

DEFICIENCY DISEASES AND THE ROLE OF THE "MINOR ELEMENTS" IN PLANT LIFE

T. E. T. BOND

"The study of the nutrition of plants has been pursued during the last forty years with great zeal and excellent results. The complete revolution which rational agriculture and forestry have experienced through the establishing of the theory of the nutrition of plants, proves how much has been accomplished in this department. The most significant result of the development of the nutrition theory mentioned is met with in the fact that we are now able to rear plants artificially — that we are in a position, with chemically pure water to which we add some few chemically pure salts, to rear artificially highly developed plants — that from inconspicuous and often scarcely ponderable quantities of vegetable substance, quantities of it as large as we choose may be produced in this way." This wrote Marshall Ward in the 1880's

in his translation of Sachs' famous "Lectures on the Physiology of Plants." (1) And indeed the theory of plant nutrition as it was then established was revolutionary enough. In these days we can hardly realize the change in outlook that it implied. Green plants were now known to depend for their food supply, not on the complex "organic juices" of the soil, but on such simple substances as the carbon dioxide of the atmosphere, water, nitrates, and certain inorganic salts in solution. Thus was inaugurated the age of artificial fertilizers — one might almost say the "NPK era" of agriculture — and, in more modern times, but in direct continuation of Sachs' water culture method, the revived and fashionable interest in soilless cultivation or "hydroponics." (2)

Unfortunately for modern agriculture, the "complete revolution" in agricultural practice that Sachs and his contemporaries viewed with so much, justifiable, satisfaction has had unforeseen consequences. One of the most significant of these (conditioned also by the increasing mechanisation of agricultural transport and machinery, and other economic changes) has been the rise to prominence of the deficiency diseases with the increasing recognition of the importance for plant nutrition of the so-called "Minor Elements."

The present article deals with a selection only of the various aspects of this recent development of the nutrition theory. Certain aspects which are not dealt with here, as for instance the more theoretical significance of the "Minor Elements" for plant metabolism, and their importance as affecting the health of the grazing animal, are briefly referred to in a review article on this subject reprinted in the *Tea Quarterly* for 1940 (Vol. XIII, pp. 148-152).

WHAT ARE THE "MINOR ELEMENTS"?

Sachs describes as necessary for the healthy development of his plants only "chemically pure water" with "some few chemically pure salts." In terms of the chemical elements involved his list of essentials, (*i.e.*, apart from carbon, hydrogen, oxygen and nitrogen) is a short one — "it is simply necessary that the nutritive mixture should contain the elements potassium, calcium, magnesium, iron, phosphorus, and sulphur, in suitable . . . combinations" — ten essential elements in all, of which three, namely, iron, magnesium, and sulphur, are usually regarded as "Minor Elements" (possibly also calcium should be included here), since they are needed in small amounts relative to the plant's much larger requirements of nitrogen (N), phosphorus (P), and potassium (K). The fact that the list of essential

"Minor Elements" is now quite rapidly being extended is due to improvements in technique and to our changed ideas of chemical purity. Water culture experiments, to be really critical, now demand some of the most elaborate and highly technical refinements of method to be found anywhere in agricultural research, although for certain purposes the simpler methods are still useful. The best authenticated of the recent additions to the list of essential elements are boron, manganese, copper, zinc, and molybdenum. ⁽¹⁾ ⁽²⁾ Claims made with regard to some other elements are still open to doubt, while there may also be elements, including such well known ones as sodium, chlorine, and silicon, that are essential for certain plants only, but not for plant life in general.

By some authorities, the attempt is made to distinguish between *nutritional* elements, which are needed in relatively large quantities, or which are known to be required by the plant for direct incorporation into the tissues (as, for instance, magnesium enters into the composition of the green colouring matter, chlorophyll), and the so-called *stimulative, catalytic, and prophylactic* elements which fulfil other, less obvious functions. However, it seems likely that, in time, most of these will be found to have some direct nutritional significance, so that this distinction will disappear. The criteria of essentiality as given recently by the foremost American workers in this field ⁽¹⁾ are worth noting. They are three in number, as follows:— (a) Deficiency must be shown to prevent the completion of the plant's normal life cycle; (b) It must be specific to the element in question, *i.e.*, an element is not essential if it can be replaced by another; (c) The element must be required by the plant itself, not merely on account of its effect on the chemical or biological equilibrium of the soil,

All the essential minor elements so far mentioned have been shown to be deficient in soils in various parts of the world and many different kinds of crops are known to be affected. Various examples of deficiency diseases will be mentioned in the course of this paper, although no attempt will be made to include more than a small fraction of those already recognised.

