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Title: THE ROLE OF SOIL-WATER DEPLETION AND PLANT-MOISTURE STRESS IN SOIL CLASSIFICATION AND CAMBIAL ACTIVITY IN DOUGLAS-FIR

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Gerald H. Simonson

Relationships between soil-water stress and plant-moisture stress were studied with respect to soil classification and cambial activity in Douglas-fir.

The study sites were forested with Douglas-fir and located in McDonald Forest and near Marys Peak in the Oregon Coast Range. Soil-water depletion was followed by the use of gypsum blocks on sites representing seven soil series and one soil phase. Plant-moisture stress was determined by a pressure bomb and recorded in conjunction with the soil-water depletion throughout the growing season. Cambial activity of a Douglas-fir tree growing on each study site was also recorded throughout the growing season. Summer soil temperatures were measured at a depth of 50 cm. Moisture tensions and bulk density for each horizon of each soil were determined in the laboratory.

Dixonville (shallow variant), Jory (west slope), Nekia, and Jory (north slope) soils were located in McDonald Forest and had a soil-water stress of 15 bars for at least 60 consecutive days within the soil-moisture control section. Current and past weather records show that this stress will occur in at least seven out of ten years. These soils are classified as xeric-mesic.

Blachly, Kilchis, Klickitat, and Hembre soils were located in the vicinity of Marys Peak and had soil-water stresses of 15 bars ranging from 21 to 47 consecutive days within the soil-moisture control section. Current and past weather records show that these soils will not develop a 15 bar stress for 60 consecutive days in seven out of ten years. Therefore, they are not xeric. The term moist-mesic is used to define such soils.

Difference in elevation within a local area is not a sufficient indicator by itself to separate the xeric and non-xeric zones.

Plant-moisture stress cannot be used to indicate soil-water stress for the purpose of soil classification. Some trees evidently obtain water from spaces within the fractured bedrock. This water source is not defined in the soil classification scheme.

There was a highly significant difference in plant-moisture stress between the study trees growing in the xeric-mesic zone and moist-mesic zone at the time of the springwood-summerwood transition. Trees in the two zones showed large differences in plant-moisture stress at the time of dormancy. In both cases, trees growing in the xeric-mesic zone had higher stresses than trees growing in the moist-mesic zone.

There were very large differences between the xeric-mesic and moist-mesic zones in the percent of available water used from the upper one-third of the soil profile at the time the trees stopped producing springwood. Large differences in the percent of available water used from the entire profile occurred between soils in the two zones at the time the trees became dormant. At both transition and dormancy, more available water was depleted from the soils in the xeric-mesic zone than the moist-mesic zone.

Trees in the xeric-mesic zone produced springwood a greater number of days than the trees growing in the moist-mesic zone without necessarily producing more springwood. Trees in the xeric-mesic zone grew an average of 27 more days than trees in the moist-mesic zone without necessarily producing more total wood.

The Role of Soil-Water Depletion and Plant-Moisture Stress in Soil Classification and Cambial Activity of Douglas-Fir

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THE ROLE OF SOIL-WATER DEPLETION AND PLANT-MOISTURE STRESS IN SOIL CLASSIFICATION AND CAMBIAL ACTIVITY IN DOUGLAS-FIR

INTRODUCTION

This investigation was initiated to study the role of soil-water depletion and plant-moisture stress in soil classification and cambial activity in Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco). The study sites were located on seven soil series and one soil phase in western Oregon's Coast Range mountains.

Numerous studies have been conducted upon plant growth as affected by soil and plant-moisture stresses. However, none have been conducted which related the soil-water regime of contrasting soils from two climatic zones as defined by soil classification to moisture stress within Douglas-fir.

Soil-water stress affects soil classification as high as the sub-order level. The U.S. Soil Conservation Service (1967) defines soils which have a soil-water stress of 15 bars for 60 consecutive days in at least seven out of ten years within the soil moisture control section[1]

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[1] The soil moisture control section was tentatively defined by an unofficial amendment to the soil classification system (U.S. Soil Conservation Service, 1968). The amendment defined the upper boundary as the depth to which the dry soil will be moistened by 2.5 cm of water within 24 hours. The lower boundary is defined as the depth to which dry soil will be moistened by 7.5 cm of water within 48 hours.

as xeric. Soils which do not have a 15 bar stress as outlined above are not xeric.

Mean annual soil temperature affects soil classification. Ranges in mean annual soil temperature have been defined by various terms. One such term is mesic. Mesic is defined by the U. S. Soil Conservation Service (1967) as a soil which has a mean annual temperature between 8°C and 15°C with the winter soil temperature being at least 5°C colder than the summer soil temperature at a depth of 50 cm.

The term xeric has a firm definition; however, a soil which is "not xeric" is not defined directly but is included in other definitions at various levels in the soil classification system.

It has proven awkward to discuss xeric vs. "not xeric" soils when "not xeric" lacks a straightforward definition. Thomas, Pomerening, and Simonson (1969) overcame this situation by using the terms xeric-mesic and moist-mesic to denote these two climatic zones. Their precedent will be followed in this dissertation.

There are not sufficient quantitative data available to differentiate these two zones in the field. The soil mapper and correlator are faced with a common problem. Where does one soil taxonomic unit stop and another begin based on the soil-water stress criterion?

Thomas *et al.* (1969) reported using indicator plants as a major aid in differentiating the xeric-mesic zone from the moist-mesic zones. This aid was utilized in selecting the study sites for this study. However, this method does not allow soils to be quantitatively classified.

Soil-water stress, unlike plant-moisture stress, is slow and cumbersome to determine. It was hypothesized that a relationship existed between soil-water stress within the soil moisture control section and plant-moisture stress. The rapid method for determining plant moisture stress by the pressure bomb (Scholander et al. 1965, and Waring and Cleary, 1967) was anticipated to give a direct value of the soil-water stress. Such a relationship would expedite soil classification in the forested regions.

No data have been published which quantitatively classifies any Oregon soil as being xeric or not being xeric. This study was designed to quantitatively classify some major soil series as being xeric or not being xeric.

Numerous articles have been published which relate site quality to available soil water; therefore, soils with low, medium, and high water holding capacities were selected from each zone. Soils from each zone ranged from shallow (less than 50 cm) to deep (greater than 100 cm). Douglas-fir trees were growing on the eight study sites. Thomas et al. (1969) showed circumstantial evidence that site quality for Douglas-fir was lower on soils occurring in the xeric-mesic zone than on morphologically similar soils occurring in the moist-mesic zone. Also, site quality was lower on shallow soils as compared to deeper soils within a given climatic zone.

The effect of soil-water depletion and plant-moisture stress upon radial growth in Douglas-fir was studied by recording the cambial activity. The springwood-summerwood transition and dormancy were the two points of interest. Kraus and Spurr (1961) established the springwood-summerwood transition in Pinus resinosa to be when the soil water was below 8 percent. They also showed that radial growth slowed rapidly after the transition. Shepherd (1964) found that mitosis ceased in Pinus radiata at the height of a drought.

The portions of the study concerned with cambial activity were undertaken to investigate the soil-water depletion and plant-moisture stress effect upon the time at which transition and dormancy occurred in Douglas-fir. Also, it was designed to determine if soil-water depletion and plant-moisture stress were the same in each zone at the time of transition and dormancy.

The four sites within each zone were considered to be replications for soil classification objectives and for the zonal effect upon the cambial-activity x moisture-stress interactions. All eight sites were considered to be replications for soil and plant-moisture stress relationships.

DESCRIPTION OF THE STUDY AREAS

Each study site consisted of one tree on one soil series or phase. Considerable time was required to locate each study site. The soil on each site was thoroughly examined to determine if it represented the desired characteristics. A young, nonpruned, dominant tree had to be present on each site. Suitable soil-tree combinations were rare.

Xeric-Mesic Zone

Sites occurring in the xeric-mesic zone were, in part, established by using vegetative indicators as listed by Thomas et al. (1969). Other aids used were low elevation and close proximity to areas with known water deficits during the growing season (Johnsgard, 1963).

Location

The four study sites in this zone were located in McDonald State Forest. All four sites supported the vegetative species which Thomas et al. (1969) used to identify the xeric-mesic zone. Elevations ranged from 198 to 328 m. This area is close to an official weather station with a known summer water deficit.

McDonald Forest is located about five kilometers north of Corvallis, Oregon. The study sites were in Sections 16 and 4, T. 11S., R. 5W. of the Willamette meridian. Figure 1 shows the location of the

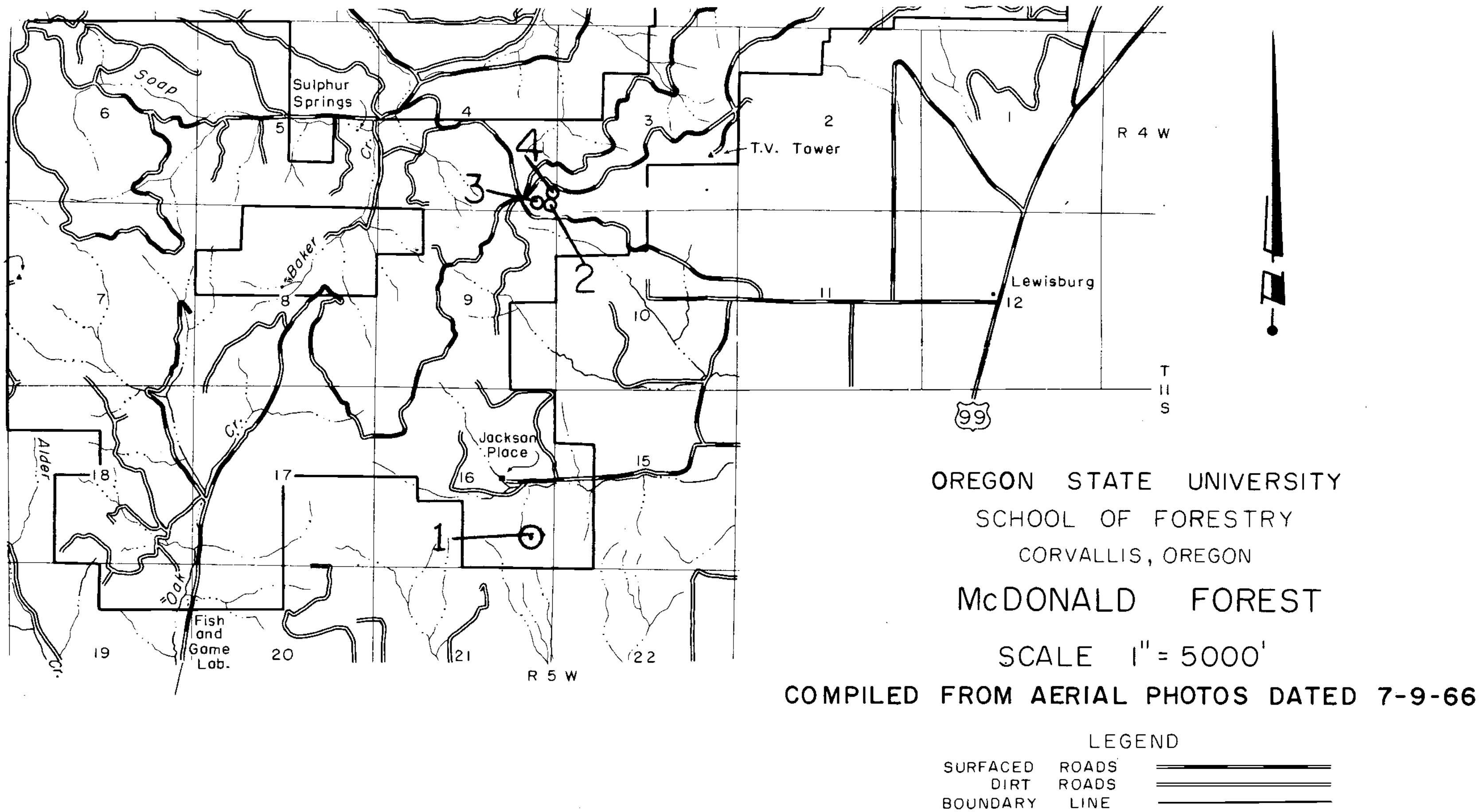

Figure 1. Location of Dixonville (s. v.) [1], Jory (w) [2], Nekia [3], and Jory (n) [4] study site.

study sites in the xeric-mesic zone. Table 1, p. 12, lists the legal locations.

Climate

A narrative climatological summary for the mid-Willamette Valley is given by Bates and Calhoun (1969). Brief exerpts of a portion of this report pertaining to the xeric-mesic zone follows:

> Marine-conditioned air masses from the Pacific Ocean leave an annual average precipitation near 100 cm on the valley floor. Most of the precipitation occurs during the winter. About seventy percent of the annual total occurs during the five months of November through March, while only five percent occurs during the three summer months.
>
> The seasonal differences in temperature are much less marked than those of precipitation. The range in mean temperatures between the coldest and warmest months is just under 30°F. The average growing season at Corvallis is 215 days.

Soils[2]

The soil series selected for the study sites were Dixonville (shallow variant), Jory, and Nekia. The Dixonville (shallow variant), hereafter called Dixonville (s. v.) is a clayey soil less than 50 cm deep. It occurred on a flat ridge top. One Jory site occurred on a

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[2] Detailed soil descriptions are given in Appendix A.

ridge top with a western aspect. It is hereafter referred to as Jory (w). The next site met the depth criterion for the Jory series (100 cm) adjacent to the site. . However, the average solum depth around the tree studied was 98 cm. Therefore, the study site meets the depth requirement for the Nekia series (<100 cm). The Nekia site had a western aspect and occurred on the same ridge top as Jory (w). The second Jory site had a northern aspect and occurred on a sideslope. It is hereafter referred to as Jory (n).

Elevations for each study site are as follows:

Dixonville (s. v.)	198 meters
Jory (w)	328 meters
Nekia	320 meters
Jory (n)	290 meters

Dixonville (s. v.) soils are members of the fine, mixed, mesic family of Lithic Ultic Argixerolls. These well drained soils have a very dark, grayish browh clay A horizon and very dark brown clay Bt horizons. The upper solum is neutral and the lower solum is slightly acid. The Dixonville (s. v.) soil for this study was derived from basic igneous rock. The solum is less than 50 cm thick. The Dixonville (s. v.) soil is underlain by saprolite.

Jory (w) and (n) soils are members of the clayey, mixed, mesic family of the Xeric Haplohumults. These well drained soils have thick granular dark reddish brown silty clay loam A horizons and thick dark red clay Bt horizons. The upper sola are medium acid and the lower sola are strongly acid. The Jory soils in this study were derived from basic igneous rock. The sola are greater than 100 cm thick. The Jory (w) soil is underlain by fractured rock. The Jory (n) soil is underlain by saprolite.

Nekia soils are members of the clayey, mixed, mesic family of the Xeric Haplohumults. These well drained soils have dark reddish brown granular silty clay loam A horizons and dark red clayey Bt horizons. The solum is between 50 and 100 cm thick. The solum is slightly acid in the surface grading to strongly acid in the lower B3t horizon. The Nekia soil in this study was derived from basic igneous rock. The Nekia soil is underlain by saprolite.

Moist-Mesic Zone

Sites occurring in the moist-mesic zone were selected by using vegetative indicators as listed by Thomas *et al.* (1969). Climatological data from other areas in the Willamette Valley (Johnsgard, 1963) were also utilized.

Location

The study sites were located in the Coast Range mountains and were adjacent to the Marys Peak road in Sections 2, and 3, T. 13S.,

R. 7W. of the Willamette Meridian. Marys Peak road leaves Highway 34 about 11 kilometers west of Philomath, Oregon.

Figure 2 shows the location of the study sites in the moist-mesic zone. Table 1 lists the legal locations.

Climate

Excerpts from the narrative climatological summary given by Bates and Calhoun (1969) which pertain to the moist-mesic zone are as follows:

> The usual movement of very moist maritime air masses from the Pacific Ocean inland over the Coast Range produces near its crest some of the heaviest yearly precipitation (nearly all rain) in the United States. An annual total of almost 430 cm has been recorded. From the ridge crest of the Coast Range, approximately 915 meters above sea level, there is a gradual decrease of rainfall downslope to the Willamette Valley floor. There the precipitation is about 100 cm. Most of the precipitation occurs during the winter.

The average annual precipitation at Valsetz, Oregon (Johnsgard, 1963) is 312 cm; however, there is a precipitation deficit during the summer months. Valsetz is located in the Coast Range mountains approximately 40 kilometers north of the study sites at an elevation of 350 meters. The average annual temperature is 10^{o}C. The average growing season is 160 days. The study sites have less precipitation than Valsetz but considerably more than the mid-Willamette

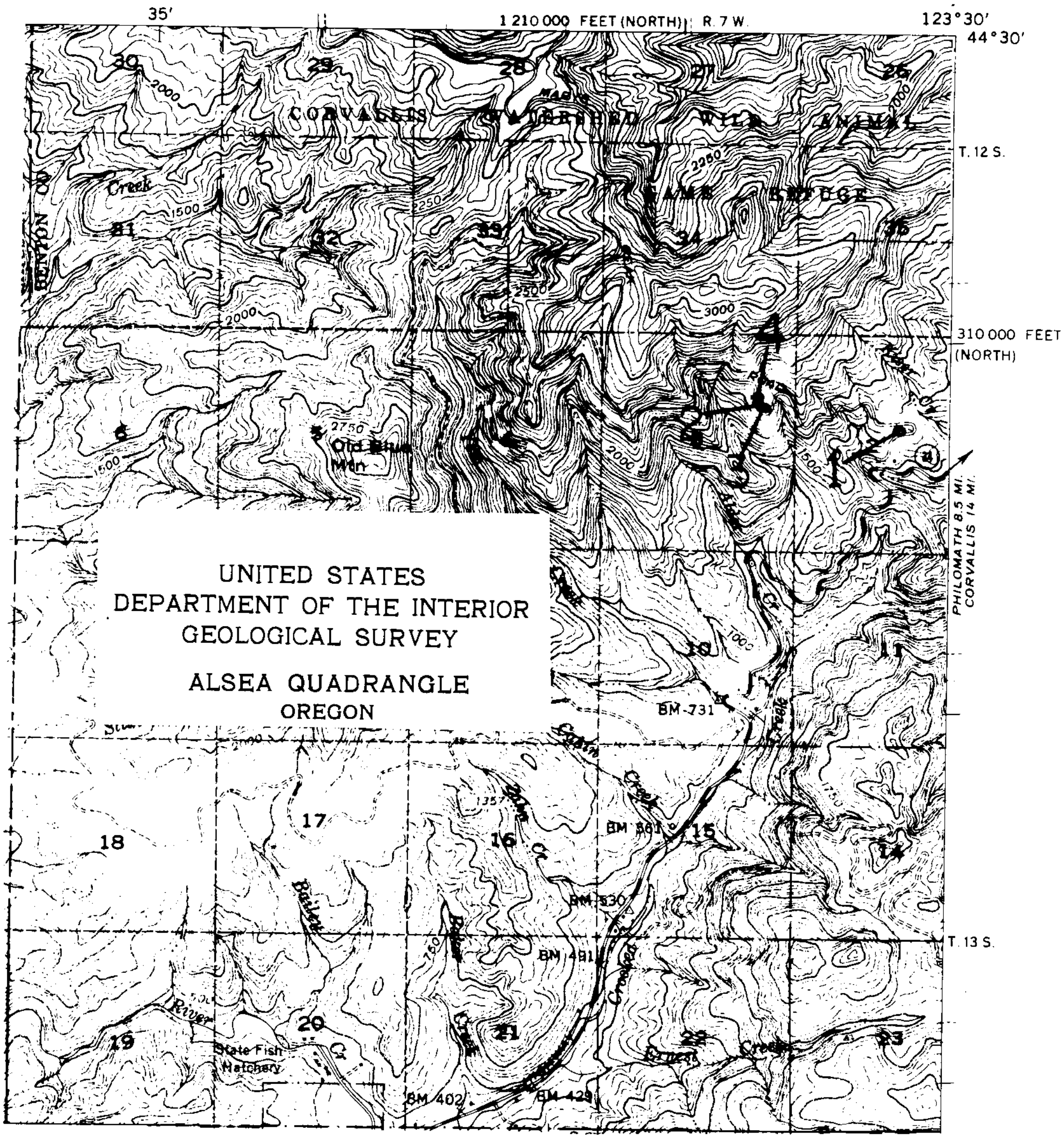

Figure 2. Location of Blachly [1], Kilchis [2], Klickitat [3], and Hembre [4] study sites.

Table 1. Location of study sites

Study sites by zone and soil series	Aspect	Elevation	General area	Location
Xeric-Mesic Zone		Meters		
Dixonville (Shallow Variant)	level	198	McDonald Forest	On flat ridge top north of power line. SE 1/4, SE 1/4, Sec. 16, T.11S., R.5W.
Jory (w)	west	328	McDonald Forest	On west facing ridge top approximately 60 m. above road. SE 1/4, SE 1/4, SE 1/4, Sec. 4, T.11S., R.5W.
Nekia	west	320	McDonald Forest	On west facing ridge top approximately 52 m. above road. SE 1/4, SE 1/4 SE 1/4, Sec. 4, T.11S, R.5W.
Jory (n)	north	290	McDonald Forest	Approximately 9 m.. above road. NE 1/4, SE 1/4, SE 1/4, Sec. 4, T.11S., R.5W.
Moist-Mesic Zone				
Blachly	south	457	Marys Peak Road	Between F.A.A. shed and lower road. SW 1/4, SW 1/4, NE 1/4, Sec. 2, T. 13S., R.7W.
Kilchis	south	625	Marys Peak Road	On ridge nose 10 m. above road. NW 1/4, SE 1/4, NE 1/4, Sec. 3, T. 13S., R.7W.
Klickitat	south	626	Marys Peak Road	On ridge noise 11 m. above road. NW 1/4, SE 1/4, NE 1/4, Sec. 3, T.13S., R.7W.
Hembre	southwest	630	Marys Peak Road	On side slope 8 m. above road. NW 1/4, SE 1/4, NE 1/4, Sec. 3, T. 13S., R.7W.

Valley (Tables 4 and 5).

Soils[3]

The soil series selected for the study sites in the moist-mesic zone were Blachly, Kilchis, Klickitat, and Hembre. The Blachly site occurred on a sideslope with a southern aspect. The Kilchis and Klickitat sites occurred on a spur ridge nose with a southern aspect. The Hembre soil occurred on a sideslope with a southwestern aspect.

Elevations for each study site are as follows:

Blachly	457 meters
Kilchis	625 meters
Klickitat	626 meters
Hembre	630 meters

Blachly soils are members of the fine, mixed, mesic family of Typic Haplumbrepts. These well drained soils have dark red granular clay loam A horizons and red silty clay B horizons. The upper solum is medium acid. The lower solum is very strongly acid. The Blachly soil is underlain by saprolite.

Kilchis soils are members of the loamy-skeletal, mixed, mesic family of Lithic Haplumbrepts. These well drained, shallow, stony

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[3] Detailed soil descriptions are given in Appendix A.

soils have dark reddish brown very gravelly loam A horizons and dark reddish brown very stony loam B horizons. The upper solum is medium acid and grades to strongly acid in the lower solum. Each horizon was screened for coarse fragment content. The visual estimation of the volume of coarse fragments screened from each horizon is as follows:

A1	0-5 cm	65% gravel
A12	5-20 cm	40% gravel + 25% stones
B1	20-35 cm	25% gravel + 45% stones
B2	35-45 cm	25% gravel + 35% stones

The soil lies on fractured basic igneous rock and is less than 50 cm deep.

Klickitat soils are members of the loamy-skeletal, mixed, mesic family of Typic Haplumbrepts. These well drained soils have dark reddish brown very gravelly loam A horizons and dark reddish brown very gravelly loam B horizons. The solum is medium acid. Each horizon was screened for coarse fragment content. The visual estimation of the volume of coarse fragments screened from each horizon is as follows:

A1	0-5 cm	60% gravel
A12	5-22 cm	55% gravel
B2	22-40 cm	60% gravel
B3	40-62 cm	50% gravel + 20% stones

The soil lies on fractured basic igneous rock and is greater than 50 cm deep.

