# CHARACTERISTICS OF NORTHWEST FOREST SOILS IN RELATION TO PRODUCTIVITY

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## ABSTRACT

*Douglas-fir grows over a wide range of environmental conditions and shows a correspondingly wide range in productivity as indicated by site index. When western Washington and Oregon are stratified into four provinces, those soil, topographic, and climatic variables that contribute to support and to the supply of oxygen, moisture, and nutrients show widely differing effects of productivity among provinces. Although there are not reversals in relation, the correlation coefficients and shapes of the regression curves show that it is necessary to maintain this stratification in order to obtain the highest degree of correlation between environmental factors and site index for Douglas-fir. These differences, along with the variation in total nitrogen in soils from different provinces, may partially explain the inconsistencies experienced in fertilizer trials throughout the region.*

## INTRODUCTION

Portions of the Douglas-fir region of the Pacific Northwest are among the most productive timber growing areas in the world. Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) grows over a wide set of environmental conditions, however, and not all of its range is in the highly productive category. Because of this tolerance for differing growing conditions, productivity as indicated by site index ranges from a low of 55 ft (16.5 m) to a high of 155 ft (46.5 m) at 50 yr above breast height (King 1968). The lower sites occur primarily on the shallow, rocky soils developing from volcanic rocks in the higher Cascades; the most productive areas are near the coast where soils are developing from sedimentary rocks.

Site studies have shown that Douglas-fir has the same height/age relationship throughout western Washington and Oregon. This is not the case for soil-site relationships, which were shown to be influenced by major differences in soil parent materials or by climatic changes (Steinbrenner 1979). Because of these differences, it was necessary to stratify soil-site observations into four distinct provinces to obtain the highest degree of correlation between individual environmental factors and site index. In western Washington and Oregon, it was found that observations obtained from residual soils developing from coastal sediments had similar relation to and could be combined with those for soils developing from volcanic rocks in the Cascades. Because of major differences in climatic variables, however, it was necessary to separate the residual soils in Washington from those in Oregon. Residual soils, as discussed here, are those developing from local parent rocks over a long period of time. They include skeletal and colluvial soils, as well as those developing in place.

Within each of these main provinces it was necessary to separate an additional province. The northern portion of western Washington was covered by continental glaciation that left an area of subdued topography covered by relatively young outwash and till soils. In western Oregon there was a geographically restricted area in the southern end of the Willamette Valley characterized by low effective-moisture relations. This area, south of Cottage Grove, includes the eastern portion of the Coast Range and the western foothills of the Cascades where average annual precipitation is under 60 in. (24 cm).

These four provinces, Washington "residual" and "glaciated," and Oregon "high" and "low," are used here to illustrate the differential relationships of certain environmental factors to the growth rate of Douglas-fir. Data were compiled from the observations in Table 1.

There are many environmental factors that can be related to tree growth, either individually or in combination. These may

Table 1. Observations used in determining four soil provinces in Washington and Oregon.

| Province | No. of observations |
|---|---|
| Washington: | |
| Residual | 118 |
| Glaciated | 73 |
| Oregon: | |
| High | 53 |
| Low | 40 |
| Total | 284 |

be categorized as climatic, topographic, or edaphic; some are easily identified and quantified, whereas others that are no less important are difficult to quantify, of few data on them exist. Those variables that influence (1) ability of the soil to provide the O needed for root respiration, (2) volume for root development and support of the tree, (3) available moisture throughout the growing season, and (4) nutrients necessary for tree growth will have the highest correlation in soil-site studies. Some of these variables will be illustrated, mostly by province, as they relate to site index for Douglas-fir.

## OXYGEN SUPPLY

Oxygen is drawn into the soil from the atmosphere as moisture is drained from the macroscopic pore spaces by the force of gravity. The quantity of macroscopic pores can be used to indicate the level of O in the soil. Since macroscopic pores in the surface soil horizons of undisturbed soils remain relatively numerous, it is the proportion in the denser subsoils that is most closely related to tree growth. Figure 1 shows the relation of macroscopic pore space in the "B" horizon to site index for 91 soils from forested areas in western Washington. The data were obtained by means of a portable air permeameter calibrated to read directly in percent macroscopic pore space (Steinbrenner 1959). The curve in this figure is not a regression, but is drawn through points that represent a group of observations (number of observations shown at each point).

No roots were found to penetrate soil horizons with less than 6% macroscopic pore space; therefore sampling was terminated at that point. From 6% to about 14% there is a rapid increase in site index with increased pore space. Apparently O limits tree growth within that range. Beyond 14%, site index decreases with increased pore space. Since O is not toxic at these levels, one can speculate that decreased growth rate at the higher levels is due to a reduction of microscopic pore space and a decrease in soil moisture-holding capacity. Nearly all the sandy glacial outwash soils measured showed high levels of macroscopic pore space.

## ROOT SUPPORT

The ability of the soil to support trees is related to the total depth available for root penetration. Total depth, however, is not as closely correlated with productivity as effective soil depth. Effective soil depth, as depicted in Figure 2,[1] is the total soil depth to a root restrictive layer, or a maximum of 60 in. (24 cm), minus the volume of gravel or rock.

All provinces show a highly significant increase in site index with increasing effective soil depth, although the degree of correlation, as well as the shape of the curve, varies for each province. Effective soil depth shows a strong positive linear relationship for Washington residual soils, where each additional inch of soil increases site index by 1 ft. (0.1 m/cm). Washington glaciated soils have the weakest correlation, showing a rapid increase in site index with increased soil depth to about 30 in. (12 cm) but little influence beyond that depth. Oregon soils have somewhat similar curves, with the greatest influence on site index occurring at the greater soil depths. Their correlation is intermediate to the two Washington provinces.

