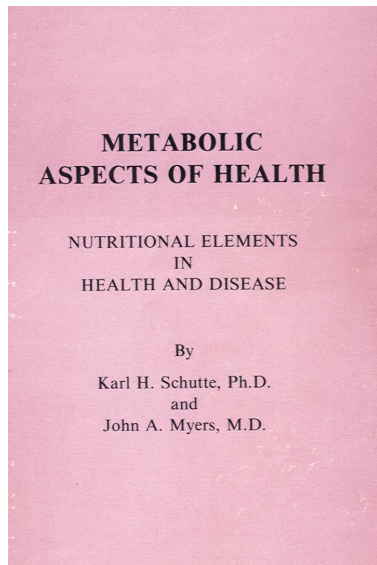


Excerpts from The Biology of the Trace Elements –Their role in nutrition by  
**Karl H. Schutte MSc PhD** (J. B. Lippincott Company, publisher),



first reprinted in his book with **John A. Myers MD** in 1979, now also out of print. Dr. Schutte was Professor of the Department of Botany, University of Cape Town, South Africa, for many years, and in Dr. Meyers' opinion, was one of the foremost authorities in his field.

### Chapter I The significance of trace elements in nutrition

{Page 1} All living organisms require a regular supply of nutrients...If there is a deficiency, or an excess, then normal development will cease, and abnormal development will result.

#### **Type of Nutrients**

Nutrients have a variety of functions to carry out. One of the most obvious is to supply *energy* to the living organism...The energy...is obtained from *organic matter*, nutrients such as fats, carbohydrates, and proteins. These complex substances are broken down by the process of digestion, which usually reduces them to water-soluble substances such as sugars and amino acids. These latter can be used by the individual living cells as a source of energy. The energy that is needed is obtained from these nutrients by the process of respiration, a complex chemical process whereby the sugars {Page 2} and amino acids are oxidized in the cells and energy is slowly liberated...plants in general use up energy at a much slower rate than animals. However, they both have the same basic requirements. They need a continuous supply of nutrients, both organic and mineral, to grow and develop.

#### **Uniqueness of the green plant**

The green plant is unique in one respect. It manufactures its own supplies of energy-giving nutrients, such as fats, carbohydrates, and proteins, from inorganic matter. It does this by means of the process of photosynthesis,

...Animals are unable to synthesize these food materials from simple substances such as carbon dioxide and water, and hence must have an outside source of these,...closer inspection shows that photosynthesis is undoubtedly the most important biological reaction on earth....The old adage 'all flesh is grass' is perfectly true.

Because of this photosynthesis, plants are more *obviously* dependent upon the soil for mineral nutrients than are animals. The influence of mineral nutrient can be more readily studied in plants than in animals.

#### **Essential elements**

...carbon, oxygen, and hydrogen account for over 94 per cent of the dry weight (of a maize plant). If the atomic composition of a plant is studied, it is perhaps even more instructive. The analysis of a human being shows a very similar picture,

{Page 3} virtually all organic matter. [...these three elements account for 93 percent of the mineral composition of man.] But other elements are equally characteristic of living matter, even if they are present in much small quantities. Nitrogen, without which there can be no proteins; phosphorus, potassium and calcium are all elements that must be present and available if life is to occur...

But in addition to these readily identifiable elements there are a large number of elements that are present in only small quantities. Most of these can be found in the ash of plant or animal materials.

{Page 4} [The elemental composition of a typical plant (dry matter)—out of one billion atoms weighing hypothetically 100 grams, less than 1/10<sup>th</sup> of a gram (= 1/10<sup>th</sup> of 1%) would be trace elements, i.e., 300 zinc atoms, 100 copper atoms, 5 molybdenum atoms, and 1 cobalt atom. etc.]<sup>1</sup> Burning result in the loss of carbon, hydrogen, oxygen and nitrogen, as well as a few other elements. but the concentration of remaining 'Ash Elements' is much higher than it was in the original matter., and so ashes can be readily analyzed for the remaining elements which are present in small quantities in the parent material.

{Page 5} [Over 98 per cent of the weight (of a human being) is accounted for by oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus. Other elements, even if present in such low concentration as iodine, can and do play a most important part in normal life and well-being.]

### **The trace elements**

As well as the above-mentioned elements, traces of very many other elements, such as iron, manganese, copper, and a host of other, are always present in living matter. At first the presence of such small quantities of elements was considered as a form of contamination, as no known function could be assigned to them. But today many of these trace elements are known to play a part in biological reactions, and some are definitely known to be *essential nutrients*.

{ Page 6} Not all the elements present in plants or animals are essential for life. Silicon, which is present in macro quantities in maize,...is not. Maize can be grown quite well in its absence, but it is of value to the plant, as it contributes to its mechanical strength...{Page 7} (Therefore,) The fact that an element is present, or even that it exerts a beneficial influence upon development, does not (automatically) qualify it for the status of an essential element...

### **Essential minor elements**

Certain essential elements, such as zinc, molybdenum, etc., exert their influence at very low concentrations. They are absolutely essential for proper development and growth, yet they are required in very small quantities, and if present in excess can be poisonous. These substances must obviously play a different role in the organism than elements like phosphorus, nitrogen, or calcium, which are needed in much larger quantities. The

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<sup>1</sup> Synopsizer's paraphrase.

*macro-elements* or *major elements*, which are present in large quantities, are mainly constituents of proteins, cell walls, or mechanical structures...

The other essential elements which are present in minute quantities, the *trace elements*, or *micro-nutrients*, or *minor elements* (they have many names, but none of them is quite suitable for all purposes) cannot have important **structural** functions assigned to them. There is just too little of them to be present. Their role is primarily *catalytic*<sup>2</sup>, although not necessarily exclusively so... **catalytic systems...control the chemical processes of organism. Their absence can prevent important reactions from taking place, and hence result in abnormal development and even in death...**Nitrogen is a component of all enzyme systems that have been isolated, and magnesium, another essential major element, is also a catalytic element to a very large extent...

#### {Page 8} **Assessment of essentiality**

It is clear that certain elements occurring in low concentrations are essential for the life of plants and animals. Unfortunately, the quantities of the trace elements which different organisms require for normal development varies so considerably that **it is not possible to define trace elements in terms of the concentrations in which they occur.** Thus, Blue-green Algae require about 100 times the amount of molybdenum that Green Algae need.

It is more enlightening to discuss mineral elements in terms of their functions. ...*trace element* (is) used (hereinafter) in a restricted sense to denote elements with a nutritional role whose functions are catalytic, even if they occur in fairly large quantities...

{Page 9}...In order to discover if an element is really essential, it is necessary to study the growth and development of plants or animals, in the absence of the element being studied. **As plants can be grown in water solutions made of pure chemicals, it is easier to study them than animals...**As a consequence, more is known about the trace-element nutrition of plants...

#### {Page 10} **Experimental difficulties**

Trace elements are frequently required in such low concentrations that it is not always easy to prepare solutions lacking them. Even the purest of chemicals are not absolutely pure and always contain some traces of these elements as impurities.

#### **Biological reserves**

Another problem that confronts the investigator is that **all living matter contains trace elements. In seeds they tend to be present in larger quantities than in other plant tissues.** In humans and animals a similar state of affairs exists, and the fetus is usually rich in trace elements...

Because living matter is involved, it is impossible to obtain absolute deficiencies of any essential nutrient, as by definition, all essential elements must be present, even if at such a low level that no normal development is possible. This is an important point to grasp, because it means that *all deficiency conditions that occur are relative deficiencies.*

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<sup>2</sup> A catalyst is a substance which in minute amounts promotes chemical changes without itself being used up in the reaction to any marked extent....The most important catalysts in biological systems are organic ones termed *enzymes*...

{Page 11} ...trace-element deficiencies are not due to absolute shortages of elements, but are *induced deficiencies*, brought about by altering the beneficial ratio of various nutrients to each other. This results in *nutritional imbalance*, with dire consequences,...

## {Page 13} Chapter II Trace elements as catalysts

### **Catalysts and their characteristics**

...very small amounts of catalyst can bring about very large changes. For example, one molecule of the enzyme *catalase*, the biological catalyst that decomposes hydrogen peroxide, can promote the decomposition of 40,000 molecules of hydrogen peroxide per second at freezing point. Like most other materials, catalysts can wear out, and must be replaced...

It must be stressed that *catalysts do not initiate chemical reactions that cannot occur in their absence*. What they do is to speed up reactions that take place only very slowly without them...Catalysts promote many reactions by decreasing the activation energy required, and so promoting the chemical reaction, which takes place more readily.

### {Page 14} **Enzymes—organic catalysis**

...Büchner (in 1898) ... extracted some enzymes from yeast and showed that they were *non-living* organic compounds. This was important...Since the trace elements are important primarily because they are either parts of enzymes or influence them, it is necessary to have a clear,...knowledge of enzymes to appreciate the biological significance of trace minerals...

### **The composition of enzymes**

Enzymes are proteins...

### {Page 15} **Trace elements as activators**

...It seems likely that there are more trace-element activators than were previously suspected.

### {Page 16} **Effect of temperature on enzymes**

...heat inactivates and denatures enzymes.

### **Inactivation of enzyme systems**

Enzyme systems can be damaged by various poisons, especially heavy metals such as mercury, and they may be inhibited temporarily by a large number of chemicals, among them narcotics and anesthetics

*All living matter is replaced continuously*,...Enzymes are no exception to this and they are being broken down and replaced by new ones all the time, even before they are worn out. *These is a continued need for the raw materials* such as amino acids, from which new enzymes can be built.

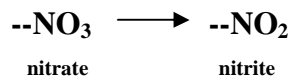
{Page 17} **Some important trace-element-containing enzyme systems**

While there are some two hundred trace-element-containing enzyme systems known (or systems influenced by trace elements), very little is known about some of these. While others do not play a very important part in major processes.

[six pages of tables illustrating]

{Page 23} **Nitrate reductase**

Molybdenum is a trace element required in minute quantities. In Australia, where molybdenum deficiency is very pronounced in some areas, only 2 oz. of molybdenum per acre (138 g per hectare) are required to make good this deficiency and restore normal growth of vegetation...(It is) a constituent of the enzyme *nitrate reductase*. This enzyme converts nitrates to nitrites.



[Even spraying the leaves with a solution of a molybdenum salt enables the plant to obtain molybdenum for its nitrate reductase]...

