BY PROF. D. R. HOAGLAND, UNIVERSITY OF CALIFORNIA

AND

DR. F. C. STEWARD, UNIVERSITY OF LONDON

Our earlier article directed the attention of the general reader to two independent series of investigations which have been in progress in different laboratories for several years. The combined investigations are extensive and deal with a variety of plant materials and environmental conditions. These apparently divergent investigations yield a consistent general picture of the process of salt uptake in plants, and we are not persuaded by Prof. Lundegårdh's arguments that this picture can be dismissed by the general reader. Our view is that salt accumulation involves vital processes in a more complex and intimate manner than would be suggested by Prof. Lundegårdh's discussion with its reference to principles expressed "in modern text-books of plant physiology" and "well-known terms of physical chemistry".

Prof. Lundegårdh's rejoinder mainly recapitulates his own earlier work. It will be recalled that we had raised the following general points.

(1) Any view of the metabolic processes concerned with salt uptake which has as its dominant feature carbon dioxide production, and especially a limited phase of carbon dioxide production conditioned only by anion uptake, is too restricted. Other vital processes are also concerned, perhaps more fundamentally. Pre-eminent are metabolic properties which are characteristic of cells still able to grow; but which are still difficult of quantitative expression.

(2) There is not, in our view, the sharp distinction in the relation of metabolism to the uptake of cations and of anions, described by Prof. Lundegårdh.

(3) The effects of salts on respiration—undoubted alike for roots and a variety of storage organs—are not related specifically to anion absorption; cations also exert an influence, which is the predominant one for some tissues, and the effects of differential absorption of cation and anion introduce additional factors.

(4) The storage tissue experiments deal with cells uniform in origin, subject to rigid control, in which the capacity for further growth is known. Root systems can never provide such uniform material; but in the experiments of Hoagland and Broyer special methods yielded root material which was replicated with accuracy well within the requirements of the investigation described. By the special control of nutrition the experimental barley plants yielded tissues with a great capacity for salt uptake, apparently much greater than that possessed by the wheat plants used by Lundegårdh.

(5) Neither respiration nor salt uptake occurs uniformly throughout the root system. In calculating an arithmetical relation between respiration and anion absorption Lundegårdh takes no cognizance of this fact, nor of the complications caused by interaction of root and shoot.

(6) Lundegårdh's references to bio-electric phenomena do not elucidate the problem. The surfaces involved were not precisely defined and in any event the origin of such bio-electrical potentials is still controversial.

We may now note those parts of Prof. Lundegårdh's second article which refer to these points.

Lundegårdh states that we did not find the quantitative relations demanded by the concept of anion respiration because:

(*a*) The choice of treatments was too restricted.

(*b*) The process of salt uptake must be studied in an "organ exclusively designed to effect this process" and therefore experiments on cells of storage roots and stems are not admissible.

(*c*) The work of Hoagland and associates on excised roots is subject to the assumed complication that salts absorbed may exude from the single cut surface back into the external solution, so that the amount in the tissue is not a correct measure of that which is absorbed.

We are unable to accept these arguments. To restrict experimental attack on problems of salt uptake to any particular organ, for example, roots of grasses, is an unjustifiable and arbitrary conception. Salt uptake is one of the most general properties of living cells during their growth, and general conclusions must embrace the results of experiments on a wide range of cells and tissues. Our views were based on experiments on roots of barley and potato, a variety of storage roots, stems and modified leaves, growing leaves of dicotyledons and monocotyledons, as well as submerged aquatics and green algæ. While the most intensive investigations have demanded a restricted choice of materials, the general picture we have presented embraces work with all.

Lundegårdh implies that in storage tissues the anion absorption is too small to reveal the anion respiration effect. However, we clearly stated that in experiments that cover a wide range of salts and salt concentrations the *entire metabolism* of the tissue (not merely respiration) responded to the salt treatment. The ion absorption *was* large enough to produce marked effects, which are different in *kind* from those described by Lundegårdh.

Lundegårdh cites no proof that submerged, excised roots continue to exude salt. In any event, Hoagland and Broyer have made numerous studies on exudates of barley roots and find that the salt present in such exudates during the brief duration of the experiments is equivalent only to a very small fraction of the total salt absorbed by an active ("low-salt, high-sugar") root system. Comparisons have also been made between the salt removed from solution by intact plants and by submerged, excised, root systems. With plants having a high capacity for salt absorption, and for the short periods of the experiments, the excised roots and corresponding entire plants absorbed salt in quantities of similar magnitude. The ion uptake, for example, of potassium and easily absorbed anions was very large, and so far as we can find a basis for comparison, was more rapid than that reported by Lundegårdh or, indeed, by any other investigators of salt absorption in plants. As in the case of the storage tissues, we are certain that the roots absorbed salt in amounts and at rates such as to produce striking metabolic effects, although certain aspects of metabolism may be more prominent in one tissue than in the other.

