"HEREDITY DEALS THE CARDS BUT ENVIRONMENT PLAYS THE HANDS —A METHOD OF ASSESSING FOREST SITE PRODUCTIVITY"

by

M.B. Shrivastava[1] and B. Ulrich[2]

Institute of Soil Science and Forest Nutrition of Goettingen University
(Federal Republic of Germany)

Abstract. This paper examines critically the problems of Forest Site Evaluation and the methods used to solve them so far. The chief components of Eco-Systems determining the growth potential of forest lands have been discussed. The dependent variable of site quality exhibiting real differences in site productivity has been suggested. An easily applicable and accurate empirical method of estimating the potential productivity of the forest lands regardless of the kind of or lack of vegetation has been suggested. The past attempts in solving the problem have also been reviewed. The studies will help the foresters in deciding the forest management operations and putting priorities on afforestations.

1. Introduction. 1.1. *Problem.* Forest management continues to become more intensive as growing demands for wood necessitates both an increase in forest production per unit area of land and the afforestation of areas which at one time were regarded as unsuitable for commercial forestry. The lack of quantitative data on the production capacity of forest soils limits the complete economic land use planning as it requires the knowledge of the potential productivity of the land in question under various types of cover.

Evaluation of forest site productivity has been a subject of continuing interest. The scientist is intrigued by opportunities to discover relationships between the factors of locality and tree growth; the practitioner is aware of economic implications attendant to differences in site quality. The study of plant-site relationships would have been largely a matter of academic interest, if all forest lands were stocked with stands suitable for direct measurement of productivity but this situation occurs seldom. Moreover, most of the accessible virgin forests are being cut and subsequently replaced by fast growing, short rotational tree species; hence for these lands too, information on the soil productivity for various species is needed. Thus estimation of site productivity by indirect methods has been the object of many studies for more than four decades.

The most of the difficulties encountered in site appraisal by indirect methods arise from the use of measurement units that are not uniquely determined by the site factors. Since each observation of site quality is derived from tree measurements which actually are

1. Research Asstt. (Site Evaluation).
2. Professor, Director and the Dean of the Forestry Faculty.

integrated expressions of all the biological and environmental variables that have influenced growth up to the time of measurement, the site evaluation should aim in isolating such components of growth and the determination of their quantitative effects which till now in soil-site studies already conducted throughout the world has doubtless been neglected more often than not. However, with growing recognition of the multiple use of forests and changing utilization trends, the need for more comprehensive understanding of woodlands as *eco-systems* is being recognized which involves the studies of site potential. The quality and quantity of timber that may be produced on a particular site depends upon the quality of forest lands and the environmental factors prevailing on the site (Chart-I). It is therefore almost obligatory to evolve a precise method of evaluating growth potential of sites. The ideal method of estimating site quality will be one which is easily applied, accurate, and applicable regardless of the type of or lack of vegetation and based on all the ecologically important factors having influence on plant growth. The present paper aims at describing such a method. The results can serve as a tool in establishing planting and thinning priorities, for predicting forest growth rates, future yield and length of cutting cycles and answering to the questions *when to cut*, *how much to cut* and *what to cut* i.e. for establishing sustained yield forest management plans.

2. Solution. 2.1. *Past Attempts.* The tremendous size of the tree organ and the longevity of the forest growth render forest site appraisal—a less certain and more difficult task. In consequence foresters have developed many different methods. These methods vary; in the facilities required for their execution, in the forest sites to which they can be applied, and in the type of information they yield. They reflect the different disciplines from which they stem; hence they are often selected for use according to the special interest of the individual investigator, and when described tend to be rather diffusely distributed in the scientific literature.

