EFFECTS OF PRESCRIBED BURNING
ON SURVIVAL OF CERTAIN WOODY PLANTS

by

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INTRODUCTION

Numerous authors (Cooper, 1961; Ahlgren and Ahlgren, 1960; Daubenmire, 1968) have suggested that widespread and periodically occurring fires were a major factor in the shaping of the vegetation patterns of North America. Grasslands, in particular, owe their origin and maintenance to fire, according to Wells (1965). He indicated that moisture is not a limiting factor in the growth of trees in the North American grasslands. Interactions of topography, wind, and fire may partly account for the exclusion of trees from the plains. Occurrence of nonriparian woodlands seems correlated with abrupt topographic breaks which provide fire protection. Without fire, more extensive woodlands would be expected.

Naturally occurring fires were not uncommon before the dawn of European influence in North America. Although many of these fires were probably caused by lightning or possibly spontaneous combustion (Viosca, 1931), the majority of fires during the last few thousand years are thought to be the effects of man. American Indians reportedly used fire without restraint in hunting, in warfare, and as a means of controlling underbrush.

As the large areas of North American prairie became settled, fires posed a grave danger to life and property. In this drought-prone region, the continuity of flat topography covered with seasonally dry grasses enabled fires to travel great distances until stopped by a break in topography (Wells, 1965). The dangers of these uncontrolled fires have been dramatized by James Fenimore Cooper, Zane Grey, and others who wrote of the perils of frontier life.

The destructive and uncontrollable nature of fires in populated areas fostered attitudes favoring complete elimination of grassland fires. Increasing settlement of grasslands made such fire control possible, and the trend to woody plant invasion was inadvertantly encouraged.

Some farmers and landowners have used burning to combat shrubby growth and to increase the palatability of forage for livestock and wildlife. Results of such burning vary with conditions of each individual fire. Recent research in Iowa, however, (Richards, 1969) has documented an increase in yield and flowering of some native herbaceous species following fire.

This study was undertaken to more precisely define the overall relationship between selected aspects of controlled fire and the survival of woody invading species in Iowa grassland. A knowledge of the effects of headfire versus backfire conditions, tree diameter, tree height, maximum temperatures attained, and slope position on survival of trees would be helpful in the prediction and interpretation of fire effects. The degree of valid prediction and interpretation possible may be reflected in the success with which fire may be used as a management tool for control of woody plants in grassland.

LITERATURE REVIEW

Hanson (1939) reviewed some of the early literature dealing with the use of fire in land use and management. He concluded that while fire is often distinctly serviceable or definitely disadvantageous, in many instances the effects are difficult to evaluate.

Grassland Fire

Fire experiments in the grasslands of the Midwest indicate prescribed burning increases the grass component at the expense of the non-grass component. Other effects of prairie fire include reduction of litter, marked increase in the number of flowering stalks of native grasses, increased yield due to greater availability of nutrients, and earlier growth. This earlier growth is due to warmer soil temperatures in early spring. The time and frequency of burning which produces the most desirable results on vegetation is a point of some disagreement (Aikman, 1955; Kucera and Ehrenreich, 1962; Kucera and Koelling, 1964; Koelling, 1965; Daubenmire, 1968; Old, 1969; Richards, 1969).

Forest Fires

While forest fires, in general, are completely unlike situations arising from grass fires, some information gained from forest burns may be useful in the interpretation of grass fire effects on woody plants. Sorting through the contradictions of the literature, Ahlgren and Ahlgren (1960) have brought together some generally accepted truths from the early forest fire research. Paramount among these truths is the variation in productivity, reproduction, and plant succession with the individual fire, even when sites are similar.

Resistance to fire damage in forests was found to be complicated by tree age, site, time and conditions of the fire, as well as other lesser factors (Starker, 1934). McCarthy and Sims (1935) have attributed survival of hardwoods largely to bark thickness in relation to the intensity and duration of the fire and the height of the tree crowns. Trees 2 inches dbh (diameter breast high) and under were found more likely to be damaged by fire, with most young trees under 2 feet tall or 0.5 inches dbh being killed (Little and Moore, 1949; Ferguson, 1961). Lethal temperature for plant tissue has been placed around 140 F (Byram, 1948). Since initial vegetation temperature varies with air temperature and the rate of temperature rise is inversely proportional to the mass of the tissue, this lethal temperature is not reached simultaneously in the entire burn or even the whole plant. The effects of wind are interrelated with those of temperature, making it difficult to compare the relative importance of these factors, especially under field situations (Baker, 1929; Byram, 1948).

It has long been recognized that fire affects the distribution of woody glade and chaparral species. Spurr (1964) attributed dominance of junipers, shrub oaks, and many chaparral species to the repeated occurrence of heavy fires. Juniperus virginiana, however, has been controlled by fire (Garren, 1943; Harper, 1912a; Harper, 1926; Arend, 1950; Martin and Crosby, 1955; Starker, 1934; Graf, 1965). Sampson (1944) found burning to be effective in the temporary control of non-sprouting chaparral species in one or two years of burning.

Fire and Prairie Invaders

Early in this century, Harper (1912b) discounted fire as an agent in formation or maintenance of the prairie. Indeed, fire was regarded as a result of the treeless condition.

Modern researchers tend to disagree. Kucera (1960) felt mowing or burning was essential to the stability of the prairie in a humid climate where forest is common. Later, Kucera, Ehrenreich and Brown (1963) showed that fire would retard young tree development. Drier fuel conditions and greater vapor pressure deficits resulted in a greater percentage of specimens being killed back. In studies dealing with *Juniperus monosperma* invasion of Arizona grasslands, Johnsen (1962) found that fire and competition from vigorous grassy regrowth were both necessary to prevent invasion. Vogl (1965) found that burning of Wisconsin brush prairie savanna significantly reduced woody plant yields even though some woody plants were able to resprout. Fire has been found to control young plants of mesquite without harm to tobosa grass range (Wright, 1969).

Temperature Measurement

Early in experimental fire research it was recognized that in order to understand the effects of a particular fire, a measurement of heat of the burn was necessary. The "Seger cone", a clay cone with a definite softening temperature, was used by Nelson and Sims (1934) to approximate the maximum temperature reached in surface fires. This early device was not highly accurate and functioned only at high temperatures.

Whittaker (1961) used pyrometers to study the temperature of heath fires. Pyrometers were constructed by placing commercially available temperature sensitive substances called "Thermocolors" on sheets of mica. These gave maximum temperatures reached by the fire.

