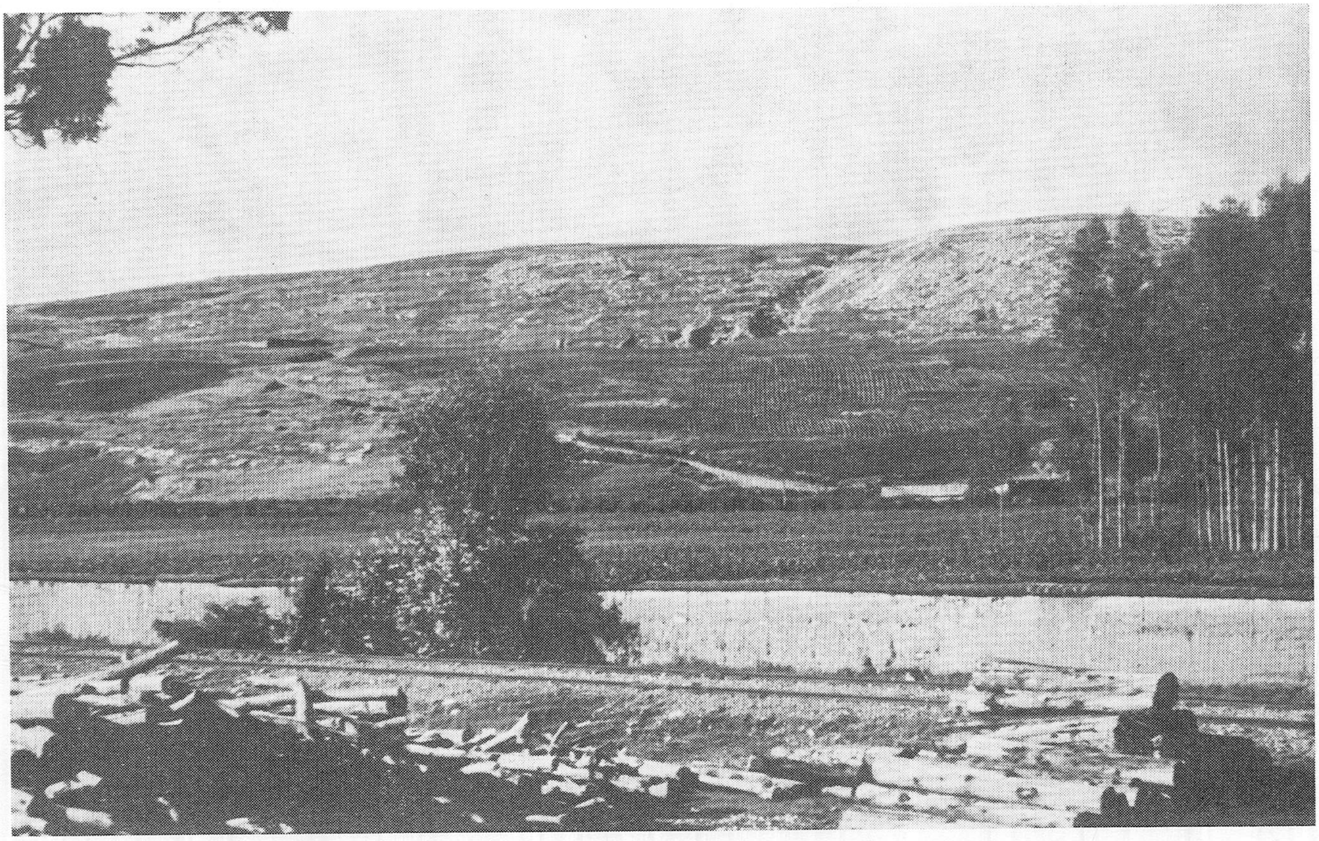

Forestry Departmental Series No. 4
May 1971

FACTORS AFFECTING Height and Diameter Growth and Site Index of *Eucalyptus globulus* (Labill.) in the HÚANACO VALLEY of PERU

Agricultural Experiment Station/Auburn University/Auburn, Alabama/E. V. Smith, Director

LIST OF TABLES

1. Basic statistical data from 20 plantations of *Eucalyptus globulus* in the Húanaco Valley of Peru.

2. Analysis of variance of the *E. globulus* data when tree height was the dependent variable and site index was not included as an independent variable.

3. Analysis of variance of the *E. globulus* data when tree height was the dependent variable and site index was included as an independent variable.

4. Adjusted mean total height by significant independent variables when site index was included in the analysis.

5. Adjusted linear regression coefficients of significant covariables when the dependent variable was tree height.

6. Analysis of variance of the *E. globulus* data when site index was the dependent variable .

7. Simple correlation coefficients expressing relationships between variables in the *E. globulus* data.

8. Adjusted linear regression coefficients of significant covariables where the dependent variable is site index.

9. Analysis of variance of the *E. globulus* data when the mean diameter breast high (d.b.h.) of the stand was the dependent variable.

10. Adjusted linear regression coefficients of significant covariables when the dependent variable is d.b.h.

Appendix Table. F values from analyses of variance of the tree height data computed using aspect values obtained from different index directions.

LIST OF FIGURES

1. Map of Peru showing location of the Húanaco Valley.
2. Scene in the Húanaco Valley showing typical terrain.
3. *E. globulus* pit props and timbers.
4. Seven-year-old *E. globulus* plantation.
5. Road cut showing nature of the soil in the study area.
6. Site index curves for *E. globulus* in the Húanaco Valley.

Appendix Figure. Trace of the value of the sine function when used as in this study.

Cover photo. Scene in the Húanaco Valley.

ACKNOWLEDGMENT

The authors express thanks and appreciation to Ronald Rochis and Milton Cone who collected the data used in this study while serving in Peru as members of the Peace Corps. They were attached to the Peruvian Forest Service and under the direction of the senior author, who was a member of United Nations Development Program Special Fund Project No. 116, FAO, Forestry/Peru. Mr. Cone was killed in action in Viet Nam in 1969 and this paper is dedicated to his memory.