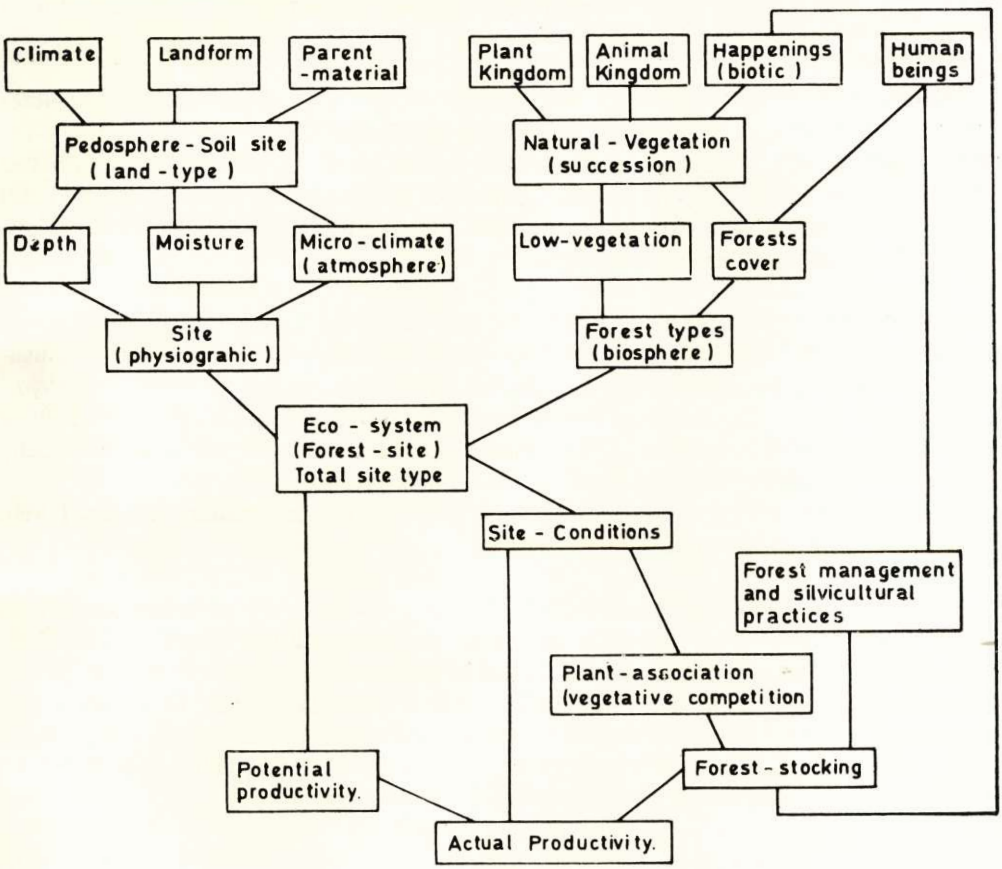
Evaluations of the various methods of site prediction have been made in detail by Heiberg and White (1956), Rennie (1962), Ralston (1964) and Carmean (1970). The occasion for the direct method of site assessment occurs seldom and thus has its restricted utility, greater hopes have been placed on indirect methods which utilize a related attribute as criterion.

Regardless of the ultimate method used to appraise site quality, initial determination is made from direct measurement of some attribute of tree growth.

Volumetric, gravimetric, calorific equivalents and height are some measurable indices proposed by different workers. Roth (1916) states that the Association of German Forest Experiment Stations after a long controversy formally agreed in 1888 to a site classification system on a volume basis using the tree age at 100 years though it was known and admitted long before that the volume of the main stand was influenced by treatments, thinnings etc. The german forester Professor Schwappach made it clear about the difficulty in using volume as a basis of site in his statement in "*Die Kiefer*" (1908 pp 45) which reads, "*The starting point is the study and determination of the height curves for the main stand. The height is the factor least influenced by treatments*". Roth (1916) supported height as the index of site for it is relatively independent of stocking and simple to measure.

CHART - 1

„ THE ECO - SYSTEMS DETERMINING FOREST PRODUCTION "



Bates (1918) contested this as he considered increment of a fully stocked stand as the only sound basis for site evaluation. However, Watson (1917), Roth (1918) and Frothingham (1918) so vigorosuly supported the height as an indicator of site that the Society of American Foresters (Sparhawk et al., 1923) recommended height as the most simple indicator of site that can be readily measured.

Mader and Owen (1961) suggested periodic volume growth (cubic feet per acre) as site index but later on Mader (1963) failed to explain the superiority of volume over height. Weck (1957) however, recommended weight standard, expressing dry matter production in gravimetric units as a better criterion of relative productivity. Woods (1960) proposed calorific equivalents of wood as a basis for determining the efficiency of various forest species in converting solar energy.

