

**PREDICTION OF DUFF MOISTURE  
DISTRIBUTION FOR  
PRESCRIBED BURNING**

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**INFORMATION REPORT BC-X-46**

**DEPARTMENT OF FISHERIES AND FORESTRY  
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### Abstract

Field measurements of moisture distribution in organic layers under mature stands and in exposed slash areas, and the effect of additional precipitation are presented and discussed. Implications of the moisture distribution to control of prescribed fires and their relation to the Stored Moisture Index and the Drought Code of the Forest Fire Behaviour system are presented in the form of guidelines for initiating the annual prescribed burning program.

### Introduction

In September 1967, operators of the Sooke Combined Fire Organization (Fig. 1) experienced extensive losses from escaped slash burns. Moisture analyses on September 28, showed the presence of both horizontal and vertical reversals of the accepted moisture regime in the organic layer; that is, moisture content is greater in the stands than in open areas and that moisture increases with depth. Horizontally, the reversal was shown by a drier organic layer in the stands than in the open slash areas. Vertically, the reversal was manifested by a general decrease in moisture content with depth. Henderson and Muraro (1967) contended these reversals were at least partially responsible for the difficulty of establishing control over the numerous persistent outbreaks that occurred during the following extreme drying period.

Turner's (1966) Stored Moisture Index (SMI) indicated the severity of the moisture deficit, which persisted in spite of more than

two inches of precipitation prior to ignition (Fig. 2). Subsequently, the Stored Moisture Index was calculated on the Muir Creek operation within the area served by the Organization. In September 1969, the approach of the SMI to the 1967 level (Fig. 2) renewed concern about slash ignition and prompted a second moisture sampling program. The results of this limited investigation, and the implications regarding slash fire control problems, are presented in this paper.

#### 1969 Precipitation Records

The 1969 seasonal precipitation, measured at four locations on the area, and the mean 30-year monthly precipitation for Jordan Powerhouse and Diversion Dam are shown in Table I (Anon., 1966). 12 Mile and Diversion Reservoir stations are shown in Figure 1 by the solid black triangles, Jordan Powerhouse being just west of the area. The monthly amounts of rainfall in Table I substantiate the presence of a precipitation gradient delineated, according to local operators, by the Jordan River Valley. An elevational gradient is also indicated by comparing Muir Creek (800 ft) with 12 Mile (1,900 ft) and Jordan Powerhouse (150 ft) with Diversion Reservoir (1,150 ft).

The Stored Moisture Index associated with these rainfall quantities for August and September and for the same period in 1967 (Fig. 2) was calculated by converting the Drought Code of the Forest Fire Behaviour Systems to SMI units. The SMI for Jordan Powerhouse was similar to that of 12 Mile.

#### 1969 Moisture Sampling

In 1969, one set of samples was obtained from all the locations

TABLE I. 1969 and Average Precipitation on the Area of the Sooke  
Combined Fire Organization.

|                     |               | Precipitation Frequency and Total by Periods (Inches) |      |      |        |           |       |       |
|---------------------|---------------|---|------|------|--------|-----------|-------|-------|
| Station             |               | May   | June | July | August | September |       |       |
|                     |               |   |      |      |        | 1-12      | 13-14 | 15-25 |
| Muir Cr.            | Days          | 6   | 4    | 3    | 10     |           |       |       |
|                     | Amount        | 1.31  | .69  | .68  | 1.46   | .16       | .28   | 5.15  |
| 12 Mile             | Days          | 7   | 5    | 6    | 11     |           |       |       |
|                     | Amount        | 2.09  | .47  | 1.91 | 2.00   | .05       | .20   | 7.08  |
| Diversion Reservoir | Days          | 5   | 6    | 7    | 12     |           |       |       |
|                     | Amount        | 3.35  | .91  | 2.23 | 4.00   | .28       | .50   | 9.55  |
|                     | 30 yr Average | 4.25  | 3.34 | 2.26 | 2.45   |           |       |       |
| Jordan Powerhouse   | Days          | 7   | 5    | 4    | 12     |           |       |       |
|                     | Amount        | 2.24  | 1.92 | .88  | 1.90   | .17       | .33   | 6.36  |
|                     | 30 yr Average | 2.65  | 2.31 | 1.41 | 1.58   |           |       |       |

shown in Figure 1 during the period from September 10 to September 12. Sampling was repeated at locations 7 and 8 only on September 15 and 25. At each location, samples from various depths of the organic layer under forest stands and adjacent or closest slash areas were sealed in containers and oven dried to determine per cent moisture content on the basis of oven dried weight (% ODW).

The organic layers mainly referred to in this paper averaged 10 inches in depth, but ranged from 8 to 16 inches (Fig. 3). They occurred under mature or overmature stands at elevations in excess of approximately 1000 feet. The deepest and most compact layers were found at the higher elevations under the oldest stands. These organic layers consist of shallow (.5 to 1.0 inch) litter (L) layers underlain by a deep (6.0 - 10.0 inch) homogenous, organic moss, dominated by a felt-like layer of mycelia. Although virtually impossible to differentiate, the upper portion of this layer was termed the fermentation (F) layer and the bottom portion the humus (H) layer. The majority of roots, up to an inch in diameter, occurred in this zone between 3 and 6 inches below the surface. The organic layer was usually physically supported by a zone 3.0 - 6.0 inches thick composed entirely of rotting wood and extensive voids, presumably from rotted wood. (The presence of these voids affects diffusive moisture exchange at the interface, but also allows ventilation for surface and subsurface fire spread.) The geographic distribution of these organic layers is probably greater than realized; however, they are known to occur as far north as Nanaimo Lakes, and throughout the Victoria Watershed.

Specific gravity and field capacity of the L, F and H layers were determined in the laboratory. For specific gravity, over-dry weight was divided by the sample volume measured at 60% moisture content to avoid the excessive shrinkage caused by dehydration and subsequent death of the mycelia. Field capacity, or maximum amount of water which the organic horizons could hold, expressed as a percentage of oven-dry weight, was determined by soaking samples in water for 24 hours and then allowing a 4-hour draining period. The following values were calculated from 8 samples dissected in the laboratory.

|                        | Litter (L) |      |      | Fermen-<br>tation (F) |      |      | Humus(H) |      |      |
|------------------------|------------|------|------|-----------------------|------|------|----------|------|------|
|                        |            | S.D. |      |                       | S.D. |      |          | S.D. |      |
| Field Capacity (% ODW) | 480        | ±    | 42%  | 470                   | ±    | 28%  | 353      | ±    | 47%  |
| Specific Gravity       | .126       | ±    | .019 | .183                  | ±    | .073 | .170     | ±    | .020 |

## RESULTS AND DISCUSSION

### September 10, 11 and 12 Results of moisture sampling

Except for the rainfall amounts which occurred on September 3 (Table I), the last appreciable rainfall prior to the first sampling period occurred on August 27. At location 1 (Fig. 1), located under an immature stand on well-drained outwash, the organic layer varied from 2-3 inches deep and had a maximum moisture content of 30%. At location 2, the 3-inch-deep organic layer contained a maximum of 40% moisture, while moss-covered rotten logs contained 78% moisture at the same depth.