Hembre soils are members of the fine-loamy, mixed, mesic family of Typic Haplumbrepts. These well drained soils have dark reddish brown loamy A horizons and yellowish red clay loam B horizons. The upper solum is medium acid and grades to strongly acid in the lower solum. The soil is underlain by severely weathered basic igneous rock.

EXPERIMENTAL METHODS

Field Methods

Eight study sites were chosen. Four sites occurred in the xeric-mesic zone and four occurred in the moist-mesic zone. Presence of a young, healthy stand of Douglas-fir was a basic criterion for each site. The final tree selected for each site was dominant in an open stand. An open-grown tree was essential because an abundance of branches near the ground was necessary to repeatedly measure the plant moisture stress. Trees selected ranged in age from 13 to 28 years.

Preliminary soil borings were made around each tree on each site to assure it was growing on the desired soil series. Soils selected from each zone represented low, medium, and high moisture holding capacities.

Soil-Water Regime

The period of interest for the soil-water regime study was from the time the trees on each site went from bud swell to dormancy. Bud swell in both zones begins each year with the soil at field capacity. The soil-water regime is then dependent on precipitation from this point forward. Johnsgard (1963) showed that at Corvallis there is an average cumulative moisture surplus of 62.5 cm at the end of

March. This is in the xeric-mesic zone. April has neither a deficit nor a surplus. Therefore, there was winter precipitation in excess of what is needed to fill a 2 meter thick soil profile to field capacity based on a 21 year average. A 3.6 cm average moisture deficit occurred at the end of May. Buds on all trees studied in the xeric-mesic zone had begun to swell by April 16, 1969.

Johnsgard (1963) calculated that Valsetz, Oregon has a 267 cm average cumulative moisture surplus at the end of May. Therefore, precipitation is far in excess of what is needed to bring the soils to field capacity at this period.

Buds on all trees studied in the moist-mesic zone had begun to swell by May 8, 1969.

The current year's data presented in this dissertation shows that the soils were at field capacity at the time of bud swell.

The foregoing discussion should emphasize to the reader that year after year the soils studied are at field capacity when the trees break dormancy.

Soil-water stress was followed by utilizing the Delmhorst cylindrical gypsum blocks[4]. Resistance of the gypsum blocks was measured by using a modal KS Delmhorst Moisture Tester (Delmhorst Instrument Company).

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[4] Delmhorst Instrument Co., Boonton, New Jersey

Precipitation for the duration of the study period was recorded on each site by homemade gauges. The gauges were made by shaping a funnel made from aluminum foil to fit into a no. 10 tin can. Precipitation was recorded each time the sites were visited. Precipitation was measured by pouring the water from the can into a 100 ml graduate cylinder. Depth of the water in the graduate cylinder was then measured in cm. The cm of water in the cylinder were correlated to cm of precipitation by using the ratio of the surface areas of the two containers.

Gypsum blocks were chosen as the method to record the water depletion because of their availability and ease of installation in skeletal soils. Hysteresis can cause errors when gypsum blocks are used to measure moisture content (Young and Warkentin, 1966). However, they are quite satisfactory when used for a drying cycle without rapid moisture fluctuations (Gardner, 1965; Young and Warkentin, 1966).

Four or five stacks of gypsum blocks were inserted into the soil beneath the crown of each study tree. They were inserted in this general vicinity because McMinn (1963) showed that the maximum root density for a 25 year old dominant Douglas-fir tree occurred within about 1.5 m of the root stock. Blocks were not placed immediately adjacent to the stem for the purpose of measuring soil water as influenced by stem flow. Additions of water to the soil by stem flow during the growing season were considered negligible. Patric (1966) found that stem flow was always less than one percent of the rainfall in a western hemlock and Sitka spruce stand, and it took almost 1.8 cm of rain before stem flow occurred.

The replications and depths of blocks inserted under each tree are listed in Table 2.

The distribution pattern of each stack around each tree is shown in Figure 3.

The stacks around trees on the Dixonville (s.v.), Jory (w), Nekia, Jory (n), Blachly, and Hembre soils were inserted in a hole made by a soil sampler tube which had a diameter slightly larger than the gypsum blocks. The bottom block was inserted first and seated firmly with a long, small diameter rod. Increments of soil were then placed on top of the block and tamped down. Increments of soil were added and tamped until the desired depth of the next block was achieved. The next block was then inserted and the process was repeated until all the desired blocks were in place.

A soil pit had to be hand dug for each stack of blocks to be inserted around the trees on the Kilchis and Klickitat soils. The stone content in these two soils made it impossible to insert the blocks otherwise. The blocks were inserted at the desired depths in the face of the pit nearest the study tree. The pit was then filled with the excavated soil. The blocks were placed in hopes of

Table 2. Number of replications and depths of gypsum blocks by soil series

Soil series	No. of Replications	Block depths (cm)	Total blocks per site
Dixonville (s. v.)	5	8, 18, 25, 51,* 76*	25
Jory (w)	5	8, 18, 25, 51, 76, 102, 117, 140, 165	45
Nekia	5	8, 18, 25, 51, 76, 102,* 140*	35
Jory (n)	4	8, 18, 25, 51, 76, 102, 152*	28
Blachly	4	8, 18, 25, 51, 76, 102, 152, 191*	32
Kilchis	5	8, 18, 25, 50	20
Klickitat	4	8, 18, 25, 51, 76, 97	24
Hembre	5	8, 18, 25, 51, 76, 102, 152,* 191*	40

*Blocks at these depths were in saprolite.

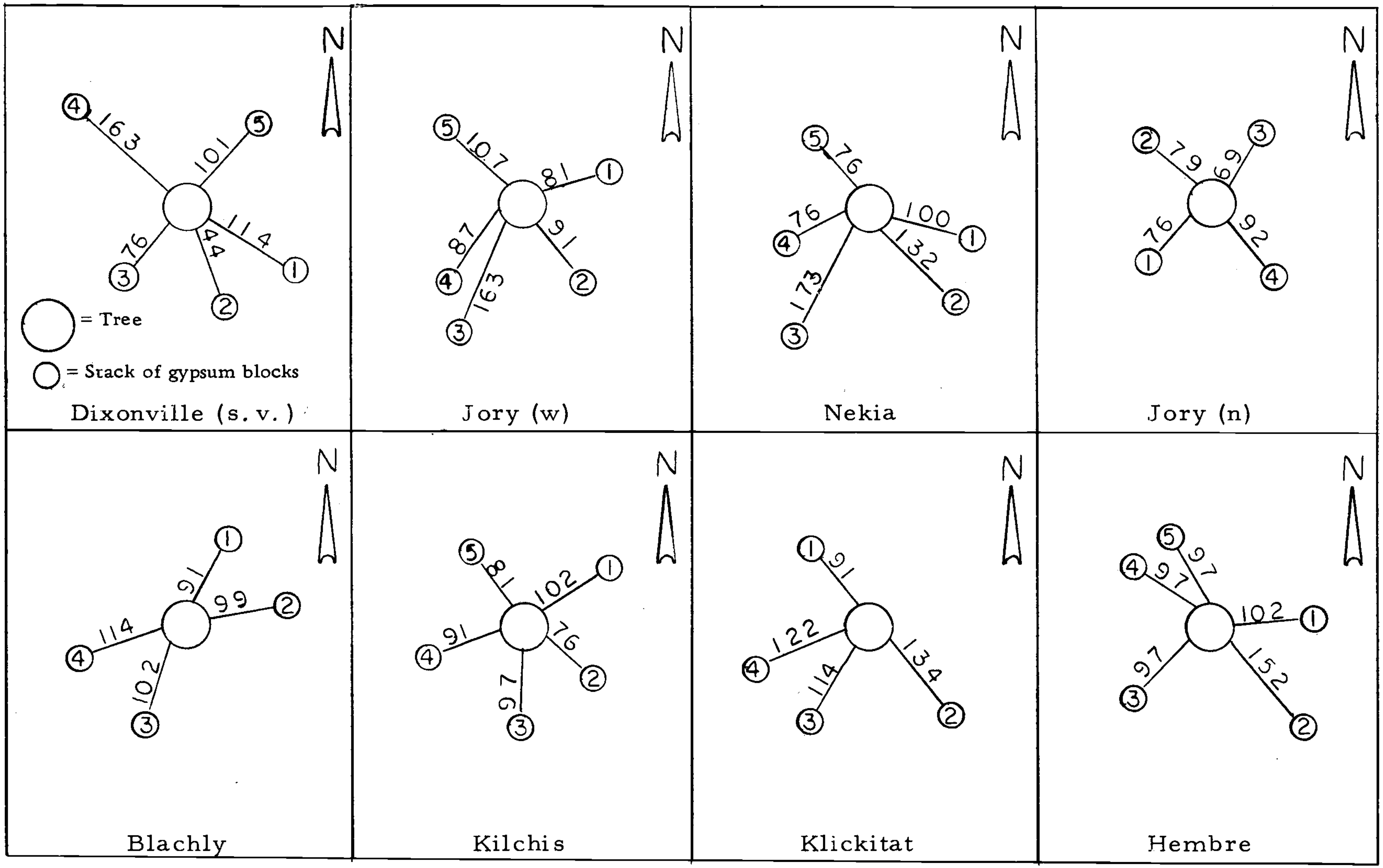

Figure 3. The direction and distance (cm) of each stack of gypsum blocks with respect to each study tree

recording a uniform depletion of soil moisture in a representative sample of the root zone. This was accomplished with surprising uniformity among the blocks within each depth replication. The only large variation among the depth replications was after rainstorms. Blocks on the windward side received more moisture than their counterparts on the leeside. This observation is consistent with some moisture interception studies in coniferous forests (McMinn, 1960; Patric, 1966). The moisture conditions were again evenly distributed after a few rainless days.

Three supplementary sites were established in the moist-mesic zone for additional moisture depletion studies. These sites were chosen along an elevational gradient. Two were at lower elevations than the main study sites and one was higher. All three additional sites were under older Douglas-fir stands which had a closed canopy. Composite soil samples were periodically collected within the soil moisture control section (see footnote 1) from each additional site during the growing season. The samples were brought into the laboratory and water content was determined gravimetrically. Water content was determined under a 15 bar stress for each site. The water content from the samples could then be compared to the 15 bar water content to see if available water was present. These determinations extended the soil-water stress transect adjacent to the Marys Peak road from elevations of 214 m to 793 m. The two lower sites were on Honeygrove soils (214 and 335 m elevation) and the upper site was on Klickitat soil (793 m elevation).

Soil Temperature

The soil temperature was measured at a depth of 50 cm on each site about the middle of June, July, and August. The average of the three monthly readings gave a summer soil temperature for each site. The U. S. Soil Conservation Service (1967) defines a soil which has a mean annual temperature between 8°C and 15°C with the winter soil temperature being at least 5°C colder than the summer soil temperature at a depth of 50 cm as mesic. Temperatures were measured with a thermometer and obtained from areas without an 0 horizon.

Plant-Moisture Stress

Plant-moisture stress measurements were made with a pressure bomb as described by Scholander et al. (1965) and Waring and Cleary (1967). The measurements were made periodically on each study tree before sunrise. During the night the nontranspiring plant comes as close to equilibrium as the total moisture regime allows. Slatyer (1967) showed that the relative water content in leaves from bulrush millet remained stable before sunrise. Waring and Cleary

(1967) demonstrated that the diurnal moisture stress in Douglas-fir was lowest before 6:00 AM.

Moisture stress was recorded to the closest five pound increment and converted to bars. The negative sign has been omitted and the tensions are hereafter reported as bars without the negative sign.

Branches for plant-moisture stress measurements were consistently removed from the same general area of each tree about 0. 5 to 1. 5 m from the ground. Scholander (1965) reported that a gravity gradient of 0. 1 bar existed for each meter in tree height. Therefore, a difference of one meter in height could not be detected when readings were made to the closest one-third bar.

Height range for seven of the study trees was 4. 8 to 8. 6 m Table 16, p. 71). Waring and Cleary (1967) warned that when soil moisture was in critical supply, the size of the tree as an index to the depth of rooting is important. McMinn (1963) studied the root distribution in Douglas-fir and showed that the root development proceeded with age. The range in size and age of the study trees was not great. Ages of seven of the study trees ranged from 13 to 20 years old. The tree on the Klickitat soil was 28 years old and 11. 1 m tall.

Cambial Activity

Cambial activity of each study tree was determined throughout the growing season by periodically marking the xylem with a no. 0 insect mounting pin as described by Wolter (1968). The two points of interest were the springwood-summerwood transition and cessation of growth.

Numerous studies have shown a relationship between tree growth and moisture supply. Kraus and Spur (1961) considered the springwood-summerwood transitions in red pine complete when the radial increment slowed down. Strand (1964) reported the radial growth of Douglas-fir slowed when soil-water stress was between 2 and 5 bars. Miller (1965) concluded that the growth of *Pinus taeda* was directly proportional to water stress in the leaves. Fraser (1956) reported that *Picea glauca* and *Betula lutea* ceased radial growth early in July on dry sites and in late July on moist sites. Boggess (1953) found in *Pinus echinata* and *Quercus alba* that basal area expansion slowed when approximately one-half of the available water was depleted from the surface meter of soil. Expansion of trees ceased when three-fourths of the available water was depleted.

Height growth is affected by moisture stress as well as radial growth. Husch (1959) reported that the height growth in young *Pinus strobus* was affected more by available soil water than any other environmental factor he measured. Shoot elongation slowed early in the season on sites that had low moisture holding capacities. Wenger (1952) showed that shoot elongation in sweetgum and pine seedlings was twice as great on soils which were watered when 40% of the available water was used as compared to the soils watered when 80% of the available water was used.

Zahner (1968) reviewed the subject of water deficits and growth of trees. The reader is directed to this review for a detailed discussion.

Site Indices

Height-age ratio was established on each study tree. Height was determined by an abney level. Total age was determined by counting the annual rings at breast height and then adding the number of whorls between breast height and the ground. Site index for each study tree is shown in Table 16, p. 71 .

Sampling Methods

Soil Samples

Soil pits were dug adjacent to each study tree after the gypsum blocks were installed. Each pit was described in standard terminology of the U. S. Department of Agriculture (1951). Samples were collected, by horizon, from each pit. Clods were taken for bulk density determinations. Core samples were taken for the 0.1, 0.5, and 1.0 bar moisture tension determinations from all sites except the Kilchis and Klickitat soils. Bulk samples were collected from all sites for the 2.0, 5.0, and 15.0 bar moisture tension determinations.

Vegetation

The relative abundance of each species occurring within a 15 m radius of each study tree was recorded. Species abundance in relation to the total vegetation was estimated by visual inspection.

Laboratory Methods

Gypsum Block Calibration

Ten blocks were randomly chosen from the shipment to make a calibration curve. The blocks were placed in a bulk soil sample inside a pressure plate apparatus and saturated for 24 hours. The pressure plate apparatus had external electrical connections similar to the one described by Haise and Kelly (1946). One-tenth bar suction was exerted upon the system after the 24 hour saturation period. Resistance of the block was periodically measured. The blocks were considered to be in equilibrium when the resistance readings remained constant over a period of time. Pressure was increased to the next desired point each time equilibrium was obtained. Tanner, Abrams, and Zubriski (1949) reported that the method described above was the most versatile and rapid.

A curve (Figure 4) was constructed relating ohms to the readings obtained on the model KS soil tester. This curve was made by connecting the model KS soil tester to sources of known resistances. The principal points on this curve were the ohms recorded at each equilibrium point obtained in the pressure plate apparatus.

The curve shown in Figure 5 shows the relationship between bars and readings on the model KS soil tester. This curve was constructed by reading the known ohms at each equilibrium point (known bars of suction) directly with the model KS soil tester. Additional points were plotted by using information from the curve shown in Figure 4.

Table 3 shows the bars of suction for each five unit increment shown on the model KS soil tester galvinometer. These conversions were used to determine the bars of suction (moisture tension) for the gypsum blocks in the field.

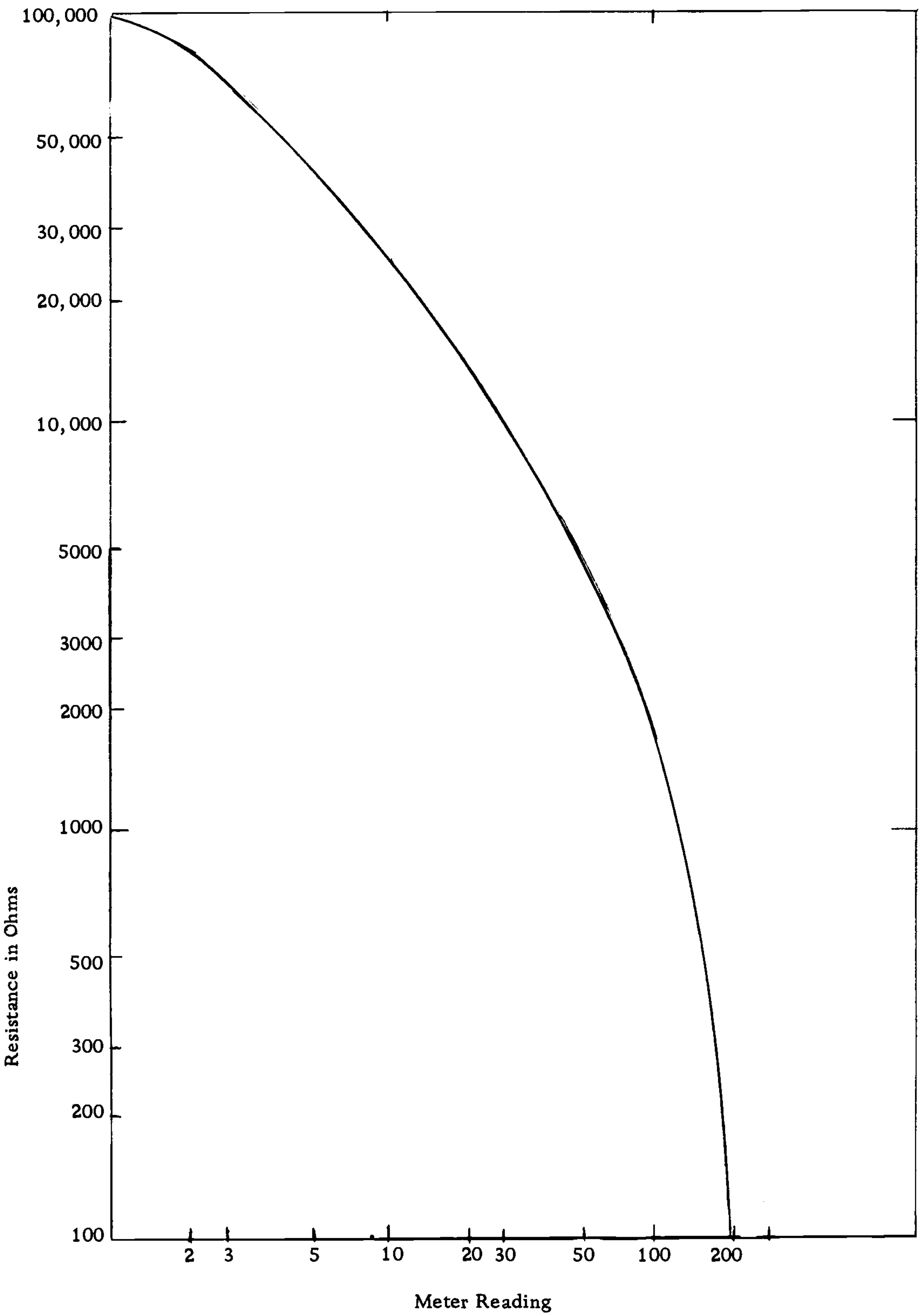

Figure 4. Relationship between resistance in ohms and reading obtained on the model KS soil moisture tester

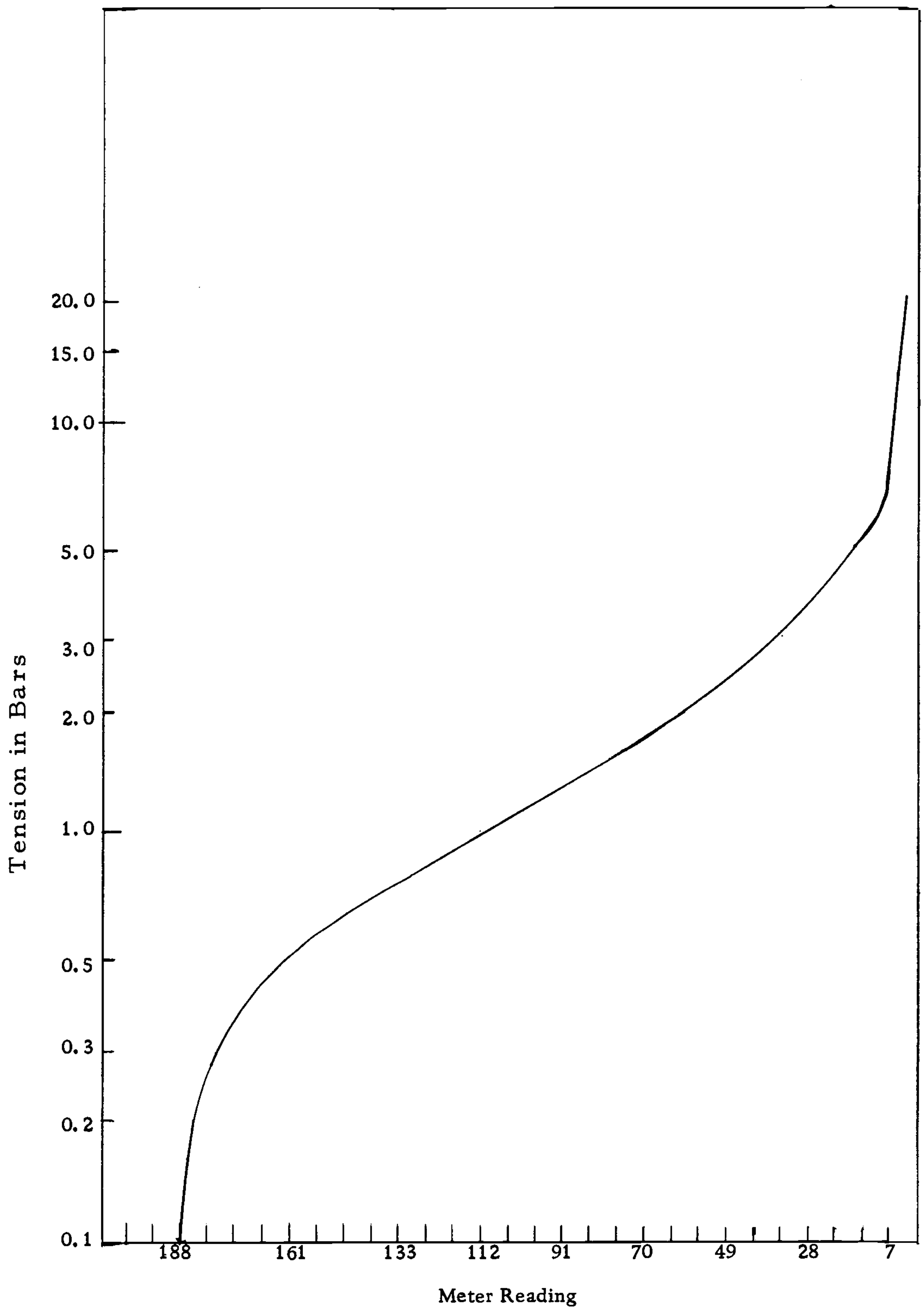

Figure 5. Curve relating readings from the model KS soil moisture tester to tensions developed in the gypsum blocks

Table 3. Correlation between readings on the model KS Delmhorst Moisture Tester and bars of tension exhibited by the Delmhorst cylindrical gypsum blocks

Meter Reading	Bars	Meter Reading	Bars	Meter Reading	Bars
0	∞	20	4.3	105	1.1
1		25	3.7	110	1.0
		30	3.4	115	1.0
3	32	35	3.1	120	.9
4	23	40	2.8	125	.9
5	15	45	2.5	130	.8
6	10	50	2.3	135	.8
7	6.6	55	2.2	140	.7
8	6.0	60	2.0	145	.7
9	6.3	65	1.9	150	.6
10	5.8	70	1.8	155	.6
11	5.6	75	1.7	160	.5
12	5.4	80	1.6	165	.5
13	5.2	85	1.4	170	.4
14	5.3	90	1.3	175	.4
15	5.0	95	1.2	180	.3
		100	1.2	185	.2
				188	.1
				190	0.0
				195	0.0
				200	0.0

Moisture Tension Determinations

Data relating soil-water tension to percent water were developed for all horizons except the Kilchis and Klickitat sites. The complete water regime could be studied for each site by this manner.