Considering the practical difficulties in measuring the height growth rapidly and accurately in tightly closed young plantations (apart from the variability in the establishment period, the major source of error) Wakeley (1937) proposed a "*growth intercept*" index based on height-growth during the five years period that begins with the year in which the breast height level is attained. This growth intercept index remained known chiefly to Wakeley's associates until reported in 1954 (Wakeley, 1954; Zahner, 1954). The limitations in the use of "growth intercepts" have been reported in detail by Gregory (1960) Coile (1960) and Wakeley and Marrero (1958).

Husch (1956) and McCormack (1956) indicate that age above breast height is preferable to total age as the variable in height/age curves in order to reduce the irregularities of the establishment period. Mean annual height increment above breast height has been used to characterize growth variation in young stands (Hansen and McComb, 1958). Hoar and Yong (1965) proposed a system for shade tolerant trees involving a free growing period instead of total age, volume increment instead of height growth, and growth of individual trees instead of a group representing the average.

Ovington (1972) defines forest eco-systems as complex photosynthetic systems whose biological efficiency can be measured by the production of organic matter, the net primary production (NPP), following the capture of solar energy by photosynthesis of the chlorophyll bearing plants. Nemeth and Davey (1974) have used net primary production (NPP) (Kilogramm per tree per year) as a site index in their recent studies.

The most popular and useful approach to site evaluation involves determination of stand height at selected age points (rotation age) on computed or graphically derived height-age curves (Ralston, 1964). Possibilities of errors in conventional site index curves have been reported by Bull (1931) and the various ways of minimising them have been dealt by Daubenmire (1961).

After many years of controversy and suggestions concrening the measurement of site quality, the use of the height growth as an indicator of site is very widely accepted and has been advocated as a standard practice. The measure of site quality on this basis is site index, the total height attained by the average dominant tree in an even aged stand at an arbitrarily selected standard or classification age (Bull, 1931) and for over 50 years this concept has remained unchallenged.

Attention may now be focussed upon indirect methods which utilize a related attribute as criterion. Carmean (1970) has divided them into three groups whereas Rennie (1962) and Viro (1961) have classified them into five groups. However, all are based on interpretation of environmental characteristics or vegetational indicators which explain the nutrient, water and temperature regimes.

To sum up, the following approaches of indirect site assessment can be recognized:

(*i*) ground vegetation (phytosociological) approach,

(*ii*) Soil Surveys and site mapping approach,

(*iii*) Soil-Site studies approach.

(*i*) *Phytosociological approach:*

Plant indicators of forest site quality are widely used in northern Europe and Canada. Cajander's classic study (Anon, 1949) of the forest types of Finland is the outstanding example of the productivity of the forest in relation to the ground vegetation. Changes in vegetation types generally are more helpful for delineating soil boundaries and variations in moisture and nutrient regime. Differences in composition and growth of lesser vegetation are associated with natural drainage, moisture and fertility status and soil types and are thus indirect indicators of the potential site productivity (Ralston, 1967). The close correlation between productivity and ground vegetation type is not always seen outside Finland (Viro, 1961).

German investigators have based their classification on the grounds that soil flora show differences in pH and the soil water supply. Of particular interest in deforested areas, is the interpretation of the foiestry potential of the land from the presence of certain indicator plants in the natural vegetation (Rennie, 1962). The plant indicator method of site evaluation has been discouraged by Carmean (1970) on account of its difficult application in recently disturbed forests or in forests having great contrasts in composition and stocking or during dormant seasons when the herbaceous plants disappear.

(*ii*) *Soil Survey and Site mapping approach:*

Soil surveys and site mapping in strict sense is not so much a related attribute as an integration of attributes. Most recent soil surveys contain tables that give interpretations of site quality for forest growth as well as for other features including competition, regeneration potential, trafficability, disease hazards etc.

In many cases interpretations are based on limited data or on the subjective opinions of soil scientists and local foresters. Accordingly such interpretations are more art than science because they depend on the experience and intuitive ability of individual soil scientists and foresters. Acceptance of these assumptions is largely a matter of faith until research can provide firm facts based on carefully collected and analysed measurements. Soil-survey reports often list site index averages for the many soil taxonomic units described in the soil survey. Close inspection of the basic data often shows that site index varies widely within soil units, while in contrast, the averages of most units are strikingly similar. Thus, the logical conclusion is that similar averages and excessive site variation with in soil units often limit the usefulness of soil taxonomic units for site quality classification. Probably much of this observed site variation is related to certain soil features that vary widely with in soil taxonomic and soil mapping units, but may not be well described in the definitions of these units.