Factors Affecting Height and Diameter Growth and Site Index of *Eucalyptus globulus* (Labill.) in the Húanaco Valley of Peru

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INTRODUCTION

THE GEOGRAPHY AND ECONOMIC STRUCTURE of Peru are dominated by the high and rugged cordillera of the Andes mountains that separates the country into three distinctly different regions. The largest of these regions lies east of the mountains, is sparsely populated, has a tropical climate, and is dominated by dense rain forests typical of the Amazon basin. West of the mountains is a relatively narrow strip of coastal desert that harbors approximately two-thirds of the nation's population and exhibits the country's most advanced economic development. The mountains, along with their associated highlands (Altiplano), form the third major subdivision of the country. Few transportation links join these three regions and those that do exist are poorly suited to heavy traffic. This is particularly true of the eastern region that is almost completely isolated from the others. These geographic factors have a profound influence on the timber economy. Although the country has enormous resources of usable timber, Peru is a net importer of sawn lumber and other forest products.

In addition to its forest wealth, Peru has extremely large reserves of copper, gold, silver, and other mineral resources. Most of these minerals are found in the central mountain region where the mining industry is most active. Most mining in this region is of the shaft type that requires large quantities of both sawn and round wood for pit props. Because of the transportation problems mentioned earlier, the great supply of wood east of the mountains is not economically available to satisfy the demand for mining wood. Transportation links from the coast to the central area are adequate for supplying wood to the mines, but this wood is extremely expensive. Because of these conditions, extensive plantings of *Eucalyptus globulus* (Labill.) have been established in the mining area. This species has been favored since it exhibits rapid growth, an ability to coppice, and resistance to drought. However, little is known concerning the silviculture or management of this species under conditions existing in the central region of Peru. This report provides some information relative to this subject.

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Site of this investigation was the Húanaco Valley, Figure 1, which lies in the midst of the mountains, cover and Figure 2. The valley floor ranges in elevation from 2,500 to 4,000 meters (8,000 to 14,000 feet) above sea level and the surrounding mountains rise to altitudes of approximately 6,000 meters (20,000 feet). Valley walls are steep and rocky. Relatively little land is suitable for growing trees. Consequently, large amounts of pit prop material must be grown in short rotations on small areas. *E. globulus,* because of its rapid height growth, has great potential in this area.

In the central region of Peru, wood for pit props is not

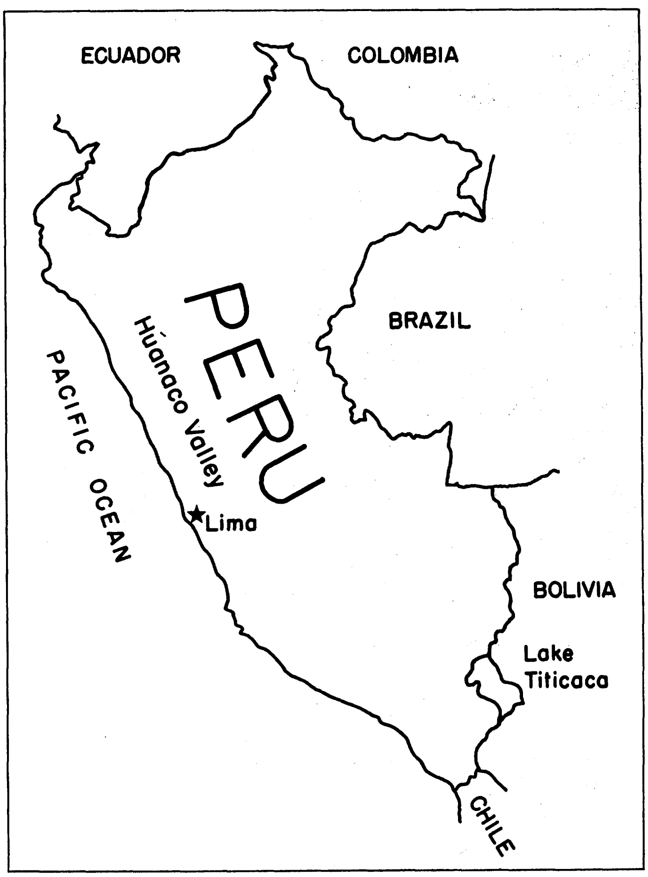


FIG. 1. Map of Peru showing location of Húanaco Valley.

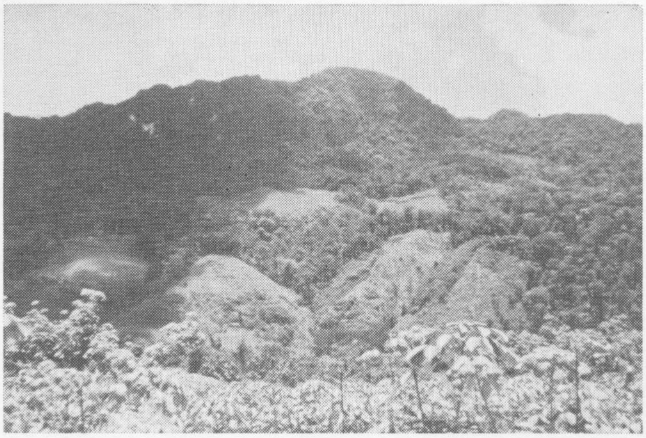


FIG. 2. Scene in Húanaco Valley shows typical terrain.

FIG. 3. *E. globulus* pit props and timbers.

bought and sold on a volume basis. Price is based solely on the individual piece, which is bought to satisfy a specific mining need. Consequently, lengths are variable, averaging about 2 meters (6 feet), whereas top diameter limits range from 10 to 15 centimeters (approximately 4 to 6 inches), with 13 centimeters (5 inches) preferred. Pieces with top diameters greater than 15 centimeters are sometimes used, but they are less valuable to the mines because their additional weight and volume increase handling and transportation problems resulting in higher costs. Larger pieces also are undesirable to producers because production costs are higher than for smaller pieces. These factors indicate that trees used for pit props should be as tall and slender as possible and should attain the desired height as rapidly as possible. Because of this, knowledge of any silvicultural or ecological factors influencing height growth would be of great potential value to producers and users of pit props in the Altiplano of Peru.

DATA COLLECTION

Twenty non-coppiced plantations, Figure 4, were selected randomly for study from all plantations in the valley. Distribution of the sample was such that plantations at 16 separate locations within the valley were sampled. Within each plantation, two to eight plots (depending on size of the plantation) were randomly located. In total, 79 plots were located and measured. However, because the data were not complete for some plots, only 72 were suitable for all phases of the study. Each plot was 20 × 20 meters (65.6 × 65.6 feet, 1/25 hectare, or almost exactly 1/10 acre) and was so located within the stand that edge-effect was not a factor.

