SOIL MOISTURE PATTERNS FOLLOWING CLEARCUT HARVEST OF A DOUGLAS-FIR FOREST

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Introduction

Plant cover exerts a profound influence on soil moisture levels through its effects on interception, infiltration, evaporation, and transpiration. In the Douglas-fir forests of the Pacific Northwest, clearcut logging and slash burning are common practices that can dramatically alter plant cover and soil moisture. Logging can increase soil moisture by temporarily reducing cover and associated water use (Bethlahmy 1963), and burning may further augment moisture levels by suppressing the survival and regrowth of vegetation (Gaweda 1983). Indeed, part of the rationale for slash burning in the region is to control shrubs and other vegetation that would otherwise compete with conifer seedlings for available moisture, light, and nutrients (Cleary and others 1978).

Within a few years after burning, however, invading vegetation may deplete soil moisture to levels comparable to forested areas (Hallin 1967). Such observations point to the value of long-term information to better understand dynamic soil moisture and plant cover responses to forest practices. In this paper we report on a soil moisture study that was initiated in 1960 to investigate the effects of patch clearcut logging and slash burning (1962-63) in an old-growth Douglas-fir forest in the Oregon Cascade Range. Since soil moisture and vegetation sampling continued regularly until 1980, this was a unique opportunity to evaluate a data set that represented nearly two decades of post-treatment information.

Study Area

The study area is located within a 101 ha watershed in the H.J. Andrews Experimental Forest (Figure 1), 60 km east of Eugene, Oregon (Lat. 44°13'N, Long. 122°15'W). The watershed extends from 500 to 1070 m in elevation, with slopes averaging about 53 percent (Fredriksen 1970). Soils in the watershed have developed from the local andesitic breccia bedrock found at 1-4 meters, and are predominantly classified as loamy, skeletal Typic Dystrochrepts. Some baseline physical properties of the soil are given in Table 1. Weather data collected since 1952 on an adjacent watershed show a mild, humid, temperate climate with an average annual temperature of 9.4°C, and an average annual precipitation level of about 225 cm (Figure 2). Precipitation normally occurs as rain, which is concentrated between October and May. Summers are typically cool (ave. July temp. = 20.6°C) and dry (Rothacher 1965).

Old-growth (300-500 yr) Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) dominates the undisturbed forest on the watershed, accompanied by numerous western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) of various ages. Local site productivity for Douglas-fir is moderate (43 m height at 100 yr), and when the study began (1960), the basal area of the Douglas-fir-Hemlock stand was about 90 m^2/ha. Major prelogging understory communities on the watershed were rhododendron-salal (*Rhododendron macrophyllum-Gaultheria shallon*), vine maple-salal (*Acer circinatum-Gaultheria shallon*), vine maple-Oregon grape (*Acer circinatum-Berberis nervosa*), cutleaf goldthread (*Coptis laciniata*), and swordfern (*Polystichum munitum*) (Dyrness 1973).

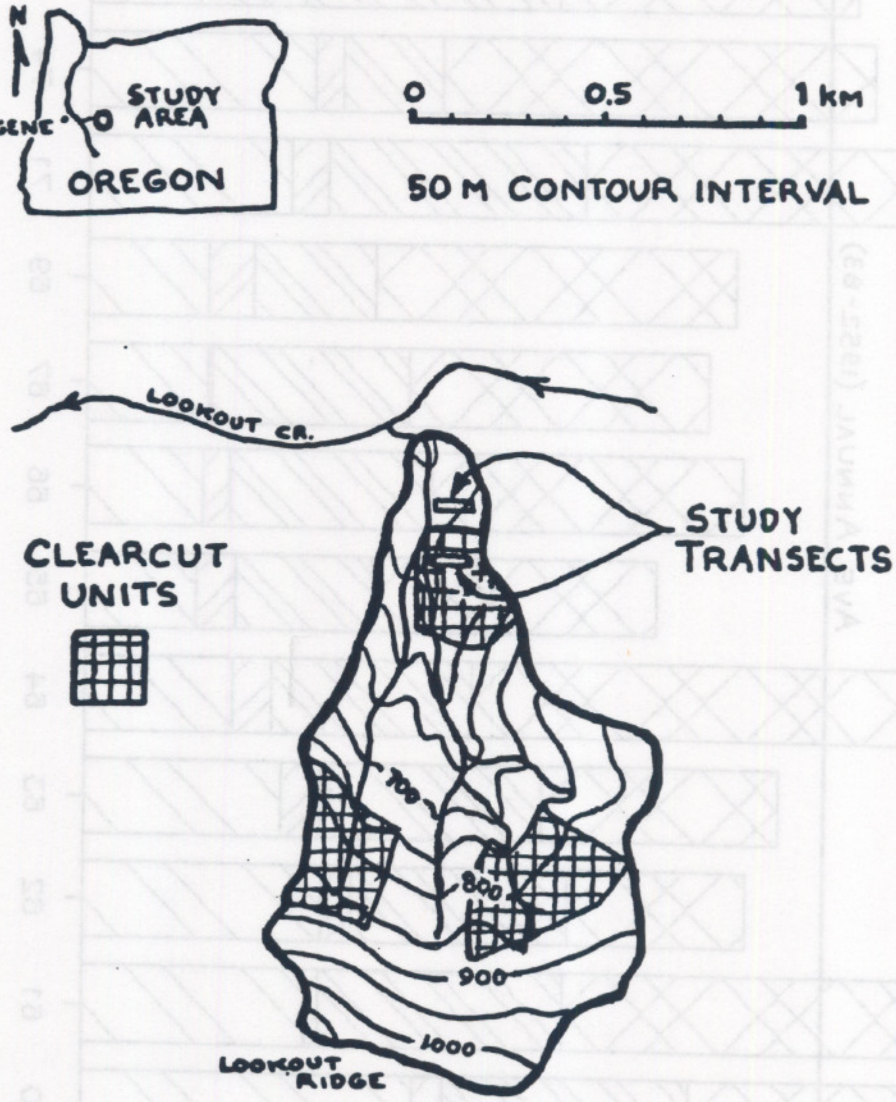

Figure 1. Study area (Watershed 3) at the H.J. Andrews Experimental Forest, Oregon.