Forest growth does not so much vary because of one attribute or factor, but through an interaction of many factors. In several countries therefore, the subject of ecological site mapping has been developed.

A detailed expose of the various site mapping methods is beyond the limits of this paper. To be frank, moreover, it would demand working experience with each method, for they tend to be highly practical and subjective on the one hand and inadequately and abstrusely described in the literature on the other. A detailed work concerning to dilluvial plains of Germany has been compiled and illustrated by Otto (1972). In a general way most methods are similar to the extent that they purport to take into account the main ecological factors of the habitat, viz. regional climate, topography, geology, soil properties and features of the vegetative cover. These factors may or may not be mapped separately, but they are all synthesized to form the ultimate site maps. Where the methods differ is in the interpretation of the ecological terms, the actual measurements made to specify them quantitatively, and in the emphasis given to different factors. Some of these differences stem from differences in working materials; some do not. The swedish (Tamm, 1950) and german (Ehwald, 1952; Kopp and Hurtig, 1960) methods are outstanding for the calibre of the studies undertaken in the various disciplines making up the ecological environments. Such site mappings are very time consuming, costly and laborious job and cannot be done in a limited period of time over a vast areas especially when funds, facilities and technical personnels are not in hand. Duchaufour (1959) argues that such detailed studies are expensive and out of proportion to the value of the mapping.

In the french, belgian (Manil,1958) and other european methods, great emphasis is placed upon the ability of the properties of the soil to portray the interaction of the environmental ecological factors. In Hill's Ontario-System, however, some conventionally regarded soil properties such as nutrient and moisture status are classed under geology (Hills and Pierpoint, 1960; Pierpoint, 1962). In the european system the soil map usually shows the major soil groups, the humus types and the soil moisture status. It is very probable that the different methods would give very much the same result if their advocates were to map the same areas to each method, the reason being the broad parallelism between different attributes serving as criteria (Rennie, 1962).

(*iii*) *Soil-Site studies approach:*

The site factors most closely related to the forest growth have been reviewed and summarized in detail by Coile (1952), Lemmon (1955), Ralston (1964), Rennie (1962) and Carmean (1970.) These reviews encompass several hundred studies based on data collected in natural stands of a single or several species. A current review shows efforts have been made to determine correlations between tree growth of many species and some of the most important elements of each of the four major habitat factors (climatic, physiographic, biotic and edaphic) regulating important physiological functions of plants. Because descriptions of details of specific studies relating to the locality factors to site quality would require more space than warranted here, reference to some of the important works in brief follows:

The broadest regional classification of forests within countries or continents have essentially a climatic basis. Individual climatic indices such as temperature and rainfall, have interested foresters since the earliest days, but for some time now attempts have been made to combine individual characteristics to give a multiple climatic index of greater relevance to forest growth. Notable examples are Martonne's humidity index and Angstroem's measure of continentality. Perhaps the latest advance is the Paterson's CVP-Index (Paterson, 1956) which indicated that mean annual increments of undisturbed, high forest types throughout the world were correlated with climatic indices which denote the combined effects of temperature amplitude, length of growing season, precipitation and solar radiation. This has slightly been modified by Weck (1970) for Indian conditions. The working group of IUFRO Congress in Vienna, 1961 concluded that an index, based on climatic data only, would not be suitable for determining the quality class of a certain forest site. Potential productivity of forest sites does not depend on climatic influences only, but also on soil factors and tree species (Weck, 1970).

Topography has no direct effect on tree growth. However, it is closely related to differences in microclimate, soil moisture and soil development, thus influencing the soil properties, nutrition status and growth of the forest stands (Nebe and Donov, 1969). Association between site quality and physiography may be evaluated either in terms of continuous topographic variates such as altitude, aspect and slope gradients or as discrete topographic position categories, i.e. ridges, slopes, slope shapes, coves and bottoms etc. The former treatment is most appropriate in areas of rugged, mountainous terrain; the later generally is to be preferred in regions of moderate relief.

The effects of slope and aspect result the differences in receipt of solar radiation which ultimately responds to the differences in soil moisture relationships from different relief factors. Concave slopes are better sites than convex where water may drain away more rapidly (Carmean, 1967). Site quality improves with increasing distance from the ridge. This better growth is no doubt partially due to additions of gravitational water to sub surface water flow from upper slope positions (Hewlett, 1961) and to more favourable micro-climatic conditions found on lower slopes. On ridges and steep southwest slopes, temperatures are higher, transpiration is greater and less soil moisture available during the growing season (Geiger, 1965). Soil development is less favourable for tree growth on southern slopes than on northern slopes (Finney et al., 1962).

