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DISTRIBUTION OF MOISTURE IN SPRUCE-FIR DUFF AND ITS RELEVANCE TO FIRE DANGER RATING

by

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INTRODUCTION

Increasing sophistication in fire control planning and operations in Alberta and elsewhere points to the need for a more refined fire danger rating system[3] than is presently available. On the basis of present and expected future use, the new danger rating system must satisfy the needs of both headquarters administrators and fire control field staff. Administrators are generally satisfied with a relative index to reflect differences between large regions whereas the fire-control officer or fire boss requires more precise guidance from a danger rating system. Both groups agree, however, that burning or fire intensity tables for a few specific fuel types would be most valuable in fire-prevention publicity, determining pre-suppression preparedness, closure of forest areas for public use and logging, and decision-making relative to suppression activities during

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[1] Based on background paper prepared for meeting on fire danger rating in Ottawa, February 26-29, 1968.

[2] Research Scientist, Canadian Forestry Service, Department of Fisheries and Forestry, Edmonton, Alberta.

[3] The new Canadian Forest Fire Weather Index is now available and it will be the basis for further refinements in fire danger rating at the regional level.

going fires. Determinations of fire spread and intensity for specific fuel types is often difficult and time-consuming but this information must be known if there is ever to be a significant improvement in rating and predicting forest fire behavior.

Moisture content, owing to its direct effect on flammability of forest fuels, must be incorporated into a fire danger rating system. Accurate indicators of moisture content in different fuels are particularly important when separate burning tables are required for major fuel complexes. In the past, the development of such indicators has been hindered by a lack of quantitative information about the amount and distribution of moisture in different fuel layers. The study reported here was carried out to clarify duff-moisture relationships in the duff layer of overmature spruce-fir (Picea glauca (Moench) Voss and Abies lasiocarpa (Hook.) Nutt.) stands and clearcuts and to provide a quantitative basis for stratifying the forest floor according to depth, weight and/or water-holding capacity.

METHODS

This study was carried out concurrently with a prescribed burning program[4] in 1967 in spruce-fire clearcuts on the lease limits of North Western Pulp and Power Limited in west-central Alberta. The overmature spruce-fir stand had 429 live stems per acre with 158 square feet of basal area. The soil on this site is poorly drained gleysolic overlain by 6 to 24 inches of needle litter and feather moss (L), partly decomposed organic material (F), and black muck (H). Clearcutting was carried out in the

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[4] Kiil, A. D. 1969. Fuel consumption by a prescribed burn in spruce-fir logging slash in Alberta. The Forestry Chronicle, Vol. 45, No. 2

winter of 1966-67.

Two duff sampling areas - one in standing timber, the other in an adjacent clearcut - were selected and an intensive sampling routine was conducted during August and September, 1967. On each sampling day, three one-square-foot duff samples were extracted at selected sampling points, placed in airtight plastic bags and taken to a field laboratory for weighing and oven-drying. No samples were taken within 18 inches of a standing tree, stump, or a large root over two inches in diameter.

To assess the relative rates of evaporation from duff in the two study areas, a set of 3 8-inch aluminum cylinders, each containing a duff sample, was set out and weighed concurrently with the one-square-foot destructive samples. Each cylinder has a 3-inch high, 0.06 inch thick wall and a 40-inch nylon screen across the bottom to facilitate free downward movement of water. A 4-inch deep duff sample was obtained by cutting through the duff and tree roots, removing the sample from place, placing it in the cylinder and inserting the cylinder and the sample into the hole left by removing the sample. It is important to point out that the cylinders were designed to eliminate both lateral water movement through the sample and transpirational water loss through plants. Thus the one-square-foot samples represent actual moisture content of the duff whereas the samples in the cylinders reflect only the effects of rainfall and evaporation.

Two of the one-square-foot samples were separated by L, F and H layers, the third by one-inch layers starting at the top of the sample. All duff samples in cylinders were taken to a field laboratory at the end of the sampling period and separated by one-inch layers. All samples were oven-dried to a constant weight for 24 to 48 hours at a little over 100°C.

Moisture content of all sample components was calculated and are given on an ovendry basis. Bulk density was determined from green sample volume and ovendry weight.

RESULTS

Weight and Moisture Content

The weight of the duff layer increased with depth (Fig. 1). Mean weight per acre-inch differed significantly between the stand and the clearcut. In the clearcut, duff weight increased from about 5 tons per acre-inch in the surface-inch to more than 18 tons per acre-inch six inches below the surface. In the stand, the corresponding figures were about 4 and 10. The total weight of the top six inches of duff in the stand exceeded 46 tons per acre compared to 68 tons per acre in the clearcut.

Bulk density increased with depth from 0.03 gm/cu cm to nearly 0.14 gm/cu cm (Fig. 2). The bulk density ratio of clearcut to stand increased from about 1.1 to 1 in the surface inch to nearly 1.8 to 1 six inches below the surface.

Average maximum water-holding capacity in terms of weight increased with depth in the top 3 to 4 inches, but decreased in the lower part of the duff layer (Fig. 3). Each one-inch layer of duff in the clearcut held about three times its weight in water compared to a nearly four-fold capacity in the stand.

