

MINERAL NUTRIENTS AND PLANT GROWTH

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The Plant Environment

IN studying the physiology of plants we are not only concerned with things going on inside the plants themselves but we always have to take environment into account, the connection between internal and external events being so close that no real separation can be made. Even animals, with their powers of free movement, cannot escape from dependence upon their surroundings; they must feed. In plants, however, the connection is more obvious because the great majority of them spend their lives rooted to a single spot. The state of adjustment which exists between plants and their environment is often very delicate, so that quite small changes in the latter, will bring about corresponding changes in the living organism.

It should be emphasised at this stage, that any study of the nutrition of plants must be considered in relation to all the conditions in which the plants live, and not merely in terms of the amounts of plant nutrients contained in or added to the soil. The requirements of plants for different nutrients may for example be affected by conditions of light, temperature, humidity, water supply and other factors of general environment. The problems of such influences in the plant environment may also be further complicated by the fact they do not act independently but their effects are modified by one another. For example the effects of light intensity or periods of daylight may vary with different temperature conditions.

The Raw Materials of Plant Growth

Research workers have established through many experiments that certain elements are essential for plant growth. Without these elements growth decreases and finally fails completely during the vegetative or reproductive cycle of a plant.

The raw materials needed for plant growth consist of carbon dioxide, water and the so-called mineral nutrients. The importance of water and carbon dioxide in the nutrition of plants will be apparent from the facts that water often comprises 80 to 90% of the total weight of growing plants, and carbon and oxygen together may account for over 80% of their dry matter, *i.e.*, the solid matter remaining after water is removed. It has also been shown in recent years that certain organic compounds known as "growth promoting substances" or "hormones" which occur in plants and some of which are also present in soils and natural manures, are capable of producing marked growth responses. It is not at present clear to what extent 'hormones' are absorbed by plants from soils although it has been shown that certain hormones which occur naturally in soils can be obtained in this way.

The Mineral Nutrients

As against the large amounts of water and organic matter, the mineral nutrients, as measured by the ash content of the plants, *i.e.*, the mineral residues obtained when the organic matter is destroyed by heat, often contribute 5 to 15% of the dry matter.

For about three-quarters of a century, it was generally assumed that only ten elements including carbon, hydrogen and oxygen were universally indispensable for the growth of higher green plants, though it was considered probable that plants of some species might have additional specific requirements. The presence of certain elements other than these ten was recognized in plant tissues by early workers but their essentially for growth had not been appreciated at that time.

Recent research, however, has established that besides carbon, hydrogen and oxygen, twelve elements are absolutely necessary for the normal healthy growth of plants. Some of these "essential elements" are needed in relatively large quantities and others only in very small amounts. The former are referred to as "major" elements and the latter as "minor," "trace" or "micro" elements. It should be emphatically stated that the terms "major" and "minor" do not refer to the relative importance of the functions of the elements in plant growth, but to the relative magnitude of their requirements in inorganic plant food. For this reason it would be preferable to adopt the term "trace" elements for the latter class. The major elements include nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur and the six trace elements are iron, manganese, boron, copper, zinc and molybdenum. In addition to these there are other elements like sodium, chlorine and silicon which produce beneficial effects on the growth of certain plants but they have not so far been proved to be absolutely essential to growth except in the case of halophytic or seawater plants. The element aluminium is also of general occurrence in plants but appears to be without direct nutritional value. The list of "essential" elements is probably not closed, and future research may add a few more.

When plants are grown in unsuitable environment, including conditions of faulty mineral nutrition involving deficiencies or excesses of the major or trace elements, they react to the particular defects in more or less specific ways. The deficiencies and toxicities of the individual elements usually produce characteristic effects on various organs of plants. As a rule foliar characters, including colour, density, size and shape of leaves; stem characters, such as strength, thickness, colour and length of internodes; root characters, such as colour, amount of fibre, abnormal thickening; blossom characters, including amount and time of opening of the flowers; and fruit characters, such as size, colour, hardness and flavour are all symptomatic of various mineral nutrient disorders.

There are some to whom the language of plants is a relatively open book. They have learned the meaning of the discoloured, gnarled or curling leaf; the outer markings or the inner imperfections of sickly fruit. They have interpreted the significance of these and other signs by which the ailing plant seeks to tell the nature of its difficulty, too often caused by lack of plant food elements necessary for good health, growth and maturity. The speech of plants as revealed in visual symptoms tells a story of crop injury due to mineral nutrient deficiencies, and the ability to recognize these particular effects forms the basis of the visual method of "symptomology" for diagnosing plant nutritional problems.

When an element has been found to be essential for growth, it is as a rule contained within the plant itself, otherwise the element could not be considered essential. The exact concentration of the element required for growth, however, is dependent on its function in the physical and

chemical processes of the plant. On the contrary, it was early recognized and proved by culture experiments that not all of the elements which enter plants from the soil are necessary to their existence. Elements such as chlorine, bromine, iodine, mercury, fluorine, silicon, sodium, lithium, rubidium, strontium, barium, aluminium, thallium, titanium, tin, lead, arsenic, selenium, cobalt, nickel and silver have been identified at various times in the ashes of plants, and though their presence gave a basis for certain presumptions, their essentiality has never been established. When they do occur they should be regarded if at all as only stimulants for plant growth.