Moisture content as a function of depth in inches, from locations 3 to 10 (Fig. 1) in the stand and in adjacent exposed slash

areas, is shown by Figures 4-9. Depth is displayed on an inverted logarithmic scale to emphasize the upper, more variable portion of the profile. Except for the profile from the wet side (west) of the Jordan River (Fig. 5) all the profiles show the prevalence of lower moisture contents in the stand than in the slash. In the fresh slash area, surface evaporation is the primary means of water depletion from the organic layer and only the immediate surface fuels are drier than in the stands. The sharp increase of moisture with depth in the slash profiles is indicative of the restricted depth affected by this means of water transport. In the stands, evaporation from the surface is reduced because of lower surface temperatures, and moisture content at this level is greater than in the slash; however, only a slight moisture increase occurs through the first inch of depth, thereafter remaining relatively constant or even decreasing. The effect of the stand is, first, to intercept rainfall and thus reduce the amount of rain reaching the forest floor and, secondly, to cause water depletion from the rooting zone through the process of transpiration. Water requirements for annual growth easily account for the 150 to 200% deficit in moisture content at the 2-inch level in the stand, compared to the nonvegetated fresh slash area. The profiles from the partially revegetated 1968 slash (Fig. 6), and the profile from the vigorous immature stand compared to the mature stand (Fig. 4) agree with relative water requirements for vegetative growth.

The moisture profiles at Walker Road (Fig. 5) (location 5) show the more common situation where more than sufficient precipitation occurs

to satisfy plant requirements, and the differences in moisture content due to vegetative growth are minimized. The profile shown for location 6 was obtained east of the sampled slash area in the direction of decreasing rainfall and shows only a tendency toward the pronounced reversal shown by the profiles in the drier samples.

#### September 15 and 25 Results of moisture sampling

Samples were collected at locations 7 and 8 on September 15 to determine the wetting effect of the rain that occurred on the night of September 12 and on September 25 to determine the effect of the rain occurring between the 16 and 25, Table I. At location 7, Valentine Mountain, samples were obtained in a stand opening, under a closed canopy, and in the adjacent fresh slash (Figs. 10, 11 and 12 respectively). In figures 13 and 14 from the Muir Creek drainage, samples were obtained in a mature stand and in a slightly removed area of 1968 slash. In each of these figures the solid line represents the results of the September 11 sampling and the two dotted lines, those of September 15 and 25.

At Valentine Mountain, the rain of approximately .20 inches that occurred on the night of September 12 increased moisture contents under both the canopy (Fig. 11) and the stand opening (Fig. 10) in the upper 1 inch, while depletion continued at greater depths. In the upper inch, moisture increase in the stand opening was about double that under the canopy. The similar depths affected suggest the dense shrub-cover intercepted nearly as much rain as the dominant canopy. The shrub-cover, however, could be more restrictive to surface ventilation and would account for the greater moisture content at the time of sampling. In

the slash, the September 15 profile (Fig. 12) exhibits a drier surface than both stand conditions and shows the pronounced drying that occurred in the 2.5 days between rainfall and sampling. At lower depths, the initial presence of larger amounts of rain and the depth of penetration is shown by the depth of highest moisture content on the curve.

In the Muir Creek drainage, .28 inches of rain occurred on September 12; the effect on the moisture profiles in both the stand and slash are similar, but more pronounced than at Valentine Mountain. In the stand, moisture was increased to a depth of 2.5 inches (Fig. 13), and throughout the entire profile in the slash (Fig. 14).

On September 25, after 5.15 and 7.08 inches of rain at Muir Creek and 12 mile, respectively, all moisture contents showed pronounced increases at all depths; however, the moisture contents in the slash exceeded those in the stands. The large amount of rain and the moisture contents measured suggest that differences in specific gravity and field capacities of the various strata were more obviously affecting moisture retention as saturation was approached.

#### Water Holding Capacity

Bulk density was used to convert percent moisture contents to equivalent inches of water and to determine field capacity moisture equivalents in the laboratory. Bulk densities of .65 lb/in/ft<sup>2</sup> and .92 lb/in/ft<sup>2</sup> were applied to the upper one inch and the remainder of the organic layer, respectively. The calculated depth of rain in the total organic layer and in the upper inch (Table II) could then be compared with the measured precipitation at each station. After the

TABLE II. Depth of Water Retained by the Upper Inch and the Full Organic Layer.

| Equivalent Rainfall in Inches |              |             |         |         |                |         |         |
|-------------------------------|--------------|-------------|---------|---------|----------------|---------|---------|
|                               |              | In Top Inch |         |         | In Total Layer |         |         |
| Location                      | From<br>Fig. | Sept.12     | Sept.15 | Sept.25 | Sept.12        | Sept.15 | Sept.25 |
| <hr/>                         |              |             |         |         |                |         |         |
| Valentine Mt.                 |              |             |         |         |                |         |         |
| Stand Opening                 | 10           | .102        | .181    | .408    | 3.13           | 3.10    | 6.40    |
| Stand                         | 11           | .112        | .146    | .291    | 2.33           | 1.90    | 5.77    |
| Slash                         | 12           | .181        | .325    | .469    | 3.34           | 4.92    | 6.51    |
| Muir Cr.                      |              |             |         |         |                |         |         |
| Stand                         | 13           | .056        | .185    | .391    | 1.78           | 1.68    | 5.69    |
| Slash                         | 14           | .102        | .374    | .521    | 4.24           | 5.25    | 6.17    |

rain of September 12, and 2.5 drying days, all stands showed a decrease of total moisture and only slight increases in the upper layer. In the slash, the increase in the upper inch alone accounted for the full amount of rain and increases in excess of an inch were calculated for the total layer, more than four times the total precipitation, indicating that horizontal water movement was occurring. In contrast, the 5.15 and 7.08 inches of rain between September 15 and 25 at Muir Creek and 12 Mile, respectively, resulted in larger increases in the stands than in the slash. However, the slash areas still retained the greatest depth of water. At Muir Creek 78% of the 5.15 inches of rain was retained in the organic layers under the stand and 18% was retained in the slash area. At Valentine Mt. 55% of the 7.08 inches of rain was retained by the layers under the stand and 22% by the layers in the slash area, the remainder being lost to either drainage or interception. Field capacities measured in the laboratory showed these layers to be capable of retaining .8 inches of water per inch of organic layer.

Figure 15 shows the relation of the Stored Moisture Index with water equivalents for the total organic layer, determined from the samples. Obviously, separate surveys are required for open slash areas and stands; brush fields and stand openings are intermediate.

#### IMPLICATIONS OF THE S.M.I. FOR PRESCRIBED BURNING

Consideration of the distribution of water in the organic layer is essential to successful prescribed burning. Coastal burning practices rely almost entirely for control on the prevalence of higher fuel moistures in the stand compared to the slash. Weather indexes, which indicate

when and where the horizontal reversals of moisture discussed herein are likely to occur, are, therefore, invaluable guides for detailing particular seasonal ignition scheduling and control procedures to be followed. Weather indexes describing these moisture regimes, such as the SMI and Drought Code, must be used as a guide for detailing burning procedures rather than purely as an indication of when to initiate the burning program.

These guides should only be used as a "go" or "no go" indicator if those responsible for control are unwilling to adapt a flexible attitude both in the selecting of areas to be burned and in initiating mop-up and patrol campaigns dependent on the weather subsequent to the burn. Users of the stored moisture index have, from experience, assigned a value of 350 (3.5 inches of water retained) or less as the hazardous zone and have recommended abstention from burning below 300 (Sworder 1969). There is a good basis for these recommendations that supersedes the normally accepted guide of initiating burning after the first late-summer rain greater than two inches, a condition that was satisfied both in 1965 and 1967 when major slash fire escapes were experienced while the SMI was lower than 300. Excellent burns may be attained at SMI values lower than these; however, the ultimate cost of these burns is fully dependent on the weather regime subsequent to the burn and the follow-up effort expended. If continued wet weather follows, extra costs will not immediately be involved. If a drying regime continued, it is then almost certain that high costs will be expended in extensive mop-up operations or even

higher costs will be required for massive control action. The SMI is not an indication of ignition ease and, in fact, ignition can be extremely difficult at SMI values of 200 or less, for short periods following recent rain.