The effects of different amounts of rainfall and time since last rainfall are illustrated in Figure 4. Figure 4(b) indicates the distribution of moisture after a rainfall of 1.40 inches whereas Figure 4(c,b) reflect the effects of longer periods of drying.

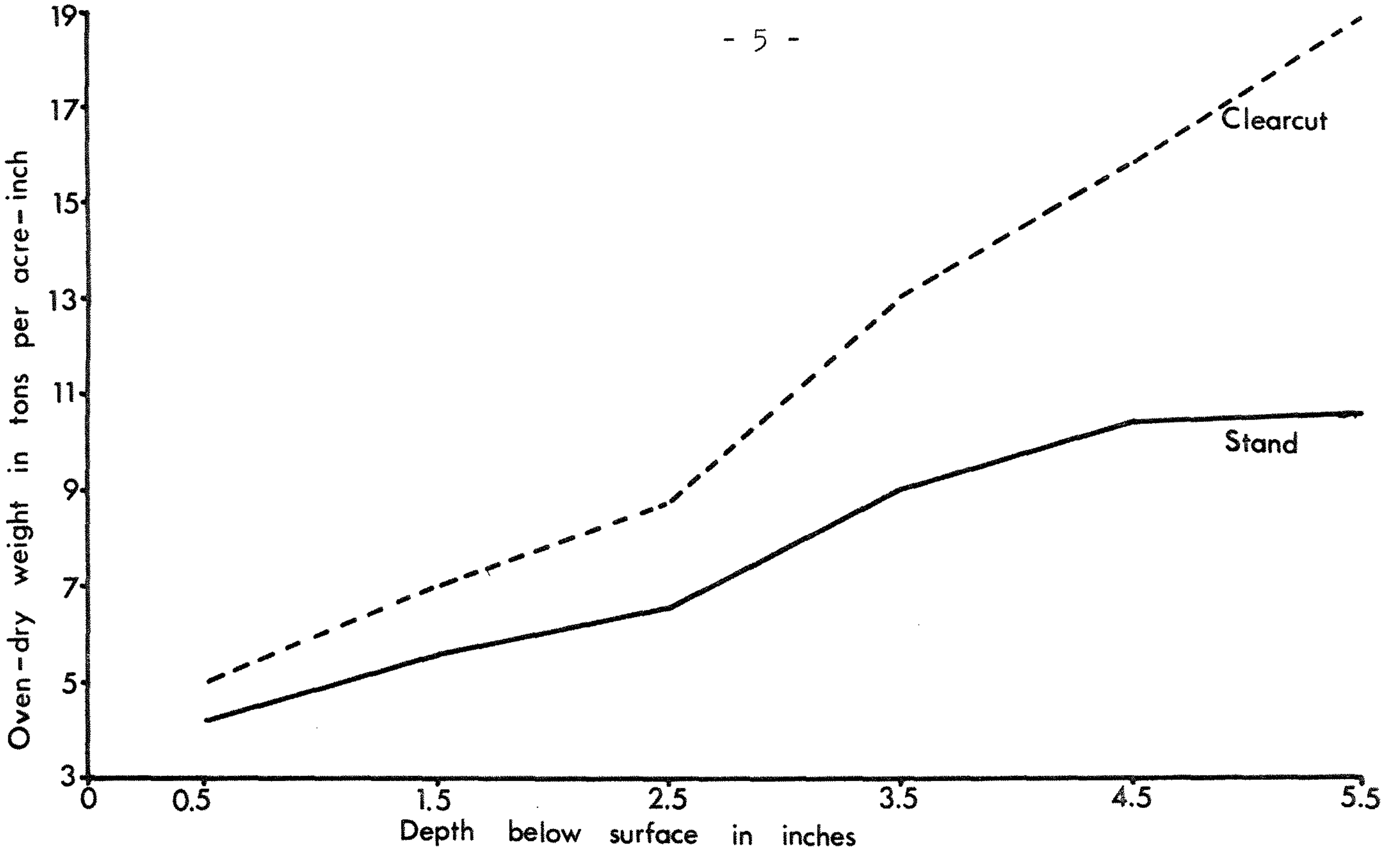


Figure 1. Duff weight in spruce-fir stand and a clearcut at different levels below the ground surface.