Moisture content at 0.1, 0.5, and 1.0 bars for each sample was determined on a porous plate apparatus (Richards, 1948). These determinations were made on undisturbed cores (diameter 5.1 cm, height 3.5 cm) which were thoroughly saturated. Several studies have shown that the release characteristic obtained on disturbed samples may vary considerably from those of undisturbed cores (Broadfoot, 1954; Elrick and Tanner, 1955; Salter and Williams, 1965). Ideally, the full water retention curve should be determined on the undisturbed cores (Salter, 1967). However, the laboratory apparatus available for tensions greater than 1 bar would not accommodate the undisturbed cores. Therefore, disturbed samples were used to determine the moisture content at 2, 5, and 15 bars on a pressure membrane apparatus similar to the one described by Richards (1947).

Elrick and Tanner (1955) found that the difference produced between core and disturbed samples was less at tensions greater than 1 bar than at tensions less than 1 bar.

A soil-moisture tension curve was constructed for each horizon because bulk density influences the moisture retention (Box and

Taylor, 1962; Hill and Summer, 1967). These curves were then used to compile the data shown in Tables 9 and 10.

Bulk Density Determinations

Bulk density for all horizons was determined by the paraffin coated clod method described in detail by Blake (1965). Bulk densities were not determined on the very gravelly or very stony Kilchis and Klickitat soils. Bulk densities from equivalent depths in the Hembre profile were used for these two soils.

Cambial Activity Determinations

The area of wood containing the insect mounting pins was chiseled from the tree September 25. This block of wood was then stored in an alcohol solution until samples for microscopic examination could be prepared.

Sample preparation and interpretations were made by Mr. Allan Doerksen of the Forest Research Laboratory, Oregon State University. The method for determining the springwood-summerwood transitions and cessation of growth was described in detail by Wolter (1968). Generally, cross sections of the cambial zone about 30-40 microns thick were cut approximately 1 mm from the pin. The cross sections were stained in aqueous safranin and fast green, washed in alcohol, and mounted on a slide.

RESULTS

Climatological Data

Xeric-Mesic Zone

Long term climatological data have been collected on Oregon State University's experimental farm (Bates and Calhoun, 1969). This climatological station is hereafter referred to as the Hyslop farm. The Hyslop farm is located about four kilometers east of the study sites.

Table 4 shows the precipitation data from the study sites in the xeric-mesic zone as compared to the current year's precipitation data from the Hyslop farm (Calhoun, 1969) and the 30 year average from the Hyslop farm (Bates and Calhoun, 1969).

As can be seen from Table 4, the 1969 monthly deviation between the study sites and the Hyslop farm does not exceed 2.55 cm. Even more significant is the fact that the largest deviation between the current year's data (up to September 17) recorded on the study sites does not deviate more than 1.05 cm from the 30 year average listed for the Hyslop farm. It was concluded from these data that the climatological information recorded at the Hyslop farm was representative for the study sites in the xeric-mesic zone.

Table 4. Periodic and monthly precipitation, in cm, during the growing season on the study sites in the xeric-mesic zone as compared to the monthly and long term precipitation on the Hyslop Farm.

Recording date	Week from March 1	Dixonville (s. v.) site	Jory (w)(n) & Nekia sites	Hyslop farm 1969[a]	Hyslop farm 30 yr. Average[b]	Percent Probability that ppt > 2.5 cm for each week.[b]
		cm	cm	cm	cm	
April 23	8	2.51	3.35			
		2.03*	1.55*			
May 7	9 & 10	.51	.51	.45		22 & 23
13	11	.15	.05	-		17
21	12	2.37	1.93	2.69		17
29	13	.56	.71	.35		3
		.46*	.48*	.66		
May Total		4.05	3.68	4.15	4.91	
June 6	14	-	-	-		7
12	15	-	-	.10		13
17	16	-	-	-		13
27	17	3.05	2.79	3.02		3
		.94*	.91*	3.13		
June Total		3.99	3.70	6.25	3.33	
July 5	18	-	-	-		3
11	19	-	-	-		0
19	20	T	T	.05		0
26	21	-	-	-		0
July Total		T	T	.05	.77	
August 1	22	-	-	-		3
9	23	-	-	-		0
16	24	-	-	-		0
23	25	-	-	-		0
29	26	-	-	-		7
August Total		0.00	0.00	0.00	1.05	
September 9	27	-	-	-		10
16	28	-	-	-		10
20	29	9.70	8.64	7.42		10
25	30	.89	1.05	1.67		7
		.25*	.25*	.10		
September Total		10.84	9.94	9.19	3.40	

* Data were recorded the following period. However, no rain fell the following month previous to the first measuring period. Therefore, data were placed in the appropriate month.

[a] Calhoun, 1969

[b] Bates and Calhoun, 1969

Moist-Mesic Zone

There is no official weather station adjacent to the study sites in the moist-mesic zone. The weather station which occurs nearest the sites in this zone is located at Valsetz, Oregon. Valsetz is located in the Coast Range mountains about 40 km north of the study site at an elevation of 269 m.

The precipitation data from the study sites, the current year's precipitation data at Valsetz (U.S. Weather Bureau, 1969), and the 21 year average precipitation data at Valsetz (Johnsgard, 1963) is shown in Table 5. The current growing season's[5] precipitation at Valsetz does not deviate from the 21 year mean more than 2.9 cm. These data show that the study sites received less precipitation than Valsetz. It also can be seen, when the current growing season's precipitation data from Table 4 is compared to the data from Table 5, that the study sites in the moist-mesic zone received more precipitation than the Hyslop farm.

Soil Temperatures

Soil temperatures were measured periodically from April 23 through August 17, 1969. Special attention was given June, July,

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[5] Growing season is defined in this dissertation to be the period from bud swell to the time three-fourths of the study trees in each zone became dormant (Table 14, p. 67).

Table 5. Periodic and monthly precipitation, in cm, during the growing season on the study sites in the moist-mesic zone as compared to the monthly and long term precipitation at Valsetz, Oregon

Recording Date	Blachly site	Kilchis, Klickitat, and Hembre sites	Valsetz 1969[a]	Valsetz 21 yr. period[b]
	cm	cm	cm	cm
May 8	.20	.20		
18	2.49	2.67		
31	3.25	3.08		
	.20*			
May Total	5.94	5.95	13.9	12.2
June 12	.05	.05		
20	-	-		
	5.77*	6.23*		
June Total	5.82	6.28	10.7	8.1
July 2	-	-		
11	.18	.18		
23	-	-		
30	-	-		
July Total	.18	.18	.64	3.5
Aug. 10	.05	.05		
17	-	-		
24	-	-		
30	-	-		
Aug. Total	.05	.05	1.32	3.6
Sept. 8	-	-		
17	-	-		
21	11.50	11.22		
26	1.70	1.86		
	.25*	.25*		
Sept. Total	13.45	13.33	20.2	9.7

* Data were recorded the following period. However, no rain fell the following month previous to the first measuring period. Therefore, data were placed in appropriate month.

[a] U.S. Weather Bureau, 1969

[b] Johnsgard, 1963

and August. The mean temperature from these three months is used in soil classification (U. S. Soil Conservation Service, 1967). The soil temperature data are shown in Table 6.

Soil and Plant Moisture Stress Correlation

Comparisons between plant-moisture stress and soil-water stress, from the soil-moisture control section, were made by plotting the bars of tension from each source on common coordinates. Time periods in which the springwood-summerwood transition and dormancy occurred are also shown. Complete data are listed in Appendix B.

Xeric-Mesic Zone

Soil-water and plant-moisture stresses for the Dixonville (s. v.), Jory (w), Nekia, and Jory (n) sites are shown in Figures 6, 7, 8, and 9, respectively.

The Dixonville (s. v.) soil maintained soil-water stresses equal to or greater than 15 bars for 69 consecutive days. The tree on this site obtained higher plant-moisture stresses than any other study tree. Large fluctuations for both stresses were related to precipitation (Appendix B). This soil is underlain by a layer of dense saprolite. The moisture tensions shown in Figure 6 are considered to be representative of the moisture regime.

Table 6. Soil temperature (°C) from each study site for the 1969 growing season

	Date							Mean summer soil temperature	Mean annual soil temperature
Xeric-Mesic Zone	4/23	5/7	5/13	6/12	6/17	7/11	8/16		
Dixonville (s. v.)	14	15	17	16	16	18	18	17	13*
Jory (w)	13	13			15	18	14	16	13
Nekia	13	13			15	18	16	16	13
Jory (n)	11	12			14	14	17	15	13
	Date								
Moist-Mesic Zone	4/24	5/1	5/18		6/20	7/11	8/17		**
Blachly			14		15	16	16	16	11
Kilchis		16	11		14	13	14	14	11
Klickitat	17		13		14	13	14	14	11
Hembre	17		11		15	15	14	15	11

* Mean annual soil temperature was approximated by adding 2°F to the mean annual air temperature recorded at the Hyslop Farm. (U.S. Soil Conservation Service, 1967)

** Mean annual soil temperature was approximated by adding 2°F to the mean annual air temperature recorded at Valsetz, Oregon (U.S. Soil Conservation Service, 1967)

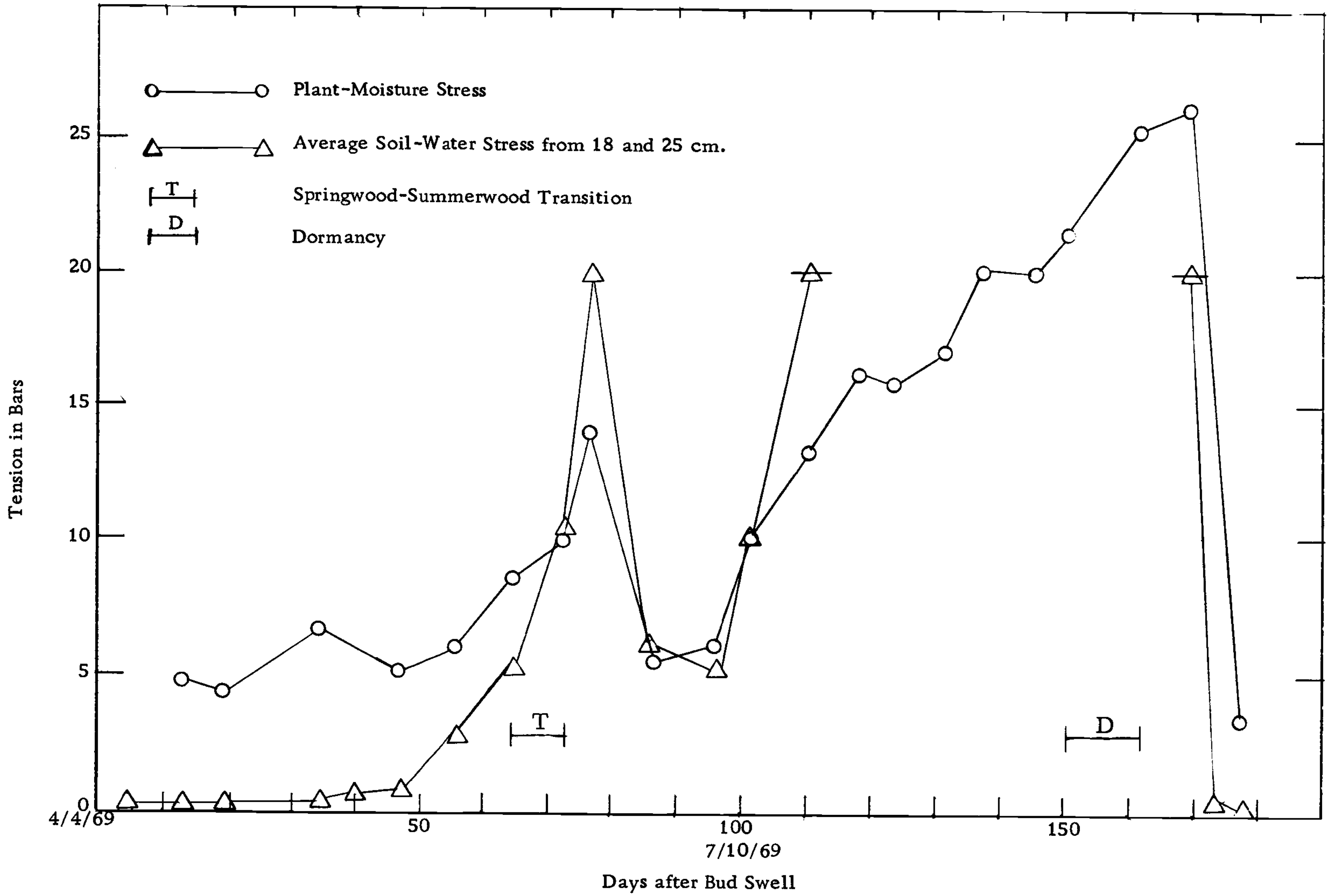

Figure 6. Relationships among plant-moisture stress, soil-water stress, and cambial activity for the Dixonville (s. v.) study site

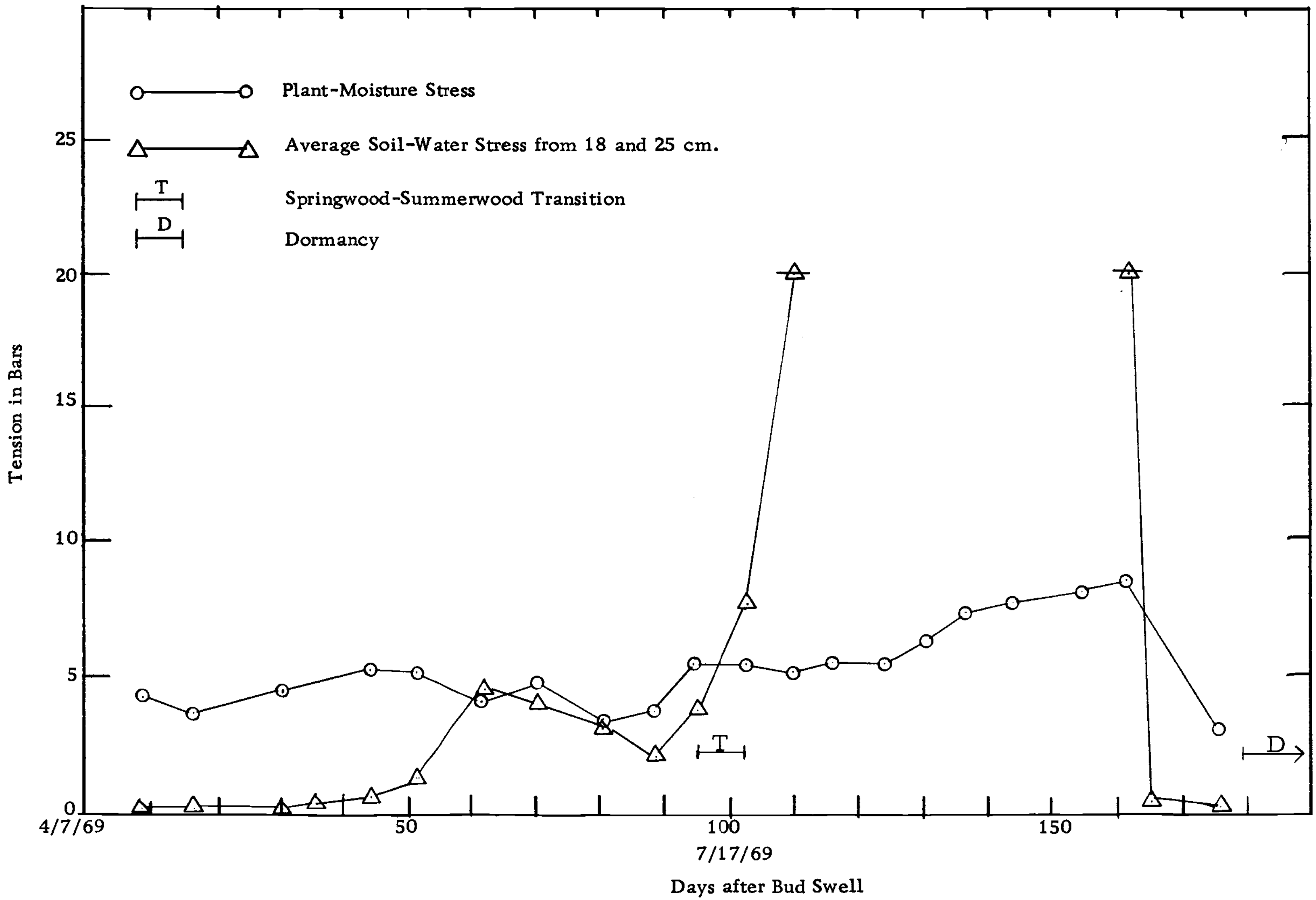

Figure 7. Relationships among plant-moisture stress, soil-water stress, and cambial activity for the Jory (w) study site

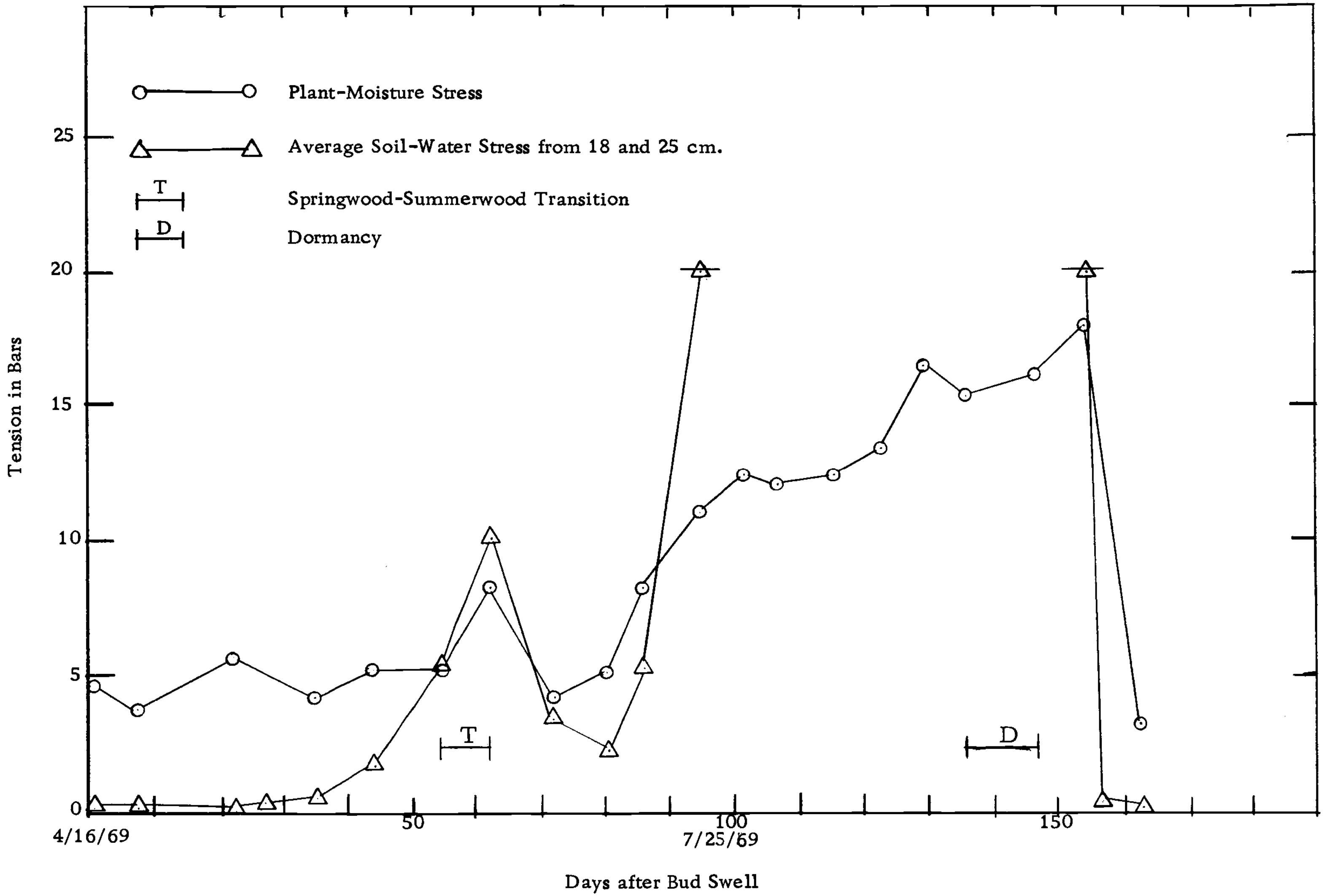

Figure 8. Relationships among plant-moisture stress, soil-water stress, and cambial activity for the Nekia study site

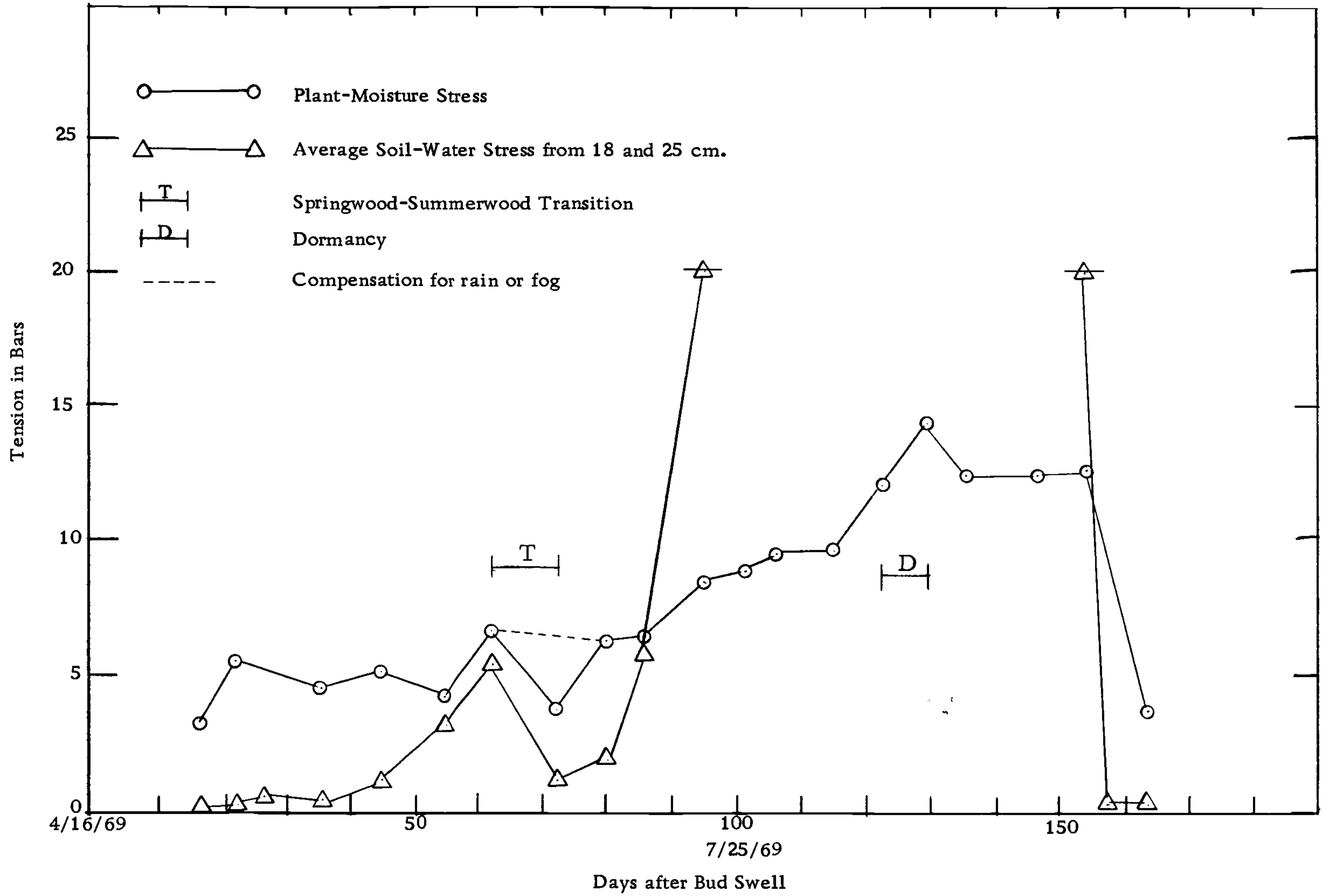

Figure 9. Relationships among plant-moisture stress, soil-water stress, and cambial activity for the Jory (n) study site

The Jory (w) soil maintained soil-water stresses equal to or greater than 15 bars for 60 consecutive days. This period includes the 24 hours in which the September rain took to reach the upper limit of the soil moisture control section. The plant-moisture stress did not exceed 8.6 bars although the solum contained no available water from August 29 to September 19. These data lead to the conclusion that the study tree was obtaining water from depths below the profile. This conclusion is substantiated by the fact that the study tree on the Jory (w) site did not become dormant until after September 25. Also, fractured bedrock was encountered at the bottom of the profile during installation of the gypsum blocks. In view of the above discussion and the available water data presented in Figure 7, it was concluded that the plant-moisture stress and soil-water stress as measured were not totally dependent upon one another.

