Why Squirreltail Is More Tolerant to Burning than Needle-and-Thread[1]

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Highlight

Squirreltail plants have a low density of dead plant material; consequently, they burn quickly, and heat penetration to the growing points is at a minimum. By contrast, the greater density of dead plant material in needle-and-thread bunches causes them to burn at higher temperatures for longer periods, so that many plants are killed. Squirreltail is also more tolerant than needle-and-thread to herbage removal by clipping.

Previous work on bunchgrasses in the sagebrush-grass region of southern Idaho (Wright and Klemmedson, 1965) has shown that squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith) is more tolerant to damage by fire than needle-and-thread (*Stipa comata* Trin. and Rupr.). A more thorough understanding of the factors that influence survival of these species would greatly improve our knowledge of community dynamics where they occur.

Although many plant species differ in tolerance to burning, we rarely know whether the plants are damaged primarily by heat or by herbage removal. In this study the duration and magnitude of temperatures in burning plants were measured so that the effects of heat could be separated from the effects of herbage removal. In addition, heat tolerance of plant tissue and characteristics of plant material that can influence temperatures in burning plants were compared between species. As these objectives were accomplished, earlier studies by Wright and Klemmedson (1965) were expanded to cover a longer season of burning and to include greater intensities of applied heat.

Literature Review

In no studies have temperatures within individual bunchgrasses been recorded while the plants were burning. On a community basis, however, maximum temperatures of fires have been recorded at soil surface and below soil surface, and these may indicate the relative magnitude of temperatures within a burning plant.

From our past work, we know that wildfires can cause temperatures greater than 400 F at the mineral soil surface in sagebrush-grass communities (Wright and Klemmedson, 1965). This is the main reason for our decision to study the effect of a higher applied temperature on bunchgrasses.

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Other researchers (Miller et al., 1955; Bentley and Fenner, 1958; and Whittaker, 1961) agree that maximum temperatures of brush fires at the soil surface are usually in the range of 350 to 800 F.

Below soil surface, temperatures decrease sharply (Heyward, 1938; Beadle, 1940; Miller et al., 1955; Bentley and Fenner, 1958; Whittaker, 1961). On scrub burns in New Zealand, temperatures at litter depths of one-half inch, three-fourths inch, and 1 inch were approximately 90 C (194 F), 50 C (122 F), and 20 C (68 F), respectively (Miller et al., 1955). Corresponding surface temperatures ranged from 200 C (392 F) to 250 C (482 F).

The time that elapses before maximum temperatures are reached in grassland fires seems to be 30 min or less, depending on the soil depth at which the record is taken. Heyward (1938) has found that maximum temperatures for the 0.25- to 0.5-inch soil depths occur within 2 to 6 min in grassland fires. At depths of 0.5 to 2 inches, the time varied from 7 to 31 min.

Temperatures and their durations in plants are only part of our concern. How much heat can plants tolerate? Several workers have determined a "thermal death point" (the lowest temperature above freezing that results in no survival after a fixed period of exposure, usually 10 min) for various species. At the cellular level for average mesophytic plants, this point is said to lie between 122 and 131 F (Baker, 1929); 140 F is frequently given as lethal for the plant as a whole (Byram, 1958). Yet Jameson (1961) determined the "lethal temperatures" for four grass species, *Bouteloua curtipendula, B. eriopoda, B. gracilis,* and *Hilaria jamesii,* to be between 140 and 165 F. The term "lethal temperature" in this case is general rather than specific because it is not related to time.

It is difficult to say what specific temperature will kill a plant, primarily because killing time plotted against temperature is an exponential relation (Hare, 1961; Yarwood, 1961). Therefore, a plant may be killed at a comparatively low temperature if it is heated for a long time. If it is heated to high temperature, it may be killed in less than 30 sec. Other factors influencing the temperature at which a given plant tissue is killed are the physiological condition of the protoplasm (which appears to be related to percent moisture), the insulating qualities of dead tissue, such as bark, which separates the living cells from the heat source, and the initial vegetation temperature (Hare, 1961).