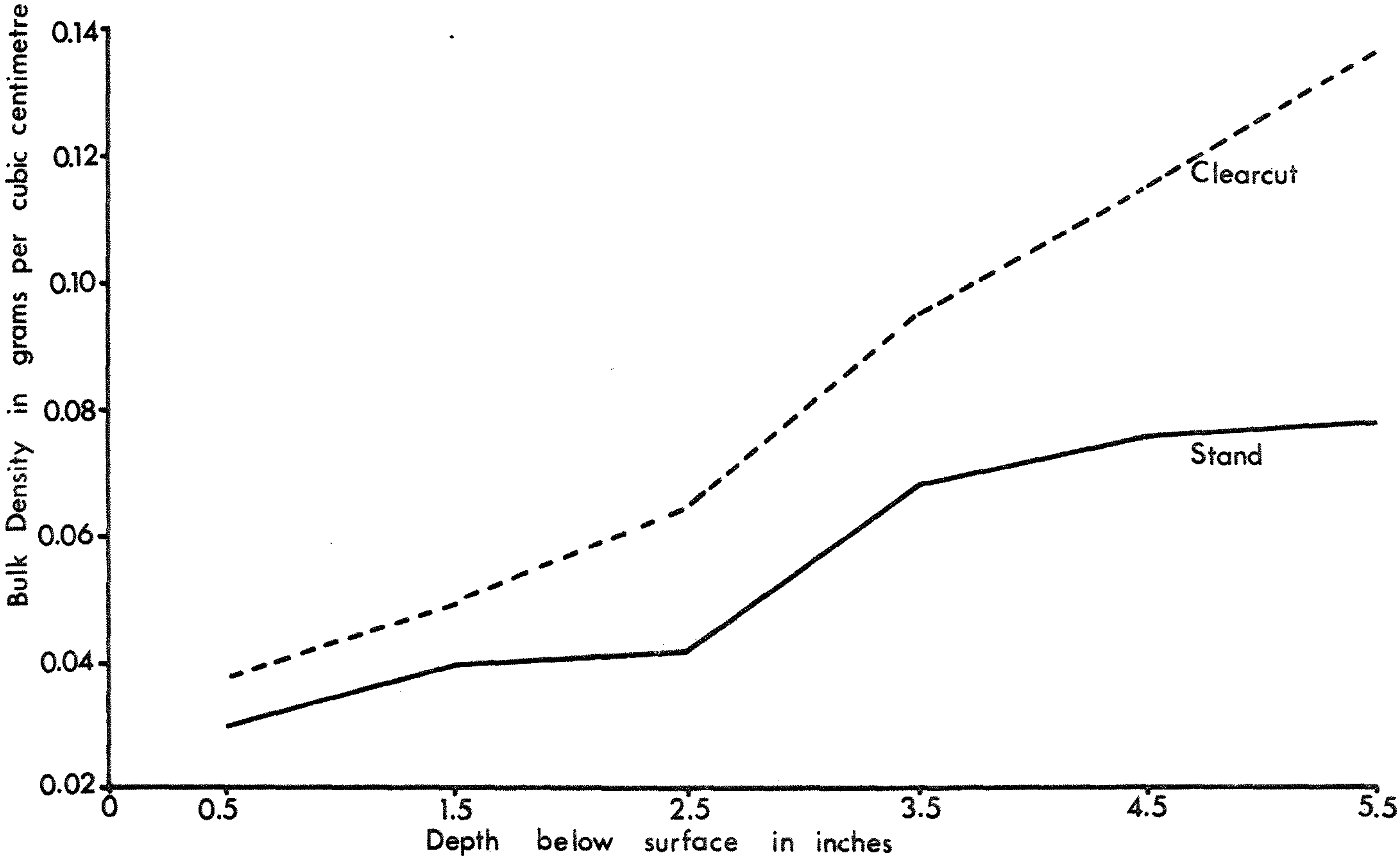


Figure 2. Bulk density of duff in spruce-fir stand and a clearcut at different levels below the ground surface.