In headfires in the southern mixed prairie of Texas, temperatures obtained from Tempil cards, another commercially available pyrometer, were found to have a very good correlation with temperature readings obtained from thermocouples (Stinson and Wright, 1969). Fahnstock and Hare (1964), in a similar study, found Tempil maximums to be 10% lower than maximums obtained from thermocouples. This may have been due to the use of 100 degree intervals on the Tempil indicators.

By using thermocouples, it became possible to measure the duration of the maximum temperature. The specific temperature and the duration of that temperature at a point have been incorporated into an index of heat involved called the "heat factor". This factor has been used to determine the amount of scorching, leaf consumption, and mortality (Lindenmuth and Byram, 1948).

Iizumi and Iwanami (1965) found mountain grassland fires to reach maximum temperature quickly after ignition. Temperatures greater than 392 F (200 C) did not exceed two minutes in duration. Maximum temperatures obtained were found to increase with the fuel level (Iwanami and Iizumi, 1966).

Temperatures recorded from eighteen surface fires in jack pine barrens indicate the amplitude of variation in maximum temperatures with the situation involved. Maximum temperatures in this study varied from 251 F to 981 F with much higher temperatures being suggested (Sparling and Smith, 1966).

Wind Effects On Temperature

The effects of wind upon temperature of a particular fire are often difficult to evaluate (Byram, 1948). Burning with or against the prevailing wind, however, may make a considerable difference in temperatures obtained. At heights up to eighteen inches above the ground, headfires have been found to be cooler than backfires. At greater heights, the reverse is generally true (Lindenmuth and Byram, 1948). Whittaker (1961) credits moderate winds with increasing temperatures 50 to 100 C at ground level. Other researchers (Sparling and Smith, 1966) found strong winds to have a temperature decreasing effect. The opposite result might occur in dense vegetation where wind would increase the supply of oxygen. Byram (1948) had realized that while wind might speed up the combustion process in a headfire, this effect would be partially offset by a conductive cooling action on plant parts and a turbulence which would retard the upward flow of heat. The absence of wind has been found to cause severe scorching of plants since the peak of heat intensity from the approaching fire line occurs at the same time as the peak from burning gases.

Effects of Other Factors

Initial temperature of vegetation greatly influences the maximum temperatures attained within plant tissue. This alone would imply a much different effect if two fires of identical intensity occurred at different times of the year (Byram, 1948). Doubtlessly, the different physiological states of vegetation at these different times would also affect survival of woody plants.

Baker (1929) felt the cooling processes occurring within tissue was due to stem mass, radiation, and conduction, but found no evidence that the transpiration stream assisted in the cooling of the tissues. Reynolds (1939) maintained that transpiration was a major factor in modifying the temperature of the cambium.

Sparling and Smith (1966) have found relative humidity in the 12 to 21.8% range to have little effect on temperature and spreading of fire after ignition.

Soil Temperatures

Surface temperatures from burning of woodland range varied from 182 F to 1260 F with increasing fuel weights in the southern mixed prairie of Texas (Stinson and Wright, 1969). Temperatures in the 200 to 250 F range were recorded on the soil surface of woodland range fire elsewhere (Bentley and Fenner, 1958).

Soil temperatures during forest fires at depths of one-eighth to one-half inch were only slightly higher than air temperatures in the longleaf pine region (Heyward, 1938) where a grassy understory is of common occurrence.

Grassland fires in Japan charred plant parts 6-11 cm above the ground without affecting underground parts (Iizumi and Iwanami, 1965). An April prairie fire in Iowa did not raise temperatures below the soil surface past 100 F at approximately 15 sites (Richards, 1969).

Heat Effects on Plants

The literature dealing with heat effects on plants is scattered.

Hare (1961) has brought much of the early material together in an obscure occasional paper.

Burning cedar (*J. virginiana*) in glade areas in Missouri killed 7% of the trees taller than 6.5 feet. The same fire killed 91% of those trees less than 3.5 feet tall. Those trees in the 3.5 foot and under class which did survive, were found in localized areas not reached by the fire. It was found that tree height and crown density increase relative resistance to fire. It was apparently necessary to burn or scorch all the foliage on a tree to kill it (Martin and Crosby, 1955).

Sprouting and Reproduction

Kucera, *et al.*, (1963) associated less crown damage with fewer sprouts in hardwoods following prairie fire. Cable (1965) looking at sprouting in mesquite, found that trees over two inches in basal diameter had more crown sprouting. Smaller trees had more basal sprouts. After one growing season, more trees had basal sprouts than had crown sprouts or no sprouts. Certain shrubs of the Sierra Nevada mountains are thought to be more resistant than the dominant conifers to fire. Indeed, heat seems to increase the germination percentage of some species. This may account for the replacement of conifers by brush fields following fire (Wright, 1931). These brush fields may be considered a fire type vegetation owing their presence to fire.

Bark Properties

Martin (1963b) investigated such physical properties of bark as conductivity, density, specific heat, and thermal diffusivity. Tree diameter is considered very important in survival since the tree stem is roughly described as a shell of bark, low in conductivity and specific heat, around a core of high conductivity and specific heat. The size of the core, by acting as a heat sink, becomes very important in determining survival (Martin, 1963a).

Early studies show fire resistance in trees is affected by the age of the tree, site, time and conditions of burning and other factors (Starker, 1934). The relationship of tree diameter to fire resistance is dependent on the rate of thickening and insulation efficiency of the bark. If heat conduction through bark obeys the inverse square law, a small increase in bark thickness might provide a great deal of fire protection (Hare, 1963). That such a relationship might exist is evidenced by the cambial temperature and bark thickness data of Kayll (1963).

Gill and Ashton (1968) found significant differences in bark thickness at different heights. They suggested that girth, in addition to bark thickness and height be compared with heat. Fahnstock and Hare (1964) found that irregularities in tree trunk surfaces affect the heating of the surface. Temperatures are lower in the fissures of the bark.

Vines (1968) found no significant difference in cambium temperature between species. It was suggested that fire sensitive trees are those whose bark is more easily damaged, allowing secondary effects to kill the tree.

Investigations of plant cells in relation to temperature (Alexandrov, 1964) indicate that frost hardening increases resistance of cells to several injurious factors, including heat. This may be partially responsible for the non-specific increase in stability which was found to occur during autumn. Heat resistance was found to increase with age of the cell.

Viability Tests

Parker (1952) used 2,3,5,--triphenyltetrazolium chloride as a test for viability of desiccated conifer leaves. Tetrazolium chloride is a dehydrogenase-reduced substance which is colored only in its reduced form. Jameson (1961) used tetrazolium chloride solution to determine viability of cambial tissue. Lethal temperatures were found to be higher in winter and lower in late spring. Kayll (1963a) used tetrazolium chloride to test heat tolerance of pine seedlings. Heat conductivity was found to increase with moisture. This effect may have been offset by an increase in thermal capacity with increasing moisture content.