Baker (1950) states, "There is no evidence that the protoplasm of one species of a vascular plant has a higher thermal tolerance than that of another when the protoplasm is well-hydrated and in an actively functional state." Konis (1949) relates heat tolerance to dehydration of the protoplasm. His investigation in Palestine showed that the leaves of heat-resistant plants contained relatively small amounts of water and had high osmotic values. Plants with the highest osmotic values were generally the most heat resistant. Richardson (1958) showed that thermal conductivity is lower as moisture content decreases.

Methods

Study Site

The study site was chosen primarily because undisturbed squirreltail and needle-and-thread stands were adjacent within 2.5 acres. The site is on an east-facing slope, ranging in gradient from 5 to 20% about 0.5 mile north of Boise, Idaho, at an elevation of 2,750 ft. The area lies at the northern edge of the Snake River Plains near the base of the Northern Rocky Mountain physiographic province. The geologic material is from the Payette formation, consisting of moderately to poorly consolidated sand, silt, and gravel of lacustrine and fluvial origin.

FIG. 1. Burner with five jets, connected to a propane gas tank, used to burn plants. The panel of five meters served to measure burning temperatures.

Needle-and-thread was the dominant plant of a climax community on sandy soil, whereas squirreltail was the dominant plant of a disclimax community on a silt loam soil. Bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn.) and thurber needlegrass (*Stipa thurberiana* Piper) are the usual dominant and codominant plants on silt loam soils.

The vegetation of both stands showed no evidence of having been grazed or burned for at least 6 years. Large amounts of herbage from past years had accumulated in the crowns of squirreltail and needle-and-thread.

Experimental Field Treatments

This study was conducted as a single experiment, using two species, five seasons (months), and four treatments in a completely randomized design with 12 replications. Observations and analyses to detect differences 1 year after burning were based on mortality and on herbage yield of surviving plants.

The following treatments were applied to both squirreltail and needle-and-thread plants at approximately monthly intervals from May 15 to September 15:

1. Burning with enough heat for 30 sec to raise the soil surface temperature to 400 F.
2. Burning with enough heat for 30 sec to raise the soil surface temperature to 800 F.
3. Clipping 1 cm above mineral soil surface; no burning.
4. Control; no burning or clipping.

To burn the plants, a specially designed propane burner was constructed from aluminum (Fig. 1). The propane burner permitted the burning of plants individually and supplied a heat source completely independent of the plot variables. All burning treatments were defined as pressure of propane gas at the nozzle in relation to time.

Since it is difficult to apply heat to the soil surface and maintain it at a constant temperature, a constant pressure of propane gas was applied. The 400 and 800 F treatments were approximated with pressures of 5 lb. and 6.5 lb., respectively. With these pressures the treatment temperatures were attained at the soil surface in 20 sec, and maximum temperatures 20% higher were usually reached at the end of 30 sec.

After the plants were ignited, crown temperatures and their durations were measured at five locations in each plant with thermocouples wired to panel meters (Fig. 1). Two recording instruments, each consisting of five panel meters, were used.

The first 12 inches of each thermocouple assembly was fitted with an Inconel[3] protection tube, 0.125 inch in diameter. The protection tube is rigid and can withstand temperatures up to 1600 F. The Inconel protection tube was placed within the plant crowns after a hole had been probed with a piece of stiff wire.

During each 4-day treatment period, 48 plants were burned and 24 plants were clipped. To avoid burning all the plants of a given species during a cool or warm period of the day, the plants of each species were placed in groups of three. The groups were burned at various times of day to insure that conditions for burning were as nearly equivalent as possible for the two species.

Litter and material of other species were cleared away from each plant (including control plants) before the burning operation began. The soil around the plants was never disturbed to a depth of more than 0.25 inch.