{Page 24} It is clear that molybdenum deficiency can seriously upset the nitrogen metabolism of the plant. If it is acute, clearly recognizable deficiency symptoms set in. In many plants, if the soil nitrate is replaced by other reduced forms of nitrogenous material, such as ammonium salts or nitrites, the need for molybdenum is not nearly so acute, and the plant continues protein synthesis fairly normally.

{Page 25} **Carbonic anhydrase**

(Carbonic anhydrase) is responsible for the rapid removal of carbon dioxide from the blood. [...the fact that zinc is a constituent is confirmed.] In its absence the carbon dioxide would accumulate and would slow up the entire respiratory process, because of the accumulation of 'waste' products....green plants need an efficient system to absorb carbon dioxide from the air in order to carry out photosynthesis...But carbon dioxide is present in very small amounts in the air; usually only about 0.03 per cent.

{Page 26} [Note that young leaves have an adequate supplies of zinc, even if grown in zinc-deficient substrate. These are derived from reserves in the seeds. (This is why younger plants often start out looking healthy and as they mature a bit, they start to die.) ...The general picture of zinc deficiency coupled with decreased carbonic anhydrase activity is quite clear.

**Xanthine oxidase**

An enzyme of great importance in animals...responsible for the final stages in of the formation of uric acid...that is eliminated via the kidneys in the urine (is *xanthine oxidase*)...In parts of New Zealand where soil molybdenum was very low serious sheep losses were experienced due to stones in the kidneys of sheep...In the near absence of molybdenum...inadequate supplies of xanthine oxidase (were present)...{Page 27} and xanthine was precipitated in the kidneys instead of eliminated, with fatal results.

## **Oxidases**

The oxidases are a group of enzymes which promote oxidative processes. Of which there are a large number in living matter. They transfer hydrogen or electrons directly to oxygen as a rule, and are of great importance, especially in respiratory processes, where they are responsible for the ultimate oxidation of the organic matter being broken down. Of these the cytochrome oxidases, many of which contain *iron* in their prosthetic groups, have been known for a long time.

### **{Page 29} Phosphorous compounds in respiration**

In respiration the main energy transfers are carried out through various organic phosphorous compounds, especially *adenosine triphosphate (ATP)*, *adenosine diphosphate (ADP)*, and *diphosphopyridine nucleotide (DPN)*.

The compounds are influenced by molybdenum, selenium, chromium, and tungsten,...

### **{Page 32} Non-enzymatic catalysis by trace-element ions**

...metal ions can function as catalysts on their own, without being associated with enzyme functions.

Krebs showed that aluminum ( $Al^{+++}$ ), iron ( $Fe^{++}$  and  $Fe^{+++}$ ) and copper ( $Cu^{++}$ ) are active in decarboxylating oxaloacetic acid, an important constituent of the respiratory cycle.

### **{Page 33} The importance of trace elements in enzyme systems**

The entire physiology of the organisms is dependent upon the biochemical changes that occur within the cells. The vast number of chemical reactions which take place in these microscopic cells are regulated by the **2000 or more different enzymes present in each of these cells**...Around all the macro-molecular structures in the living cell hovers a cloud of metal ions, jostling for position on the surface of the large molecules and according to their numbers and characters, in the case of enzymes, helping or hindering the movement of molecules—substrates or products—to and fro.

### **{Page 35} Chapter III Deficiency and excess**

#### **Historical background**

It must be stressed that trace-element deficiencies are widespread, and have been known from the earliest historic times. Their causes were not understood, but the conditions were recognized, and in some cases successfully treated.

For instance, simple iron deficiency anemia was known in Roman times, and was treated with dilute iron salt solutions, as it is today...Simple iron-deficiency anemia is still a serious health problem, and is very widespread.

Simple goiter is so widespread that in many parts of the world the slight swelling at the base of the throat, which is found in mild cases, is not even recognized as abnormal. It is also very widespread in animals....Yet 2000 years ago the Greeks treated this condition quite successfully by giving sufferers the ash of sponges to eat. This

material is very rich in iodine, and so helped to cure the goiter, which is an iodine-deficiency disease. Thus, a knowledge of modern chemistry was not necessary therapeutically to treat this condition. In fact, it was only within the last century that goiter was recognized to be a disturbance of iodine metabolism.

{Page 36}...What is the cause of (diarrhea) “scours”? Today we know that it is due to too high a level of molybdenum in the vegetation, which *induces* a relative copper deficiency. Cattle and sheep favor a marked copper requirement, while that of horses is much lower...The scours can be cured by giving the animals extra copper, and when their copper requirements are met they can thrive on such pastures (‘i.e., ‘teart’ pastures in England.)

In parts of the mid-west USA large areas are quite unsuited for raising stock because of chronic selenium poisoning termed ‘alkali disease’...

{Page 37} Just as these trace-element deficiencies and excesses are known in man and the animals, so they are well known in plants as well. ‘Brown rot’...and ‘heart rot’ in sugar beet are caused by boron deficiency; ‘little leaf’ of citrus and deciduous fruit is a zinc deficiency; ‘gray speck’ of oats and ‘marsh spot’ of beans are due to inadequate supplies of available manganese; and ‘whip tail’ in cauliflower is a molybdenum deficiency...only within the last thirty years ...the causes of these conditions have been identified (i.e., since about 1950).

#### {Page 39} **The new era in trace-element nutrition**

... fluorine toxicity is recorded in all five continents.

#### {Page 40} **Variability of requirement**

...horses will flourish on ‘teart’ lands, where cattle and sheep pine and die. It is certainly true that domestic ruminants have a higher copper requirement than horses, but it is not true of all ruminants. In Africa, where extensive areas of copper-deficient pastures are found as on the Kwango Plateau of the Republic of the Congo, on which domestic cattle die, buck and local wild ruminant thrive. They are obviously adapted to these conditions, or they would not have survived. Adapted vegetation is all found. This adaptation is a phenomenon to which a few words must be devoted.

#### **Adaptation to unbalanced nutritional conditions**

In plants, as in animals, there is a very wide range of requirements even between closely related forms. The manganese requirements of oats are higher than those for either barley or wheat, and so ‘grayspeck’ in oats, a manganese deficiency, is well known while its equivalent in the others is not nearly so common. Wild cereals flourish where domestic ones cannot survive.

This is certainly true of the copper-deficient North German Plain, a region stretching from Holland to Russia...

This ability to absorb copper rapidly is obviously genetically determined. Studies of grasses adapted to grow on ore dumps show that some members of a given species may be ‘tolerant’ to very high levels of lead, zinc, nickel, etc., in the soil, while other plants of the same species just cannot develop normally on these poisoned soils.

### {Page 41} **Interaction of elements**

The fact that deficiencies and excesses of elements occur might lead one to conclude that an absolutely fixed minimum and maximum level for any element might be established in a given organism. (In fact,) every element in a nutrient solution influences the others, and a balance must be maintained between all nutrients, if healthy, efficient growth is to take place. Mulder's Interaction Chart shows this relationship between the elements very clearly.

{Page 42}...an organism's requirements are influenced by a host of factors besides its genetical constitution...It is quite obvious that increasing concentrations of manganese depress the iron content of the soybean plants. The higher substrate level of the iron, the more marked is the depression. There is a clear-cut antagonism between the iron and manganese, which can influence the mineral composition of the plant to a very considerable extent.

An iron:manganese ratio of about 2:0 is found in normal plants...Mulder's Interaction Chart...depicts typical responses in plants...high levels of phosphorus in the soil will antagonize both copper and zinc uptake or use. The plant will require larger quantities of these nutrients if it is to remain normal...

{Page 43}... Induced deficiencies are widespread and constitute a serious agricultural problem...

For normal development, a *balanced* nutrition is essential. If there is too little or too much of any given nutrient, then this balance is upset, and either deficiency or toxicity symptoms of some sort will develop, for these symptoms clearly demonstrate the presence of disequilibrium, or *imbalance*, in the nutrition...the fact that the balance of nutrients is the important factor in normal development precludes absolute levels being established.

### {Page 44} Chapter IV Yields in relation to trace elements

#### **Essential nutrients and yields**

The fact that the yields of crops, and the size and vigor of animals are dependent on their nutrition is well known, and is the basis of the practice of fertilizing agricultural land and of supplying supplementary feeding to animals.

As trace elements are essential nutrients, ... hence their relative deficiency or excess can potentially influence optimal development to a considerable extent. That this is actually the case, and the trace elements are in fact the *limiting factor in determining yield size in many places is quite clear*...

Liebig's law of the Minimum makes it clear that the rate of growth and development is controlled by the nutrient in *relative* minimum, while Voisin stresses the growth inhibition caused by *excess*...Trace elements are not a novel cure-all, (but) they must be seen as part of the general problem of mineral nutrition.

{Page 46} **Increase of Plant Yield by trace-element applications**

Experimentally, it can be demonstrated very clearly that trace element {deficiencies} can limit yields. [A fruit farm in Cape Province, South Africa with adequate soil applications of NPK, became 'worn out'. Yields remained consistently low. Sprays of zinc and manganese compounds caused marked increases in yield of apples and pears.] {Page 47} Simply by curing these deficiencies the fruit production rose from 6,000 to 26,000 boxes within four years. [It is worth noting that it can take more than one season to obtain the full benefit results of spraying. {Page 46}]

{Page 47} **Other crop yield data**

In Australia molybdenum deficiency is widely linked with phosphorus and sulphur deficiency. *Until these deficiencies were cured by application of fertilizers to the soil the addition of molybdenum to the crop had hardly any effect. It cannot promote growth if other mineral nutrients are deficient and limiting growth;* but when the major nutrients were supplied in adequate quantity, then the application of 2 oz. of molybdenum per acre increased the yield of annual subterranean clover from 829 to 1,5223 lb./acre of dry matter (930 – 1,687 kg./ha.)

{Page 48}

(Partial) **Table 9**

**Potential crop improvements in Waitaki County, New Zealand, by use of molybdenum fertilizers**

<b>CROP AND SOIL</b>	<b>CONTROL, NO MOLYBDENUM</b>	<b>YIELDS WITH MOLYBDENUM</b>	<b>% INCREASE</b>
Lucerne on sandstone soil	3,060	13,920	353
Lucerne on clay soil	13,664	19,488	43

...even in Holland which is generally recognized as the most progressive agricultural country in Europe, [Lehr 1956] claims that 50 percent of the land is potentially deficient in trace elements.