WHAT QUANTITIES OF THE "MINOR ELEMENTS" DOES THE PLANT NEED?

An outstanding feature of "Minor Element" nutrition is the extremely small quantity of the elements required. In fact, many of them are distinctly poisonous to plants if supplied in any considerable amount and this applies especially to the four more recently discovered essential elements boron, manganese, copper and zinc. It is easy to see how the necessity for these elements came to be overlooked for so long. Water culture solutions in any case are surprisingly dilute. Sachs' original solution, for instance, contained about 0.3% of dissolved salts, giving some 0.94 parts of potash (K O) and 0.14 parts of nitrogen (N) per thousand. The naturally occurring soil solution is still more dilute and it has been estimated to have a total concentration of about 0.1% of dissolved substances.⁽¹¹⁾ Compared with these figures the concentration of the "Minor Elements" needs to be almost incredibly low. Thus, in a recent Australian paper⁽⁹⁾ dealing with copper deficiency in oats and other plants, we read that considerable responses were obtained to quantities of that element corresponding to three millionths of a gram to the litre of culture solution — a concentration of 0.000003 parts per thousand. Notwithstanding, a deficiency of copper is the cause of a serious disease of oats and cereals generally — usually called "reclamation disease." from its common occurrence on

recently reclaimed peat soils — in Australia as well as in many parts of Europe. The observation that "reclamation disease" could be controlled by the application of copper sulphate was actually made several years before a conclusive proof of the essential nature of the element copper was forthcoming.

Some idea of the effectiveness of small quantities of the "Minor Elements" can also be gained from the applications necessary to cure deficiency symptoms in the field. One of the best known deficiency diseases in Britain is the disease of swede turnips known as "brown heart" or "raan."⁽⁵⁾ This is particularly prevalent in Scotland and is cured by applications of 10-20 lbs. of borax (representing 1.15 to 2.30 lbs. of the element boron) per acre. This small quantity, to be applied evenly, must be mixed with dry soil or sand (or with other artificial fertilizers) so that the total amount reaches at least a hundredweight. It may be noted that, unlike the case of copper deficiency quoted above, the first field proof of the occurrence of boron deficiency was preceded by the proof of essentiality of the element, obtained from water culture experiments.

SOME EXAMPLES FROM TEA

Tea in Ceylon is not known to suffer from any deficiency diseases, although a few years ago the suggestion was made that *phloem necrosis* might be a disease of this kind — perhaps due to a deficiency of boron. However, this view has received no support from experiments that have been carried out and need no longer seriously be considered.⁽⁹⁾ In other countries, the best known and most important deficiency disease of tea is the "yellows" disease, in Nyasaland, which is caused by a deficiency of sulphur. This disease was first reported in 1926, and the cause of it was not ascertained until Storey and Leach⁽¹²⁾ published their account of it in 1933. A review of

this paper was published in the *Tea Quarterly* for that year (Vol. VI, pp. 121-127), so no further account of the symptoms of the disease need be given. Tea "yellows" is interesting as the first case of sulphur deficiency so far reported in the field: it is cured by the application of fertilizers containing sulphates, or by the direct addition of sulphur in quantities as low as 24 lbs. per acre. The acute sulphur shortage of the Nyasaland tea soils cannot yet be fully explained, and Storey and Leach are careful to point out that full symptoms of sulphur deficiency are developed only in the presence of an adequate supply of the other necessary inorganic nutrients.

Interest in deficiency diseases was recently increasing in Java where serious symptoms of potash deficiency had become noticeable in certain districts. This was followed up by the Proefstation, West Java, and a full account, based on field observations and sand culture experiments, was published in 1940. This was also reviewed in the *Tea Quarterly* (Vol. XIII, pp. 139-145). The sand cultures were extended to cover certain of the recognised "Minor Elements" and in a later paper⁽⁴⁾ various experimentally induced deficiency symptoms were described. Some of these are noted briefly below:—

Calcium.—Tea plants without calcium grow well at first but later develop pronounced symptoms, especially on the young leaves, of marginal yellowing, spreading inwards between the veins and eventually becoming brown or "scorched." A downward curl of the apex and margins of the leaf also occurs.