Factors Affecting Nutrient Absorption

There are various factors including soil, climate, growing period, plant variety and management which influence the intake of nutrients and affect their concentration in the plant tissues. There is in fact an inter-relationship of the factors themselves, and no one factor can be regarded as being entirely responsible for the concentration of nutrients in any plant grown in the field.

The soil, besides serving as a source of water, and anchorage for the plant, is also the source of the mineral nutrients. Soils with the same concentration of a given nutrient may or may not meet the requirements of a crop, depending on its chemical composition and the chemical interactions of the nutrients themselves. The mineral nutrients may not be present in an available form and may be locked in the soil. Under ordinary conditions, however, the nutrient supply from soils, high in nutrients, should be adequate, but where the soil volume is restricted by an impervious clay or hard-pan layer, high water table or a toxic zone then even the high nutrient concentration may be inadequate for the plant especially after a period of prolonged cultivation as a sole crop, *e.g.*, coconuts.

The climate affects the nutrient requirements of a crop in many ways, and as a rule, plants are able to utilise more nutrients during favourable weather than during adverse weather conditions. It has also been observed that climates which conduce to heavy fruiting, tend to enhance the intake of nutrients by plants.

The time factor is important, in the sense that, during the growth cycle of a plant, the actual nutrient requirements depend on the growing period of the crop. It has been found as a rule that earlier in the growth cycle, nutrient requirements are higher than at the later stages. In fact the addition of nutrients, just before or at the time of harvest, produces little effect on the yield of the crop.

Plants of different genera, species or even different varieties of the same species have been found to differ profoundly in their nutrient uptake when grown under similar conditions. The kind and extent of root development in the different varieties appear to be the factor influencing the unequal absorption of the nutrients.

Soil management and cultural methods, such as drainage, tillage, irrigation, liming and ploughing in of crop residues, are also obvious factors affecting nutrient absorption. *The mere addition of nutrients to the soil does not always ensure their proper absorption by the plants, growing on them.*

The Functions of the Nutrient Elements

The functions of the various mineral elements, especially the trace-elements, which are effective in minute amounts in plant growth and metabolism, are still in a large measure obscure although various suggestions can be made based on physiological researches. It is usually presumed

that the trace elements act principally as catalysts, or assisters. A study of the main functions of the mineral nutrients, however, should be an advantage in understanding the deficiency symptoms they produce on various plants.

Nitrogen.—Nitrogen compounds comprise from 40% to 50% of the dry matter of protoplasm, the living substance of the plant cells. Its importance in plant metabolism can therefore be realised, and it will be obvious that without an adequate supply of nitrogen to the plant, all growth processes would be restricted and they will remain stunted when this element is deficient. Proteins which are found in plant organs like seeds, and chlorophyll, the green pigment in leaves, all contain nitrogen. It will therefore be apparent that any inadequacy of nitrogen will tend to produce a pale green colour of the leaves due to the limitation of chlorophyll formation which is a characteristic symptom of this deficiency.

Numerous organic compounds such as amino-acids and alkaloids are compounds of nitrogen, and are of great importance in plant physiology. Any shortage of nitrogen will therefore impede the synthesis of these substances. Certain of these nitrogen compounds play a part in the translocation of food materials, as they have the property of being very mobile in plant tissues. Such transference usually takes place from old tissues to tender growing points when there is a shortage of nitrogen. This explains why symptoms of nitrogen deficiency appear first in the older parts of plants and why the growing points are the last to be affected.

Phosphorus.—This element enters into the composition of the nucleus of plant cells and is therefore vitally concerned with growth processes, the same as nitrogen. Phosphorus compounds are also of great importance in the production and ripening of seeds and fruits, the metabolism of fats, in respiration, in the efficient utilisation of nitrogen, and in root development. The symptoms of phosphorus and nitrogen deficiencies are similar, probably because their respective functions are inter-related.

Potassium.—The functions of this element are difficult to determine, as it does not appear to enter into the composition of any of the major plant constituents, like carbohydrates, proteins, fats or chlorophyll. It is, however, found as a rule in large proportions in all parts of plants and seems to be contained in the cell sap.

Potassium is very mobile in plants, and highly soluble, and hence during shortages it is readily re-utilised by tender tissues. It appears to accelerate enzyme action and act as a catalyst in the production of certain complex substances. It also appears to function in the processes of transpiration and photosynthesis. When potassium is moderately deficient, symptoms appear in the older tissues progressing towards the growing points. When the deficiency is acute, however, growing points are severely affected resulting in die-back, and general collapse of the plant.

Calcium.—This element occurs primarily in tissues of the leaves, and it is a constituent of the cell wall. Being basic in nature, it serves for the neutralization of organic acids, and seems to be concerned with activities of the growing points. Calcium is not very mobile and does not appear to move freely from the older to the younger parts of plants which accounts for the fact that the mature tissues contain more calcium than the younger parts. This perhaps could be associated with the fact that any deficiency effects begin at the apex of the shoots.