The following data items were recorded for each **plantation:**

1. Age of plantation, in years (which should have been the same as tree age since, with this species, only about 3 months elapse between seed germination and outplanting);
2. Planting method used (bare root or in cans);
3. Whether fertilizer had been applied (type and quantity of fertilizer as well as timing of application were unknown);
4. Whether the site had been prepared for planting (site preparation consisted of plowing or hand cultivating sites prior to planting);
5. Whether the plantation had been irrigated at any time in its existence (no information was available concerning amount of water used or the timing of its application.)

At each **sample plot** the following information was obtained:

1. Altitude above sea level, in meters, using a barometric altimeter;
2. Slope, in degrees, using an Abney level;
3. Aspect, in degrees of azimuth from true north (see Appendix);
4. Initial planting space per tree, in square meters;
5. Number of trees per hectare at time of data collection;
6. Basal area, in square feet per hectare;
7. Soil pH, determined using a field kit of unknown type;
8. Depth, in centimeters, of the A plus B soil horizons;
9. Average diameter breast high (d.b.h.) in inches, of all stems (breast height was set at 4.5 feet rather than 1.3 meters);
10. Total height in meters and d.b.h. in inches of 6 to 12 of the dominant trees on the plot; and,

FIG. 4. Seven-year-old *E. globulus* plantation.

TABLE 1. BASIC STATISTICAL DATA FROM 20 PLANTATIONS OF *Eucalyptus globulus* IN THE HÚANACO VALLEY OF PERU, 1966-67

Variable	Arithmetic mean			Standard deviation			Range		
	Metric	English	Other	Metric	English	Other	Metric	English	Other
Age			10.4 yr.			±2.2 yr.			6-17 yr.
Altitude	2,728 m.	8,317 ft.		±515.8 m.	±1,573 ft.		1,900-3,650 m.	6,200-12,000 ft.	
Slope			13.9°			±10.3°			0-35°
Planting space/tree	5.21 m.^{2}	56.1 ft.^{2}		±3.10 m.^{2}	±34.4 ft.^{2}		0.90-13.50 m.^{2}	9.7-145.3 ft.^{2}	
Number of trees	2096/ha.	848/acre		±1,053/ha.	±426/acre		576-7250/ha.	233-2934/acre	
Basal area	27.60 m.^{2}/ha.	120.2 ft.^{2}/acre		±12.39 m.^{2}/ha.	±54.0 ft.^{2}/acre		3.47-66.05 m.^{2}/ha.	15.1-287.7 ft.^{2}/acre	
Soil pH			6.55			±0.90			4.5-8.0
Per cent sand			50.0			±7.5			34.0-66.0
Per cent silt			30.4			±4.9			22.0-48.0
Per cent clay			19.7			±5.8			8.0-39.0
Depth of A&B horizon	39.1 cm.	15.4 in.		±18.3 cm.	±7.2 in.		15-100 cm.		5.9-39.0 in.
Total height	23.3 m.	76.4 ft.		±7.0 m.	±23.0 ft.		9-60 m.	30-197 ft.	
D.b.h. of all trees in stand	13.5 cm.	5.3 in.		±4.2 cm.	±1.67 in.		6.6-24.9 cm.	2.6-9.8 in.	

FIG. 5. Road cut showing nature of soil in study area.

11. The nature of the parent material was recorded as being either solid or decomposed bedrock.

In addition, a soil sample was collected from each sample plot, Figure 5, and mechanically analyzed in the laboratory to determine percentages of sand, clay, and silt.

DATA ANALYSIS AND DISCUSSION

Table 1 summarizes the basic statistical information obtained in the course of the study.

Tree height, rather than d.b.h. or volume, was chosen as the primary dependent variable since it is the critical factor influencing utilization and economic value of the trees composing these plantations. To provide additional information, however, effects of the measured variables on d.b.h. and site index also were investigated. Data were available from 489 trees for the tree height analysis.

Data were analyzed using the "Least-Squares and Maximum Likelihood General Purpose Program" developed by W. R. Harvey of Ohio State University. Planting method (P), irrigation (I), site preparation (S), and fertilization (F) were considered to be the variables giving rise to the main effects, whereas age, altitude, slope, aspect (see Appendix), planting space, number of trees per unit ground area, basal area per unit ground area, soil pH, per cent sand, per cent silt, per cent clay, and depth of the combined A and B soil horizons were considered covariates. The statistical model was as follows:

$$Y_{ijklm} = \bar{y} + \text{(P)lanting method}_i + \text{(I)rrigation}_j + \text{(S)ite}_k + \text{(F)ertilizer}_l + (PI)_{ij} + (PS)_{ik} + (PF)_{il} + (IS)_{jk} + (IF)_{jl} + (SF)_{kl} + \sum_{m=1}^{n} \beta_m X_m + \epsilon_{ijklm}$$

Tree Height

Table 2 shows the analysis of variance that was obtained when tree height was the dependent variable. Of the main effects and interactions, S, F, PxI, PxS, IxS, and IxF were

TABLE 2. ANALYSIS OF VARIANCE OF THE *E. globulus* DATA WHEN TREE HEIGHT WAS THE DEPENDENT VARIABLE AND SITE INDEX WAS NOT INCLUDED AS AN INDEPENDENT VARIABLE

Source	d.f.	M.S.	F	Level of significance
Planting method (P)	1	36.192	2.132	N.S.
Irrigation (I)	1	59.001	3.476	N.S.
Site preparation (S)	1	135.388	7.976	0.005
Fertilization (F)	1	99.048	5.835	0.025
PxI	1	93.920	5.533	0.025
PxS	1	263.687	15.534	0.005
PxF	1	60.829	3.583	N.S.
IxS	1	386.820	22.788	0.005
IxF	1	81.699	4.813	0.050
SxF	1	57.543	3.390	N.S.
Age (linear)	1	36.437	2.147	N.S.
Altitude (linear)	1	345.476	20.352	0.005
Slope (linear)	1	6.533	0.385	N.S.
Planting space (linear)	1	63.267	3.727	N.S.
Number of trees/ha. (linear)	1	350.170	20.629	0.005
Basal area/ha. (linear)	1	3570.502	210.343	0.005
pH (linear)	1	0.115	0.007	N.S.
Per cent sand (linear)	1	6.822	0.402	N.S.
Per cent silt (linear)	1	10.835	0.638	N.S.
Per cent clay (linear)	1	4.544	0.268	N.S.
Depth of A&B (linear)	1	7.765	0.457	N.S.
Aspect (linear)	1	722.275	42.550	0.005
Residual	466	16.975		