We have not found anything in Lundegårdh's rejoinder to warrant discarding our view that the implications for the problem of salt uptake of bio-electric measurements are still obscure—we only wish it were otherwise. Amongst those who favour this line of work there cannot be said to be agreement concerning the nature or origin of the phenomena they investigate. Lundegårdh's re-statement still does not convey to us a clear picture of the boundaries which he regards as the seat of the phenomena he measures; that is, whether this membrane is one of cells, for example, piliferous layer (epidermis of Lundegårdh), root cortex, or endodermis separating an external and internal intercellular fluid, or is a protoplasmic boundary membrane, across which the phenomena of ion accumulation in cells actually occur. Such phrases as "root tip" relative to electrode measurements require much more precise definition before they convey any anatomical meaning.

To return to the constant 'k' of anion respiration. It is said to be "fairly constant" for an anion present only as a given salt (although in the experiments with barley roots this function would not be constant even with this restriction). With different cations the value of 'k' is now said to "change somewhat", and it varies also with the ratio of absorbed anions to cations. So versatile a "constant" seems to us to lack utility.

Our purpose in this and our former communication is to suggest to the general reader the complexity of the problem of salt absorption by living cells, and also that the theory of Prof. Lundegårdh has not yet been established and generally accepted by plant physiologists. With regard to the quoted work of van Eijk on the salt marsh composite *Aster tripolium*, we note that it is rather the principle of a salt effect on respiration which van Eijk confirms (with which we are not in disagreement) and not the reality of the special anion effect, which even by van Eijk seems to be regarded as an open question. Van Eijk's values for the quantity "K" do not show that this has a constant value specific for each anion.

Finality cannot be obtained by further exchange of views in the columns of NATURE. Although we hope that the present discussion may serve a useful purpose, its continuance in this journal could not be justified.

STATISTICS AND ENGINEERING PRACTICE

DR. B. P. DUDDING and W. J. Jennett, of the G.E.C. Research Laboratories at Wembley, have contributed a paper on "Statistics" to the Institution of Electrical Engineers which was published on January 5 and should prove useful in engineering applications. Although there was no spoken discussion, the authors have made some minor changes so that it can be read as a contribution to a general written discussion which will be concluded not later than February 5.

The theory of statistics as a distinct branch of science did not begin to flourish until the last quarter of the nineteenth century; in England, the work of Galton and Karl Pearson laid the foundations of the applications of the theory to many fields of science. Research workers in biological sciences and in agricultural industry were the first to turn these more recent advances to practical use. Great interest was stimulated by a series of lectures given by Dr. Shewhart at University College, London, in 1932. Later, the British Standards Institution formed a committee charged with the following terms of reference:

(1) To report on the application and use of statistical methods in standardization and specification of quality; (2) to draw up a short report which would serve to awaken interest in the application of statistical methods on the part of manufacturers and others concerned with problems of standardization and specification; (3) to consider what encouragement is necessary for the development of research on improved statistical methods and their application to industry; and (4) to consider what steps should be taken to provide for co-operation with bodies in the United States of America and elsewhere instituted for similar objects.

Out of this activity also grew the formation of the Industrial and Agricultural Research Section of the Royal Statistical Society. The meetings of this Section have provided opportunities for technicians employed in industry to meet statisticians and for statisticians to meet and discuss with technical people the difficulties which arise in trying to apply statistical methods to the examination of industrial data. Many institutions have been interested in this development. At the present time, there are few industrial products which are not expected to conform with some standard of quality. Measures are taken to ensure that finished products will conform with quality standards demanded by consumers.

The main object of Messrs. Dudding and Jennett was to emphasize the essential statistical nature of many technical problems and the part that chance plays in many technical decisions, and to demonstrate the need for a technique which will give assistance in making deductions from test data.

The following technical improvements and economies accrue to those industrialists who cultivate the statistical outlook and apply statistical methods to the scrutiny of their data. The errors of judgment arising from ambiguities due to the effect of chance, which lead to incorrect action, are reduced. Development work involving reasonably large-scale production can be planned most economically and the results rightly appraised. The efficiencies of the specifications used can be improved, and simple and efficient systematic methods of presenting data requiring daily scrutiny can be readily devised.

The authors explain fully the academic method of considering the frequency distribution of observations by the Gaussian curve, and the use of mean and standard deviations is explained. The importance of the methods given for carrying out specifications which involve sampling is clearly stated.

Numerical examples are included which will help those beginning the study of variance. An example has been given where an experienced engineer lacking statistical knowledge, and the statistician lacking practical knowledge, would probably have come to the same erroneous conclusion. Correct diagnosis of the difficulty in the factory was only possible by a combination of the attributes of the two.