

SPECIES SITING: CLIMATE, SOIL AND PRODUCTIVITY*

D. S. JACKSON†

SYNOPSIS

Species siting for exotic afforestation depends upon the provenances available, and the forester's interpretation of their site requirements. These are based initially upon homoclimal and habitat comparisons, but subsequent performance has often not corresponded with that expected.

The wood yield per acre of many trees exotic to New Zealand is unusually high, by world standards; but the relative yield of different species varies greatly with local climate and soil type. Maximum yields are not necessarily obtained only under conditions identical with those of a species' natural habitat, and there is need for a clear distinction between the ecological and physiological limits of productivity.

The validity of this distinction increases as management and land use become more intensive. Its implications for more precise species siting are discussed and illustrated.

The aim of species siting in forest land use is to determine, by correct allocation of tree species to site, the soundest possible basis for sustained production of utilizable wood. This poses some of the most complex problems in the whole of forest management.

During the early stages of forest exploitation, management is concerned mainly with the efficient logging and extraction of existing tracts of indigenous forest and these problems do not arise: the objective of sustained yield is sought through manipulation of ecological processes to secure regeneration of the timber-producing species. With increasing pressure for efficient use of land, the emphasis in management shifts towards more intensive production of wood that can be converted readily for specified uses. In New Zealand many exotic species meet this dual criterion more satisfactorily than any of its native timber trees, and have thus become the foundation of intensive management based on reforestation. This has been the experience of foresters in many other countries also (*vide* 32, 23, 29), particularly in the Southern Hemisphere.

Initially, the establishment of plantations of exotic trees poses two distinct problems:

- (1) The choice of suitable provenances of the species selected for introduction.
- (2) Allocation of these to the sites available in their new habitat.

Considered historically, these two theoretical problems merge as overlapping stages in the development of local afforestation practice. In the first stage there has often been widespread, more or less haphazard introduction of fortuitously available provenances,

* Paper presented at 11th N.Z. Science Congress, Auckland, 1965.

† Principal Scientific Officer, Forest Research Institute, Rotorua.

although numerous attempts have been made to rationalize the basis for selection (3, 8, 39). Corresponding with the technique of agroclimatic analogues used in agricultural science (19, 9), those species are sought the climate of whose natural range most nearly approximates to that of the region of proposed introduction. Many different systems of classifying these so-called homoclimes have been used (12, 30, 27, 21, 3); but, whatever the basis of classification, care is needed to avoid the assumption that climatic definition of the natural distribution of a species circumscribes both its potential environmental limits and the optimum conditions for production under management.

Not only may a species perform better as an exotic than in its natural habitat (examples of this are given hereunder), but its range of tolerances is generally considerably wider than the natural limits would suggest. This phenomenon has been rationalized by invoking such concepts as "adaptability" (32) or "plasticity" (39). Ellenberg (6) visualizes it, more cogently, as a distinction between the "physiological optimum" and the "ecological optimum" of a species; the latter being determined by the biotic associates of the species concerned, especially its competitors and pathogens. He shows not only that there may be considerable differences between the two parameters of growth, but also that the biotically determined range is generally very much less than that which the species is physiologically capable of occupying. The latter can be expressed only in pure culture. In relation to the forest, management approaches closer and closer to this condition as silvicultural practice increases in intensity. Examples of this are: exclusion of many natural pests and diseases by removal of a species to a completely new habitat; elimination of competitors by establishment of monocultures; and partial control of environment during certain critical life stages (namely, culture of seedlings in special nurseries, use of herbicides to reduce weed competition, burning-off and other forms of land preparation, development of planting techniques, release cutting, etc.).

The great wealth of exotic tree species that have been introduced into New Zealand has been summarized by Weston (36), and one of the outstanding features of many of these is that their productivity is very high even when compared with maximum yield classes in their native habitat.

For example, the mean and periodic annual increments (M.A.I. and C.A.I. respectively, expressed in cubic feet per acre) of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) grown in the Pacific Northwest and in New Zealand may be compared as follows:

	At age 30 years		At age 50 years		At age 70 years	
	M.A.I.	C.A.I.	M.A.I.	C.A.I.	M.A.I.	C.A.I.
Pacific Northwest						
Site Class I*	158	275‡	203	235‡	207	185‡
North Island						
pumice plateau†	299	530	405	555	439	503

* See reference 17. † See reference 28. ‡ A recent publication (33) indicates that managed stands of Douglas fir in the same region may attain C.A.I.s of 410, 313 and 231 cu. ft per acre, respectively, at these ages.