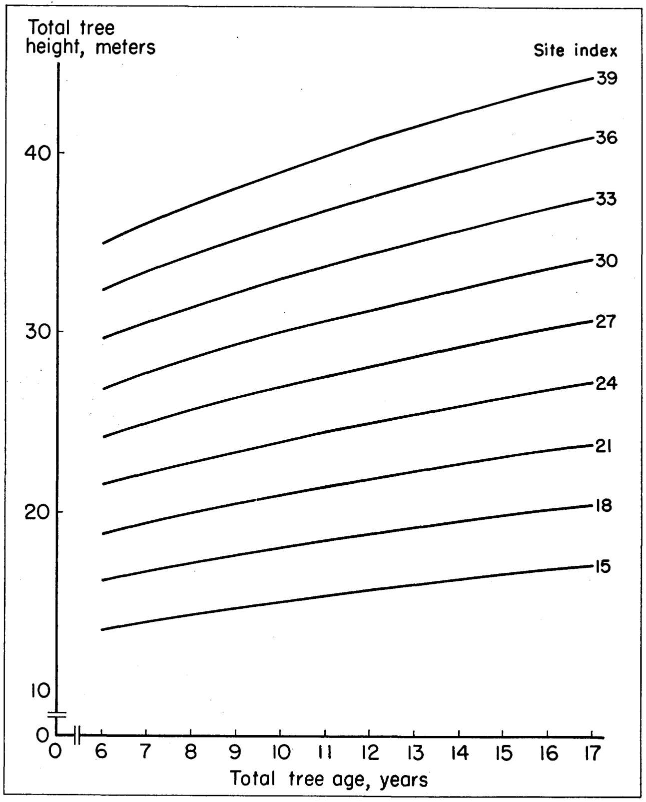


FIG. 6. Site index curves for *E. globulus* in the Húanaco Valley of Peru.

significant, along with the covariables altitude, number of trees per hectare, basal area per hectare, and aspect.

Results of the analysis of variance in Table 2, which indicate that stand density was the strongest independent variable and that age had no effect, are contrary to the usual assumptions on which site index is based. This suggested that some powerful variable was not being considered in the analysis, and this variable was deduced to be site quality. Consequently, the family of site index curves in Figure 6 was developed from the available data. The procedure used to develop these curves is that described by Chapman and Meyer[1]. This procedure is relatively crude, since it does not recognize polymorphism, but sketchiness of the data precluded use of more sophisticated procedures. The guide used in construction of the curves is the trace of the equation:

$$H = 12.3266 + 3.3069A^{1/2}$$

Where: H = total tree height (in meters), and
A = tree age (in years).

The index age was set at 10 years and the interval between curves was set at 3 meters. Despite crudeness, these curves may be useful to forest managers in the Húanaco Valley since site index curves for *E. globulus* in that area apparently are unavailable.

These site index curves were used to obtain site index values for each sample plot in the study. These values were used as an additional covariable and the tree height data were reanalyzed on this basis. No attempt was made to transform other independent variables in this analysis.

Utilization of this, or any other, set of site index curves in a study of this type undoubtedly will cause adverse comment. Site index actually refers to the height attained by dominant or codominant trees at a given age. Consequently, site index is closely correlated with tree height. Inclusion of site index in an analysis of variance of this type would show it to be a powerful contributor to variability of the dependent variable. Furthermore, if any other independent variables were correlated with site quality, and many of those used in this study would be expected to be so correlated, their roles in tree height growth could be obscured effectively in the analysis of variance. However, since these interrelationships could be evaluated in a subsequent analysis of variance of the **site index** data, the decision to reanalyze tree height data with site index as a covariable was reasonable.

Results of the analysis of variance that included site index as a covariable, Table 3, are far more conventional than those obtained in the first analysis. As expected, site index and age have strong influences on tree heights, and basal area no longer appears as a significant variable. However, the appearance of soil depth and aspect as significant variables was unexpected. These are site quality variables and ordinarily would be expected to be obscured by site index.

Insofar as the main effects and their interactions are concerned, only site preparation (S) and the interactions PxS, IxS, and IxF were significant, Table 3. Table 4 gives the adjusted mean total heights associated with these effects. Included in Table 4 are results of a series of Duncan's new mutiple range tests made to isolate the combinations of effect that were acting differently from the others and causing the interactions to appear significant.

The information in Table 4 indicates that site prepara-

TABLE 3. ANALYSIS OF VARIANCE OF THE *E. globulus* DATA WHEN TREE HEIGHT WAS THE DEPENDENT VARIABLE AND SITE INDEX WAS INCLUDED AS AN INDEPENDENT VARIABLE

Source	d.f.	M.S.	F	Level of significance
Planting method (P)	1	38.408	3.326	N.S.
Irrigation (I)	1	2.368	0.205	N.S.
Site preparation (S)	1	69.770	6.044	0.025
Fertilization (F)	1	0.143	0.012	N.S.
PxI	1	27.130	2.350	N.S.
PxS	1	233.382	20.216	0.005
PxF	1	5.403	0.468	N.S.
IxS	1	82.188	7.119	0.010
IxF	1	67.085	5.811	0.025
SxF	1	38.323	3.320	N.S.
Age (linear)	1	136.553	10.962	0.005
Altitude (linear)	1	7.641	0.662	N.S.
Slope (linear)	1	2.650	0.230	N.S.
Planting space (linear)	1	8.543	0.740	N.S.
Number of trees/ha. (linear)	1	24.174	2.094	N.S.
Basal area/ha. (linear)	1	1.632	0.141	N.S.
pH (linear)	1	21.887	1.896	N.S.
Per cent sand (linear)	1	1.446	0.125	N.S.
Per cent silt (linear)	1	4.218	0.365	N.S.
Per cent clay (linear)	1	1.295	0.112	N.S.
Depth of A&B (linear)	1	108.127	9.366	0.005
Aspect (linear)	1	222.317	19.257	0.005
Site index (linear)	1	2541.952	220.185	0.005
Residual	465	11.545		

[1] CHAPMAN, H. H. AND W. H. MEYER. 1949. Forest Mensuration. McGraw-Hill Book Company. New York (522 pp.).