A few authors have investigated the effects of such biotic factors as turpentining, stand density, competing vegetation, surface cover disturbances, planting out side of a species's natural zone as factors influencing site index (Gaiser and Merz, 1951; Lorenz and Spaeth, 1947; Moosmayer and Schoepfer, 1972; Ralston, 1951). Such factors have not been used to any great extent as clues for predicting site quality. It is essential, however, to be aware of their possible influences when working out correlations with other habitat factors.

Assuming that climatic, physiographic and biotic factors have been incorporated into a site assessment programme, then soil variation is the principal remaining factor of the physical environment that may have an appreciable bearing on tree growth. The determination of soil productivity on the basis of its properties is the most important object of forest soil research but is the most difficult task because productivity seldom depends upon a single factor or even a few factors but is usually determined by the combined action of many. The productivity of soil for forest growth is conditioned by the quantity and quality of growing space for tree roots. Soil properties that may be classed under these two categories may have direct effects on growth, both direct and indirect effects (interaction) or only indirect effects (Coile, 1952).

Dokuchaiv's demonstration (Clarke, 1957) that the soil expresses collectively the forces of the environment, and Mueller's classic studies (1879, 1884) on forest humus types have all focussed attention upon soil as the fountainhead of forest growth. The soil medium affects forest growth in proportion to its capacity to supply water nutrients and air in amounts required for optimum growth. Much work has been done in studying the effect of physical conditions of the soil on tree growth. Less attention has been given to the chemical site factors. Study of soil morphology including substratum provides a means for evaluating variation in site productivity within climatic and topographic strata. Although the status of water, air and mineral supplies can not be determined precisely from morphology, it appears, nevertheless, that soil features defining approximate levels of these variables within the root zone are useful in estimating differences in site quality which are described in detail by Ralston (1964). Soil properties presumed to reflect these variables have been reported to be associated with site productivity on numerous occasions. Most recent authors reporting studies aimed at predicting site quality have based their correlations on physical properties of the soil as primary factors. These physical properties are texture, permeability, thickness, plasticity and water holding capacity of the several horizons; color, compactness, drainage, silt plus clay content, imbibitional water values, colloidal content, weight volume relationships, total effective depth, gravel content, capillary and non capillary pore space and moisture equivalents. Varying degrees of success have been obtained in arriving at significant correlations. Very high order correlations have been obtained with some factors in some cases, whereas else-where these same factors failed to show significant effects. Soil moisture supply probably has received more attention in studies of forest site quality than any other single soil characteristic (Zech and Cepel, 1970; Lowry, 1975 etc.). The availability of a nutrient to the plant, however, is strongly dependent upon a host of both chemical and physical site factors and it may be a very difficult task to determine the first or the most important link in the chain of events leading to nutrient availability. Among the more important are total quantity of a nutrient, form or forms in which it exists, quantities of other nutrients, differential ion activity, mass action effects and ion antagonism, factors affecting solubility, and such conditions affecting the metabolic activity of roots as carbohydrate supply, oxygen and carbon dioxide levels in the root environment, temperature, presence of stimulatory or toxic substances etc. (Leyton, 1954).

Auten (1945), Haig (1929), Storie and Wieslander (1948) and Tarrant (1949) are among the recent authors reporting studies of forest growth as influenced by chemical properties of the soil. These properties include the amount of available N, P. Organic matter content general nutrient level and soil reaction (pH). Low fertility levels have been shown to be a limiting factor for growth (Forristal and Gessel, 1955; Heiberg and White, 1950). Quite apart from the emphasis upon the humus types itself (Kubiena, 1953) and the inclusion of some of the more conventional techniques described above, interest has centred on the dynamics of processes, especially biological ones. Thus attention has been paid to C/N ratio (Landouceur, 1956), rate and type of humus decomposition (Houba, 1949; Handley, 1954), availability of nitrogen (Wittich, 1952) carbon dioxide production (Smirnov, 1955) and to microbial and faunal activity (Nef, 1957).