Laboratory Determination of Thermal Death Times

Concurrently with the fieldwork, thermal death times for the growing points were determined in the laboratory for each species during each season. One-inch culm base segments (stripped of dead leaves) were placed in dry stoppled test tubes and immersed in a constant temperature bath. The tissues were heated at various time intervals at 10 F intervals from 120 to 200 F until the thermal death time was determined. A 1% solution of tetrazolium was used to detect death of plant tissue. If no pink or red color could be seen on the tissue after 24 hours, the tissue was considered dead.

From the thermal death times, computations may be made to determine whether combinations of time and temperature in burning plants are lethal. The method used is discussed fully by Wright (1970) and therefore will not be repeated here. The term *necrotherm,* which will be used in this paper as an index, should be explained, however. A necrotherm of 1.0 indicates that the plant received just enough heat to kill the plant tissue at the point where the necrotherm was measured; a larger number of necrotherms, such as 30.0, indicates that the plant received many times more than enough heat at that particular location to kill plant tissue.

Observations and Measurements

Since measurements of herbage yield were to be made 1 year after burning or clipping of plants, the initial basal area of dead plus living plant material and the number of living culms before treatment were measured as covariants for the response (dry weight produced). Basal area of the crown was calculated to the nearest cm² (0.394 square inch)

[3] Trade names used for identification only and do not imply endorsement by the U. S. Department of Agriculture or the Forest Service.

Table 1. Mortality of needle-and-thread plants (percent[1]) in relation to season and treatment, Boise, Idaho, 1963.

	Treatment			
Season	400 F	800 F	Clipped	Control
May	0	0	0	0
June	0	42	0	0
July	67	75	33	0
August	42	75	17	0
September	50	67	0	0

[1] Based on 12 plants per treatment per month.

from four diameter measurements per plant. The basal area measurements and culm counts on all plants except those burned on May 15 were taken in June 1963 before treatment. Plants for the May treatment were measured on May 14. One year after application of treatments, all plants were clipped at the end of the growing season to measure the response to treatments.

Temperatures were recorded continuously in treatments 1 and 2 at five thermocouple locations: (1) 0.75 inch above the soil surface in the center of plants, (2) at the soil surface in the center of plants, (3) at the soil surface 0.25 inch within the edge of plants, (4) at the growing point (base of culms) in the center of plants, and (5) at the growing point 0.25 inch within the edge of plants. The growing points for these species were approximately 4 cm below the soil surface.

The initial temperature for each thermocouple was recorded before burning. After burning had started, the first time was recorded (in min) at 110 F. For example, if the thermocouple took 6.2 min to reach 110 F, 6.2 was the time recorded. Thereafter, the times were recorded at 10 F intervals—120 F, 130 F, etc.—until the maximum temperature had been reached. As the thermocouples began to cool, the times were again recorded at 10 F intervals until they reached 120 F.

To obtain necrotherms, the number of minutes that the plant remained at each temperature (10 F intervals) was estimated by computation and divided by the corresponding thermal death time (for details see Wright, 1970). A total of necrotherms recorded at each thermocouple was thus derived. The data were analyzed for each of the five thermocouple positions within each plant.

To characterize burning conditions throughout each 4-day burning period, weather data were taken hourly with a field weather kit. Dry and wet bulb temperatures, relative humidity, wind velocity and direction, and sky conditions were determined. Fuel moisture of separated plant material (living and dead) was determined for 12 untreated plants of each species during each burning period. This is expressed as percent of ovendry weight.

Results

Response to Treatments

Mortality.—Twenty-five percent of the squirreltail plants died after the 800 F treatment during July and August only. No other treatment on squirreltail caused mortality. By contrast, needle-and-thread plants died after burning from June through September. Although only the 800 F treatment killed plants in June (Table 1), during the

Table 2. Average herbage weight (g) per plant for squirreltail and needle-and-thread 1 year after burning, related to season and treatment, Boise, Idaho, 1963.