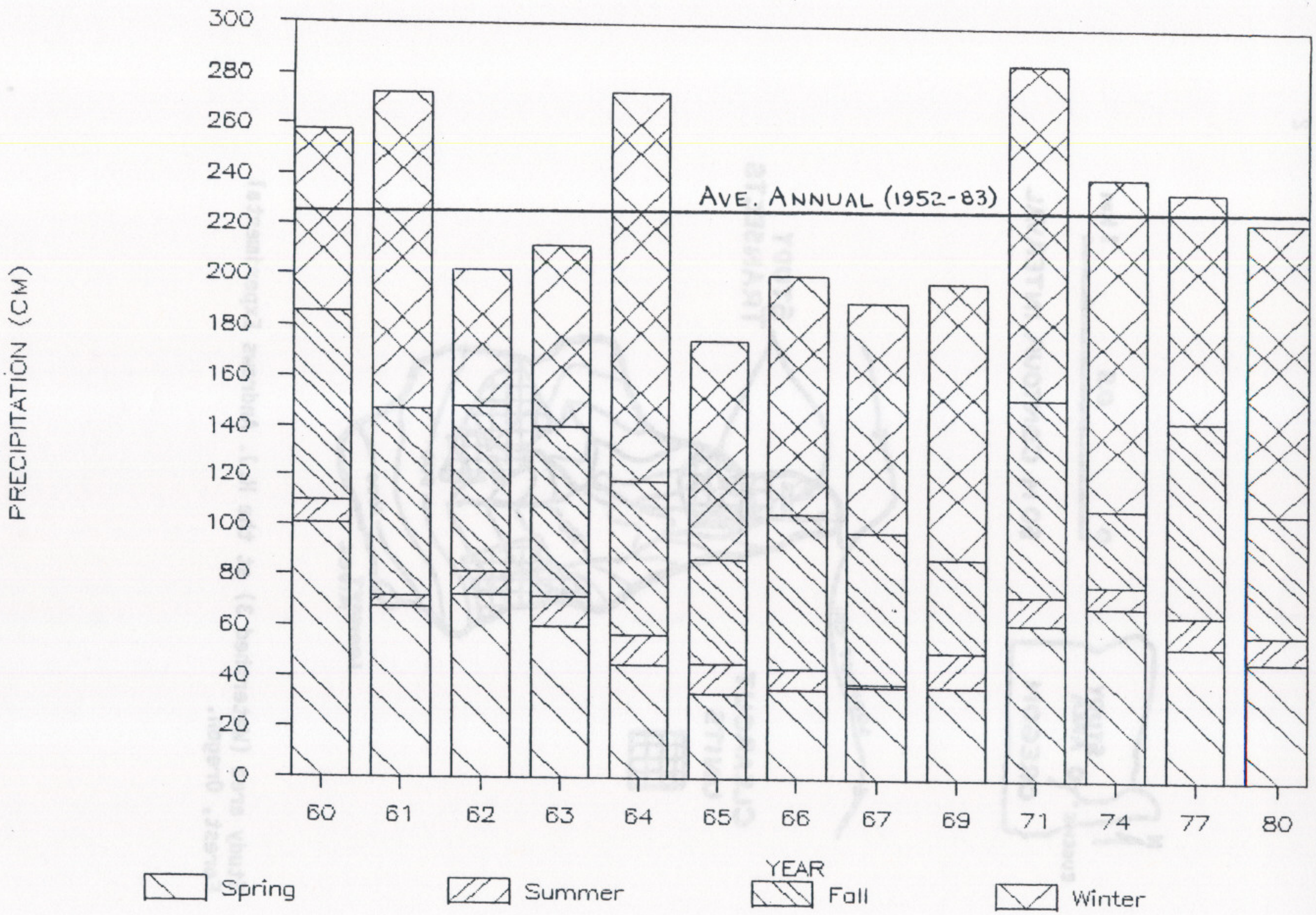

Figure 2. Seasonal (Spring = Mar-May, Summer = Jun-Aug, Fall = Sep-Nov, Winter = Dec-Feb) and total annual precipitation (1960-80) at Watershed 2, adjacent to study area, H.J. Andrews Experimental Forest, Oregon.

Table 1. Some physical characteristics of soils in the study area at the H.J. Andrews Experimental Forest, Oregon.[1]

Soil Depth (cm)	Coarse Fragments (% by vol)	Sand	Silt	Clay	Bulk Density (g/cm^2)	Field cap. H_2O Plant-Avail. (cm)	Tot.
		---	(% by wt)	---			
0-12.5	-	35	38	27	0.80	-	-
12.5-120	-	17	42	41	0.98	-	-
0-30	-	-	-	-	-	5	11
30-60	-	-	-	-	-	6	13
60-120	-	-	-	-	-	13	29
0-120	22	-	-	-	-	24	53

[1]Soil texture data and bulk density data after Dyrness (1969).

In the winter of 1962-63, 25 percent of the watershed was clearcut logged with a high-lead cable system in three patches of 5, 9, and 11 ha. The logged patches were broadcast burned in September of 1963, followed soon by planting of Douglas-fir seedlings. Log yarding resulted in largely minor and shallow soil disturbance in the cutover areas (Dyrness 1965), and moist conditions during burning produced only light, discontinuous charring of the surface litter (Fredriksen 1970).

Methods

In 1960, two random, parallel transects, each about 125 m long, were laid out up and down a 30 percent, SW facing slope on the watershed. One of the transects was located well within one of the patches (9 ha) that was clearcut in 1962-63, while the other was in undisturbed forest for the entire study. Five sample points were established at regular intervals (about 25 m apart) along each transect.