Yields of the American southern pines—loblolly pine (*Pinus taeda* L.), slash pine (*P. elliottii* Engelm.), and longleaf pine (*P. palustris* Mill.)—in New Zealand may likewise be compared with those of natural stands of maximum site class at age 20 years. Mean annual volume increments at this age, in cubic feet per acre, are:

	Loblolly pine	Slash pine	Longleaf pine
Eastern U.S.A. (24)	213	174	64
Auckland Conservancy	423*	414†	180‡

(Permanent sample plots: *A.137 at 19 yr; †A.31 at 20 yr; ‡A.84B at 21 yr.)

For our most outstanding exotic species, *Pinus radiata* D. Don, there are unfortunately almost no yield data available from its native habitat, although Scott (26) quotes a tentative M.A.I. of 220 cu. ft per acre at 20 years, and Wright (39) gives a maximum height of 120 ft for native stands, compared with 160 ft in New Zealand. For sites of only average quality in this country, unthinned stands will yield 300 to 350 cu. ft per acre per annum by 20 years old (16), and Beekhuis's latest yield tables (cited on pp. 64-5 of Brown (2)) predict 400 to 460 cu. ft under proper management.

As afforestation proceeds, species whose performance is inadequate (not infrequently this has been because the wrong provenance was introduced) are eliminated from further trial, and practice develops towards a more refined allocation to the available sites of the species that have proved amenable to management in their new habitat. Because of the wide physiological range of tolerance of many tree species, it is found that all but the most patently adverse sites are capable of sustaining several exotic species, often from quite separate and apparently very different climatic regions. Compare, for example, the habitats of the six following species of pine, all of which have been successfully established on pumice soils of central North Island: *P. radiata*, *P. patula*, *P. taeda*, *P. nigra* (*laricio*), *P. pinaster* and *P. ponderosa*. From the point of view of exotic forest management, the chief difference between these species is their relative production per acre—the corresponding mean annual volume increments at 15 to 20 years old would range from 400 cu. ft to about 150 cu. ft per acre, in the order listed.

In these circumstances of extensive overlap between individual site requirements, the best soils will be allocated to the species that produce the greatest and most valued yields. Species of lesser productive capacity, or whose produce cannot command a large share of the overall market for forest products, are accordingly not planted on the most productive sites. They are allocated to land which is marginal for such staple species as *P. radiata* and Douglas fir—species which, probably because they are capable of such a large annual increment, are also relatively more demanding in their requirements for moisture and soil nutrients. Conversely, the slower-growing and less demanding species frequently produce larger increments than *P. radiata* on the poorer soils; e.g., on the strongly leached brown granular Whatoro clay at Waipoua, increments at 12-19 years may be compared as follows:

	<i>P. taeda</i>	<i>P. elliottii</i>	<i>P. radiata</i>
M.A.I. (cu. ft/acre)	308	291	255

while on strongly podzolized Te Kopuru sands the overall depression of increment is even greater, *P. radiata* producing less than half its maximum increment:

	<i>P. elliotii</i>	<i>P. pinaster</i>	<i>P. radiata</i>
M.A.I. (cu. ft/acre)	256	229	199

The origin of this depressed productivity, in an otherwise suitable climatic zone, is almost certainly to be sought in a depleted supply of one or more nutrients, brought about by leaching and podzolization. Where, as not uncommonly on gumland soils of the Auckland region, an element such as phosphorus is insufficient for vigorous growth, yields may be increased by appropriate applications of artificial fertilizer. Such methods are considered by Will (38) and by Weston (37).

However, an alternative approach is to use a species which is less demanding of the factor in deficient supply. In the examples quoted, for instance, the relative performances of *P. elliotii* and *P. radiata* are consistent with what is known of the critical level of phosphorus in the soil for satisfactory growth of these two species—the minimum for *P. radiata* is 66 ppm whereas for *P. elliotii* it is only 24 ppm (40).