While the tetrazolium chloride test does not entirely follow carbon dioxide release rates (Parker, 1952) its convenience may make it a useful tool in obtaining estimates of woody plant survival.

METHODS

Locations and Descriptions of Study Sites

Five individual plots at two different Story County sites were examined in this study. These plots were selected on the following criteria: (1) the plot should be readily accessible yet not heavily used; (2) the plot should have been free from major disturbance for several years; (3) the plot should contain some native herbaceous vegetation; (4) the plot should contain a number of small woody plants; (5) the plot should present a definite slope aspect; (6) the plot should be sufficiently vegetated to carry a fire and permission to burn should be available; (7) adjacent control areas should be available for comparison. Three plots were chosen on the Scenic Overlook area on the west side of Interstate 35, north of Ames, Iowa. This area is in the southwest quarter of the northwest quarter of Section 32, T85N, R23W, Howard township.

The history of this area is not known, although some grazing influence can be seen in the vegetation. Presumably, management practices have been limited to an occasional mowing since the acquisition of the area by the Iowa State Highway Commission in 1966.

Herbaceous vegetation of the area includes many species common to Iowa roadsides, abandoned fields, and waste areas. Species represented include *Monarda fistulosa*, *Poa* spp., *Asclepias verticillata*, *Melilotus* spp., *Andropogon scoparius*, *Bouteloua curtipendula*, *Trifolium* spp., *Lobelia spikata*, *Cannabis sativa*, *Solidago* spp., and numerous other species in less abundance. Woody plants are principally *Juniperus virginiana* with occasional specimens of *Ulmus americana* and *Gleditsia triacanthos*.

Scenic area plot 1 was located on the south and plots 2 and 3 on the northwest aspect of the perimeter slope.

The first of these plots (plot 1) is a south-facing slope with a good herbaceous cover which included prairie species, bluegrass, and various annuals. The woody component of the slope was represented mainly by Juniperus virginiana which ranged in size from a few inches to over twenty feet in height within the plot. The plot was roughly sixty feet wide and extended about one-hundred-fifty feet down the slope to the perimeter of the Scenic Area. Total rise in the sigmoid slope was approximately thirty feet.

The second plot (plot 2) at the Scenic Area, located on a west-facing slope, was approximately 50 x 100 feet. Herbaceous vegetation included perennial grasses and forbs, particularly of Poa pratensis and Melilotus spp. Vegetation on plot 2 appeared much less dense than that on plot 1. Annuals and pasture species are found in greater abundance on plot 2 than on plot 1. Woody species included Juniperus virginiana although the largest specimen was something less than seven feet in height.

Scenic Area plot 3, the third plot at the Scenic Area was immediately north of, and adjacent to, plot 2. Vegetation was similar though less dense. Melilotus spp. dominated the lower one-third of the slope.

The fourth and fifth plots chosen for this study lie within the biology teaching area of the Ames High School, Ames, Iowa. Locally designated as the Ames High School Prairie, this area is in the northwest quarter of section 34, T83N, R24W, Franklin township, Story County, Iowa.

Ames High School plot 4 is a triangular plot with base approximately 60 feet wide at the west and extending about 150 feet up the west-facing slope to its apex. Herbaceous cover on this plot consists almost entirely of native perennial grasses and forbs of the tall grass prairie. Woody species of the plot included *Ulmus* sp., *Pyrus ioensis*, *Crataegus mollis*, *Rosa* sp., and a single specimen of *Acer negundo*. Most of these woody plants were less than four feet high.

Plot ~~4~~ 5 is a south-facing slope at the Ames High School teaching area. The rectangular plot was approximately 50 feet wide at the top of the slope, extending 150 feet to the base of the slope. Herbaceous cover is similar to that of plot 4. Woody species represented in plot 4 are found in plot 5. Also in plot 5 are specimens of *Acer negundo* and *Juglans nigra*. Woody plants in plot 5 ranged from a few inches to over 20 feet in height.

Burning

Prior to each burn fire lanes were raked along those plot borders judged to present potential control problems. When necessary, these lanes were mowed or cut free of brush before raking. This not only provided a physical barrier to the flames but allowed easy access to the perimeter of the plot.

The afternoon of April 15, 1969, after several days of damp cloudy weather, plots 1 and 2 at the Scenic Overlook area were burned. Air temperature, wind direction and wind velocity were measured at the site. Relative humidity was measured with a sling psychrometer.

While at no time was control a problem, a backfire was first set along each firelane on the opposite edge of the plot from the direction of the wind. The main part of each plot was then burned by a headfire.

The third plot at the Scenic Overlook (plot 3) was burned the afternoon of April 23, 1969. Again, air temperature, relative humidity, wind velocity and direction, and fuel weight estimates were obtained. Vegetation included Monarda fistulosa, Melilotus spp., Poa spp. Trifolium sp. and Asclepias verticillata as well as some native grasses and Juniperus virginiana. Plot 3 was burned completely by controlled backfire (Fig. 1 and 2).

Plot 4 at the Ames High School was burned April 21, 1969. Air temperature, relative humidity, wind velocity and direction, and fuel weight estimates were recorded. The complete plot was burned by a controlled backfire.

Plot 5, too, was burned by controlled backfire but at a different time of year. The afernoon of September 12, 1969, after taking the usual measurements of wind velocity, relative humidity and fuel, a strip of south-facing slope fifty feet wide was burned (See Fig. 3).

Temperature Measurement

Point estimates of maximum temperatures attained at various levels were desirable for interpretation of fire effects. A type of pyrometer was constructed from birch dowels usually three-fourths inch in diameter (See Fig. 4). Temperature sensitive materials were attached at various levels. Thermopapers (Paper Thermometer Company, Natick, Mass.) were attached at the soil surface such that they extended below the soil surface in the manner described by Richards (1969). At 20 cm, 50 cm and 80 cm Tempilaq (Tempil Corporation, New York, N. Y.), a temperature sensitive paint, was applied directly to the wood and allowed to dry. Although not every temperature indicator was used at every level, indicator values

Fig. 1. Plot 3 of the Story County Scenic Area showing *Juniperus virginiana* and herbaceous vegetation before burn of April 23, 1969

