ADVANCED AGRICULTURAL SCIENCE

Decline in Nutrients in Soils and Foods, and the Role of Nutrients

A SUMMARY AND ANALYSIS OF THE LITERATURE

Oasis Agri (PTY) LTD

Francis Yeatman Kent Yeatman

francis@oasis-agri.co.za kent@oasis-agri.co.za

www.oasis-agri.co.za

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Over the past few decades various studies have indicated that nutrients (elements/minerals) have begun to decline in both our soils and in our foods. This is of serious concern, if the research is correct, as the majority of micronutrients that have been stated to have declined are essential to the health of plants, animals and humans.
In the write-up of several of these studies, we looked primarily at the decline in micronutrients (trace elements) in various crops and critically analysed the data and causes for reports of declining nutrients.

Crops require a variety of mineral nutrients in order to grow and produce optimally. These nutrients in turn are taken up by livestock and humans through the food they eat, to enable optimum metabolic functioning.
These nutrients include nitrogen (N), phosphorous (P), potassium (K), magnesium (Mg), calcium (Ca), sulphur (S), boron (B), copper (Cu), chloride (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn), cobalt (Co), selenium (Se), silica (Si) and nickel (Ni).
Some are needed in larger quantities than others.

What are micronutrients?

Micronutrients are essential elements that are used by plants in small quantities. It has been found that yield and quality of agricultural products increased with the correct micronutrient application.

What are macronutrients?

Macronutrients are essential elements that are needed in higher quantities for plant growth and to sustain plant health.

The table below indicates the nutrients for crops grouped according to the quantities needed by the crop, the effect of the nutrient on increased yield per kilogram and the duration of the residual effect.

Nutrient group	Elements	Increased yield/kg	Residual effect
Macronutrients	N, K	Low	Short – Average
Mesonutrients	Ca, Mg, P, S	Average	Average – Long
Micronutrients	B, Cu, Fe, Mn, Mo, Zn	High	Long
Supplementary	Al, Cl, Co, Na, Ni, Se, Si	-	-

[9]

REASON FOR CONCERN

The World Health Organisation (WHO) has already defined this lack of micronutrients as "hidden hunger". Unlike energy-protein undernourishment, which is easy to identify because of visible symptoms, micronutrient deficiency is not easily seen [1]. The WHO estimates that more than two billion people globally suffer from micronutrient deficiency [1,3]. The loss of both macro- and micronutrients has led to an increased concern regarding the negative effect of nutrient deficiency on food security in both developed and developing nations, as well as the disease burden and mortality that it carries [3].

Micronutrients play various roles in plant and animal function, with deficiencies having various effects and possible disease manifestation in both plants and animals. An element like selenium may not have much benefit for the plant, but it is vital for humans and livestock.

The concern is that in agriculture, most farmers use NPK fertilisers but neglect micronutrients. NPK fertilisers are macronutrient based, and they have visible effects when used such as larger leaf mass and better root structures. But they do not necessarily increase yield significantly, are used rapidly by the plant, are lost to the atmosphere through various processes and are locked in the soil a few weeks after application.

Micronutrients on the other hand remain in the soil and are available to the plant for longer and have the added benefit of increased yields [9]. A list of micronutrient functions for plants as well as animals and humans is available at the end of this document.

The main concern is that a lack of micronutrients in the soil and plant will result in poorer crop quality and yield for the farmer and poor nutritional intake for the consumer.

DECLINE IN NUTRIENTS

The following information has been gathered from various scientific articles and is a collection of the data summarised. In the next section, "Possible Causes for Decline", the reasons for changes are discussed.

In *Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands of Africa* (Henao, J. and Baanante, C., 1999), it was calculated that between 1945 and 1990, nutrient depletion in Africa caused light degradation of 20.4 million ha, moderate degradation of 18.8million ha, and severe degradation of 6.6 million ha [2].
Average rates of nutrient depletion between 1960 to 1990, from cultivated land in 37 countries excluding South Africa, indicated losses of about 660 kg/ha of nitrogen, 75 kg/ha of phosphorus, and 450 kg/ha of potassium per year [2].