Laboratory-calibrated fiberglass resistance blocks were installed at a random location near each sample point to monitor soil moisture at three depths: 0-30 cm, 30-60 cm, and 60-120 cm. Resistance measurements were taken about every three weeks from mid-spring to mid-autumn in 1960-63, along with numerous bulk soil samples for gravimetric analysis and field calibration of the resistance units. Due to a constantly shifting calibration, however, the resistance units were abandoned in 1963 in favor of gravimetric samples (1964-65) and neutron probe measurements (1966, 1967, 1969, 1971, 1974, 1977, 1980) taken over a similar seasonal schedule. Neutron measurements were taken with a calibrated probe at three randomly located access tubes around each sample point, with gravimetric samples also taken periodically to verify probe results.

All soil moisture data were converted to percent by volume and cm of moisture values using local soil bulk densities and coarse-fragment contents (Table 1). Field capacity moisture contents were measured using soil cores collected 3-10 days following rain in winter. Plant-available moisture content was calculated as the field capacity moisture content minus the moisture content at -15 atm, using the pressure membrane method (Richards 1965). Available moisture capacity has since been more carefully defined to consider plant uptake of moisture at potentials lower than -15 atm (Flint and Childs 1984). Moisture at these lower potentials may only represent 2-4 percent water by volume (Flint 1983), however, so the data are still considered representative of nearly all of the available moisture in these soils.

Vegetation type and cover was measured on four, 4.0 m² plots orthogonally located around each sample point on the transect in the treatment area. Nine systematically located 0.1 m² subplots of each larger plot were used to measure herb and low shrub (<60 cm tall) cover, whereas the entire 4.0 m² plot was used for measurements of trees and vegetation >60 cm tall. Vegetation surveys were conducted in late July or early August starting in 1964, and subsequently in the same years as the soil moisture measurements. Data for individual species were stratified into herb and low shrub or tree and tall shrub cover consistent with Dyrness (1973). Data from different transects used by Dyrness (1965) provide estimates of plant cover in 1963.

Results and Discussion

During the three sampling seasons prior to clearcutting and burning (1960-62), soil moisture in the treatment area varied similarly to the control area (Table 2). Although slight differences between the treatment and the control area were common (shown by regression slopes ≠ 1.00), none of these differences for any individual sampling date in 1960-62 were significant ($\alpha = 0.10$). This indicates that there were generally uniform soil, vegetation, and environmental conditions in the two areas prior to treatment.

Table 2. Equations relating soil moisture contents in the treatment area (y) to those in the control area (x) prior to clearcutting and burning (1960-62).

Soil Depth (cm)	Regression Equation	R^2
0 - 30	$y = 0.99x - 1.21$	0.95
30 - 60	$y = 1.25x - 9.08$	0.94
60 - 120	$y = 1.30x - 11.08$	0.95

Soil moisture in the treatment area during 1962, a fairly typical year with respect to precipitation patterns and amounts (Figure 2), is shown in Figure 3. Soil moisture generally declines during the dry summer months, and then is recharged during the wet fall and winter months. As expected for this heavily vegetated, well-drained location, the upper soil layer shows the lowest moisture levels. It is noteworthy, however, that some significant summer rainfall can temporarily increase the moisture content of the upper soil layers.

Variation in soil moisture contents immediately before (1962) and after (1963) clearcutting is shown in Table 3. Soil moisture variability was generally lowest in the spring, apparently when soils throughout the study area were at or near field capacity (Table 1). Similarly, the high soil moisture contents observed in the summer and fall following clearcutting were characterized by relatively low variation. With respect to soil depth, the surface 0-30 cm layer generally showed the highest variation in soil moisture content.

Table 3. Variation in soil moisture content (% by vol.) before (1962) and after (1963) clearcutting in treatment (CC) and control (FOR) areas.

	SPRING (APR-MAY)			SUMMER (JUN-AUG)			FALL (SEPT-NOV)		
AREA-YR	MEAN	S.D.	C.V.(%)	MEAN	S.D.	C.V.(%)	MEAN	S.D.	C.V.(%)
				0-30 CM					
CC-62	43.4	7.0	16.1	31.4	7.6	24.2	31.5	9.2	29.2
FOR-62	40.5	6.3	15.6	31.5	7.6	24.1	33.5	8.9	26.6
CC-63	36.5	3.0	8.2	34.0	3.8	11.2	39.7	6.5	16.4
FOR-63	36.4	3.9	10.7	29.3	5.6	19.1	31.0	6.7	21.6
				30-60 CM					
CC-62	44.9	3.8	8.5	38.3	6.9	18.0	37.1	6.5	17.5
FOR-62	43.7	5.5	12.6	37.6	6.4	17.0	38.3	6.5	17.0
CC-63	44.5	5.5	12.4	41.8	3.8	9.1	46.0	5.8	12.6
FOR-63	40.5	3.7	9.1	34.4	5.4	15.7	37.1	5.8	15.6
				60-120 CM					
CC-62	48.3	3.3	6.8	42.0	6.1	14.5	39.4	8.0	20.3
FOR-62	44.9	5.4	12.0	41.1	5.8	14.1	41.8	9.0	21.5
CC-63	47.4	3.8	8.0	46.8	5.0	10.7	44.3	4.8	10.8
FOR-63	44.3	5.7	12.9	39.2	5.6	14.3	40.0	7.1	17.8

In spring 1963 following logging, there were no significant differences ($\alpha = 0.050$, t-test of inequality) in soil moisture between the clearcut area and the old-growth forest (Figure 4). However, presumably as overstory removal and disturbance of lesser vegetation decreased summer evapotranspiration rates, markedly higher soil moisture levels became evident through the upper 120 cm of soil. Although vegetative cover was not monitored along the soil moisture transect in the clearcut prior to 1964, other sampling in this area indicated that logging had reduced the total cover to about 10 percent in summer 1963 (Dyrness 1965).

