DETERMINING THE TYPE OF RELATIONSHIP BETWEEN PLANTS AND ENVIRONMENTAL FACTORS

D. SCOTT

Plant Physiology Division (Substation), D.S.I.R., Lincoln

INTRODUCTION

Plant growth is probably controlled by a combination of all environmental factors. But in particular situations some factors will exert greater influence than others, so that, for practical purposes, it is unnecessary to consider all factors in attempting to predict plant growth. The interaction between plant and environment could be one of several types:

(a) the major aspect of growth is influenced by a single factor,
(b) growth is influenced by a few factors and each is of similar importance,
(c) a few factors influence growth but the importance of each is different, and
(d) growth is influenced by a multitude of factors and the effect of each is different.

I believe it is possible to determine which of these various alternatives applies by using the results of a step-wise multiple regression analysis involving plant response and measurements of many environmental factors. The method is explained and examples given from earlier work on the relationship between measurements of standing crop and 55 environmental factors on 50 sites in a Wyoming alpine tundra (Scott and Billings 1964).

CRITERIA AND EXAMPLES

In stepwise multiple regression analysis, such as that of the relationship between measurements of plant growth and environmental factors, a series of regression equations is formed which relate the variation in the dependent variable (growth) to various sets of the independent variables (environmental factors). One of the procedures for forming these sets is as follows: The independent variable which is most highly correlated with the dependent variable is first selected, then all pairs of independent variables which include the first are considered and the pair which shows the highest significance based on the F ratio is selected, then all combinations of three variables including the first two are considered — and so on. This process of inclusion is continued until none of the remaining factors result in a significant decrease in the variance when included in the regression equation. At each stage, one can determine the statistical significance of each of the environmental factors included in the regression equation.

I propose that the number of factors which reach acceptable levels of significance and the manner in which the level of significance of a particular factor changes as each additional factor is incorporated into the equation provides an index of the type of relationship. The method may be illustrated by considering the four possibilities mentioned earlier and each can also be represented diagrammatically. In the accompanying figure each graph compares the levels of significance of each factor included in the regression equation with the total number of factors included in the regression equation at each stage. Since the variables on the abscissa are discontinuous they are represented by bar diagrams in which the height (and area) of each bar gives the significance of the particular factor and the area under all bars indicates the significance of the regression as a whole. The dashed line indicates the level which must be exceeded by any factor to attain statistically-acceptable levels of probability. The factors in each graph have been arranged in decreasing order of significance.

(a) *The major aspect of growth is influenced by a single factor*

The important environmental factor would be the first and only factor included in the regression equation and it would have a very high level of significance. The top set of the accompanying diagram shows this expected relationship when only one factor reaches acceptable levels of probability even when one or two of the most likely additional factors are included in the equation.

No clear example of this type was obtained. The nearest is shown in the upper right-hand graph where total standing crop is correlated with soil movement with a high level of significance. The second factor has a very low level of significance and in this instance even upsets the apparent signi-