{Page 51} **Latent trace-element deficiencies**

The widespread distribution of trace-element deficiencies is not generally recognized, even by man investigators, because too much stress has been laid on visual clinical symptoms, such as chlorosis of the leaves or abnormal growth. These symptoms are of the greatest value in indicating the presence of nutritional deficiencies, *but it must be appreciated that not all deficient plants show them.* Deficiencies not acute enough to show visual signs may be severe enough to halve the potential yield.

{Page 53} **Animal growth and trace elements**

What has been written about plants applies equally to animals although less accurate information is available.

...*The influence of cobalt upon the live weight of sheep...*

This element, which is {Page 54} not essential for plants as far as we know, is very important I animals, particularly ruminants. It is required in very small quantities. The deficient sheep were very unthrifty, but the application of cobalt to the soil, and hence to the herbage, resulted in almost doubling of the body weight of full grown sheep. [Hopkirk and Patterson]

Zinc promotes growth in young growing pigs...

Copper is an element that plays an important part in pig farms....too high a level definitely {Page 55} inhibits growth, while low concentrations stimulate it. [Barber et al 1957]..a high calcium content in the diet increased the requirement for zinc. Calcium *antagonizes* zinc in the diet.

The effect of oral selenium supplementation is strikingly obvious in the Aberdeen-Angus calves studied by [Hartley 1961]. In less than a year the animals receiving selenium weighed over a third more than the controls not supplied with this element.

### **Induced trace-element deficiency in animals**

...molybdenum *antagonizes* the copper, and so in practice, copper {Page 56} injections to raise the copper level of the stock to an adequate level do in fact combat the high level of the molybdenum in the herbage, and enable the animals to feed on it and thrive.

In rats sulfide increases the antagonistic effect of molybdenum.

([Grashuis 1961] {Page 57} demonstrated that) a manganese deficiency (seriously disturbed) the reproductive cycle of cows.

{Page 58} Overliming is the commonest cause of induced trace-element deficiency. The drop in pH caused by this practice results in all the trace elements except molybdenum being made less available to plants. Excess potash fertilization results in an induced boron deficiency. As a result, crops receiving heavy potash fertilization have a higher boron requirement, and unless this can be met ... soil deficiencies must result. In some states of the USA boron is added to the potash fertilizer to meet this extra need.

{Page 60}...Dairy cows in milk require from 2 to 20 mg iodine per day, depending on the milk production, while other cattle only need 1 to 5 mg iodine daily. Lack of this decreases milk yield...milk yield is related to the blood-serum copper content, and that the lower the serum copper, the lower the yield. [Deijs et al 1955].

## Chapter V Quality of plant and animal products in relation to trace-element nutrition.

{Page 62} Another aspect of these micro nutrient elements is the very considerable effect that they can exert upon quality...Unfortunately, quality is a difficult concept to define accurately, and it is seldom used in scientific work

### Taste

Manganese deficiency gives a very unpleasant taste to potatoes. Boron deficiency in turnips gives a bad taste to the roots...Deficiencies of this element also result in 'corky pit' disease of apples...in oranges lack of boron results in thickened rind with discolored patches.

{Page 63} More than 1.5 ppm copper in milk rapidly gives rise to a rancid tallowy taste, although lower concentration of 0.2- 0.5 ppm are compatible with good keeping quality [Underwood 1956]. Copper levels of over 2.0 ppm give cheddar cheese a very metallic flavor [Stine et al 1953].

Biological quality of foods

A very important aspect of crops is their food value, and this is not readily determined by simply inspecting and tasting materials. The mineral and vitamin content, the amount and nature of the carbohydrates, fats, and proteins all contribute to the nutritional value of crops as foods, but the determination of these must be undertaken in the laboratory.

Mineral content

As has been mentioned, the mineral content of plants and animals varies considerably. There are marked differences between species based upon genetically determined differences in requirements. Even within a species, the genetically determined differences can be very {Page 64} large as **Table 11** shows. The sixteen varieties of wheat tested showed a range of copper contents from 5.6 – 16.7 ppm ...

**TABLE 11**

*Variation in the copper content of different varieties of wheat grain grown on the same soil. [...Greaves and Anderson 1936]*

VARIETY OF WHEAT	PPM COPPER IN GRAIN
Montana 36	17.7
Kubanka	16.4
Turkey 926	13.9
Tenmarq	12.3
Kharkov Hayes 2	11.8
Newturk	11.0
Regal	9.4
Early Baart	9.3
Karamont	7.8
Black Hull	7.6
Hard Federation	7.4
Marquis	7.0
Kofod	6.5
Alton	6.4
Chul	5.9
Kofod x Turkey	5.6

{Page 66} **Vitamins**

The fact that trace elements have a marked effect upon the vitamin content of vegetation is not as widely appreciated as it should be. (This) is of considerable practical importance, (since)...vitamin deficiencies are still widespread in both humans and animals.

{Page 67} Manganese with the trace elements copper and zinc, or with macro-elements NPK, increases the carotene content considerably...manganese dressings lowered the choline (one of the Vitamin B complex) and increased the tocopherol (Vitamin E) level.

{Page 68} **The vitamins of the B-complex are also influenced by trace elements.** Boron levels influence the thiamine and niacin levels in turnip greens...[**Lyon and Beeson 1948**] {Page 69} Manganese decreased the choline content of soybean leaves, although it promotes Vitamin E (tocopherol) as well as carotene synthesis [**Burger and Hauge 1951**].

More is known about Vitamin C (ascorbic acid) than about the other vitamins. The addition of copper to deficient barley ...and oats, and *autumn-growth* spinach increases their Vitamin C content, but for some unknown reason does not do this in either tomatoes or *spring-grown* spinach [**Lucus 1948**]. Manganese appear to influence this vitamin very considerably in certain fruits [**Von Bronsart 1950**].., but once again **too high levels of manganese result in a decrease in vitamin content**...Boron depresses this vitamin in turnip greens.

This relationship between trace elements and vitamins is not confined to plants, but less is known about it in animals...

#### {Page 69} **Amino Acids**

Another aspect of biological quality that is of very great importance is the amino-acid content of foods. Human beings as well as animals have a very definite amino-acid requirement. The body cannot synthesize certain of these amino acids from raw materials, and is thus dependent upon outside sources for these essential amino acids...

Proteins and their breakdowns are the main source of amino acids, as they are composed of chains of various amino acids linked together. Hence, if a protein is relatively poor in an essential amino acid, as the maize protein zein is in lysine, or many legume proteins are in methionine, its nutritional value must be low. As a {Page 70} result of this, there is a very wide range in the food value of different proteins.

It has been shown conclusively that fertilizers do influence both the protein content and the protein composition in plants. It is also known that the trace elements do play an important part in determining the amino-acid composition in plant proteins...

[**Koehler and Albrecht 1953**], in a very informative experiment clearly demonstrated the enhanced nutritional value of Lucerne fertilized with trace elements and magnesium by feeding this to rabbits. The application of trace elements, or of magnesium on its own, did not improve the nutritional quality as measured by weight gains of rabbits, but when combined they gave an increase of about 15 per cent...

#### {Page 71} **Wool**

Wool is another protein that is influenced by trace elements...copper deficiency in the diet results in 'steely' wool...{Page 72} This wool is coarse and has very little 'crimp'..., i.e., the tight wavy pattern that characterizes good wool. Within 24 hours of being supplied with adequate copper the nature of the wool changes, and good 'crimpy' wool is again produced (Figure 28).

### {Page 73} **Fat**

In animals, such as pigs, produced for meat, body weight is not the only important factor. A fat pig gives fatty bacon and ham, which is not popular with housewives. A good bacon is a lean one. Hence in pig breeding, while large and heavy animals are desirable, fat ones are not, as they give rise to ...low-quality produce.

It is of interest that manganese deficiency does, in fact, give rise to fat pigs. The animals are excessively fat, have reduced body length and height, and shorter legs than comparable animals fed manganese at a level of 40 ppm in their diet [Plumlee et al 1956] ...The lean animals have a higher market value.

### **Goitrogenic milk**

...plants of the cabbage family contain *goitrogenic* substances which can induce goiter if the level of iodine in the diet is not fairly high. (...Goitrogens may pass through the milk of a cow, increasing the iodine requirement of children...) [Greer 1960]...Iodine fertilization can increase the iodine content of the milk, and so counteract the baneful effect of the goitrogens.

### {Page 75} **Egg quality**

...The less (breakability of a hen's egg) is determined, among other things, by the level of manganese in the diet...The breaking strength of eggs rose from an average of (6.6 to 9.3 lbs. when hens manganese intake increased from 6.5ppm to 100 ppm.) Calcium and phosphorus in the diet antagonizes the manganese in the diet and increases the animal's requirement of the latter.

Manganese is found mainly in the yolk. Like many embryonic structures, the egg accumulates high levels of trace elements, and these often reflect the parental diet...

The hatchability of eggs is obviously of importance in chick raising and iodine has been found to play an important part in determining this quality. Deficiency of this element results in an increase in the length of incubation and also in a large increase in the number of dead embryos...{Page 76} (Eggs with sufficient iodine showed a 90% hatch rate by the 21<sup>st</sup> day compared to deficient eggs in which 40% hatched significantly later. [Rogler 1959].

### {Page 77} **Fermentations**

In crops such as tea the weight of the harvest is not the only consideration, as the leaves have to be fermented before they give rise to the product that is sold commercially as tea. And the fermentation is of the utmost importance in determining the quality of the tea produced. Work in Ceylon has shown that the fermentation of black tea does not proceed properly unless the tea leaves contain at least 15 ppm copper. [Ramaswamy 1960]

...(a similar situation exists with cocoa leaf harvesting...[Hewitt 1950] )

### **Alkaloids**

(Alkaloids are the by-products of slightly unusual cellular processes.) In fact, the concentration of one of these alkaloids, nicotine, has been found to be very closely linked to soil boron levels in tobacco plants...boron deficiency results in over a five-fold increase in nicotine content....{Page 79} (Boron also has an influence upon celery fibers.)

{Page 80} CHAPTER VI NORMAL AND ABNORMAL ANATOMY ASSOCIATED WITH TRACE ELEMENTS

The term trace element can be misleading, at times. It may give the impression that these elements are not as important as the major elements. Nowhere is the falsity of this impression more obviously evident than in the study of the anatomical implications of these minor elements. As they are essential, their absence or presence exert a tremendous influence; just as great as that of the major elements. It must be stressed that trace or minor only refers to the concentrations at which they are effective and not to their effect. This can be very clearly seen in the marked anatomical variations caused by or linked to pathological conditions associated with trace element imbalance.

