EFFECT OF CERTAIN CHEMICAL ATTRIBUTES OF VEGETATION ON FOREST INFLAMMABILITY[1]

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INTRODUCTION

Forest Service administrators and fire-research men have long felt the need of information concerning the effect of vegetation such as shrubs, grasses, and forbs (nongrasslike herbs) on the rate of spread of fires. To date, all knowledge of the subject has been acquired empirically in the field, or deduced from knowledge of fire behavior as influenced by the condition of deadwood, duff, etc.[3] It is known that the luxuriant green vegetation of late spring and early summer does not lend itself to dangerous, fast-spreading fires, and that the matured and naturally cured or dried vegetation of September and October materially augments forest inflammability. Beyond this, the whole matter is one of conjecture. No information is available as to quantitative effects of forest undergrowth conditions on rate of fire spread, and no method has been evolved for determining readily and accurately whether these conditions at any particular time are such as would retard fire spread. Furthermore, little is known as to variation in volume of vegetation from season to season. Consequently, forest officers rating fire conditions and forecasting the approach of fire danger do not know what significance to assign to volume and condition of vegetation. Before fire danger can be properly rated on areas bearing large volumes of shrubs, grasses, and forbs, methods must be devised for evaluating these factors with reference to the spread of fire and for integrating data on these factors with measurements of the factors being utilized in fire-danger ratings at the present time—wind velocity and moisture content of dead fuels.

The problem of evaluating the effect of vegetation on rate of fire spread is fundamentally that of determining the heat-energy balance, that is, the ratio between the total heat energy available and the heat required to eliminate the moisture present, in whatever form. If the energy consumed in dissipating the plant moisture and bringing about combustion of the vegetative material is less than the energy produced by the combustion, the vegetation accelerates the spread of fire; if greater, the vegetation retards the spread.

The Northern Rocky Mountain Forest and Range Experiment Station, which has pioneered in the field of fire-danger rating, began, in 1935, studies of vegetation conditions in order to refine the methods of danger rating. The purpose of this work is to find measurable

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[3] HAWLEY, L. F. THEORETICAL CONSIDERATIONS REGARDING FACTORS WHICH INFLUENCE FOREST FIRES. Jour. Forestry 24: 756–763. 1926.

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factors that will represent vegetation conditions throughout each fire season and to incorporate measurements of these factors into the scheme now being used to rate fire danger. The project is divided into three phases: Vegetation volume and appearance studies, dealing with current and total volume growth and visible physical changes that occur in the plants; chemical investigations; and test fires, which are essential for determining actual behavior of fires as affected by vegetation volume and condition. The first two phases should evolve a theory or hypothesis susceptible of being proved or disproved by the third. The physicochemical variations of certain typical plants as revealed by the exploratory work to date are described in this report.

The plants selected as typical of vegetative fuels on open forest areas of northern Idaho are: Shrubs, snowbrush (*Ceanothus velutinus*), ninebark (*Opulaster pauciflorus*), and willows (*Salix* spp.); grasses, downy chess or "cheatgrass" (*Bromus tectorum*) and pinegrass (*Calamagrostis* sp.); forb, fireweed (*Chamaenerion angustifolium*).

At the beginning of the chemical investigation, in 1935, the plan was to examine the vegetation with respect to moisture and fuel content, giving special attention to seasonal variations of both factors. It was assumed that the available fuel content could be represented by the crude fiber plus the crude fats or ether extractives, that is, the resins, waxes, and oils. The crude fats are of special interest because of their high inflammability. The crude fiber determinations were discontinued in 1936, because they had failed completely to show any significant variations corresponding to changes in fire behavior after the plants attained their structural growth. To determine more exactly the relation between the water content and the potential heat energy of vegetation, calorific determinations were begun in 1936. Moisture content, calorific value, and crude fat content were measured throughout the 1936 and 1937 fire seasons in one locality, the environs of the Priest River experimental forest in northern Idaho.

PROCEDURES AND RESULTS

In all cases, only green or curing material was collected; thoroughly cured portions were excluded. Of the shrubs only the leaves were used, but of the other plants the entire aerial portions.

A 500-gm. sample of each species was collected every 10 days throughout the summer season. The sampling was always done at 8 a. m., to reduce the effects of diurnal variations. Samples for moisture determination were sealed in moisture-proof cans and taken directly to the laboratory for weighing. The materials to be used in the crude fat and calorific determinations were allowed to dry on wire trays in a warm, well-ventilated room, then were ground to a powder and passed through a 60-mesh sieve.

Moisture content was determined by drying the materials in an oven at 105° C. until there was no further significant loss of weight. Results for the 1937 season are given in table 1.

A Parr peroxide bomb calorimeter was used satisfactorily in the calorific determinations. The size of the particles to which the oven-dried vegetation had been reduced insured complete combustion. The chemicals were passed through an 80-mesh sieve before use. Results for the 1937 season are given in table 2.