Season	Treatment			
	400 F	800 F	Clipped	Control
Squirreltail				
May	3.94[1]	5.48	7.41	22.58
June	6.96	8.50	7.26	20.09
July	8.51[1]	4.32[1,2]	13.25	14.01
August	7.50[1]	9.42	11.58	16.61
September	10.44	6.11[1,2]	10.21	21.97
Needle-and-thread				
May	14.69[1]	14.11[1]	7.82	31.82
June	9.16	4.23[2]	7.65	36.77
July	0.20	0.08	1.71	16.97
August	0.64	0.03	1.75	17.34
September	0.86[1]	1.62[1]	5.35	14.34

[1]Differences from the clipped treatment significant at the 5% level of probability.

[2]Differences from the 400 F treatment significant at the 5% level of probability.

other months both the 400 F and 800 F treatments were effective in killing plants.

In all months, more plants died from the burning treatments than from the clipping treatment. Clipping killed only a few needle-and-thread plants (Table 1), and it killed no squirreltail plants.

Herbage weight.—The yield of both species 1 year after treatment was compared with that of the control plants. Burning during all seasons reduced yields, but was not as detrimental to squirreltail as to needle-and-thread except during May (Table 2). Generally, burning harmed squirreltail most during May and somewhat less thereafter. In contrast, burning harmed needle-and-thread least during May, somewhat more in June, and most from July to September.

Like burning, clipping reduced the yield of both species during all seasons, except for squirreltail in July. In general, the effect of clipping was either the same as burning or slightly less severe for both species (Table 2).

Differences in herbage weight between plants receiving the 400 and 800 F burning treatments were seldom significant. They were significant only during July and September for squirreltail and only during June for needle-and-thread.

The control plants of needle-and-thread for July, August, and September produced only half as much herbage as the control plants of May and June. This difference must have been due to a difference in the time of removal of vegetation and litter from the base of the plants. This had been done to all plants by late June, but litter was removed earlier from the May and June control plants, before the burning treatments were applied. Evidently, removal of litter and other vegetation in June from the base of the July-September plants caused a drastic change in soil temperatures, which had some detrimental effect on plant growth.

Table 3. Time required (minutes) to kill needle-and-thread and squirreltail tissue at 140 F, Boise, Idaho, 1962.

Species	Season				
	May 19	June 10	July 21	August 20	September 21
Needle-and-thread	2.60	3.25	13.50	45.00	55.00
Squirreltail	4.00	5.50	18.50	28.00	33.50

Table 4. Lethal combinations of temperature and exposure time, according to thermocouple location,[1] for squirreltail and needle-and-thread.

Species	Temp.	Date of burning				
		May	June	July	Aug.	Sept.
Squirreltail	400F	1	1	1	1	1
		2	2	2	2	2
		3	3	3	3	3
		4	4	4	4	4
		5	5	5	5	5
	800F	1	1	1	1	1
		2	2	2	2	2
		3	3	3	3	3
		4	4	4	4	4
		5	5	5	5	5
Needle-and-Thread	400F	1	1	1	1	1
		2	2	2	2	2
		3	3	3	3	3
		4	4	4	4	4
		5	5	5	5	5
	800F	1	1	1	1	1
		2	2	2	2	2
		3	3	3	3	3
		4	4	4	4	4
		5	5	5	5	5

[1]Number code for thermocouple locations:

1--0.75 inch above surface center
2--Surface center
3--Surface edge
4--Growing point center
5--Growing point edge

The combination of temperature and exposure time was lethal in at least one-half of the plants at the location indicated.

The combination of temperature and exposure time was lethal in at least one plant, but not more than one-third of the plants at the location indicated.

Heat Tolerance of Plant Tissue

An indication of heat tolerance is found from thermal death times determined in the laboratory for 140 F (Table 3). Tissue of squirreltail was more tolerant to heat than tissue of needle-and-thread until July. In August and September needle-and-thread tissue was a little more tolerant. However, tissue of both species became increasingly tolerant to heat throughout the period from May to September.