Other site conditions under which our most highly productive staple timber species are so unthrifty as not to be worth planting include:

- (1) Areas of poor surface or internal drainage with seasonally high water-tables and/or deficient aeration.
- (2) Very porous soils (e.g., gravels and limestones) on sites with excessive runoff or in districts of low rainfall.
- (3) Shallow soils with a clay, iron, or silica pan within 20 in. of the surface.
- (4) Saline or other soils with accumulations of toxic substances.

In each instance, artificial methods of site improvement may be applied, if this is considered economic. Alternatively, certain other species are now available that are tolerant of some of these conditions, and are capable of producing a worthwhile yield.

Although the regions where such extreme conditions prevail are fortunately rather limited (except perhaps in Westland or the hinterland of Poverty Bay), the extent and range of intermediate conditions make it necessary to devise means of site classification that will enable alternative species to be allocated more precisely. The method proposed by Anderson (1) utilizes the vegetation already established in a region to define what he calls "type-communities". These are used to correlate sites for afforestation with similar sites for which actual data on forest production are already available. Comparison of the yields from different tree species within any one such type-community provides the basis for site allocation in subsequent planting. Ure (34) devised a similar method, using combinations of certain indicator species within the relatively restricted area of Kaingaroa Forest, to predict the yield class for *P. radiata* and Douglas fir; with the very poorest frost-prone sites, characterized by dominance of monoao (*Dracophyllum subulatum*), allocated to *P. ponderosa* and *P. contorta*. Hills (14, 15) describes a system of "forest site regions" and "gradient classes" ". . . for

RAINFALL	30"	40"	50"
GRAVELS etc.	Cup. arizonica Pinus ponderosa Pinus pinaster Euc. sideroxylon (9-10*)		
LIMESTONES	Corsican pine Deodar Cup. torulosa Euc. bosistoana (9-10*) Euc. cladocalyx (5-8*) Euc. umbellata (9-10*)		
DEEP LOAMS	Larch Cup. macrocarpa Thuja plicata Acacia melanoxylon Robinia Euc. scabra (9-13*) Pop. robusta Euc. gigantea (17-20*) Pinus ponderosa Pinus radiata Euc. obliqua (13-15*) --- optimum --- soil-depth --- Euc. fastigata (13-15*) --- 30" --- Euc. bosistoana (9-10*) --- 20" --- Corsican pine Cup. lusitanica Euc. umbellata (9-10*) Euc. cladocalyx (5-8*) Euc. botryoides (7-9*) Pinus pinaster Euc. muelleriana (9-12*) Euc. saligna (9-12*)		
SHALLOW CLAY etc. PANS	Uneconomic for planting Euc. camaldulensis (10-12*) Euc. ovata (13-20*) Acacia melanoxylon Pop. deltoides		
SHALLOW WATER-TABLES	Particularly prone to wind-throw, disease and sudden 'inexplicable' mortality		
COASTAL EXPOSURES	Cup. macrocarpa Pinus pinaster Euc. botryoides (7-9*) Euc. cladocalyx (5-8*) Pinus radiata		

Fig. 1: Site allocation of species for forest production in Hawke's Bay district, showing annual rainfall and edaphic characteristics. Species should not be planted on sites with less rainfall or on soils more shallow than indicated by their position in the diagram. Degrees of frost tolerance for tender species are indicated in parentheses.

rating the capability of sites for forest production . . . founded on a background experience in observing trends in the variation of production within environmental gradients". His gradients include land form, regimes of soil moisture, soil nutrients, rooting depth, and ecoclimate, which are quantitatively described (but apparently not measured). Although Hills's system was not specifically designed for purposes of afforestation, it is comprehensive enough to serve the needs of species siting, and a very similar method has recently been used by Prior *et al.* (22) for the Otago Land District. This is the stage of technical development that has now been reached in many districts of New Zealand.

The analysis of homoclimes may be integrated with data available from existing plantations to construct charts of the form presented in Fig. 1—in this instance, to aid in the selection of species for particular combinations of rainfall and soil within Hawke's Bay. Temperature is not included as a variable in the chart since field experience indicates that it has relatively little effect on survival and growth of most introduced tree species in Hawke's Bay. Some of the more valuable eucalypts provide an exception to this statement; their proneness to damage by frost makes it necessary to specify certain local limitations as to minimum temperature.

