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# Long-term patterns in soil moisture and revegetation after a clearcut of a Douglas-fir forest in Oregon

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ABSTRACT

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Soil moisture levels during 1960–1980 were compared for two areas within a 101 ha watershed in the Oregon Cascade Range. In winter 1962–1963, the old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forest in one area was clearcut. The site was then lightly broadcast-burned in September 1963. An adjacent forested area was left undisturbed as a control. In summer 1963, the upper 120 cm of soil in the clearcut averaged over 10 cm more moisture than that in the forested control. By 1967 these surpluses in the clearcut had declined to become deficits of at least 2 cm less moisture than in the control. These deficits, which were presumably caused by a rapid increase in plant cover after the light slash burn, persisted in the upper 30 cm of soil throughout the rest of the study. The fluctuations in soil moisture in the treated area are extensive enough to influence forest regeneration and watershed hydrology.

## INTRODUCTION

In the Douglas-fir forests of the Pacific Northwest, clearcut logging and slash burning can markedly alter soil moisture. Logging temporarily reduces the plant cover, thus decreasing interception losses and moisture uptake and increasing soil moisture levels (Bethlahmy, 1963). Burning further increases moisture retention by suppressing plant survival and regrowth (Gaweda, 1983). In this region, slash burning is used to reduce hazardous fuels, but also to control shrubs and other vegetation that would otherwise compete with conifer seedlings for available moisture, light and nutrients (Cleary et al.,

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1978). A few years after a burn, however, invading vegetation may deplete soil moisture to levels comparable with those for forested areas (Hallin, 1967, 1968).

Such observations indicate the value of long-term studies of how soil moisture and plant cover respond to logging and burning. In this paper we describe a comparison of soil moisture and vegetation in two adjacent areas of an old-growth, Douglas-fir forest in the Oregon Cascade Range. One area was clear-cut and then slash-burned less than a year later. The other area was left undisturbed. Even though direct extrapolation of our results is limited by the lack of replication over a broad range of site conditions, analysis of our long-term sampling (1960–1980) has offered unique insights into nearly two decades of post-treatment response.

## METHODS

### *Study area*

The study area is located within a 101 ha watershed (HJA-3) in the H.J. Andrews Experimental Forest (44°13′N, 122°15′W), 60 km east of Eugene, OR (Fig. 1). The elevation is 480–1070 m, and the slopes average about 53% (Fredriksen, 1970). Soils are classified as loamy, skeletal Humic Hapludult and are derived from the local andesitic breccia bedrock found at 1–4 m. Some baseline properties of the soil are given in Table 1. Weather data collected from 1952 to 1983 for an adjacent watershed (HJA-2) show the climate is mild, humid and temperate; the annual average temperature is 9.4°C and the average annual precipitation is about 228 cm (Fig. 2). Precipitation normally occurs as rain, mainly between October and May. Summers are typically cool (average July temperature is 20.6°C) and dry (Rothacher, 1965).

Old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) 300–500 years old dominates the undisturbed forest on the watershed. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) of various ages is also abundant. Local site productivity for the Douglas-fir is moderate (43 m height at 100 years). When the study began in 1960, the basal area of the Douglas-fir/western hemlock stand was about 90 $m^2$ $ha^{-1}$. Major understory communities on the watershed before logging were rhododendron–salal (*Rhododendron macrophyllum* G. Don–*Gaultheria shallon* Pursh), vine maple (*Acer circinatum* Pursh)–salal, vine maple–Oregon grape (*Berberis nervosa* Pursh), cutleaf goldthread (*Coptis aciniata*), and swordfern (*Polystichum munitum*), (Dyrness, 1973).