Using the Drought Code (DC) as a Prescribed Fire Guide

The Drought Code of the Forest Fire Behaviour system (1970) incorporates a simplified calculation of the SMI expressed in a linear fashion rather than on an exponential scale. Use of this code is advocated because it is incorporated in the daily calculation of the Fire Weather Index and thus avoids the necessity of calculating a separate index. For those who are acquainted with the present form of the SMI, a conversion graph is appended (Appendix I). A conversion table is also included in Table IIIa of the Fire Weather Index (1970).

For the organic layers described, the following guidelines are tentatively recommended for using the Drought Code (DC) for prescribing the seasonal burning policy.

I. Drought Code (DC) Less than 300 (SMI Greater than 375):

Adequate moisture will be present in deep organic layers under both slash and stands, surface moisture will be less in slash and moisture will increase with depth in stands and slash. Usual precautions and guides for fire behaviour should be followed; usual attention to mop-up and patrol, with closer attention to critical perimeters as a code value of 300 is approached.

II. Drought Code (DC) from 300 to 500 (SMI 375 to 230):

Moisture reversals between slash and timber will occur; moisture content may decrease with depth. Control problems posed by critical edges on each area should be appraised carefully and only those areas where complete containment can be accomplished should be ignited. More than the usual control equipment must be on hand and spot fires in the adjacent stands should be handled promptly. Extensive mop-up of edges should be initiated immediately and continuous patrol instigated unless extensive rains follow the burn. Extra cost should be anticipated for burns conducted at these code values. As the code nears the upper half of this class, more attention should be paid to guideline III.

III. Drought Codes (DC) Greater than 500 (SMI less than 230):

Organic layers in the stand will certainly be much drier than in the slash; vertical reversals of moisture will most likely be present. All proposed burns should be considered with extreme care and only those areas that pose no peripheral problems should be ignited. No areas should be ignited if there is any indication of a continuing drying trend following the burn. Mop-up and control should be immediate and in force. Spot fires in adjacent stands should be extinguished promptly. The probability of exceptionally high costs must be anticipated.

CONCLUSION AND RECOMMENDATION

Experience has shown the Stored Moisture Index to be a reliable guide for determining the prescribed burning policies for a particular season's burning program. The results of this study provide evidence that these guides were well-founded and that there was cause for alarm during the 1969 burning season in the area of the Sooke Combined Fire

Organization.

Weather stations should be located to sample both sides of known precipitation gradients and the Stored Moisture Index or its equivalent calculated to avoid needless expenditure or lost burning opportunities.

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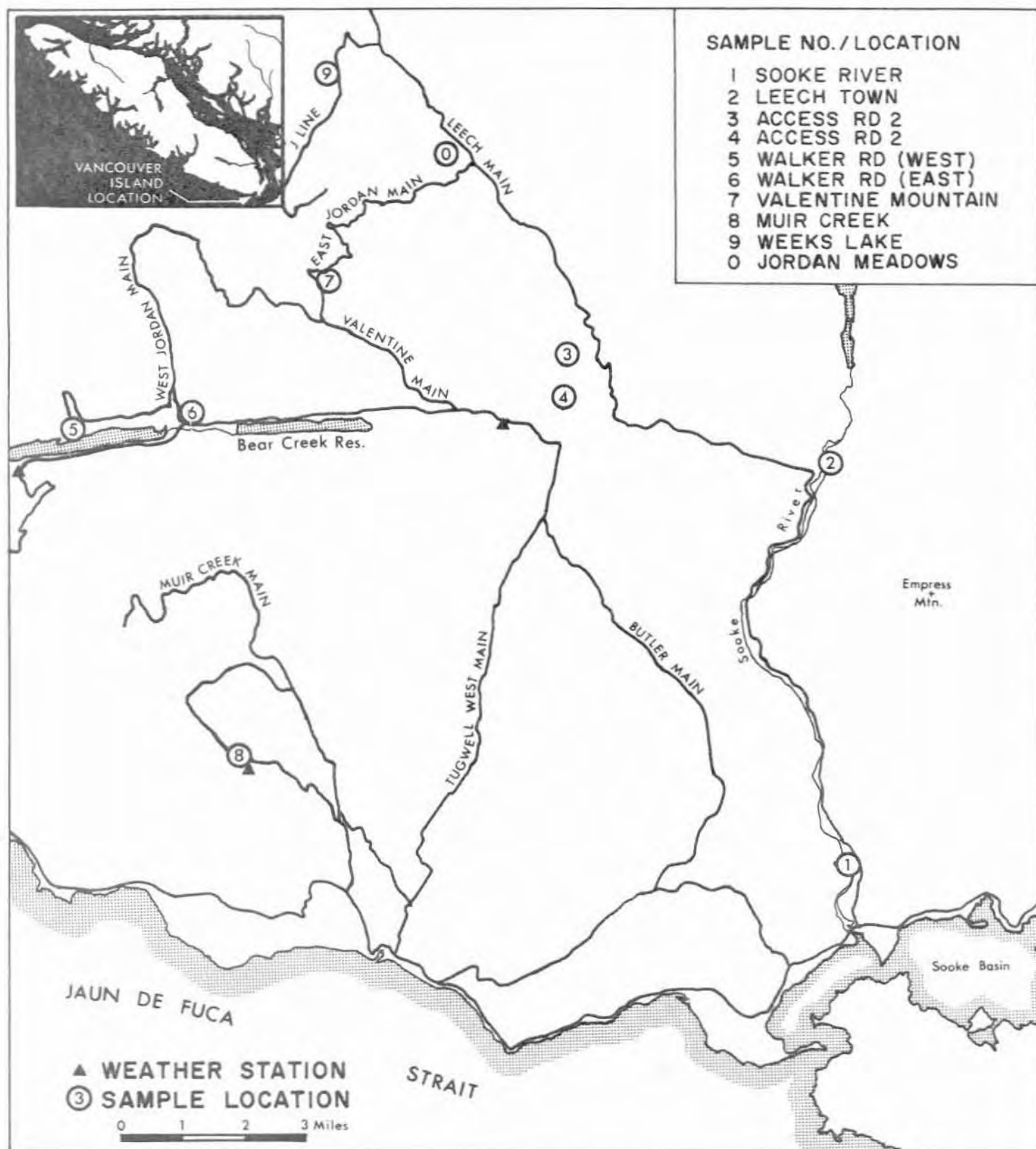


Fig. 1 Location of sample points and weather stations on area of Sooke combined fire organization.