## MOISTURE RELATIONSHIPS

There are several environmental factors that affect the ability of the soil to supply moisture for tree growth throughout the

1. Figures 2 through 8 show the simple correlation of the environmental factor, as the independent variable, with site index for Douglas-fir, the dependent variable. Numbers in parentheses are the correlation factors $(R)^2$ and indicate the percentage of variation in site index accounted for by the independent variable. Asterisks show the degree of statistical significance (**$p$ + 0.1; *$p$ + 0.5). Curve lengths show the range of values for that independent variable.

Figure 1. Relationship of macroscopic pore space (percent) in the "B" horizon to site index of Douglas-fir in western Washington (Steinbrenner 1959).

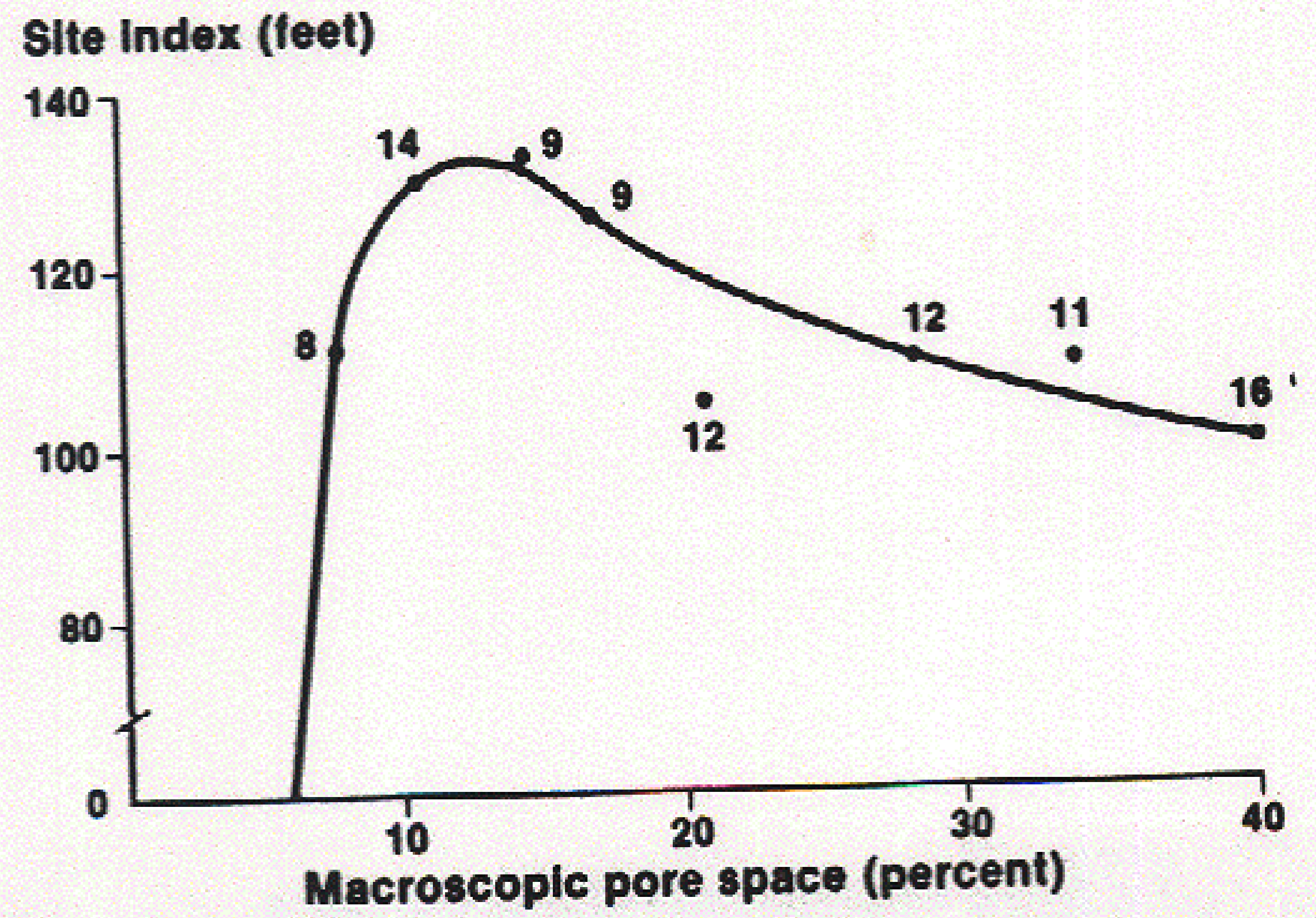
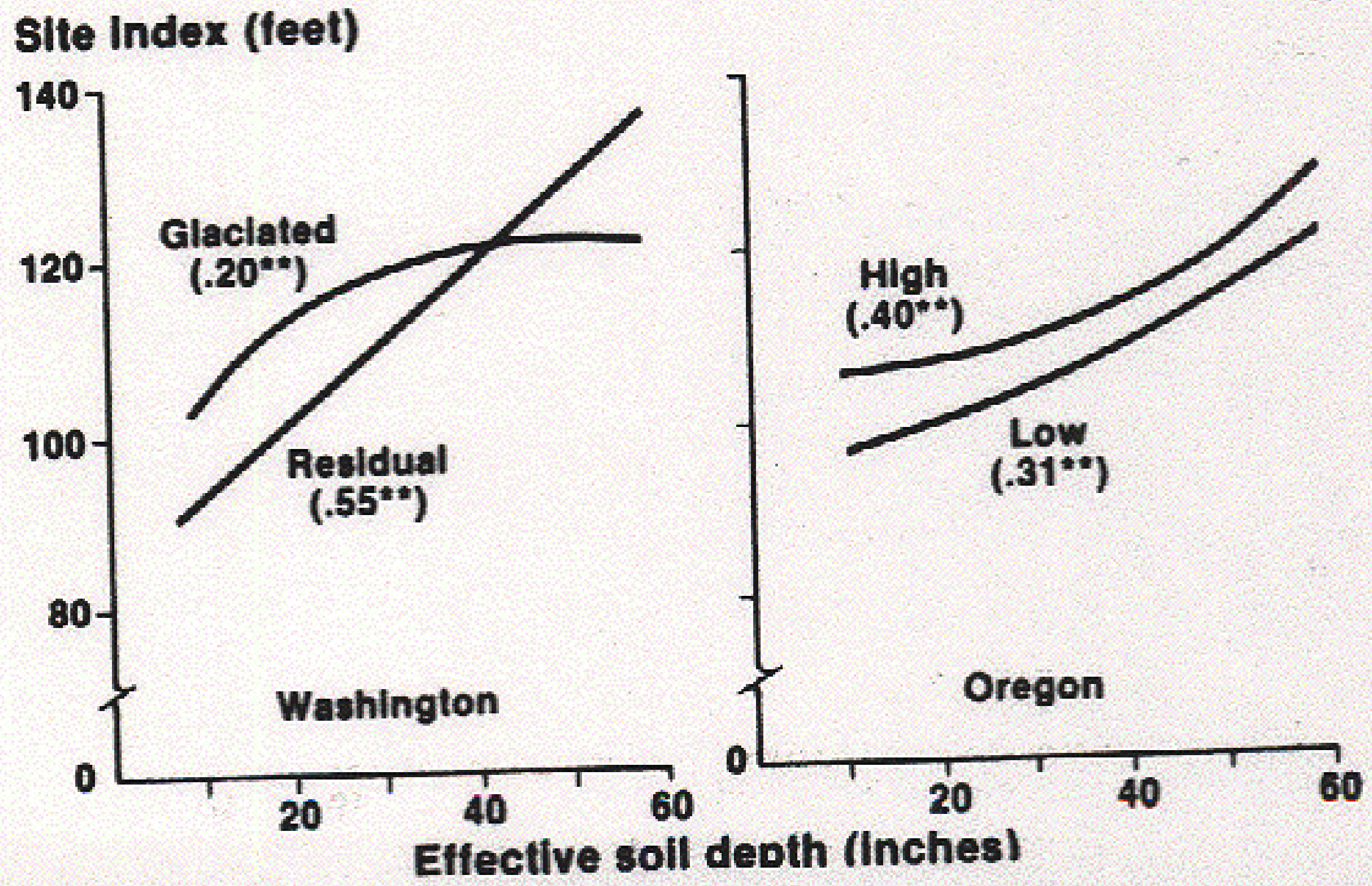