Magnesium.—This is a vital constituent of the green pigment, chlorophyll. Magnesium is also known to function as a carrier of phosphorus, especially in fatty seeds. Chlorosis of the leaves is a characteristic symptom of magnesium deficiency. This element is very mobile like nitrogen and potassium, and its shortage is reflected in symptoms appearing first in the oldest leaves, progressing towards the youngest ones.

Sulphur.—This occurs as a constituent especially of proteins. Though it does not enter into the composition of chlorophyll, it seems to have some function in its production. There is a marked similarity or even identity of symptoms of sulphur and nitrogen deficiencies, possibly because both elements are associated with proteins and chlorophyll.

Iron.—This is not a constituent of chlorophyll, but is involved in its formation being probably catalytic in function. Iron deficiency, therefore, results in chlorosis of the leaves. This element has some function in respiration possibly acting as an oxygen carrier. Iron is very immobile in plant tissues, and sometimes its deficiency means purely its lack of mobility. This seems to be affected by factors such as the presence of manganese, the light intensity and potassium deficiency.

Boron.—This element is supposed to have a role in the formation of pectin compounds. Great emphasis has been given to the possible inter-relations between calcium and boron. They both produce identical symptoms when they reach deficiency levels. Both deficiencies are strikingly reflected in the failure of growth in the growing regions of the plant. Boron, in a still unknown way, has a role in the determination of the state in which calcium is present in the tissues, including its concentration, and degree of solubility.

Boron cannot, however, replace calcium. It appears to function as a catalyst or reaction regulator especially in nitrogen absorption and the adjustment of potassium/calcium ratios in plants. Boron deficiency as a rule leads to a collapse of growth processes, with severe derangements of metabolism.

Zinc and Copper.—These two elements also appear to function as catalysts or regulators in plant nutrition. It has been found also that in some cases zinc deficiency causes inhibition of seed formation and its subsequent development. The availability of zinc to plants is sometimes determined by soil micro-organisms which offer competition for minute amounts of zinc in the soil. As a rule, deficiencies of zinc and copper are characterised by chlorosis of the leaves and a general collapse of growth processes.

Fruit trees affected by zinc deficiency show small leaves and stunted growth and the disease is said to occur mostly on light sandy soils, which are rather high in lime content.

Manganese.—It is believed that manganese like molybdenum promotes the assimilation of nitrogen through the root tips but this hypothesis has only been partly confirmed.

Toxicity of Mineral Nutrients

All mineral elements, whether essential or non-essential can have toxic or poisonous effects on plants. As a rule, however, the macro-nutrients are less toxic than the trace-elements. In other words, there is a fair safety margin for excess of "luxury" consumption for the major elements, but this margin is very narrow for the trace-elements.

Certain plants are quite tolerant to the non-essential elements but others are injured by relatively small amounts of them. The deleterious effects of nutrient excesses, however, are sometimes the result of direct injury to the protoplasm leading to the speedy death of the plant, and at other times due to interactions of various elements leading to their chemical fixation. As an example of the latter the lack of availability of boron in heavily-limed soils could be quoted, where due to chemical reaction the boron is fixed in the soil by the calcium. These facts should, therefore, serve to stress the importance of judicious application of artificial fertilizers especially to sensitive crops.

Practical Aspects of Nutrient Problems and Conclusion

Soils are not invariably capable of supplying enough nutrients to maintain the healthy growth of plants. This does not necessarily mean a question of absolute deficiency in the total quantity of the elements present in the soil, but rather includes physiological deficiencies arising from insufficient availability of the elements to the plants. In other words, not enough of the elements can be absorbed and distributed in the plant for its physiological needs at each successive phase of growth.

During the past ten years, thousands of cases from many parts of the world have been reported of crop failure or plant disease resulting from deficiencies especially of the trace-elements. These are important enough to warrant the view that the recognition of nutrient deficiencies constitutes a development in applied plant nutrition of major significance. Animals too depend in part for their supply of inorganic elements effective in minute amounts on the plant. What the plant absorbs from the soil is therefore of consequence to the nutrition of the animal consuming the plant and thus the study of mineral nutrients is of convergent importance in both plant and animal nutrition.

Based on the facts outlined in this paper, it is axiomatic that a plant diagnostician has to consider certain factors in endeavouring to solve nutrient problems in plants. The factors to be investigated could be roughly summarised as follows :—

- (1) Soil deficiencies due to inadequacy of nutrients.
- (2) Soil toxicity due to over-concentration of nutrients.
- (3) Soil nutrient antagonism, due to chemical inter-actions of nutrients.
- (4) Soil balance, *i.e.*, to establish whether the nutrients are present in the correct relative proportions.
- (5) Soil pH, *i.e.*, the strength or intensity of acidity or alkalinity of the soil and,
- (6) Soil aeration.

In spite of judicious diagnosis, nutrient problems can prove to be very baffling and complicated, depending on the severity and multiplicity of the causative factors involved.