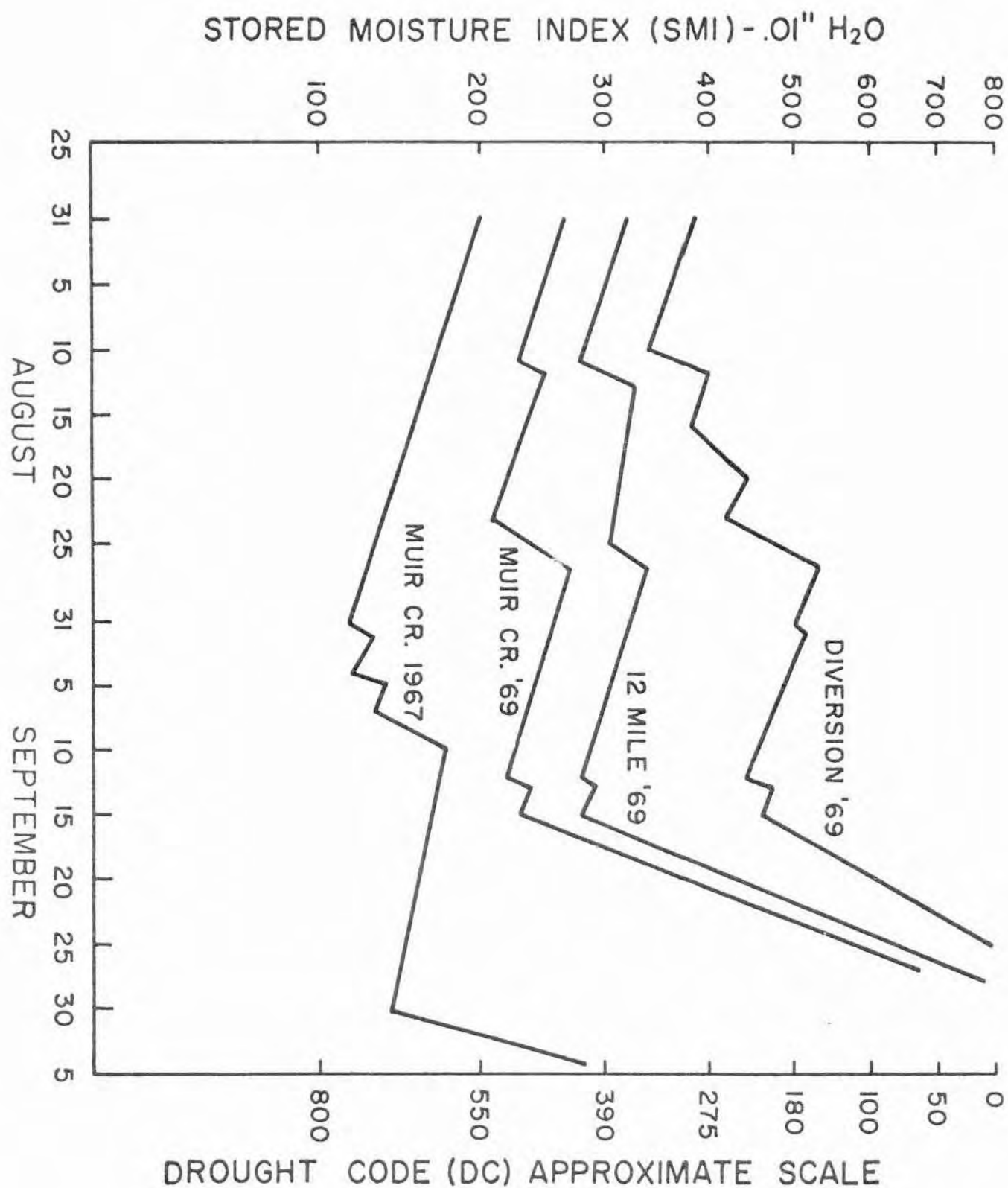


Fig. 2 Stored Moisture Index (SMI) and approximately scaled Drought Code (DC) from Fire Weather Index (FWI) for selected stations for August and September of 1967 and 1969.

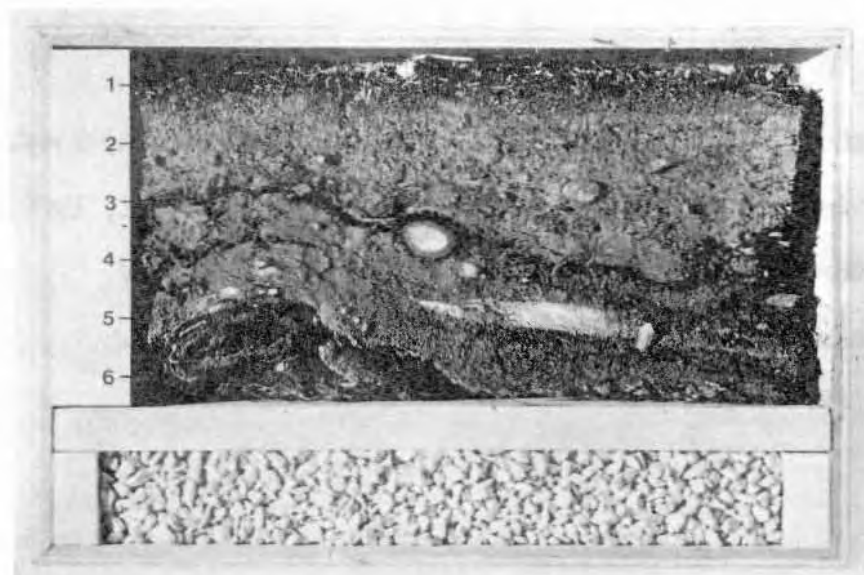


Fig. 3 Cross section of upper portion of typical organic layer showing rooting zone and portion of bottom layer composed of voids and rotting wood (lower left).

Fig. 4 Moisture profiles at locations 3 and 4 on Sept. 10, 1969.

Fig. 5 Moisture profiles at locations 5 and 6 on Sept. 11, 1969.

Fig. 6 Moisture profiles at location 7 on Sept. 11, 1969.

Fig. 7 Moisture profiles at location 8 on Sept. 11, 1969.