Fig. 2. Plot 3 of the Story County Scenic Area immediately following the burn

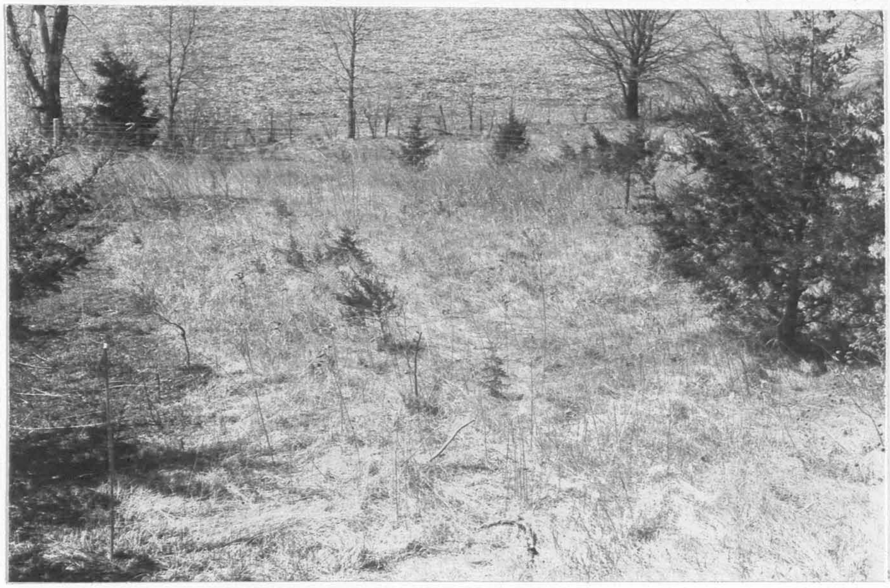


Fig. 3. Blackened corner of plot 5, burned September 12, 1969, is seen in lower left of photo. Area to the right of trail represents plot 4, burned April 21, 1969

Fig. 4. Temperature indicator stake is shown with burned juniper seedling. Charring of the stake indicates height of maximum temperature

ranged from 113 to 800 F with as large a part of this range as possible being represented at each level.

While this method provides useful information as to maximum temperatures, major limitations of these pyrometers include their failure to measure duration of temperatures attained, error due to the necessary use of intervals of indicators, and the effect of the stake itself upon the temperature of the indicator.

It was therefore desirable to try other means of monitoring temperatures during the fire. Accordingly, five chromel-alumel thermocouples were used in the burn of plot 5. These were distributed throughout the plot with the hot junction placed roughly 10 cm above the soil in conjunction with a tree stem or temperature stake. The cold junction was buried at least 5 inches deep. The temperature of the cold junction was determined with a mercury thermometer. A Leeds and Northrup portable potentiometer with a cold junction compensator was used to obtain temperature readings at 30-second intervals as the fire approached and passed by the thermocouple. This method, too, was found to be not without its deficiencies. The mass of the 18 and 24 gauge hot junctions was, by design, minimal, in order to respond quickly to the passing front of the grass fire. Indeed, this mass was so sensitive to slight temperature change that the convection currents caused by the fire frequently caused enough variation in the temperature of the junction to make the potentiometer impossible to balance within the 30 second interval.

Another attempt to easily obtain accurate temperature estimates employed a battery operated, industrial type optical pyrometer. The readings from this equipment which was designed for use indoors, vary with differences in light intensity and background radiation. In the field, the shadow of a cloud may cause an instant reduction of the reading by 1500 degrees or more.

Survival Estimates

Following the spring fires, damage estimates were made along transects through each plot. These observations included estimated foliage consumption or damage, bud characteristics, obvious stem damage, and any evidence of resprouting, for those plots having mostly deciduous species. In those plots where Juniperus represented the dominant woody growth, transects were also established six feet in width stretching diagonally across the respective plots. Observed damage classes were arbitrarily established. Trees falling within each transect were placed in one of the following damage classes:

Class	Damage
1	no apparent damage
2	1-25% of leaves scorched
3	25-50% of leaves scorched
4	50-75% of leaves scorched
5	75-95% of leaves scorched
6	95-100% of leaves scorched
7	defoliated
8	branches all or nearly all consumed

It is not known how long is necessary for primary effects of fire to be manifested upon the vegetation. This hinges upon the definition of primary effects, the implications of which will not be dealt with here. However, since two weeks to several months of good growing conditions may be helpful in damage assessment, effects of autumn fires do not lend themselves to this type evaluation until the following year. After this length of time secondary effects may account for mortality of some trees (Starker, 1934). It was, therefore, desirable to apply other techniques to estimate damage to woody plants following autumn grassfire.

Survival Monitoring

One method employed involves the use of 10% 2,3,5-triphenyltetrazolium chloride in a procedure similar to that used by Jameson (1961). Twig segments, approximately three inches long were collected at a measured length above the ground. A tangential cut was made along one side of each twig. Each twig was then cut into two segments, each about one and one-half inch long. One segment was placed in a vial of the tetrazolium solution while the other segment was placed in a test tube containing about one-half inch of distilled water. The tube without distilled water was plugged lightly with cotton and allowed to incubate at room temperature for one week.

The corresponding segments of twigs in the vials of tetrazolium were placed in the dark at room temperature for twenty-four hours. The twigs were then examined for a red color in or around the cambium. This color would indicate the presence of hydrogen ions from an active dehydrogenase, and is used as an indicator of viable tissue.

After incubation, the twigs in the tubes with distilled water were examined for callous tissue proliferation of the cambium. Such growth was considered evidence of viable tissue.

OBSERVATIONS AND DISCUSSION

Spring Burns

Headfires

The techniques of backfiring plot boundaries caused a limited area next to a boundary to be burned under backfire conditions. Because of the relatively stiff breeze (5 mph) coming up the south-facing slope when plot 1 was burned, this backfire area was extended to 12-15 feet wide at some points to ensure adequate protection to surrounding vegetation. Temperature measurements were made with temperature stakes in both the backfired and headfired areas.

After backfiring the northern (top of slope) and eastern edges of plot 1, a headfire was started along the southern edge of the plot. The fire moved relatively slowly through the predominantly bluegrass vegetation along the foot of the slope and then swept up the backslope at a greatly accelerated rate. This resulted in more foliar damage to junipers occurring on the backslope than those occurring at any other position. Temperature means and standard deviations within plot recorded for headfire and backfire conditions are shown in Tables 1 and 2, respectively.

Although the above measurements are lacking in precision, the association of higher temperature maximum with backfire conditions is apparent. A relationship between maximum temperatures and height above the soil surface is indicated.

Many factors affect the temperature reached at a given point within a plot. Microrelief, microclimate, fuel distribution, and the temperature sensing device itself may cause considerable differences in temperature

Table 1. Temperature maximums for that portion of plot 1 burned by headfire

Level	Mean temperature	S.D.
Surface (4)*	213**	28
20 cm (9)	572	78
50 cm (9)	439	71
80 cm (9)	389	91
100 cm (1)	350	--

*Number of observations.