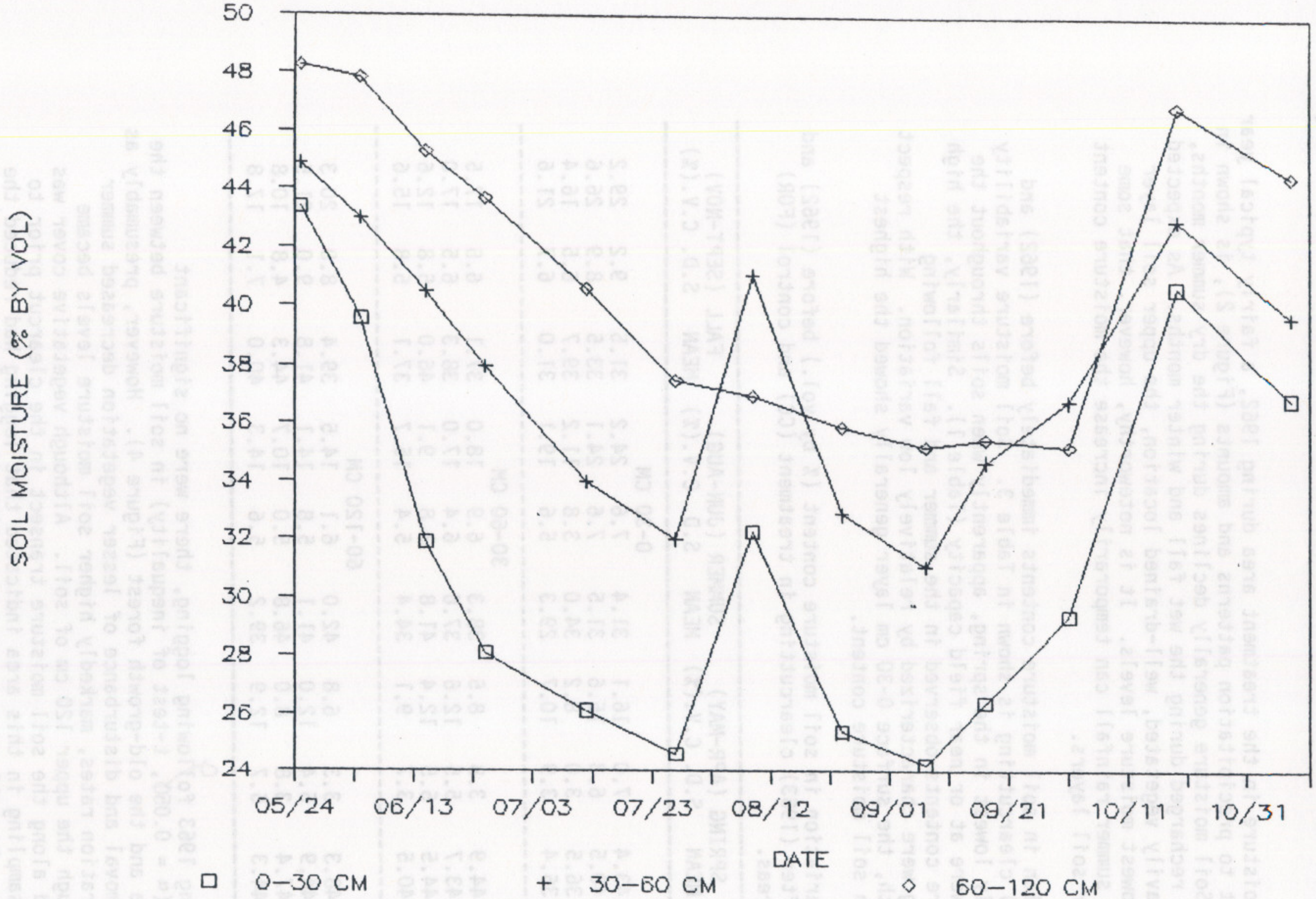

Figure 3. Soil moisture levels (May-Oct. 1962) at three depths in the treatment area prior to clearcutting.