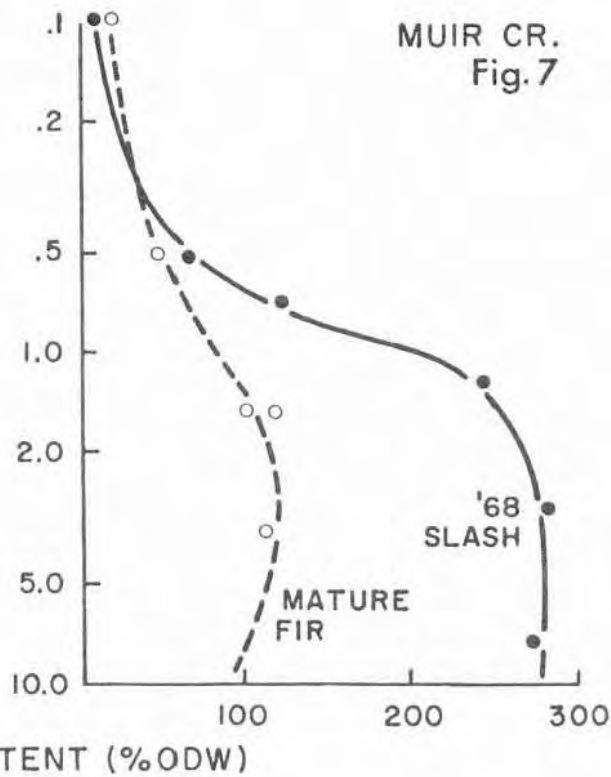
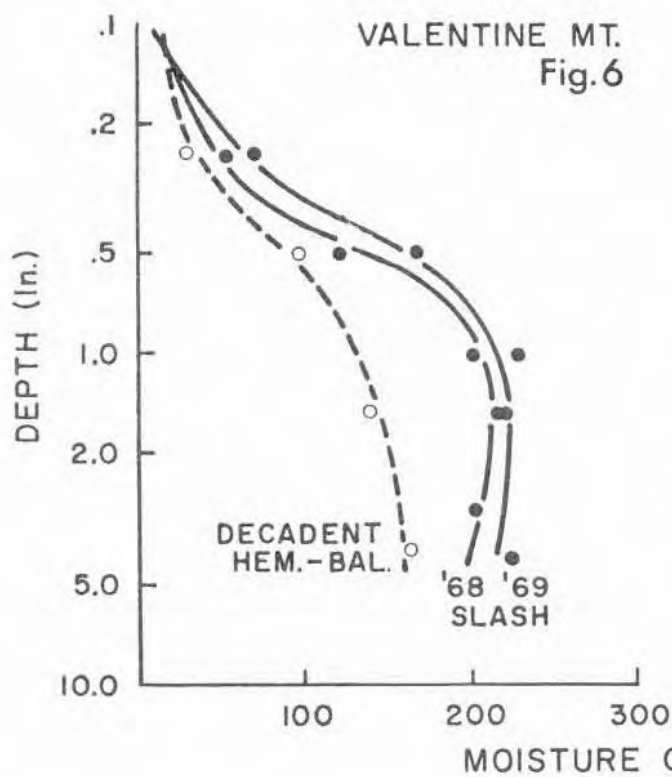
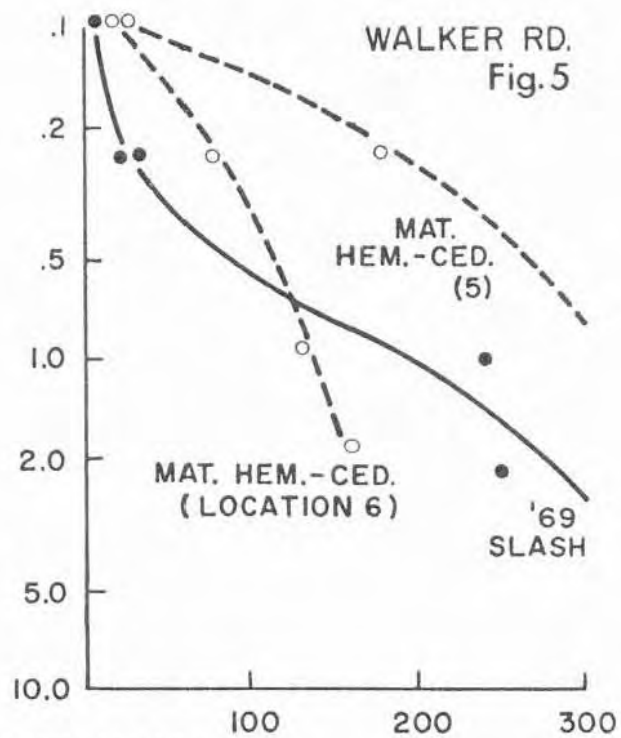
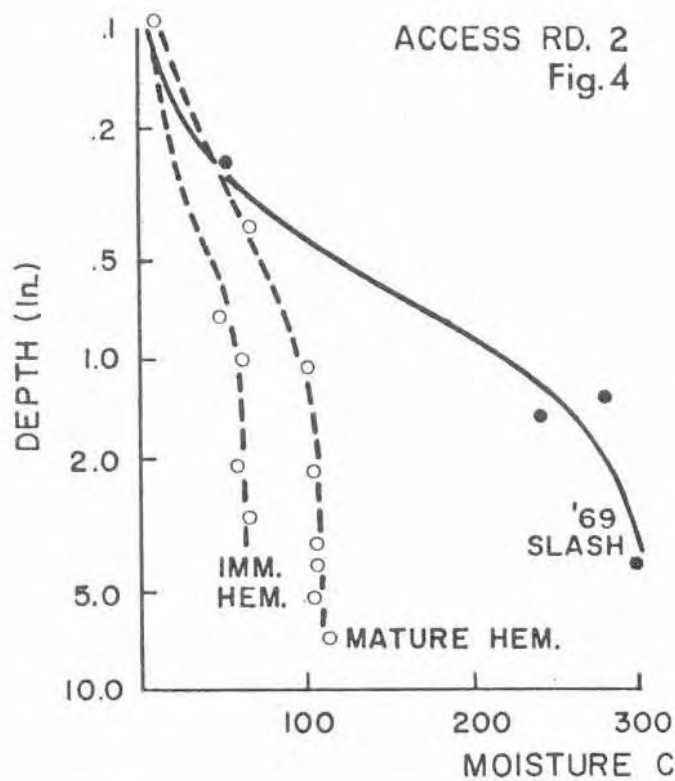
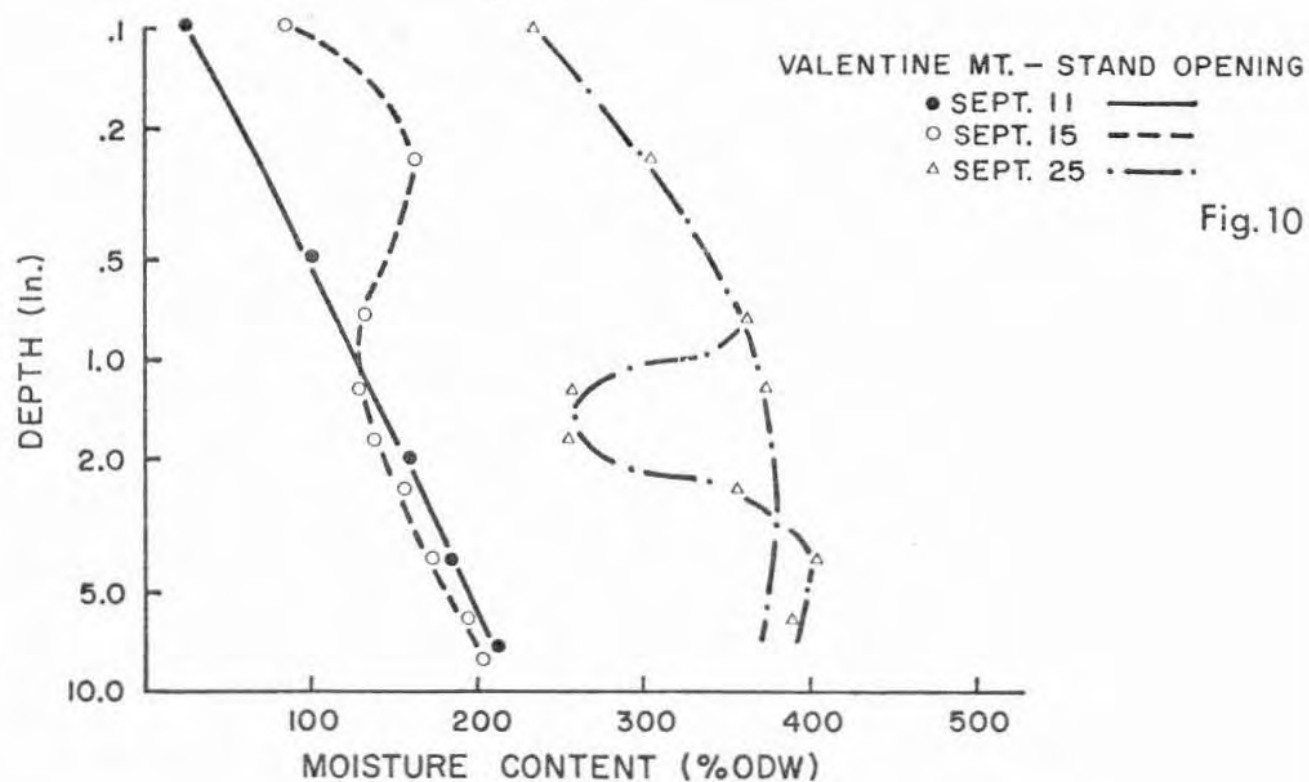