Table 4 shows whether the heat received at the various thermocouple locations within treatment, season, and species was potentially lethal to plant tissue. If at least one necrotherm was received at a thermocouple position, the combination of temperature and exposure time was considered lethal. Notice that a lethal combination of temperature and exposure time occurs in plant tissue last at the growing point edge (thermocouple 5).

Lethal combinations of temperature and exposure time at the growing points (thermocouples 4 and 5) are most important. Mortality occurs only if heat is lethal at both of these locations. Heat usually kills tissue at the center of the plant before it kills tissue on the periphery of the plant.

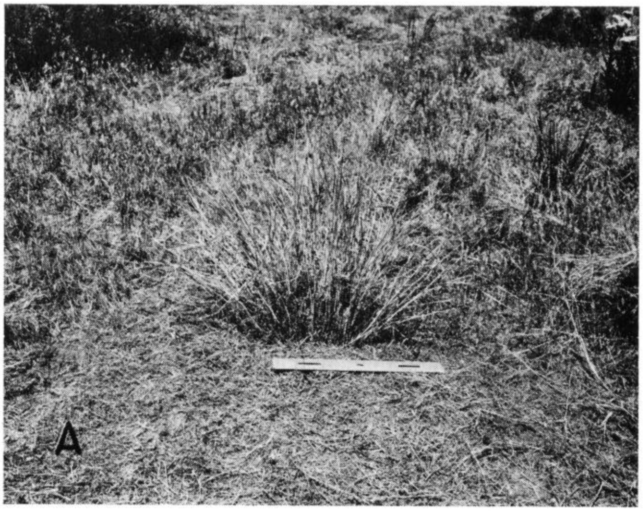
Mortality of needle-and-thread plants by fire was actually higher during July and August than indicated by the number of necrotherms. But this higher mortality can be expected since clipping without the added effects of heat caused mortality during July and August (Table 1). Where mortality was significant, it was at least as high as indicated by the number of necrotherms at the growing point on the edge of the plant (thermocouple position 5 in Table 4). Hence, in this study one necrotherm at the growing point edge indicated the minimum percent mortality.

Proportions of Living and Dead Plant Material

Needle-and-thread had twice as much dead plant material per unit basal area as squirreltail, but both species had the same amount of living material per unit basal area. This is shown by the following tabulation of dry weight (g) of living and of dead material per square centimeter of basal area.

Species	Weight of living material	Weight of dead material
Squirreltail	0.26	0.52
Needle-and-thread	.23	.94

If we calculate the total moisture in both species based on the amount of living and dead material and using the moisture contents shown in Table 5, we find that the percentage of moisture in squirreltail is about one third greater than in needle-and-thread during May and June. Thereafter, the species do not differ in their percentage of moisture content. However, from May to September there is a continuous reduction in the moisture content of both species. The reduction is rapid from June to July; thereafter, it is slow.



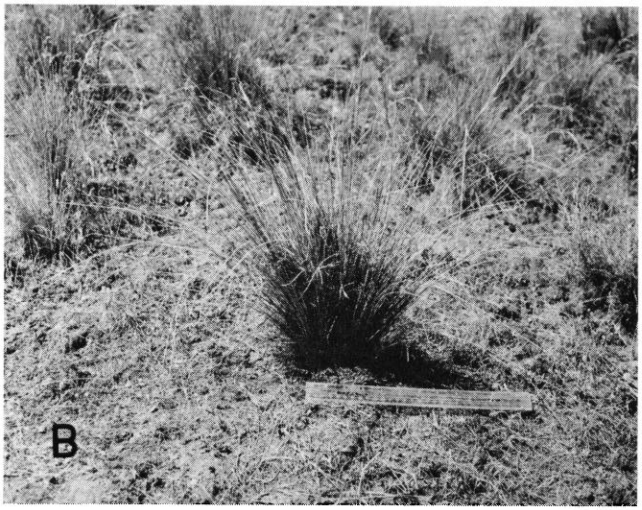


FIG. 2. Comparative density of plant material. A. Plant material is not very dense at the base of squirreltail plants. B. Plant material is very dense at the base of needle-and-thread plants.