### *Procedures*

In 1960, two randomly selected, parallel transects, each about 125 m long, were laid out along a southwest facing, 30% slope of the watershed. One tran-

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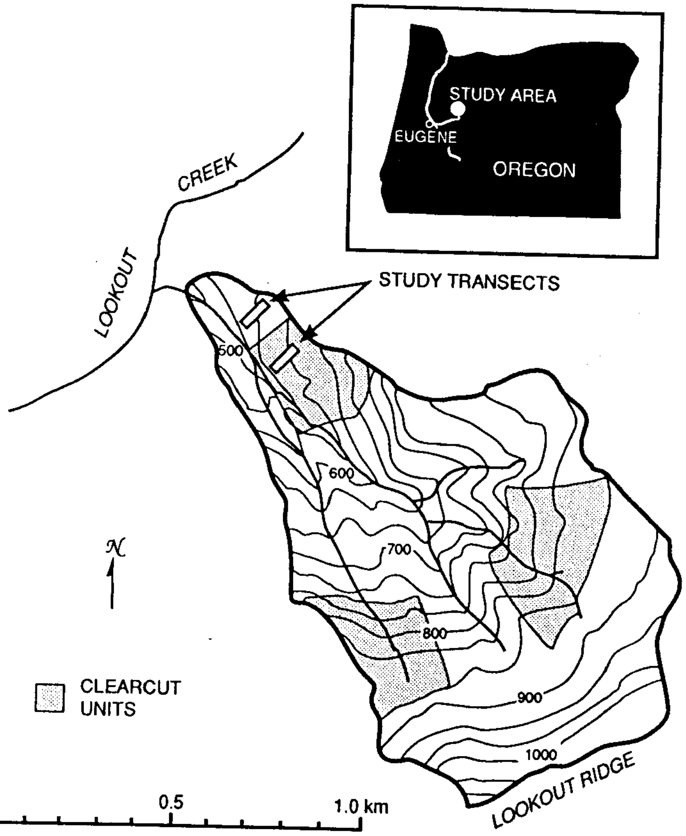


Fig. 1. Study area HJA-3 at the H.J. Andrews Experimental Forest near Eugene, OR.

TABLE 1

Physical characteristics of soils in the study area at H.J. Andrews Experimental Forest near Eugene, Oregon

| Depth (cm) | Coarse fragments[a] (% by vol) | Soil texture[a] (% by wt) | | | Bulk density[a] ($g\ cm^{-2}$) | Field capacity (cm $H_2O$) | Available moisture (cm $H_2O$) |
|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | | | |
| 0–30 | –[b] | 29 | 43 | 28 | 0.84 | 11 | 5 |
| 30–60 | – | 20 | 46 | 34 | 0.95 | 13 | 6 |
| 60–120 | – | 10 | 50 | 40 | 1.02 | 29 | 13 |
| 0–120 | 22 | – | – | – | – | 53 | 24 |

[a]Adapted from Dyrness (1969) and Paeth (1970).
[b]Measurements not determined.

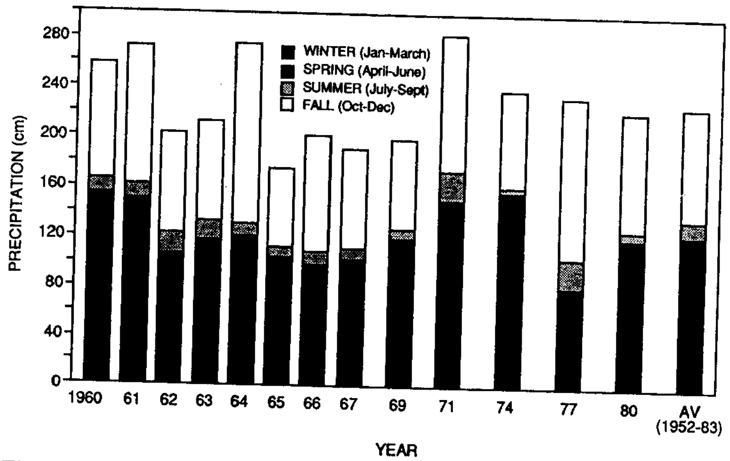


Fig. 2. Seasonal precipitation at watershed HJA-2 (adjacent to the study area) during years when soil moisture was collected on HJA-3. Bar at far right represents seasonal averages for 32 years of record.

sect ('treatment') was located about 75 m within the boundary of a 9 ha patch that was clearcut 2 years later; the other transect ('control') was in undisturbed forest (Fig. 1). Five sampling points were established at regular intervals (about 25 m apart) along each transect.