Useful as such a presentation may be for practical application within a limited region, it has several deficiencies. Of these the more important are concerned with the need for:

- (1) More accurate correlation of yields with quantitatively defined characteristics of land capability, for land-use decisions.
- (2) Quantitative predictions and comparisons of the productivity of species, required by modern forest management.
- (3) A more widely based rationale of relationships between forest yield and environment.

These requirements can be met by a comprehensive resynthesis of data on the performances of individual species both within their natural range and their areas of introduction. The quantitative and empirical methods developed by Coile (4) and Schumacher (25) provide the means for this. It has been repeatedly shown, through the use of these techniques, that site productivity for tree growth is strongly affected by the volume of soil available to tree roots and by the storage capacity of this volume and the availability of moisture within it. A variety of measures has been used to express these factors; for example, the depth either of the A horizon or to the least permeable zone in the soil has been found to be significantly correlated with the productivity of many species of trees—loblolly, shortleaf, slash, longleaf, pond, and jack pines, yellow poplar, and white, black and scarlet oaks. Similarly, available moisture capacity of soil has been shown strongly to influence the growth of Scots and jack pines and Douglas fir. A commonly used index of available moisture per unit volume of soil is the silt and clay fraction, which is significantly correlated with site productivity of aspen, white oak, and jack, red, shortleaf, slash, and loblolly pines. These relationships have been reviewed by Coile (4) and Jackson (13).

The interrelation between effective soil depth and the texture and consistence of the limiting horizon is neatly integrated by Coile's texture/depth index, which may be expressed as the silt-

plus-clay percentage of the B horizon divided by the depth of the A horizon. Over part of the range of shortleaf pine the optimum value of this index lies between 4 and 6. The further interaction of optimum soil depth with rainfall regime has been explored by a few other workers, notably McClurkin (18) and Zahner (41). The latter found the optimum depth for loblolly and shortleaf pines under a rainfall of 46 to 52 in. per annum to be about 18 to 20 in.

A survey of the growth of slash pine over a wide range of environmental conditions, both within and outside its area of natural distribution (13), has recently indicated that the annual height growth of this species is strongly influenced by mean annual rainfall, as shown in Fig. 2. The diminishing rate of growth with advancing age of the tree indicates that, on average, peak height growth was attained at or before the age of 10 years. At any particular age there was a highly significant correlation between mean

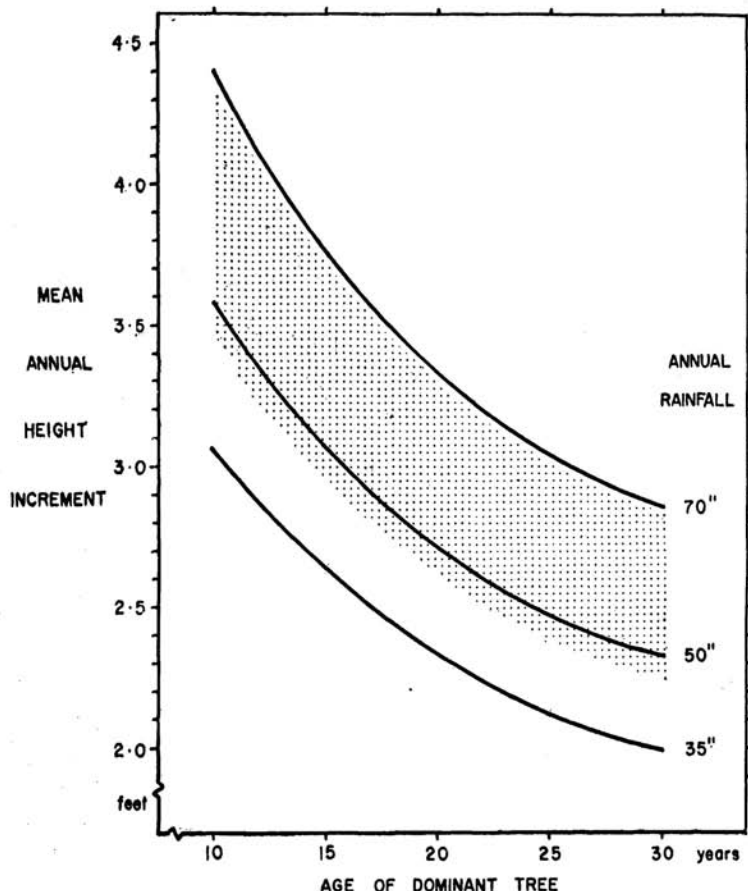


Fig. 2: The relationship between mean annual height increment of slash pine, age at breast height, and mean annual rainfall of the site. (The range of mean annual rainfall within the species' natural range is shown stippled.)

annual height increment and rainfall, over the range tested (35.3 to 71.5 in. per annum).