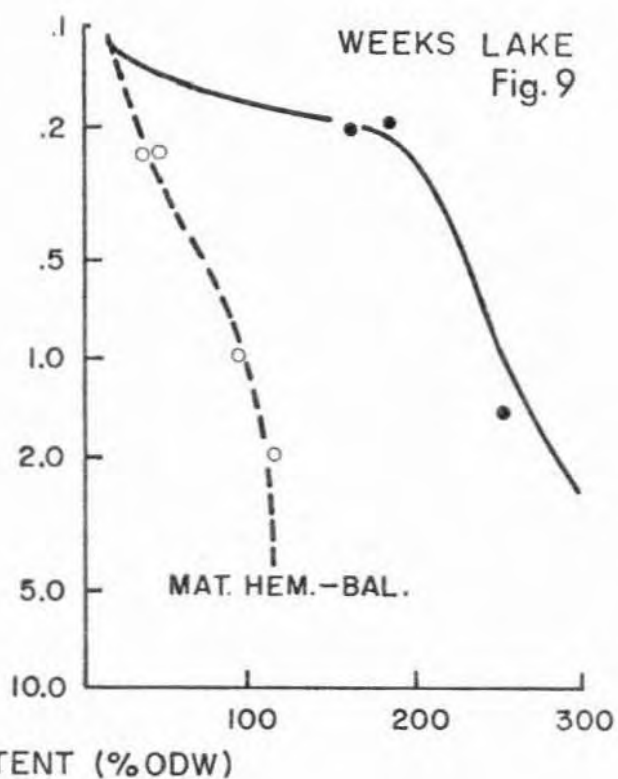
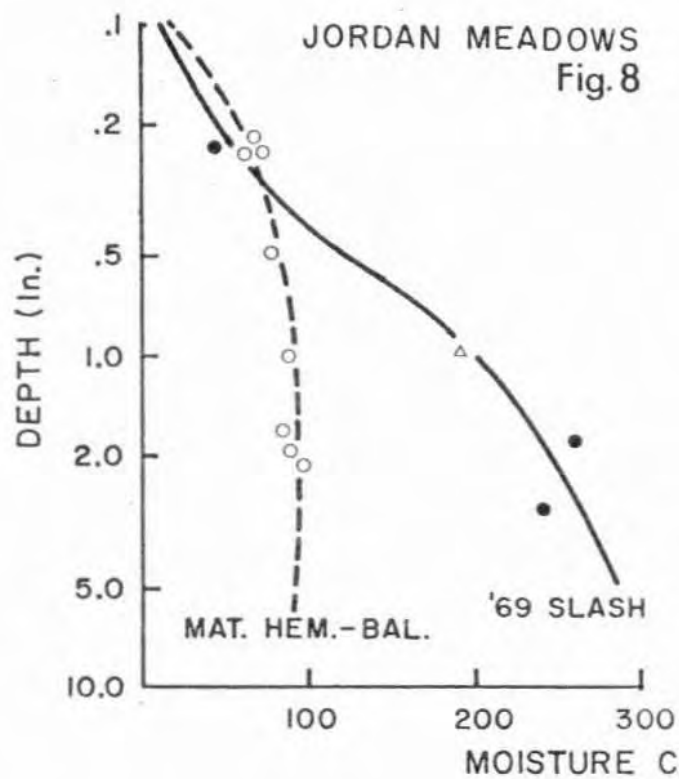
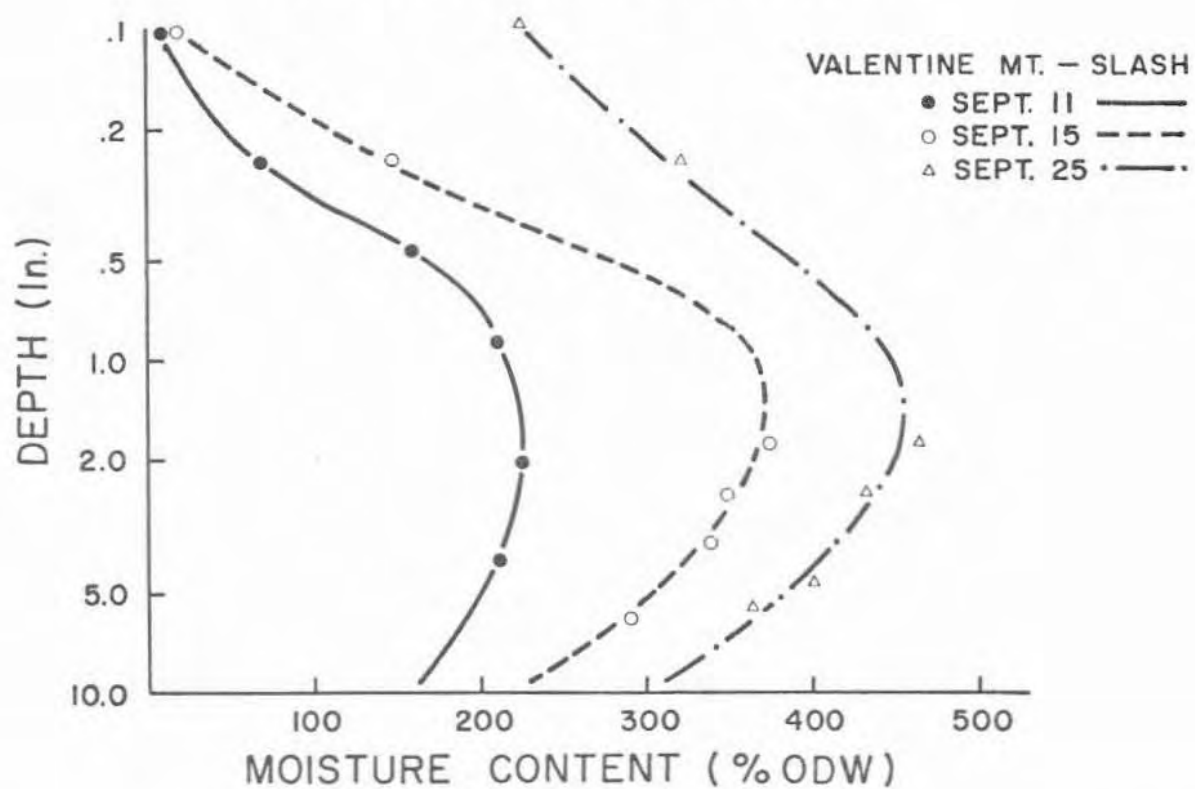
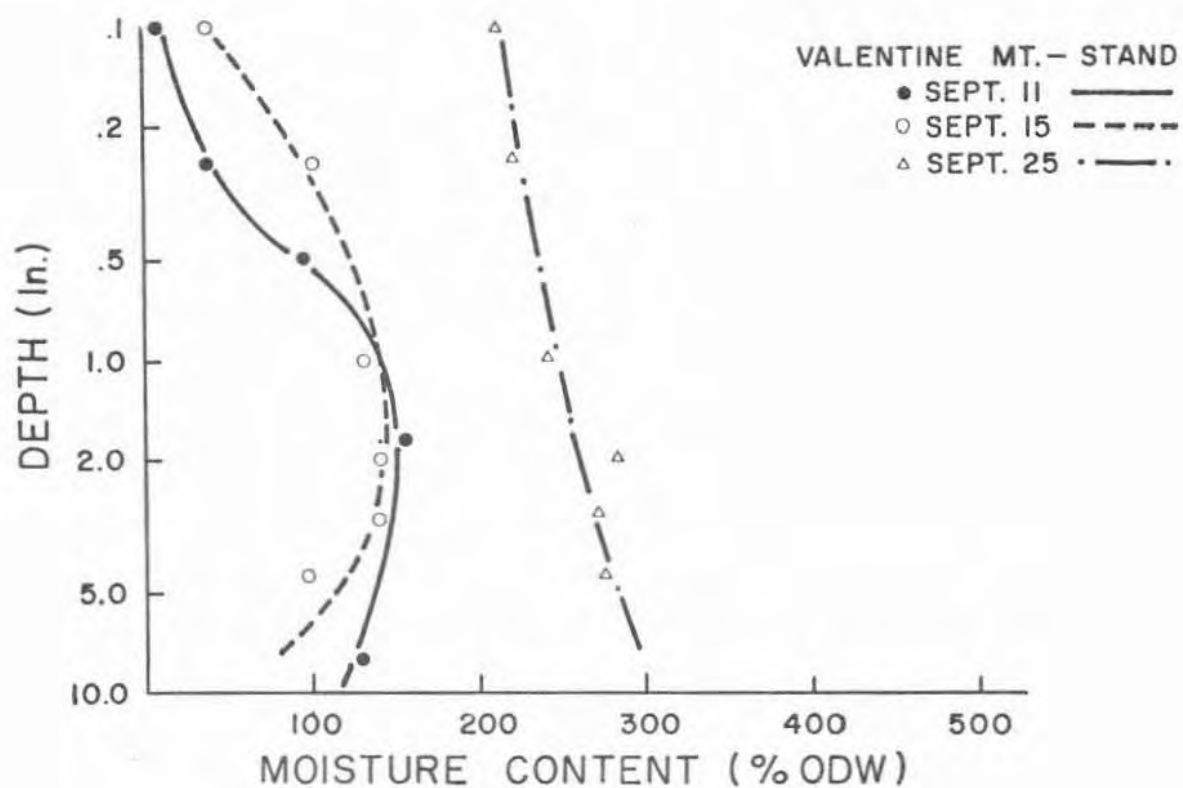