In winter 1962–1963, 25% of the total watershed was clearcut with a high-lead cable system in three areas, a 5 ha patch, a 9 ha patch and an 11 ha patch (Fig. 1). These logged areas were broadcast-burned in September 1963, and soon replanted with Douglas-fir seedlings. Log yarding caused mostly minor, shallow soil disturbance in the cutover areas (Dyrness, 1965). Because of moist conditions during the burning, the surface litter was only lightly charred in scattered areas (Fredriksen, 1970).

Laboratory calibrated, fiberglass resistance blocks had been installed in 1960 at a random location near each sampling point to monitor soil moisture at three depths: 0–30, 30–60 and 60–120 cm. The use of consistent sampling depths seemed most suitable for these variable, weakly developed soil profiles, although the three depths were generally found to correspond to the A1, B1 and B2 horizons, respectively.

Resistance measurements were made about every 3 weeks from mid-spring to mid-fall for the next 3 years. In addition, numerous bulk soil samples were taken for gravimetric analysis and field calibration of the resistance units. Because of a constantly shifting calibration, the resistance units were abandoned in 1963 in favor of first, gravimetric sampling (during 1964–1965) and then, neutron-probe measurements, during 1966, 1967, 1969, 1971, 1974, 1977 and 1980. All of these later measurements were taken at the same depths and regularity as the resistance measurements. Neutron measurements were made with a calibrated probe at three access tubes randomly located around each sampling point. These measurements were also periodically checked by taking some samples for gravimetric analysis.

We converted all soil moisture data to values expressing percent $H_2O$ by volume and centimeters of moisture by using local soil-bulk densities and coarse-fragment contents (Table 1). Field capacity moisture was estimated from soil cores collected 3–10 days after winter rainfalls. Available moisture was then calculated by subtracting the moisture content at −15 atm from the field capacity moisture. This was done by using the pressure-membrane method (Richards, 1965). Since these evaluations were done, available moisture has 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 represent only 2–4% water by volume (Flint, 1983) however, so the data reported here are still considered representative of nearly all available moisture in these soils.

During 1960–1962, soil moisture was measured on 46 dates in the area to be clearcut and burned, as well as in the control area. Because none of the differences in soil moisture between the two areas was significant ($\alpha=0.10$, $t$-test of inequality) for any of the individual pretreatment sampling dates, we assumed that the soil, vegetation and environmental conditions were sufficiently uniform to permit detailed comparisons after treatment.

Vegetation type and amount of cover were examined on four, 4.0 $m^2$ plots orthogonally located around each sampling point on the transect in the treatment area. Nine systematically located, 0.1 $m^2$ subplots were used for ocular estimates of herb and shrub cover less than 60 cm tall, whereas the entire plot was used for ocular estimates of trees and vegetation greater than 60 cm tall (Dyrness, 1973). Where multiple layers of vegetation occurred, cumulative cover could exceed 100%. Vegetation surveys were conducted in late July or early August in 1964, 1965, 1966, 1967, 1969, 1971, 1974, 1977 and 1980. Data for individual species were stratified into herb and low-shrub or tree and tall-shrub cover types consistent with Dyrness (1973). Data from different transects used by Dyrness (1965) provide estimates of plant cover in 1963.

## RESULTS AND DISCUSSION

### *Background patterns and variability*

Precipitation patterns and amounts in 1962 were fairly typical for the watershed adjacent to the study area (Fig. 2). Soil moisture generally declined during the dry summer months, and then was recharged and maintained at about field capacity during the wet and cool fall, winter and spring months (Fig. 3). As expected for this heavily vegetated, well-drained location, the upper soil layer (0–30 cm) consistently showed the lowest moisture levels.