Figure 2. Influence of effective soil depth on site index of Douglas-fir, by province, in western Washington and Oregon.



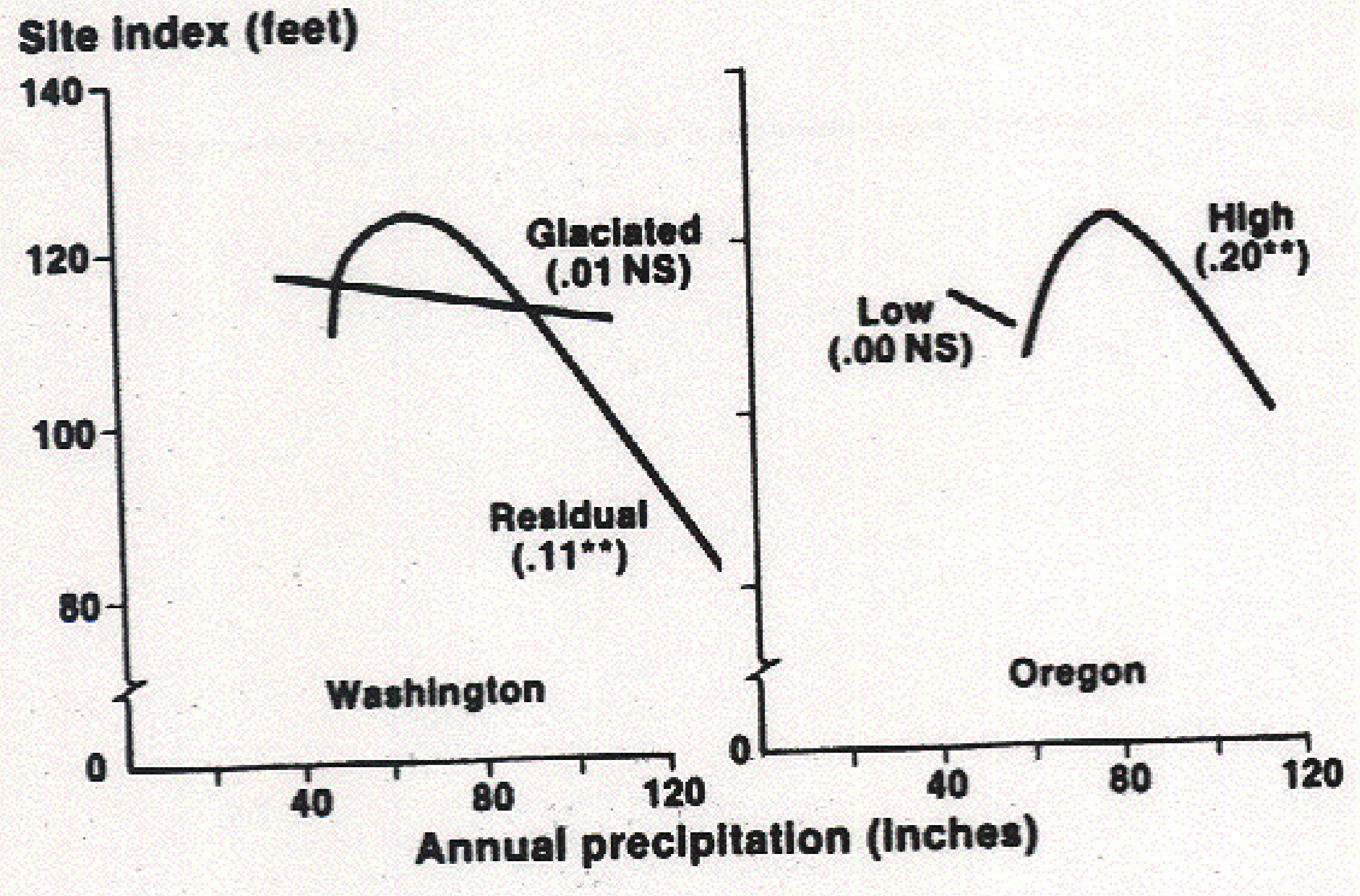



Figure 3. Influence of average annual precipitation on site index of Douglas-fir, by province, in western Washington and Oregon.

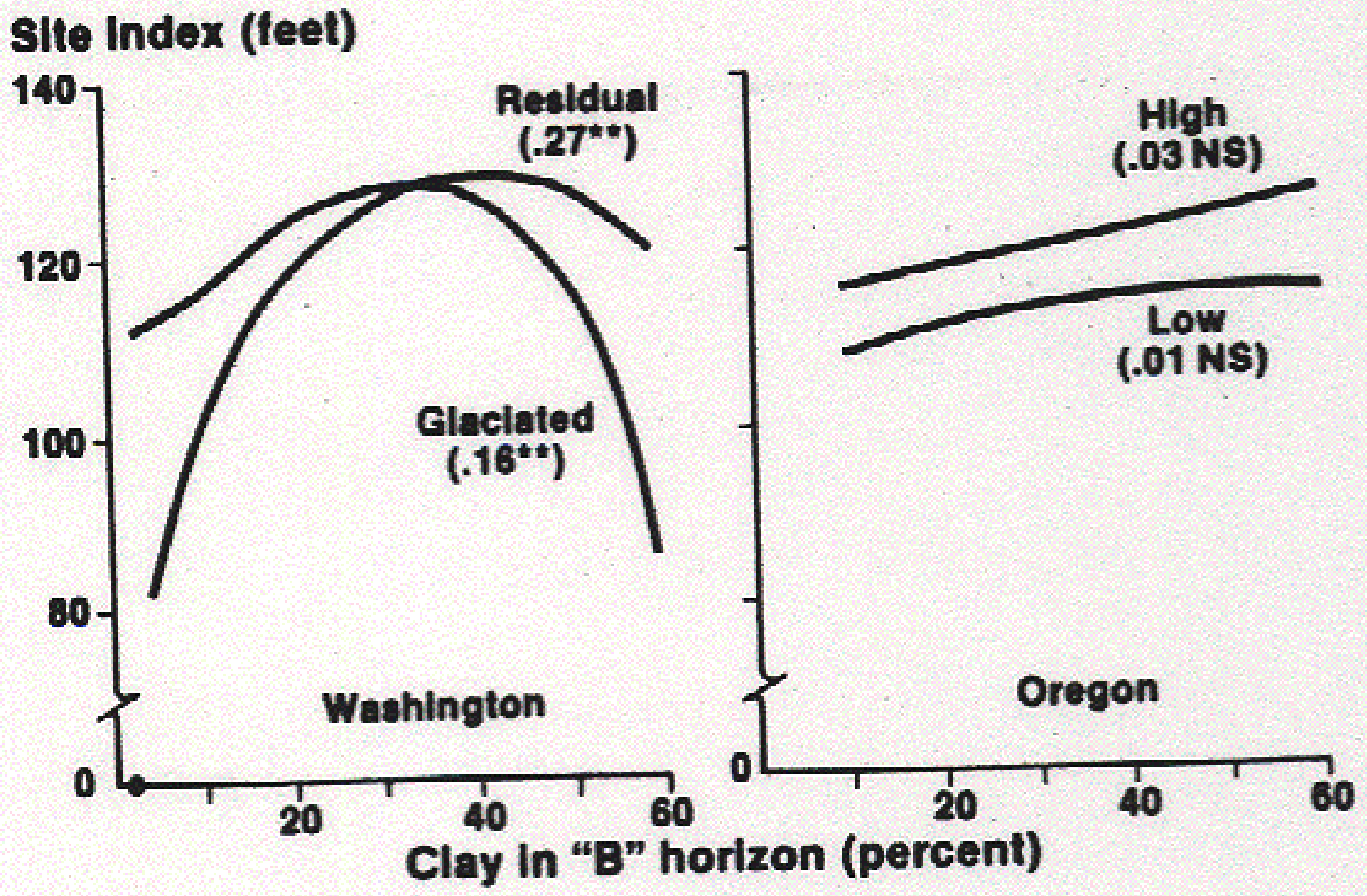



Figure 4. Influence of percentage of clay in the "B" horizon on site index of Douglas-fir, by province, in western Washington and Oregon.

growing season. Total moisture supply as indicated by average annual precipitation, soil moisture-holding capacity as related to the clay in the "B" horizon, lateral movement of moisture in the soil profile as influenced by slope gradient and position on the slope, and temperature relations that affect evaporation rates are to be illustrated as individual variables.