A study by Davis et. al. (2004) identified an average decrease of 25% calcium, 14% phosphorus and 24% iron in fruit and vegetable crops between 1950 and 1999 [6]. This study was assessed by Mayer et. al. (2007) and used as comparative data. She found significant declines in calcium, magnesium, copper and sodium in vegetables as well as declines for magnesium, iron, copper and potassium in fruit. Phosphorous was the only nutrient to increase over a similar time period (Davis et. al.). [10].

Another study looked at five editions of The Composition of Foods by McCance and Widdowson as a summary of changes in nutrient composition of foods in the United Kingdom from 1940 to 1991 [7]. This study looked at 27 varieties of vegetables, 17 varieties of fruit, 10 cuts of meat and several dairy products. It indicated significant declines in the minerals and micronutrient values of foods over the 51 years, with the exception of phosphorus, which increased in vegetables and fruit, probably because of the global increase in the application of fertilisers containing phosphorous.

This study indicated the following [7]

Summary of Changes in the Mineral Content of Vegetables, Fruit and Meat between 1940 and 1991				
Year of Analysis	Minerals	Vegetables (27 Varieties)	Fruit (17 Varieties	Meat (10 Cuts)
1940	Sodium			
1991	(Na)	Less 49%	Less 29%	Less 30%
1940	Potassium			
1991	(K)	Less 16%	Less 19%	Less 16%
1940	Phosphorous			
1991	(P)	Plus 9%	Plus 2%	Less 28%
1940	Magnesium			
1991	(Mg)	Less 24%	Less 16%	Less 10%
1940	Calcium			
1991	(Ca)	Less 46%	Less 16%	Less 41%
1940	Iron			
1991	(Fe)	Less 27%	Less 24%	Less 54%
1940	Copper			
1991	(Cu)	Less 76%	Less 20%	Less 24%

In a second study of *The Composition of Foods* by Thomas (2007), which included the 6th edition in 2002, more information was gathered to show the trend of declining nutrients in foods with the inclusion of 11 years of more data (addition from 1991 – 2002).

[8]

Historical Essential Mineral Depletion - Changes in 5 Categories of Food Products						
	1940 to 1991 Vegetables	1940 to 1991 Fruit	1940 to 2002 Meat	1940 to 2002 Cheeses	1940 to 2002 Dairy	Weighted Average
Sodium	-49%	-29%	-24%	-9%	-47%	-34%
Potassium	-16%	-19%	-9%	-19%	-7%	-15%
Phosphorous	9%	2%	-21%	-8%	34%	1%
Magnesium	-24%	-16%	-15%	-26%	-1%	-19%
Calcium	-46%	-16%	-29%	-15%	4%	-29%
Iron	-27%	-24%	-50%	-53%	-83%	-37%
Copper	-76%	-20%	-55%	-91%	-97%	-62%

This study found declines in sodium, potassium, magnesium, calcium, iron and copper over the period of assessment and an increase of phosphorous - similar findings to the previous study of McCance and Widdowson's work.

Davis et. al. (2004) found that statistically significant decreases from 1950 to 1999 were seen for calcium (–16%), phosphorous (–9%) and iron (–15%) [10].

Ekholm et al. (2007) assessed 18 vegetables, 16 fruits and berries and the cereals wheat, rye, barley and oats. They found that several of the trace minerals decreased significantly on a weight per dry matter basis: manganese, zinc, copper and nickel. The levels of selenium increased because of increased use of selenium as a mineral nutrient in agricultural fertilisers [10].

Fan et. al. (2008) studied mineral nutrient analyses of wheat grains and soil samples that had been archived over the last 160 years by the Broadbalk Wheat Experiment, established in 1843. They found that the grain concentrations of zinc, iron, copper and magnesium remained stable between 1845 and mid 1960s but since then significant decreases were seen in Zn, Cu and Mg. These decreases coincided with the introduction of semi-dwarf, high-yielding cultivars, with the suggestion that declines in mineral nutrient concentrations in wheat grain were associated with varieties having an increased grain yield [10].

Rosanoff (2013) combined analytically determined data from three major studies regarding magnesium food content change over time. Magnesium concentrations in grain have dropped by 7% to 25% and magnesium concentrations in vegetables have dropped by 15% to 35% [10].