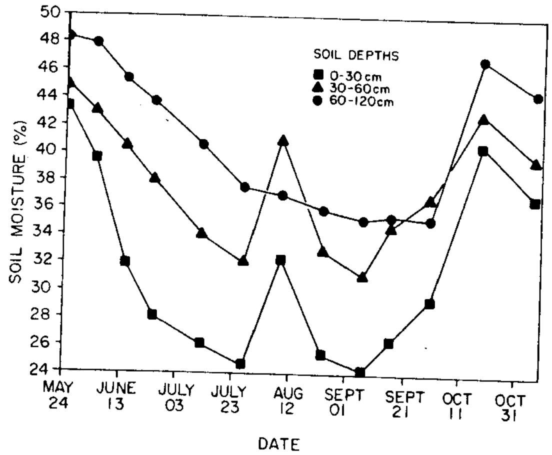


Fig. 3. Soil moisture in late spring to midfall 1962, at three depths in the treatment area before trees were clearcut.

Moisture in the upper (0–30 cm) and middle (30–60 cm) soil layers markedly increased after significant summer rainfall (6.9 cm between soil-measurement dates), and then decreased rapidly because of apparently high evapotranspiration losses.

The variation in soil moisture contents at different depths and within specific seasons immediately before (1962) and after (1963) clearcutting is shown in Table 2. Soil moisture variability was often lowest in the spring, apparently when soils throughout the study area were at or near field capacity (Table 1). Similarly, the higher soil moisture contents observed in the summer and fall after clearcutting usually exhibited lower variation. The surface layer of soil (0–30 cm deep) generally showed the highest variation in soil moisture content. Bethlahmy (1963) also found higher moisture variation near the soil surface at sites in the Cascade Range about 140 km north of our study area. However, in contrast to our results, he observed greater variation in clearcut plots than in forested plots.

When the soil moisture data were pooled by season, they showed two significant differences ($\alpha=0.05$, $t$-test of inequality) between the moisture contents of the treatment and the control areas before clearcutting and burning (Fig. 4). However, because these limited examples are the exception over 3 years of pretreatment data, with no apparent pattern or explanation, the assumption of relatively uniform conditions between the areas was still considered valid.

*1963–1964: Higher moisture*

In spring 1963, a few months after the logging, the amount of soil moisture was not significantly different between the clearcut area and the old-growth

TABLE 2

Variation of seasonal[a], soil moisture contents at three depths in the treatment and the control areas of a study site at H.J. Andrews Experimental Forest near Eugene, OR, 1962–1963

| Year | Area | Spring | | | Summer | | | Fall | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean[b] | s.d.[c] | CV[d] | Mean | s.d. | CV | Mean | s.d. | CV |
| **0–30 cm** | | | | | | | | | | |
| 1962 | Control | 36.2 | 6.1 | 16.8 | 26.7 | 6.0 | 22.5 | 35.6 | 7.1 | 19.9 |
| | Treatment | 35.7 | 7.8 | 21.8 | 26.5 | 4.0 | 15.1 | 35.7 | 9.8 | 27.5 |
| 1963 | Control | 36.5 | 3.9 | 10.7 | 29.3 | 6.1 | 20.8 | 32.0 | 7.0 | 21.9 |
| | Treatment | 36.5 | 3.0 | 8.2 | 36.0 | 6.3 | 17.5 | 41.5 | 5.2 | 12.5 |
| **30–60 cm** | | | | | | | | | | |
| 1962 | Control | 40.8 | 5.2 | 12.7 | 34.0 | 5.8 | 17.1 | 38.3 | 4.5 | 11.7 |
| | Treatment | 41.6 | 4.8 | 11.5 | 34.3 | 6.6 | 19.2 | 39.8 | 5.6 | 14.1 |
| 1963 | Control | 41.3 | 3.9 | 9.4 | 34.6 | 6.0 | 17.3 | 38.1 | 5.4 | 14.2 |
| | Treatment | 44.5 | 5.5 | 12.4 | 44.6 | 6.6 | 14.8 | 45.5 | 4.3 | 9.5 |
| **60–120 cm** | | | | | | | | | | |
| 1962 | Control | 43.9 | 5.1 | 11.6 | 37.6 | 5.3 | 14.1 | 41.9 | 7.3 | 17.4 |
| | Treatment | 46.3 | 3.6 | 7.8 | 36.9 | 5.4 | 14.6 | 42.2 | 8.1 | 19.1 |
| 1963 | Control | 44.3 | 6.4 | 14.4 | 37.9 | 5.6 | 14.8 | 41.2 | 7.8 | 18.9 |
| | Treatment | 47.4 | 3.8 | 8.0 | 46.2 | 5.0 | 10.8 | 47.1 | 4.9 | 10.4 |