The Nekia soil maintained soil-water stresses equal to or greater than 15 bars for 67 consecutive days. The rooting depth of the study tree on this site was limited by a layer of saprolite. All the holes made for the gypsum blocks ended in saprolite and soil depth did not exceed 100 cm. The data presented in Figure 8 are considered to be representative of the actual soil and plant moisture relationships.

Jory (n) soil maintained soil-water stresses equal to or greater than 15 bars for 65 consecutive days. This soil is deep and is underlain by saprolite. As in the previous soils, the large fluctuations were influenced by precipitation. The moisture tension data shown in Figure 9 are considered to be representative of the actual soil and plant moisture relationships.

Moist-Mesic Zone

Soil-water and plant-moisture stresses for the Blachly, Kilchis, Klickitat, and Hembre sites are shown in Figures 10, 11, 12, and 13, respectively. Complete data are listed in Appendix B.

The Blachly soil maintained a soil-water stress in the moisture control section equal to or greater than 15 bars for 47 consecutive days. It does not meet the 60 consecutive day stress requirement for xeric classification. The Blachly soil was deep and the entire rooting depth was considered to be included in the soil water measurements. Moisture tension data shown in Figure 10 were considered to be representative of the actual soil-plant moisture interactions.

Kilchis and Klickitat soils maintained a soil-water stress equal to or greater than 15 bars for 22 and 21 consecutive days, respectively. These data are contrary to the concepts of shallow and moderately deep skeletal soils having a limited available water holding capacity. The plant-moisture stresses exceeded the soil-water stresses until late in the season. The rapid rise in plant-moisture stresses indicates the study trees did indeed experience depletion of available soil-water although the data show that soil-water was still available.

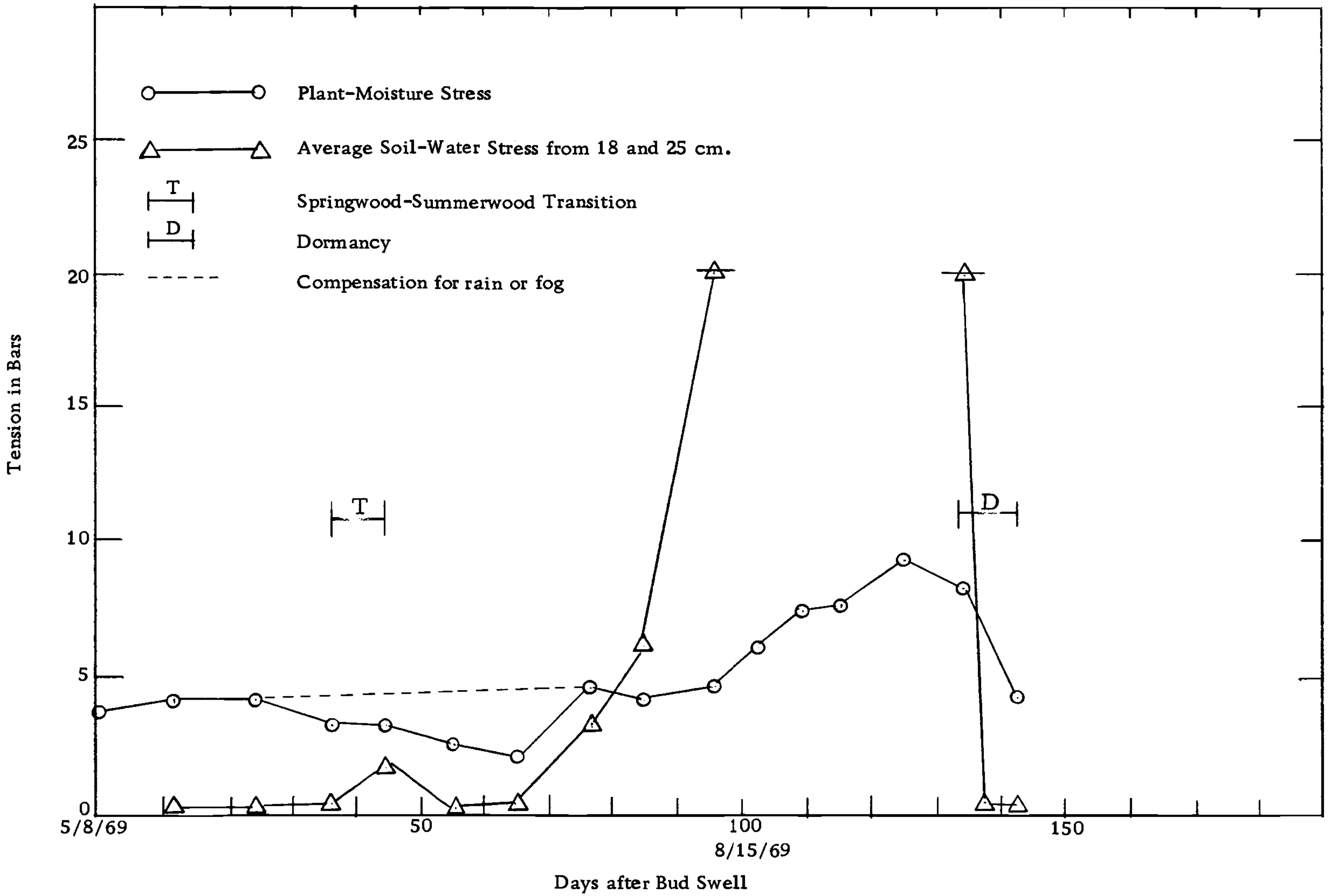

Figure 10. Relationships among plant-moisture stress, soil-water stress, and cambial activity for the Blachly study site

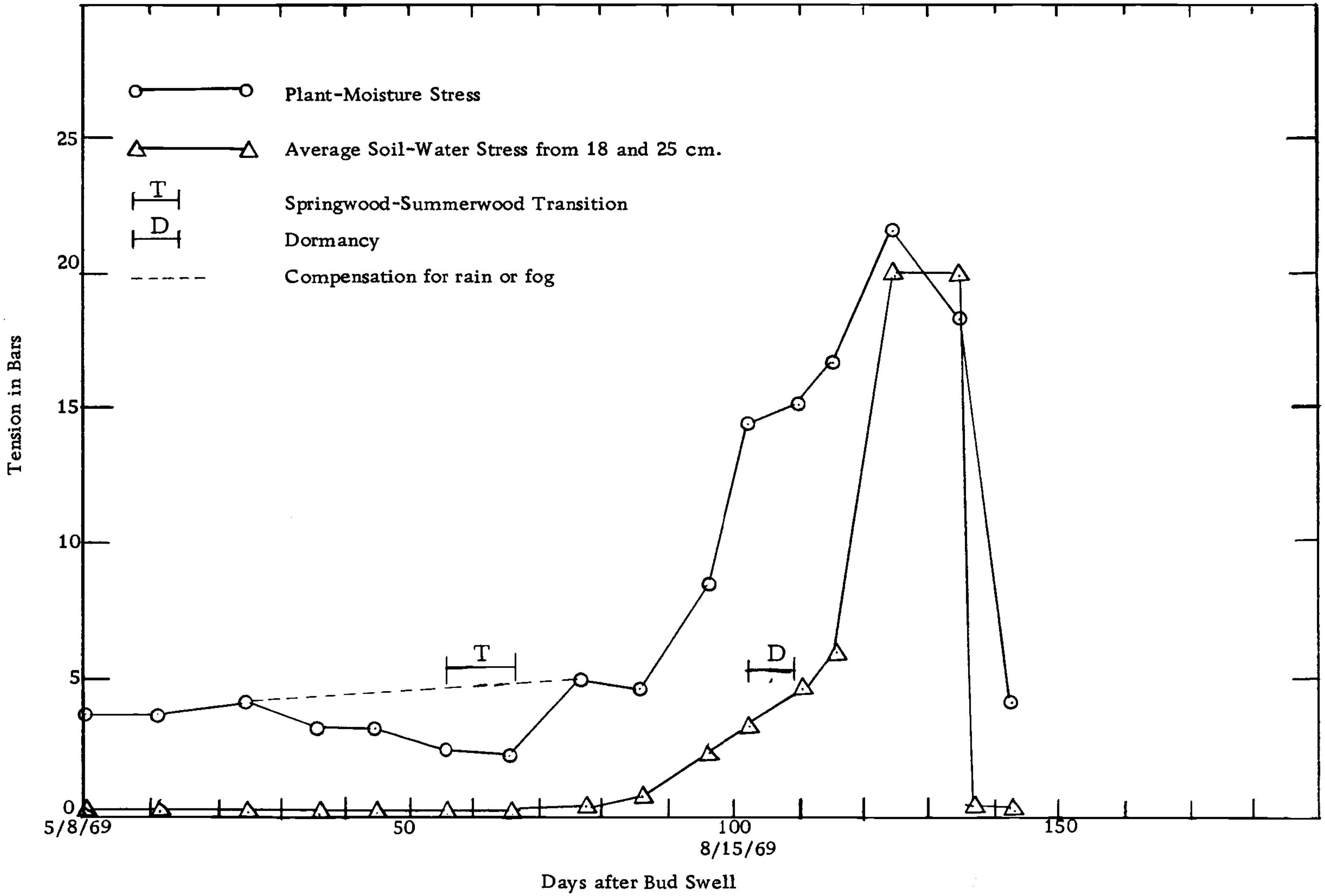

Figure 11. Relationships among plant-moisture stress, soil-water stress, and cambial activity for the Kilchis study site

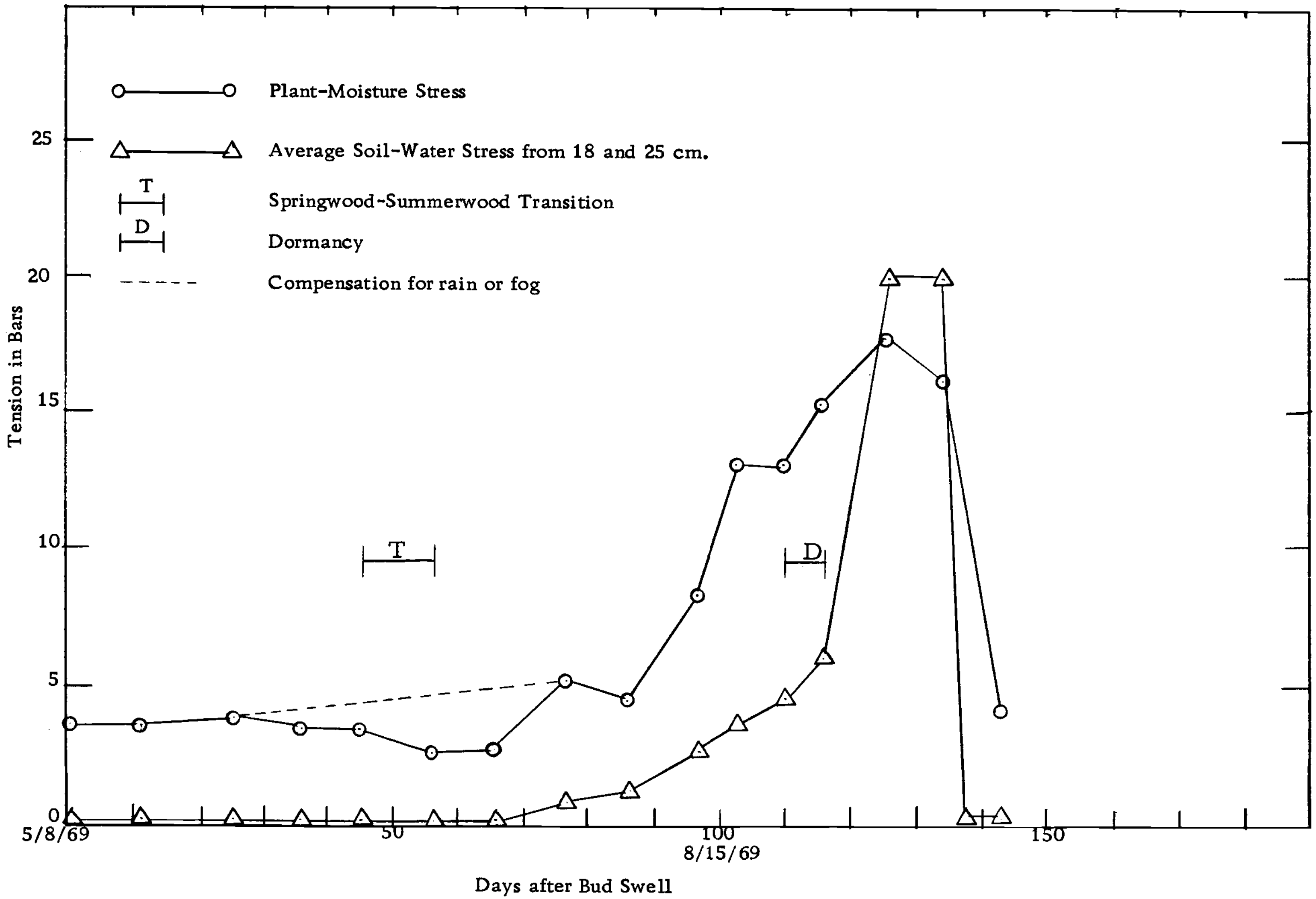

Figure 12. Relationships among plant-moisture stress, soil-water stress, and cambial activity for the Klickitat study site

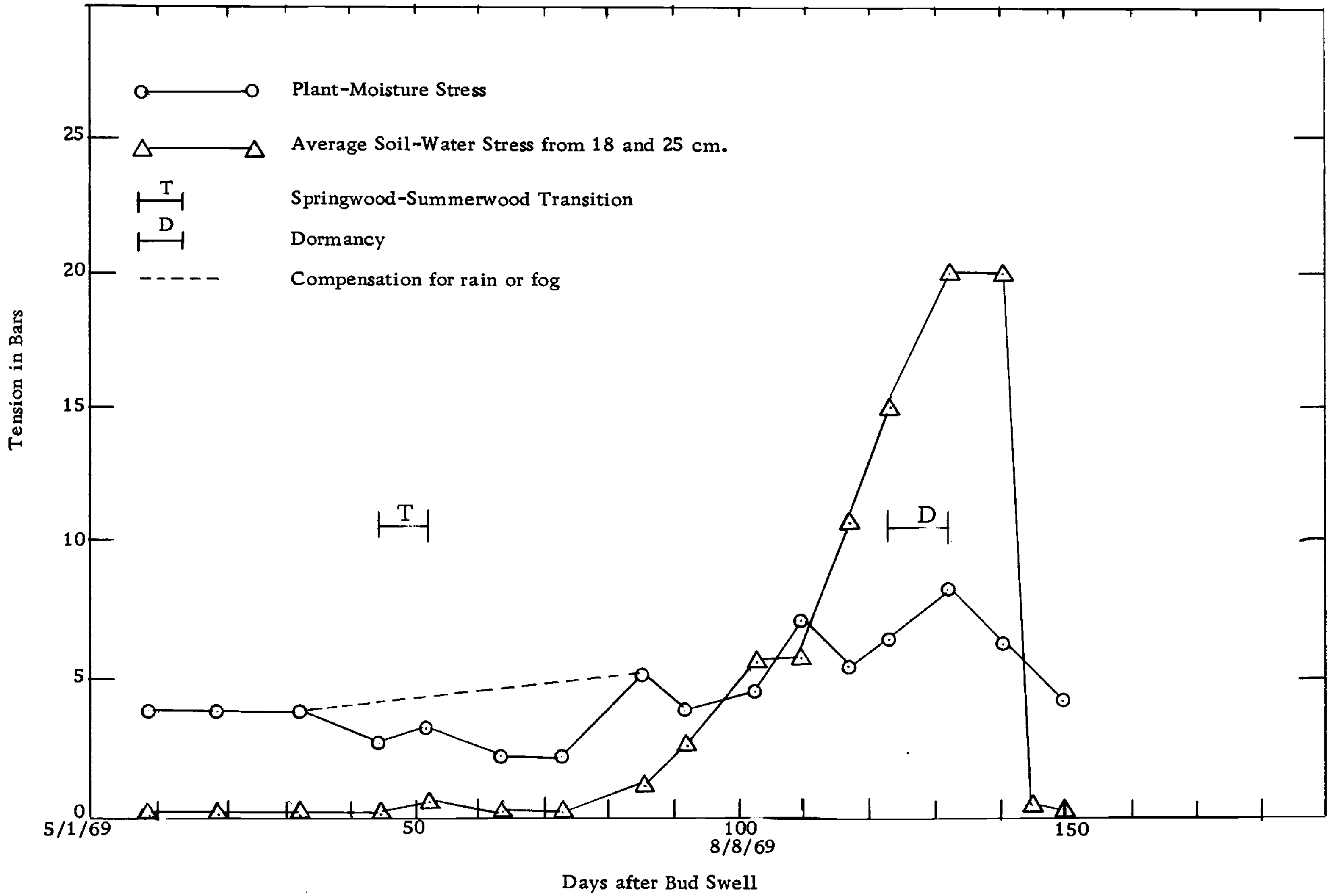

Figure 12. Relationships among plant-moisture stress, soil-water stress, and cambial activity for the Hembre study site

The Hembre soil maintained a soil-water stress equal to or greater than 15 bars for 25 days. The plant-moisture stress never exceeded 8.2 bars. The Hembre soil was very deep and graded into saprolite. Data presented in Figure 13 were considered to be representative of the actual soil-plant moisture interactions.

Soil-Water Depletion

The cm of available water removed periodically from each horizon for each soil was calculated. The calculations reflect the additional moisture from precipitation. Hence, some surface horizons show that all the available moisture was used, replenished, and used again.

Centimeters of available water for each horizon were calculated by the following equation:

$$\text{cm available water} = \text{(horizon thickness)(bulk density)(available water percentage)}$$

Tables 7 and 8 give the basic data required for the computations. In some instances, horizons had to be combined in order to incorporate the data from one gypsum block. Bulk densities and available water

Table 7. Basic data required to calculate the cm of available water for each soil horizon

Soil series	Horizon	Horizon depth	Horizon thickness	Depth of gypsum block	Bulk density	Available water percentage	Available water for each horizon
		cm	cm	cm	g/cc		cm
Dixonville (s. v.)	A1	0-5 }		8	1.55 {1.43	12.4 {13.4	1.9
	B1	5-10 }	10		1.68	11.5	
	B21t	10-30	20	18	1.84	10.4	3.8
	B22t	30-45	15	25	2.02	14.0	4.2
	R	45-65+	-	51	1.95	-	-
Jory (w)	A1	0-10	10	8	1.30	8.4	1.1
	IIA12	10-25	15	18	1.55	11.8	2.7
	IIB1	25-45	20	25	1.68	7.9	2.6
	IIIB21t	45-57 }	35	51	1.70 {1.72	4.7 {4.9	2.8
	IIIB22t	57-75 }			1.69	4.5	
	IIIB23t	75-95	20	76	1.52	6.8	2.1
	IIIB3t	95-115	20	102	1.46	7.8	2.3
	IIICt & R	115-162	47	117	1.49	10.0	7.0

Table 7. Basic data required to calculate the cm of available water for each soil horizon (Cont.)

Soil series	Horizon	Horizon depth	Horizon thickness	Depth of gypsum block	Bulk density	Available water percentage	Available water for each horizon
Nekia	A11	0-8	8	8	1.37	8.7	1.0
	A12	8-25	17	18	1.54	10.3	2.7
	B1	25-37	12	25	1.64	10.8	2.1
	IIB21t	37-63	26	51	1.78	13.0	6.0
	IIB22t	63-77	14	76	1.70	8.7	2.1
	IIB23t	77-87			1.54	13.1	
	IIB3t	87-97			1.53	12.8	
	(IIB23t + IIB3t, bracketed)		20	102	1.53	12.9	4.0
	IICt*	97+	-	140	1.47	-	-
Jory (n)*	A11	0-8	8	8	1.39	16.4	1.8
	A12	8-25	17	18	1.40	15.1	3.6
	B1	25-42	17	25	1.62	13.1	3.6
	IIB2t	42-75	33	51	1.70	7.6	4.3
	IIB3t	75-102	27	76	1.50	11.7	4.7
	IIC1t	102-132	30	102	1.38	10.7	4.4
	IIC2t	132-165	-	152	1.37	10.4	-

* Lower depths adjusted to correspond to profile which existed under the study tree.

Table 7. Basic data required to calculate the cm of available water for each soil horizon (Cont.)

Soil series	Horizon	Horizon depth	Horizon thickness	Depth of gypsum block	Bulk density	Available water percentage	Available water for each horizon
Blachly	A1	0-10	10	8	0.72	6.3	1.1
	A12	10-28	18	18	1.21	11.8	2.6
	A3	28-48	20	25	1.24	10.8	2.7
	IIB1	48-65	17	51	1.25	10.6	2.2
	IIB21	65-105	40	76	1.42	9.8	5.6
	IIB22	105-135	30	102	1.42	7.2	3.1
	IIB3	135-180	45	152	1.38	8.6	5.3
	IIC	180-191	10	191	1.49	9.0	1.3
Kilchis	A1	0-5 }	20	8	1.12 { 1.14**	4.1***	0.9
	A12	5-20 }		18	1.10**		
	B1	20-35	15	25	1.25**	2.8***	0.6
	B2	35-45	10	50	1.51**	4.0***	0.6

Table 7. Basic data required to calculate the cm of available water for each soil horizon (Cont.)