POSSIBLE CAUSES FOR DECLINE

There are various suggestions for why nutrients have declined. Marles (2016) critically analyzed many of the articles used in this report and came up with a few conclusions. [10]

Deficiencies in soil can be natural - some soils can be highly acidic or alkaline - and as a result of human activity, such as soil depletion caused by farming without adequate fertilisation [9].

Water availability, intensification of land use, population pressure and a shift into arid and semi-arid areas have resulted in restricted crop diversity and poor farming management practices [2].

Poor farming practices include fertiliser mismanagement (under- and over-fertilisation), standard application of NPK fertilisers and no addition of micronutrients, over-grazing with resultant erosion of nutrient rich topsoil [2], shifting into previously indigenous forests where virgin land is cultivated and farmers not taking crop removal as an aspect of farming management.

Changes in the way vegetables and other crops are grown and distributed contribute to the decline in nutrients. These include changes in the cultivated varieties (cultivars) used, cultural practices (historical use of fertilisers, pesticides, and irrigation), the location of major production and distribution methods (transport effect on products) [6].

Other causes of micronutrient deficiency in plants could include micronutrient depletion of the soil itself (from areas of naturally poor levels of micronutrients, and from crop removal), the excessive use of NPK fertilisers (phosphate can restrict the availability of iron, zinc and copper for crops), changes in varieties of plants and the loss of micro flora/fauna within the soil through poor farming techniques [7, 9].

The crop itself can affect soil pH due to nutrient absorption and excretion through the roots which can in turn influence the availability of micronutrients. The free ions in the soil solution ultimately determine the micronutrient deficiencies for plants, and therefore the deficiencies for humans and livestock as well [9].

Soil biology plays an important role, especially the mycorrhizas. Because they have a vast network of mycelium, they have much more contact with the mineral reserves and can also absorb minerals in forms that are usually unavailable and make them accessible. However, mycorrhizas also require calcium and copper as nutrients. Hence a copper deficiency can limit the growth of mycorrhizas and thereby exacerbate deficiencies of other micronutrients [9].

When looking at sampling techniques and analysis of samples in the study by Davies et al (2004), he uses Mayer's research, which noted that potential sources of deviation included possible differences in the methods of sampling, methods of analysis (although older methods were characterised as taking longer but no less accurate); mixed sources of data for the 1991 edition, greater use of imported and "out of season" produce, different storage and ripening systems, changes in varieties bred for higher yield, response to modern methods of agriculture, post-harvest handling qualities and cosmetic appeal.

It should also be noted that Mayer et. al. (2007) indicated that water content increased significantly and dry matter content decreased significantly in fruits between the new and old data [10].

A possible explanation for lower mineral nutrient concentrations put forward by Davis et al. (2004) was related to changes in cultivars selected for yield, rapid growth, pest resistance, herbivory resistance and number versus size of seeds. They suggested that these changes may result in differences between cultivars in their ability to extract soil minerals, transport them within the plant and to synthesise proteins, vitamins and other nutrients. However, they recognised that these differences are "unpredictable in magnitude" [10].
It is put forward that historical nutrient content differences were attributed to a combination of several factors. Cultivar selection for yield may have changed acquisition and synthesis of nutrients and enhanced the dry matter or carbohydrate (starch, sugar and/or fibre) and water fractions of vegetables without proportionate increases in other nutrients, "dilution effect*". On the other hand, a large and unpredictable degree of genetic variability caused other cultivars to have increased levels of nutrients [10].
- *(*"dilution effect" of increased yields on the mineral nutrient concentrations)*

In line with the dilution effect, Garvin et al. (2006) identified that zinc and iron content decreased significantly with both increasing yield and more recent varieties of crops, whereas selenium content decreased significantly with more recent varieties in their study [10].