[a]Spring = April–June, summer = July–September, fall = October–November.
[b]Moisture content is given as percent per volume.
[c]Standard deviation.
[d]Coefficient of variation.

forest (Fig. 4). This situation soon changed. Tree removal and reduced vegetation presumably decreased the summer evapotranspiration rates, so that soil moisture markedly increased throughout the upper 120 cm of soil. Although vegetative cover was not monitored along the sampling transect in the clearcut before 1964, other measurements in this area indicated that logging had reduced the total cover to about 10% in summer 1963 (Dyrness, 1965).

Soil moisture continued to be significantly higher in the clearcut area than in the forested area in fall 1963 (Fig. 4), when the clearcut was broadcast-burned. Burning probably suppressed or eliminated some of the residual and pioneer vegetation on the site (only 8.4% total cover was measured in the following summer (Fig. 5)). However, the fall burning was apparently not severe enough to reduce water movement into the soil noticeably. Reduced soil wettability and infiltration after wildfire have been observed elsewhere in the Oregon Cascades (Dyrness, 1976).

Evapotranspiration losses from the forested area during a relatively dry spring in 1964 (Fig. 2) probably caused subsoil moisture to be lower than that in the clearcut. These differences became more pronounced by summer

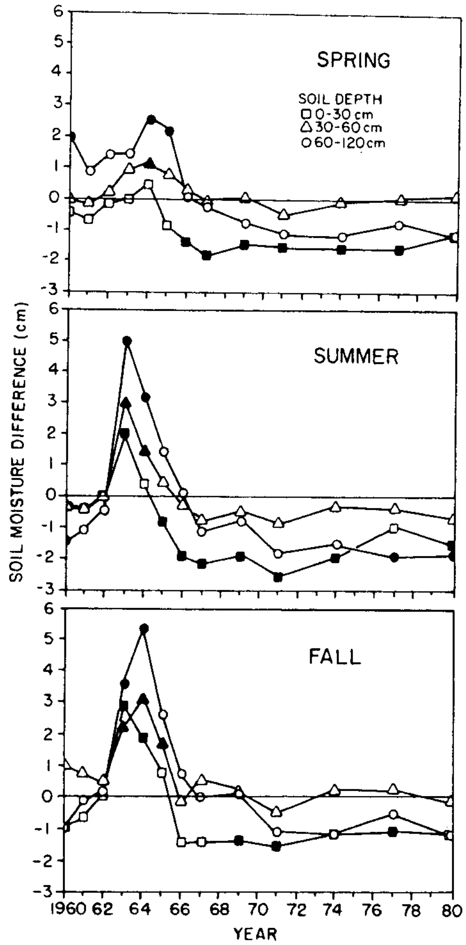


Fig. 4. Average differences in soil moisture between the clearcut and the forested areas during spring (April–June), summer (July–September), and fall (October–November), 1960–1980. Positive values indicate higher soil moisture in the clearcut area. Solid data points represent significant differences ($\alpha=0.05$, *t*-test of inequality) between the clearcut and forested areas.

that year, when revegetation of the clearcut was still sparse (Fig. 5). The contrasts in moisture between the clearcut and the forested areas in summer 1964 were not as large nor as well distributed throughout the soil profile as in summer 1963. However, by fall 1964 the overall differences between the two areas were the largest observed over the duration of the study.