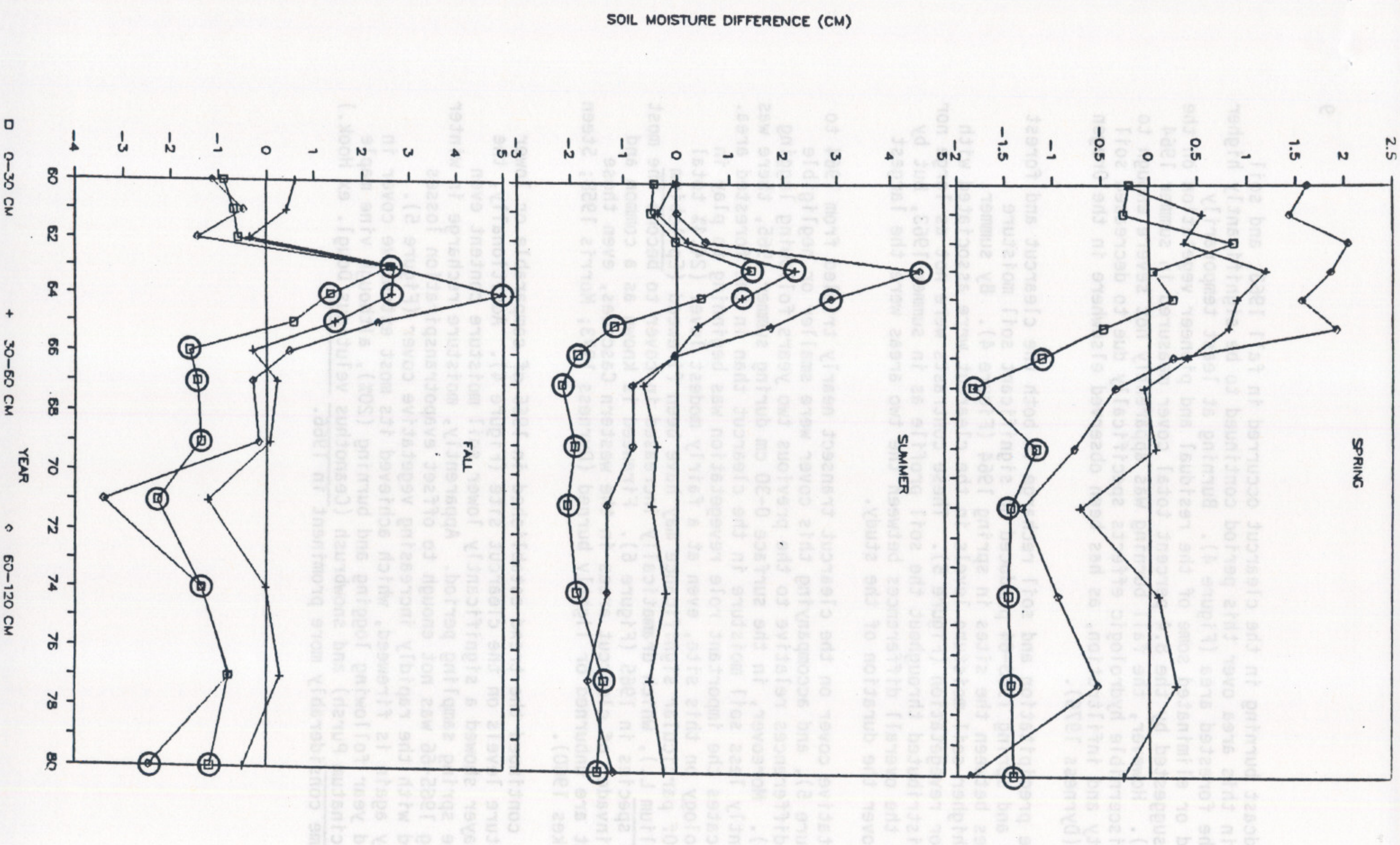

Figure 4. Average differences in soil moisture between clearcut and forest areas during spring (Apr-May), summer (Jun-Aug), and fall (Sep-Nov), 1960-80. Significant differences ($\alpha = 0.05$, t-test of inequality) are shown by circled data points.

Broadcast burning in the clearcut occurred in fall 1963, and soil moisture in this area over this period continued to be significantly higher than in the forested area (Figure 4). Burning at least temporarily suppressed or eliminated some of the residual and pioneer vegetation on the site, as suggested by the 8.4 percent total cover measured in summer 1964 (Figure 5). However, the fall burning was apparently not severe enough to produce discernible hydrologic effects specifically due to decreased soil wettability and infiltration, as has been observed elsewhere in the Oregon Cascades (Dyrness 1976).

Ample precipitation and soil recharge in both the clearcut and forest in winter and spring 1963-64 produced no significant soil moisture differences between the sites in spring 1964 (Figure 4). By summer, however, higher soil moisture levels in the clearcut were associated with still minor revegetation (Figure 5). These contrasts were not as large nor as well-distributed throughout the soil profile as in summer 1963, but by fall 1964 the overall differences between the two areas were the largest observed over the duration of the study.

Vegetative cover on the clearcut transect nearly tripled from 1964 to 1965 (Figure 5), and accompanying this cover were smaller or negligible moisture differences relative to the previous two years following logging (Figure 4). Moreover, in the surface 0-30 cm during summer 1965, there was significantly less soil moisture in the clearcut than in the forested area. This indicates the important role revegetation was beginning to play in soil hydrology on this site, even at a fairly modest level (24.4% total cover). Of particular significance may have been fireweed (Epilobium angustifolium L.), which dramatically increased in cover to become the most prominent species in 1965 (Figure 6). Fireweed is known as a common and prolific invader of clearcut areas in the western Cascades, even those sites that are unburned or lightly burned (Dyrness 1973; Morris 1958; Steen 1966; Yerkes 1960).

1966 continued the trend established in 1965 of comparable or lower soil moisture levels on the clearcut site (Figure 4). Additionally, the 0-30 cm layer showed a significantly lower soil moisture content even during the spring sampling period. Apparently, moisture recharge in winter and spring 1965-66 was not enough to offset evapotranspiration losses associated with the rapidly increasing vegetative cover (Figure 5). Noteworthy again is fireweed, which achieved its most extensive cover in this third year following logging and burning (20%), although vine maple (Acer circinatum Pursh) and snowbrush (Ceanothus velutinus Dougl. ex Hook.) also became considerably more prominent in 1966.