On the assumption that the availability of soil nutrients could best be measured by the amounts of nutrients present in the leaves, foliar diagnosis of nutrient status has gained increasing recognition during the last two decades. Leyton (1958) has made a comprehensive review on the application of foliar analysis in forest trees. In his continental studies Viro (1961) found soil chemical analysis more reliable and superior one over foliar analysis to show the nutritional status of site. The disadvantages of the foliar analysis has been explained in detail by Viro (1961), Rennie (1962) and Wehrmann (1959).

The last soil criterion to be mentioned constitutes an approach of its own. It was developed by Coile (1935), and consists of examining statistically, by multiple regression analysis, the relationship between some growth characteristics viz. site index and a number of soil-site characteristics. Della Bianca and Olson (1961) appear to hold the record for the maximum number (63) of combinations of soil and site variables tested. Gaiser (1951) found good correlation by transforming all non-linear relations to linear one while applying multiple regression method.

This literature review helps illustrate the complexities of the problem. It indicates the improbability of finding a simple solution which will work throughout the world for predicting site quality without the presence of a suitable stand of timber for measurement. It shows the need for different studies applicable to specified zones or areas and individual species in which satisfactory correlations are developed between timber growth and some specific, easily recognizable, measurable and mappable factor or factors.

2.2. *Attempts Proposed for Future Studies.* The observed tree growth—the measure of site productivity is the highly organized resultant of physiological processes that are conditioned by a complex of both *biological* and *environmental* factors (Kramer, 1956). Both the influences therefore must be considered in derivation of site appraisal system. Major biological determinants are species composition, genetic variation, stand density, competing vegetation, diseases, pests and insects. To overcome the influences due to species composition, site potential should be determined for the individual tree species. The influence of biological factors such as genetic variation, competing vegetation and diseases etc. are assumed to be insignificant relative to the environmental factors. The validity of this assumption has been provided by the magnitude of the residual variation (Ballard, 1971) and thus the environmental parameters have explained most of the variations in site productivity.

The influence of stand density on site quality estimates is minor or negligible when height of the dominant stand is used as the criterion of site quality (Baker, 1953; Bennett, 1960). Afforestation spacing experiments have revealed no differences in height growth of dominant trees within desirable ranges of stocking (Ware and Stahelin, 1948; Walters and Schubert, 1969). This response has also been verified by a number of thinning and pruning studies which demonstrate that the different grade of thinning and pruning up to 80% of the live grown has little or no effect on height growth (Bassett, 1969; Bennett, 1955). Moreover, the influence of stand density, competing vegetation, infestation of insects, pests and diseases etc. can be easily eliminated by proper selection of normal representative stands and discarding the abnormal trees during the course of increment borings and mensurational studies.

In spite of the effects of biological factors on growth, the environmental factors must be measured and is still profitable to study site influences, for as has been stated succinctly, "*Heredity deals the cards but environment plays the hands*". An outstanding example of this plant growth axiom is given by an almost miraculous transformation of the picturesque scrub like growth form of *spruce* and *fir* forests in the extreme north of the great and the trans-Himalayan zones to that of a giant forests in more favourable habitats in middle Himalayas.

If one becomes convinced that habitat conditions have a bearing on forest productivity and feels compelled to pursue the matter further, the question of *what* to study soon arises. Certain advocates of the "*Holoistic*" or "*total site*" school would like studies to be all—inclusive but in view of the enormous complexity of this approach, in actual field practice, site evaluation is primarily a process of abstraction which focusses attention on the elements of the total environment that appear important to various purposes of a particular observer. The view point taken here is that most forest trees are able to adjust to minor fluctuations in environment, and therefore, one should look for large differences in major environmental variables in studies of effects of site factors on tree growth. One may perceive, after even a brief dip in metaphysical waters, that perhaps all events in the universe are interrelated. However, causal connections surrounding any particular event become fairly remote beyond a few direct effects and first—and second—order interactions. Thus, analysis of environmental factors related to site quality need not be all inclusive but merely sufficiently detailed to include all the important variables and sufficiently astute not to overlook any of them. Judging from past experience site parameters most likely to influence growth are those related to meteorological, topographical and edaphic variables.