Since trees do require a large quantity of moisture for growth, one might assume that the more precipitation that falls on the soil the more rapidly trees will grow. As can be seen in Figure 3, this is not the case. Average annual precipitation significantly influences site index to a maximum of 70–80 in. (28–32 cm), with a rapid decrease beyond that level for the Washington residual and Oregon high-precipitation soils. This relation is significant but not very strong. The Washington glaciated and Oregon low-precipitation curves show a nonsignificant relation. In both provinces, most of the observations were made at low elevations with a restricted range in precipitation.

In the Douglas-fir region, most of the precipitation occurs during the winter months, when the soils become saturated. Normally, there is little recharge of soil moisture during the active growing seasons; therefore tree growth is dependent on the ability of the soil to retain winter moisture or receive moisture through internal flow from upper slopes. Because it is least affected by evaporation, the content of clay in the "B" horizon, as shown in Figure 4, is the soil moisture-retention factor most closely associated with site index. This variable is not significant over a wide range of clay contents in Oregon, no doubt because of the interaction of other soil properties. In Washington, however, both provinces show a significant increase in site index with an increase in clay to a level of 30%–40%, and a decrease in tree growth beyond that level. One explanation for this relationship is that the moisture is more tightly held by higher clay concentrations, thus reducing the amount available for tree use.

The influence of slope gradient on site index is shown in Figure 5. This topographic variable is associated with the rate of internal downhill movement of soil moisture. There is no relation indicated for glaciated soils; no doubt the moisture in

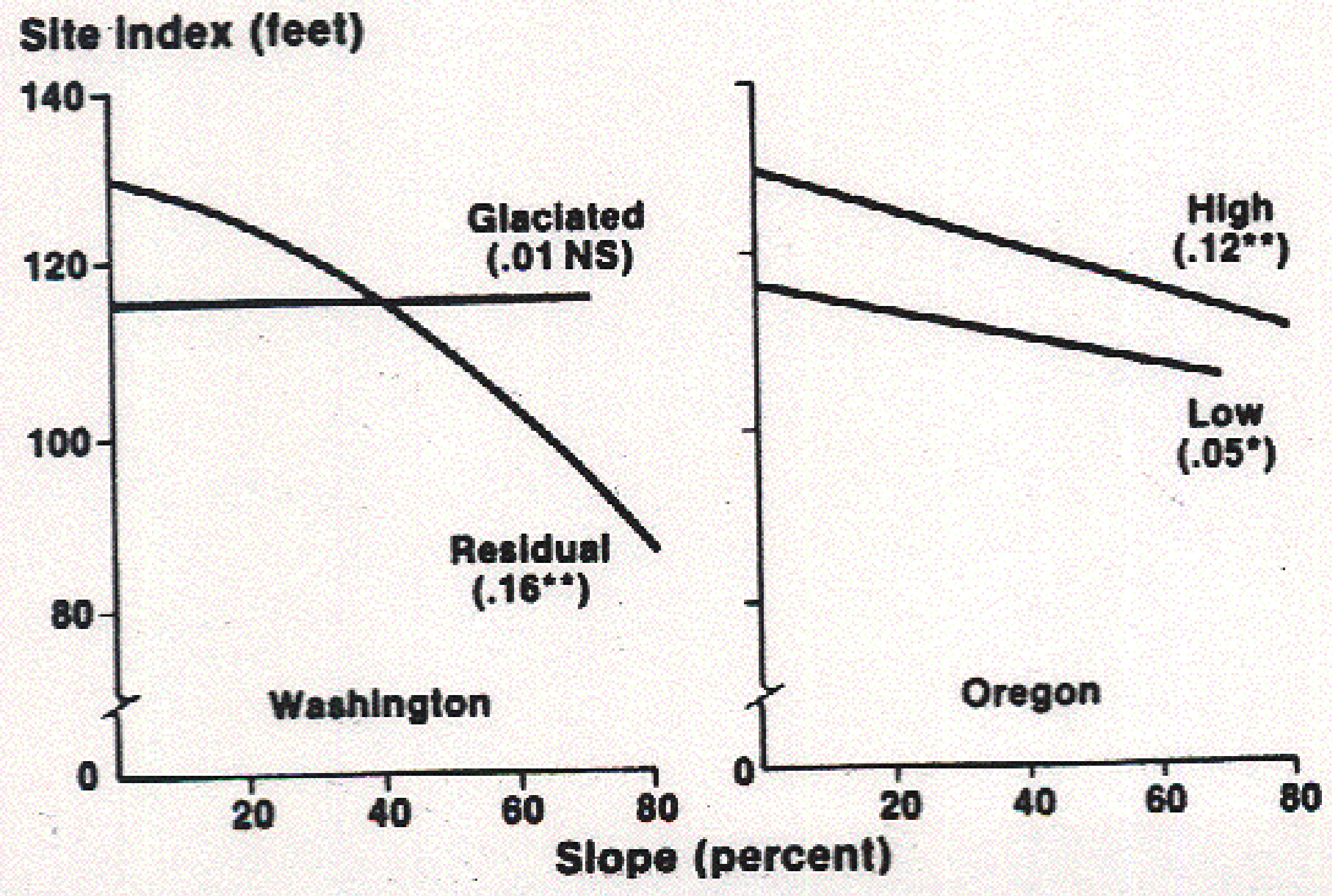



Figure 5. Influence of slope percent on site index of Douglas-fir, by province, in western Washington and Oregon.