Discussion and Conclusions

Species Differences

Why is squirreltail more tolerant to burning than needle-and-thread after June? Two differences are most obvious. First, squirreltail is more tolerant to herbage removal than needle-and-thread. This difference appears to be related to dormancy (Wright, 1967). Second, squirreltail has only half as much dead plant material per unit basal area as needle-and-thread.

This lower quantity of dead plant material per unit basal area influences the burning time and subsequently the amount of heat transmitted to the growing points. The less dense plant material of squirreltail (Fig. 2a) causes a quick hot flame on

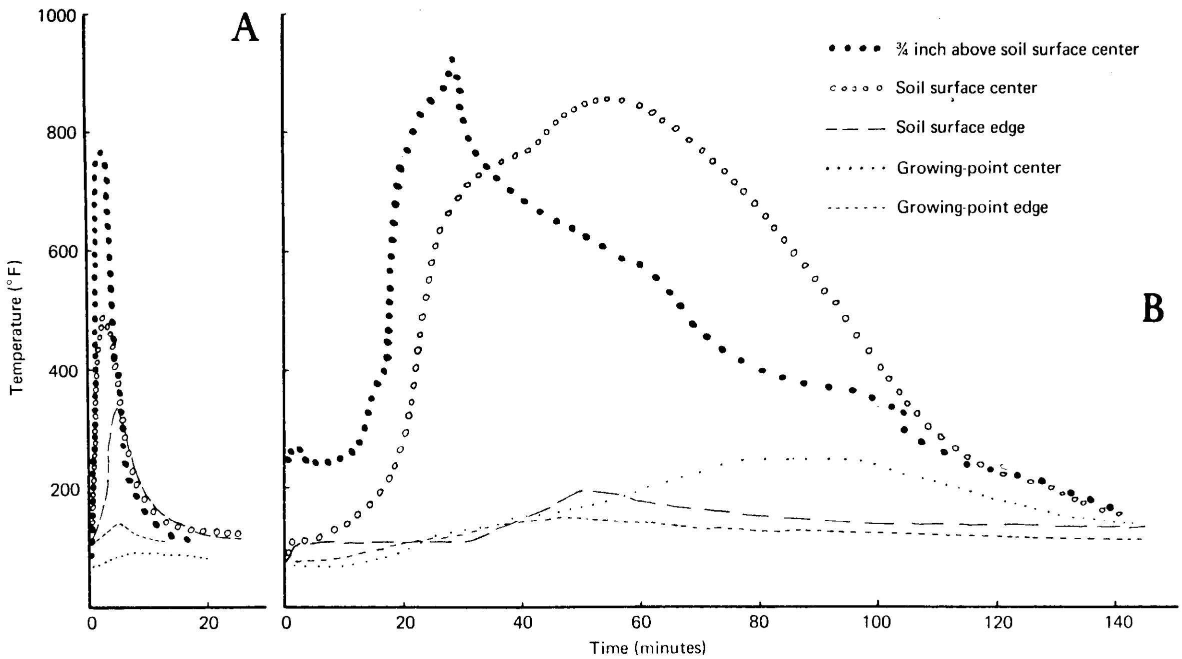


FIG. 3. Temperature in relation to time for five thermocouples in a plant burned at 400 F for 30 seconds on September 17, 1962. A. Squirreltail. B. Needle-and-thread.

the crown surface with a minimum of heat penetrating to the growing points (Fig. 3a). On the other hand, the very dense plant material of needle-and-thread (Fig. 2b) burns more slowly and longer than squirreltail (Fig. 3b). Charring down to the growing points is very noticeable in needle-and-thread (Fig. 4a), but less noticeable in squirreltail (Fig. 4b).

