NOTES ON STATISTICAL METHODOLOGY IN FOREST TREE IMPROVEMENT WORK

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Geneticists generally look upon tree growth as an interaction of genes under particular environmental conditions. The chief purpose of their tree-improvement work is to select or produce strains which are not only

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resistant to frost, drought, disease, and insect attacks, but which also give the highest return of good-quality wood per unit of area.

In order to be able to separate genetic effects from those attributable to environment, or to make best use of inherent qualities under a particular set of conditions, the tree-improvement men must know not only the genetic principles involved, but also the basic requirements of research methodology, including proper sampling, efficient experimental designs, and valid interpretation of data.

IMPLICATIONS OF SCIENTIFIC RESEARCH AND EXPERIMENTAL DESIGNS

The initial stage of every research undertaking involves four basic considerations:

1. Precise definition and formulation of the problem.

2. Avoidance of bias.

3. Consideration of comparable conditions in the study of desired effects.

4. Selection of proper criteria and employment of efficient sampling and experimental designs.

A clear-cut statement of objectives will not only clarify the aim of the study but will also help to narrow down the research effort to some definite or specific channels. There is a common tendency among research workers to spread the effort too thinly over a large area instead of concentrating it at some specific points. The delimitation of the problem is also helpful in avoiding possible confusion in gathering and interpreting data.

Bias can be both intentional and unintentional. It may enter from many sources and under different names regardless of the bona fide attitude of research workers. It may occur as a result of poor planning or from the failure to recognize some important interactions in numerous cause-and-effect relationships. It may also come as an unforeseen change in the environment. Every effort should be made to minimize these types of bias at the planning stage of an experiment. Experience, competence, and imagination play an important role in obtaining more uniform and efficient data.

Experiments are often regarded as a study of variation. The observed variance is a reflection of many causes, and is the sum total of the variances produced by several independent factors. If this is so, then obviously one who studies the effects attributable to one cause should try to equalize whenever possible the effects of other contributing factors. Consequently, any effort to classify environmental conditions into separate categories will not only help to achieve uniformity but also will be very helpful in both the interpretation and application of the observed results.

Modern statistical methodology abounds in various types of experimental designs, In planning an experiment, the investigator should try to select an experimental design that fits the requirements of the problem, gives a valid estimate of the experimental error, and provides most accurate results per dollar spent. Also, proper criteria and the type of measurements needed should be decided upon at the start.

Scientific methods recognize only valid estimates since evidence is the only basis for inference. The validity of the experimental evidence depends on how much attention was given at the start to the three basic R's of statistical methodology, namely: randomization, representation, and replication.

Randomization, by which independence and equality of chances in selection are observed, serves a threefold purpose: (1) to minimize any bias in selection, (2) to provide a basis for our inference guided by the laws of chance, and (3) to guard against distortion of statistical errors.

Every sample should be representative. Even if the population is not homogeneous, it can be stratified and each stratum sampled or represented proportionally.

Replication of tests on different locations is also extremely important, Like randomization, it also serves a threefold purpose: (1) to reduce the sampling error, (2) to study the effects under conditions differing from each other, and (3) to guard against the failure of the entire experiment if a complete set of plots all established in one place is lost, Such heavy losses through fire or other causes do occur more frequently than we realize.

Some experiments are designed to test merely "what happens" under certain sets of conditions. Other experiments aim to provide additional information on "why" things happen the way they do, Frequently we fail to design experiments in such a way as to get more data at very little additional cost.

A large number of efficient experimental designs have been gradually developed during the last 30 years because of the nature and the variety of problems confronting research workers in different fields of science. One hears of randomized blocks, Latin squares, split-plot designs, factorial designs, balanced lattices, balanced and partially balanced incomplete blocks, and several other modifications of experimental layouts. Most of the basic and common designs are now well described in standard textbooks on the subject. In the time allotted to me, I can only touch upon some of the underlying assumptions employed in these designs.

All designs assume the same general thesis that the treatment and the environmental effects are additive and that the residual or unexplained effects, considered as the experimental errors, are independent from observation to observation. It is further assumed that the experimental errors follow the pattern of normal distribution and that the error variance is constant over all observations. The analysis of variance, basic to all methods, consists of breaking down the sum of squares of the observed values into 4 component parts, 1 attributable to the general mean, 1 to differences between treatment or variety effects, 1 to differences in environmental effects associated with location, and 1 to residual effects, or experimental error.

All designs stress the importance of randomization and the reduction of the experimental error by increasing the number of replications, refinement of experimental techniques, uniform application of the treatments, and control of external influences. In short, they aim to eliminate bias and to provide comparability of the results.

Although different designs may employ different groupings or arrangement of experimental units, they all aim at elimination of simultaneous variation from a number of different sources. This is basic to all research.

All designs provide an unbiased setup to judge the significance of the observed results. Although the "true differences" between the various effects can never be evaluated with absolute certainty, the techniques employed in all correct designs enable the research workers to test their hypotheses with the assurance that the risk of erroneously accepting or rejecting them is, at least, very small. This, too, is basic to all research.

TREE GROWTH AND HEREDITY

Forest growth is correlated with a large number of factors. It is governed by heredity, environment, and competition for space and nutrients, Any measure of growth must be studied, therefore, in relation to several independent or associated factors. Ideally, in every growth study, care must be exercised to keep all other factors except the one which is being investigated as constant as possible, As a rule, the factors to be equalized should be those which are considered to be influential but not correlated with each other. In this way, a series of individual comparisons of well-matched groups can be made on a rather simple basis. However, this experimental approach is not always possible. When individual comparisons cannot be paired without too much sacrifice in the amount of data, or when some of the factors are correlated with each other, thus producing joint effects, a regression technique becomes very useful.