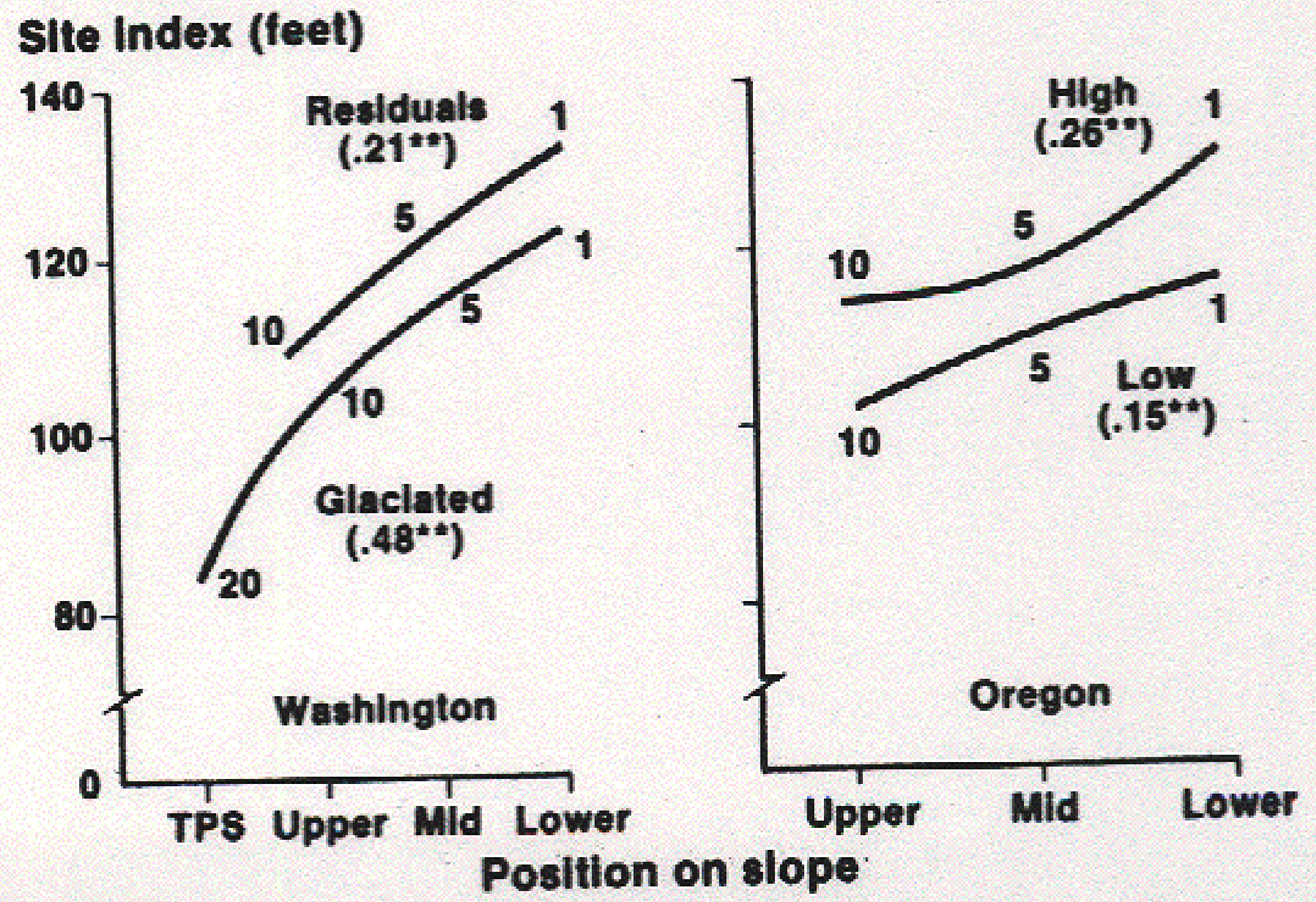



Figure 6. Influence of position on slope on site index of Douglas-fir, by province, in western Washington and Oregon. (Numbers along curve are values assigned for each slope position; *TPS* refers to till plain slopes.)

these soils on the slopes moves either too rapidly or not all, because of the sandy, gravelly texture. All residual soils show a negative influence on site index as slope increases. This relation is slightly curvilinear for Washington soils, with a greater effect as slope increases. Oregon soils show a linear relation, although it is not great.

Of more importance is the influence of position on the slope, as illustrated in Figure 6. This topographic variable is significant in all provinces, showing that the lower positions that receive moisture have a higher site index than the upper positions that supply this moisture. High-precipitation soils in Oregon indicate a similar site index for upper and midslopes, whereas midslopes are intermediate in effect for the other provinces. Position on the slope is the most important environmental variable influencing productivity in the glaciated region, accounting for nearly half the variation in site index. Position on slope encompasses landform and slope combinations that affect moisture relations. The lower position includes river terraces, till plains, and lake beds, which have the most favorable moisture relations. Midslopes include soils with restrictive layers and slopes of 5%–10%. Upper slopes include excessively drained outwash plains. Till plain slopes are an additional category, and include soils with restrictive layers and slopes over 10%.