Studies of plant-site relations have always been an empirical science. There are, however, different degrees of empiricism. A large number of people have studied correlations between site properties on one hand and forest yield (or some other "dependent" variable) on the other hand. An increasing number of scientists have tried to explain the effect of site factors by means of physiological experiments, manipulating the factor(s) under study. The last decades have given both types of investigators more powerful and more expensive tools. Modern computer technique has become favourable play ground for the "*comparative*" school and there seems to be no end to the sophistication possible for physiological equipment, even for field work. More recently also the physiologists have started to use the computer for simulation of photosynthesis and other processes. They point out to the well established physiological relations between processes in the plant and environmental factors and conclude that plant performance should be forecasted from these relations in combination with direct measurements of abiotic factors (Kramer, 1963). However, the complexity both of the environment itself and of the physiological reactions makes it extremely difficult to build up a realistic model for site productivity relations from physiological informations and we consider it rather premature on account of inadequate information and knowledge to base site classification on the existing knowledge of the tree reactions to various environmental factors. Although many skilled plant physiologists in various parts of the world now work on ecological photosynthesis studies, aiming at a simulation of the production processes from environmental data, as far as our knowledge goes, we are not ourselves convinced whether we will ever be able to forecast forest yield over large areas with satisfactory precision from mathematical models based only on physiological experiments and measurements on the environmental data needed in the model. The reason is not that the approach is impossible but that the measurements needed to increase precision above obtained with relatively crude measures of radiation, temperature and water supply will be so expensive that the value of the yield forecast can hardly cover the cost apart from the difficulties to find the numerical expressions of some of the environmental variables like availability of the nutrients, density and activity of the roots and mycorrhyza system, physiological situation in the plants, effects of insects and pests, and past happenings like fire, erosion, suppression etc. which have a direct bearing on physiological processes of plants. It is thus agreed that complete simulation of physiological processes in forest is an approach confronted by many difficulties and is impracticable. We do not deny the usefulness of deductive analysis in understanding important processes involved in plant production e.g. transpiration or energy exchange; on the contrary, we should like to stress the value of "*a priorie*" information on biological and other processes, which can and should be used in more empirical approach.

In our opinion, there is at present one only but scientific and rigid way of solving the problem of site evaluation on the basis of site observation: to collect a large material of site and stand data from sample plots carrying the desired tree species, then to study the stand properties as functions of the various site properties. In case the suitable stands of the desired species do not exist, the plantations should be raised and waited till they are of measurable size to provide suitable dependent parameter. The degree of success attained in demonstrating relationships between environmental factors and growth of trees is largely determined by the investigators judgement, that is judgement in selecting the independent variables (site factors) that are believed to be related to tree growth in various ways in different combinations. Also the degree of success is effected by heterogeneity or spread in magnitude of the independent variables. How well the investigator samples the entire population of soil and other site factors, determine the general applicability of the results.

Within the frame work of this conception, the study should aim to evolve a relationship between the site quality and the growth of the species in question, occuring over the vast diversified areas. As it is not always easy to decide beforehand which information on environmental conditions will be most important, it seems desirable to base the site studies on the widest possible variety of data and phenomena and then to try to group the numerous units distinguished in the first approach into higher categories similar in the respect deemed to be of greatest importance for the purpose of the moment. As such the maximum possible variety of climatic, topographic and biotic site data along with the edaphic one should be collected.

Given a number of sites described with respect to all or most properties and with known site index (height) the computer work may be started to discover correlations between growth and site properties. Usually we may find that several characteristics are intercorrelated. Sophisticated statistical techniques will give some help and the studies will be ended probably with more or less close correlations between site index and the several site factors pooled together through multiple regression analysis.

Although prospects of general analysis of environmental influence on growth appear remote, partial solution based on quantitative evaluation of local variation in climatic, physiographic and edaphic factors are feasible in many areas. The results thus obtained will help us to rank our sites and make the predictions for future on new sites. Such studies, though empirical and approximate in nature, will serve as starting point for comprehensive basic studies that ultimately will lead to more complete understanding and control of environmental factors limiting forest production.

Site-quality assessment methods based upon natural forests, newly planted areas and inferior sites unfit for agriculture will be of ever-increasing demand in the future. They are expected to pay increasing attention to the soil, the vital basis of all forest growth. No method, however, can be stronger than the calibre of the underlying knowledge gained from studies in soil-site-forest relationships. They constitute the *Rosetta Stone* of appraisal methods and, indeed, of sustained forest production. Its inscription, therefore, needs always to be legible.

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