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THE MINOR ELEMENTS IN SOIL FERTILITY AND PLANT NUTRITION

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Manuring to improve yield and quality of crops in ancient times was largely done with stable or crop refuse. During the past century an important fertilizer industry developed to supply the three major plant food elements most often needed - namely, nitrogen, phosphorous and potassium, in readily available chemical form. For the past century seven additional elements have been generally recognized as essential although usually present in normal neutral soils in sufficient amounts to meet plant needs. The soil must supply calcium, magnesium, sulfur, and iron while air and water are the source of carbon oxygen and hydrogen and may be indirect sources of the major plant-food nitrogen.

In the past two decades replacement of animal power by farm tractors and large production of pure synthetic fertilizers as well as intensive specialized agriculture, have contributed to manifestation of some deficiency diseases of crop plants.

During the past twenty years the essential nature of very small amounts of several of the so-called minor or trace elements has gradually become apparent. Various obscure types of unhealthiness in plants are prevented or corrected by the presence of traces of such elements as boron, manganese, zinc, copper or others for which essentiality is not so well established.

Minor Elements

In order to determine the essentiality of a trace element it may be necesssary to grow large numbers of plants under carefully controlled conditions in solution culture built up from purified chemicals in re-distilled water, and perhaps from successive generations of seed. Most of these trace elements are helpful only at concentrations of the order of one-fourth part per million while two parts per million in solution may be toxic, so great care is needed in their use.

1. Possible Functions of the Rarer Elements

Responses of plants to the presence of minor elements varies with different plants, and with different soil environments. Functions which these elements may perform are the following:

(1) They may be essential nutrients for life and growth.
(2) They may serve as substitutes for other elements.
Ex. Calcium by strontium.

(3) They may help form enzymes or coenzymes.
(4) They may antidote toxicity. Ex. Sodium injury is reduced by trace zinc.
(5) One element may aid in keeping another reduced.
(6) One element may liberate another element.
(7) They may oxidize or reduce.
(8) They may increase resistance to disease.
(9) The addition of, or presence of, one element may precipitate ions of another element.
(10) An indirect effect may occur from effect on reaction or action of an element upon microorganisms or antidote bacteria by formed toxin.
(11) Many have stimulative effects.
(12) Colloidal effects are possible.

Manganese.

(1) May function in the synthesis of chlorophyll.
(2) Stimulate the rate of reproduction.
(3) May act as a catalyst.
(4) It may increase oxidation.
(5) It may increase the absorption of calcium.

Manganese applied to peat land as a sulfate in 1929 by the writer gave 30 per cent increase in yield of tomatoes and 15 per cent increase in peas. In the same trials sulfates of zinc, copper, tin, or magnesium gave negative results.

2. Zinc.

(1) Stimulates heterotrophic plants, is toxic to autotrophic plants, thus, stimulates non-chlorophyllous plants.
(2) Stimulates the germination of seeds.
(3) Probably affects the soil microörganisms in a stimulating way.
(4) Is apparently more necessary for growth of stems and leaves, than roots.
(5) Is a specific remedy for citrus fruit mottle-leaf, and pecan rosette.

Zinc was shown to be essential to development of maize some 20 years ago by Maze' in France. It has been extensively used in California for control of leaf mottling or "littleleaf" or "rosette" of citrus. This treatment has been used successfully in Oregon beginning in 1933 by O. T. McWhorter and W. W. Lawrence to control this trouble in stone fruits near The Dalles, Cove and Milton. The use of injections or zinc tacks is being replaced by an early-season application of a zinc sulfate spray, using 10 pounds or less per 100 gallons of water, applied after 4 p.m. Zinc content of leaves from three affected kinds of stone fruit trees is lower than for leaves of healthy trees according to determinations by J. S. Jones (who used the Method of Hibbard*) who found 7 to 12 p.p.m. zinc.

* Ind. Eng. Chem. Anal. Ed. 9:127, (1937)

3. Boron.

(1) May aid in the development of nodules on legumes.
(2) Apparently it is necessary for maintenance in good condition of the conducting tissues of the stem.
(3) It is apparently necessary for proper cell division and to the growing tip.
(4) Lettuce develops improperly in absence of boron.
(5) May control nutritional deficiency diseases such as "heart rot" of beets, and "yellow top" of alfalfa.

Boron was shown to be essential to normal development of broad beans by Warrington in England in 1923. Boron has been used to control "top sickness" of tobacco, Brown Heart in turnips, "cork spot" in apples, "yellow top" in alfalfa and crown-rot, or heart-rot of sugar beets especially on alkaline soils. Old soils derived from igneous rocks seem most apt to be deficient in boron. Soil reaction or lime and moisture contents, perhaps also temperature may affect its availability.