TABLE 4. ADJUSTED MEAN TOTAL HEIGHT BY SIGNIFICANT INDEPENDENT VARIABLES WHEN SITE INDEX WAS INCLUDED IN THE ANALYSIS (INCLUDED ARE RESULTS OF A SERIES OF DUNCAN'S NEW MULTIPLE RANGE TESTS)

Variable and level	Mean	Comparison level of significance 0.05	0.01
Site preparation			
Site prepared	24.10		
Site not prepared	20.90		
Planting method x site preparation			
Bare rooted & plowed	25.00	│	│
In cans & not plowed	24.26	│	│ │
In cans & plowed	23.20		│
Bare rooted & not plowed	17.55		
Irrigation x site preparation			
Not irrigated but plowed	24.77		
Irrigated & plowed	23.43		│
Irrigated & not plowed	22.19		│
Not irrigated or plowed	19.61		
Irrigation x fertilization			
Irrigated & fertilized	24.36	│	│
Not irrigated nor fertilized	23.60	│	│
Irrigated & not fertilized	21.26	│	│
Not irrigated but fertilized	20.78	│	│

tion by "plowing" prior to planting had, in general, a beneficial effect on tree height growth.

The effect of site preparation (compared to no site preparation) on trees planted in cans was negligible. However, trees that had been planted with bare roots on plowed land did somewhat better than trees planted in cans on either plowed or unplowed sites. Bare-rooted trees planted on plowed land did much better than trees planted with bare roots on unplowed land.

Irrigation alone had no discernible effect on height growth. However, trees responded differently to irrigation when other factors were considered in conjunction with it.

Irrigation and site preparation showed evidence of an interrelationship only when a site was not plowed prior to planting and the trees were not irrigated following planting. This combination of no soil disturbance and no irrigation yielded poorer results than any other treatment or set of treatments. This suggests that plowing and/or irrigation would be required for good results.

The pattern of response to irrigation and fertilization was unusual in that it made little difference whether, on the one hand, the trees had been irrigated and fertilized or, on the other hand, the trees had been neither irrigated nor fertilized. However, application of fertilizer in the absence of irrigation had a negative effect. It is possible that the application of fertilizer created a situation where uptake of water normally available was reduced because of an unfavorable osmotic potential. Addition of fertilizer can result in osmotic potentials so low as to retard plant growth[2]. Watering alone was better than fertilizer alone, but yielded results poorer than those associated with either irrigation and fertilization or with no irrigation or fertilization treatment. This situation probably was produced because the limited watering encouraged herbaceous weed growth that utilized the shallowly penetrating

[2] KRAMER, P. J. 1969. Plant and Soil Water Relationships: A Modern Synthesis. McGraw-Hill Book Company. New York (482 pp.).

TABLE 5. ADJUSTED LINEAR REGRESSION COEFFICIENTS OF SIGNIFICANT COVARIABLES (DEPENDENT VARIABLE IS TREE HEIGHT)

Covariable	b
Age	+ 0.678 meter of tree height per year
Depth of A&B horizons	− 0.0357 meter of tree height per centimeter of soil depth
Aspect	+ 0.000040 meter of tree height per sine unit (0.00001) of the azimuth from N 45° W
Site index	+ 1.325 meters of tree height per meter of site index

water along with natural precipitation and thus decreased available soil water for the deeper rooted *Eucalyptus*.

Adjusted linear regression coefficients of age and site index are positive, Table 5, indicating that tree height increases with increasing age and site quality, which is to be expected. However, increasing soil depth apparently has an adverse effect. Though this was unexpected, since good sites usually are associated with deep soils, it is not unreasonable when the character of the soil (mostly coarse, gravelly sand) is considered. The deeper this soil, the easier and faster the rainfall or irrigation water can percolate beyond the root system of the trees. The effect of increasing azimuth of slope from northwest (aspect) was to increase height growth. This conforms to the theory that better sites and, consequently, taller trees occupy the cooler, wetter slopes. However, the appearance of soil depth and aspect as significant variables when site index was included as a variable was not expected and raised many questions.

Site Index

Inclusion of site index into the analysis of variance of tree height data effectively obscured effects of most variables that actually control site quality (and, inexplicably,

TABLE 6. ANALYSIS OF VARIANCE OF THE *E. globulus* DATA WHEN SITE INDEX WAS THE DEPENDENT VARIABLE

Source	d.f.	M.S.	F	Level of significance
Planting method (P)	1	42.203	0.097	N.S.
Irrigation (I)	1	449.348	1.035	N.S.
Site preparation (S)	1	308.125	0.709	N.S.
Fertilization (F)	1	482.952	1.112	N.S.
PxI	1	387.242	0.892	N.S.
PxS	1	101.726	0.234	N.S.
PxF	1	470.985	1.084	N.S.
IxS	1	1185.951	2.730	N.S.
IxF	1	63.894	0.147	N.S.
SxF	1	151.923	0.350	N.S.
Age (linear)	1	253.805	0.584	N.S.
Altitude (linear)	1	2713.156	6.246	0.025
Slope (linear)	1	14.437	0.033	N.S.
Planting space (linear)	1	1007.155	2.319	N.S.
Number of trees/ha. (linear)	1	6750.411	15.541	0.005
Basal area/ha. (linear)	1	36321.356	83.620	0.005
pH (linear)	1	86.859	0.200	N.S.
Per cent sand (linear)	1	199.066	0.458	N.S.
Per cent silt (linear)	1	24.128	0.056	N.S.
Depth of A&B (linear)	1	139.762	0.322	N.S.
Aspect (linear)	1	1141.092	2.627	N.S.
Residual	50	434.362		

did not obscure two of the site quality variables). Thus, it was necessary to study effects of these variables on site index itself. This was done in the analysis of variance given in Table 6. It should be noted that this variance is based on 72 rather than 489 observations since, in this case, only one observation per plot was available. Because of this loss in degrees of freedom, analysis of the site index data is considerably less sensitive than was the tree height analysis.

Results obtained from the analysis were not as expected. Of the variables usually associated with site quality, only altitude was significant. Furthermore, altitude appeared to have less effect on site index than did stand density. In an attempt to clarify these results, a study of the pattern of correlations between the continuous variables was made, based on information in Table 7.