An interaction between effective soil depth and rainfall during the growing season also emerged from this study. With total annual precipitation held constant at any particular level above 35 in., it was apparent that growth diminished as the proportion of rain falling during spring and summer increased. This reduced productivity was particularly marked on soils more shallow than 30 in., but relatively unimportant on deep porous soils — see Fig. 3. Moreover,

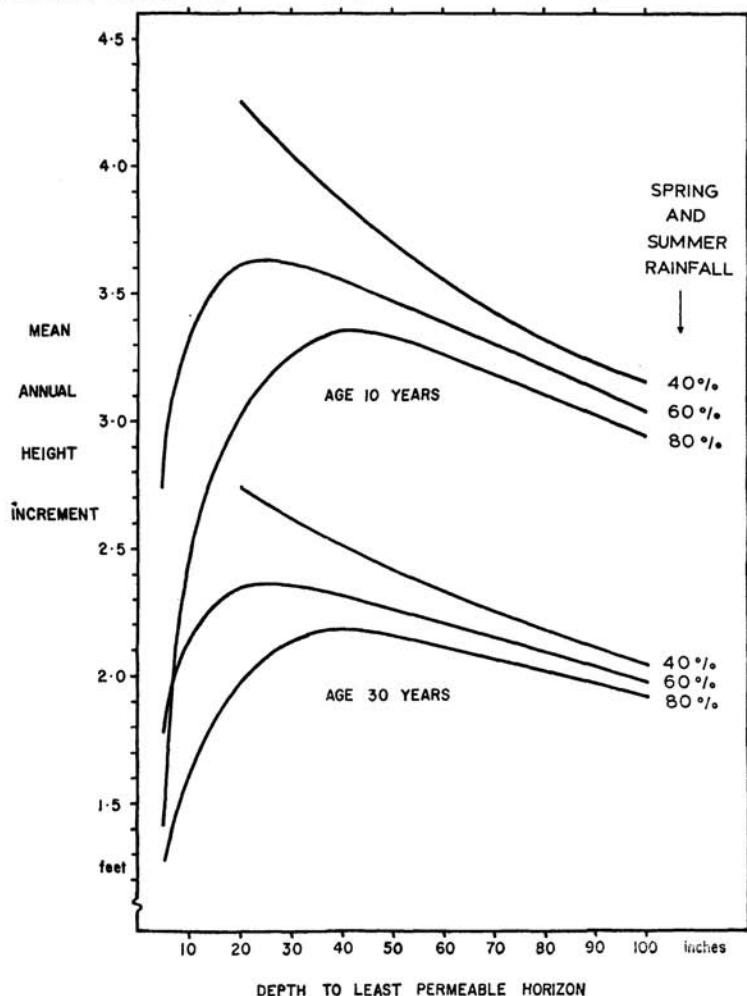


Fig. 3: The relationship between mean annual height increment of slash pine and the depth to least permeable horizon of the soil, in interaction with percentage of annual rainfall falling during the six months of spring and summer — at ages of 10 and 30 years at breast height, and with 50 in. total annual rainfall.

the optimum depth of soil appeared to increase as the proportion of rain falling during the growing season increased. On very shallow soils with high rainfall during the spring and summer, even the normal age-dependent trends are obscured, growth remaining uniformly low throughout what is normally the most productive stage of life. (*Vide* also McClurkin (18) for similar trends with longleaf pine.) Gessel (7) has shown that, in northwest Washington, Douglas fir site index was much reduced when the depth to an impermeable layer in the soil profile was less than 24 in. For soils over a porous substratum, the optimum annual rainfall was about 40 in., and with this combination maximum site indices were attained by stands on topsoils of medium texture.