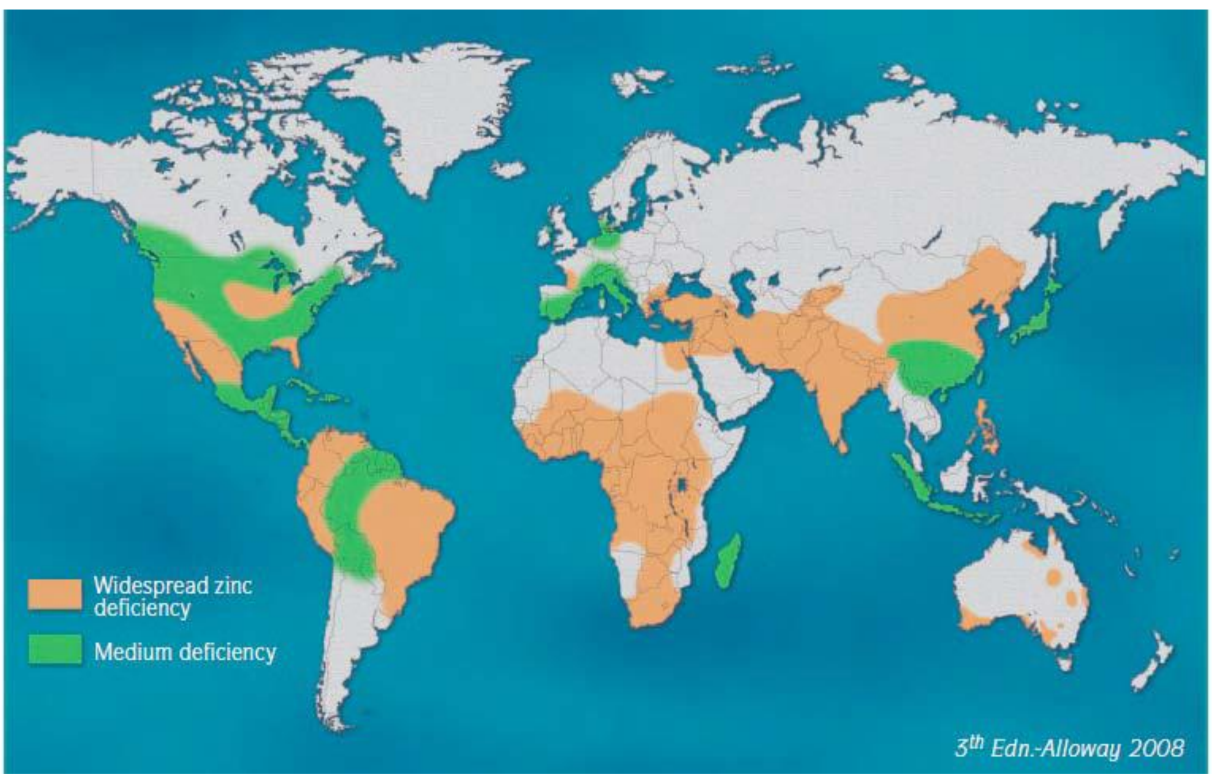
Murphy et al. (2008) found that modern cultivars had higher yields than the historical cultivars, but historical cultivars had significantly higher grain mineral concentrations than the modern cultivars, which showed that most of the variation was due to genotype rather than year [10]. Their results suggested a significant dilution effect only for Magnesium and zinc.

Declines noted by Rosanoff (2013) are suggested to be primarily due to the change to high-yield varieties (dilution effect) and to food processing losses [10].

In a study by Lyne and Barak (2000), evidence for depleted soils causing a reduction in the mineral content of food crops, as suggested by comparison of United States Department of Agriculture food composition data, was reviewed. They found that for calcium, magnesium, and potassium of selected fresh produce crops, there was no real loss in the balance of mineral nutrition. "*They stated that widespread use of soil testing and fertilizers as part of the strategy for the increasing yields of modern agriculture argues strongly against the notion of widespread soil depletion of mineral nutrients. They concluded that although it may be hypothesized that a decline in soil quality has led to an apparent decline in food nutrition, more controlled studies are needed to factor out the many variables associated with the food composition tables and this type of analysis*." [10]

In conclusion, there are a variety of reasons for a decline in nutrients in food sources. From the studies used, these factors can be divided into natural causes, agricultural causes, as well as sampling techniques.