### *1965: Transition*

Vegetative cover on the clearcut transect nearly tripled between 1964 and 1965 (Fig. 5). Accompanying this vegetation were soil moisture differences

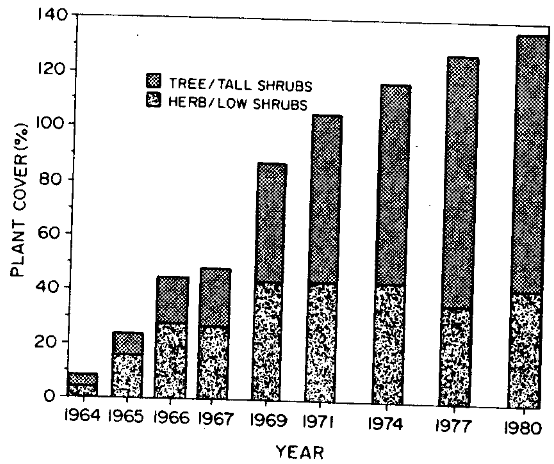


Fig. 5. Amounts of herbaceous vegetation and low-shrub cover as well as tree and tall-shrub cover on the clearcut area from 1964 to 1980.

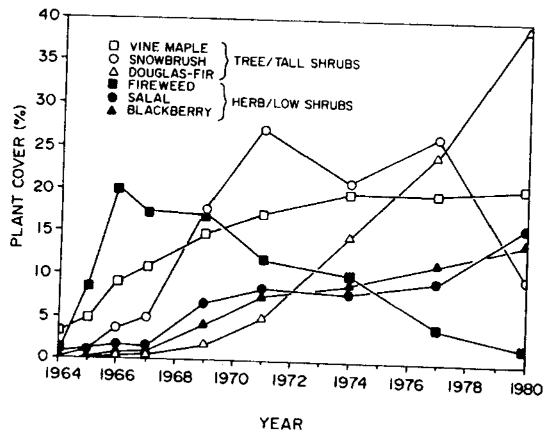


Fig. 6. Dominant plant cover (by species) on the clearcut area from 1964 to 1980.

from the forested area that were smaller or negligible compared with those in 1963 and 1964 (Fig. 4). Moreover, the surface layer of soil contained significantly less moisture in the clearcut than in the forested area during summer 1965. This indicates the important role revegetation was beginning to play in soil hydrology on the clearcut site, even at a fairly modest level (24.4% total cover). Fireweed (*Epilobium angustifolium* L.) may have been significant because it spread dramatically until it became the most prominent plant species in 1965 (Fig. 6). Fireweed is a common and prolific invader of clearcut areas in the western Cascades, even those sites that are unburned or lightly burned (Morris, 1958; Yerkes, 1960; Steen, 1966; Dyrness, 1973).

*1966–1980: Lower moisture*

The trend established in 1965 for soil moisture on the clearcut site to equal or be less than that on the forested site continued in 1966 (Fig. 4). The upper soil layer showed a significantly lower moisture content even during the spring sampling period. Apparently, below-normal precipitation from fall 1965 to spring 1966 (Fig. 2) was not enough to offset moisture depletion near the soil surface by the rapidly increasing shrub cover (Fig. 5). It was also during this time that fireweed achieved its most extensive cover (20%) after logging and burning (Fig. 6). Vine maple and snowbrush (*Ceanothus velutinus* Dougl.) also became considerably more prominent in 1966.

In 1967, the surface soil in the clearcut showed its largest significant negative moisture difference for spring in the entire course of the study (Fig. 4). In that year the negative moisture differences for the surface soil also began to level off over time for each sampling season. Apparently, most of the effect of revegetation on moisture deficits in at least the upper 30 cm of soil can occur well in advance of full occupation of the site because total cover in 1967 was only 48%. Even as total plant cover increased to well over 100% 12–18 years after logging (Fig. 5), surface soil-moisture effects remained comparable to those from earlier years. It may be that herb and low-shrub cover exerts the greatest influence on surface soil moisture because this type of cover remained at a fairly uniform level from 1969–1980. Cover of individual herb and low-shrub species did shift considerably during the later years, however, as fireweed declined and salal and blackberry (*Rubus ursinus* Chamb. and Schlecht) increased (Fig. 6).