Temperature, as a climatic component affecting forest production, has usually been investigated only indirectly—by studying deviations of annual growth patterns from long-term trends, or of sporadic brief departures from the seasonal cycle. The general preoccupation with temperatures during a limited growing season, which is so distinctive a characteristic of cool continental climates, is reflected in climatic coefficients such as those of Weck (35) and Paterson (20). Paterson's so-called C.V.P. index (for climate, vegetation, and productivity) is given by:

$$I = \frac{T_v P G E}{T_a 12.100}$$

wherein T_v is the mean temperature of the warmest month (in °C);

T_a is the difference between the mean temperature of the warmest and coldest months;

P is the mean annual precipitation (in mm);

G is the length of the growing season, determined by temperature and rainfall limits;

and E is a factor for solar radiation at the site concerned.

On the basis of the close correlation found between this index and the known forest productivity of certain sites, Paterson has computed the potential production of forest areas throughout the world. (It is of interest that this synthesis showed few countries outside the tropics to possess, over all, such high potential forest production as New Zealand.)

Two major criticisms have been directed at the C.V.P. index:

- (1) A cogent comparison can only be based upon total dry matter production, and not simply upon the utilizable timber volumes used by Paterson to express productivity. While this is certainly true, and must be the long-term aim in all such studies, the practical value and ready availability of volumetric data will not soon be superseded. (The most practicable approach would be a composite investigation that included wood density or specific gravity. It is therefore pertinent to note that Harris (10) has recently found that the specific gravity of the outer wood of *P. radiata* in New Zealand is very closely correlated with mean annual temperature at the site where it was grown.)

(2) A second deficiency is the absence from the C.V.P. equation of any factor expressing interactions of soil with climate. Some of these have been briefly discussed already.

Further occasions for criticism of this, as of all equations relating productivity to environment, are provided by the act of pre-selecting certain parameters of climate—just as this paper considers only precipitation and temperature, and perforce excludes insolation, exposure, aspect, and humidity. Selection cannot be avoided, but personal bias can be reduced by testing an acceptable range of indices. In the slash pine study already mentioned, seven different temperature indices were tested. Of these, the only two that were found to be significantly correlated with mean annual height increment were the mean daily range of temperature during the growing season and the mean temperature of the coldest month. The relationships are depicted in Fig. 4 (the range of conditions within the species' natural habitat is shown stippled).

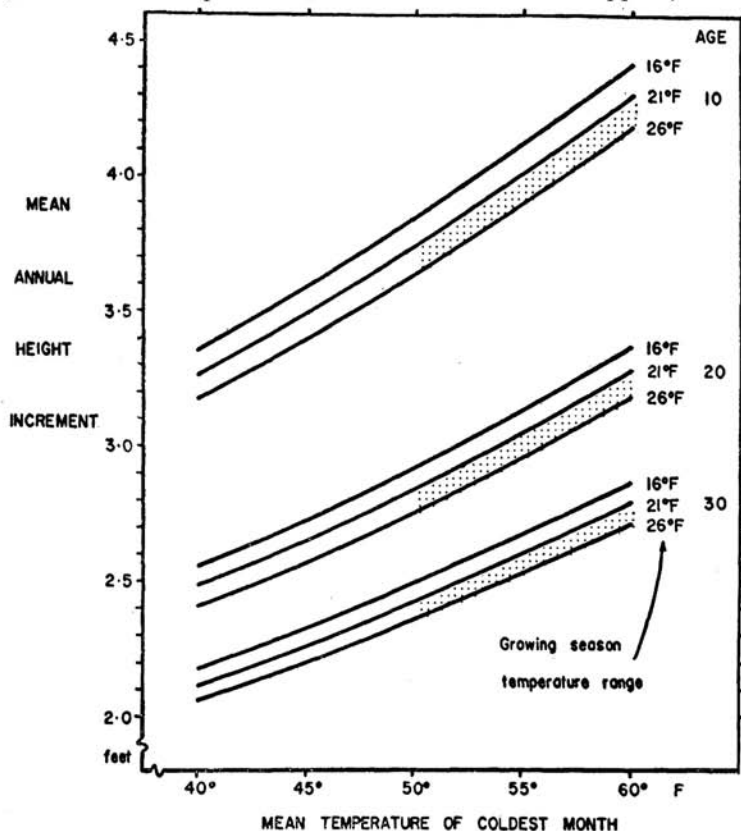


Fig. 4: The correlation between mean annual height increment of slash pine and temperature regime at the site (as expressed by mean temperature of the coldest month and the mean daily temperature range during the growing season) at three different ages. (Range of the temperature variables within the species' area of natural distribution is shown stippled.)