**Balanced nutrition**

Nutrition is known to have a very pronounced influence upon the appearance and behavior of man, animals, and plants...*Balanced nutrition* can occur at various levels, and sparse diets are not necessarily deficient ones, although they often are.

**Plant abnormalities**

*Whip-Tail in cauliflower.* (This occurs if the cauliflower is deficient in molybdenum.)

{Page 81} **Zinc deficiencies**

Zinc deficiencies also result in very abnormal growth. "Little leaf" and "rosette" are conditions found in both deciduous and citrus fruit trees, as a result of zinc deficiency. The shoots of the trees give rise to {Page 82} very small pointed leaves, in contrast to large flat ones...{Page 83} (...Zinc-deficient leaves exhibit a large percentage of non-functional stomata...)

Boron deficiencies

In celery, a plant with very pronounced boron requirements, a deficiency results in abnormal cells developing just behind the true meristems. These cells tend to be larger than normal, and they collapse and die, giving rise to the so-called necrotic or dead zones just behind the growing tips. In sugar beet, these necrotic regions are extensive and give rise to the characteristic 'crown rot' which forms a large necrotic hollow region inside the stem and root {Page 84}....(boron deficiency in cauliflower may result in the breakdown of the central stem tissue and browning.)

{Page 85} **Cell alterations**

These abnormalities resulting from boron deficiencies must be associated with marked alterations in the cells themselves. [Reed 1947].the nature of the cell protoplasm is altered, and the presence of phenolic substances can be demonstrated...investigations of the olive plant show that phloem, the vascular tissue that conducts the bulk of the plant's organic nutrient, disintegrate rapidly when boron deficiency is experienced.. both the sieve tubes and the companion cells vacuolated prematurely and disrupt their contents; then they become filled with a dark viscous melanotic material which prevents the sieve tubes from carrying out their normal role in the translocation of sugars and amino acids.

...{Page 86} In maize lack of boron results in ears without either stamens or stigma.

### Lodging of cereals

Lodging, i.e., plants lying on the ground instead of standing vertically, is a condition in cereals that causes great economic loss, as it makes harvesting difficult, if not impossible and if the soil is wet, promotes {Page 87} fungal infection...the investigations which show that copper and manganese prevent lodging...are of real practical consequence in agriculture.

Russian scientists [Polukhina and Masljanaja 1961] have shown that copper influences the vascular anatomy of oats. Increasing the copper content gives rise to a vascular distribution that tends to prevent lodging.

### {Page 89} **Abnormalities in man and animals**

(Chicks receiving a mere 10 ppm manganese in their diet showed a pronounced thickening and shortening of bones due to this deficiency compared to healthy chicks receiving 50 ppm.) Unfortunately, although imbalances in humans, and to a lesser extent animals, are of greater interest to most people, accurate information concerning the role of trace elements is not very plentiful, except perhaps in the case of iodine...

### {Page 90} **(More) Bone abnormalities**

In poultry the disease termed *perosis* or 'slipped tendon' [Underwood 1956]...is caused by (the) lack of manganese. (With this condition) the Achilles tendon frequently slips out of place and...the animals in extreme cases walk on their hocks...) Manganese deficiency in rabbits result in gross deformity of the front legs.

{Page 91} Manganese deficiency leads to a reduced calcification of the bones and to many characteristic changes within the bones themselves. In dogs a very similar condition, in which the legs are very bowed and the flat-footed appearance is found, can be caused by copper deficiency.... Both manganese and copper deficiency lead to reduced calcium in the bones, but for completely different physiological reasons.

Elements such as vanadium and strontium have been recorded as {Page 92} having a marked stimulatory influence upon the mineralization of bones and teeth in animals. The incidence of caries was higher in animals deficient in these elements than in controls [Nason 1958].

{Page 93} It has been shown ... that molybdenum reduces the incidence of caries in experimental rats [Stookey et al 1962]...The observation made in New Zealand that children eating vegetables from the molybdenum-rich Napier area had fewer caries than those fed on vegetable from other areas, such as Hastings, is in complete agreement with these findings.

Fluorine is a very toxic element...and fluorine toxicity or fluorosis is found in many parts of the world, where both stock and man are affected. In mild cases excess fluorine leads to a characteristic mottling of the teeth, which tends to be more unsightly than dangerous, as the teeth themselves remain functional. The enamel is abnormally thin in places, pitted, and lacks the luster and translucence of normal enamel. This

condition is found in Mecca [**Anon 1959**], as well as many other parts of the world where the fluorine content of the drinking water is high. Even in countries like Britain, widespread mottling of the teeth has been recorded.

{Page 95} **Nerve and muscular abnormalities.**

A number of conditions involving muscular or nerve abnormalities are known which are linked to trace-element imbalances. In swine iron deficiency was reported to result in a 50 per cent increase in heart weight relative to body weight, while copper deficiency resulted in a 200 per cent increase. Deficiency of copper in the diet of either cattle or sheep results in animals which cannot co-ordinate the movement of their limbs properly. This results in a staggering gait, and usually in a swaying of the hind-quarters, which gives the name 'swayback' to this condition (Figure 42).

{Page 96} The fact that selenium is a very beneficial element and probably an essential one has already been made (Chapter IV), and that excess of it results in Alkali Disease...with its distressing foot malformations. Selenium is a component of Factor 3, a substance that prevents liver necrosis in rats [**Schwarz and Foltz 1957**]. A congenital condition in lambs termed 'White Muscle Disease' was found to respond to selenium. In this disease muscular dystrophy results in white or grayish areas of degenerated muscle fibers, which are limited in extent and give white patches in the meat. This obviously impairs muscular function, and often result in lameness. [**Anon 1961**] Injection of Vitamin E (•-tocopherol) or of selenium prevent this condition, while ewes in late pregnancy, if injected with selenium, had a marked decrease in deaths caused by this disease in their lambs.

{Page 98} Animals (also) suffer extensively from goiter. The symptoms are similar to those of human goiter.

{Page 99} Cellular changes precede the gross anatomical changes, and there is a decrease in stainable colloids in the cell vacuoles...Goiter is very widespread among all kinds of animals, and can cause sever economic problems in parts of the world.

{Page 100} However, it must not be supposed that all goiters are simple iodine deficiencies, for they are not (see Chapter VIII).

### **Anemia**

It is not generally appreciated that iron-deficiency anemia is responsible not only for the facial pallor it produces, but in severe cases also can bring about or be associated with the formation of spoon-shaped fingernails, roughness of the tongue and cracking of the edge of the mouth...

It is clear, from these examples cited here, that trace elements can and do play a great part in anatomical development. They show clearly how essential mineral elements are necessary for normal growth and normal functioning, as any imbalance results in abnormal development.

{Page 101} CHAPTER VII THE ROLE OF TRACE ELEMENTS IN REPRODUCTION AND SOME OTHER PHYSIOLOGICAL PRECESSES

The micro elements play a very important part in reproductive processes in all forms of life, and the consequences of imbalances are truly spectacular.

**Micro-organisms and fungi**

Simple bacteria and fungi require trace elements as well as other nutrients for their normal development.

The mould fungus *Asperigillus niger* is a test organism that has been studied intensively, and that is, in fact, used for microbiological assays of trace elements [Mulder 1954].

In the bacterium *Azobacter chroococcum* the normal black pigment does not develop in the absence of copper.

{Page 102} **Seed and fruit production**

The important part that micro nutrients play in the reproduction of higher plants is often seen by the marked decrease in grain yields of cereals and fruit yields when deficiencies occur. For instance, in the manganese deficiency of oats called 'Gray Speck' there are usually many 'blind heads' that is to say, flowers that have not set seeds...Copper deficiency in many crops results in a marked reduction in generative development, although the vegetative growth need not be disturbed to anything like the same extent [Rademacher 1940].

Clearly, reproduction can involve a variety of biochemical processes, any of which can result in the decreased production of viable seed or of fruit formation. (The work of) [Reed 1942] makes it quite clear that much higher levels of zinc are required for seed production than for vegetative growth.

{Page 103} As far as the fertilization process is concerned, it has been known for a long time that boron is necessary for the proper germination of many pollens [Gauch and Duggar 1954] In the absence of boron the pollen tubes burst, or become so distorted that male gametes are either not formed or that sexual fusion is impossible.

**Animal reproduction**

In animals more information about the influence of trace elements on reproduction is available than in plants. (Several elemental) imbalances result in well-known reproductive failures.

**Iodine in mammalian reproduction**

The widespread deficiency of iodine in farm animals gives rise to much infertility. (Still born, or weak and hairless offspring are classical examples of lack of parental iodine.) (Without iodine the production of the hormone thyrozone is impaired resulting not only in the connected symptoms of cretinism, but impaired sexual vigor, delayed maturation of genitalia and often, sterility.)

{Page 104} in the field, cows on iodine-fertilized pastures had stronger heat and were more fertile, conceiving in fewer copulations per conception, than those of normal pastures. Their milk yields were also higher [Sharrer and Schwaibold 1933]...In birds iodine deficiency can result in longer incubation periods, with higher percentages of dead embryos

In humans the greatest iodine requirements appear to be linked to the phase of sexual development in females.

### **Manganese and reproduction**

Manganese has a marked influence upon both male and female animals. In male rabbits and rats deficiency leads to a lack of libido...it is also accompanied by a marked testicular degeneration...

In cattle manganese levels are certainly an index of fertility, and deficient heifers are slower in showing estrus and in conceiving than normal ones.

Manganese content of cattle hair can be used as a gauge of the {Page 107} manganese status of the animal. In Hanover animals with a hair content of less or more than 10-20 ppm manganese had decreased fertility [Allcroft 1959].

### **Copper and reproduction**

Copper is another element that plays an important part in reproduction. The fact that low levels of copper are associated with poor growth and retarded milk production...constitute serious agronomic problems. But copper deficiency also results in impaired fertility in cattle. [Grashuis 1961, Van Koetsveld 1958]...It appears as if the copper deficiency restricts the rapidly growing embryonic tissues much more severely than the more mature maternal tissues.

### **{Page 108} Zinc in mammalian reproduction**

Zinc is an element that is present in fairly large quantities in mammals, being about half the concentration of iron and considerably more than that of such elements as copper...