Total crude fat was determined by extraction with ether according to methods outlined by the Association of Official Agricultural Chemists.[4] Results for the 1937 season are given in table 3.

TABLE 1.—*Percent of moisture*[1] *in vegetation of open forest areas as determined at 105° C. in 1937*

Species[2]	June 20	June 30	July 10	July 20	July 30	Aug. 10	Aug. 20	Aug. 30	Sept. 10
Snowbrush	215	212	191	177	165	146	131	120	112
Ninebark	197	218	206	148	150	137	115	101	109
Willows	230	235	183	162	156	137	123	120	113
Downy chess[3]	150	116	24	9					
Pinegrass	182	176	160	152	138	129	118	107	110
Fireweed	426	341	305	290	294	257	244	249	241

[1] All values were calculated on the basis of oven-dry weight of single samples, checked by 2 or more similar determinations made in the course of other phases of this project.
[2] The snowbrush sample was composed of leaves of various ages in proportion to those on the plant. For ninebark and willows, leaves of the current year only were collected. For downy chess, pinegrass, and fireweed, the entire aerial portion (current year's growth) was used.
[3] On July 30 and later no green growth was present.

TABLE 2.—*Calories per gram, on basis of oven-dry weight,*[1] *determined on vegetation of open forest areas in 1937*

Species	June 20	June 30	July 10	July 20	July 30	Aug. 10	Aug. 20	Aug. 30	Sept. 10	Average
Snowbrush	4,600	4,800	4,900	5,000	5,000	5,000	5,100	5,200	5,200	4,990
Ninebark	[2] 5,000	4,500	4,600	4,600	4,700	4,800	4,700	4,600	4,700	4,690
Willows	4,600	4,800	4,800	4,800	4,700	4,700	4,700	4,700	4,800	4,730
Downy chess[3]	4,300	4,300	4,400	4,300						4,330
Pinegrass	4,200	4,000	4,100	3,900	3,900	4,100	4,000	3,900	3,800	3,990
Fireweed	4,300	4,300	4,300	4,400	4,400	4,400	4,400	4,400	4,400	4,360

[1] All determinations were computed to an accuracy of 1 calorie per gram, but for the sake of comparison the figures are rounded off to the nearest hundred. Each tabulated value is the average of 2 determinations agreeing within 30 calories.
[2] Probably affected by a sampling error.
[3] On July 30 and later, no green growth was present.

TABLE 3.—*Percent of crude fat*[1] *in vegetation of open forest areas, 1937*

Species	June 20	June 30	July 10	July 20	July 30	Aug. 10	Aug. 20	Aug. 30	Sept. 10
Snowbrush	5.3	7.2	7.0	7.6	9.2	12.8	11.2	10.5	11.8
Ninebark	[2] 7.2	3.7	5.7	5.5	6.6	7.1	6.5	6.4	7.3
Willows	5.7	6.4	6.1	6.0	6.6	6.6	6.7	6.0	6.2
Downy chess[3]	2.5	2.6	3.3	2.2					
Pinegrass	4.4	3.4	4.1	3.6	4.0	5.2	4.8	5.0	5.8
Fireweed	4.0	4.2	3.4	4.3	5.1	6.0	5.5	5.7	6.8

[1] Averages of 2 determinations.
[2] Possibly affected by a sampling error.
[3] On July 30 and later, no green growth was present.

DISCUSSION

Before considering the data, it should be pointed out that climatically the growing season of 1937 at the Priest River experimental forest was exceptional. The month of May was the driest recorded in 25 years of observation, and both April and June were the wettest on record. July precipitation, although not establishing a record,

[4] ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS . . . Ed. 2, 417 pp., illus. Washington, D. C. See p. 72.

was well above average,[5] and that of August was 31 percent below average.

Plant moisture content undoubtedly plays the major role in the influence of vegetation conditions on rate of fire spread, as was suggested by Hawley's conclusions. Moisture content varies widely, not only seasonally for each species but also on the same date among different species growing side by side (table 1). Especially noteworthy are the data for downy chess and fireweed. The former, which cures very early, was definitely inflammable early in July. Collections of downy chess were discontinued after July 20, because all green color had disappeared and the sample plants were definitely cured. In this state, with only 9 percent of moisture, each gram of this cured material was found capable of producing 3,900 calories to contribute to the spread of fire. Fireweed, in contrast, registered at the end of the season, September 10, a moisture content of 241 percent, which is higher than that of any of the other plants of this group when they were wettest, and on June 20 and 30. With its fuel value of nearly 4,400 calories per gram and moisture content of 241 percent, this plant was capable of producing only 1,300 calories per gram on complete combustion. It is conceivable that, 71 percent of its composition being water, fireweed continues even at the end of the season to exert a retarding effect on the spread of fire.