Although subsoil moisture levels between the clearcut and forested areas did not differ significantly from 1966 on, a weak trend of progressively less moisture in the soil layer 60–120 cm deep in the clearcut became apparent (Fig. 4). This may reflect the concurrent increase in tree and tall-shrub cover over time (Fig. 5), particularly that of the planted Douglas-fir (Fig. 6), a species whose roots may extend well into the subsoil even at a young age (Stein, 1978).

We studied the relationship between vegetative cover and soil moisture levels on the clearcut area further through regression analysis of the data collected during the summer seasons in 1964–1980. The analysis again focused on the differences in soil moisture between the clearcut and the forested areas, in order to minimize other influences such as antecedent precipitation. Because the graphic plots of plant cover vs. soil moisture differences were typically curvilinear (Fig. 7), a logarithmic regression model was used.

Not surprisingly, plant cover, particularly the herbaceous and low-shrub types, showed generally good statistical relationships with the observed soil-moisture differences during the summer (Table 3). Levels of these types of plant cover clearly accounted for much of the variation in moisture differ-

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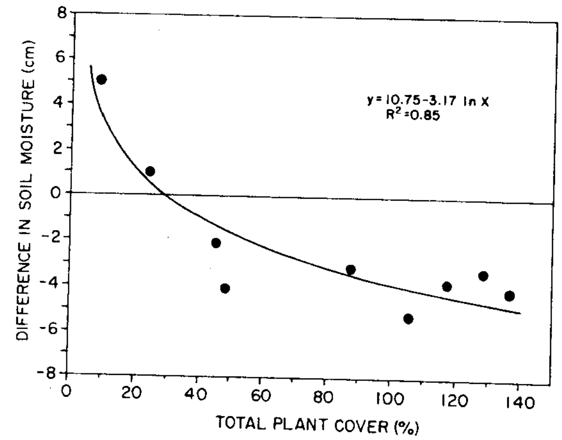


Fig. 7. Regression relationship between total plant cover on the clearcut area and summer soil moisture (0–120 cm depth) differences for the clearcut and forested areas, 1964–1980. Positive values indicate higher soil moisture in the clearcut area.

TABLE 3

Regression and determination coefficients for equations[a] relating average summer[b] soil-moisture differences between clearcut and forested areas with herbaceous vegetation and low shrubs (HLS), trees and tall shrubs (TTS), or total cover (TO)

| 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* | $R^2$ |
| HLS | 1.87 | −1.03 | 0.73 | 2.67 | −0.88 | 0.86 | 6.71 | −2.91 | 0.89 | 11.18 | −4.07 | 0.92 |
| TTS | 0.24 | −0.51 | 0.40 | 1.52 | −0.52 | 0.65 | 4.60 | −1.49 | 0.91 | 6.32 | −2.50 | 0.76 |
| TO | 1.36 | −0.70 | 0.52 | 2.50 | −0.67 | 0.75 | 6.97 | −1.83 | 0.95 | 10.75 | −3.17 | 0.85 |

[a] $y = a + b \ln x$ where $y$ is cm moisture difference (positive values indicate higher moisture in clearcut area) and $x$ is percent cover.
[b] July–September.

ences near the soil surface. Relationships with subsoil moisture were even stronger. Tree and tall-shrub cover showed only a modest relationship with surface-soil moisture differences. Instead, it appeared to be primarily associated with subsoil moisture.