In reproduction zinc is particularly associated with the testicles and sperm, and in experimental rats a deficiency leads to irreversible atrophy of the testes, and hence sterility in the male [Miller et al 1954].

### **Trace elements in reproduction**

The general picture that emerges from an investigation of the part played by micro nutrient in reproduction is that they are important in many phases of this process...{Page 109} The link between trace elements and normal reproduction is obviously a very strong one.

## **{Page 110} CHAPTER VIII HEALTH AND DISEASE AS A FUNCTION OF TRACE ELEMENT LEVELS**

The fact that disturbed trace-element nutrition can result in appreciable anatomical abnormalities...has already been discussed in Chapter VI. But other differences between

healthy and diseased organisms, particularly biochemical ones, may be equally striking, and of great importance...

...Antagonisms among elements lead to an altered mineral requirement.

It is not always appreciated that in plants it is not easy to determine health. Vigorous growth is only one criterion, and it can exist in plants that are susceptible to infections, or cold, or drought. Yet this susceptibility must also be regarded as an absence of complete health...and healthy (plants) can resist (these influences) to a considerable extent.

### **Chlorosis**

...In most higher plants the leaves of healthy individuals are a uniform fairly dark-green color (due to the green pigment chlorophyll). How {Page111} ever, in mineral deficiencies, and to some extent in excesses, this uniform pigmentation is upset, and the leaves may be pale green with dark-green veins, or only the inner part of the leaf may be pigmented, etc. A large number of pigmentation patterns are known. The uneven pigmentation is known as *chlorosis*... Chlorophylls are similar to such substances as hemoglobins, except that they contain magnesium instead of iron in their molecules.

Severe *chlorosis* leads to decreased photosynthesis, and hence to impaired growth...Boron, influences photosynthesis by regulating the rate of sugar translocation from the cells involved [Gauch and Duggar 1954].

### **Iron in mammals**

The varying need of organisms for different mineral nutrient can be well exemplified by reference to iron, and to a lesser extent copper, in mammals and particularly in humans.

{Page 112} In normal healthy humans there is a considerable store of iron, especially in the liver, which is the main storage organ, and in the blood, which has a large quantity in the red iron-containing respiratory pigment, hemoglobin... (However), humans seldom absorb more than 10 % of the iron in food.

As piglets grow very rapidly (twice as fast as calves), {Page 113} the low iron content of milk is not sufficient for normal development, and they develop 'thumps', an anemia associated with very labored breathing, which is frequently lethal. On open pastures these animals would meet their iron requirements by rooting around, but in pens their iron requirements frequently must be met by such procedures as injection of iron salts [Underwood 1956].

### **Differences in iron requirements between sexes**

{Page114} During their fertile years women lose on an average of 200 mg iron per annum through their menstrual flow. In pregnancy,...the growth of the fetus and its associated structures are a heavy drain on iron, and parturition involves a loss of about 350-450 mg iron. It is not surprising that nutritional anemias are more frequent in women than in men.

### **Copper in mammals**

Copper is normally present in much lower concentrations than iron, and in man is present at about 1/10 the concentration of non-hemoglobin iron. Just as with iron, new-born infants have a much higher level of copper than adults do.

Human milk (and other milks) are poor sources of copper, and copper content decreases with the length of lactation.

{Page 115} (Curiously, serum copper increases with the onslaught) of many diseases and infections, including the common cold...

(Consequently)..., blood copper is not a reliable index, but liver biopsies can be undertaken in living animals [**Van Der Grift 1955**]. As the liver is the main store for copper, and its copper levels are not subject to sudden and rapid fluctuations, this is a very valuable technique.

### **{Page 116} Anemia and hemopoiesis**

Both copper and iron play an important part in anemia...Cobalt, which is a constituent of Vitamin B also plays an important role (in blood formation.)

{Page 117} The beneficial influence of vanadium upon hemopoiesis is stressed by Trummert and Boehm, and it is of real value in the treatment of anemias. In rabbits its application doubles reticulosis. Certainly, mixtures of vanadium, cobalt, and copper have a very stimulating effect upon red blood-cell formation in blood [**Trummert and Boehm 1957**].

### **Goiter and upset iodine metabolism**

...iodine does not cure all goiters, so the etiology of goiter, although it is undoubtedly affected by iodine supplies, must be more complex.

Goiter may be absent in areas low in iodine and still persist in areas with adequate iodine, or where iodine supplementation is practiced...{Page 118} The thiocyanates in the brassicas (*CRUCIFERAE*-cabbage family), thiourea, excess calcium, and sulphonamides all act as goitrogenic factors in the diet, while high levels of the halogens, chlorine, bromine, or fluorine may induce goiter by stimulating the excretion of iodine from the body.

Heavy doses of iodine have been reported to cause goiter [**Burrows et al 1960**]...

Adequate supplies of copper appear to be necessary for the utilization of iodine...

Cobalt is an element that also plays a part in thyroid metabolism.

The fact that goiter is common in pregnant women has been discussed in the last chapter, as was the fact that lack of thyroid activity reduces the reproductive ability of man and animals. Lack of Vitamin B<sub>12</sub> also leads to reproductive failure.

### **{Page 120} Cancer and trace elements**

Trace elements appear to play some part in cancer. It is quite certain that in man the trace-element distribution is disturbed as a consequence of this disease.

... in his study on cancer and soil [**Voisin 1959**], lays great stress on the important role that copper may play in cancer. It is interesting {Page 121} that Kiederling (*sic*), working from clinical data, came to a similar conclusion quite independently [**Keiderling and Scharpf 1953**].

...some trace elements have on occasion been shown to exert an inhibiting influence on cancer development. Thus, manganese malate inhibits new growths of tumors in rats and mice. [**Bach and Banga 1957**]. Other workers have shown that copper compounds can have an inhibiting effect on tumor formation [**Takamiya 1960, Howell 1959**]. ...in his book on cancer [**Bergel 1961**] points to the beneficial therapeutic action of vanadium in certain kinds of cancer.

Further investigations have revealed that not only organic matter but zinc, cobalt, and chromium levels in the soils are positively related to stomach cancer [**Stocks and Davis 1960**]....In south Africa, esophageal cancer is not uniformly distributed, (but) 89 per cent of the cancerous regions are ground on poor soils derived from Beaufort sedimentary rocks. On the other hand, 64 per cent of the of the completely cancer-free sites were on rich soils derived from igneous dolerite. It looks as if poor soils produce food that is progressively less nutritious as a result of soil impoverishment; this may play a part in carcinogenesis.

{Page 122}...iodine supplementation has been claimed to lower the incidence...of thyroid carcinoma [**Wespi and Eggberger 1961**].

(...Maps [**Legon 1952**] of Wales) show the non-uniform distribution of stomach cancer...There is a correlation between cancer and high organic matter in the soil...

In this case the high soil organic matter may induce a copper deficiency in the soil [**Voisin 1959**]...the implications of this...) leave little doubt that trace elements do play a part in the development of, as well as the resistance to, this lethal disease.

### **Environmentally linked diseases**

{Page 123} In North-West Kazakhstan high levels of boron in the soil produce enteritis in 3.5 % of the sheep and some of the children of this area...

#### **Arteriosclerosis (*Atherosclerosis*) and cholesterol**

The fact that vanadium can inhibit cholesterol synthesis is thus of great practical interest [**Anon 1960**]

{Page 124} In a group of normal healthy young men ...treatment with vanadium resulted in small but significant lowering of the serum cholesterol [**Curran et al 1959**].

### **Hypertension**

Another contemporary health problem is the widespread existence of hypertensive states. Manganese appears to play an important part in these conditions [**Cotzias 1958**].

#### **{Page 125} Diabetes and zinc**

That a relationship exists between insulin and zinc has been known since it was shown that zinc combines with insulin to form crystalline insulin [**Scott and Fisher 1935**]. Further work showed the relationship between insulin and zinc in the bovine pancreas, the organ which is responsible for insulin synthesis [**Scott and Fisher 1938**].

Studies show that zinc and insulin fluctuate in a similar way in experimentally produced diabetes, and substances that reduce the zinc content of the pancreas are, in fact, diabetogenic [**Kodata 1950**].

...Lucerne is rich in manganese, and it was shown experimentally that drinks of manganese chloride solutions, but not of sodium, magnesium, cobalt, iron, or zinc salts. Brought about (a) dramatic drop in blood sugar [**Rubenstein et al 1962**].

#### *Phalaris* staggers

A condition in cattle and sheep termed 'Phalaris staggers' is of interest, as it shows the need for cobalt as a detoxicant. Animals grazing on pastures of the grass *Phalaris tuberosa* growing on cobalt-deficient soils, suffered from muscular tremors, incoordination, rapid breathing, and pounding of the heart. This disease could be prevented by oral administration of cobalt, or by applying it as a top dressing to the pastures [**Davis 1958, Lee 1956**].

#### {Page 126} **Disturbances of trace-element metabolism in some diseases**

A number of diseases are accompanied by serious disturbances of the metabolism of trace elements, although they are not necessarily due to nutritional factors. The fact that blood copper rises very appreciably in fever and even schizophrenia, as well as in pregnancy has already been mentioned (on page 115).

...in beri-beri, a thiamin (Vitamin B) deficiency of man, [**Eggleton 1939**] showed a marked *decrease* in the zinc content of blood, hair, skin, and nails of sufferers, which was correlated to the deficiency. The pronounced drop in the zinc content of the prostate gland in cancer has already been discussed [**Mawson and Fisher 1952**].

#### **Psychological phenomena and trace elements**

Organic illness, malnutrition, and excessive physical strain all result in psychological alterations in man and animals. Diet governs mental health to a considerable degree, so it is not surprising that *essential nutrients* should play some part in psychological processes, although this is seldom stressed. Yet trace elements are known to be involved in some very marked alterations of behavior.

{Page 128} Cretinism is a pathetic condition in which the thyroid gland is atrophied, and it is thus a condition produced by lack of the iodine-containing hormone thyroxine, rather than by a simple lack of iodine. Cretins, who are malformed and mentally sub-normal individuals, are found most commonly in goitrous areas.

Toxicities of non-essential elements are also well known, and of these, mercury poisoning is perhaps the most interesting in this context. It results in people being very prone to blush in embarrassment (erethism), apt to lose self-control, and being timid and easily discouraged [**Cumings 1959**].