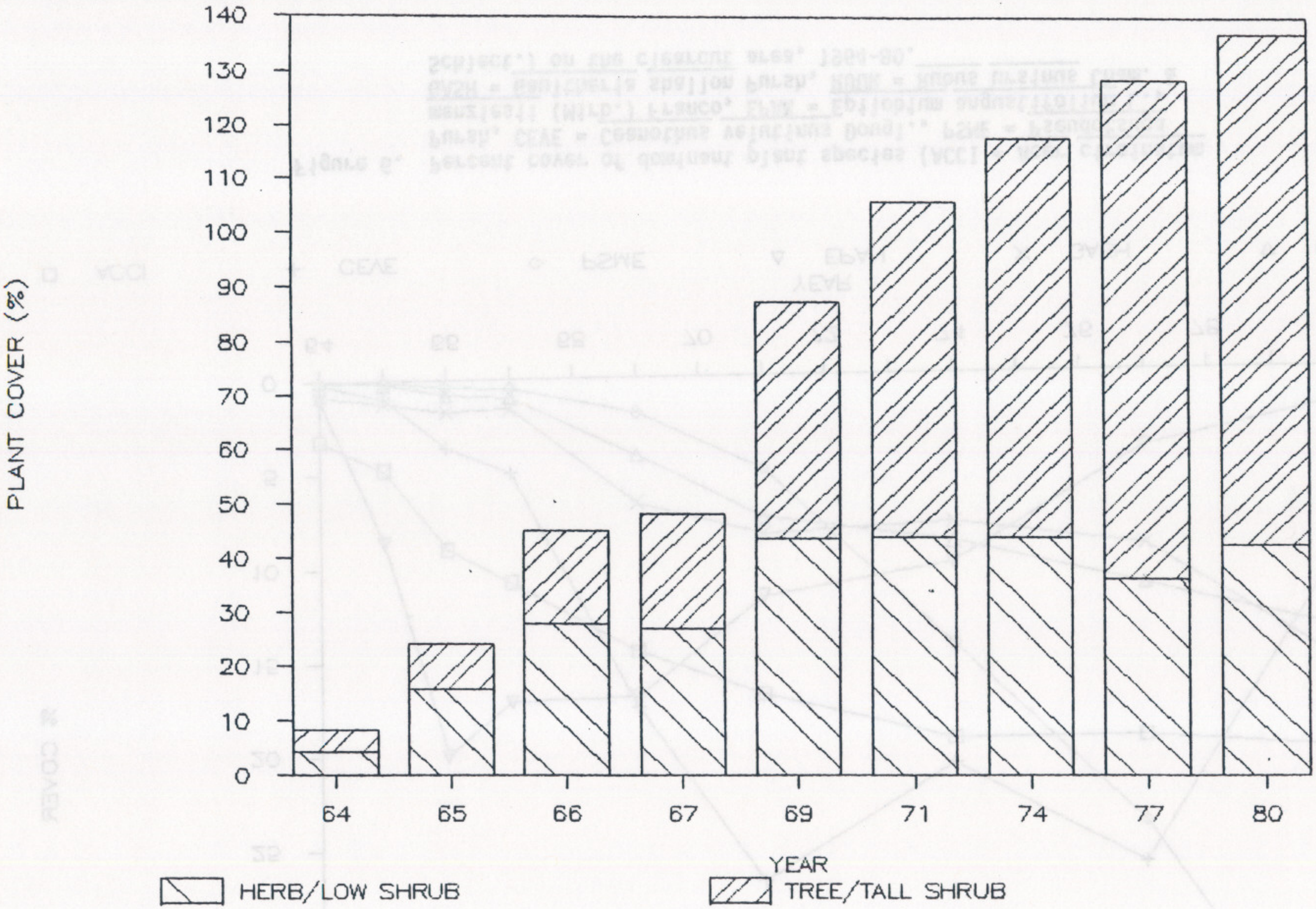

Figure 5. Herb plus low shrub cover and tree plus tall shrub cover on the clearcut area, 1964-80.

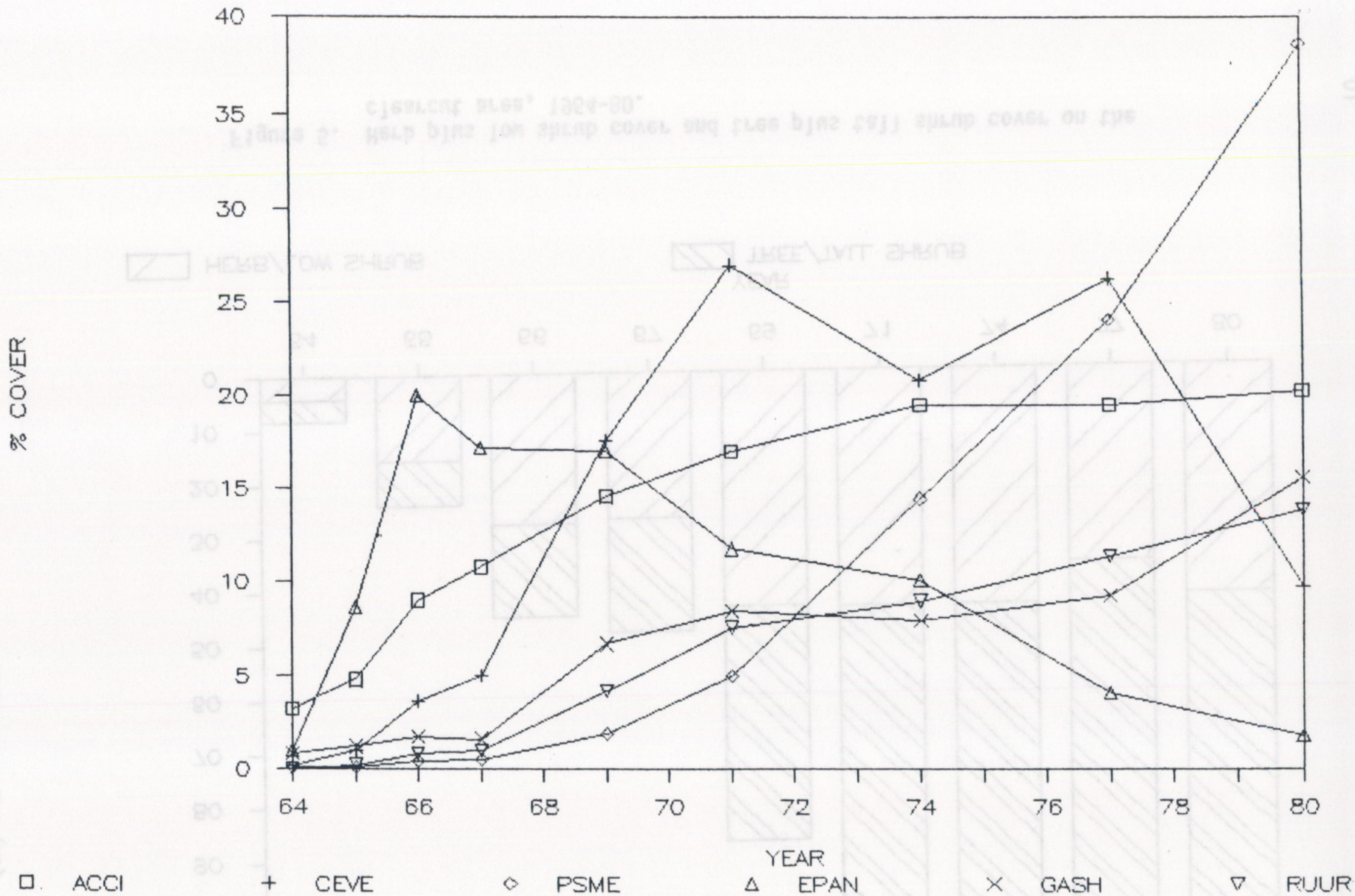

Figure 6. Percent cover of dominant plant species (ACCI = *Acer circinatum* Pursh, CEVE = *Ceanothus velutinus* Dougl., PSME = *Pseudotsuga menziesii* (Mirb.) Franco, EPAN = *Epilobium angustifolium* L., GASH = *Gaultheria shallon* Pursh, RUUR = *Rubus ursinus* Cham. & Schlect.) on the clearcut area, 1964-80.