Soil series	Horizon	Horizon depth	Horizon thickness	Depth of gypsum block	Bulk density	Available water percentage	Available water for each horizon
Klickitat	A1	0-5	22	8	1.12 { 1.14**		
	A12	5-22		18	1.10**	5.4***	1.3
	B2	22-40	18	25	1.25**	1.0***	0.2
	B3	40-62	47	51	1.51 { 1.51**	2.8***	
	B3*	62-87		76	1.51**		2.0
Hembre	A1	0-10	10	8	1.14	15.0	1.7
	A12	10-30	20	18	1.10	17.5	3.8
	A3	30-42	12	25	1.25	13.5	2.0
	B1	42-62	20	51	1.51	10.4	3.1
	B2	62-102	40	76	1.39	12.7	7.1
	B3	102-127	25	102	1.19	15.2	4.5
	C & R	127-185	29	152	1.19	19.1	6.6

* Lower depths adjusted to correspond to profile which occurred under the study tree.

** Taken from equivalent depths within the Hembre profile.

*** (Bulk density of Hembre soil from equivalent depth) (% available water calculated from the Hembre depth) (% soil < 2 mm)

Table 8. Percent moisture content of each horizon of each soil at various bars of tension

Soil series	Horizon	Percent moisture at indicated bars					
		0.1	0.5	1.0	2.0	5.0	15.0
Dixonville (s.v.)	A1	41.1	36.0	34.9	-	27.5	25.1
	B1	38.4	33.9	32.7	-	26.9	24.7
	B21t	39.9	35.6	34.2	32.1	29.4	27.4
	B22t	46.1	39.7	38.3	34.5	31.5	28.9
	R	-	-	-	25.0	21.8	20.1
Jory (w)	A1	35.8	32.5	31.9	-	28.8	25.6
	IIA12	39.0	35.8	35.0	31.3	28.8	25.6
	IIB1	34.6	31.8	30.6	30.3	28.2	25.3
	IIIB21t	33.6	30.8	29.7	-	-	27.2
	IIIB22t	36.9	33.5	32.0	-	-	30.8
	IIIB23t	39.9	36.2	34.4	-	-	31.2
	IIIB3t	43.1	39.4	37.7	-	36.2	33.4
	IIICt&R	43.9	39.4	37.5	-	33.8	31.6
Nekia	A11	38.9	33.9	33.0	32.2	29.5	26.8
	A12	39.5	35.4	34.4	31.2	27.9	26.6
	B1	40.0	35.5	34.1	30.1	28.3	26.1
	IIB21t	39.1	34.9	33.6	31.2	28.9	27.9
	IIB22t	42.6	37.7	36.6	35.0	32.3	31.2
	IIB23t	45.4	40.5	39.5	36.6	34.0	31.2
	IIB3t	48.2	43.0	41.8	37.7	36.6	33.6
	IICt	53.2	47.4	45.6	39.4	37.4	33.2
Jory (n)	A11	43.2	40.2	38.9	32.5	29.6	25.2
	A12	41.7	39.1	38.0	32.2	29.7	25.5
	B1	38.9	36.7	36.0	30.1	27.8	24.8
	IIB2t	37.2	33.9	32.9	-	30.7	27.8
	IIB3t	43.5	39.1	37.7	36.5	33.4	29.7
	IIC1t	42.7	38.6	37.2	-	34.4	29.9
	IIC2t	42.6	37.6	36.4	-	34.3	29.9

Table 8. Percent moisture content of each horizon of each soil at various bars of tension (Cont.)

Soil series	Horizon	Percent moisture at indicated bars					
		0.1	0.5	1.0	2.0	5.0	15.0
Blachly	A1	49.5	45.2	43.9	41.5	36.5	31.1
	A12	45.5	41.2	39.9	-	35.5	31.5
	A3	43.4	38.8	37.5	35.2	32.3	30.3
	IIB1	41.3	36.2	34.7	33.3	30.8	29.2
	IIB21	39.9	35.1	33.6	31.5	29.3	27.7
	IIB22	37.4	34.0	33.1	32.4	30.2	28.4
	IIB3	39.3	35.4	34.0	32.3	30.7	28.8
	IIC	39.7	35.7	34.3	32.3	30.3	28.7
Kilchis*	A1	10.2	9.3	9.2	-	8.4	6.0
	A12	11.9	10.8	10.4	9.9	8.4	6.7
	B1	9.0	7.9	7.5	-	7.1	5.7
	B2	12.8	11.2	10.5	-	9.7	8.0
Klickitat*	A1	13.1	12.0	11.9	11.6	9.8	8.1
	A12	15.5	14.1	13.5	13.2	11.0	8.6
	B2	12.6	11.3	10.8	-	9.4	7.2
	B3	8.6	7.6	7.2	-	7.0	5.4
Hembre	A1	45.5	41.8	41.4	39.6	34.9	28.6
	A12	46.7	42.4	40.7	37.8	33.0	27.0
	A3	42.1	37.7	36.2	35.2	31.4	26.4
	B1	40.6	35.9	34.1	-	32.5	27.9
	B2	44.1	38.4	36.1	-	34.5	29.4
	B3	50.0	44.3	41.1	-	40.2	32.1
	C & R	56.7	48.1	43.8	-	-	33.5

* Percent moisture was adjusted for coarse fragment content.

percentages were averaged into one reading when combinations were made. Blocks adjacent to the Dixonville (s. v.) B22t, Nekia II B23t and IIB3t, Blachly A3 and IIB22, and Kilchis B2 horizons were utilized for determining the moisture content for those horizons.

The 0.1, 0.5, and 1.0 bar water percentage could not be determined by the undisturbed core method for the very stony Kilchis and Klickitat soils. The water percentage, of the soil fraction less than 2 mm, for the Kilchis and Klickitat soils was calculated by using the water percentage from equivalent depths or horizons within the Hembre soil. The soil fabric from the Hembre, Klickitat, and Kilchis soils was considered to be very similar except for coarse fragment content. The calculations were made by using the Kilchis and Klickitat/Hembre water percentage ratios from the 2.0, 5.0, and 15.0 bar tensions. The ratio from these three tensions were then averaged for each horizon. The available water percentage from the equivalent Hembre horizon was then multiplied by the average of the ratios. This figure was then corrected for the coarse fragment content. Any error introduced by the above calculations was considered insignificant when figuring the cm of available water from any one horizon. This is especially true once the cm of available water for each horizon has been corrected for the high percentage of coarse fragments.

Xeric-Mesic Zone

Table 9 shows the soil-water depletion in cm, by date, for each horizon of the Dixonville (s. v.), Jory (w), Nekia, and Jory (n) soils.

Moist-Mesic Zone

Table 10 shows the soil-water depletion in cm, by date, for each horizon of the Blachly, Kilchis, Klickitat, and Hembre soils.

Supplemental Studies. Results from the supplemental soil-water study sites, which were established along an elevational gradient, are shown in Table 11. Comparable data from the major study sites are also shown.

The Honeygrove site at the 335 m elevation occurred on a moist sideslope near the bottom of a draw. The soil samples were taken from an area which had widely spaced trees and sparse ground cover.

Cambial Activity

Data in this section are grouped for the xeric-mesic zone and the moist-mesic zone. Effects of plant-moisture stress and soil-water depletion upon the time that springwood-summerwood transition and dormancy occurred in Douglas-fir were studied. The four sites from the xeric-mesic zone and moist-mesic zone served as replications from each of these areas.

Table 9. Centimeters of available water used, by date, for each horizon of each soil occurring in the xeric-mesic zone.

Soil series	Horizon	Depth	Available water	Date																										
		cm	cm	4/7/69	4/8	4/16	4/23	5/2	5/7	5/13	5/21	5/29	6/6	6/9	6/12	6/17	6/27	7/5	7/11	7/19	7/26	8/1	8/9	8/16	8/23	8/29	9/9	9/16	9/20	9/25
Dixonville (s.v.)	A1 & B1	0-10	1.9		0.0	0.0	0.0	.	0.0	1.1	0.5	1.4	1.7		1.9*	-	.9	.9	1.9	-	-	-	-	-	-	-	-**	-	0.4	0.3
	B21t	10-30	3.8		0.0	0.0	0.4		0.4	1.2	1.4	2.6	3.1		3.8	-	3.1	3.1	3.4	3.8	-	-	-	-	-	-	-	-	1.0	0.8
	B22t	30-45	4.2		0.0	0.0	0.0		0.0	0.9	1.1	2.4	3.2		3.5	4.0	3.5	3.5	4.0	4.2	-	-	-	-	-	-	-	-	.4	0.0
Jory (w)	A1	0-10	1.1	0.0		0.0	0.0		0.0	0.2	0.2	0.3		0.4		0.5	0.2	0.2	0.3	0.6*	1.1	-	-	-	-	-	-	-	0.0	0.0nd
	IIA12	10-25	2.7	0.0		0.0	0.0		0.0	0.1	0.3	0.7		1.4		1.7	1.0	0.7	1.5	2.0	2.7	-	-	-	-	-	-	-	0.1	0.0
	IIB1	25-45	2.6	0.0		0.0	0.0		0.0	0.0	0.5	0.8		1.2		1.5	1.6	1.2	1.6	2.3	2.6	-	-	-	-	-	-	-	0.2	0.0
	IIIB21t & IIIB22t	45-75	2.8	0.0		0.0	0.0		0.0	0.0	0.8	1.7		2.0		2.3	2.3	2.3	2.3	2.8	-	-	-	-	-	-	-	-	0.4	0.0
	IIIB23t	75-95	2.1	0.0		0.0	0.0		0.0	0.0	0.9	1.0		1.1		1.2	1.2	1.3	1.4	1.5	2.1	-	-	-	-	-	-	-	1.1	1.1
	IIIB3t	95-115	2.3	0.0		0.0	0.0		0.0	0.0	0.0	0.3		0.9		1.0	1.1	1.1	1.2	1.2	1.3	1.3	2.1	1.6	2.1	2.3	-	-	1.1	1.2
	IIICt & R	115-162	7.0	0.0		0.0	0.0		0.0	0.0	0.0	0.8		2.3		2.7	2.9	3.0	3.3	3.6	4.2	4.6	5.5	5.5	5.7	6.3	7.0	-	3.9	4.9
Nekia	A11	0-8	1.0	0.0		0.0	0.0		0.0	0.3	0.3	0.7		0.7		1.0*	0.7	0.7	1.0	-	-	-	-	-	-	-	-**	-	0.3	0.0
	A12	8-25	2.7	0.0		0.0	0.0		0.0	0.0	0.4	1.3		2.4		2.6	1.6	1.3	2.4	2.7	-	-	-	-	-	-	-	-	0.1	0.0
	B1	25-37	2.1	0.0		0.0	0.0		0.0	0.3	0.5	1.3		1.7		2.0	1.6	1.4	1.7	2.1	-	-	-	-	-	-	-	-	0.1	0.0
	IIB21t	37-63	6.0	0.0		0.0	0.0		0.0	2.3	3.0	3.5		5.2		6.0	-	-	-	-	-	-	-	-	-	-	-	-	1.9	1.9
	IIB22t	63-77	2.1	0.0		0.0	0.0		0.0	0.0	0.0	0.6		1.2		1.7	1.9	1.9	2.0	2.1	-	-	-	-	-	-	-	-	0.3	0.6
	IIB23t & IIB23t	77-97	4.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0		0.6		1.2	1.7	2.0	2.3	2.6	2.9	3.0	3.2	3.2	3.3	4.0	-	-	3.0	2.0
Jory (n)	A11	0-8	1.8					0.0	0.0	0.2	0.1	0.2		1.0		1.3	0.3*	0.3	1.1	1.8	-	-	-	-	-**	-	-	-	0.2	0.2
	A12	8-25	3.6					0.0	0.0	0.4	0.0	0.6		2.2		2.6	0.6	1.3	2.7	3.6	-	-	-	-	-	-	-	-	0.2	0.0
	B1	25-42	3.6					0.0	0.0	0.4	0.4	0.3		2.2		2.8	0.3	2.2	2.9	3.6	-	-	-	-	-	-	-	-	0.0	0.0
	IIB2t	42-75	4.3					0.0	0.0	0.5	0.9	1.4		2.0		2.3	2.5	2.8	2.9	3.1	4.3	-	-	-	-	-	-	-	1.8	0.5
	IIB3t	75-102	4.7					0.0	0.0	0.0	0.0	0.9		1.5		1.8	1.8	2.1	2.2	2.2	2.9	3.2	4.2	3.5	4.2	4.7	-	-	1.2	1.1
	IIC1t	102-132	4.4					0.0	0.0	0.0	0.0	0.0		1.2		1.1	1.4	1.4	1.5	2.0	2.1	2.2	2.5	2.6	2.7	4.4	-	-	2.0	2.0

* Date that the springwood-summerwood transition was completed.

** Date that dormancy was completed.

Table 10. Centimeters of available water used, by date, for each horizon of each soil occurring in the moist-mesic zone

Horizon	Depth	Available Water	5/1	5/4	5/8	5/18	5/31	6/12	6/20	7/2	7/11	7/23	7/30	8/10	8/17	8/24	8/30	9/8	9/17	9/21	9/26
	cm	cm							*	**Blachly**											**
A1	0-10	1.2			0.0	0.0	0.0	0.3	0.7	0.0	0.2	0.8	1.2	-	-	-	-	-	-	0.0	0.0
A12	10-28	2.6			0.0	0.0	0.0	0.5	1.1	0.0	0.3	1.5	1.9	2.6	-	-	-	-	-	0.0	0.0
A3	28-48	2.7			0.0	0.0	0.0	0.3	0.8	0.0	0.3	1.6	2.2	2.7	-	-	-	-	-	0.3	0.3
IIB1	48-65	2.2			0.0	0.0	0.0	0.0	0.7	0.0	0.0	1.1	1.6	2.0	2.2	-	-	-	-	0.8	0.0
IIB21	65-105	5.6			0.0	0.0	0.0	0.7	1.5	0.7	1.5	2.1	3.5	4.3	4.7	4.9	5.6	-	-	2.7	1.9
IIB22	105-135	3.1			0.0	0.0	0.0	0.7	0.1	0.1	0.7	0.9	1.2	1.6	1.8	2.3	2.4	3.1	-	1.8	1.1
IIB3	135-180	5.3			0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.1	1.5	2.0	2.1	2.3	2.9	3.1	3.8	4.1	3.7
IIC	180-191	1.3			0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.4	0.5	0.6	0.6	0.6	0.9	0.9	0.9
										Kilchis											
A1 & A12	0-20	0.9	0.0	0.0		0.0	0.0	0.0	0.0	0.0	* 0.0	0.1	0.1	0.2	0.3	** 0.4	0.9	-	-	0.1	0.0
B1	20-35	0.5	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.3	0.5	-	0.0	0.0
B2	35-45	0.6	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	-	-	0.1	0.1
										Klickitat											
A1 & A12	0-22	1.3		0.0	0.0	0.0	0.0	0.0	0.0	* 0.0	0.0	0.2	0.2	0.4	0.6	0.7	** 1.0	1.3	-	0.1	0.1
B2	22-40	1.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.4	0.5	0.5	1.0	-	0.0	0.0
B3	40-87	2.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.7	0.7	0.8	0.9	1.6	2.0	-	0.0	0.0
										Hembre											
A1	0.10	1.7	0.0		0.0	0.0	0.0	0.2	* 0.0	0.0	0.1	0.7	1.1	1.7	-	-	-	** -	-	0.2	0.1
A12	10-30	3.8	0.0		0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.8	1.7	2.6	2.6	3.8	-	-	-	0.2	0.0
A3	30-42	2.0	0.0		0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.5	0.8	1.3	1.3	1.4	1.6	2.0	-	0.1	0.0
B1	42-62	3.1	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	1.4	1.4	1.5	1.7	1.8	2.0	0.3	0.0
B2	62-102	7.1	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	2.2	3.4	3.5	3.7	3.8	4.0	4.2	2.4	1.4
B3	102-127	4.5	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.5	1.8	1.9	1.9	2.0	2.0	2.1	1.0	0.4
C & R	127-185	6.6	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.9	2.7	3.1	3.2	3.2	3.4	3.6	3.4	3.3

* Date that the springwood-summerwood transition was completed.

** Date that dormancy was completed.

Table 11. Comparisons of moisture content, 15 bar water percentage, and number of days the soil-moisture control section was equal to or greater than 15 bars tension for all study sites in the moist-mesic zone

Sample Location	Elevation in meters	Date	Percent Water	15 bar water percentage	Number of days soil moisture stress $\geq$ 15 bars
		Supplemental study sites			
Honeygrove	214	7/23	30.2	26.6	
		7/31	28.5		
		8/30	17.6		
		9/16	15.6		30 to 48
Honeygrove	335	7/23	24.6	18.2	
		7/31	25.0		
		8/30	25.4		
		9/16	24.0		0
Klickitat	793	7/23	74.0	29.4	
		7/31	67.8		
		8/30	50.7		
		9/16	48.0		0
		Major study sites			
Blachly	457				47
Kilchis	625				22
Klickitat	626				21
Hembre	630				25

Plant-Moisture Stress and Growth

The range, in bars of tension, in which the transition and dormancy occurred, was delimited by using the reading previous to the time the changes had taken place and the reading when the changes were completed. Thus, the changes took place between the two recorded tensions.

The midpoint of the range was then arbitrarily chosen to represent the tension at which the changes occurred.

Endpoints of the transition range for the Jory (n), Blachly, Kilchis, Klickitat, and Hembre sites were measured on foggy or rainy mornings. Therefore, the readings did not give a true indication of the daily plant-moisture stress.

It is well documented that plants absorb moisture from the atmosphere which, in turn, temporarily reduces the internal moisture stress (Breazeale, McGeorge, and Breazeale, 1950; Breazeale, McGeorge, and Breazeale, 1951; Gendal, 1966; Monteith, 1961; Slayter, 1960; Slayter, 1967; Stalfelt, 1963; Stone, 1957; and Stone, 1958). Johnston (1964) demonstrated that an overnight rainfall of about 32 mm reduced the leaf-water deficit in *Pinus radiata* by about six percent.

A dashed line was drawn on Figures 9, 10, 11, 12, and 13 which connect readings taken on clear mornings before and after the changes were complete. Plant-moisture stress data given in Table 12 for the range were then read from the dashed line instead of the plant-moisture stress line.

Range and midrange for the plant-moisture stresses for each site at the time the changes took place are shown in Table 12. Bars of tension at the midrange from the xeric-mesic zone were compared to the bars of tension at the midrange from the moist-mesic zone. Differences in tensions between the two zones were analyzed by Student's two-tailed, t test (Mendenhall, 1967).

Study trees growing in the xeric-mesic zone had higher plant-moisture stresses at transition and dormancy than the study trees growing in the moist-mesic zone. Differences in bars of plant-moisture stress was highly significant (2% level) at time of transition and significant at the 10% level at time of dormancy (Table 13).

Soil Water Depletion and Growth

The cm of available water depleted from the upper one-third of each profile at the time of springwood-summerwood transition is shown in Table 12. The range and midrange for the soil-water depletion at transition and dormancy were established in the same manner as described for plant-moisture stress. The upper one-third of the profile, more than any other depth range, was correlated with the maximum percentage of available water used at the time of transition.

Table 12. Range and midrange of plant-moisture stress and soil-water depletion at springwood-summerwood transition and dormancy

Zone and soil series	Plant-moisture stress: Springwood-summerwood transition, Bars of tension: Range	Midrange	Plant-moisture stress: Dormancy, Bars of tension: Range	Midrange	Soil-water depletion: Springwood-summerwood transition, Cm of available water used in upper 1/3 of profile: Range	Midrange	Percent of available water used in upper 1/3 of profile	Soil-water depletion: Dormancy, Cm of available water used in entire profile: Range	Midrange	Percent of available water used in entire profile
Xeric-mesic zone										
Dixonville (s. v.)	8.6-10.0	9.3	21.6-25.4	23.5	2.5-2.8	2.7	96	9.9-9.9	9.9	100
Jory (w)	5.5-5.5	5.5	nd-8.6-nd	nd	4.2-5.8	5.1	70	nd	nd	nd
Nekia	5.1-8.2	6.7	15.4-16.1	15.8	4.1-4.8	4.5	92	18.1-18.1	18.1	100
Jory (n)	6.6-6.9	6.8	12.0-14.4	13.2	6.7-7.6	7.2	80	19.4-20.2	19.8	89
		7.1*		17.5*						
Moist-mesic zone										
Blachly	4.3-4.4	4.4	- 8.2	nd	1.1-3.3	2.2	25	nd	nd	nd
Kilchis	4.7-4.9	4.8	14.4-15.1	14.8	0.0-0.0	0.0	0	0.9-1.1	1.0	50
Klickitat	4.2-4.5	4.4	13.0-15.1	14.1	0.0-0.0	0.0	0	2.1-3.1	2.6	60
Hembre	4.1-4.3	4.2	6.5-8.2	7.4	0.0-0.7	0.4	4	17.8-18.7	18.2	63
		4.4*		12.1*						

* Average bars of tension for each zone.

Table 13. Statistical analysis comparing the plant-moisture stresses between the xeric-mesic zone and the moist-mesic zone at the time of springwood-summerwood transition and dormancy (t test)

	d.f.	Calculated t	$t_{.05}$ (10% level)	$t_{.25}$ (5% level)	$t_{.01}$ (2% level)
Springwood-Summerwood Transition	6	3.250		2.447	3.143**
Dormancy	4	2.160	2.132*	2.776	3.747

Ho: There is no difference in plant-moisture stress between the xeric-mesic zone and the moist-mesic zone at the time transition and dormancy occurred.

* Significant at the 10% level.

** Highly significant at the 2% level.

Results shown for the Kilchis and Klickitat soils are considered somewhat dubious as discussed later.

The percentage of available water used in the total profile best reflected the soil-water regime at the time of dormancy. Available water depleted in the upper one-third of the profile could not be used because some of the soils did not have available water in the upper profile for seven weeks prior to dormancy.

Radial Growth

The time elapsed from bud swell to springwood-summerwood transition and dormancy for each study tree is shown in Table 14 along with the mm of radial growth and cm^2 of cross sectional growth. The tree was assumed to be symmetrical. Time of bud swell was used as a reference point because it was a visible indication that dormancy was being broken. Chalk (1930) reported that radial growth in Douglas-fir was initiated 12 days prior to bud swell.

Trees in the xeric-mesic zone were active more days to time of transition and dormancy than the trees in the moist-mesic zone. But, radial growth per day was slower in the xeric-mesic zone than in the moist-mesic zone.

Table 14. Relationships between length of growing time and amount of springwood and summerwood for each study tree

Zone and soil series	Date of bud swell	Days and date from bud swell to midrange of		Radial growth at b. h. for 1969*			Area growth at b. h. for 1969 growing season		
		Transition	Dormancy	Springwood	Summerwood	Total	Springwood	Summerwood	Total
Xeric-mesic zone		days	days	mm	mm	mm	cm^2	cm^2	cm^2
Dixonville (s. v.)	April 4	66 (June 9)	151 (Sept. 4)	2.37	0.75	3.12	71.15	22.59	93.74
Jory (w)	April 7	98 (July 15)	>170 (>Sept. 25)	3.75	≥ 2.50	≥ 6.25	130.84	≥ 87.72	≥ 218.57
Nekia	April 16	58 (June 13)	140 (Sept. 4)	3.62	1.12	4.75	92.54	24.05	121.59
Jory (n)	April 16	67 (June 22)	125 (Aug. 20)	2.75	2.00	4.75	65.04	47.60	112.65
		72**	≥ 147**						
Moist-mesic zone									
Blachly	May 8	40 (June 16)	139 (Sept. 23)	2.87	1.87	4.75	82.31	54.19	136.51
Kilchis	May 8	60 (July 6)	105 (Aug. 20)	2.37	1.25	3.62	75.54	39.99	115.53
Klickitat	May 8	49 (June 26)	112 (Aug. 27)	3.25	1.37	4.62	154.50	65.33	219.83
Hembre	May 1	47 (June 16)	126 (Sept. 4)	3.25	1.75	5.00	82.99	44.96	127.96
		49**	120**						

* Measured on the wood slice prepared for determining the time of transition and dormancy.