Of the variables under discussion, altitude, slope, soil pH, per cent sand, per cent silt, per cent clay, soil depth, and aspect usually are considered to be associated with site quality. Site index was correlated significantly and relatively strongly with two of these, altitude and slope, and significantly but relatively weakly correlated with soil pH, per cent silt, soil depth, and aspect. Site index was not correlated significantly with the other variables.

Site index increased as both altitude and slope increased, which is logical since at higher altitudes the sites are subjected to lower temperatures and shorter growing seasons and soil on steeper slopes retains less water for use by plants. These conditions are compounded by the strong positive correlation between altitude and slope, which indicates that slopes become steeper as altitude increases. The strong correlation between altitude and slope results in only one (altitude) appearing significant in the analysis of variance in Table 6. Only a minor change in the data probably would have resulted in slope being significant and altitude not significant.

Correlations between soil depth and altitude and soil depth and slope are significant but not strong. In general, soil depth decreases as altitude and slope increase, following the pattern of site index. As soil depth decreases, the per cent of clay decreases and per cent of sand increases. This is logical since clay particles are transported downward by water more easily than are sand particles. Clays are deposited on the more gentle lower slopes while sands remain above on steeper slopes. High pH values are more likely to be associated with clays than with sands. The data in Table 9 are consistent with this pattern. Thus, the significant correlation between soil depth and pH is a reflection of the correlation between soil depth and per cent clay and between per cent clay and pH. This also explains the relationship between pH and altitude and slope. In short, one would expect to find deep, clay soils with high pH values on gentle slopes at low elevations, whereas on steep slopes at high altitudes the soil would be shallow, sandy, and acid. Because of interlocking correlations among all these variables, only altitude appears significant in the analysis in Table 8. The lack of significance on the part of slope, soil depth, mechanical composition of soil, and soil pH does not mean, however, that these factors have no effect on site quality.

As aspects change from northwest to southeast site indices increase, but the correlation is so weak that it is barely significant where 489 observations are available.

TABLE 7. SIMPLE CORRELATION COEFFICIENTS EXPRESSING RELATIONSHIPS BETWEEN VARIABLES IN THE *E. globulus* DATA

	Age	Altitude	Slope	Planting space	No. trees /ha.	Basal area/ha.	pH	Pct. sand	Pct. silt	Pct. clay	Depth	Aspect	Site index	Height	D.b.h.[2]
Age	1.0000	−0.1228	0.0361	0.7317	−0.3093	−0.1395	0.1381	0.0021	−0.1756	0.1471	−0.2015	−0.3091	0.0128	0.0692	0.2714
Altitude		1.0000	0.5638	0.0361	−0.0105	−0.3482	−0.3934	0.3819	−0.2261	−0.3014	−0.2072	0.0750	−0.4238	−0.2351	−0.3363
Slope			1.0000	0.1818	−0.0785	−0.6036	−0.3053	0.1455	−0.0128	−0.1809	−0.2558	−0.0572	−0.5773	−0.4512	−0.4097
Planting space				1.0000	−0.6758	−0.2604	0.0090	0.0361	−0.1354	0.0684	−0.1164	−0.4499	0.1076	0.1234	0.4856
No. trees/ ha.					1.0000	0.2679	−0.1035	−0.0606	0.1571	−0.0571	0.0458	0.2461	−0.2325	−0.1516	−0.4060
Basal area/ ha.						1.0000	0.2124	0.1109	−0.1671	−0.0011	0.2485	0.2176	0.7839	0.6624	0.6294
pH							1.0000	−0.3030	−0.1774	0.5534	0.2380	−0.0985	0.2057	0.1526	0.1977
Pct. sand								1.0000	−0.6462	−0.7498	0.2224	−0.0522	0.0420	0.0535	0.1291
Pct. silt									1.0000	−0.0176	−0.0460	0.1229	−0.1417	−0.1062	−0.2486
Pct. clay										1.0000	0.3304	−0.0374	0.0671	0.0223	--------
Depth											1.0000	−0.0304	0.2978	0.1359	0.1018
Aspect												1.0000	0.1109	0.1777	−0.0915
Site index													1.0000	0.8337	0.8679
Height														1.0000	1.0000
D.b.h.															

[1] All except d.b.h. based on 489 observations. The critical values for significance are therefore: 0.087 at the 0.05 level and 0.116 at the 0.01 level.
[2] D.b.h. based on 72 observations. The critical values for significance are: 0.229 at the 0.05 level and 0.298 at the 0.01 level.

TABLE 8. ADJUSTED LINEAR REGRESSION COEFFICIENTS OF SIGNIFICANT COVARIABLES WHEN THE DEPENDENT VARIABLE IS SITE INDEX

Covariables	b
Altitude	—0.0038 meter of site index per meter of altitude
Number of trees per hectare	—0.0017 meter of site index per tree per hectare
Basal area per hectare	0.3232 meter of site index per square meter of basal area per hectare

As aspect changes from northwest to southeast, however, ages decrease, and this is a relatively strong correlation. This series of correlations indicates that poorer sites faced northwest and were the first planted. Therefore, a logical correlation between age and site index should have been negative. However, the actual correlation was weak and not significant even with 489 observations. In short, while relationships do exist among these variables they are so feeble that an analysis of variance based on only 72 observations was not sufficiently sensitive to detect the effects.

Number of trees per hectare could be considered a stand density variable, but when considered without reference to tree size it is difficult to explain the effect of number of trees per hectare in a stand density context. Usually number of trees per unit area is inversely proportional to stand age, and this is generally true in this case, Table 8. Furthermore, site index is inversely proportional to the number of trees per hectare. This should indicate that site index is related to the number of trees per hectare through age. However, the correlation between site index and age is not significant. Consequently, the relationship must exist through some other (and perhaps obscure) channels. There simply is no good explanation for this relationship. Its cause may be happenstance, but the relationship seems too strong for such an explanation.

Basal area per hectare is clearly a stand density variable, but the influence of this factor on site index is not easily explained. According to the assumptions on which site index is based, height growth of dominant and codominant trees (such as those in this study) is dependent only on age and site quality. Stand density in reasonably closed stands has little or no influence on height growth. This is not precisely correct with some species, but the error introduced by ignoring this effect when determining site index usually is quite small. Consequently, the very profound effect of basal area per hectare on tree height and site index in this study is surprising. The only logical explanation is that *E. globulus* is highly sensitive to stand density insofar as height growth is concerned. As stand density increases, trees grow faster in height. If this be the case, use of site indices with this species would be invalidated and some other measure of site quality would have to be used.