**All temperatures in degrees Fahrenheit.

Table 2. Temperature maximums for that portion of plot 2 burned by backfire

Level	Mean temperature	S.D.
Surface (3)*	317**	54
20 cm (3)	650	123
50 cm (3)	188	49
80 cm (3)	183	10

*Number of observations.

**All temperatures in degrees Fahrenheit.

measurements obtained at various points (Daubenmire, 1968). We must assume these effects to be randomly distributed throughout each plot with the mean of each effect being equal to zero. Subjectively randomized placement of temperature indicators should, then, provide mean values for the plot as a whole. The large variance of the above mentioned effects is reflected by the standard deviations given.

Temperature stakes placed in non-burned control plots did not exhibit changes in temperature sensitive materials. Such changes of materials within the burned plot were, therefore, attributed to the fire.

Within plot 1, two generalizations seem to hold. First, the headfire was cooler near the soil surface and hotter at the higher points measured. Furthermore, of all heights measured, highest temperatures were reached at 20 cm above the soil surface. These results seem in agreement with early observations of Lindenmuth and Byram (1948). If the plot may be considered randomly homogeneous, the backfire condition seems to involve more extreme temperatures than a headfire on the same plot.

On examination of plot 1 fourteen days after the burn, immediate damage to trees was apparent. During the fire, temperature stakes had been placed next to the trunks of six trees. These same trees were examined for percentage of foliar damage. These results are shown in Table 3.

Table 3. Damage to selected trees in plot 1

No.	Max. temp.	% foliar damage	Fire type
1	450*	50-75	backfire
2	750	100	headfire
3	750	100	headfire
4	700	50-75	headfire
5	750	50-75	headfire
6	650	100	headfire

*Temperatures in degrees Fahrenheit at 20 cm.

These results also bear out the findings of Lindenmuth and Byram (1948) in that if the basal diameter is considered to be not significantly different in each case maximum temperatures alone do not explain differences in fire effects. A concept of temperature duration seems necessary to an understanding of the response of an individual tree.

Examination of 25 trees in a diagonal transect revealed two apparent categories of fire effects. Trees less than three feet in height suffered more foliar damage than those trees greater than three feet tall (Table 4).

Table 4. Damage classes in plot 1; April 29, 1969

% foliar damage	Less than 3 ft. tall	Greater than 3 ft. tall
25-50	0	16.7%
50-75	0	16.7%
75-95	0	16.7%
95-100	68%	33.4%
Defoliated	5%	16.7%
Branches consumed	26%	0

According to Martin and Crosby (1955), it is necessary to burn or scorch all or nearly all of the foliage of a juniper in order to kill it. This indicates complete mortality of those trees less than three feet tall and approximately fifty per cent of those trees of height greater than three feet. Observations of those trees greater than three feet tall indicate damage was greatest to smaller trees on the backslope.

Observations at the site on June 8, 1969, seven weeks after the burn, revealed green foliage on only eight of the junipers within the plot. These eight were trees of considerable size. In a random transect of sixteen junipers, two (12.5%) were found to have some living foliage while fourteen (87.5%) were judged to be dead.

Partial damage was also evident in the few deciduous trees within the plot. One elm approximately ten feet tall had an absence of green leaves on its lower branches. Basal sprouting, while not found among the junipers, was much in evidence among *Ulmus* and *Gleditsia*.

Plot 2, a northwest facing slope, at the Story County Scenic Area was also burned the afternoon of April 15, 1969. Burning was initiated along the foot of the slope and one edge of the plot. The flames were borne across the plot causing all temperature indicators to be exposed to headfire conditions.

Temperature means at various levels above the soil surface and their respective standard deviations are given in Table 5.

Table 5. Indicated maximum temperatures of plot 2

Level	Mean maximum	S.D.
Surface (3)*	260**	96
20 cm (7)	286	50
50 cm (7)	250	24
80 cm (6)	192	6
100 cm (3)	175	18

*Number of observations.

**All temperatures in degrees Fahrenheit.

Maximum temperatures attained in this plot were considerably lower than those recorded for plot 1. This, in part, reflects moisture and fuel differences due to slope aspect. Weather conditions are not thought to have made a significant contribution to differences in temperatures since plots 1 and 2 were burned consecutively the same afternoon. Again, however, the highest mean temperature was recorded at 20 cm above the soil surface.

Data from those trees which were closely associated with temperature measurements did not show a relationship between maximum temperature and the percentage of foliage damaged (see Table 6).

Table 6. Foliar damage of selected trees in plot 2

No. of tree	Maximum temp. recorded	% foliar damage
1	350*	75-95
2	450	100
3	500	75-95
4	350	100
5	300	100
6	250	100
7	550	100

*All temperatures in degrees Fahrenheit.

Examination of a random transect in plot 2, on April 29, 1969, two weeks after the burn, gave the results shown in Table 7.

Table 7. Foliar damage and tree height on April 29, 1969, in plot 2

% foliage scorched	Trees under 3 ft. tall	Trees over 3 ft. tall
75-95	2%	50%
100	37%	50%
Defoliated	33%	none present
Defoliated with most branches burned off	16%	none present

While this table represents forty trees, it should be pointed out that only two trees fell into the "over 3 ft. tall" class. The table does indicate 98% mortality of junipers less than three feet tall and a corresponding general increase in damage to the shorter trees.

A common problem when conducting research in a public or easily accessible area is the chance of damage to plot markers by pranksters or well intentioned citizens who would "clean up" the area. Such removal necessitated the establishment of a similar, though somewhat longer transect on June 8, 1969, nearly eight weeks after the burn. This transect contained fifty junipers.

Without regard to height of tree, two junipers within the transect appeared to have some living foliage. This does not indicate a significant increase in mortality over that shown by the examination of April 21, 1969. It is assumed, then, that tree deaths apparently eight weeks after the burn are due to the primary effects of the fire.

Only seven junipers in the entire plot had any living foliage. Two of these seven surviving trees were less than three feet tall but had stem diameters approximating one inch. In those trees not scorched completely by flames, basal diameter seems to have a greater effect on survival than does distance of the twigs above the fire. In no case was sprouting seen among the junipers of this plot.

Backfires

Plot 3, at the Story County Scenic Area, was burned the afternoon of April 23, 1969. Relative humidity was 42%. Air temperature was 61 F. Wind was measured at 10 mph NNW with gusts up to 15 mph. After randomly placing temperature indicator stakes, the plot was burned by a relatively cool backfire. Maximum temperatures are given in Table 8.