Natural Zinc Deficient Soils Globally [9]



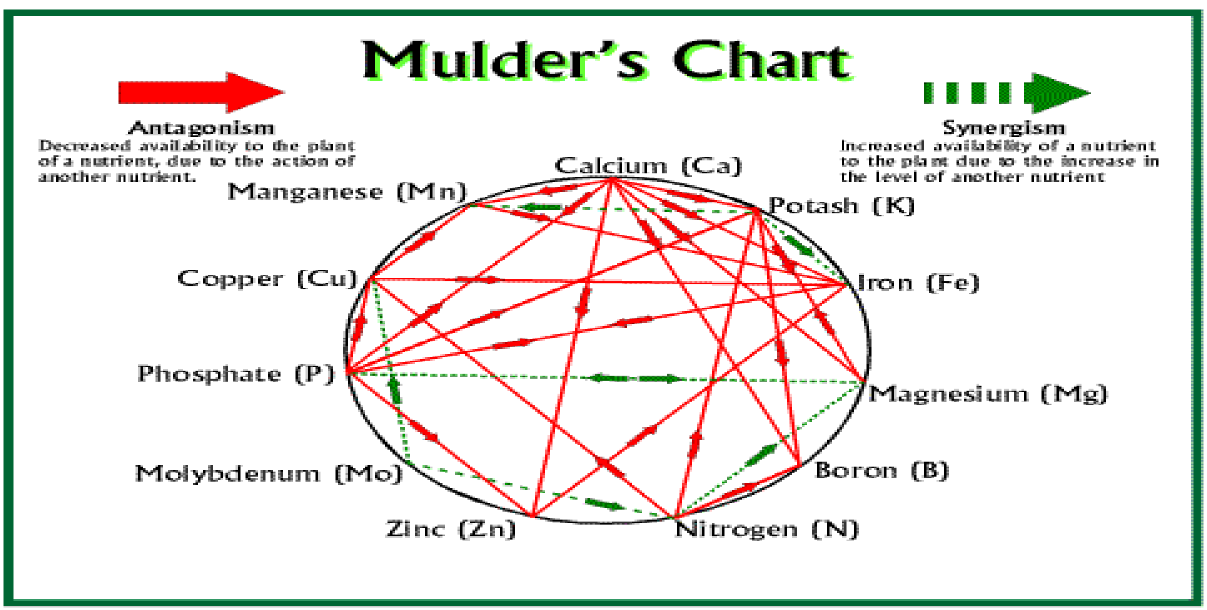
HOW TO RECTIFY THE SITUATION

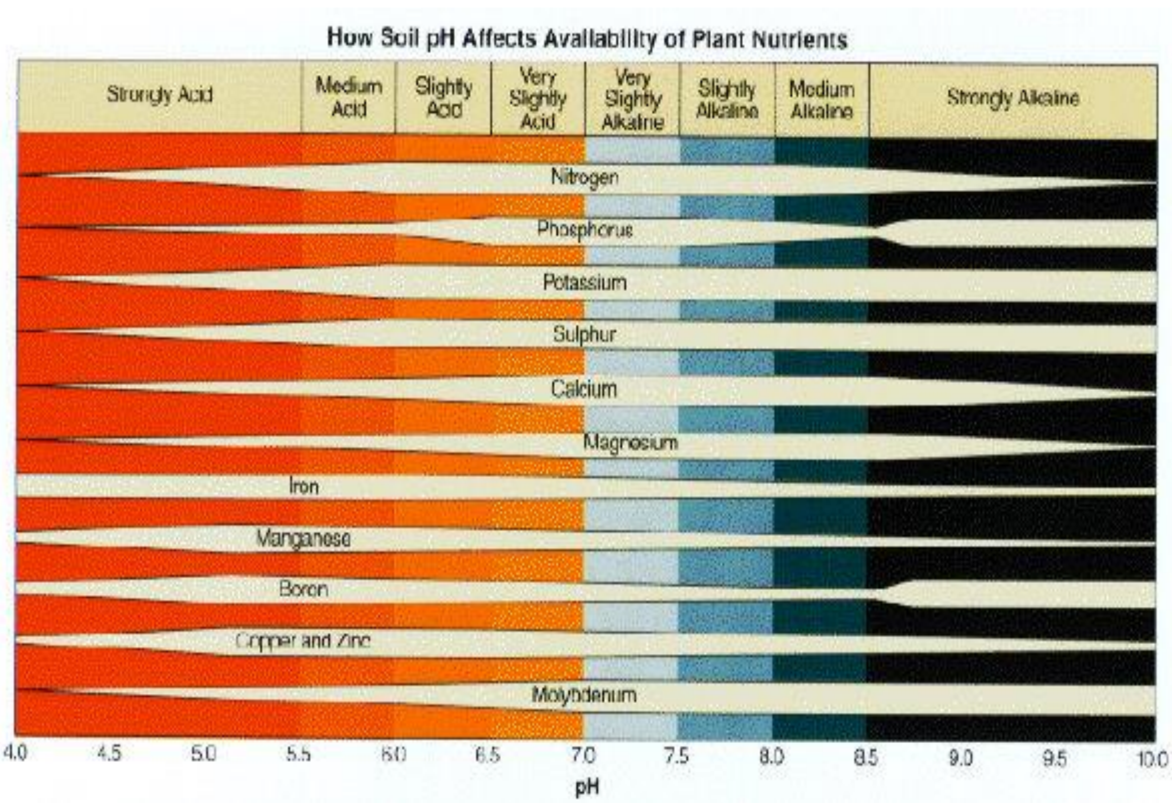
There are various ways to rectify the situation, through correct farming practices such as application of mineral fertilisers; long-term management practices such as the use of soil conservation measures (no till, reduced tillage, strip tillage, multi-specie cover crops and crop rotations); recycling of crop residues; improved livestock management and the use of organic fertilisers [2].