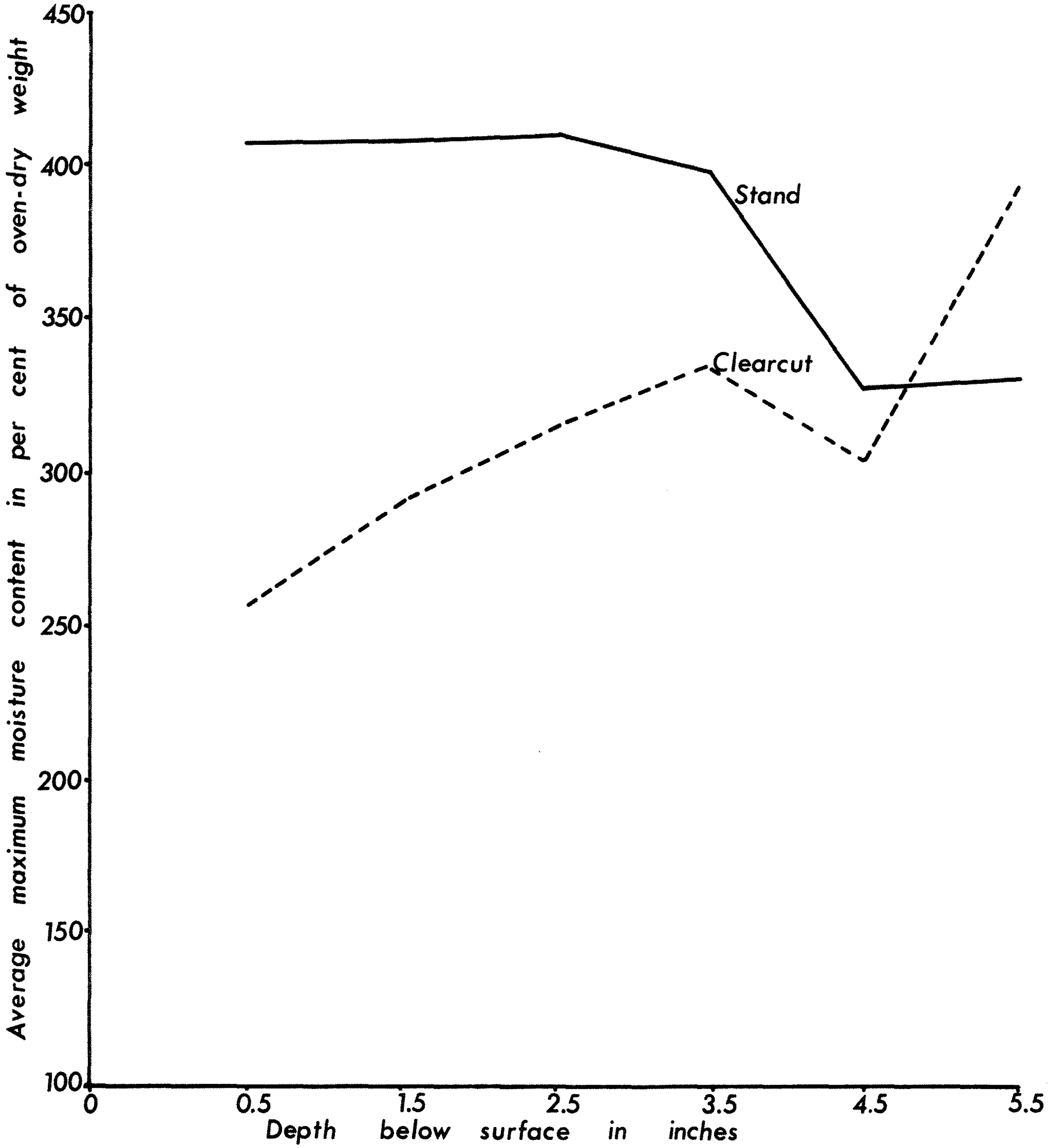
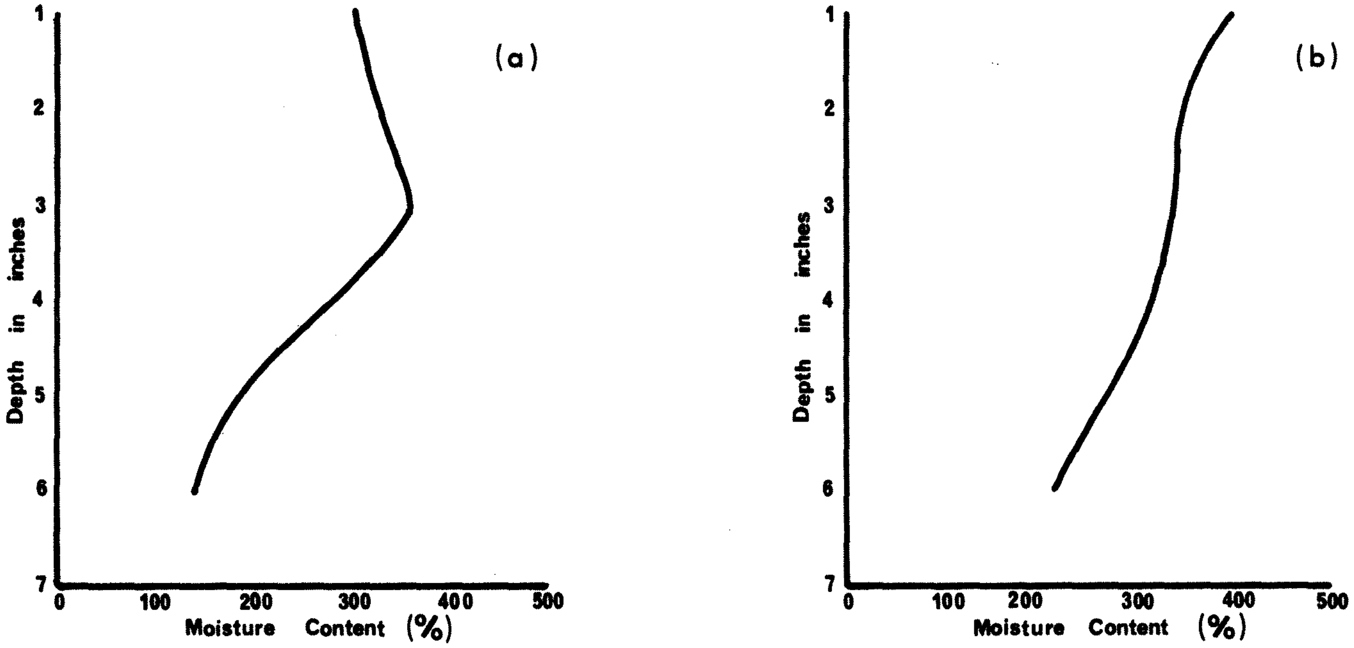
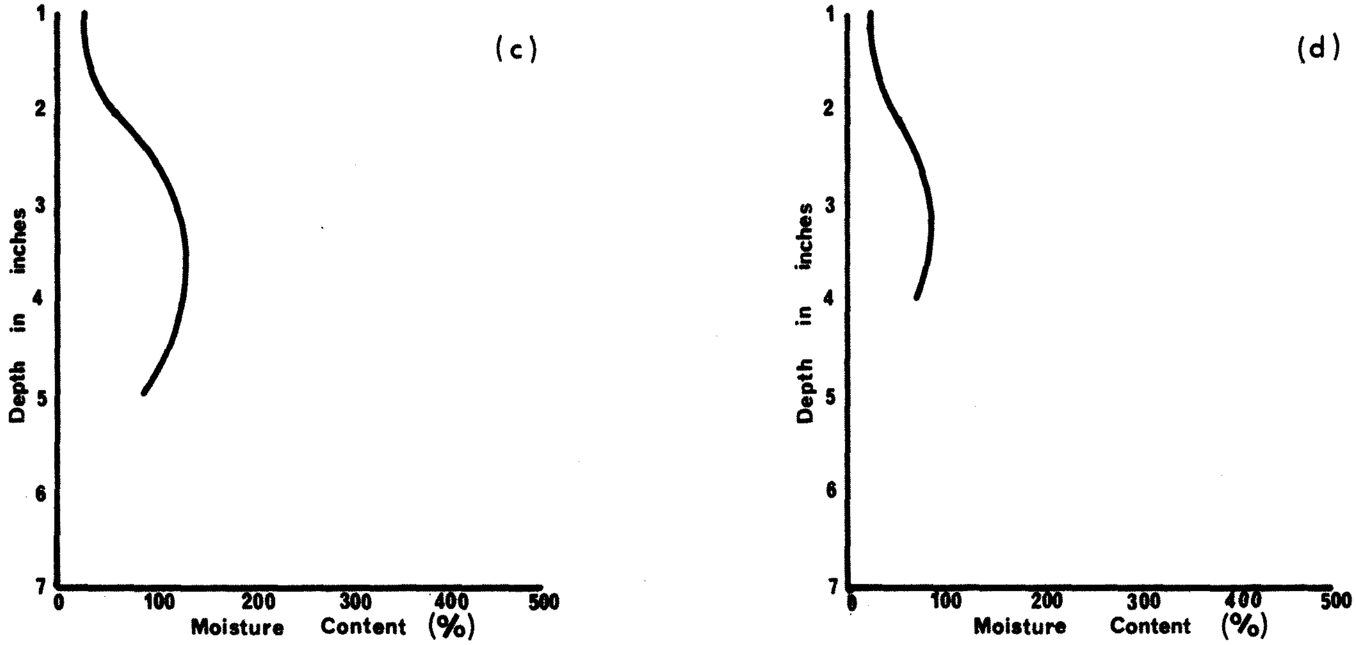