The influence of elevation on site index of Douglas-fir is presented in Figure 7. This climatic variable is closely related to the temperature patterns in the region. It is included in this section because it affects soil moisture evaporation and greatly accentuates the influence of topographic factors at higher elevations. Elevation is one of the strongest factors influencing productivity for the Washington residual soils, with a negative linear effect on site index; however, it is nonsignificant for the glaciated soils, which are restricted in elevation. Oregon high-precipitation soils also show a negative effect that increases rapidly above 1500 ft (450 m). Oregon low-precipitation soil data included several observations from the rain shadow areas in the higher Cascades that increased the significance of this variable.

## NUTRIENT RELATIONSHIPS

Since most of the available nutrients in forest soils stem from the relatively rapid mineralization of organic matter and the depth of incorporation is related to the total organic level, the depth of the "A" horizon can be used to indicate the approximate nutrient level in a given soil (Figure 8). This variable is especially important in western Washington and Oregon, where N has been found to be the nutrient most limiting growth of Douglas-fir. Previous studies have shown that the level of total organic matter is closely related to N level. In all provinces, increases in depth of the "A" horizon are associated with increased site index for Douglas-fir. This is one of the most highly correlated soil variables for residual soils in Washington, accounting for nearly 60% of the variation in site index. The relationship is not so strong for glaciated soils, which are younger and have not had time to develop the deeper "A" horizons. The range, as depicted, is quite wide, but includes several observations from deep-"A"-horizon prairie soils that were invaded by Douglas-fir. Oregon soils have nearly parallel curves, with the low-precipitation province showing a wider range in depth but little influence on site index at the shallower "A" horizons.

In conjunction with a comprehensive soil survey program by the Weyerhaeuser Company, a complete chemical characterization has been made on many modal soils. The total N in the profiles of 118 of these soils, representing 40 soil series, is

Figure 7. Influence of elevation on site index of Douglas-fir, by province, in western Washington and Oregon.