Udo de Haes et. al. (2012) suggest modified farming practice will prevent erosion and leaching such as the use of good water management and sufficient levels of clay and/or organic matter [9].

Key factors for the release of ions are the pH (*see pH chart below), moisture content, temperature and the interactions with other nutrients (*see Mullers Chart below). The pH of soil has a major influence on nutrient availability. If the pH increases by one unit, for example from pH 5 to pH 6, then the availability of zinc and copper falls by a factor of 100. This also applies to other metals with the exception of molybdenum where the opposite effect takes place [9].

Biofortification methods include agricultural practices such as mineral fertilisation, addition of soil microorganisms such as mycorrhizal fungi and nitrogen-fixing bacteria, intercropping of dicot with grass crops and both conventional and transgenic crop breeding methods [10].





It is important to note that the image above indicates a ***water pH***. To determine a ***CaCl (calcium chloride) pH*** you deduct roughly 0.5 from water pH and to determine a ***KCl (potassium chloride) pH*** you deduct roughly 1 from water pH.

ROLE OF NUTRIENTS IN PLANTS

Nitrogen (N)

- Integral component of many essential plant compounds
- Major part of all amino acids – building blocks of proteins (including enzymes for various biological processes)
- Form part of nucleic acids – including DNA for duplication of genetic material from parent cell to daughter cell
- Part of chlorophyll – therefore essential to photosynthesis
- Essential for carbohydrate use within the plant
- Stimulates root growth and nutrient uptake

Phosphorus (P)

- Essential component of ATP (energy storage and transfer) – used for most plant processes
- Essential component of both DNA (genetic inheritance) and RNA (directs protein synthesis)
- Cell membrane component as phospholipids, strengthens cell
- Enhances photosynthesis, nitrogen fixation, flowering, fruiting, seed production, and maturation
- Large amounts needed in meristematic tissue
- Encourages root growth, especially lateral roots and fibrous rootlets
- Some plants exhibit increased disease tolerance with adequate phosphorous

Potassium (K)

- Acts as an activator for enzymes (energy metabolism, starch synthesis, nitrate reduction, photosynthesis, sugar degradation)
- Lowers cellular osmotic water potentials, therefore reducing loss through leaf stomata and increasing roots ability to uptake water. Controls stomata opening and water transpiration
- Essential to photosynthesis (ATP synthesis, production and enzyme activity, CO_2 absorption through leaf stomates, maintenance of electroneutrality during photophosphorylation), protein synthesis, nitrogen synthesis in legumes, starch formation and translocation of sugars
- Assists the plant in adapting to environmental stressors - improved drought tolerance, improved winter hardiness, improved resistance to certain fungal infections, greater tolerance to insect pests
- Enhances quality of flowers, fruits and vegetables by improving flavour and colour and strengthening stems