** Average number of days for each indicated zone.

Vegetation

Species Present

Relative abundance of species growing on each site is shown in Table 15. These data are not quantitative and are used only to show trends. The size of sample area from each zone was very small and does not indicate the true range of the listed species.

Site Indices

The site index and class for each study tree is given in Table 16. King's (1966) site tables have a 50 year base and are used because they are more applicable to young trees than are McArdle's (1949) site tables which have a 100 year base.

Site class ratings for various soils in the Willamette Valley have been listed by Thomas et al. (1969). These ratings were based on McArdle's site tables. A list of ratings for the soils used for this study are as follows:

Dixonville (s. v.)	no rating
Jory (w)	III
Nekia	III
Jory (n)	II-
Blachly	II
Kilchis	IV
Klickitat	III
Hembre	II

Table 15. Estimated percentage of trees and other vegetative cover on the study sites

Scientific name	Common name	Xeric-mesic zone				Moist-mesic zone			
		Dixonville (s.v.)	Jory (w)	Nekia	Jory (n)	Blachly	Kilchis[1]	Klickitat[1]	Hembre
Tree species:									
Acer macrophyllum	Big-leaf maple		10	10	5				
Alnus rubra	Red alder		3	3	10				
Arbutus menziesii	Madrone		2	2				1	
Castanopsis chrysophylla	Chinquapin		5	5				1	
Pseudotsuga menziesii	Douglas-fir	100	78	78	85	100	100	98	100
Shrub species:									
Acer circinatum	Vine maple					5	15	15	30
Berberis nervosa	Oregon grape					1	2	3	5
Crataegus sp.	Hawthorn	5	2	2					
Gaultheria shallon	Salal					65	50	40	59
Holodiscus discolor	Ocean spray		5	5	10				
Rhus diversiloba	Poison oak	5	15	15	5				
Rosa sp.	Wild rose	10	5	5				2	
Rubus ursinus	Trailing blackberry		5	5	5	2			1
Symphoricarpos albus	Snowberry		24	24		2			
Vaccinium parvifolium	Red huckleberry					5			
Forb species:									
Achillea lanulosa	Western yarrow	5							
Cirsium sp.	Thistle		2	2					
Daucus carota	Wild carrot	10							
Fragaria sp.	Wild strawberry	5			3				
Galium sp.	Bedstraw	5							
Iris tenax	Oregon iris	10							
Lonicera ciliosa	Honeysuckle			3					
Oxalis organa	Oregon oxalis			5					
Plantago sp.	Plantain	10							

Table 15. Estimated percentage of trees and other vegetative cover on the study sites (Cont.)

Scientific name	Common name	Xeric-mesic zone				Moist-mesic zone			
		Dixonville (s.v.)	Jory (w)	Nekia	Jory (n)	Blachly	Kilchis[1]	Klickitat[1]	Hembre
Forb species: (Cont.)									
Pteridium aquilinum	Braken fern	5	4	4	35	20	3	5	5
Rubus spectabilis	Salmonberry		8	8	15				
Smilacina sp.	False Solomon's seal				5				
Trillium ovatum	Trillium				5				
Viola sempervirens	Violet			2					
Xerophyllum tenax	Beargrass		10	5					
Grass species:									
Grass sp.	Grass	30	30	30					

[1] Kilchis and Klickitat sites had approximately 20 and 30% bare ground, respectively.

Table 16. Site index and class for each study tree by King's (1966) tables

Zone and site	Radius inside bark	Height	Breast height age	King's Tables	
				Site Index	Site Class
Xeric-mesic zone	cm	m	years		
Dixonville (s.v.)	4.8	4.8	12	50	V-
Jory (w)	5.6	7.5	11	92	IV+
Nekia	4.1	5.4	7	104	III
Jory (n)	3.8	6.3	9	96	III-
Moist-mesic zone					
Blachly	4.6	8.6	10	120	II
Kilchis	5.1	6.6	16	52	V-
Klickitat	7.6	11.1	23	66	V
Hembre	4.1	8.4	10	116	II-

DISCUSSION

Soil Classification

Soil-Water Stress

The xeric-mesic zone is differentiated from the moist-mesic zone by having a soil-moisture stress of 15 bars for 60 consecutive days in at least seven out of ten years within the soil-moisture control section. Thus, it is important to establish that the precipitation during the 1969 growing season was representative of at least 70 percent of the years.

Xeric-Mesic Zone. Precipitation data from the study sites in McDonald Forest were compared to the data from a nearby official weather station (Table 4).

During the 1969 growing season, data from the study sites and the official weather station show that precipitation did not vary more than 2.55 cm. Data from the study sites show that the precipitation did not vary more than 1.05 cm. from the 30 year average listed for the official weather station. In light of these data, it seems safe to assume the official weather station's records suffice nicely to represent the long term precipitation of the study sites. This is especially true when, by definition, it requires more than 2.54 cm. of precipitation to influence the soil-moisture control section.

The next step was to establish that the current growing season's precipitation will not be significantly exceeded seven out of ten years. It is meant by "significantly exceeded" that the precipitation will not exceed the current year's precipitation by 2.54 cm. within a 48 hour period. The only way to make such a prediction is to examine past records.

The calculations of percent probability that ppt. $\geq$ 2.5 cm. for each week (Table 4, p. 35) shows that for any one week, from May 13 to September 20, the chance for precipitation to be equal to or greater than 2.5 cm. is less than 17 percent. Also, each monthly cumulative chance for precipitation to be equal to or greater than 2.5 cm. (June 1 to September 20) does not exceed 30 percent.

It requires an excess of 2.54 cm. of precipitation within a 48 hour period to influence the soil-moisture control section. The chance for this amount to occur in an entire week during the growing season is less than 17 percent. The cumulative monthly chance (excluding water consumption and evaporation) is less than 30 percent. Chances that the weekly precipitation will exceed the 1969 growing season's precipitation by 2.5 cm. is less than two out of ten years. The chances that the cumulative monthly total will exceed the 1969 growing season's precipitation by 2.5 cm. is less than three out of ten years.

All sites in McDonald Forest had a 15 bar soil-water stress for at least 60 consecutive days within the soil-moisture control section. Therefore, it is appropriate to predict that the amount of precipitation which fell in the 1969 growing season will not be exceeded by 2.5 cm in seven out of ten years. The sites located in McDonald Forest are well within the defined xeric zone.

Moist-Mesic Zone. There were no official weather stations near the study sites located adjacent to the Marys Peak Road. The nearest one was about 40 km. north at Valsetz, Oregon. The growing season's precipitation at Valsetz exceeded the precipitation at the study sites (Table 11).

From May 8 to Sept. 16, 1969, the monthly precipitation at Valsetz did not deviate more than 2.9 cm. from the 21 year mean. This is interpreted to mean that the current growing season's precipitation at Valsetz was normal.

It was established in the preceeding section that the precipitation during the growing season at McDonald Forest was normal. Also, the precipitation during the growing season at Valsetz was normal. From this one can conclude the precipitation in the general area was normal. If this is true, the precipitation recorded at the Marys Peak Road study sites was normal. The study sites did not have a soil-water stress of 15 bars for 60 consecutive days[6] within the

[6] The number of consecutive days of a 15 bar stress for each site is: Blachly - 47, Kilchis - 22, Klickitat - 21, and Hembre - 25.

soil-moisture control section. Therefore, it is safe to conclude the sites adjacent to the Marys Peak Road are not within the defined xeric zone.

Results from the supplementary moisture studies (Table 11) show that none of the sites had a soil-water stress of 15 bars for 60 consecutive days within the soil-moisture control section.

The two sites lowest in elevation (214 m and 335 m) could not be considered as xeric. Comparison of these elevations with the elevational range of the McDonald Forest sites (198-328 m) shows a definite overlap. An example like this illustrates that elevation alone is not an adequate criterion for soil classification, even in a local area.

Soil Temperature

Table 6, page 39, shows the results of the measured soil temperatures for each site during the summer of 1969. The mean annual soil temperature was calculated by adding 2^{o}F to the mean annual air temperature recorded at the nearest official weather station (U. S. Soil Conservation Service, 1967). Mean annual soil temperatures from all the sites fell within the 8 to 15^{o}C range required by definition to be classified as mesic.

Plant-Moisture Stress

One of the principal parts of this study was to determine if a consistent relationship existed between plant-moisture stress and the soil-water stress within the soil-moisture control section, or any other portion of the soil profile. If such a relationship existed, soil classification would be greatly expedited in the Douglas-fir region.

Pierpoint (1967) found that different species gave different results when the soil-water tension was compared to plant-moisture stress under growth chamber conditions. For all species he showed that plant-moisture stress increased as the soil dried. Harms (1969) showed for potted pines, that a relationship existed ($R^2 = 0.85$) between plant-moisture stress and percent soil water. Also, at soil-water tensions from one to four bars, the plant-moisture stress was low and nearly independent of soil-water. As soil-water tensions increased above four bars, the plant-moisture stress increased rapidly with small decreases in soil water. Gardner (1965) reported that, for most soils, when tensions were less than about five bars, only a small tension gradient is needed to move water rapidly enough to meet transpiration demands.

Fisher and Stone (1968) reported that the best red pine seedling survival occurred in soils over fractured bedrock and the greatest mortality occurred when the trees were in a soil over consolidated bedrock. They also reported that the relative turgidity of the two year old needles was significantly correlated with soil-water content. Dry weight of the current year's needles was correlated to current year's moisture during the growing season.

Figures 6 through 13 show the relationship between plant-moisture stress and soil-water stress within the soil moisture control section. These figures show the general relationship discussed by Harms (1969) and Gardner (1965). That is, at low soil-water tensions, the plant-moisture stress is relatively low. Plant-moisture stress usually increases sharply as the soil-water stress becomes greater. Data from the Jory (w) site (Figure 7) were very interesting. Soil-water was depleted from the entire profile without causing the plant-moisture stress to increase sharply or exceed nine bars. Also, the tree was still growing as of September 25. In view of these data, it is logical to assume the study tree on the Jory (w) site was obtaining water from some area below the soil profile. This assumption was strengthened by the fact that fractured bedrock was encountered at the base of the profile when the gypsum blocks were installed. Undoubtedly, this particular tree had some of its roots in the fractured bedrock and the fractured bedrock contained adequate water to sustain growth. Mueller-Dombois (1964) reported that optimum growth of tree seedlings occurred when roots were growing in the capillary fringe of a water table. Shachori _et al._ (1967) drilled access holes for a neutron-scattering probe to a depth of nine m in limestone beneath one m of soil and found that Maqui scrub withdrew water to a depth of about eight m.

Results just the opposite of those described above occurred on the Kilchis and Klickitat sites (Figures 11 and 12). Plant-moisture stress increased as would be expected on shallow and moderately deep skeletal soils during a dry period. However, high soil-water stresses beneath the crown did not take place until after the plant-moisture stress had greatly increased.

A logical explanation for these anomalous results is that the blocks did not truly measure the soil-water depletion in the root zones of the study trees. Two factors help explain why. First, the gypsum blocks were inserted in the wall of hand-dug pits. The root system was severed for a much larger area than where the blocks were inserted in a hole made by a soil sampler tube. Second, a rooting system from trees which have limited rooting depth and are growing in soils which contain 65 percent stones must have a large lateral root development to enable them to grow. Therefore, the gypsum blocks beneath the crowns probably did not measure the moisture regime from a significant portion of the root zone on the Kilchis and Klickitat sites.

The Jory (w), Kilchis, and Klickitat sites did not exhibit the expected soil-plant water stress relationships. Results for the situations cited above undoubtedly are caused by what Rutter (1968) referred to as the failure to sample the total rooting area.

The remaining sites exhibit the relationship that plant-moisture stress increases as the soil-water is depleted. Plant-moisture stress increases sharply as the soil-water stress within the soil-moisture control section reaches about five bars in the xeric-mesic zone and about three bars in the moist-mesic zone.

Overall, the data show that plant-moisture stress is not always a good indicator of soil-water stress within the soil-moisture control section. Examination of data for the total soil-water regime (Tables 9 and 10 and Appendix B) show that a general relationship between plant-moisture stress and soil-water stress does not exist for the Jory (w),Kilchis, and Klickitat sites at any of the following levels: soil-moisture control zone, solum depth, profile depth, or any portion of these zones or depths.

The curves for the remaining sites show that the soil-plant water relationships are generally the same.

Cambial Activity

It is not understood at this time what mechanism triggers the physiological change from springwood to summerwood. Larson (1964) stated that the effect of environment on xylem formation is largely indirect. The direct effect of environment is on vegetative growth of the crown, the production site of the auxins. The auxins regulate the xylem activity. Whitmore and Zahner (1966) reported that moisture stress is known to affect cell expansion independently of auxins. They found the extractable auxin content in irrigated and dry trees to be the same. They also state that the rate of cambial division is probably regulated by growth substances but not limited to those produced in expanding shoots. The process is affected by moisture and ultimately limited by intrinsic patterns of growth.

Zimmermann (1964) reviewed the subject of formation of wood. The reader is directed to this reference for a detailed discussion.

Plant-Moisture Stress

Regardless of the mechanisms involved in transition and dormancy, the results of this study show that Douglas-fir trees in the two climatic zones differ with respect to plant-moisture stress at the time of springwood-summerwood transition and dormancy.

Differences in plant-moisture stress between the xeric-mesic and moist-mesic zones at time of transition were highly significant at the two percent level (Table 13). The mean stress in the xeric-mesic zone was 7.1 bars while the mean stress in the moist-mesic zone was 4.4 bars (Table 12, page 64). Differences in plant-moisture stress between the xeric-mesic and moist-mesic zones at the time of dormancy are also shown in Table 12. These differences were significant at the ten percent level (Table 13, page 65). Data were not available for the Jory (w) site as the tree had not become dormant. Data for the Blachly site were omitted because heavy rainfall between the last two readings left doubts as to where dormancy occurred with respect to moisture stresses.

Mean plant-moisture stress was 17.5 bars for trees in the xeric-mesic zone at time of dormancy as compared to 12.1 bars for trees in the moist-mesic zone.

These data show that Douglas-fir trees respond significantly differently to the two climatic zones as distinguished by the soil classification system.

Considerable variation in stress existed at transition and dormancy among trees in the xeric-mesic zone. The Dixonville (s. v.) tree had higher tensions at transition (9.3 bars) and dormancy (23.5 bars) than the other trees in this zone. The Jory (w) tree had the lowest stress of all the trees in this zone at transition time (5.5 bars). Extrapolation of data from Figure 7 indicates that the Jory (w) site would have had the lowest stress at dormancy.

The variations in stress described above coincide with other data (Table 9, and Figures 6, 7, 8, and 9) which show that the Dixonville (s. v.) site contained the least amount of available water (9.9 cm) and had a maximum plant-moisture stress of 26.1 bars. The tree on the Jory (w) site, which was undoubtedly obtaining moisture from an underground source, had a maximum plant-moisture stress of 8.6 bars. This was the lowest maximum stress for the study trees in the xeric-mesic zone.

The Nekia soil held 18.1 cm of available water and the Jory (n) soil held 22.4 cm of available water. The trees growing on these two sites went into summerwood production at the same plant-moisture stress, but the Nekia tree with its 18.1 cm of available water went to dormancy at 15.8 bars tension while the Jory (n) tree with its 22.4 cm of available water went to dormancy at 13.2 bars.

These data seem to suggest that, in addition to the trees responding differently to the two climatic zones, they also responded differently to the specific sites, upon which they were growing within a climatic zone. These data were not analyzed further because adequate samples were lacking to overcome microclimatic and genetic variations.

Mooney and West (1964) reported that young plants can rapidly adjust to a new environment. Their findings help substantiate the trend mentioned above. They grew plants from seeds which were collected from different elevational sources. The plants were grown in a central area and distributed to different climatic zones. After three weeks they were returned to the central growing area and the photosynthetic rate was measured at different temperatures. They found that the plants which were growing in a cool climate for three weeks had a more efficient photosynthetic rate when phytosynthesis was measured under cool conditions. Likewise, the plants acclimatized to warm conditions for three weeks had a more efficient photosynthetic rate when photosynthesis was measured under warm conditions.

Variations in moisture-stress data obtained from the sites in the moist-mesic zone were not as great as those obtained in the xeric-mesic zone; however, the same relationships held. The Kilchis study tree grew on a soil with the lowest moisture holding capacity (2. 1 cm) and had the highest stress of all the study trees in this zone at the time of transition (4. 8 bars) and dormancy (14. 8 bars). Klickitat soil had the next lowest moisture holding capacity (3. 5 cm). The tree growing on this soil had a stress of 4. 4 bars at transition and 14. 1 bars at dormancy. Hembre soil had the highest moisture holding capacity (28. 8 cm) of all the sites. The study tree growing on this soil had a tension of 4. 2 bars at time of transition and only 7. 4 bars at time of dormancy.

Variations in moisture stress within the moist-mesic zone are parallel with those within the xeric-mesic zone which indicate that individual trees tend to adapt to the specific site upon which they are growing.

Table 14, page 67, shows the number of days elapsed from bud swell to transition and from bud swell to dormancy for each study tree within each climatic zone. Table 14 also shows the linear growth in mm and cross sectional growth in cm^2 for the springwood and summerwood produced for the 1969 growing season. These measurements were taken at one location on each tree.

The main point of interest is that the trees in the xeric-mesic zone grew springwood for an average of 72 days and summerwood for an average of about 75 days for an average overall growing season of about 147 days. Trees in the moist-mesic zone grew springwood for an average of 49 days and summerwood for an average of 71 days for an average overall growing season of 120 days. These data show that growth was more rapid in the trees from the moist-mesic zone and that these trees had a shorter growing season.

The above results agree with the remarks made by Zahner (1968). He reported that the decreased rate of cell division coincides with the high internal water deficits. Also that there is overwhelming circumstantial evidence (presented in his review) that the summer period of water stress does cause a direct reduction in the rate of cell division in the cambial meristem of trees.

There are different results reported for Pinus resinosa. Whitmore and Zahner (1966) reported that drought initiated summerwood in Pinus resinosa approximately 30 percent sooner than in watered trees. Zahner and Oliver (1962) studied the influence of thinning and pruning on the date of initiation of summerwood. They found that the transition occurred approximately two weeks later in thinned stands than in the check stands.

It was shown by Pierpoint (1967) that different species react differently to moisture stresses. Slatyer (1957) went one step further. He proposed that the individual plant under study is a major factor since the osmotic pressure of the plant leaves is fundamentally the factor which determines at which point permanent wilting occurs.

Other workers have reported relationships between rainfall and growth with respect to species. Zahner and Donnelly (1967) plotted relations between widths of annual rings of Pinus resinosa and rainfall. A correlation existed between width and total rainfall from July 1 to August 31, for the previous year plus rainfall from May 16 to September 15, for the current season. Fritts, Smith and Stokes (1965) reported that in conifers, up to 90 percent of the variation in width of annual rings had been attributed to water stress in a semi-arid climate. The conditions in southwest Colorado that contribute to narrow rings in mature Douglas-fir trees were found to be a hot and dry previous summer and a dry current winter, spring or summer. Phipps (1961) reported that high air temperatures during periods of low soil water in midsummer were consistently associated with temporary and sometimes permanent, cessation of growth of all deciduous trees in the Neotoma forest communities.

Growth for some species was greatly influenced by the previous years climatic conditions. Growth for other species was greatly influenced by the current years conditions. Some species had their growtn influenced by the previous and current years climatic conditions.

Soil-Water Depletion

Boggess (1956) reported that diameter growth in shortleaf pine and white oak stopped when the available soil-water was depleted. Also, cumulative basal area expansion in both species slowed when approximately one-half the available water depleted from the surface meter of soil. Kozlowski (1967) showed that the stem of a box elder had no expansion at night and the diurnal stem contraction predominated as soil moisture was depleted. McClurkin (1958) and Fritts (1958, 1960) found a direct correlation between slow radial growth and low levels of available soil-water. These experiments were on short leaf pine and beech.

Research data cited above shows that rate of radial growth slows as water is depleted. Radial growth ceases as soil-water stresses become great or the available water has been consumed.

Percent of available soil water which was depleted from the upper one-third of the profile at time of transition is shown in Table 12, page 64. The maximum percent of available water used in the xeric-mesic zone at transition was correlated more closely to the upper one-third of the profile than any other depth range.

The percent of available water used at time of dormancy was best correlated to the entire profile because the upper one-third of the profile (in most soils) lacked available water for long periods of time before dormancy.

Data from Table 12 for the moist-mesic zone at transition time show definite inadequacies. The Kilchis and Klickitat sites show 0 cm. of available water used but had trees growing on them for 60 and 49 days, respectively. How, then, did these trees sustain growth without depleting available water from the soil? There are two probable reasons. First, there was ample rainfall from bud swell to the time of transition (Appendix B) to keep the soils recharged and provide water for tree growth. Second, as was discussed earlier, it was felt the moisture tension blocks placed beneath the crown did not sample an adequate portion of the active rootzone of the trees growing on these skeletal soils.

It was felt that the measured percent of available water used by the trees at the time they became dormant was representative. The only discrepancy was the Dixonville (s. v.) site. Table 9 shows that the Dixonville (s. v.) soil profile was completely void of available water for six weeks prior to dormancy. Dixonville (s. v.) data in Appendix B shows this site had available water deep in the saprolite and that dormancy did not occur until the available water was depleted to a depth of 76 cm. This was somewhat surprising as it was not anticipated that the moisture could move from this dense saprolite, which did not contain observable roots, into the root zone rapidly enough to sustain tree growth. The only other alternative was that the roots were indeed present in this zone. In either case, the moisture was difficult to extract as shown by the high plant-moisture stress before dormancy.

Differences in percent available water removed at time of dormancy were quite great between the sites in the xeric-mesic zone and the moist-mesic zone. The trees in the xeric-mesic zone extracted almost all the available water before they became dormant. Trees in the moist-mesic zone had only extracted about 60 percent before dormancy.

CONCLUSIONS

Soil Classification

The current growing season's precipitation data, as correlated to present and past records, show that the study sites on McDonald Forest received the normal amount of rainfall. Records show that rainfall is not expected to exceed the current year's rainfall by more than 2. 5 cm. in seven out of ten years. This deviation does not influence soil classification. All study sites in McDonald Forest had a soil-water stress of 15 bars tension for at least 60 consecutive days within the soil-moisture control section. Without doubt these sites meet the xeric criteria as defined by the soil classification system.

Two official weather stations located closest to the study sites in the Marys Peak area recorded the normal precipitation for the current growing season. Therefore, it is logical to assume that the study sites received the normal amount of precipitation. None of the Marys Peak study sites had a soil-water stress of 15 bars for 60 consecutive days within the soil-moisture control section; therefore, these sites are not xeric.

Additional sites located on an elevation gradient adjacent to Marys Peak did not have a 15 bar stress for 60 consecutive days. None of these sites can be defined as xeric, yet one is lower in elevation than some of the xeric sites and another is only 7 m higher than the highest site on McDonald Forest. This elevational overlap shows that elevation alone is a poor indicator of soil classification differences based on soil-water stress.

Vegetative indicators listed by Thomas et al. (1969) proved to be the most valuable field guide to separate these zones from one another.

Data show that sites selected for the Dixonville (s. v.), Jory (w), Nekia, and Jory (n) soils are definitely within the defined xeric-mesic zone. Sites selected for the Blachly, Kilchis, Klickitat, and Hembre soils as well as the supplementary sites of Klickitat and Honeygrove soils are not in the xeric-mesic zone.

Insofar as the study sites are representative of the soil series, the present classification of these series as xeric or not xeric is substantiated.

Soil temperature data and related air temperature data from official weather stations show that both the McDonald Forest sites and Marys Peak sites meet the mesic criteria as defined by the soil classification system.