#### **Susceptibility to disease and trace elements**

The fact that badly nourished plants, animals and (people) are more prone to many kinds of disease is well known not only to farmers and doctors but also to gardeners and mother. It might be expected therefore, that imbalance of the micro-nutrient elements would also influence susceptibility to disease. While it is known that this is, in fact, the case, this aspect of trace-element nutrition has hardly been studied in any detail.

{Page 129} Sunflower infection by mildew is used as an indicator of boron deficiency in the USA [**Butler 1949**].

### {Page 130} **Animals**

Very similar phenomena may be observed with animals...cattle and sheep suffering from latent as well as visible cobalt deficiency are usually heavily infected with worms [**Hopkirk and Patterson**]...Cobalt in the diet makes worm control a relatively easy matter...In Florida 'salt sick' cattle (a dual copper and cobalt deficiency) had chronic hookworm infection [**Neal and Ahmann 1937**].

Copper deficiency has been found to be associated with heavy lungworm infections, with **severe trichostronglyosis** (worm infection) and other internal parasite infections [**Bremner and Keath 1959**].

In Germany oral applications of trace elements were successfully used to treat vaginitis in cows [**Strauch 1953**]. In America cows suffering from brucellosis (Bang's bacillus infection) were fed on fodder produced on trace-element fertilized soils. They are reported to have recovered completely and to have given birth to healthy calves. Similarly infected animals fed on ordinary fodder did not recover [**Balfour 1951**].

### **Hookworm anemia in man**

... **Hookworm anemia is primarily an iron-deficiency disease**, and must be treated as such [**Cruz 1948**]. {Page 131} ... It is only when the iron nutrition is inadequate that anemia is found.

## (Page 132) CHAPTER IX THE PREVALENCE AND DISTRIBUTION OF TRACE ELEMENT IMBALANCES

### **Geographic extent**

If imbalances of trace elements were rare in nature, and deficiencies or excess only occurred very infrequently, then they would still be of interest to scientists, but would be of very slight practical importance. But in actual fact these conditions are found very extensively and are recorded from all part of the globe. They result in considerable economic losses, as well as ill health in plants, animals, and man.

### **Goiter**

Sea-water and marine plants and animals are a rich source of {Page 134} iodine, and this has led many people to believe that distance from the sea was an important predisposing factor in goiter. In actual fact, coastal areas may be very goitrous...

Nor is goiter confined to humans, Animals, especially cattle and {Page 135} sheep, suffer from 'swollen neck' on a large scale. The seriousness of this deficiency can be gauged when it is appreciated that in Montana...*one million (1,000,000) pigs died annually* before iodized fodder were introduced [**Anon 1956**].

...Sedimentary rocks like Old Red Sandstone have a tendency to give rise to goitrogenic soils, while igneous or metamorphic rocks, such as granites and basalts, rarely do.

### **Extensive deficiencies**

Spectacular though the iodine picture is there is no reason for believing it to be unique...In Australia, well known for its trace-element deficiencies, about 300 million acres (approximately 388,000 sq. miles) of adequately watered land is undeveloped agriculturally, primarily due to lack of trace elements. These regions can be as readily reclaimed as the zinc-and copper-deficient Ninety Mile Desert, which is now a flourishing farming area [**Anderson and Underwood 1959**].

### **Europe**

Trace-element deficiencies are not confined to poorly developed areas. Even in Holland, which is probably the most efficient agricultural country in Europe, acute trace-element problems exist, ... and {Page 136} half of Holland is potentially deficient in trace elements [**Lehr 1956**].

The North German Plain, which stretches from the Baltic Sea, across Germany and Denmark, into Holland, is a region that is copper efficient. [**Rademacher 229**]. These are mainly humus-rich sandy soils.

{Page 138} in Spain peaches and pears are widely deficient in iron, copper, and zinc, and potatoes in manganese [**Roach 1955**]. [The manganese deficiency in North-West France...appears to be spreading due to excessive applications of marl and shell sand fertilizer very rich in calcium carbonate, and is a cause for concern, as this deficiency can result in considerable losses to the extensive dairy industry of this area.

### {Page 139} **America**

Trace-element deficiencies are as widespread in the Americas as in Europe. (In 1958 the conditions) were mapped in the USA by [**Thacker and Beeson 1958**] and this map (fig. 60) shows extensive deficiencies of manganese, copper and zinc. In plants, boron deficiency is found particularly in plants growing on the Atlantic coastal plain...Manganese deficiencies are especially acute in Florida, but found in the muck soils of the Great Lakes Region, as well as in Southern California and the Atlantic Coastal Plain...

In South American the iron deficiency in humans has already been discussed [**Cruz 1948**]. In the state of São Paulo severe cobalt deficiency exists in cattle [**Corrêa 1955**], and zinc and magnesium deficiencies occur widely in crops. Boron, copper and molybdenum deficiencies are also known...

### {Page 141} **Africa**

Trace-element imbalances of various kinds constitute a serious agricultural problem in Africa, affecting plants, animals and man.

In the Republic of South Africa, where these conditions have been more intensively investigated, it would appear that about 80 per cent of agricultural land is affected.

### **Australia**

Australia is undoubtedly the continent in which acute deficiencies are most widespread. As the agricultural problems are so extensive, it is not surprising that Australian research work in this branch of science, as well as its practical application. Leads the world in

many respects...The podsollic soils of eastern Australia are nearly all more or less molybdenum deficient. They stretch for 1,000 miles along the coast, and are also found in Tasmania...{Page 143} This deficiency is more complex than a simple molybdenum deficiency, and the best results in the field are obtained by applying molybdenum with a super-phosphate fertilizer. The doses of molybdenum are so minute, 1-2 oz. of sodium molybdate per acre remaining effective for six (6) years, that a real problem exists in distributing such small quantities evenly over the lands [**Anderson 1956**].

#### {Page 144} **Asia**

Although Asia is the largest continent, it is not possible to assess the significance of trace elements in it. Very extensive iodine deficiencies exist, and boron is widely deficient in Japan and South-East Asia [**Oram 1959**]...In Delhi applications of boron and of molybdenum have significantly improved the yields of berseem (*Trifolium alexandrinum*) [**Joshi and Joshi 1952**], and sugar cane shows some beneficial effects from various trace-element sprays in the Punjab [**Perry et al 1955**]...In Malaya, one of the big rubber-producing areas of the world, iron and manganese deficiencies are known in the field [**Bolle-Jones 1956**].

#### **Toxicities**

No discussion concerning the distribution of deficiencies would be complete without reference to areas of excessive or toxic levels of these elements. These also occur, although on a very much more restricted scale. {Page 145} Perhaps the most widespread of these conditions is excess of fluorine, which causes 'fluorosis' of stock and of man. (USA, North and South Africa, particularly in Tanganyika many areas are afflicted.)

In the semi-arid regions of the Great Plains (USA) animals suffer from a disease termed 'alkali disease' or 'blind staggers'; it is frequently fatal. This has been shown to be due to selenium poisoning, which is prevalent in these soils. It is accentuated by the existence of accumulator plants such as *Astragalus* spp. (a member of the *LEGUMINOSAE* family) which concentrate the selenium and increase the toxicity of the herbage. This high level of selenium results, particularly, in badly deformed hooves...There is no definite evidence that human disease results from these soils, probably because human eating habits are such as to make man far more independent of the immediate surroundings, his food coming from many dispersed areas, and so toxic concentrations do not accumulate in the body.

Boron toxicity is more restricted in its distribution, and is often induced by poor agricultural techniques. In dry regions unwise irrigation can result in salts crystallizing out of the water, and 'brack' conditions can be formed. Borates separate out and may poison the vegetation. In California this has been shown to occur [**Oram 1959**]. Certain plants which have a very low boron requirement, such as many grasses and cereals, certain grain legumes, rubber, tea, and cocoa, are very sensitive to high levels, and readily show toxicity symptoms.

Toxicities of non-essential trace elements such as cadmium, nickel and aluminum are known and result in abnormalities of plants and animals and men.

### **Adaptation to special environments**

Not all animals and plants have the same requirements, and some can survive, and even flourish, in habitats that are quite unsuitable for most organisms. These plants and animals that can survive in these regions are specially adapted to these conditions.

Adaptation can be of two kinds, either genetically or physiologically determined. These are not mutually exclusive grouping, and phy-[{Page 147}](#)siological factors can vary the expression of a genetically predetermined adaptation.

### **Genetic adaptation**

The specific differences between plants are genetically determined, as is the ability to tolerate apparently toxic levels of certain elements, as in the case of mine-dump floras.

...where oats (*GRAMINEAE*) are shown to respond well to copper applications, while the growth of mustard (*CRUCIFERAE*) is depressed at the same concentrations, is of genetical nature.

...Fluorine is an element that most plants can tolerate in small doses, [{Page 148}](#) and some can even accumulate it. Camellia species tend to accumulate very appreciable levels of this element, and tea, especially China tea, may contain more than 100 ppm fluorine [**Monier-Williams 1950**]. Yet this same element, which is present as hydrofluoric acid in certain industrial waste gases, is so toxic to plants like gladioli, tulips and maize, that these plants cannot be grown in the vicinity of certain manufacturing areas [**Zimmerman and Hitchcock 1955**].

### **Physiological adaptation.**

...It is well established that deficiencies of boron, copper, manganese, and zinc detrimentally influence transpiration [**Schmied 1953, Schütte 1959**]...*adequate supplies of boron result in plants being better adapted to dry conditions* and having a better xerophytic behavior.

[{Page 149}](#) It is clear that radishes receiving full balanced mineral nutrition (control) are less prone to wilting than deficient ones.

[{Page 150}](#) that frost resistance can be altered by trace elements has been known since the 1920s...[**Freckmann 1934**] More recently, both boron and copper have been reported to show this protective action in the Northern Transmurals [**Storozheva 1954**] On the other hand, deficiencies of molybdenum and of manganese lowered the frost resistance of Lucerne [**Bortels 1941**] In contrast to this, heat resistance has been studied in the parts of the Volga exposed to intense summer heat, and enhanced levels of zinc are reported to increase heat tolerance of vegetation [**Petinov and Molotkovsky 1962**].

### **The influence of the environment on trace-element requirement**

Climatic conditions are of great importance in the development of deficiency diseases. Long dry summers, in which the soils are dried out, result in widespread deficiencies of copper, boron and manganese. These elements are not readily available under the oxidizing conditions of a well-aerated and dry soil.