The apparent importance of the mean temperature of the coldest month, rather than of the growing season, may be attributed to the fact that in none of the investigated stands could mean growing season temperatures be considered unfavourable. They ranged between 61.9° and 85.8°F—well within the probable range of maximum photosynthetic rate for tree species (5, 31). On the other hand, the mean temperatures of the coldest month (ranging between 37.9° and 58.6°F) all fell well below this, and within the lower zone of diminishing net assimilation rate. The New Zealand stands were intermediate in temperature of coldest month, but had about the lowest mean growing season temperatures—a combination which must be fairly close to the optimum for net photosynthesis. Slash pine in the North Island grows almost throughout the year, and the same is true of *P. radiata*. There are indications here of some at least of the temperature factors contributing to the high forest productivity of New Zealand's climate.

Beyond the scope of this paper are features of site such as microclimate and topography, which often have an overriding influence upon overall climatic and edaphic factors. Moreover, although it is considered that the integrated approach advocated in this paper will provide a more consistent and reliable basis for species siting, there are other conditions which also influence its outcome—the susceptibility of different species to local diseases and pests, risks of damage by periodic hazards, effective means of site preparation and establishment, access for tending and harvest, and the objects of management for the individual forest (11).

Exotic afforestation in New Zealand is now entering a third phase of development, when not only must production per acre be intensified but it is also becoming increasingly necessary to match species to market demand and to specialized purposes—including those of farm shelter, soil conservation, and watershed protection. In the overall context of land-use policy, not only must forest management substantiate its claim to fertile land near centres of population; it must also examine very carefully the bases of any commitment to much of the land that is still readily available for afforestation. This land inevitably will present a more extensive range of sites than that hitherto encountered.

The complexity of these problems and the acute need for more accurate solutions demand both a reappraisal of underlying concepts and a more comprehensive synthesis of the data available.

ACKNOWLEDGEMENT

Appreciation is expressed to G. H. Hocking and I. Thulin for suggesting several improvements which have been incorporated in the final draft of this paper.

REFERENCES

1. Anderson, M. L., 1950. *The Selection of Tree Species*. Oliver & Boyd, Edinburgh. 151 pp.
2. Brown, G. S., 1964. Forest Research Institute meeting on thinning and pruning, July, 1963. *N.Z. J. For.*, 9: 59–77.
3. Champion, H. G.; Brasnett, N. V., 1958. Choice of tree species. *FAO For. Developm. Pap. 13*. Rome, Italy.