Figure 3. Average maximum water-holding capacity of the top six inches of duff in a spruce-fir stand and a clearcut.



August 5
1 day after 0.50" of rain

August 8
after 1.20" of rain during preceding 3 days



August 21
after 13 rainfree days

September 18
after 1.20" since August 21

Figure 4. Distribution of moisture in duff under a spruce-fir stand after different period of drying, 1967.

Comparison of Direct and Indirect Sampling Methods

The moisture content of the top 4 inches of duff in the clearcut and the stand as determined from the samples in the 8-inch cylinders is presented in Figure 5. The moisture content of the duff in the stand exceeded that in the clearcut. The differences in moisture content between the stand and the clearcut ranged from about 30% to over 100% and increased with decreasing moisture content.

Figure 6 gives the moisture content of the top 4 inches of duff in the stand and the clearcut as determined from the one-square foot samples. With one exception on August 18, the moisture content of the duff in the clearcut exceeded that in the stand. The differences in moisture content between the clearcut and the stand ranged from about 5% to over 75% and increased with decreasing moisture content. Both the direct and the indirect sampling methods gave roughly comparable moisture content values in the clearcut whereas there were important differences between the figures for the stand. These differences are attributed largely to the effect of transpiration on moisture content of the duff in the stand although the possibility of the design of the cylinders contributing to the differences should not be overlooked.