Multiple regression equations are frequently used to estimate tree growth by reference to the values of other associated factors. With several factors affecting growth, it is imperative to know the relative importance of each. With the aid of multiple and partial correlation methods, a combined effect of a series of related factors is determined and the effect of any one factor is evaluated by holding the influence of other causative factors constant. When the relationship between two characters independent of the accompanying variation due to the other variables can be determined, the growth analysis becomes quite meaningful. By means of this approach, men engaged in forest tree improvement work can tackle many problems: Is growth related to genotypes and to what degree? How successfully can the effects of environment and competition be evaluated and isolated from the genetic effects? Can an elite tree be recognized in a forest stand?

The partial correlation analysis consists of computing estimating equations where the effect of each factor is expressed in relative weights, and calculating all possible partial-regression coefficients and their significance as influential factors. If, for example, observations seem to indicate that geographic latitude and weight of seed are correlated with growth, the method of partial correlation analysis will not only bring out the association of growth with latitude but will also evaluate this association independent of the accompanying variation due to weight of seed. If the length of day varying with latitude forms genotypes differing in the rate of growth, this can be demonstrated by the correlation analysis. Furthermore, the effect of latitude can be studied under a variety of environmental conditions as well as the interrelationship between them.

The partial correlation analysis need not be considered as an entirely independent approach. Any properly designed experiment will yield both efficient and sufficient data for most correlation studies. Frequently, however, the regression approach is used on data obtained by sampling widely separated areas.

In correlation studies involving growth, the choice of independent factors affecting it is very important. This implies familiarity with the subject and a careful approach in providing comparable results. By way of illustration, I shall take the problem of selection of elite trees.

In the attempt to use exceptionally high growth as a criterion for selecting superior trees, the chief problem is to separate the environmental effects from those considered attributable largely to inheritance. Exceptionally good growth, for example, may be nothing more than the result of a combination of external conditions favorable to tree growth. On the other hand, if, under similar conditions of site, age, and competition, one encounters unusually high growth, it is justifiable to assume that some effectual hereditary qualities are involved.

The problem of separating environmental effects from those attributable to heredity is not a simple one because growth or tree size portrays an interaction of both intrinsic and external causes. Site index, for example, so commonly used in forestry to express the growth potential cannot be employed to separate soil and other site effects because tree height can be greatly affected by heredity alone. Thus, if site and heredity effects are confounded, it appears that the proper solution must lie in the equalization of site conditions rather than in the elimination of site effects on the basis of height growth itself.

The effects of crown competition or any lack of it, however, can be evaluated more successfully. The space allotted per tree controls its crown development and consequently its rate of growth. By assuming, for example, that one-sixth of total height is the radius of an ample cylindrical space for tree development (with height equal to the length of crown) and estimating the proportion of this space unoccupied by other competing crowns, one can obtain a measure of relative freedom. Similarly, by dividing the tree basal area by the average basal area of the surrounding trees whose crowns occupy wholly or partly the allotted space, one can obtain a measure of the severity of competition which is exerted upon the tree, The volume production can then be related to these controlling factors. Here it is not the tree diameter and height which are used for evaluating the rapidity of growth but rather the causative conditions, such as availability of space or the degree of competition to which growth is so strongly related. Any unusual tree development, after allowing for space and competition effects, can then be regarded as very likely related to the superior origin of seed, particularly when allowance is made not only for site but also for the influence of other factors, such as age.

In the selection of superior trees, the approach can be reduced to the following scheme:

1. A hypothesis is made that plus trees, aside from being of good form, are those which exhibit exceptionally good development under similar conditions of site, age, and available space.

2. All effort should be made to see that other surrounding trees have developed under similar conditions of site as characterized by soil aeration, topography, climate, aspect, position on the slope, and water regime. This strict emphasis on uniformity delimits the selection of plus trees to rather small or restricted areas which are comparable in site conditions.

3 In addition to watching for comparable edaphic conditions, one should guard against other interfering factors, It is better, for example, to disregard trees which show signs of prolonged past suppression or sudden release from competition.

4. After the similarity of site conditions has been ascertained and non-comparable trees eliminated from consideration, the remaining trees, including possible plus trees, are scrutinized as to their growth performance in relation to their age and the degree of competition under which they have developed, By considering the ample space for crown development to be denoted by a cylinder whose radius is one-sixth of the total height and whose height is equal to the length of crown, and estimating the proportion of this space unoccupied by crowns of neighboring competitors, one would obtain a measure of freedom for development. By dividing the basal area of the tree under scrutiny by the average basal area of trees overlapping the cylindrical space, one would obtain a measure of the degree of competition involved. All these factors portraying the available space and the

degree of competition can be combined into one expression which may be called space-competition index, Such an index would provide a measure of an independent causative condition.

5. Now it will become possible to correlate volume or growth of trees with age and space-competition index, using the well-known techniques of partial correlation analysis. If such studies are made on the basis of many spot tests, convenient tables or graphs can be constructed which will aid others in depicting trees of certain species which show unusual development under the same conditions governing growth in a given space.

CONCLUSIONS

I have briefly outlined some of the statistical phases involved in the relatively new field of tree improvement work. My chief purpose was to show that when the joint effects of hereditary and environmental factors are interlaced, extreme caution should be used in attempting to distinguish one from the other.

Whatever approach is taken, the problem can be solved only by the use of proper statistical methods. There are many good designs and techniques already available for almost any type of experimentation. Coupled with the knowledge of genetic principles and the peculiar characteristics of the tree species involved, these statistical designs and techniques will contribute a great deal to the acquisition of fundamental knowledge on the road which lies ahead.