4. Coile, T. S., 1952. Soil and the growth of forests. *Adv. Agron.*, 4: 329-96.
5. Decker, J. P., 1944. Effect of temperature on photosynthesis and respiration in red and loblolly pines. *Plant Physiol.*, 19: 679-88.
6. Ellenberg, M., 1956. Grundlagen der Vegetationsgliederung IV. (I). *Aufgaben und Methoden der Vegetationskunde*. E. Ulmer, Stuttgart.
7. Gessel, S. P.; Lloyd, W. J., 1950. Effect of some physical soil properties on Douglas fir site quality. *J. For.*, 48: 405-10.
8. Golfari, L., 1963. Climatic requirements of tropical and subtropical conifers. *Unasylva*, 17: 33-42.
9. Hanson, H. C., 1949. The agro-climatic analogue technique in plant introduction and distribution of new selections. *Agron.*, 41: 168-88.
10. Harris, J. M., 1963. The influence of environment on the wood density of radiata pine grown in New Zealand. *FAO World Consult. For. Genet.* 7/3: 1-8.
11. Hocking, G. H., 1958. Species siting. *N.Z. J. For.*, 7 (5): 23-6.
12. Ilvessalo, L., 1920. Ueber die Anbaumöglichkeit ausländischer Holzarten. *Acta For. Fenn.*, 17: 1-42.
13. Jackson, D. S., 1962. Parameters of site for certain growth components of slash pine (*Pinus elliotii* Engelm.). *Duke Univ., Sch. For. Bull.* 16.
14. Hills, G. A., 1952. The classification and evaluation of site for forestry. *Ontario Dep. Lands For., Div. Res., Res. Pap.* 24.
15. ——— 1958. Soil-forest relationships in the site regions of Ontario. *Nth. Amer. For. Soils Conf.*, pp. 190-212.
16. Lewis, E. R., 1954. Yield of unthinned *Pinus radiata* in New Zealand. *N.Z. For. Serv. For. Res. Notes* 1 (10).
17. McArdle, R. E.; Meyer, L. H., 1930. The yield of Douglas fir in the Pacific Northwest. *U.S. Dep. Agric. Tech. Bull.* 201. 64 pp.
18. McClurkin, D. C., 1953. Soil and climatic factors related to the growth of longleaf pine. *Stn. For. Exp. Sta. Occas. Pap.* 132.
19. Nuttonson, M. Y., 1947. International co-operation in crop improvement through the utilization of the concept of agroclimatic analogues. *Interagra*, 1: 116-22.
20. Paterson, S. S., 1956. *The Forest Area of the World and its Productivity*. Univ. of Göteborg, Sweden.
21. Prescott, J. A.; Lane-Poole, C. E., 1947. The climatology of the introduction of pines of the Mediterranean environment to Australia. *Trans. Roy. Soc. Stn. Aust.*, 71: 67-90.
22. Prior, K. W.; Washbourn, R. W.; Priest, R. M., 1963. Afforestation in the Otago Land District. *N.Z. J. For.*, 8: 707-27.
23. Schober, R., 1955. Die Ertragsleistung der Nadelholzer in Grossbritannien und in Deutschland. *Fw. Cbl.*, 74: 36-59.
24. Schumacher, F. X.; Coile, T. S., 1960. *Growth and Yields of Natural Stands of the Southern Pines*. T. S. Coile, Inc., Durham, N.C. 115 pp.
25. Schumacher, F. X.; Meyer, H. A., 1937. Effect of climate on timber-growth fluctuations. *J. Agric. Res.*, 54: 79-107.
26. Scott, C. W., 1960. *Pinus radiata*. *FAO For. & For. Prod. Stud.* 14. 328 pp.
27. Seth, S. K.; Khan, M. A., 1959. Bioclimate and plant introduction in dry zone. *Indian For.*, 85: 376-84.
28. Spurr, Stephen H., 1963. Growth of Douglas fir in New Zealand. *N.Z. For. Serv. Tech. Pap.* 43.

29. Streets, R. J., 1962. *Exotic Forest Trees in the British Commonwealth*. Clarendon Press, Oxford. 765 pp.
30. Swain, E. H. F., 1938. Climatic Index. *N.S.W. For. Comm. Bull.*
31. Tranquillini, W., 1955. Die Bedeutung des Lichtes und der Temperatur für die Kohlensäureassimilation von *Pinus cembra* Jungwuchs an einem hochalpin Standort. *Planta*, 46: 154-78.
32. Troup, R. S., 1932. *Exotic Forest Trees in the British Empire*. Clarendon Press, Oxford. 259 pp.
33. United States Forest Service, Pacific Northwest Forest and Range Experiment Station Division of Forest Economics Research, 1963. Timber trends in western Oregon and western Washington. *U.S. For. Serv. Res. Pap. PNW-5*. 154 pp.
34. Ure, J., 1950. The natural vegetation of the Kaingaroa Plains as an indicator of site quality for exotic conifers. *N.Z. J. For.*, 6: 112-23.
35. Weck, J., 1955. *Forstliche Zuwachs und Ertragskunde*. Neumann Verlag, Berlin.
36. Weston, G. C., 1957. Exotic forest trees in New Zealand. *N.Z. For. Serv. Bull. 13*. Govt. Printer, Wellington. 104 pp.
37. ——— 1958. The response of radiata pine to fertilizers. *N.Z. Soc. Soil Sci. Proc.*, 3: 13-9.
38. Will, G. M., 1965. *Nutrient Demands of Forest Crops and the Role of Fertilizers in Promoting Forest Productivity*. Paper presented to 11th N.Z. Sci. Congr.
39. Wright, J. W., 1963. Tree introduction. *Unasylva*, 17: 28-32.
40. Young, H. E., 1948. The response of loblolly and slash pine to phosphate manures. *Queensland J. Agric. Sci.*, 5: 77-105.
41. Zahner, R., 1958. Site-quality relationships of pine forests in southern Arkansas and northern Louisiana. *For. Sci.*, 4: 162-76.