Fig. 8 Moisture profiles at location 9 on Sept. 12, 1969.

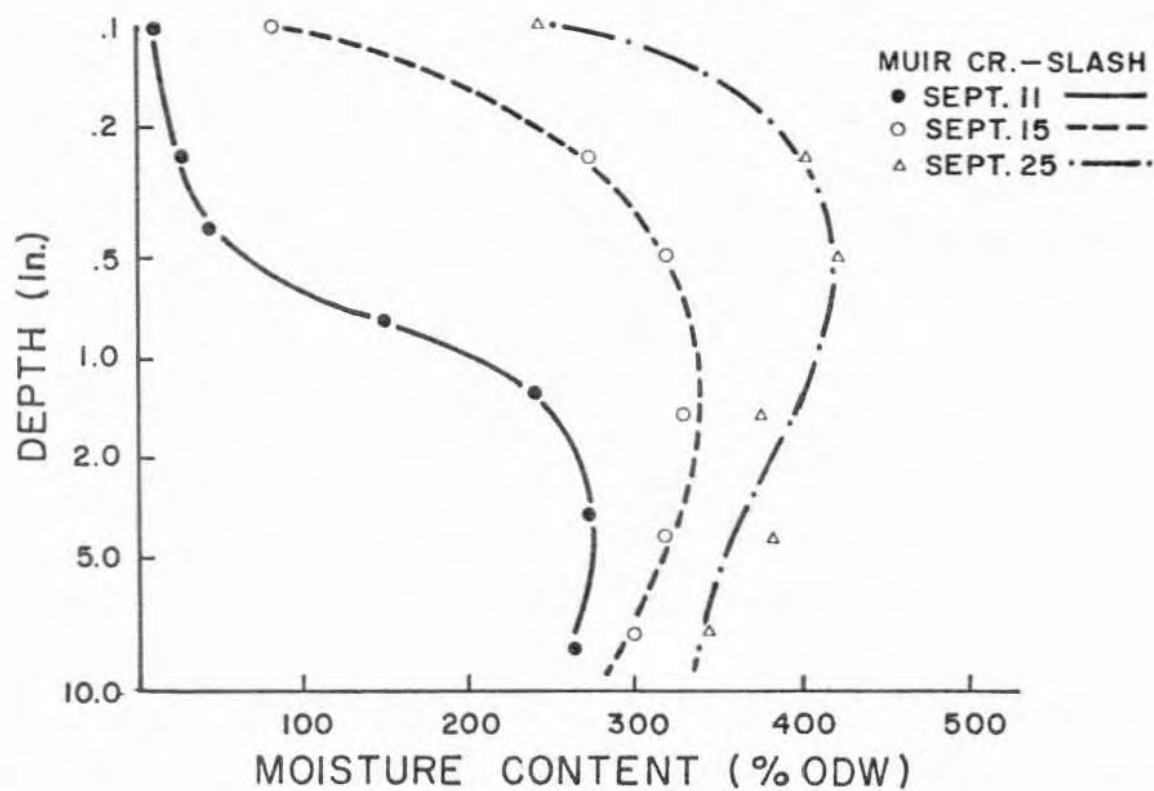
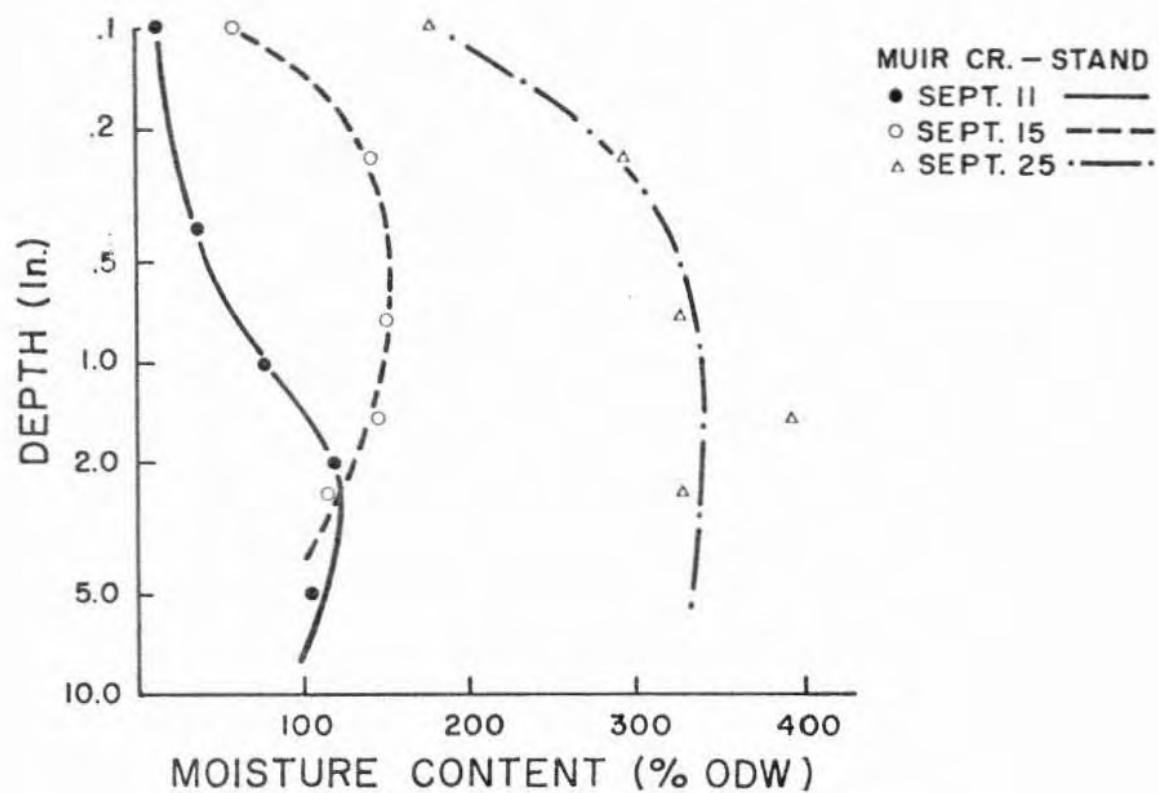
Fig. 9 Moisture profiles at location 10 on Sept. 12, 1969.