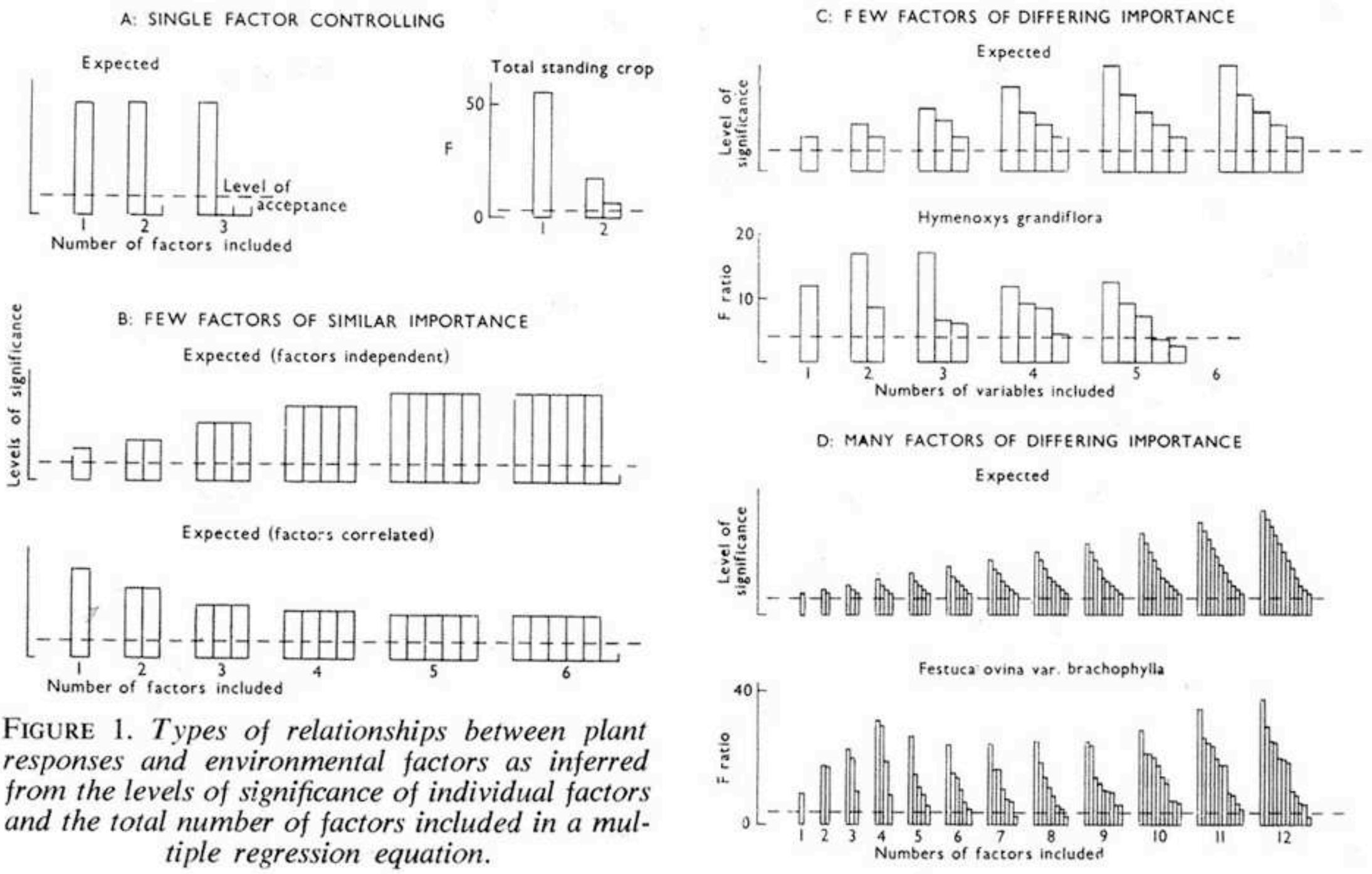

FIGURE 1. *Types of relationships between plant responses and environmental factors as inferred from the levels of significance of individual factors and the total number of factors included in a multiple regression equation.*

ficance of the first variable. In the examples given the magnitudes of the F ratio have been used rather than conversions to probabilities.

(b) *Growth is influenced by a few factors and each is of similar importance*

There is a range of possibilities in this instance, depending on whether the environmental factors are independent of, or correlated with, each other. The expected relationships for two instances are given where there are five factors, each of equal importance. In both, the deduction that the factors were of equal importance would be derived from the observation that at each stage all factors included had similar levels of significance. That only a few factors were important would be deduced from the observation that only five reached acceptable levels of significance even when the next most likely factor was considered.

At each stage the significance of the factors already in the equation would be expected to change as further factors were included. This change would be caused by both the reduction in the residual sum of squares as new factors were included and by the correlation between previously and newly included variables. Should the included factors tend to vary independently of each other, then the significance of all factors would increase as more of the important ones were included. This is because the newly-included factors would reduce the residual variance. However, if the environmental factors correlated with each other, the sums of squares attributable to any one factor might be reduced as other factors correlated with it were subsequently included in the regression equation. In both instances the overall significance of the equation would increase.

There was no clear example of either of these types of relationship.

(c) *A few factors influence growth and the importance of each is different.*

The characteristic feature in this instance would be the decrease in significance of successive factors included in the regression equation. There would also be a general increase in significance of all fac-

tors in the equation as each important factor was introduced. There would be a large difference between the levels of significance for the few controlling factors and any other factor that might be included. The growth of *Hymenoxys grandiflora* illustrates this type of relationship.

(d) *Many factors influence growth but each is of different importance.*

This case would differ from the preceding one only by the inclusion of many more factors and by the level of significance of successive factors decreasing and slowly approaching the level of acceptance. The relationship between *Festuca ovina* and the environmental factors illustrates this type of relationship.

DISCUSSION

The observation leading to the speculations given here was the manner in which the levels of significance of particular factors changed as additional factors were included in the multiple regression equations which were to test the correlation between the standing crop (above ground) of alpine species and a range of environmental factors (Scott and Billings 1964). A feature which appeared in the analysis of many species was that in the early stages of an analysis factors were included at only low levels of significance; however, later in the analysis there was a rapid increase in the statistical significance of the factors already included and, for a time, many more factors were available for inclusion. The number of factors involved and the manner in which their levels of significance changed seemed to imply that there were definite relationships between groups of variables (as would have been hoped) but that the type of relationship varied in different instances.

The suggestions given here seem to provide a biological interpretation for what may be a purely statistical phenomenon. It is, perhaps, not surprising that standing crop in the majority of the 45 species examined showed a correlation with few to many factors of different importance, and that only a very few species approached the types showing a correlation with a single factor or a few factors of similar importance. Though there may be criticisms of this multiple regression technique (Scott 1966) the criteria given here may provide an appropriate guide to the type of relationship that exists between aspects of plant growth and environmental factors.

REFERENCES

SCOTT, D., and BILLINGS, W. D. 1964. Effects of environmental factors on the standing crop and productivity of an alpine tundra. *Ecol. Monogr.* 34: 243–270.

SCOTT, D. 1966. Interpretation of ecological data by path analysis. *Proc. N.Z. Ecol. Soc.* 13: 1–4.