The relatively low temperatures in the table reflect the sparse

Table 8. Maximum temperatures indicated in plot 3

Level	Mean temperature	S.D.
Soil surface (3)[*]	167[**]	20
20 cm (3)	225	47
50 cm (2)	150	--[***]
80 cm (2)	163	18

[*]Number of observations.

[**]All temperatures in degrees Fahrenheit.

[***]Mean based on single measurement; standard deviation not applicable.

nature of the vegetation of the plot. Density and distribution of the fuel were such that a few localized areas entirely escaped the flames. These areas were, for the most part, disturbed areas near one side of the plot and were not sampled for juniper survival.

A random line transect was established diagonally across the plot on May 8, 1969, two weeks after the burn. Damage was assessed on junipers which occurred within three feet on either side of the line transect. Damage classes for the 45 trees occurring in this transect are shown in Table 9.

Table 9. Damage classes of trees in plot 3

Per cent damage	Percentage of trees within each class
1-25% foliage scorched	2%
50-75% foliage scorched	7%
75-95% foliage scorched	7%
95-100% foliage scorched	76%
Complete defoliation	7%
All or most branches burned off	2%

Within this transect, 84% of the trees were apparently dead two weeks following the fire. This represents less damage than was evident from the first two plots a comparable time after the fire. The difference is probably attributable to differences in fuel density and distribution coupled with the effect of backfire conditions on plot 3.

Examination of the same transect four weeks later, June 8, 1969, found vigorous regrowth of the herbaceous component of the vegetation. Only twenty-five of the junipers could be relocated at this time. This loss of countable trees was due to the difficulty of finding small burned stem remains beneath the heavy herbaceous cover and the loss of such stems because of weathering and breakage. All of the trees located in the transect were apparently dead.

Of the seven trees in the entire plot which had some green foliage, none had less than one-fourth of its total foliage scorched. All trees were taller than four feet. Sprouting was not observed in any tree within the plot.

The temperatures attained by this backfire were not as high as those generated by the headfires of the first two plots. Two weeks after the fire, less damage was evident in plot 3 than was evident in plots 1 and 2, after two weeks. Six weeks after the fire, however, mortality rates for the three plots were not significantly different.

Plot 4, a triangular west-facing slope of relict prairie was burned April 21, 1969, chronologically before the burning of plot 3. The air temperature on the afternoon of the burn was 64 F. Wind was from the west at 10 mph with gusts up to 35 mph. Relative humidity was 40% before the burn and about 30% immediately after the burn.

Maximum temperature indications were obtained from temperature indicator stakes. Tempilaq was applied to the trunks of two small woody plants outside the burn plot to check for toxicity of the indicator. No such effect was found. Two trees were treated similarly within the burned area.

Temperatures indicated by the temperature stakes and the painted trees are given by Tables 10 and 11, respectively.

Table 10. Maximum temperatures obtained in plot 4 by temperature stakes

Level	Mean temperature	S.D.
Soil surface (3)*	323**	66
20 cm (6)	313	69
50 cm (6)	188	17
80 cm (6)	167	15

*Number of observations.

**All temperatures in degrees Fahrenheit.

Table 11. Temperatures obtained from plot 4 from painted trees

Level	Mean temperature	S.D.
30 cm (3)*	517**	102
60 cm (3)	342	160
90 cm (1)	250	--***

*Number of observations.

**All temperatures in degrees Fahrenheit.

***Standard deviation not applicable since temperature based on single reading.

Effects of the fire were evident in vegetation response about two and one-half weeks after the burn. On May 8, 1969, the herbaceous component of the vegetation did not appear damaged despite heavy rainfall immediately following the burn. Indeed, prairie forbs were flowering within the grassy regrowth.

Trees and shrubs were essentially devoid of living leaves below a level of three feet above the surface. Above this level, leaves were not significantly different in number from leaves in the control area. In some cases, buds less than three feet above the ground appeared to have opened. The young leaves had then died before complete unrolling could occur. This may be an effect of the fire on vascular tissue of the stem, heat effects on individual buds, secondary diseases made possible by the fire, or, more probably, a combination of the above effects. The effect was particularly noticeable on the lower half of the plot (i.e. the steepest part of the slope).

Examination of this plot on June 8, 1969, showed approximately two-thirds of the buds of young trees within the plot had never opened. Those plants which had open buds had evidently died shortly thereafter. It is suspected that this mortality accompanied increasing translocation demands as photosynthesis was initiated.

Selected trees which had been previously tagged were examined for percentage foliage present and number of basal sprouts. One tree had approximately 2% live foliage present. Two trees showed some dead leaves. The rest were devoid of foliage.

Basal sprouting was encountered in all species with the exception of the solitary box elder (<u>Acer negundo</u>) specimen. No obvious relationship was apparent between species and number of basal sprouts occurring. The mean number of sprouts per burned tree examined was four. Sprouts ranged from 2-14 inches in height. Burned elms up to about seven feet tall appeared dead above the soil surface.

Basal diameter of those trees showing some surviving foliage was at least one inch in each case examined. This, again, seems to indicate a relationship between stem diameter and mortality. This relationship has been examined by Martin (1963a), who postulated that the center of the stem acts as an effective heat sink. This sink enables the tree to withstand a temperature for a short period of time which would be lethal if prolonged.

Trees in the adjacent control plot were well leafed out. The trees in this plot which had been painted with Tempilaq exhibited no discernible difference from other trees within the plot.

After autumn frosts had occurred, the plot was examined to determine if the abundance of the above mentioned basal sprouts was, indeed, more pronounced in the burned plot. Accordingly, a subjectively random transect was established from the top of the slope to the bottom. Ten points were established along this transect at four meter intervals. The two closest trees to each point were measured. For each tree, the height, basal diameter, number of sprouts, height of tallest sprout, and species were recorded. Measurements were recorded for the burn and the control plots on November 2, 1969.

Of the twenty trees examined in each plot only 10% (two trees) in the unburned plot had basal sprouts. These trees had only one sprout each.

Within the burned plot, however, 80% of the trees examined had basal sprouts. The mean number of sprouts of those trees in which sprouting had occurred was 3.8, agreeing closely with earlier field estimates. Average height of sprouts was 30.1 cm, while mean basal diameter of the parent trees was 9.4 mm. Parent tree height averaged 37.0 cm. Species notwithstanding, sprouts were much more common and more numerous per parent plant within the burned plot as compared with the unburned area.

Late winter observations (February 22, 1970) showed no buds had formed on trees less than six feet tall. Where trees exceeded this height, buds were generally not formed on twigs occurring less than this critical distance from the soil surface. No elm trees were found with buds in this plot.