Seasonal Effects

The moderate tolerance of needle-and-thread to damage by burning during May and June is attributed primarily to its relatively high tolerance to herbage removal at this season. High percent moisture in living and dead plant material (Table 5) and least favorable weather for burning (Table 6) were concurrent variables that also had a noticeable effect in May. During this month about one third of the plant material was left standing after the burning treatments.

The tolerance of needle-and-thread to damage by burning was lowest during July, August, September (Tables 1 and 2); this is attributed to its low tolerance to herbage removal at this season. High respiration rates for the green leaves and low soil moisture are probable causes for needle-and-thread's low tolerance to clipping during these months (Wright, 1967). Low percent moisture (as it influences flammability) in plant material and favorable weather for burning were other factors contributing to needle-and-thread's low tolerance, especially during September (Tables 5 and 6).

For squirreltail, the yield after burning was less than that for needle-and-thread for the May treatments, about the same for the June treatments, and

Table 5. Moisture content (%, ovendry weight) of living and dead tissue of squirreltail and needle-and-thread at time of treatment.

Species	Season				
	May 19	June 10	July 21	August 20	September 21
Living tissue					
Squirreltail	166	127	53	38	28
Needle-and-thread	158	129	82	66	61
Dead tissue					
Squirreltail	13.8	7.8	5.1	5.8	4.3
Needle-and-thread	13.0	6.7	4.6	3.9	4.5

Table 6. Average weather conditions during actual time of burning for each month of burning.

Month of burn	Air temperature (°F)	Relative humidity (%)	Wind velocity (mph)
May	68	38	4
June	70	32	5
July	79	24	4
August	88	24	3
September	78	23	3

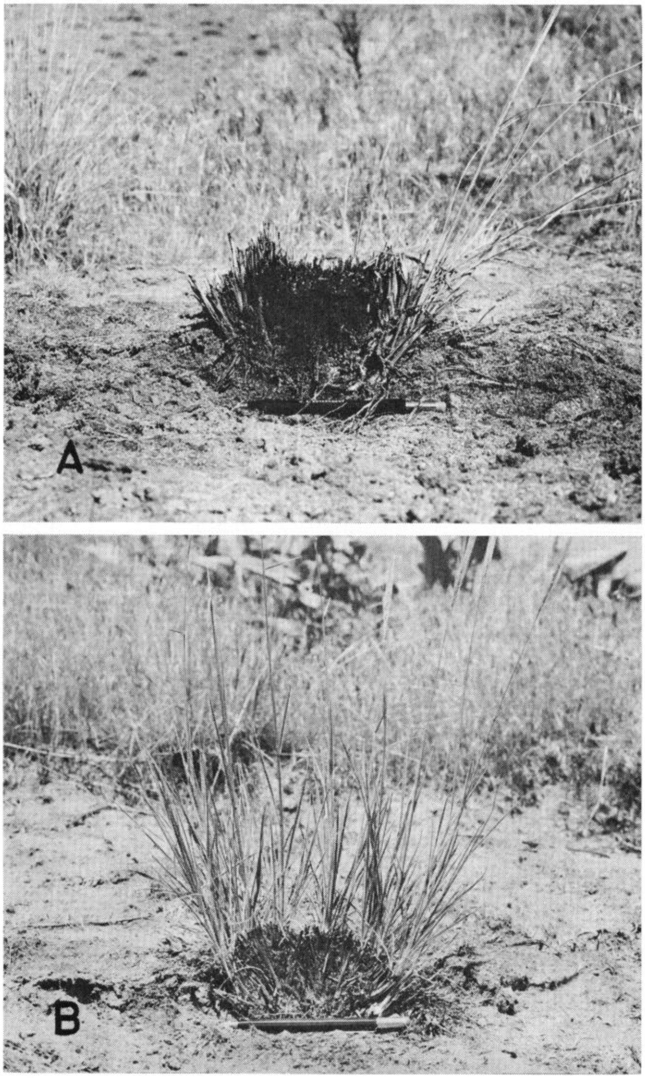


FIG. 4. Comparative effect of charring. A. Severe charring down to the growing points of needle-and-thread is common. B. Charring is less severe and less damaging to the growing points in squirreltail.