DISCUSSION

Important differences existed between the spruce-fir stand and the clearcut in weight, bulk density and moisture content of duff. Fuel compaction increased with depth but the rate of increase was greater in the clearcut than in the stand. The latter condition is attributed to the compacting effect of mechanical logging, drying and shrivelling of the

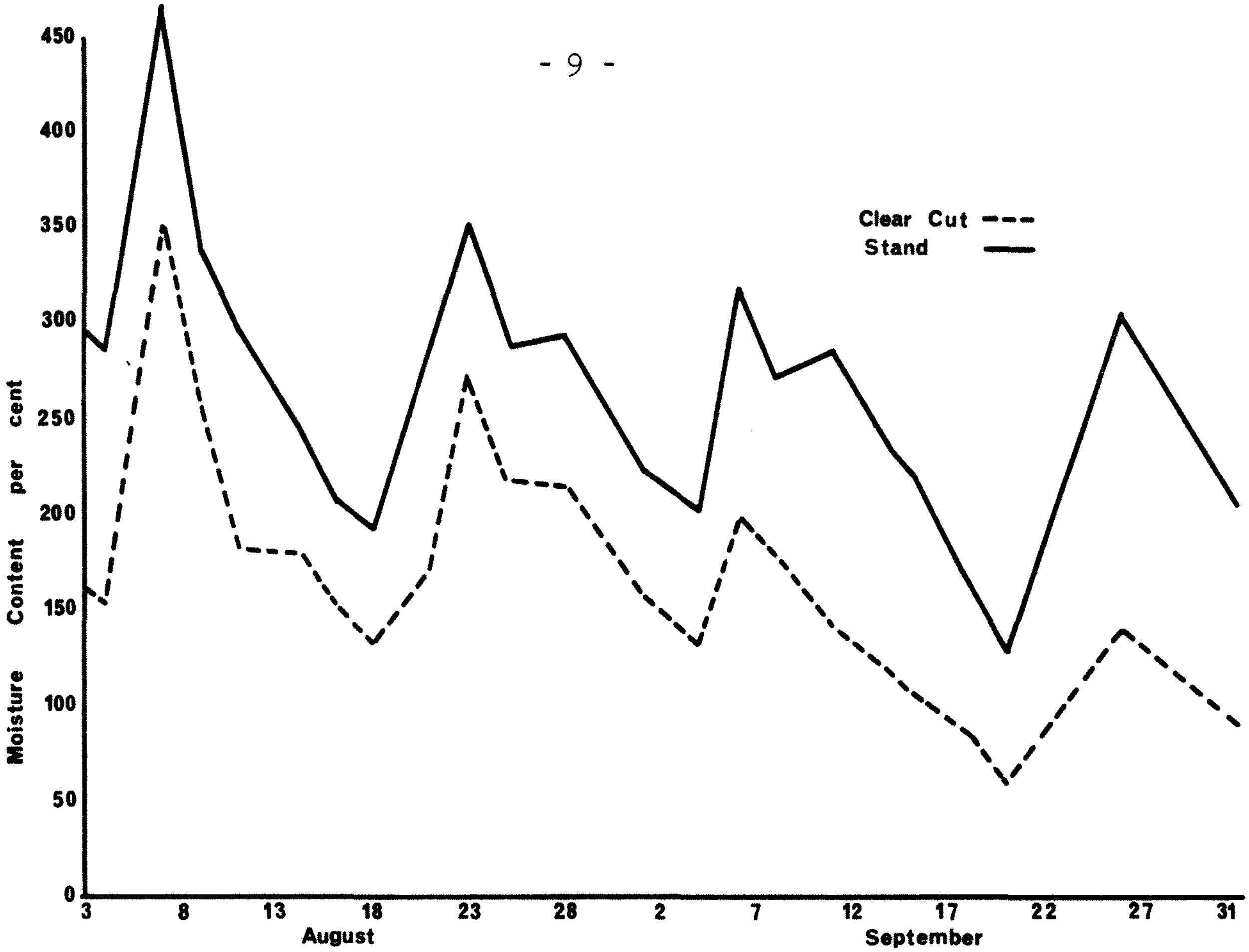


Figure 5. Moisture content of duff in 8-inch perforated-bottom aluminum cylinders in a spruce-fir stand and a clearcut.

