City and Post sites.

Treatment	Colorado City July, 1972	Post July, 1974	Post Nov., 1974
Control	838 a[1]	824 a	2066 a
Clipped	1571 b	707 a	2149 a
Burned	2652 c	721 a	2109 a

[1] Means within a column fllowed by the same letter are not significantly different ($P < 0.05$).

Drought conditions on the Post site during the spring growing period in 1974 (April 5 to July 28) minimized treatment effects and limited tobosagrass yields at 700 to 824 kg/ha (Table 6), which were considerably lower than the 1,300 to 2,400 kg/ha produced on similar range sites during years of normal precipitation (Wright 1972). Warmer spring soil temperatures on litter-free plots compared to controls, generally an important factor in stimulating increased plant growth on burned plots (Ehrenreich 1959; Ehrenreich and Aikman 1963; Old 1969), were ineffective during the 1974 growing season due to inadequate soil moisture for optimal growth of tobosagrass.

Under favorable moisture conditions in the late summer and fall growing period (July 28 to November 1, 1974), warm soil temperatures and adequate soil moisture at Post favored rapid growth of tobosagrass on all plots. Again, as in the spring, none of the treatments affected tobosagrass yields (Table 6).

During years of inadequate soil moisture, tobosagrass yield is not increased by burning. When soil moisture is adequate, however, warmer soil temperatures, resulting from removal of litter, stimulates tobosagrass growth and increases herbage yield.

Ash seems to have a fertilizing effect only during some years, and its value as a fertilizer may be related to a nutrient tie-up in vegetation produced the previous fall growing season.

Conclusions

Tobosagrass yields increased following burning in years of normal precipitation, primarily because of higher soil temperatures, which also accelerate bacterial activity (Coleman 1916; Black 1968) on burned areas compared to the cooler unburned areas. During dry years, or years when rainfall is delayed until the fall, there is little advantage to burning because moisture, not soil temperature or the associated nitrate production, limits yields of tobosagrass during these times.

Although warmer soil temperatures stimulate nitrate ion production on burned areas compared to unburned areas, both water and nitrate are taken up more rapidly on burned areas to support the more luxuriant plant growth there. Thus, soil moisture and soil nitrate levels decline more rapidly on burned than on control areas even though more nitrate is produced on the burned areas.

Literature Cited

Austin, R. C., and D. H. Baisinger. 1965. Some effects of burning on forest soils of western Oregon and Washington. J. Forest. 53:275-280.

Black, C. A. 1968. Soil-plant relationships. John Wiley and Sons, Inc., New York. 792 p.

Burns, P. Y. 1952. Effects of fires on forest soils in the pine barren region of New Jersey. Yale Univ., School of Forest., Bull. 57. 50 p.

Coleman, D. A. 1916. Environmental factors influencing the activity of soil fungi. Soil Sci. 2:1-65.

DeBell, D. S., and C. W. Ralston. 1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Amer. Proc. 34:936-938.

Dix, R. L. 1960. The effects of burning on the mulch structure and species composition of grasslands in western North Dakota. Ecology 41:49-56.

Dix, R. L., and J. E. Butler. 1954. The effects of fire on a dry thin-soil prairie in Wisconsin. J. Range Manage. 7:265-168.

Ehrenreich, J. H. 1959. Effect of burning and clipping on growth of native vegetation in Iowa. J. Range Manage. 12:133-137.

Ehrenreich, J. H., and J. M. Aikman. 1963. An ecological study of the effect of certain management practices on native prairie in Iowa. Ecol. Monogr. 33:113-130.

Finn, R. F. 1934. The leaching of some plant nutrients following burning of a forest litter. Black Rock Forest Papers 1:128-134.

Fowells, H. A., and R. E. Stephenson. 1934. Effect of burning on forest soils. Soil Sci. 38:175-181.

Heirman, A. L., and H. A. Wright. 1973. Fire in medium fuels of West Texas. J. Range Manage. 26:331-335.

Hesselman, H. 1918. Om vara skogsforyngrinsatdarders inverkan pa salt-peterbildinigen i marken och dess detydelse for barrskogens foryngrind. (English summary in J. Ecol. 7:213, and J. Forest. 17:69-73.)

Heyward, F., and R. M. Barnette. 1934. Effect of frequent fires on chemical composition of forest soils in longleaf pine region. Univ. Florida Agr. Exp. Sta. Tech. Bull. 265. 39 p.

Hulbert, L. C. 1969. Fire and litter effects in undisturbed bluestem prairie in Kansas. Ecology 50:874-877.

Isaac, L. A., and H. G. Hopkins. 1937. The forest soil of the Douglas-fir region and changes wrought upon it by logging and slash burning. Ecology 18:264-279.

Kucera, C. L., and J. H. Ehrenreich. 1962. Some effects of annual burning on central Missouri prairie. Ecology 43:334-336.

Mayland, H. F. 1967. Nitrogen availability on fall-burned oak-mountain-mahogany chaparral. J. Range Manage. 20:33-35.

Metz, L. J., T. Lotti, and R. A. Klawitter. 1961. Some effects of prescribed burning on coastal plain forest soil. Southwestern Forest Exp. Sta. Pap. No. 133. 10 p.

Neal, J. L., E. Wright, and W. B. Bollen. 1965. Burning Douglas-fir slash: physical, chemical, and microbial effects in the soil. Forest Res. Lab., Oregon State Univ. Res. Pap. 32 p.

Nelson, D. W., and J. M. Bremner. 1972. Preservation of soil samples for inorganic nitrogen analysis. Agron. J. 64:196-199.

Old, S. M. 1969. Microclimate, fire, and plant production in an Illinois prairie. Ecol. Monogr. 39:35-381.

Stinson, K. J., and H. A. Wright. 1969. Temperatures of headfires in the southern mixed prairie of Texas. J. Range Manage. 22:169-174.

Vogl, R. J. 1965. Effects of spring burning on yields of brush prairie savanna. J. Range Manage. 18:202-205.

Weaver, J. E., and N. W. Rowland. 1952. Effects of excessive natural mulch on development, yield, and structure of native vegetation. Bot. Gaz. 114;1-19.

Whittaker, E. 1961. Temperatures in heath fires. J. Ecol. 49:709-715.

Wolters, G. L. 1971. Response of southern bluestems to pine straw mulch, leachate, and ash. J. Range Manage. 25:20-23.

Wright, H. A. 1969. Effect of spring burning on tobosagrass. J. Range Manage. 22:425-427.

Wright, H. A. 1972. Fire as a tool to manage tobosa grasslands. Proc. of Tall Timbers Fire Ecol. Conf. 12:153-167.