more for the July-to-September treatments (Table 2). Squirreltail's less-than-full growth in May permitted heat from the burner to penetrate slightly below the soil surface. Thus burning was more severe than clipping. In June, burning had the same effect as clipping. Then during July and August burning was more severe than clipping, probably because plant tissue was more flammable and weather for burning was ideal. In September, clipping and burning again had the same effect. Since air temperatures were lower, the effect of fire was no more severe than clipping. Here it is important to point out that squirreltail tolerance to clipping, which was highest after June, is related to summer dormancy (Wright, 1967).

Treatment Effects

The principal difference between the clipping and burning treatments for needle-and-thread was in plant survival only (Table 1), since herbage yields the following year did not show significant differences except for the May treatment (Table 2). The most pronounced differences between the two burning treatments also showed up as mortality (Table 1). Mortality was 39% higher for the 800 F treatment than for the 400 F treatment for plants burned June to September. The higher intensity of burn may have had a greater drying effect on the herbage, enabling more of the current growth to burn. Such burning would be detrimental to more of the growing points on the periphery of the plants, thus causing a higher mortality.

Squirreltail was not harmed as severely by clipping as by burning. Over all seasons, clipped plants yielded 12% more herbage the following year than burned plants. In my opinion this difference reflects the difference between the height of clipping and the depth to which plant crowns burned.

Thermocouple Location

Lethal combinations of temperature and exposure time occurred lastly at the growing point on the edge of a plant, for several reasons (Table 4). First, the growing point on the edge of a plant is below the soil surface at a greater depth than any of the other growing points. Second, on the edge of a plant there is a higher ratio of living plant material to dead material, the former of which is more difficult to burn. Lastly, heat can escape in more directions through a dense medium from the growing point edge than at any other place in the plant. Temperatures in the center of the plant are highest because of the high proportion of dead plant material. The slower rate of burning with increased depth in the center of the plants is probably related to a decreased availability of oxygen.

Wind Effects

Burning temperatures of plants were sometimes increased or hastened by gusty winds. Observations indicate that squirreltail plants were affected more by winds than needle-and-thread plants unless they had been burning about one-half hour before the wind. There were many instances when winds did not seem to affect the burning temperatures of plants. Winds supply oxygen to the burning plants, which should aid in the combustion of plant material.

Ecological Implications

Burning is generally harmful to both needle-and-thread and squirreltail during late spring and summer. However, midsummer burns are least harmful to squirreltail. Thus, if a community is composed largely of squirreltail, midsummer burns will probably favor this species over other perennial species.

When prescribed burns can be conducted, usually sometime after June 1 depending on the year, fall burns will generally be least harmful to needle-and-thread. However, if the plants include much dead material, fall burning can be almost as detrimental as summer burning. The fuel within the plant generates enough heat to kill it, regardless of the heat generated by the fire sweeping over the plants. In such cases heavy fall or winter grazing 1 year before a planned burn may lessen the damage to plants especially mortality. Burning after a fall rain may also lessen damage but by this time weather is usually so uncertain that planning a burn is difficult.

A few general statements may be made as to the effect of fire on other species. If plants are leafy and have more than ½ g of dead plant material per square centimeter they may be severely damaged by fire because in many instances the fuel within the plant will generate enough heat to kill it. If plants are stemmy and have less than ½ g of dead plant material per square centimeter, the effect of fire will be about the same as removal of photosynthetic material. Also, since plant tissue becomes more tolerant to heat as the tissue becomes drier, fall burns should be less damaging than summer burns. But if dead plant material is abundant in the plants, summer and fall burns will be equally damaging.

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