Another problem was lack of significance of the effects of irrigation and fertilization on site index, Table 6, particularly since some effects of these variables on tree height growth had been detected, Table 3. Again the apparent effects were so small that they could not be detected in an analysis of variance based on a sample of only 72 observations. It is possible, however, that the irrigation and fertilization were applied at the wrong time and/or in improper quantities, causing the effect to be negligible. Further study in this area might lead to more precise and effective treatments.

D.b.h. Data

To complete the study, an analysis of variance of the mean plot d.b.h. values was performed using the same independent variables (including site index) that were used in the tree height analysis, Table 9.

The three stand density variables (planting space, number of trees per hectare, and basal area per hectare) were significant as expected. Regression coefficients associated with these variables are given in Table 10. The more space available to recently planted seedlings, the faster these seedlings grew in diameter. As the number of trees per hectare declined through mortality, there was a corresponding increase in mean diameter of the residual stand. The regression coefficient in Table 10 for basal area per hectare indicates that d.b.h. increased as basal area per hectare increased. This can be explained by the fact that average d.b.h. increases at a rate faster than basal area because of higher mortality in the smaller size

TABLE 9. ANALYSIS OF VARIANCE OF THE *E. globulus* DATA WHEN THE MEAN DIAMETER BREAST HIGH (d.b.h.) OF THE STAND WAS THE DEPENDENT VARIABLE

Source	d.f.	M.S.	F	Level of significance
Planting method (P)	1	36.185	1.278	N.S.
Irrigation (I)	1	22.985	0.812	N.S.
Site preparation (S)	1	9.953	0.352	N.S.
Fertilization (F)	1	4.546	0.161	N.S.
PxI	1	0.019	0.001	N.S.
PxS	1	0.332	0.012	N.S.
PxF	1	75.161	2.655	N.S.
IxS	1	28.584	1.010	N.S.
IxF	1	19.751	0.698	N.S.
SxF	1	2.373	0.084	N.S.
Age (linear)	1	76.207	2.692	N.S.
Altitude (linear)	1	57.828	2.043	N.S.
Slope (linear)	1	0.051	0.002	N.S.
Planting space (linear)	1	706.307	24.948	0.005
Number of trees/ha. (linear)	1	149.174	5.269	0.025
Basal area/ha. (linear)	1	534.068	18.865	0.005
pH (linear)	1	1.995	0.070	N.S.
Per cent sand (linear)	1	0.327	0.012	N.S.
Per cent silt (linear)	1	4.925	0.174	N.S.
Depth of A&B (linear)	1	141.706	5.005	0.050
Aspect (linear)	1	1.780	0.063	N.S.
Site index (linear)	1	354.419	12.519	0.005
Residual	50	28.311		

TABLE 10. ADJUSTED LINEAR REGRESSION COEFFICIENTS OF SIGNIFICANT COVARIABLES (DEPENDENT VARIABLE IS d.b.h.)

Covariable	b
Planting space	+0.3003 inch of d.b.h. per square meter of planting space
Number of trees per hectare	—0.0003 inch of d.b.h. per tree per hectare
Basal area per hectare	+0.0641 inch of d.b.h. per square meter of basal area per hectare
Depth of A&B horizons	—0.0097 inch of d.b.h. per centimeter of soil depth
Site index	+0.1277 inch of d.b.h. per meter of site index

classes. These results are reasonable and agree with existing theories.

The appearance of depth of A and B horizons as a significant variable in the analysis of d.b.h. data in the presence of site index as an independent variable was not anticipated because depth of these horizons is normally expected to be an integral contributor to site index. The A and B horizons are zones that contain the greater portion of the available nutrient capital and the most readily available water supply. Thus, it apears that the deeper these horizons, to a point, the better the site quality. This, then, indicates that the harmonic site index curves developed in this study are inadequate. The use of soil depth as an independent variable, along with height and age, probably would improve the predicting power of the site index values.

SUMMATION

This attempt to establish the importance of certain silvicultural and ecological influences on height growth of *E. globulus* has been limited to factors for which data were available. It is only a foundation for further study and understanding of the culture of this species in the Húanaco Valley of Peru. In spite of this, certain general observations can be made that should be of value to persons working with this species in Peru.

Site preparation significantly contributes to increased height growth. Planting seedlings in cans or on prepared sites improves height growth. Irrigation plus fertilization on prepared sites also improves tree height growth.

Special note must be made of the stand density characteristics (number of trees per hectare and basal area) that apparently affect height growth more strongly than would be expected from experience with most forest species. More study into this subject is warranted.

Site index and its components (aspect, soil depth, pH, soil type) also were shown to have effects on height growth, as was expected. However, the strong effect of altitude, even when site index was included in the analysis, warrants mention as an important and powerful restraint on height growth. The provisional site index curves developed in this study obviously need refinement so as to recognize the unexplained aspects of these factors. It is possible that the site index curve equation should include, as independent variables, altitude and expressions of soil characteristics, in addition to age.

Diameter growth, not unexpectedly, was found to be affected most powerfully by stand density. What is surprising, however, is that all these expressions of stand density (planting space, number of trees per hectare, and basal area per hectare) were significant contributors in the presence of one another. Wider spacing, fewer trees per hectare, and greater basal area per hectare all showed significance at the same time. One would expect that any one of these would mask the others. The presence of all three as significant variables needs study.

Site index also showed a strong positive relationship with diameter growth. In addition, one of the components of site index, the depth of A and B soil horizons, had a significant effect. As the depth increased diameter growth decreased. The reason this factor was significant at the same time as was site index must be determined.