...Waterlogging of the soil ...can (influence) so much manganese being made available that toxicity may result.

Light is another factor of importance, and it is particularly associated with zinc requirements. Intensive illumination results in an increased zinc requirement, and often in an induced zinc deficiency. On fruit trees the side nearest the sun usually shows much severer deficiency symptoms than the rest of the plant. In fact, the relationship between zinc and the growth hormone has been studied.

{Page 151} But other light effects are also found. Shade prevents injury to beans and tobacco grown on soil with toxic levels of manganese in them, and reduces their uptake of this element [Löhnis 1951].

As well as light intensity, light duration is also of importance, as it regulates the photoperiod, i.e., time exposed to light, of plants. Some of these are very sensitive to changes in photoperiod. In certain soybeans, buckwheat, and cockle-burr, boron deficiency only develops under long-day conditions, but not under short-day exposure to light. The boron requirement is enhanced by more than 14 hours of daylight. Yet in plants such as tomatoes or sunflower the duration of the daylight does not alter the mineral requirements [Struckmeyer and MacVicar 1948].

Temperature is also an important environmental factor, and beans can tolerate levels of manganese at high temperatures that would be toxic at lower ones. [Löhnis 1951]

{Page 154} ...deep-rooting plants can reach the lower layers of the soil, where adequate copper supplies exist. Hence in the same soil deep-rooting plants may be quite healthy while shallow-rooting ones, such as certain cereals, may be acutely deficient. This phenomenon is found in many parts of the world and in South African orchards deep plowing, with its resultant sub-soil aeration which it brings about, results in deep healthy rooting systems developing, with a frequent disappearance of trace-element deficiencies [Beyers 1954]

**TABLE 35**

*Indicator plants—of soil nutritional status*

<b>DEFICIENT ELEMENT</b>	<b>PLANT</b>
Boron	Apple
Iron	Cauliflower, broccoli, marrow-stem kale, cabbage, apple, and pear, plum, raspberry
Manganese	Sugar beet, mangold, globe beet, apple, sweet cherry, and raspberry
Molybdenum	Cauliflower
Zinc	Orange and apple

These plants have a marked requirement for certain of the nutrient elements, and when these are low in the soil, or not readily available to the plant, they show characteristic and readily identifiable deficiency symptoms. As a result, they can be used to *indicate* the nutritional status of the soil.

{Page155} The calamine violet *Viola calaminaria* Lej. is almost restricted to ...zinc carbonite rich soils, as are *Thlaspi calaminae* Lej., *Thlaspi cepaeafolium* Koch, and *Viola lutex* Sur [Dorn 1937].

**TABLE 36**  
*Indicator Plants for ore deposits*

These plants indicate the presence of certain elements, ores, or rock types. They occur primarily or exclusively on these sites, For instance, serpentine flora are found on soils that other plants cannot colonize due to the presence of high level of nickel, chromium, or cobalt salts.

...Many members of the *Caryophyllaceae* indicate Copper  
{Page 156}

*Amorpha canescens* Nutt. (indicates) Lead sulfide

*Erigononum ovalifolium* (indicates) Silver

{Page 157} In prospecting, this ability to concentrate elements which are present in very small quantities in the soil, and so make chemical analysis easier, is exploited. In Canada leaves and twigs of relatively ordinary vegetation are used to identify ore deposits. Balsam Fir (*Abies balsamea*) and Blueberries (*Vaccinium ovalifolium*), which contain significantly higher levels of copper and zinc when growing over ore deposits, are used for finding and mapping these [Warren et al 1955]. The level of these metals is not high enough to warrant classifying these plants as accumulators.

True, accumulator plants can be a source of serious trouble. *Astragalus* spp. and *Oenopsis* spp. accumulate so much selenium from the soil that they poison stock grazing on pastures in which they are growing...The seeds of *Astragalus racemosus* can contain over 2000 ppm selenium, while many of the plants contain so much of this element that they give off a garlic-like odor, which is characteristic of certain selenium compounds.

The reason why plants act as accumulators is not known...Certain blue oysters obtain their color from accumulated copper, an element that is toxic at very low levels to most marine forms of life.

### {Page 159} **Changing environments**

In many parts of the world...the soil is now so impoverished that the indigenous flora is no longer adapted to these new conditions, and in some parts shows severe deficiencies of trace elements, as is clear from Figure 68. These plants are being replaced by alien vegetation more adapted to these conditions [Schütte 1960].

...it is obvious that the trace elements have a number of important ecological facets...Certainly rabbits and other vermin show a preference for trace-element fertilized fields, and cattle and other animals will travel long distances to satisfy their requirements for iron and other trace elements. And in parts of the world where rivers of almost {Page 161} pure water, which drain very leached soils, are found, their fauna is strictly limited.

Full *balanced* nutrition is essential for optimal growth and development.

### **Methods for determining deficiencies or excesses of trace elements in plants**

(i) *Visual symptoms*. Severely deficient plants have a characteristic clinical appearance, and many symptoms of both deficiencies and excesses in crop plants are known and recorded [Wallace 1951]. These symptoms can be of great value in preliminary investigations and, used by no expert, can yield much useful information.

From the practical agricultural point of view, visual symptoms are of limited value because they only appear when the deficiency is severe, and are of no value in establishing latent deficiencies. Also, it must be appreciated that simple deficiencies of only one element are rare in nature. It is more usual to find multiple deficiencies, and these alter the visual symptoms very considerably...

(ii) *Soil Analysis*. As imbalance nutrition is usually the result of disequilibria in the soil salts, it would seem that chemical analysis of the soil might give the desired insight into the mineral requirements.

{Page 163} But unfortunately no satisfactory method for analyzing the plant available nutrient in the soil exists...

Chemical analysis of soil can determine absolute, i.e., total, levels of various nutrient elements accurately. *This method can show up absolute deficiencies or excesses*. It is a good method for determining the amount of material that is plant available in a soil. (However,) plant availability depends on far more than mere presence in the soil. Iron chlorosis is frequently encountered on red laterite soils, which are very rich in total iron, but may be poor in available iron. From the chemical point of view, it (has been) almost impossible to determine what is plant available, as availability varies, first with the species of {Page 164} plant, then with the physical nature of the soil, climate, microbial activity of the soil, etc.

(iii) *Leaf analysis*. This is a very useful and widely used technique, in which leaf samples are analysed. As the mineral content of the leaf is a very good index of the available elements in the soil, and also for the plant's requirements, this method is used extensively for routine analysis. Most of the elements are estimated by sensitive and rapid spectrographic analyses of leaf ash, and its sensitivity and speed have made it very popular...{Page 165} It is clear that leaf-analysis techniques are both rapid and convenient, but again they must be interpreted in an empirical background of experience. As they reveal the composition of the plant, they are of more value than soil analyses, although they do not show directly the plant's physiological status or requirements.

### **Leaf injection techniques**

It is misleadingly termed an injection technique. Apart from its simplicity, this method is useful because it measures biological responses...

### **Fertilizer trials**

Perhaps the most informative method for studying plant nutrient requirements in the field is by means of fertilizer trials. Their great drawback is that they are difficult to lay out, and may take a number of years to complete. Hence they are very expensive.

{Page 167} The simple addition of nutrients to a soil does not mean that they are automatically available to the plant and if the soil is alkaline, then many are converted into forms which are not available to the plant. Others are not readily available in acid soils...{Page 168} Thus, agricultural techniques which make the soil alkaline may induce deficiencies. In practice, over-liming causes much trouble,...

Sulfuring, or the use of fertilizers like ammonium sulfate, tends to turn soils acid. This again alters the balance of the available nutrients in the soil, and in some areas may induce molybdenum deficiency.

It must be clear that it is not easy to develop a good fertilizer mixture, and that it is almost impossible to develop one that is optimal under a wide range of agricultural conditions. There are no 'cure-for-alls' in either medicine or agriculture.

### Corrective treatment

The widespread existence of trace-element deficiencies calls for effective practical methods to overcome these imbalances. The fact that the modern agricultural techniques result in progressively heavier crops being removed from the soil means that the amount of trace-element material removed is greater than formerly.

{Page 169} The organic manures are not an unduly rich source of trace elements,...As these organic materials are very bulky, and it is seldom possible to give optimal applications of these to fields, they must be regarded as relatively poor sources of trace elements, and are not always likely to make good, soil deficits. However, organic manures (may) increase the activity of soil micro-organisms which transform *total* mineral elements to *available* elements. Although a number of fertilizer mixtures contain some of the trace element in them, it is more usual to supply the trace element separately...But the application of trace elements is not always so easy, as element such as copper, manganese, or iron get 'fixed' very rapidly by the soil. This means that they are rapidly turned into unavailable forms in the soil...in such cases, the trace elements can be supplied as foliar sprays, which is a very efficient way of supplying these nutrients. As they can be mixed with the fungicidal sprays, the nutrients can be applied two to three times in a season at a relatively slight expense.

{Page 170} As many of the deficiencies in the field are complex deficiencies of two or more elements, spraying is one of the simplest methods of treating these conditions when intensive agriculture is being practiced.

### Chelates

...the *chelates*, with their very special properties, are of particular interest.

A chelate is a compound formed between a metallic ion and an organic molecule having two neighboring groups capable of simultaneously combining with the metal to form a ring structure.

{Page 171} Chelates have very high stability, and as a result, the metal in them is no longer available for many of its usual reactions, and many biological, chemical and physical properties of the metal are changed. [Chenoweth 1956, Wallace 1962, Smith 1959]

...metals are frequently translocated as chelates within tissues [**Timberlake 1959**] and it is possible that boron chelates may play an important part in the translocation of sugar within plants [**Gauch and Duggar 1953**].

...Iron is an element that is rapidly made unavailable under (normal) conditions, and tissues often experience great difficulty in obtaining adequate supplies, even in the presence of large quantities of total iron. Chelating agents enable plants to tap soil reserves or iron efficiently, and in culture solutions iron chelates maintain the level of available iron in the solutions [**Brown and Tiffin 1962**]. Chelates of nutrient metals can also be sprayed onto vegetation.

### **Methods for determining trace-element imbalance in animals**

In general, visual symptoms are of greater importance in animal studies than in plants.

#### **Fodder analysis**

A knowledge of the mineral composition of animal fodder gives valuable insight into the nutritional status of the animal. This is {Page 172} particularly true of herbivores, which do, in fact, constitute the bulk of the agricultural animals involved in trace-element disequilibria.