In 1967, the clearcut showed its largest significant spring surface moisture deficit during the course of the study (Figure 4). 1967 also marked the onset of a general leveling off of the surface layer deficits for each sampling season over time. It thus appears that most of the effect of revegetation on moisture deficits in at least the surface 0-30 cm of soil can occur well in advance of full occupation of the site, since total cover in 1967 was only 48.4%. Even as total plant cover increased to well over 100% 12-18 years after logging (Figure 5), surface soil moisture effects remained comparable to earlier years. It may be that herb and low shrub cover exerts the greatest influence on surface soil moisture, since this type of cover remained at a fairly uniform level from 1969-80.

Although there were few significant differences in subsoil moisture levels between the clearcut and forest from 1966 on, there did appear to be a weak trend of increasing deficits in the 60-120 cm layer in the clearcut (Figure 4). This may reflect the concurrent increase in tree and tall shrub cover over time (Figure 5), particularly the planted Douglas-fir (Figure 6), whose roots may extend well into the subsoil even at a young age (Stein 1978).

The relationship between vegetative cover and soil moisture levels on the clearcut area was further studied through regression analysis of the data collected from 1964-80. The analysis again focused on the differences in soil moisture between the clearcut and the forested areas, so as to minimize other influences such as antecedent precipitation. Since the graphic plots of plant cover versus soil moisture differences were typically curvilinear (Figure 7), a logarithmic regression model was used.

Not surprisingly, plant cover showed generally good statistical relationships with the observed soil moisture differences, particularly the herbaceous and low shrub cover (Table 4). Levels of this cover type were clearly superior in explaining the variation in moisture differences near the soil surface, which supports earlier suggestions of its importance. Tree and tall shrub cover appeared to be primarily related to soil moisture differences at 60-120 cm, but little more so than herb and low shrubs over the first 18 years after clearcutting.

Table 4. Regression and determination coefficients for logarithmic equations ($y = a + b \ln x$) relating summer soil moisture differences (cm) between clearcut and forest areas (y) with herb and low shrub (HC), tree and tall shrub (SC), or total (TC) percent cover (x).

COVER	SOIL DEPTH 0-30 cm			30-60 cm			60-120 cm			0-120 cm		
	a	b	R^2	a	b	R^2	a	b	R^2	a	b	R^2
HC	1.54	-0.93	0.79	2.18	-0.69	0.84	6.10	-1.94	0.89	10.02	-3.62	0.92
SC	0.01	-0.45	0.41	1.29	-0.41	0.64	4.19	-1.31	0.90	5.66	-2.21	0.76
TC	1.06	-0.63	0.56	2.05	-0.53	0.75	6.29	-1.61	0.93	9.62	-2.82	0.85

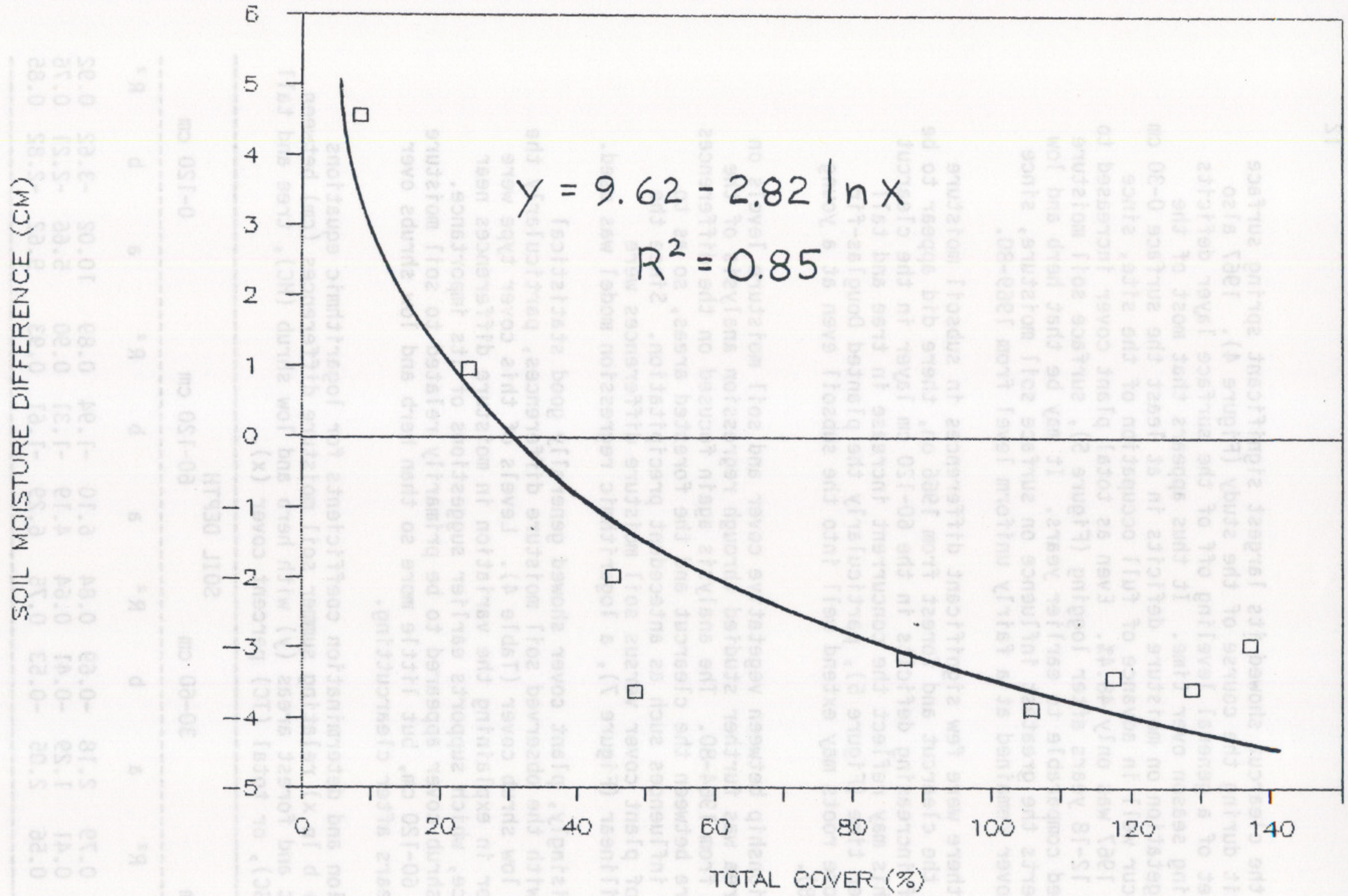

Figure 7. Relationship between total plant cover on the clearcut area and soil moisture differences between the clearcut and forest areas, 1964-80.