Irish Free State Department of Agriculture is reported to recommend 21 pounds borax in 900 pounds fertilizer per acre beets for 1937.

In Oregon recent experiments by the writer have demonstrated that yellow-top of alfalfa can be controlled on various soils by use of as little as 10 to 20 pounds of boric acid an acre applied in solution with a sprinkler. Normal color was restored in the field within thirty days and with controlled conditions in the greenhouse within a few days. Boric acid has been used periodically in our experimental culture solutions for a decade to overcome a certain type of chlorosis or yellowing of foliage. One-half part per million has proven sufficient and may safely be used. The injurious effect of an excess is difficult to distinguish from that of a deficiency. Chemical analyses by Professor J. S. Jones (using Method of Scott and Webb*) show unfavorably low boron content in soils and alfalfa from affected area.

4. Copper.

(1) May aid in the assimilation of phosphorus, magnesium and calcium.
(2) Seems necessary for formation of chlorophyll.
(3) May inactivate soil toxins.
(4) May affect soil algae.
(5) May affect oxidation and absorption of other soil compounds, i.e. aid assimilation of ammonium ion (Hoagland)
(6) May increase resistance of plants to disease.
(7) May change appearance without changing vigor, as in hydrangia.
(8) May affect soil colloids.
(9) Affects absorption and respiration.

Copper sulfate has been found to be very helpful in preventing "reclamation disease" or increasing yield and quality in Florida and Holland. Application of 20 to 40 pounds an acre of copper sulfate before planting peanuts or tomatoes on Florida saw-grass peat is an established practice. Negative results have been obtained with Oregon peats. There is some evidence that a trace of copper will increase yield on certain soils of John Day and Illinois Valleys.

* Journal of Industrial and Chemical Engineering Anal. Ed. 4:180.

5. Iodine increases the iodine content of plants and may increase yield. Majority of thorough trials seems to show increase. Iodine may stimulate germination and growth or activity of microörganisms. Baumann in (1895) found its absence in plants affects thyroid.

Using modified Harvey Method the iodine is found to be low in the waters, soils and vegetation over much of the Pacific northwest. Iodine in our soils may run from .5 to 15 parts per million. In Oregon water .01 to 2 parts per billion. Relation is sharpest between water content of iodine and goiter. Soil iodine seems to associate with organic matter and in sedimentary soil. Significant increases in yields of head lettuce were secured in 1929, by the writer in water culture solutions and subsequently with alfalfa and corn. Mr. Waldo Carlson who has extended these studies exhaustively for a Doctor's thesis problem in association with Dr. J. R. Haag and the writer on an Adams fund project has found good evidence that the effect of iodine is indirect and that microörganisms are involved with the potassium iodide added perhaps changing to organic form before it is effective.

Significant increases in growth have been obtained from two pounds Kl per acre on Aiken and Deschutes soil series. This might be added in irrigation water, or large seed may absorb sufficient for plant needs.

6. Soil Toxins may include reduced forms of substances such as may be found in bogs or impervious subsoils where nitrate may be reduced to nitrite or ferric salts to ferrous forms. Ferrous chronite seems to be the toxic substance in Serpintine soils of Southern Oregon. The poisonous properties of selenium and vanadium have been recognized in certain areas outside of Oregon. Sulfur is reported to inhibit selenium absorption. A trace of metallic element may act as an oxidizing agent or antidote bacterial toxins.

Lead arsenate spray residue accumulation in surface soils and its toxicity to or absorption by shallow rooted plants has been studied by Jones and Hatch. Basic soil reaction seems to increase solubility and toxicity.

Toxicity or Utility of a Trace of Gas. Noxious gasses are toxic in concentrations of a few parts per billion depending on various conditions. At the suggestion of the writer Dr. Zimmerman grew plants in sulfur free cultures solutions and exposed them to one-tenth part per million of sulfur dioxide in Thomas type cages. The growth increase was 92 per cent. This discovery that a plant can assimilate nutrient from the gas phase has far reaching implications.

In general deficiency diseases may actually be more prevalent than formerly; they are somewhat better understood and more promptly recognized. In the future foliary diagnosis will be increasingly useful. Frequently the plant need may be more readily detected by appearance and analysis of the plant leaves than of the soil. Early recognition of the cause of trouble may avoid economic loss. Because only traces of the minor elements may be needed and more than a trace may be extremely toxic, applications should be made only where they are known to be needed and in carefully determined amounts.

Colloids are probably unavailable to plants as such, the particles associated as satellites may be. "Fool-proof" methods of commercialization of "complete" water cultures are not yet provided. It seems inadvisable to include trace elements in fertilizers. For general use, these should still be purchased on the basis of cost per unit nitrogen, phosphoric acid and potash contained.