### *Net moisture differences for total soil depth studied*

The differences in average seasonal moisture in the upper 120 cm of soil between the clearcut and the undisturbed forest sites during 1960–1980 are shown in Fig. 8. The graph clearly illustrates that clearcutting can markedly

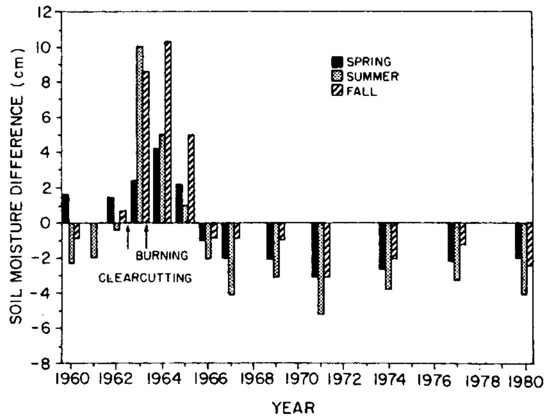


Fig. 8. Differences in average seasonal moisture in soil at depths of 0–120 cm between the clearcut and the forested areas from 1960 to 1980. Positive values indicate higher moisture in the clearcut area.

affect soil moisture in the Douglas-fir zone of the Oregon Cascades. Furthermore, moisture levels can vary from as high as 10.3 cm to as low as −5.2 cm relative to an adjacent mature forest, depending on the time after harvest and the degree and type of associated revegetation. Specific effects of light slash burning (1963) were less obvious from this study, although burning probably delayed 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 for the mixed conifer zone of southwest Oregon. However, our results contrast with those of Ziemer (1964), who reported soil-moisture increases that persisted for at least 12 years in subalpine forest clearcuts in the Sierra Nevada Range of California. Those increases were presumably caused by slower revegetation there. In our study area, the eventual decreases in soil moisture have persisted for at least 15 years on the clearcut site. These decreases may last even longer, because recent data collection does not indicate a trend toward moisture levels comparable to the forested area.

## MANAGEMENT IMPLICATIONS

The soil moisture differences we observed after clearcutting are large enough to interest resource managers in the region. For example, 1-2 cm less moisture at a depth of 0–30 cm on the clearcut site would have brought the soil to the wilting-point level (−1.5 MPa) during the summers of 1966 and 1967. Similarly, low levels of soil moisture occurred in other Cascade Range clearcuts with heavy snowbrush, fireweed, and blackberry cover, causing measurable moisture stress in 5-year-old Douglas-fir plantations (Petersen et al., 1988). Subsequent elimination of this competing vegetation with herbicides resulted in significantly greater tree diameters (+55 to 89%) and heights (+38 to 49%) after 8 years.

Antecedent precipitation can be another key influence on summer soil-moisture regimes (Herring, 1970), and the relatively low precipitation during 1965–1969 probably also contributed to any impaired seedling growth that may have occurred at the study site. Because growing-season moisture is difficult to predict and brush species compete for more than moisture, resource managers should consider brush-control programs to improve the growth of young plantations on similar sites.

The general soil-moisture patterns shown in Fig. 8 only partly conform with annual streamwater yields from HJA-3, which increased over those of the adjacent forested watershed (HJA-2) in each year during 1963–1980 (Harr, 1983). Because most of the post-logging increase in annual water yields occurs during the rainy season in this region (Harr, 1983), the surface soil changes we observed from April to November probably had only a small influence on annual flows from HJA-3. Of course, the limited depth and spatial distribution of our sampling precludes a thorough understanding of the water budget for the entire watershed.

Annual increases in water yield from HJA-3 did generally become smaller from 1966 to 1980 (Harr, 1983), as would be expected from the amount of revegetation that occurred during that period. The soil moisture changes from logging and this revegetation probably had a marked effect on summer streamflows from HJA-3, as the changes follow Harr's (1983) observations of first higher, and then lower, summer flows from a nearby clearcut watershed (HJA-1) in the years after logging. However, because only small areas of large watersheds will be in a uniform stage of clearing or revegetation, such local flow changes should have little consequence for downstream water uses.

ACKNOWLEDGEMENTS

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