The results of this study indicate that plant-moisture stress cannot be used in lieu of soil-water stress as a basis for soil classification. Plant-moisture stresses within one species are influenced by factors very difficult to evaluate in the field. Available water within the total rooting area of a plant cannot be determined unless the roots are confined in some manner or a better scheme is devised to measure soil water throughout the root zone. Plant-moisture stress measured on foggy or rainy mornings does not reflect the existing soil-water conditions. Likewise, water conditions in the soil-moisture control section do not necessarily reflect moisture stress or growth conditions within the plant. This is probably because the control section does not always encompass the entire root zone.

Plant-moisture stress was shown not to be a consistent indicator of soil-water depletion in the moisture control section, or any other combinations of soil depth.

Cambial Activity

Significance of the xeric -mesic and moist-mesic zones is accentuated by the difference demonstrated in plant response to moisture stress in each zone.

The plant-moisture and soil-water stresses at the summerwood-springwood transition and at dormancy were studied. Douglas-fir trees in the xeric-mesic zone went into the springwood-summerwood transition at a plant-moisture stress which was very significantly higher than that of Douglas-fir trees in the moist-mesic zone. Douglas-fir trees in the xeric-mesic zone had significantly higher plant-moisture stress when they became dormant than trees in the moist-mesic zone.

Percent of available water removed from the upper one-third of the profile at the time the study trees reached springwood-summerwood transition was much greater in the xeric-mesic zone than in the moist-mesic zone. Percent of available water removed from the entire profile at the time the study trees became dormant was also much greater in the xeric-mesic zone.

Douglas-fir trees in the xeric-mesic zone produced springwood a greater number of days than trees growing in the moist-mesic zone but did not necessarily produce a greater amount. Also, Douglas-fir trees generally grew a greater number of days in the xeric-mesic zone than they did in the moist-mesic zone but did not necessarily produce more total wood.

It was concluded that Douglas-fir trees growing on xeric-mesic soils responded significantly different to moisture stresses than trees growing on soils classified as moist-mesic. These differences show that the classification criteria which separates soils into xeric and nonxeric zones are pertinent.

There were indications that the individual tree adapted to the specific site upon which it occupied. A study designed to test this individual adaptation characteristic may help narrow the broad current thinking concerning Douglas-fir growth with respect to climate.

BIBLIOGRAPHY

Bates, E.M. and W. Calhoun, Jr. 1969. Local climatological data for Oregon State University, 1967. Corvallis, Oregon State University. Agricultural Experiment Station. Special Report No. 277.

Blake, G.R. 1965. Bulk density. In: Methods of soil analysis, ed. by C.A. Black, Madison, Wisconsin, American Society of Agronomy Inc. p. 374-390.

Boggess, W.R. 1953. Diameter growth of short leaf pine and white oak during a dry season. University of Illinois Agriculture Experiment Station. Forestry Note 37.

Boggess, W.R. 1956. Weekly diameter growth of short leaf pine and white oak as related to soil moisture. Proceedings of Society American Foresters p. 83-89.

Box, J.E. and S.A. Taylor. 1962. Influence of soil bulk density on matric potential. Soil Science Society of America Proceedings 26:119-122.

Breazeale, E.L., W.T. McGeorge and J.F. Breazeale. 1950. Moisture absorption by plants from an atmosphere of high humidity. Plant Physiology 25:413-419.

Breazeale, E.L., W.T. McGeorge, and J.F. Breazeale. 1951. Water absorption and transpiration by leaves. Soil Science 72:239-244.

Broadfoot, W.M. 1954. Core vs. bulk samples in soil moisture tension analysis. In: Some field, laboratory, and office procedures for soil-moisture measurement. New Orleans. p. 22-25. (U.S. Southern Forest Experiment Station. Occasional Paper 135).

Calhoun, W. 1969. Record of evaporation and climatological observations. Unpublished records. Corvallis, Oregon Agricultural Experiment Station, Dept. of Farm Crops.

Chalk, L. 1930. The formation of spring and summer wood in ash and Douglas-fir. Oxford Forestry Memoirs, No. 10.

APPENDICES

Delmhorst Instrument Company. Operating instructions for model KS soil moisture tester. n.p.

Fisher, R.F. and E.L. Stone. 1968. Soil and plant moisture relations of red pine growing on a shallow soil. Soil Science Society of America Proceedings 32:725-728.

Fraser, D.A. 1956. Ecological studies of forest trees at Chalk River, Ontario, Canada. II Ecological conditions and radial increment. Ecology 37:777-789.

Fritts, H.C. 1958. An analysis of radial growth of beech in a central Ohio forest during 1954-1955. Ecology 37:705-720.

Fritts, H.C. 1960. Multiple regression analysis of radial growth in individual trees. Forest Science 6:334-349.

Fritts, H.C., D.G. Smith and M.A. Stokes. 1965. The biological model for paleoclimatic interpretations of Mesa Verde tree-ring series. American Antiquity 31:101.

Elrick, D.E. and C.B. Tanner. 1955. Influence of sample pretreatment on soil moisture retention. Soil Science Society of America Proceedings 19:279-282.

Gardner, W.H. 1965. Water content. In: Methods of soil analysis. Part I, ed. by C.A. Black, Madison, American Society of Agronomy Inc., p. 82-127.

Gardner, W.R. 1965. Dynamic aspects of soil water availability to plants. Annual Review of Plant Physiology 16:323-342.

Gindel, I. 1966. Attraction of atmospheric moisture by woody xerophytes in arid climates. Commonwealth Forestry Review 45:297-321.

Haise, H.R. and O.J. Kelley. 1946. Relation of moisture tension to heat transfer and electrical resistance in plaster of paris blocks. Soil Science 61:411-422.

Harms, W.R. 1969. Leaf-water deficits of tree seedlings in relation to soil moisture. Forest Science 15:58-63.

Hill, J.N.S. and M.E. Summer. 1967. Effect of bulk density on moisture characteristics of soils. Soil Science 103:234-238.

Husch, B. 1959. Height growth of white pine in relation to selected environmental factors on four sites in northeastern New Hampshire. New Hampshire Agriculture Experiment Station Technical Bulletin No. 100.

Johnsgard, G.A. 1963. Temperature and the water balance for Oregon weather stations. Corvallis, Oregon State University. Agricultural Experiment Station. Special Report No. 150.

Johnston, R.D. 1964. Water relations of Pinus radiata under plantation conditions. Australian Journal of Botany 12:111-124.

King, James E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forestry Research Center. Centralia, Washington. 49 p. (Weyerhaeuser Forestry Paper No. 8)

Kozlowski, T.T. 1967. Diurnal variations in stem diameters of small trees. Botanical Gazette 128:60-68.

Kraus, J.F. and S.H. Spurr. 1961. Relationship of soil moisture to the springwood-summerwood transition in southern Michigan red pine. Journal of Forestry 59:510-511.

Larson, P.R. 1964. Environment effects on wood formation. In: The formation of wood in forest trees, ed. by M.H. Zimmermann, New York, Academic Press. p. 345-365.

McArdle, R.E., W.H. Meyer and D. Bruce. 1949. The yield of Douglas-fir in the Pacific Northwest. Washington, D.C. 74 p. (U.S. Dept. of Agriculture Technical Bulletin 201).

McClurkin, D.C. 1958. Soil moisture content and shortleaf pine radial growth in north Mississippi. Forest Science 4:232-238.

McMinn, R.G. 1960. Water relations and forest distribution in the Douglas-fir region of Vancouver Island. Ottawa, Ontario. (Canadian Dept. of Agriculture, Division of Forest Biology, Publication No. 1091).

McMinn, R.G. 1963. Characteristics of Douglas-fir root systems. Canadian Journal of Botany 41:105-121.

Mendenhall, William. 1967. Introduction to probability and statistics. Second edition, Belmont, California. Wodsworth Publishing Company, Inc. 388 p.

Miller, L. N. 1965. Changes in radiosensitivity of pine seedlings subjected to water stress during chronic gamma irradiation. Health Physics 11:1653-1662.

Monteith, J. L. 1961. Dew: Facts and falacies. In: The water relations of plants ed. by A. J. Rutter and E. H. Whitehead. London, Blackwell. (Third Symposium of the British Ecological Society p. 37-56.)

Mooney, H. A. and M. West. 1964. Photosynthetic acclimation of plants of diverse origin. American Journal of Botany 51:825-827.

Mueller-Dombois, D. 1964. Effect of depth to water table on height growth of tree seedlings in the greenhouse. Forest Science 10:306-316.

Patric, J. H. 1966. Rainfall interception by mature coniferous forests of southeast Alaska. Journal of Soil and Water Conservation 21:229-231.

Phipps, R. L. 1961. Analysis of five years dendrometer data obtained within three deciduous forest communities of Neotoms. Columbus, Ohio Agriculture Experiment Station Research Circular No. 105.

Pierpoint, G. 1967. Direct measurement of internal moisture deficits in trees. Forestry Chronicle 43:145-148.

Richards, L. A. 1947. Pressure membrane apparatus - construction and use. Agricultural Engineering 28:451-455.

Richards, L. A. 1948. Porous plate apparatus for measuring moisture retention and transmission by soil. Soil Science 66:105-110.

Rutter, A. J. 1968. Water consumption by forests. In: water deficits and plant growth.. Vol. 2, ed. by T. T. Kozlowski, New York, Academic Press. p. 23-84.

Salter, P. J. 1967. Methods of determining the moisture characteristics of soils. Experimental Agriculture 3:163-173.

Salter, P. J. and J. B. Williams. 1965. The influence of texture on the moisture characteristics of soils. I. A critical comparison of techniques for determining the available-water capacity and moisture characteristic curve of a soil. Journal of Soil Science 16:1-15.

Scholander, P. F. et al. 1965. Sap pressure in vascular plants. Science 148:339-346.

Shachori, A., D. Rosenzweig, and A. Poljakoff-Mayber. 1967. Effect of Mediterranean vegetation on the moisture regime. In: Forest Hydrology, ed. by W. E. Sopper and H. W. Lull, Oxford, Pergamon. 813 p.

Shepherd, K. R. 1964. Some observations on the effect of drought on the growth of Pinus radiata D. DON. Australian Forestry 28:7-22.

Slatyer, R. O. 1957. The significance of the permanent wilting percentage in studies of plant and soil water relations. Botanical Review 23:585-636.

Slatyer, R. O. 1960. Absorption of water by plants. Botanical Review 26:331-392.

Slatyer, R. O. 1967. Plant-water relationships. New York, Academic Press Inc. 366 p.

Stalfelt, M. G. 1963. On the distribution of the precipitation in spruce. In: The water relations of plants, ed. by A. J. Rutter and F. H. Whitehead, Oxford, Blackwell. p. 115-126.

Stone, E. C. 1957. Dew as an ecological factor. I. A review of the literature. II. The effect of artificial dew on the survival of Pinus ponderosa and associated species. Ecology 38:407-422.

Stone, E. C. 1958. Dew absorption by conifers. In: The physiology of forest trees, ed. by K. V. Thimann. New York. Ronald Press, Chapter 7.

Strand, R. F. 1964. Soil and growth studies in Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] stands near Molalla, Oregon. Doctoral dissertation. Corvallis, Oregon State University, 193 numb. leaves.

Tanner, C.B., E. Abrams, I.C. Zubiski. 1949. Gypsum moisture - block calibration based on electrical conductivity in distilled water. Soil Science Society of America Proceedings 13:62-65.

Thomas, B.R., J.A. Pomerening, and G.H. Simonson. 1969. Reconnaissance soil survey of the Willamette Basin, Oregon. Segment III: Uplands outside national forests. Corvallis, Oregon State University. Agricultural Experiment Station. Special Report No. 269.

U.S. Department of Agriculture. 1951. Soil survey manual. Washington, D.C. 503 p. (Handbook No. 18, and 1962 sup. replacing p. 173-188).

U.S. Soil Conservation Service. 1967. Supplement to soil classification system (7th approximation) Washington, D.C. 207 p.

U.S. Soil Conservation Service. 1968. Amendments to the March 1967 supplement to the soil classification system. Washington, D.C. July 25.

U.S. Weather Bureau. 1969. Climatological data: Oregon. Vol. 75.

Waring, R.H. and B.D. Cleary. 1967. Plant moisture stress: evaluation by pressure bomb. Science 155:1248-1254.

Wenger, K.F. 1952. Effect of moisture supply & soil texture on the growth of sweetgum and pine seedlings. Journal of Forestry 50:862-864.

Whitmore, F.W. and R. Zahner. 1966. Development of the xylem ring in stems of young red pine trees. Forest Science 12:198-210.

Wolter, K.E. 1968. A new method for marking xylem growth. Forest Science 14:102-104.

Young, R.N. and B.P. Warkentin. 1966. Introduction to soil behavior. New York, The Macmillan Co. 451 p.

Zahner, R. 1968. Water deficits and growth of trees. In: Water deficits and plant growth. Vol. 2, ed. by T.T. Kozlowski, New York, Academic Press, p. 191-254.

Zahner, R. and J.R. Donnelly. 1967. Refining correlations of rainfall and radial growth in young red pine. Ecology 48:525-530.

Zahner, R. and W.W. Oliver. 1962. The influence of thinning and pruning on the date of summerwood initiation in red and jack pines. Forest Science 8:51-63.

Zimmermann, M.H. (ed.) 1964. The formation of wood in forest trees. New York, Academic Press. 562 p.

APPENDIX A

Soil Profile Descriptions for Study Sites Occurring in the Xeric-Mesic Zone

Dixonville (shallow variant)

A1 -- 0.5 cm. --Very dark brown (10YR 2/2 crushed) clay, very dark grayish brown (10YR 3/2) dry; strong medium and fine granular structure; extremely hard, firm, sticky, very plastic; plentiful fine roots; porous; shot present; neutral (pH 6.6); clear smooth boundary.

B1 -- 5-10 cm. --Very dark grayish brown (10YR 3/2 crushed) clay, dark brown (10YR 3/3) dry; weak medium subangular blocks breaking to strong fine subangular blocky structure; extremely hard, firm, sticky, very plastic; plentiful fine and medium roots; porous, faint patchy clay films in cavities; dark stains on ped surfaces; many shot; neutral (pH 6.6); clear smooth boundary.

B21t -- 10-30 cm. --Very dark brown (10YR 2/2) clay, very dark brown ped surface (10YR 2/2) dry; very dark grayish brown ped interior (10YR 3/2) dry; moderate medium subangular blocks breaking to strong fine subangular blocky structure; extremely hard, very firm, very sticky, very plastic; plentiful medium roots, abundant medium tubular pores; prominent patchy clay films on peds and in pores and cavities; dark stains on ped surfaces; many shot; neutral (pH 6.6); clear wavy boundary.

B22t -- 30-45 cm. --Dark brown (10 YR 4/3 crushed) clay; moderate medium prisms breaking to strong medium subangular blocky structure; extremely hard, very firm, very sticky, very plastic; few fine roots; few medium tubular pores; prominent broken clay films on peds and in pores and cavities; many sand sized particles of basalt; slightly acid (pH 6.4); abrupt smooth boundary.

R -- 45-65 + cm. --Saprolite forming a paralithic contact.

Colors are for moist conditions unless otherwise noted.

pH by indicators.

Location: On flat ridge top north of power line, SE 1/4, SE 1/4, sec. 16, T. 11S., R. 5 W.

Aspect: Flat

Elevation: 198 meters

Jory (west slope)

01 -- 1-0 cm. --Needles, mosses, twigs, and leaves.

A11 -- 0-10 cm. --Dark reddish brown (5YR 3/3 crushed) gravelly silty clay loam, reddish brown (5YR 4/3) dry; strong fine and medium granular structure; hard, firm, sticky, plastic; many fine and medium roots; porous; 30% gravels; slightly acid (pH 6.4); clear smooth boundary.

IIA12 -- 10-25 cm. --Dark reddish brown (5YR 3/3 crushed) silty clay, reddish brown (5YR 4/3) dry; weak fine subangular blocks breaking to strong fine and medium granular structure; very hard, very firm, very sticky, very plastic; plentiful medium roots; porous; 10% gravels; slightly acid (pH 6.2); clear wavy boundary.

II B1 -- 25-45 cm. -- Dark reddish brown (2.5YR 3/4 crushed) clay, dark reddish brown (5YR 3/3) dry; strong medium subangular blocky structure; extremely hard, extremely firm, very sticky, very plastic; plentiful medium roots; many fine tubular pores; faint patchy clay films in pores and cavities; 10% coarse gravel; many very fine shot; medium acid (pH 6.0); clear wavy boundary.

IIIB22t -- 57-75 cm. -- Dark red (2.5YR 3/6 crushed) clay; moderate coarse prismatic structure; extremely hard, firm, very sticky, very plastic; few fine roots; many pores; prominent complete clay films; 10% stones; many very fine shot; medium acid (pH 5.8); clear wavy boundary.

IIIB23t -- 75-95 cm. -- Dark red (2.5YR 3/6 crushed) silty clay; moderate medium prismatic structure; hard, firm, sticky, plastic; few very fine roots; many pores; distinct broken clay films; 10% stones; many very fine shot; medium acid (pH 5.6); clear wavy boundary.

IIIB3t -- 95-115 cm. -- Red (2.5YR 4/6 crushed) silty clay loam; weak medium prisms breaking to moderate medium subsngular blocky structure; hard, firm, slightly sticky, plastic; very few fine roots; many pores; distinct patchy clay films; 20% stones and gravel; dark stains on ped surfaces; many fine shot; very strongly acid (pH 4.8); clean smooth boundary.

IIICt&R -- 115-162 _ cm. -- Dark red (2.5YR 3/6 crushed) clay loam, yellowish red (5YR 5/6) dry; massive; friable, slightly sticky, plastic; faint patchy clay films; 40% fractured rock; dark stains; very strongly acid (pH 4.6).

Colors are for moist conditions unless otherwise noted.

pH by indicators.

Location: On west facing ridge top, approximately 60 meters above road. SE 1/4, SE 1/4 SE 1/4, sec. 4, T. 11S., R. 5 W.

Aspect: West

Elevation: 328 meters

Nekia Site [7]

01 -- 1-0 cm. -- Leaf litter, mosses, and twigs.

A11 -- 0-8 cm. -- Dark reddish brown (5YR 3/2) silty clay loam, dark reddish brown (5YR 3/4) dry; moderate fine and medium granular structure; hard, friable, slightly sticky, slightly plastic; many fine and medium roots; many fine shot; 10% gravel; slightly acid (pH 6.4); clear wavy boundary.

A12 -- 8-25 cm. -- Dark reddish brown (5YR 3/3 crushed) silty clay, dark reddish brown (5YR 3/4) dry; strong medium and fine granular structure; hard, firm, slightly sticky, slightly plastic; many fine and medium roots; many fine shot; 5% gravel; slightly acid (pH 6.2); clear smooth boundary.

B1 -- 25-37 cm. -- Dark red (2.5YR 3/6 crushed) silty clay, reddish brown (2.5YR 4/4 crushed) dry; moderate medium and fine subangular blocky structure; hard, firm, sticky, plastic; many fine and medium roots; many fine pores; many very fine shot; 5% gravel; faint broken clay films in pores; dark coatings on peds; medium acid (pH 6.0); clear smooth boundary.

IIB21t -- 37-63 cm. -- Dark reddish brown (2.5YR 3/4 crushed) clay, red (2.5YR 4/6) dry; strong coarse prisimatic structure; very hard, very firm, very sticky, very plastic; few fine roots; medium and fine pores; faint complete clay skins; many fine shot; 10% weathered stones and gravel; medium acid (pH 6.0); gradual smooth boundary.

IIB22t -- 63-88 cm. -- Red (2.5YR 4/6 crushed) clay; strong coarse prismatic structure; extremely hard, extremely firm, very sticky, very plastic; very few fine roots; faint complete clay films, many fine and medium shot; 5% gravel; medium acid (pH 5.8); gradual smooth boundary.

IIB23t -- 88-100 cm. -- Dark red (2.5YR 3/6 crushed) clay; strong coarse prismatic structure; extremely hard, very firm, very sticky, very plastic; distinct complete clay films on peds; many fine shot; 5% gravel; medium acid (pH 5.8); clear smooth boundary.

IIB3t -- 100-112 cm. -- Red (2.5YR 4/6 crushed) silty clay; moderate medium prismatic structure; hard, firm, sticky, plastic; distinct broken clay films on peds; many fine shot; 5% gravel; strongly acid (pH 5.4); clear smooth boundary.

IICt -- 112-187 + cm. -- Dark red (2.5YR 3/6 crushed) clay loam, yellowish red (5YR 4/6) dry; massive; friable, sticky, plastic; faint patchy clay films in cracks and pores; no roots; dark stains; 30% stones; strongly acid (pH 5.2).

Colors are for moist conditions unless otherwise noted.

pH by indicators

Location: On west facing ridge top, approximately 52 meters above road in SE 1/4, SE 1/4, SE 1/4, sec. 4, T. 11 S., R. 5 W.

Aspect: West

Elevation: 300 meters

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[7] The profile described meets the depth criterion for Jory. However, the average depth around the tree studied was 98 cm.

<u>Jory (north slope)</u>

01 -- 1-0 cm. -- Leaves, needles, twigs, and stems.

A11 -- 0-8 cm. -- Dark reddish brown (5YR 3/3 crushed) silty clay; moderate and fine medium granular structure; hard, firm, sticky, plastic; many fine, medium and few coarse roots; 2% gravel; slightly acid (pH 6.2); clear smooth boundary.

A12 -- 8-25 cm. -- Dark reddish brown (5YR 3/3 crushed) silty clay; weak fine subangular blocks breaking to strong medium and fine granular structure; very hard, very firm, sticky, very plastic; many fine and common medium and coarse roots; many fine shot; 2% gravel; medium acid (pH 6.0); clear wavy boundary.

B1 -- 25-42 cm. -- Dark reddish brown (2.5YR 3/4 crushed) clay; moderate fine and medium subangular blocky structure; very hard, very firm, very sticky, very plastic; common medium and coarse roots; many fine pores; faint patchy clay films; few fine shot; 5% gravel; medium acid (pH 6.0); gradual smooth boundary.

IIB2t -- 42-75 cm. -- Dark red (2.5YR 3/6 crushed) clay; moderate medium and coarse prismatic structure; extremely hard, extremely firm, very sticky, very plastic; common medium roots, many fine pores; distinct broken clay films; common fine shot; 10% gravel; medium acid (pH 5.8); clear smooth boundary.

IIB3t -- 75-102 cm. -- Dark red (2.5YR 3/6 crushed) silty clay loam; weak medium prismatic structure; hard, firm, sticky, very plastic; common fine roots; distinct broken clay films; 5% gravel; strongly acid (pH 5.2); clear wavy boundary.

IIC1t -- 102-165 + cm. -- Red (2.5YR 4/6 crushed) clay loam; massive; hard, friable, slightly sticky, plastic; distinct broken clay films; dark stains; 5% gravel; strongly acid (pH 5.2).

Colors are for moist conditions unless otherwise stated.

pH by indicators

Location: On north facing slope, approximately 9 meters above road in NE 1/4, SE 1/4, SE 1/4, sec. 4, T. 11 S., R. 5 W.

Aspect: North

Elevation: 290 meters

Soil Profile Descriptions for Study Sites Occurring in the Moist-Mesic Zone

Blachly

01 -- 2-0 cm. -- Needles, leaves, and twigs.

A1 -- 0-10 cm. -- Dark reddish brown (5YR 3/3 moist) very shotty clay loam; moderate fine and medium granular structure; soft, friable, slightly sticky, slightly plastic; many fine and medium roots; 35% soft shot; slightly acid (pH 6. 4); clear wavy boundary.

A12 -- 10-28 cm. -- Dusky red (2.5YR 3/3 crushed) heavy clay loam; strong medium and fine granular structure; soft, friable, sticky, slightly plastic; many roots, many shot; medium acid (pH 6.0); clear wavy boundary.

