

## METHODS IN THE QUANTITATIVE ANALYSIS OF PLANT GROWTH—A REPLY TO CRITICISM.

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THE Chief Statistician at the Rothamsted Experiment Station in his criticism of the methods put forward by us in recent articles (4 & 5) on The Quantitative Analysis of Plant Growth, summarises his remarks as follows. "The methods of calculation formulated by Briggs, Kidd and West for the analysis of plant growth are inaccurate." We feel that this sweeping statement standing in the forefront of the conclusions of what might appear to be an authoritative utterance by a statistician cannot be allowed to pass unanswered, the more so in that it is not supported by evidence or argument in the body of Mr Fisher's paper.

### *The Method.*

The general method proposed by us for a quantitative analysis of plant growth is to obtain from primary data recorded at frequent intervals throughout the life of the plant, secondary relations<sup>1</sup>. We proposed the following as being probably the most useful at the outset.

1. Relative Growth Rate.
2. Leaf-Area Ratio.
3. Unit Leaf Rate.
4. Relative Leaf Growth Rate.

We suggested that by a careful comparison of these with each other and with records of environmental factors one might be able to disentangle problems of plant growth and thus eventually to evaluate plant constants. We do not wish it to be concluded that we proposed these as the only significant secondary relations. For example, from an analysis of the results of growth experiments carried out by us more recently it appears that the ratio of the rate of growth to the rate of respiration is a further significant secondary relation.

The question of the value of this general method is not dealt with by Mr Fisher, and indeed can only be decided by the results obtained from its application.

<sup>1</sup> For details of these secondary relations the reader is referred to (5).

*The Methods of calculating Secondary Data.*

The question then arises, are the methods put forward by us for calculating the above secondary relations inaccurate? This seems to be the second possible interpretation of Mr Fisher's summary and is, moreover, what he literally states. In the first place, in spite of the conclusion quoted above, Mr Fisher deals only with the methods proposed for calculating Relative Growth Rate,  $R$ , and says nothing about the methods for calculating the other secondary data mentioned above. We defined  $R$  (5, p. 204) as the weekly percentage rate at which the dry weight increases, and stated that if the rate were continuous compound interest the equation for calculating  $R$  would be

$$\frac{R}{100} = \log_e W_2 - \log_e W_1 \dots\dots\dots(1),$$

and if the rate were simple interest the equation would be

$$\frac{R}{100} = \frac{W_2 - W_1}{W_1} \dots\dots\dots(2).$$

Both these methods of calculation were put forward(5)<sup>1</sup>. Mr Fisher urges the use of the first, and states the second to be inaccurate. As a matter of fact both methods of calculation are perfectly in concordance with our definition and neither of them can be in itself characterised as inaccurate.

*The Use of Relative Growth Rate Values.*

A third possible explanation of Mr Fisher's criticism is that, instead of meaning the charge of inaccuracy to apply to our methods of calculation, he means it to apply to the use we have made of the values of the Relative Growth Rate calculated by means of equation (2). So far we have published a paper(4) in which the fact has been recorded that the Relative Growth Rate, calculated by *either* of the two methods described above, follows the generalised form of curve shown in Fig. 9 of the paper in question, and that the Leaf-Area Ratio curve follows a closely similar course. It was pointed out at the time that, for the purpose of demonstrating this fact, it is immaterial which of the two methods of calculation is utilised, and indeed, in Fig. 1 a comparison was made of the results obtained by the two methods. Mr Fisher has only

<sup>1</sup> The definition of Relative Growth Rate given in (4, p. 105) is for the rate calculated on the simple interest basis. It must be understood that we do not suggest that the growth of a plant is a process of accumulation of dry-weight at either "continuous compound" or "simple" interest. On the one hand, the whole of the new material is not put out as new capital, and on the other hand there is an unknown time interval before any new material can become new capital.

elaborated this comparison. It was decided to present the majority of the results in that paper in the form adopted (*i.e.* calculated by equation (2)) in order that the calculation might be perfectly intelligible to non-mathematical readers. Mr Fisher's attack centres round this point and amounts to a statement that for statistical purposes the results obtained by equation (1) are preferable to those obtained by equation 2. Since we did not attempt any statistical correlations in the paper under consideration his criticism is irrelevant.

Miss Brenchley, with Mr Fisher's help, has utilised Relative Growth Rates calculated by equation 1 for determining the correlation between growth rate and temperature and sunshine respectively (3). We agree that the values calculated from our first formula (equation 1) are the values to be utilised for statistical correlations provided due consideration be given to the complexity of the problem. We propose to consider this question in detail in another place.

The explanation of Mr Fisher's misunderstanding is most probably to be traced to the discrepancy between our definition of Relative Growth Rate and Mr Fisher's and to the fact that he imputes his definition to us. While we define the Relative Growth Rate as the weekly percentage rate at which the dry-weight increases, in a previous number of this *Journal* (4), p. 104) we pointed out, as Mr Fisher himself quotes, that "the principle of the proposed method of expressing rate of growth is analogous to that of the method by which the rate of most reactions, both chemical and physiological, are expressed, namely, amount of change per unit of material per unit of time." This precise physico-chemical definition, to which we say our definition is only analogous, Mr Fisher adopts as a definition of Relative Growth Rate and imagines we have done likewise, which we have not. Our attitude is that until we gain a more thorough knowledge of the complexity of the processes involved in plant growth, the adoption of a definite physico-chemical conception is not warranted since it may lead to the mistaken impression that its adoption constitutes in itself an advance in physiological knowledge.

His charges of "inconsequent arbitrariness in method of calculation when contrasted with precision of definition," and his imputation that our choice of method of calculation is explainable by "the mistaken impression that the use of the logarithmic formula involves the assumption that the relative rate of increase is independent of time," when viewed in the light of the above discrepancy of definition can be readily explained.

With regard to the second paragraph of Mr Fisher's summary we do not wish to reopen the discussion on the significance of the "Efficiency Index." Equation (1) given above for calculating relative growth rates is the same as Blackman's formula for calculating the "Efficiency Index(1)." There is nothing original in the formula itself, but whereas we propose an analysis by an evaluation of the Relative Growth Rate for weekly or for shorter periods<sup>1</sup> throughout the life-cycle, Blackman(1) and Brenchley(2) used this formula indiscriminately for periods of widely varying length and covering widely different portions of the life-cycle.

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#### REFERENCES.

- (1) BLACKMAN, V. H. The Compound Interest Law and Plant Growth. *Ann. Bot.* xxxiii. 353, 1919.
- (2) BRENCHLEY, W. E. Some Factors in Plant Competition. *Ann. Appl. Biol.* vi. 142, 1919.
- (3) — On the Relations between Growth and the Environmental Conditions of Temperature and Bright Sunshine. *Ann. Appl. Biol.* vi. 211, 1920.
- (4) BRIGGS, G. E., KIDD, F., and WEST, C. A Quantitative Analysis of Plant Growth. *Ann. Appl. Biol.* vii. 103, 1920.
- (5) WEST, C., BRIGGS, G. E., and KIDD, F. Methods and Significant Relations in the Quantitative Analysis of Plant Growth. *New Phytologist*, xix. 200, 1920.

<sup>1</sup> We have used weekly periods as no data for shorter periods are at present available. Daily or half-daily measurements would provide data for a much deeper analysis.