Herbage analyses from Germany would indicate that low levels of such elements as manganese and copper are so widespread as to constitute a serious agricultural problem.

#### **Table 43**

If the critical level for copper is 5 mg Cu/kg., then over half of the hays in the Mecklenburg area (at the time of the corresponding study) were deficient in copper. It is more usual to regard 8 mg. Cu/kg as the critical level in fodder for cattle (rendering) the bulk of the hays...as unsatisfactory [**Nehring and Borchmann 1961**].

#### **{Page 173} Indicator organs**

...figures show the close relationship between the manganese content of hair and fertility in cows [**Meyer and Engelbertz 1960**]...{Page 174} The almost linear relationship between liver copper and copper intake is shown in Figure 50 (on page 115). New techniques enable liver biopsies to be conducted quite safely on both cows and calves, and these appear to be the most accurate way in which to gauge copper status [**Van Der Grift 1955**].

Liver, blood, ovaries and hair are the main tissues used in investigations of animals. From the analysis supplies, practical steps can be taken to remedy the imbalance.

#### **{Page 175} Trace-element therapy in man**

Reference has already been made to the prophylactic addition of iodine to salt in an effort to combat goiter.... As iron salts often have an unpleasant taste, and, moreover, are not readily absorbed in the {Page 176} digestive tract, injections or the use of iron chelates are of the greatest practical importance.

...while vanadium, if not essential, at least plays a very beneficial role [Seelegmann et al 1954].

{Page 177} Chapter XII The abuse of the major element fertilizers: some consequences

**'Four fertilizer mentality'**

How is it possible, when it is generally recognized that at least thirteen elements are essential for plant growth and development, that most agricultural practices still continue to base their fertilizer applications on the assumption that three, or maybe four, elements are all that is necessary in practical agriculture. This 'four fertilizer mentality' is still so widespread, and its consequences so detrimental to good agriculture, that it must be discussed in some detail.

It must be stressed that it is frequently overlooked in practice that all nutrient elements interact and influence each other to a considerable extent...Mulder's interaction chart shows how nutrient antagonize or stimulate each other's availability in the soil. It is clear that heavy applications of one element can result in a marked depression in the availability of another, and the nutrient *balance* can be upset very readily. *The level of one nutrient in soil cannot be changed without influencing the others.*

Heavy dressing of one element may induce relative deficiencies of others, and Liebig's Law of the Minimum points out, it is the element in the *relative minimum* that governs the yield.

...Yields have increased at a fabulous rate, and many agricultural lands are yielding up to four times what they did at the turn of the century...{Page 178} The consequences of all this increased productivity is that the removal of the trace elements from the soil has gone on at a much greater rate than formerly, and deficiencies are frequently found on the most progressive farms. Crops remove trace elements in very appreciable amounts [Gericke 1957, Braun 1962].

{Page 179} **Liming**

Limestone or chalk is usually added to soil to make it less acid, and so more suitable for agriculture. In general, it is supplies as a soil conditioner, rather than as a nutrient. But because it can alter the acidity of the soil, its abuse in over-liming leads to many nutritional difficulties. The influence of pH on the availability of micro-nutrient elements is clearly shown... Over-liming results in the soil becoming alkaline, and it is clear that iron, manganese, copper, boron, and zinc become less available as a result of this...[Wear 1956] showed that applications of 2,000 lb. CaCO<sub>3</sub> (Calcium Carbonate) per acre reduced the {Page 180} zinc content of sorghum (while) the pH of the soil rose from 5.7 to 6.6. On the other hand 2,000 lb. ca SO<sub>4</sub> (Calcium Sulfate) per acre increased the zinc content of the plants, *but decreased* the soil pH to 4.8. When other salts, such as sodium carbonate, which also turns the soil alkaline, also induce zinc deficiency, then there is little doubt that over-liming is harmful because it alters the soil pH in an unbeneficial way.

**It must be stressed that over-liming is the bad agricultural practice, not liming.** But even here, it is not always easy to generalize, for heavy liming may be very beneficial under conditions where molybdenum is in short supply. Legumes such as lucerne (alfalfa), crimson clover, and Austrian winter-peas, which have an appreciable molybdenum requirement, benefit from such treatment, as it makes the molybdenum more plant available.

(However the) increased molybdenum uptake is not always as beneficial as it may appear at first sight, because if the level of this element rises too much a molybdenum-induced copper deficiency may very easily be found in grazing animals.

### {Page 181} Nitrogen fertilizers

There is no doubt whatsoever that correct use of nitrogen-containing fertilizers is one of the really practical ways of promoting lush vegetable growth. It is equally clear that in many parts of the world greater use could be made of these compounds. But what is not so well known is that there are real dangers associated with the abuse of these fertilizers. (Certain) field experiment(s show) how heavy soil dressing of nitrogenous fertilizers can depress grain yield in wheat. Nitrogen gives increase yields as long as adequate copper supplies are available. If a relative copper deficiency is induced, yields drop. On the other hand if copper is supplied, then much higher yields of nitrogen can be utilized beneficially.

As nitrogenous fertilizers bring about increases in crops, it is also clear that the plant's requirements for all other essential nutrients increases, if balanced nutrition is to be maintained. But as there is also an antagonism on occasions between these elements, this requirement can be greater than expected at first sight. [Jungermann 1962] found {Page 182} that all his nitrogenous fertilizers, except one, decreased the copper concentration of his barley on unlimed plots.

Mulder's [1954] graph (figure 73) shows the limiting action that lack of copper can exert on the beneficial effects of nitrogen fertilization. In a field with a relatively low copper status, added nitrogen gave increased yields within limits. Any additions of more than 80 kg. (of) nitrogen per hectare<sup>3</sup> *resulted in marked and appreciable yield decreases.*

The fact that high levels of nitrogen can result in decreased copper levels in vegetation is of great practical significance in animal production.

...{Page 183} In maize heavy nitrogen fertilization results in an increased crop, but the nutritionally poor protein, zein is also increased to a marked extent [Schütte 1961]. The influence of manganese upon the zein concentration in maize ... decreases the amount of this undesirable protein.

### Phosphatic fertilizers

In many parts of the world low levels of available phosphorus constitute the greatest limiting factor in agriculture, and phosphatic {Page 184} fertilizers are essential for increasing the fertility of the soil and maintaining it...As a result, certain conditions, such as phosphate-induced zinc deficiency, are very common in greenhouse crops like

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<sup>3</sup> One hectare is the metric unit of area equal to 10,000 square meters, or approximately 2.471 acres . (i.e., a square acre measures 208' 8.52" on each side, or 43,560 square feet. 80 kg = 176 lbs. That would mean a safe application of under 73 pounds of nitrogen per acre—a mere dusting!

tomatoes. Again this kind of disturbed nutrition is more common on modern intensively cultivated farms than it is on carelessly run and rather neglected ones.

[**Bingham et al 1958, 1960**]...showed that the addition of phosphates decreased the absorption of boron, copper, and zinc, even though the addition decreased the soil pH...Nineteen soils were examined and (revealed) that excess phosphate result in acute copper deficiency {[Page 186](#)}...excess phosphates can not only decrease the copper content of herbage, but also (causes a chain reaction due to the) increase the level of the molybdenum (in cattle by way of this deficiency from eating the deficient herbage).

### **Potassium fertilizers**

The influence of high levels of potassium on mineral imbalance is seldom studied, yet in the USA 'alfalfa yellow' (boron deficiency) following potash applications is sufficiently well known for certain states to incorporate boron into their potash fertilizers. In soybeans potash fertilizers often depress the growth and yield, but in practice, if a two pounds of boron are mixed within 2 million pounds of soil, there is sufficient boron present to enable soybean to grow at all levels of potassium that are likely to be supplied.

### {[Page 187](#)} **Some other problems**

...we must bear in mind not only the need for one or other essential element..., but the importance of *balanced* nutrition. Otherwise in our effort to solve one problem we may quite unwittingly and unnecessarily develop another. This is very clearly shown by the event that took place in Holland after the Second World War [**Grashuis 1961**].

...very heavy applications of nitrogenous, phosphoric and potash fertilizers in the belief of the soil and vegetation....milk production, reproduction and health of the farm animals was seriously disturbed...There was no doubt at all about the serious consequences of the disequilibria brought about by unbalanced fertilization...{[Page 188](#)} High levels of phosphorous and of calcium in the diet result in a marked increase in the manganese requirement of the birds, and unless this is supplied, deficiency set in [**Caskey and Norris 1938**].

If production and quality is to be improved *balanced nutrition must be maintained*. All essential elements must be present and available in adequate amounts. If copper shortage exists, increased nitrogen fertilization is not only useless—it is uneconomic and senseless...{[Page 189](#)} It is up to the fertilizer industry to warn their customers against the abuse of their products and to see that they receive good and competent advice on imbalance problems when they are suspected. **The fact that total balanced nutrition is stressed does not constitute either an attack on the artificial fertilizer industry or a threat to it. It is in their own interest to appreciate this, and to recognize that to pursue a policy of selling the maximum of fertilizer irrespective of its effects is both anti-social and ultimately very bad business.**

## {Page 190} Conclusion

Nutrition is involved in virtually all living processes to some extent, and the contention that we are what we eat is not just a smart cliché, but a very profound concept. It cannot be over-emphasized that for proper development balanced nutrition is of the utmost importance...There is no balance of nutrients that is optimal for all species,...From a practical point of view, it is essential to grasp the fact that trace-element imbalances do exist on a very extensive scale, and that there are very real trace-element problems. It is only when this has been properly appreciated that really effective measures can be taken to remedy the 'problems', which are so widespread as to be a very normal part of our environment...thousands of animals are below par because their mineral requirements have not been met. The fact that trace elements play a part in such conditions as cancer, atherosclerosis, and hypertensive states makes them particularly interesting... (they) play such an important part in the enzymatic activity of the cell, they might be expected to be seriously involved in such conditions...health of mind and body is dependent upon the food we eat and upon the trace elements which they contain.

### Please Note:

- Cultural spelling differences have been harmonized to fit the American viewpoint.
- *Italics in lower case*, are the original author's own, but sometimes substituted by the Synopsizer for consistency's sake. *CAPITALIZED ITALICS* of scientific names are more often than not the addition of the Synopsizer to reflect additional knowledge on the subject.
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