Magnesium.—Deficiency symptoms are noticeable only on the older leaves, which become very pale yellow, only the veins remaining green. There may also be a slight marginal scorch. The authors consider that this deficiency may occur in the field in Sumatra.

Sulphur.—Symptoms produced experimentally agree closely with the symptoms of "yellows," the plants remaining small with practically no flush, the leaves being mottled with yellow especially between the veins. Tea "yellows" is not considered likely to occur in the field in the Dutch East Indies.

THE AVAILABILITY OF THE "MINOR ELEMENTS" IN THE SOIL

The occurrence or otherwise of deficiency diseases cannot simply be predicted from the amount of the different "Minor Elements" known to occur in various soils, although in some cases such a general relationship can be shown to exist. Thus, in S. Ayrshire, Scotland, there is definite evidence that "brown heart" of swedes is less severe on those soils derived from rocks containing tourmaline, a mineral rich in boron⁽⁵⁾ though in a very insoluble form. More commonly it is a question, not of the total amount, but of the "availability" of the element in question, as affected by certain other soil factors, the most important of which are (a) water relations, (b) pH and lime content, (c) soil micro-organisms. To a certain extent these three factors are interrelated, but it will be convenient to discuss them separately, in the ensuing paragraphs.

Rainfall, and the water relations of the soil, may affect the occurrence of deficiency diseases in two ways. Firstly, it is a matter of general observation that such diseases are more in evidence during drought and in dry seasons than with normal rainfall. Thus, severe attacks of "heart rot" of sugar beet (a boron deficiency disease corresponding to "brown heart" of swedes) may be expected when a rainy spring, which has led to vigorous growth and feeding of the young beet seedlings, is followed by a dry spell in summer, when the plant's absorption of soil nutrients receives a check.⁽⁶⁾ Tea "yellows," also, is most in evidence

at the end of the dry season, after which there is usually a gradual improvement up to the end of the rains.⁽¹³⁾ Secondly, the leaching effect of heavy rainfall needs to be taken into consideration. Deficiency diseases are usually more prominent on light, sandy, soils than on the heavier more retentive types, although actual differences in total nutrient content also play their part here. The best example of a "Minor Element" deficiency caused primarily by leaching is that of "sand drown" of tobacco, which occurs in the United States, Canada, and Nyasaland, and which is due to a deficiency of magnesium.⁽¹⁴⁾ Symptoms of this disease take the form of a severe chlorosis in which only the veins retain their green colour, while the curing properties of the leaf are also affected. Magnesium is one of the commoner soil elements but it is also one of the most easily soluble and is quickly leached out of the surface layers. For this reason, it seems likely that actual deficiencies of this element in the soil may be much more widespread than is usually realized.⁽¹⁵⁾

The reaction of the soil and its lime content are among the most potent factors affecting the availability of the minor elements. The two properties are so closely related that it is not easy to separate one from the other. In most cases, however, the actual occurrence of free calcium appears to be of more direct importance than the degree of alkalinity with which it is associated. Thus, deficiencies of boron, zinc and iron are frequently induced by lime, the elements though present in the soil being rendered insoluble or otherwise unavailable in the presence of this substance. Iron, especially, is a major constituent of soils and it is doubtful whether true iron deficiency is ever met with. Lack of this element results invariably in chlorosis, or pallor due to deficient development of the normal green colour, and the relationship to lime is now so widely known that this condition is commonly spoken of as "lime-induced chlorosis." In Great Britain, there is a definite risk of this disease in planting fruit trees on certain calcareous soils.⁽¹⁶⁾ As a preventative, the trees can be sprayed with iron sulphate solution, or this substance can be applied as a dressing on pruning cuts and other wounds. A more economic method of control is to grow cover crops under the trees, which, by their root action, are found to increase the availability of the iron already in the soil and hence counteract the harmful effect of lime. Still another method of increasing the supply of iron to the trees is by injection.