Autumn Backfire

Plot 5, also at the Ames High School area, was burned by backfire conditions September 12, 1969. The air temperature was 84 F with winds at 5-6 mph SSW. Relative humidity before the burn was 65%. About 2:00 pm a backfire was initiated at the top of the slope.

Two 20 x 50 cm quadrats were clipped prior to the burn. Fresh weight, dry weight, and per cent moisture are recorded in Table 12 for both biomass and litter.

Temperature indicator stakes, chromel-alumel thermocouples, and an optical pyrometer were utilized to arrive at some indication of temperatures generated during the burn. Average temperature stake readings are given in Table 13.

These data again show the gradient of maximum temperatures from the ground up with the highest temperatures being found close to the soil

Table 12. Fuel estimates in plot 5

	Quadrat #1	Quadrat #2
Fresh weight		
Biomass	28*	56
Litter	35	22
Dry weight		
Biomass	18	27
Litter	28	17
Per cent moisture		
Biomass	36%	52%
Litter	20%	23%

*All weights in grams.

Table 13. Average temperatures for plot 5

Level	Mean temperature	S.D.
Soil surface	450*	81
20 cm	275	48
50 cm	200	43
80 cm	180	36

*All temperatures in degrees Fahrenheit, average of 5 observations.

surface. These high temperatures declined sharply beginning at the surface of the soil, progressing downward.

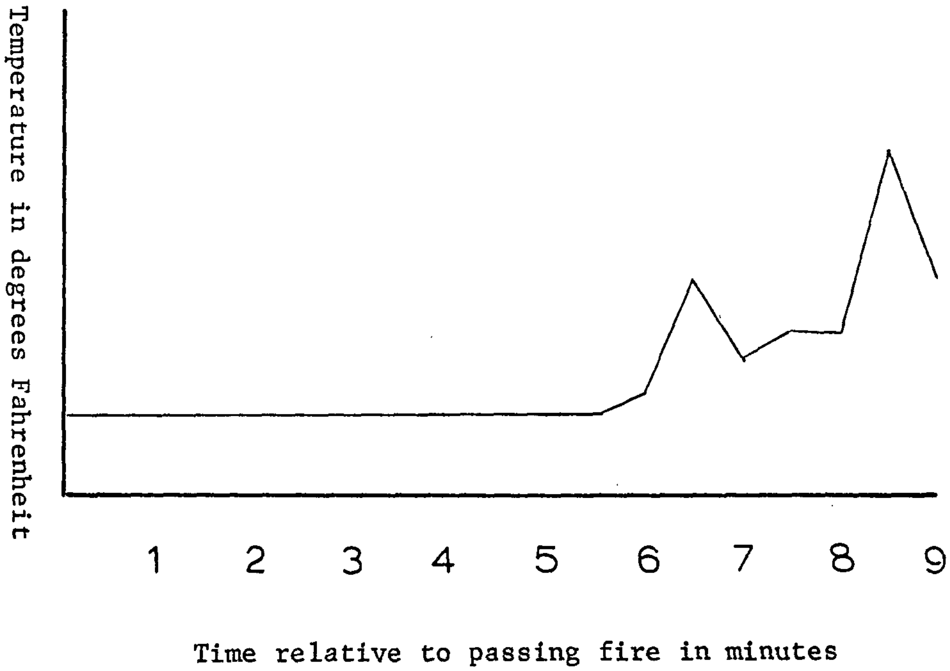
Thermocouple readings were poorly correlated with the above maximums obtained with Tempilaq indicators. Since the Tempilaq surrounded the stakes placed with random paints facing the fire, it is assumed that the average maximums represent the average maximum reached on any side of the wooden stake. The thermocouples, however, were all placed on the side of the tree or stake which faced the oncoming fire. Assuming the thermocouple measurements to be without significant error, the lack of agreement between temperature stake readings and thermocouple readings may be largely due to the "chimney effect" of fire around tree stems (Fahnstock and Hare, 1964).

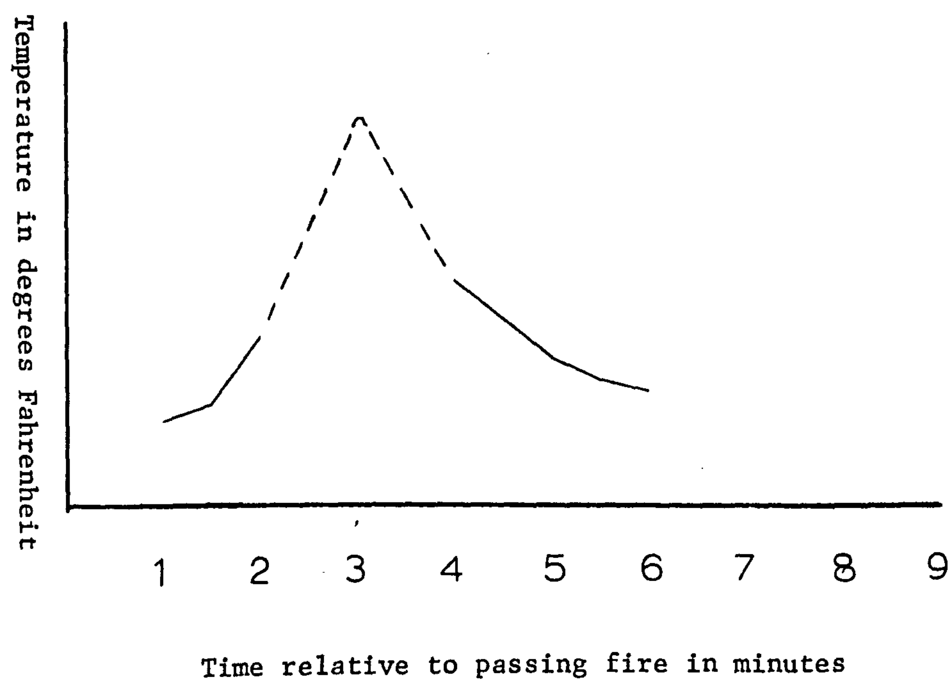
Readings from three of the thermocouples were very difficult to interpret. It is felt that tension on the lead wires caused the unanchored cold junctions to be pulled out of position and subjected to varying temperatures near the surface. If a similar, though lesser, tension moved the cold junctions of the other thermocouples, it is conceivable that the cold junctions may have been in contact with a part of the soil profile having a temperature different from that measured. Assuming the above to have occurred, the individual measurements would be inaccurate. Even so, the shape of the time versus temperature curves would remain as shown in Figs. 5 and 6 for two of the thermocouple sites. Similarly shaped curves may be drawn from data collected from the other three thermocouples if the direct millivolt readings (n) are first coded to (2.0-n) millivolts before conversion to their equivalents.