Summary and Conclusions

The average annual moisture differences in the upper 120 cm of soil between the clearcut and the forest sites during 1960-80 are given in Figure 8. They summarize the dramatic effect that clearcutting (1962) can have on soil moisture in the Douglas-fir zone of the Oregon Cascades. Furthermore, the moisture differences can vary from positive to negative, depending upon the time after harvest and the associated degree and type of revegetation. Less obvious are specific effects of light slash burning (1963), except perhaps to delay the influence of revegetation.

The long-term data sets from the study sites clearly show that clearcutting only briefly increased moisture levels in the upper 120 cm of soil, consistent with Hallin's (1967) findings. In contrast, subsequent soil moisture decreases on the clearcut persisted for at least 15 years. These decreases may last even longer, since there is little indication of a trend in the later years of data collection toward moisture levels comparable to the forest.

The magnitude of both the increase and decreases in soil moisture observed after clearcutting certainly appear large enough to show some relationships with such management concerns as seedling moisture stress and watershed runoff. The precise nature and significance of these relationships await further investigation, however.

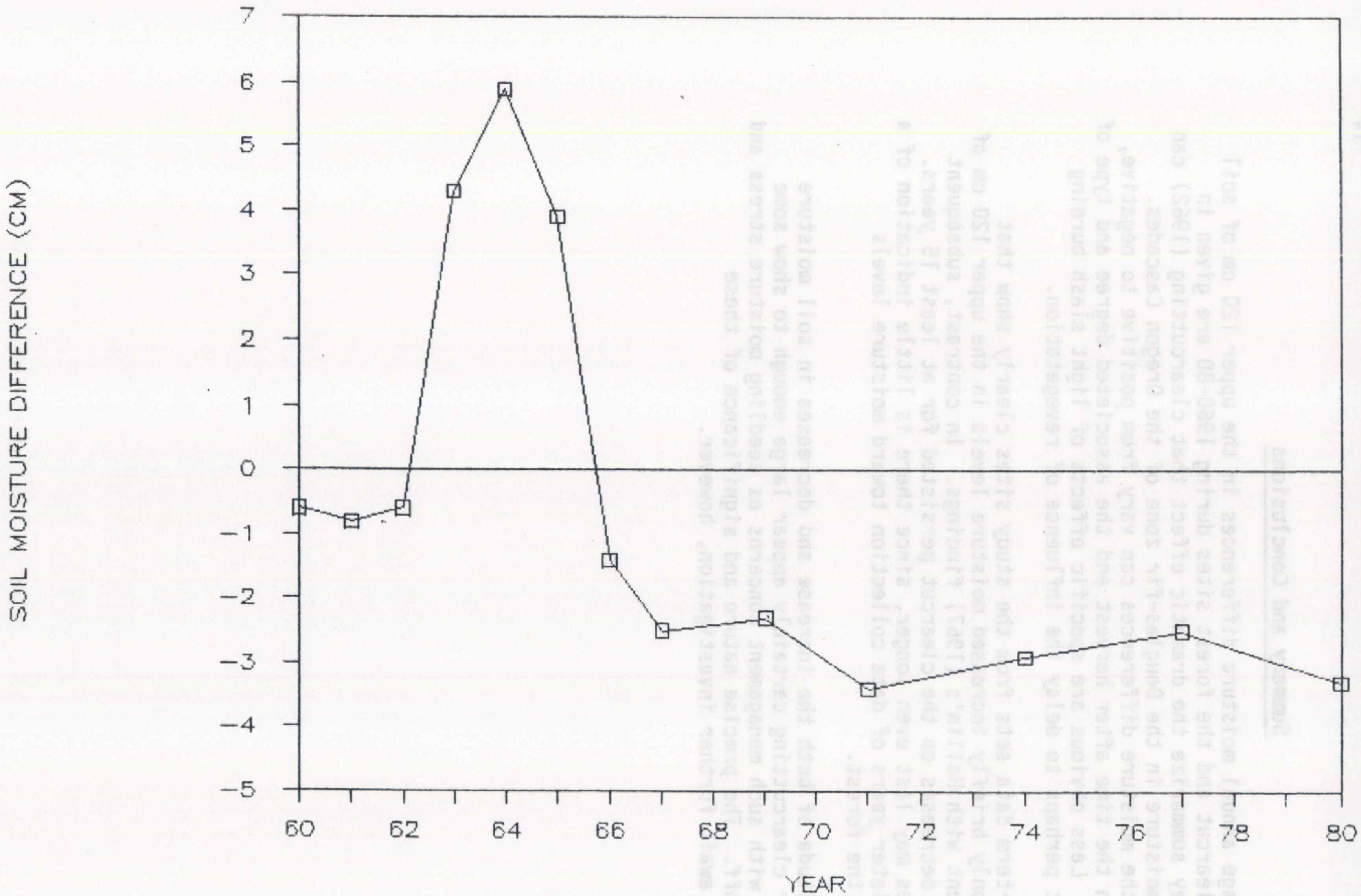

Figure 8. Average annual (Apr-Nov) soil moisture differences between the clearcut and forest areas, 1960-80.

Acknowledgements

Jack Rothacher established and supervised the soil moisture study from 1960-63. R.L. Fredericksen supervised the soil moisture study from 1964-80, and established and supervised the vegetation survey from 1964-80. A.L. Levno assisted in much of the data collection from 1963-80. D. Henshaw provided assistance in computer entry and summary of the data.

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