The importance of soil organic matter, and the micro-organisms which it supports, is receiving increasing emphasis in recent work on the deficiency diseases. The relationship is in many cases obscure and new interpretations of the observed effects are constantly being given. One or two examples will be sufficient here. One of the best of these is the "reclamation disease" of cereals, already mentioned as induced by copper deficiency. This is usually associated with highly organic, peaty soils, and the beneficial effect of adding copper sulphate has been interpreted by various authorities as due to a transformation of the physical condition of the organic colloids leading to improved water relations, to precipitation or inactivation of an organic soil toxin or to the replacement of copper rendered unavailable by the action of anaerobic soil bacteria.⁽¹⁷⁾ Copper is, however, truly essential to plant life so that the last mentioned alternative may prove to be the most feasible. A well substantiated case of this kind is provided by Gerret

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sen's recent work⁽⁶⁾ on the "grey-speck" disease of oats, also prevalent on reclaimed moor or peat soils, but associated with a deficiency of manganese. According to Gerretsen, the manganese is rendered unavailable in the first place by precipitation in an insoluble form through the activity of certain bacteria. The symptoms of "grey-speck" are induced in the plant, not as a direct result of lack of manganese, but as a result of the increased susceptibility of the roots to the invasion of bacteria from the soil. They do not occur in the same manganese-deficient soils after sterilization, *i.e.*, in the absence of bacteria. Gerretsen also showed, however, that even under aseptic conditions, normal growth was impossible without a certain minimum quantity of manganese, so that this element can be regarded as truly essential for oats, (and other plants) in a direct sense as well as in the more complicated manner revealed by the occurrence of the "grey-speck" disease.

DIAGNOSIS AND CURE OF DEFICIENCY DISEASES

In the foregoing examples it has been assumed that a deficiency of a given element can be recognised by the characteristic symptoms produced in the plant and that the treatment to be followed consists of a simple manurial application of a compound containing the element in question to the soil. In the majority of cases, particularly with annual crops as cereals and "roots," this is the only feasible procedure. So many of the "Minor Elements" are poisonous in all but the smallest amounts that it is rarely advisable to apply them to the soil until definite evidence of their deficiency has been obtained. Recently, some attempts have been made to test the soil in advance by using it for the growth of some simple organism, such as an alga or fungus, that will quickly complete its life cycle in the laboratory. Ordinary methods of

chemical analysis would be too tedious and besides, they would not necessarily distinguish between "total" and "available" amounts of the element in question in the same way that the growing plant will. As an example of a microbiological test of this sort is the use of the fungus *Aspergillus* (a common mould) to test the sufficiency of available copper, in connection with studies on "reclamation disease."⁽⁷⁾ The fungus is grown on a synthetic nutritive medium containing no copper, to which is added a measured quantity of the soil to be tested, when it is found that a black colouration of the spores denotes a healthy soil (containing 1 in 400,000 parts by dry weight of available copper), while brown and brownish-yellow to yellow spores respectively denote varying degrees of copper deficiency and of liability to the disease.

With perennial crops, particularly fruit trees, where the number of plants per acre is relatively small, and the crop from each plant correspondingly valuable, it becomes more important to be able to diagnose a deficiency at the earliest possible stage, *i.e.*, before the yield has been impaired. For this purpose, the method of direct injection into the plant is proving very valuable. Besides, by this procedure there is no danger of the element supplied being rendered unavailable, as it quite frequently is when added to the soil. Injection of woody plants has been known and practised for a very long time, for certain special purposes. In the fifteenth century, for instance, it was recorded that apples could be rendered poisonous by injecting arsenic into the trees at the time that the fruit was ripening. Other, more innocuous, ends have been served from time to time by injections of spices and honey to improve flavour in fruits, of dyes to colour flowers, and of preservatives to improve the injected timber.⁽⁸⁾ From Sachs' time, injection for curative purposes became increasingly common.

especially the injection of iron salts to cure the ubiquitous iron-deficiency or lime-induced chlorosis, already mentioned. The modern use of injection methods for the diagnosis of mineral deficiency diseases has been largely worked out by Roach⁽¹⁰⁾ and his co-workers at the East Malling fruit research station in Kent. Roach's methods depend on injecting the test liquid in such a way that a limited part only of the plant receives it. This may be a single branch, leaf, or even a part of a leaf. Any response that is induced, such as a slight change in colour or texture of the injected part, will then stand out sharply against the untreated remainder. Working in this way, unsuspected mineral deficiencies have been diagnosed in a week, or even less, and the existence of widespread and potentially serious malnutrition in the British fruit-growing industry has been demonstrated.

An interesting extension of the injection method has been to apply it to the injection of nutrient salts and other substances including disinfectants designed to have a specific effect in reducing the incidence of insect attack and of parasitic diseases. Further progress in this direction is to be expected in the next few years and some important changes in the practice of disease control in woody plants may be foreshadowed.

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