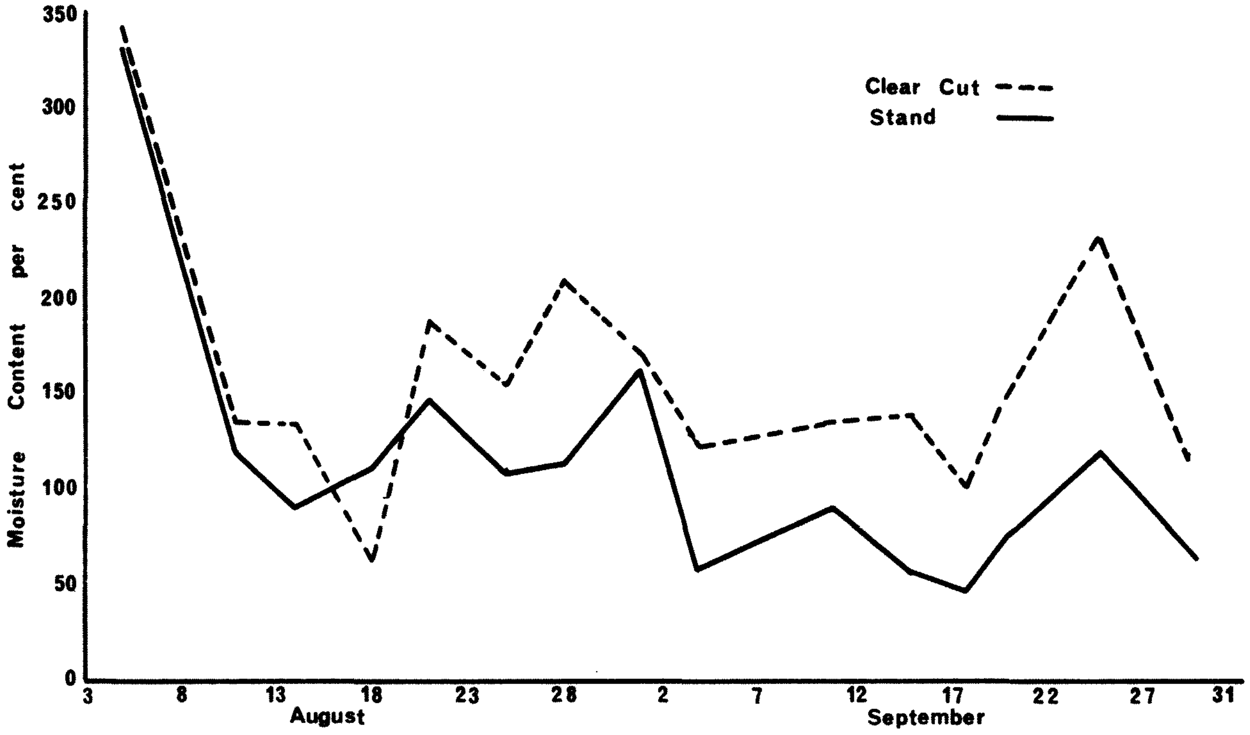


Figure 6. Moisture content of one-square-foot duff samples in a spruce-fir stand and a clearcut.

moss layer, the inability of the dead root systems to hold the soil, and plugging of the non-capillary pores. These differences are likely to persist and even increase with time since logging.

The total weight of the top 6 inches of duff in the clearcut exceeds that in the stand by 48%. This change in bulk density reduced the average maximum moisture content of the duff layer from about 400% in the stand to 300% in the clearcut but the total amount of water in the duff after a saturating rainfall may still be greater in the clearcut than in the stand. Thus the top six inches of duff in the clearcut has the capacity to hold about 2 inches of water compared to about 1.5 inches in the stand. The total amount of water held in the duff in the stand, however, probably exceeds that in the clearcut because of the greater total depth and the ability of the live roots in the lower part of the duff to prevent compaction.

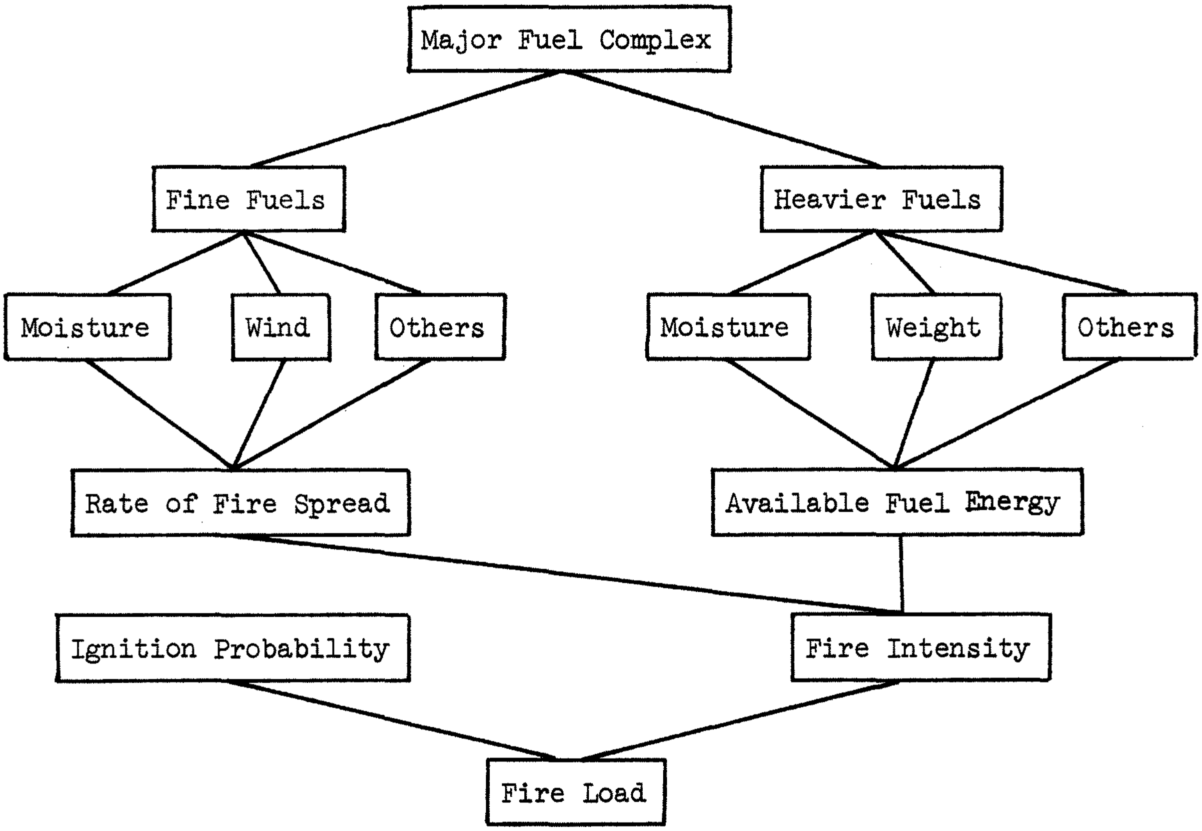
A comparison of moisture content in the top 4 inches of the duff indicates that the indirect sampling method (duff cylinders) cannot be relied on to provide accurate results in an overmature spruce-fir stand and that destructive sampling (one-square-foot samples) is likely to be more reliable. Both methods gave roughly comparable results for the clearcut where transpirational losses are negligible. These findings, if corroborated by additional sampling, have important implications relative to fire hazard in stands and clearcuts. It is important to point out that the study reported here was carried out on a site with a relatively heavy concentration of tree roots in the deep organic layer, and during an abnormally dry period. Thus the magnitude of the difference in moisture content of the duff between stands and clearcuts is likely to be less on shallow-organic sites where a greater proportion of transpirational losses are from the mineral soil.