A3 -- 28-48 cm. -- Dark red (2.5YR 3/6 crushed) heavy clay loam; weak medium subangular blocks breaking to strong medium granular structure; hard, friable, sticky, plastic; few fine and coarse roots and common medium roots; many fine and medium pores; few fine shot; medium acid (pH 5.6); clear smooth boundary.

IIB1 -- 48-65 cm. -- Dark red (2.5YR 3/6 crushed) silty clay loam; weak medium subangular blocky structure; hard, friable, sticky, very plastic; few very coarse roots, many medium and fine roots; many fine and medium pores; few fine shot; 2% gravel; ando feeling; strongly acid (pH 5. 2); clear smooth boundary.

IIB21 -- 65-105 cm. -- Red (2.5YR 4/6 crushed) silty clay; weak medium prismatic structure breaking to moderate medium subangular blocky structure; hard, firm, very sticky, very plastic; common medium roots; faint broken clay films; dark stains on peds; few fine shot; very strongly acid (pH 4.8); clear wavy boundary.

IIB22 -- 105-135 cm. -- Red (2.5YR 4/6 crushed) silty clay; moderate medium subangular blocky structure; hard, firm, very sticky, very plastic; common medium roots and few coarse roots; faint patchy clay films; dark stains; few shot; very strongly acid (pH 4. 6); clear wavy boundary.

IIB3 -- 135-180 cm. -- Red (2.5YR 4/6 crushed) silty clay; weak medium subangular blocky structure; hard, friable, very sticky, very plastic; few medium roots; faint patchy clay films; many dark stains; few shot; extremely acid (pH 4. 4).

IIC -- 180-190 + cm. -- Red (2.5YR 4/6 crushed) silty clay loam; massive; hard, friable, sticky; few medium roots; few dark stains; few shot; extremely acid (pH 4.4).

Colors are for moist conditions unless otherwise noted.

pH by indicators.

Location: On property boundary between F.A.A. shed and road. SW 1/4, SW 1/4, NE 1/4, sec. 2, T. 13 S., R. 7 W.

Aspect: South of southeast

Elevation: 457 meters

Kilchis

6-0 cm. -- Gravel mantle

A1 -- 0-5 cm. -- Dark reddish brown (5YR 2/2 crushed) very gravelly loam; moderate fine granular structure; loose, friable; common fine and medium roots; 65% gravel; medium acid (pH 5.8); clear smooth boundary.

A12 -- 5-20 cm. -- Dark reddish brown (5YR 3/3 crushed) very gravelly loam; moderate medium granular structure; slightly hard, friable; many fine and medium roots; 25% stones, 40% gravel; medium acid (pH 5.6); clear wavy boundary.

B1 -- 20-35 cm. -- Dark reddish brown (5YR 3/4 crushed) very stony loam; moderate fine subangular blocky structure; slightly hard; friable; common fine and medium roots; 25% gravel, 45% stones, strongly acid (pH 5.4); gradual smooth boundary.

B2 -- 35-45 cm. -- Yellowish red (5YR 3/6 crushed) very stony light clay loam; moderate medium and fine subangular blocky structure; slightly hard, friable, slightly plastic; common fine and medium roots; 25% gravel, 35% stones; strongly acid (pH 5.4).

R -- 45 + cm. -- Fractured basic igneous bedrock with some soil in upper fractures.

Colors are for moist conditions unless otherwise noted.

pH by indicators.

Location: On ridgenose 10 meters above road. NW 1/4, SE 1/4, NE 1/4, sec. 3, T. 13 S., R. 7 W.

Aspect: South

Elevation: 625 meters

Klickitat

5-0 cm. -- Gravel mantle

A1 -- 0-5 cm. -- Dark reddish brown (5YR 2/2 crushed) very gravelly loam; moderate fine granular structure; loose, friable; many fine and medium roots; 60% gravel; medium acid (pH 5.8); clear smooth boundary.

A12 -- 5-22 cm. -- Dark reddish brown (5YR 3/2 crushed) very gravelly loam; weak medium granular structure breaking to moderate fine granular structure; slightly hard, friable; many fine and medium roots; 55% gravel; medium acid (pH 5.8); gradual smooth boundary.

B2 -- 22-40 cm. -- Dark reddish brown (5YR 3/4 crushed) very gravelly loam; moderate fine subangular blocky structure; slightly hard, friable; few coarse roots, common medium roots; 60% gravel; medium acid (pH 6.0); gradual smooth boundary.

B3 -- 40-62 cm. -- Dark reddish brown (5YR 3/4 crushed) very gravelly loam; weak fine subangular blocky structure; slightly hard, friable; few coarse roots, common medium roots; 50% gravel, 20% stones; medium acid (pH 5.8).

R -- 62 + cm. -- Fractured basic igneous bedrock.

Colors are for moist conditions unless otherwise noted.

pH by indicators.

Location: On ridgenose 11 meters above road. NW 1/4, SE 1/4, NE 1/4, sec. 3, T. 13 S., R. 7 W.

Aspect: South

Elevation: 626 meters

Hembre

01	--	3-0 cm. -- Leaves, needles, twigs, and branches.
A1	--	0-10 cm. -- Dark reddish brown (5YR 3/3 crushed) gravelly loam; moderate fine and medium granular structure; slightly hard, friable; many fine and medium roots; 30% gravels; slightly acid (pH 6.2); clear smooth boundary.
A12	--	10-30 cm. -- Dark reddish brown (5YR 3/3 crushed) gravelly loam; moderate medium and fine granular structure; slightly hard, friable; many roots; 20% gravel; medium acid (pH 6.0); roots or animal holes present; clear smooth boundary.
A3	--	30-42 cm. -- Dark reddish brown (5YR 3/4 crushed) loam; weak fine subangular blocky structure; slightly hard, friable, slightly plastic; many roots; 10% gravels, old root channels present; medium acid (pH 5.8); clear smooth boundary.
B1	--	42-62 cm. -- Reddish brown (5YR 4/4 crushed) clay loam; weak medium subangular blocky structure; slightly hard, friable, slightly sticky, plastic; many roots; 5% gravel; old root channels present; medium acid (pH 5.6); clear wavy boundary.
B2	--	62-102 cm. -- Yellowish red (5YR 4/6 crushed) heavy clay loam; moderate medium subangular blocky structure; hard, friable, slightly sticky, plastic; many roots; many pores; faint patchy clay films on peds; old root channels present; strongly acid (pH 5.2); clear wavy boundary.
B3	--	102-127 cm. -- Yellowish red (5YR 4/8 crushed) gravelly loam; weak medium subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; many roots; many pores; 25% weathered rocks occurring in pockets; dark stains on peds; very strongly acid (pH 5.0); clear wavy boundary.
C & R	--	127-185 + cm. -- Yellowish red (5YR 4/8 and 5/8 crushed) gravelly loam; massive; slightly hard, friable, slightly plastic; few medium roots, many pores; approximately 1/3 - 1/2 of horizon is weathered basic igneous rock; very strongly acid (pH 4.8).

Evidence of mixing down from A3.

Colors are for moist conditions unless otherwise noted.

pH by indicators.

Location:	On sideslope 8 meters above road. NW 1/4, SE 1/4, NE 1/4, sec. 3, T. 13 S., R. 7 W.
Aspect:	Southwest
Elevation:	630 meters

APPENDIX B

Condensed Field Data

Dixonville (shallow variant)

Date	Days since bud swell	PPT in cm	Pin No.	Plant-moisture stress in bars	Soil-water stress (bars) at indicated depths 8 cm	18 cm	25 cm	51 cm	76 cm
4/8/69	4				0	.3	.2	0	0
4/16	12			4.95	.3	.3	.2	0	0
4/23	19	2.51		4.4	.2	.4	.2	0	0
5/7	33	2.54		6.9	.3	.4	.3	.2	.2
5/13	39	.15			2.8	1.2	.5	0	.1
5/21	47	2.37		5.1	.8	1.1	.7	0	.2
5/29	55	.56	1	6.2	4.3	3.7	1.9	.2	.1
6/6	63	.46	2	8.6	6.6	6.3	4.3	.5	.1
6/12	69	---	3*	10.0	32+	15	5.8	.8	.2
6/17	74	---	4	14.1	32+	32+	10	1.2	.2
6/27	84	3.05	5	5.5[1]	2.3	5.8	6.6	2.0	.4
7/5	92	.94	6	6.2	2.2	5.0	6.0	2.2	.5
7/11	98	---	7	10.0	15	10	10	2.8	.3
7/19	106	---	8	13.7	32+	32+	23	3.7	1.2
7/26	113	---	9	16.5	32+	32+	32+	5.0	1.9
8/1	119	---	10	16.1	32+	32+	32+	5.6	2.3
8/9	127	---	11	17.2	32+	32+	32+	6.0	3.7
8/16	134	---	12	20.6	32+	32+	32+	10	3.7
8/23	141	---	13	20.6	32+	32+	32+	23	5.0
8/29	147	---	14	21.6	32+	32+	32+	23	5.0
9/9	158	---	15**	25.4	32+	32+	32+	32+	5.4
9/16	165	---	16	26.1	32+	32+	32+	32+	5.8
9/20	169	9.70		---	.7	.4	.4	.5	4.3
9/25	174	.89	17	3.4[1]	.5	.2	.3	.6	5.0

* Springwood-summerwood transition completed.

** Cambium dormancy completed.

1 Datum was collected on rainy or foggy morning.

Jory (west slope)

Date	Days since bud swell	PPT in cm	Pin No.	Plant-moisture stress in bars	Soil-water stress (bars) at indicated depths								
					8 cm	18 cm	25 cm	51 cm	76 cm	102 cm	117 cm	140 cm	165 cm
4/7	0				0	0	0	0	0	0	0	0	0
4/16	9	---		4.1	.2	.1	.1	0	0	0	0	0	0
4/23	16	3.35		3.8	.2	.1	.1	0	0	0	0	0	0
5/7	30	2.06		4.5	.2	.1	.1	0	.2	.1	0	0	0
5/13	36	.05		---	.7	.4	.2	.1	.1	.3	0	0	0
5/21	43	1.93		5.1	.6	.5	.6	.5	.6	.3	.3	0	0
5/29	51	.71	1	5.1	1.1	1.2	1.3	1.2	.9	.4	.4	0	0
6/9	62	.48	2	4.1	2.2	2.3	3.1	3.4	1.3	.9	.6	0	.2
6/17	70	---	3	4.8	3.4	3.7	4.3	5.4	2.3	1.2	.9	0	0
6/27	80	2.79	4	3.4	.7	1.4	5.0	6.3	3.1	1.9	1.1	.6	.3
7/5	88	.91	5	3.8	.7	1.2	3.1	6.0	3.7	2.2	1.3	1.0	.4
7/11	94	---	6	5.5	1.9	2.5	5.4	6.6	4.3	2.3	1.7	1.6	1.6
7/19	102	---	7*	5.5	4.3	5.6	10.0	23.0	5.8	2.8	2.2	2.3	.8
7/26	109	---	8	5.1	23	23	32+	32+	23	3.4	3.1	3.4	1.4
8/1	115	---	9	5.5	32+	32+	32+	32+	23	3.7	3.7	5.0	1.3
8/9	123	---	10	5.5	32+	32+	32+	32+	32+	10	5.6	5.8	2.2
8/16	130	---	11	6.5	32+	32+	32+	32+	32+	5.8	5.2	6.6	2.5
8/23	137	---	12	7.6	32+	32+	32+	32+	32+	10	6.3	15	3.4
8/29	143	---	13	7.9	32+	32+	32+	32+	32+	32+	10	32+	4.3
9/9	154	---	14	8.2	32+	32+	32+	32+	32+	32+	15	23.0	5.8
9/16	161	---	15	8.6	32+	32+	32+	32+	32+	32+	15	32+	6.0
9/20	165	8.64		---	.3	.4	.4	.4	1.0	1.6	2.5	32+	15.0
9/25	175	1.05	16**	3.1[1]	.3	.3	.3	.5	1.0	2.3	3.1	15	6.0

* Springwood-summerwood transition completed.

** Cambium still active.

1 Datum was collected on rainy or foggy morning.

Nekia

Date	Days since bud swell	PPT in cm	Pin No.	Plant-moisture stress in bars	Soil-Water stress (bars) at indicated depths 8 cm	18 cm	25 cm	51 cm	76 cm	102 cm	140 cm
4/7					0	0	0	0	0	0	0
4/16	0			4.8	.2	0	0	0	0	0	0
4/23	7	3.35		3.8	.2	0	.1	0	0	0	0
5/7	21	2.06		5.8	.1	0	0	.2	0	0	0
5/13	27	.05		---	.9	.2	.6	.4	0	0	0
5/21	35	1.93		4.1	.7	.5	1.0	.6	.3	0	0
5/29	43	.71	1	5.1	2.3	1.8	2.0	1.1	.6	0	0
6/9	54	.48	2	5.1	2.2	5.0	5.3	3.4	2.2	.4	0
6/17	62	---	3*	8.2	23.0	10.0	10.0	5.6	4.3	.8	0
6/27	72	2.79	4	4.1[1]	2.0	2.2	4.3	23.0	6.3	1.2	.2
7/5	80	.91	5	5.1	2.2	1.8	2.5	5.2	6.6	1.6	.1
7/11	86	---	6	8.2	15	5.4	5.0	6.6	10.0	1.9	.3
7/19	94	---	7	11.0	32+	32+	32+	23	23	2.5	.4
7/26	101	---	8	12.4	32+	32+	32+	32+	32+	3.7	.6
8/1	107	---	9	12.0	32+	32+	32+	32+	32+	4.3	.8
8/9	115	---	10	12.4	32+	32+	32+	32+	32+	5.6	1.0
8/16	122	---	11	13.4	32+	32+	32+	32+	32+	5.8	1.2
8/23	129	---	12	16.5	32+	32+	32+	32+	32+	6.6	1.3
8/29	135	---	13	15.4	32+	32+	32+	32+	32+	10.0	1.6
9/9	146	---	14**	16.1	32+	32+	32+	32+	32+	23.0	1.6
9/16	153	---	15	18.2	32+	32+	32+	32+	32+	23.0	1.8
9/20	157	8.64		---	.9	.4	.4	.3	.4	.9	1.9
9/25	162	1.05	16	3.1[1]	.4	.3	.3	.3	.6	1.6	1.9

* Springwood-summerwood transition completed.

** Cambium dormancy completed.

1 Datum was collected on rainy or foggy morning.

Jory (north slope)

Date	Days since bud swell	PPT in cm	Pin No.	Plant moisture stress in bars	Soil-water stress (bars) at indicated depths 8 cm	18 cm	25 cm	51 cm	76 cm	102 cm	152 cm
4/16	0										
5/2	16			3.1	0	.1	.1	.2	.2	0	0
5/7	21	2.06		5.5	0	.3	.2	.2	.2	0	0
5/13	27	.05		---	.6	.6	.7	.4	.2	0	0
5/21	35	1.93		4.5	.4	.2	.7	.5	.3	.2	.5
5/29	43	.71	1	5.1	.8	1.0	1.2	1.0	.5	.3	.2
6/9	54	.48	2	4.1	2.2	3.1	3.1	2.0	1.2	.8	.4
6/17	62	---	3	6.9	5.3	5.6	5.0	3.4	1.8	.7	.4
6/27	72	2.79	4*	3.8[1]	1.0	.9	1.2	4.3	1.8	1.2	.6
7/5	80	.91	5	6.2	1.1	1.6	2.3	5.3	2.2	1.2	.6
7/11	86	---	6	6.5	3.1	5.8	6.0	5.8	2.5	1.6	.8
7/19	94	---	7	8.6	32+	23	23	6.6	3.4	2.2	.9
7/26	101	---	8	8.9	32+	32+	32+	15	4.3	2.8	1.2
8/1	107	---	9	9.3	32+	32+	32+	32+	5.4	3.4	1.4
8/9	115	---	10	9.6	32+	32+	32+	32+	10.0	5.0	2.2
8/16	122	---	11	12.0	32+	32+	32+	32+	6.6	5.3	2.3
8/23	129	---	12**	14.4	32+	32+	32+	32+	10.0	5.8	3.1
8/29	135	---	13	12.4	32+	32+	32+	32+	23	6.0	3.4
9/9	146	---	14	12.4	32+	32+	32+	32+	32+	15.0	4.3
9/16	153	---	15	12.7	32+	32+	32+	32+	32+	15.0	5.0
9/20	157	8.64		---	.7	.4	.3	.7	.8	2.3	5.0
9/25	162	1.05	16	3.8[1]	.7	.3	.2	.4	.7	2.3	4.3

* Springwood-summerwood transition completed.

** Cambium dormancy completed.

1 Datum was collected on rainy or foggy mornings.

Blachly

Date	Days since bud swell	PPT in cm	Pin No.	Plant-moisture stress in bars	Soil-water stress (bars) at indicated depths 8 cm	18 cm	25 cm	51 cm	76 cm	102 cm	152 cm	191 cm
5/8/69	0			3.8								
5/18	11	2.49		4.1	.2	.2	0	0	0	0	.1	0
5/31	24	3.25		4.1	.3	.2	0	0	.1	0	0	0
6/12	36	.05		3.1[1]	1.2	.5	.4	.3	.4	.5	.2	.1
6/20	44	---	1*	3.1[1]	4.3	1.7	.9	.5	.5	.4	.2	.1
7/2	56	5.77	2	2.7[1]	.3	.2	.2	.1	.4	.4	.3	.3
7/11	65	.18	3	2.1[1]	.6	.4	.4	.3	.5	.5	.4	.4
7/23	77	---	4	4.8	5.8	3.7	2.5	1.2	.9	.7	.5	.5
7/30	84	---	5	4.1	32+	6.6	5.8	3.7	1.9	1.2	.7	.5
8/10	95	.05	6	4.8	32+	32+	23	6.6	4.3	2.5	1.0	.8
8/17	102	---	7	6.2	32+	32+	32+	23	5.4	3.4	1.2	1.0
8/24	109	---	8	7.6	32+	32+	32+	32+	6.6	5.0	1.4	1.3
8/30	115	---	9	7.9	32+	32+	32+	32+	23	5.8	1.8	1.8
9/8	124	---	10	9.3	32+	32+	32+	32+	32+	15	2.3	2.3
9/17	133	---	11	8.2[1]	32+	32+	32+	32+	32+	23	4.3	3.4
9/21	137	11.5		---	.3	.3	.4	.6	1.4	3.4	5.0	3.4
9/26	142	1.7	12**	4.1	.3	.3	.4	.3	.8	1.4	3.7	3.1

* Springwood-summerwood transition completed.

** Cambium dormancy completed.

1 Datum was collected on rainy or foggy morning.

Kilchis

Date	Days since bud swell	PPT in cm	Pin No.	Plant-moisture stress in bars	Soil-water stress (bars) at indicated depths 8 cm	18 cm	25 cm	50 cm
5/1/69	0	2.74			.3	.3	.3	0
5/8	0	.20		3.8	.1	.1	.2	0
5/18	11	2.67		3.8	.2	.2	.2	0
5/31	24	3.08		4.1	.2	.2	.3	0
6/12	36	.05		3.1[1]	.2	.2	.2	0
6/20	44	---	1	3.1[1]	.3	.3	.3	0
7/2	56	6.23	2	2.4[1]	.3	.2	.2	0
7/11	65	.18	3*	2.1[1]	.3	.2	.2	0
7/23	77	---	4	5.1	.6	.4	.6	.5
7/30	85	---	5	4.8[1]	1.2	.7	1.1	1.3
8/10	96	.05	6	8.6	2.8	1.8	2.8	4.3
8/17	102	---	7	14.4	4.3	3.1	3.7	5.8
8/24	109	---	8**	15.1	6.3	4.3	5.4	10.0
8/30	115	---	9	16.8	23	6.3	6.0	32+
9/8	124	---	10	21.6	32+	23.0	23.0	32+
9/17	133	---	11	18.2[1]	32+	32+	32+	32+
9/21	137	11.22		---	.7	.4	.4	.6
9/26	142	1.86	12	4.1	.4	.3	.3	.4

* Springwood-summerwood transition completed.

** Cambium dormancy completed.

1 Datum was collected on rainy or foggy morning

Klickitat

Date	Days since bud swell	PPT in cm	Pin No.	Plant-moisture stress in bars	Soil-water stress (bars) at indicated depths 8 cm	18 cm	25 cm	51 cm	76 cm	97 cm
5/4		2.74			0	0	0	0	0	0
5/8	0	.20		3.4	0	0	0	0	0	0
5/18	11	2.67		3.4	0	.2	.1	0	0	0
5/31	24	3.08		3.8	.1	0	.2	0	0	0
6/12	36	.05		3.1[1]	.1	.2	.1	.1	0	.1
6/20	44	---	1	3.1[1]	.4	.1	.2	.2	.2	.2
7/2	56	6.23	2*	2.4[1]	.2	.3	.2	.2	0	0
7/11	65	.18	3	2.7[1]	.2	.3	.2	.2	0	0
7/23	77	---	4	5.1	.4	1.2	.7	.6	.6	.2
7/30	85	---	5	4.5[1]	1.3	1.0	1.3	1.4	.9	.6
8/10	96	.05	6	8.2	3.1	2.0	3.1	3.4	1.8	1.4
8/17	102	---	7	13.0	5.0	3.1	4.3	5.3	2.3	2.2
8/24	109	---	8	13.0	5.8	4.3	5.4	6.6	3.1	3.1
8/30	115	---	9**	15.1	15.0	6.0	6.0	23.0	3.7	3.7
9/8	124	---	10	17.9	32+	15	23	32+	5.4	5.0
9/17	133	---	11	16.1[1]	32+	32+	32+	32+	6.0	5.8
9/21	137	11.22		---	.7	.4	.4	.3	.2	.3
9/26	142	1.86	12	4.1	.6	.3	.3	.3	.1	.2

* Springwood-summerwood transition completed.

** Cambium dormancy completed.

1 Datum was collected on rainy or foggy morning.

Hembre

Date	Days since bud swell	PPT in cm	Pin No.	Plant-moisture stress in bars	Soil-water stress (bars) at indicated depths 8 cm	18 cm	25 cm	51 cm	76 cm	102 cm	152 cm	191 cm
5/1	0	2.74			.2	.2	.2	0	0	0	0	0
5/8	8	.20		3.8	0	0	.1	.2	.2	0	0	0
5/18	18	2.67		3.8	.2	.2	.2	.2	.3	0	0	0
5/31	31	3.08		3.8	.3	.2	.2	.2	.3	.1	0	0
6/12	43	.05		2.7[1]	.5	.1	.2	.1	.3	0	0	0
6/20	51	---	1*	3.1[1]	.2	.6	.4	.2	.2	.2	.1	0
7/2	63	6.23	2	2.1[1]	.3	.1	.1	.1	.2	.1	.1	.1
7/11	72	.18	3	2.1[1]	.4	.2	.2	.1	.2	.2	.1	.1
7/23	84	---	4	5.1	3.4	1.0	.9	.4	.4	.5	.4	.3
7/30	91	---	5	3.8[1]	6.3	2.8	2.5	.8	.5	.8	.6	.3
8/10	102	.05	6	4.5	15.0	6.0	5.6	1.8	1.0	1.4	.9	.5
8/17	109	---	7	7.2	23.0	6.0	5.8	2.5	1.3	1.9	1.2	.6
8/24	116	---	8	5.5	32+	15	6.6	3.4	2.0	2.3	1.6	.8
8/30	122	---	9	6.5	32+	32+	10	4.3	2.8	2.8	1.8	.9
9/8	131	---	10**	8.2	32+	32+	23	5.8	3.7	3.7	2.2	1.1
9/17	140	--	11	6.2[1]	32+	32+	32+	6.6	4.3	5.0	3.1	1.3
9/21	144	11.22		---	.7	.4	.4	.4	.6	.6	2.3	1.2
9/26	149	1.86	12	4.1	.4	.3	.3	.3	.4	.4	1.9	1.2

* Springwood-summerwood transition completed.

** Cambium dormancy completed.

[1] Datum were collected on rainy or foggy mornings.