Observations on test fires in 1935 and 1936 indicated entirely different reactions and burning properties for snowbrush, ninebark, and willows, although the moisture content and calorific values of the plants at the time were similar. As had previously been noted by trained field observers while on actual fires and test burns, the willows exhibited superior fire resistance. At any one time during the 1937 season the differences in water content of snowbrush, ninebark, and willows were not large, never as much as 20 percent (table 1).

This raised the question of the relative tenacity with which plants of different species hold their moisture when subjected to fire. The rate of loss of water might, for instance, be significantly influenced by the fact that part of the water content of green plants is colloidally bound. Evaporation tests were therefore undertaken specifically to determine the rate of water loss at moderately high temperatures. On September 10, by using a temperature of 170° C. and weighing the samples every half hour, it was found that loss of moisture in the first 30 minutes amounted to 48 percent of total moisture content for freshly picked green leaves of snowbrush, as against 38 percent for similar samples of ninebark and only 32 percent for willow. At a temperature of 170° C., morphological differences of the leaves cannot account for the differences noted in rate of loss of moisture. What, then, are the water-retention forces involved, and how can the energy necessary to overcome these forces be measured? An effort is being made to extend the present study to include an investigation of the nature of the plant juices as a possible partial explanation.

According to the calorific determinations in table 2, only snowbrush and pinegrass varied markedly during the season in total or potential heat energy, the former exhibiting a small gain, the latter a midseason dip, a recovery, and then a late-season decline. The mid-

[5] The exceptional wetness of April, June, and July offers a possible explanation of some significant results of the vegetation volume phase of this study. According to the volume measurements, based on oven-dry weight, the plants made 50 percent more total growth in 1937 than in either 1935 or 1936, seasons with rainfall slightly below the mean.

season dip of the pinegrass probably was due to sampling technique, which until after July 30 did not eliminate the possibility of collecting samples from plants that had previously been clipped. The August 10 to September 10 data are believed to indicate the true condition of the species.

The 600-calorie increase noted in snowbrush would seem to be a significant gain in available energy that should cause a marked difference in the fire behavior of this plant as the season progressed. The concurrent decrease of moisture represents a further increase in available heat energy. For example, 1 gm. of the fresh green plant in the field on June 20 contained 0.68 gm. of water and 0.32 gm. of solid material, representing only 1,400 calories. On September 10, 1 gm. of this same plant contained 0.53 gm. of water and 0.47 gm. of solid matter, representing 2,400 calories. The increase of 1,000 calories per gram is possibly significant from the standpoint of the fuel energy/water content relation.

From the information available at present, the quantity of energy necessary to rid living vegetation of its water can be only roughly approximated. On the basis of the thermal capacity of free water, the heat of vaporization, and the specific heat of water vapor, it is estimated that to dissipate the 0.68 gm. of water contained in each gram of green snowbrush on June 20 would require approximately 500 calories. On this same basis, it is estimated that to dissipate the 0.53 gm. of water in the snowbrush on September 10 would require roughly 350 calories. When this decrease from 500 to 350 calories is considered in relation to the concurrent increase of 1,000 calories per gram of green vegetation, it is obvious that the potential rate of spread of fire through snowbrush brush fields should be expected to increase between June 20 and September 10.

As a rule the calorific values of the crude fats are considerably higher, and their ignition temperatures are measurably lower, than those of cellulose. Any significant change in either quantity or nature of these constituents might readily alter the burning properties of the plants. Particularly is this the case for snowbrush, which has been provided by nature with a liberal covering of oleaginous material on the upper surface of the leaf. The crude fat data obtained in these examinations (see table 3) are of interest not only because of the seasonal variations indicated in the quantity of these materials and the relatively large proportion of the total weight that they constitute, but also because of the differences and similarities evidenced between species.

To date, no effort has been made to ascertain the nature of the constituents making up the crude fats. It is conceivable that the continued increase in the calorific value of snowbrush after August 10, despite the crude fat decrease, may be due to a change in the nature of the fats. An increase in the hydrocarbon fraction of the volatile oils would tend to increase calorific values and also introduce an additional danger factor, that of lower ignition temperatures due to increased ease of vaporization. Therefore, it would seem advisable to include this phase in future considerations.

CONCLUSIONS

Quantitative variations in the moisture content of the vegetation on this area in the northern Rocky Mountains appear to exert the dominant influence on the fire behavior of the plants through the fire season. Moisture content of plants of each of the species studied varied widely, and in some cases wide differences in moisture content were exhibited by neighboring plants of different species. In all the species, a decided decrease in moisture content took place as the season advanced; undoubtedly, this decrease is the principal cause of increased inflammability. As critical fire conditions develop, factors other than total free moisture may gradually assume increased importance. The tenacity with which a given plant holds its free or chemically combined moisture may determine whether it exerts a retarding effect, no effect, or an accelerating effect on the rate of spread of forest fires. As yet insufficient data are at hand to permit any conclusions to be drawn concerning the significance of calorific variations. At present it is impossible to estimate, for example, in any but the most general way, what effect an increase of 600 calories per gram would have on rate of spread.