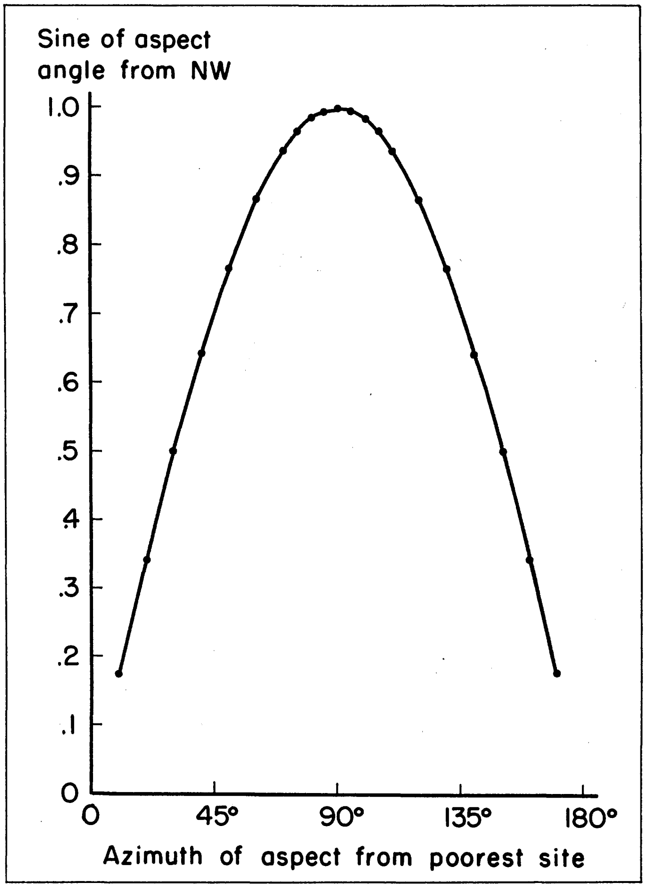
No attempt has been made to fully explain why certain relationships exist as were found in this study, although an attempt has been made (speculatively) to explain most of them. However, this effort hopefully may serve as a guide to further the study of this valuable species to the Peruvian forest economy.

APPENDIX

Determination of the Index Direction for the Measurement of Aspect

Since it is not logical to assume that height growth would vary according to direction of slope when measured using the azimuth from north, the aspect data collected in the field had to be modified. In temperate portions of the northern hemisphere the most productive upland sites usually are found on northeast-facing slopes. These slopes usually are relatively cool and damp and thus provide a more favorable water regime than slopes facing in other directions. Conversely, the poorest site (those that are hottest and driest) usually are found on southwest-facing slopes. Extending this principle to the southern hemisphere would lead one to expect that the best upland sites would be found on southeast-facing slopes and poorest upland sites would be found on northwest-facing slopes.

To describe this relationship mathematically, aspect is expressed as the sine of the azimuth of the slope, meas-



APPENDIX FIG. Trace of the value of the sine function when used as in this study.

APPENDIX TABLE. F VALUES FROM ANALYSES OF VARIANCE OF THE TREE HEIGHT DATA COMPUTED USING ASPECT VALUES OBTAINED FROM DIFFERENT INDEX DIRECTIONS

Source	F values with aspect from								
	Due W	N80°W	N70°W	N60°W	N50°W	N40°W	N30°W	N20°W	N10°W
Planting method (P)	0.481	0.523	0.761	1.563	2.934	3.321	1.653	0.651	0.435
Irrigation (I)	0.014	0.020	0.251	0.728	0.534	0.000	0.665	0.550	0.214
Site preparation (S)	1.639	1.775	2.266	3.680	5.683	6.304	4.152	2.339	1.825
Fertilization (F)	0.015	0.069	0.156	0.180	0.017	0.145	0.386	0.134	0.012
PxI	0.659	0.653	0.753	1.235	2.145	2.450	1.495	0.786	0.618
PxS	10.656	10.237	10.573	13.098	18.229	22.201	19.727	14.513	12.079
PxF	0.103	0.111	0.148	0.257	0.426	0.476	0.282	0.144	0.108
IxS	2.860	2.857	3.150	4.347	6.433	7.334	5.247	3.403	2.838
IxF	3.396	3.942	4.922	6.082	6.164	4.195	1.857	1.770	2.249
SxF	0.198	0.209	0.361	1.145	2.869	3.964	2.455	0.824	0.381
Age (linear)	9.361	8.203	7.016	6.854	9.339	13.695	16.223	13.610	11.485
Altitude (linear)	1.421	1.569	1.147	0.256	0.137	0.633	0.003	0.840	1.662
Slope (linear)	0.850	0.671	0.395	0.227	0.256	0.820	2.843	2.316	1.777
Planting space (linear)	3.074	2.710	2.018	1.216	0.806	1.054	2.567	3.458	3.540
No. tree/ha. (linear)	1.992	1.832	1.688	1.586	1.789	2.357	2.768	2.548	2.256
Basal area/ha. (linear)	0.343	0.323	0.260	0.214	0.194	0.320	0.769	0.762	0.645
pH (linear)	2.283	1.683	1.021	0.751	1.411	3.529	6.065	4.880	3.688
Per cent sand (linear)	0.053	0.034	0.026	0.019	0.045	0.110	0.086	0.060	0.038
Per cent silt (linear)	0.380	0.319	0.274	0.207	0.225	0.329	0.343	0.354	0.324
Per cent clay (linear)	0.078	0.063	0.057	0.045	0.056	0.090	0.073	0.068	0.057
Depth of A&B horizons (linear)	10.784	11.660	12.598	12,658	10.612	7.923	7.088	8.488	9.818
Site index	256.112	250.741	240.798	227.270	220.094	230.186	261.688	270.101	267.348
Aspect	0.857	0.029	0.832	6.044	15.646	22.795	18.370	8.726	3.759

ured clockwise or counterclockwise to a maximum of 180° from the direction of the poorest site. The Appendix Figure shows the reason for using this function. The sine value is lowest when the slope is in the direction associated with the poorest site and is greatest when the slope is in the direction associated with the best site.

The proximity of the Equator to the study area is not considered in the preceding discussion. However, it is possible that slope directions associated with the poorest and best sites are not northwest and southeast, respectively, in an area such as the Húanaco Valley, which is only 10° south of the Equator. To give aspect a proper weight in the analysis of height data, measurements would have to be taken from the appropriate direction. To do this, the data were analyzed first when the index direction was N80°W, then when it was N70°W, and continuing at 10° intervals to N10°W. F values associated with these analyses are given in the Appendix Table. From this table, the F value associated with aspect was greatest when the index direction was N40°W. This indicates that aspect has its greatest effect when measured from this approximate direction. Consequently, it was assumed that the initial hypothesis (that the poorest site was associated with a northwest-facing slope) was substantially correct and the subsequent analysis was made using this base for the aspect variable.