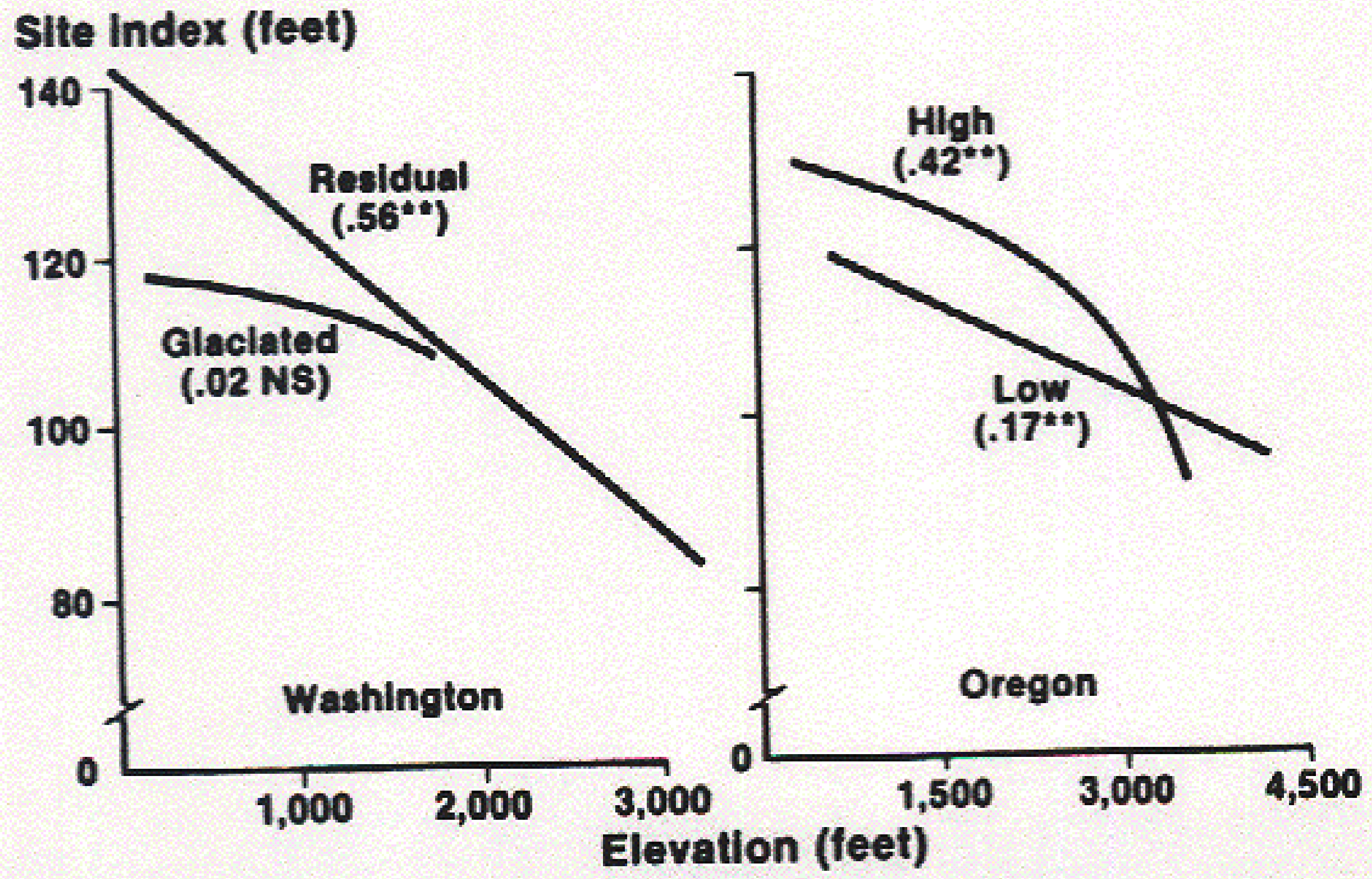
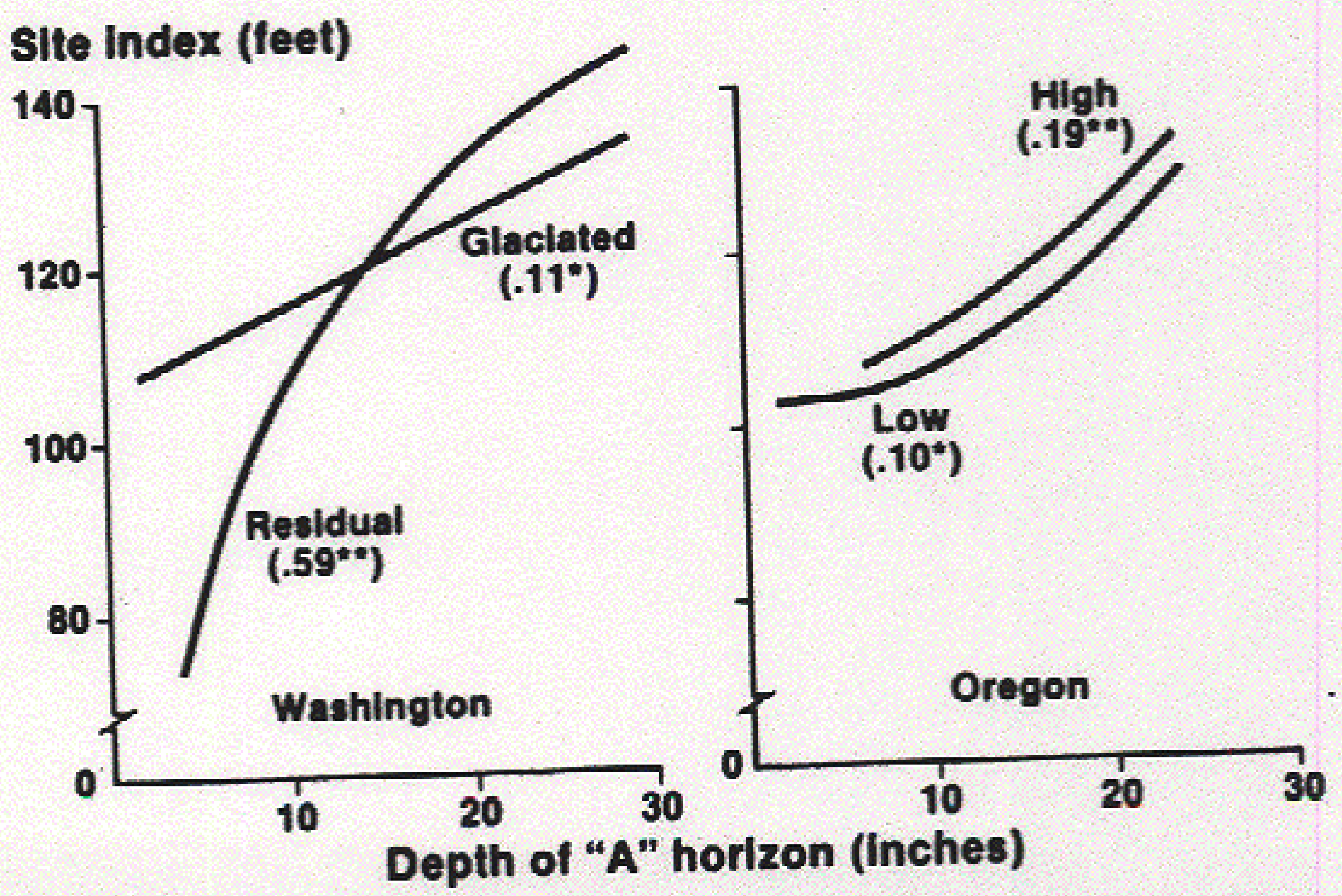



Figure 8. Influence of depth of "A" horizon on site index of Douglas-fir, by province, in western Washington and Oregon.



summarized on Table 2 by province and parent rock. Coastal soils have by far the highest levels of total N in the profile, with similar levels regardless of parent rock. Soils developing from volcanic materials in the Cascades have only about half as much total N, and glaciated soils show the least, averaging about one-third as much as in the coastal region. These regional differences in total N levels explain to some extent the magnitude of variations in response encountered in fertilizer studies throughout western Washington. It is also interesting to note the proportion of the total N occurring in subsoils. Although there might be some organic material in these horizons, most of this N is ionic and held on the soil exchange. One should keep in mind that these data are averages of many observations; where replications of a soil series were analyzed, the variation in total N was in some cases as great as 50%.

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Table 2. Total N in the profile of some modal soils in western Washington (in pounds per acre).

| Region and parent rock type | Number of observations | "A" horizon | "B" horizon | "C" horizon | Total profiles |
|---|---|---|---|---|---|
| Coastal sedimentary rocks | 39 | 8239 (56%) | 4506 (30%) | 1851 (14%) | 14,596 |
| Coastal volcanic rocks | 11 | 9183 (63%) | 5443 (37%) | | 14,626 |
| Cascade volcanic rocks | 54 | 3854 (52%) | 2669 (36%) | 934 (12%) | 7,457 |
| Glaciate outwash and till | 14 | 2472 (47%) | 1946 (37%) | 818 (16%) | 5,236 |