Fig. 10 Effect of rainfall on moisture profiles at location 7 in a stand opening.





Figs. 11 and 12 Effect of rainfall on moisture profiles at location 7 in the stand (top) and in the slash (bottom).



Figs. 13 and 14 Effect of rainfall on moisture profiles at location 8 in the stand (top) and in the slash (bottom).

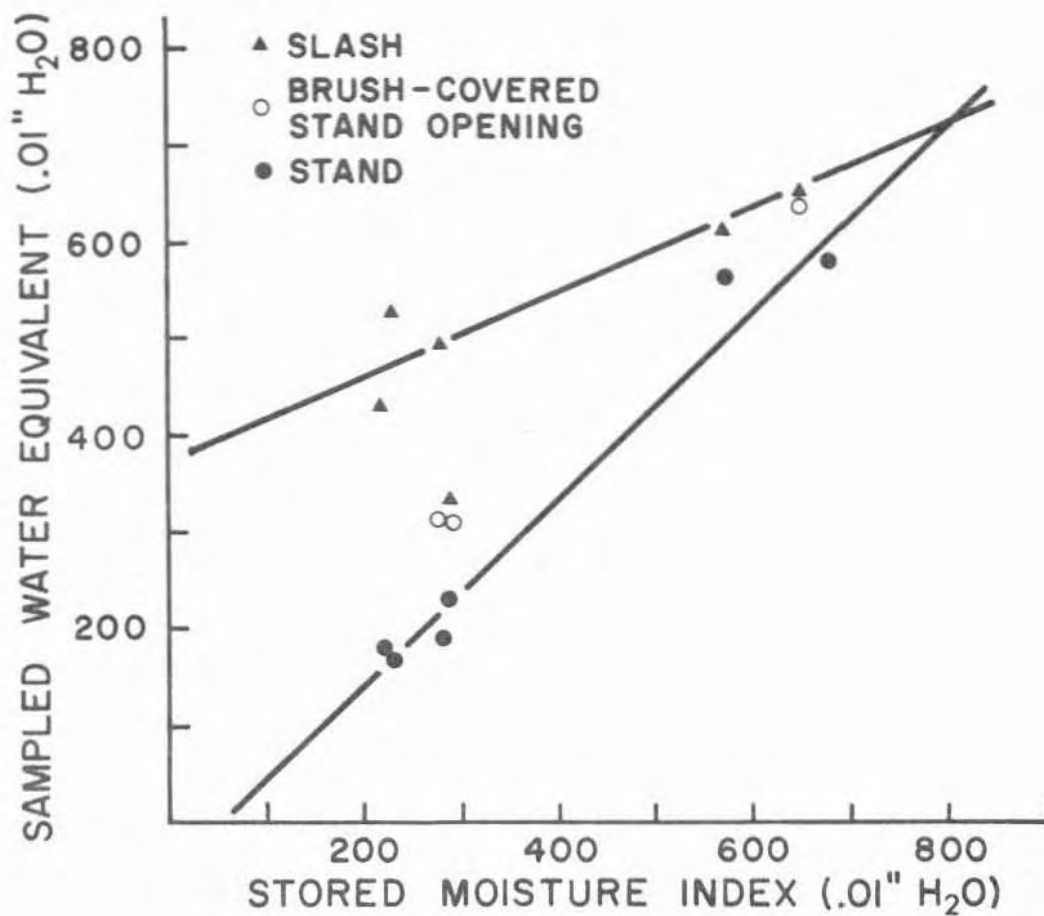
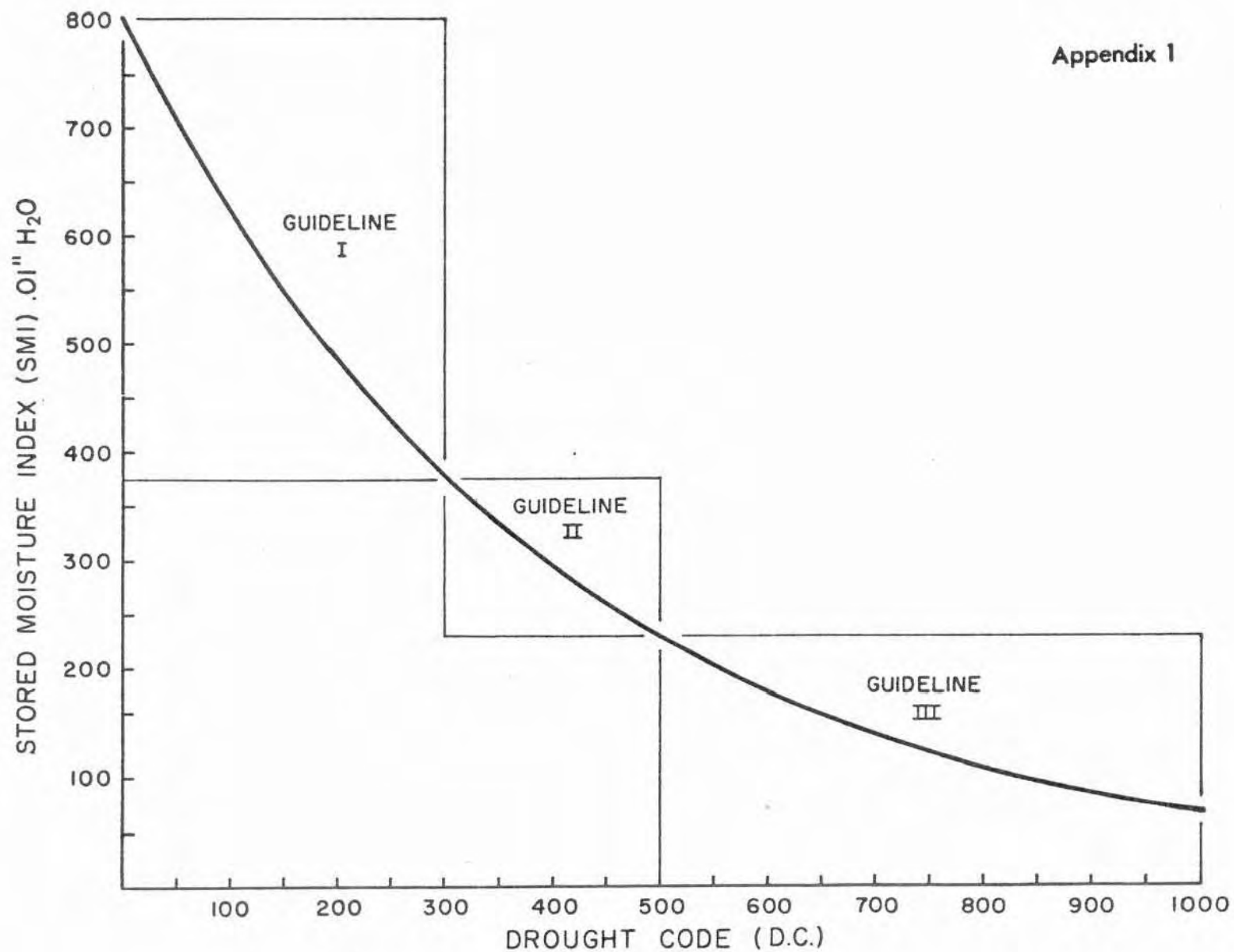


Fig. 15 Relation of actual water equivalents in the organic layer under a stand, in a brush-covered stand opening, and in a slash area, compared with water equivalents indicated by the stored moisture index.

Appendix 1



Stored moisture index and drought conversion curve showing guideline zones.