Furthermore, other indirect methods such as large nylon-covered duff trays are likely to yield more accurate results than the cylinders used in this study.

Quantitative information about fuel-moisture relationships is important in a number of applications. For example, forest-floor fuels in this cover type can now be classified according to fuel depth, weight or energy content, and the maximum water-holding capacity of different layers provides a framework for further studies of moisture distribution in these fuels. While fuel-moisture relationships in a spruce-fir stand are likely to differ considerably from those in other cover types they are, nevertheless, believed to be indicative of conditions in all stands. The findings will therefore help in developing more accurate and efficient sampling procedures, categorization of fuel complexes according to energy content, and identification of important fuel factors for the fire behavior rating.

Owing to the considerable range in weight of the forest-floor, three categories of these fuels may have to be used to provide reliable estimates of moisture conditions and fuel available for burning under a range of burning conditions. Certainly every burning index for fine fuels must contain a measure of moisture to accurately reflect the potential for fires starting and spreading. Some fuel complexes, such as black spruce, overmature spruce-fir and many mixedwood stands have an organic layer six inches or more in depth and the moisture content of this layer, or of strata therein, needs to be known if the available fuel for burning is to be determined. While an extremely low moisture level in deep duff is unlikely to have a pronounced effect on rate of spread of surface fires, it may, nevertheless, contribute significantly to the development and spread of crown fires through its effect on the moisture content of foliage, spotting in advance of the main fire front, and difficulty of mop-up.

Past experience with forest fire behavior lends weight to the assumption that the fuel characteristics of forest stands which determine fire behavior are also closely related to forest cover types. Thus the forest cover type (major fuel complex) appears to provide the best basis for the development of burning tables and fuel-typing procedures. A basic framework for developing burning indices for a major fuel complex is given below:



A major fuel complex is a forest association with identifiable weight, energy, size, and distribution of fuel components which will result in a predictable fire spread and intensity over a range of topographic and weather factors. Rate of fire spread is determined from moisture content of the top layer of duff (about 1/10 lb./sq.ft.) and prevailing wind. Available fuel energy is based on the total energy and moisture content of selected fuels. This category includes the energy content of fine fuels and crown fuel components if these fuels contribute to energy transfer. Fire intensity is the heat yield per unit of time per foot of fire front. Fire intensity and a measure of ignition probability give fire load.

The present study has contributed toward a better understanding of the physical characteristics and moisture distribution in overmature spruce-fir duff. Results of similar studies in Alberta and elsewhere reflect important differences in fuel and moisture parameters between forest types. A statistical description of major fuel complexes is therefore considered a prerequisite for preparing rate of spread and fire intensity tables. It is recommended that the development of burning tables (Spread and Intensity Tables) proceed as follows:

(1) Selection of a major fuel complex according to fuel weight, energy content, size, and possibly an integrated measure of the horizontal and vertical continuity of aerial fuels.

(2) A series of test fires sufficiently large to accurately reflect aspects of fire behavior such as rate of spread, flame height and depth, and fuel consumption. These test fires will be used to determine fuel-moisture-fire behavior

relationships in a range of burning conditions from low to the crowning-threshold level.

(3) When burning conditions preclude safe experimentation, the necessary data should be obtained during and after going wildfires, or from reliable fire reports. Rate of spread and fuel consumption during crowning are two important prerequisites for developing burning tables; more reliable techniques for estimating them are required. Fire modelling techniques are also worthy of attention.

(4) A fuel-type classification should be developed simultaneously with burning indices to aid the fire control officer or fire boss in interpreting the fire hazard in a specific fuel complex. The fuel-type classification and mapping program should be related to Spread and Intensity Indices for the major fuel complexes and adjustment should be made for effects of slope and aspect on fire behavior.