Typically, two peaks occur in the above mentioned curves. The slope of the line is relatively flat until the radiant heat of the advancing flames begin to push the slope up. The first peak is reached as the flames surround the thermocouple. A brief but sharp decline then occurs, followed closely by a sharp rise to the second peak. This second peak seems to correspond to a time when the flames are a few feet beyond the

Fig. 5. Variation of temperature during burning at one point in plot 5 using thermocouples

Fig. 6. Variation of temperature during burning at one point in plot 5 using thermocouples; broken line is an extrapolation to maximum temperature indicated by pyrometers


Temperature in degrees Fahrenheit
1
2
3
4
5
6
7
8
9
Time relative to passing fire in minutes


Temperature in degrees Fahrenheit
1
2
3
4
5
6
7
8
9
Time relative to passing fire in minutes

indicator point. The peak may, therefore, be due to the previously mentioned "chimney effect" of the backfire after the stake has been passed by the flames.

Fig. 6 does not show dual peaks since the top of the curve was extrapolated from temperature stake data which recorded maximums only. This was necessary since the curve rose so sharply that recording it was impossible with the equipment being used.

While each of these peaks obviously offer great potential for killing woody tissue, they do not, either separately or together, represent the total killing ability of this, or any, fire. Lindenmuth and Byram (1948) have defined the "heat factor" as representing the potential of a fire to cause mortality of tissue. This factor is a function of temperature and duration of that temperature. Since the temperature sustained between the two peaks is usually higher than initial temperature, the heat factor of the entire time interval which includes both peaks represents the potential of the fire. The importance of this prolonged interval becomes more apparent when the heat sink effect of the center of the tree (Martin, 1963a) is considered. During the first peak and following interval, the center of the tree may become heat saturated to some degree. This may have caused the second peak to have been more damaging to stem tissue than would be expected in light of its short duration.

The interrelationship of wind, fuel, and temperature has been summarized by Daubenmire (1968). Aspects of this relationship not previously mentioned are recognized, but do not lend themselves to the design of this study.

Nine preliminary twig samples were taken October 8, 1969. These were subjected to tetrazolium stain and callous culture. Species included were Ulmus americana, Crataegus sp., Pyrus ioenis, and Acer negundo. All twigs from the unburned plot had a positive response to the tetrazolium stain and to the callous tissue culture. Sixty per cent of the twigs from the burned plot formed callous tissue when incubated in moist test tubes. Only 50% of these twigs exhibited definite staining by the tetrazolium solution, though slight staining was observed on other twigs.

Ten elm twigs were collected from the burned plot on October 20, 1969. An additional ten twigs were taken from the unburned plot. All twigs were subjected to tetrazolium stain and callous culture tubes. Twig diameters ranged from 2 to 8 mm. Twig height above the soil surface ranged from 29 cm to 125 cm. Results of these treatments are given in Table 14.

Table 14. Response of Elm twigs to tetrazolium and callous tests

Plot	No. of twigs	% staining positively	% forming callous
Burn	10	10%	0%
Unburn	10	100%	100%

Positive staining of one twig in those from the burned plot may indicate viable tree tissue. In several twigs where no cambial staining was observed, some staining had occurred around fungal tissue under the bark. This type of staining was attributed to the presence of a dehydrogenase formed by the fungus, and was discounted as not being indicative of viable tree tissue. It is possible that the stain found in one twig from the burned plot has been displaced from such a fungal colony.

Segments of bark tissue were removed from twenty trees and exposed to the same tests as were the twigs. Results of such tests were not meaningful since physical characteristics of the bark peels did not lend themselves well to the techniques used. Also, an abundance of fungal spores associated with bark caused gross proliferations of hyphae within the callous culture tubes.

Twigs of mixed species were gathered October 18, 1969, from the burned area. Stain and callous responses of these twigs are shown along with approximate slope position in Table 15.

Table 15. Response of mixed species to tetrazolium and callous tests

Position	Positive staining	Callous formed
Summit (2 trees)	0%	50%
Shoulder (10 trees)	30%	40%
Upper backslope (17 trees)	35%	30%
Lower backslope (10 trees)	20%	20%
Footslope (11 trees)	55%	36%

Twig height above soil surface, twig diameter, basal tree diameter as well as species were recorded for each twig. While these data were not analyzed statistically, no obvious correlations were evident.

If actual survival in the first few months following the burn is interpreted as an average of the callous and stain percentage values for a particular slope position, the survival rate decreases from the shoulder of the slope to the footslope. This is possibly a result of a lessening of wind effects as the fire advanced into the relative protection of the heavier woody vegetation extending upward from the flood plain. The large increase in survival at the foot of the slope can be explained by the great reduction in amount of grass fuel as the vegetation shifted toward a predominance of the woody component.

Examination of this plot February 22, 1970, showed no buds had formed closer than about 40 inches to the soil surface. Where trees were taller than 40 inches, buds were generally not present on twigs less than this critical distance from the surface. This seemed generally true of all species within the plot.

SUMMARY

While effects of grassfires appear to vary individually, it is desirable to be able to predict such effects in a general way. From observations of five different fires in central Iowa, some generalizations seem to hold true for the effects on woody plant species.

1. Maximum temperatures for Iowa grass fires occur close to the soil surface regardless of headfire or backfire conditions, though headfires are cooler at the mineral soil surface.

2. No linear relationship was seen between foliar damage of a particular tree and maximum temperature recorded at that site.

3. *Juniperus virginiana* exhibited a zero survival rate for trees less than three feet tall.

4. For junipers three feet tall or over, a basal diameter of one inch seemed to be a fair indicator of survival. This diameter appeared to be critical in all species examined.

5. Sprouting was not observed in plots where *Juniperus virginiana* represented the woody component. A single burn might provide control of this species.

6. Leaves of deciduous trees did not develop below a level of three feet in a plot burned by a spring backfire before the buds had opened.

7. Overwintering buds did not develop below a level of six feet on *Ulmus* sp. following a spring burn.

8. Sprouting was observed in plots where the woody component was represented by *Ulmus* sp. The average number of basal sprouts per young elm burned was about four. This species might be controlled only by

consecutive burning.

9. Neither the optical pyrometer nor the thermocouple arrangement used in this study provided highly satisfactory monitoring of temperatures generated during the burn.

10. Fair agreement was found between the results of vital staining with 2,3,5-triphenyltetrazolium chloride and the culturing of callous tissue of burned twigs.

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