Sulphur (S)

- Constituent of various amino acids (e.g. methionine, cysteine and cystine)
- Various vitamins contain sulphur (biotin and thiamine)
- Forms part of proteins (catalytic or structural properties) and enzymes that regulate photosynthesis (assists in synthesis of chlorophyll) and nitrogen fixation
- Needed in combination with nitrogen in the process of protein and enzyme synthesis. Needed for the synthesis of coenzyme A – involved in oxidation and synthesis of fatty acids and amino acids as well as oxidation of intermediates of the citric acid cycle
- Component of aromatic plants (taste and smell)

Calcium (Ca)

- A major component of the cell lamella, give rigidity to cell wall (maintains integrity and structure of cell membranes)
- Involved in cell elongation and division, membrane permeability, osmoregulation, and activation of several critical enzymes
- Protects cells from toxicity of other elements
- Important for nitrogen metabolism and protein formation by enhancing nitrate (NO_3-) uptake
- Essential for translocation of carbohydrates and nutrients

Magnesium (Mg)

- Central component of chlorophyll, therefore has a role in photosynthesis
- Synthesis of oils and proteins
- Activation of enzymes involved in energy metabolism
- Magnesium forms a bridge connection between ATP molecules to enzymes that catalyse numerous physiological processes that involve phosphorylation
- Structural component of ribosomes

Zinc (Zn)
- Present in a variety of enzymes with both structural and functional purposes
- Activates a variety of enzymes, some of which are involved in DNA replication, transcription and regulation of gene expression
- Protein synthesis role
- Carbohydrate metabolism
- Promotes growth hormones and starch formation
- Promotes seed maturation and production
- Involved in chlorophyll synthesis
- Cell membrane integrity

Iron (Fe)
- Present in a variety of enzymes - important in chlorophyll synthesis and nitrogen fixation
- Participates in oxidation-reduction reactions as porphyrin molecules in respiration and photosynthesis
- Forms part of chloroplast and mitochondrial membranes

Copper (Cu)
- Involved in energy transfer during photosynthesis and respiration
- Forms part of various proteins which are present in lactase and several oxidase enzymes, enzymes for lignin formation (strength and disease resistance), and enzymes found in the chloroplast responsible for detoxification of oxygen and energy transfer
- Important in protein and carbohydrate metabolism and nitrogen fixation
- Has a role in lipid metabolism
- Plays a role in pollen formation and fertilisation

Manganese (Mn)
- Activates a variety of enzymes (decarboxylase, dehydrogenase, oxidase), and enzyme activation for lignin synthesis
- In photosynthesis, helps in the production of oxygen from water
- Important in nitrogen metabolism and nitrogen assimilation
- Role in metabolic processes of protein, carbohydrate and lipid formation
- Cell division and cell extension role

Nickel (Ni)
- Essential for several enzymes including urease, hydrogenase and methyl reductase
- Needed for grain filling, seed viability, iron absorption, urea and ureide metabolism (nitrogen metabolism)
- Possible earlier germination and growth

Boron (B)
- Activates certain dehydrogenase enzymes
- Facilitates sugar translocation (carbohydrate and protein metabolism) especially towards the roots where exudates increase and increases soil microbes around the root (vesicular arbuscular- and ectomycorrhizae)
- Synthesis of nucleic acids and plant hormones
- Essential for cell division and development especially in root elongation
- Important for transport of photosynthetic sugars to meristematic tissue (root tips, leaves, buds, storage and connective tissues). Increases flower production and retention (pollen germination and pollen tube growth), and seed and fruit development
- Primary function is plant cell wall synthesis and structural integrity as cross links between polysaccharides (important for cell expansion, regulates H+ transport, retention of cellular calcium, control of lignin production)
- Membrane function in plasma membrane where phosphorus uptake is facilitated by boron and increases ATPase activity

Molybdenum (Mo)
- Present in nitrogenase and nitrate reductase enzymes, essential for nitrogen fixation and nitrogen assimilation
- Assists in iron absorption (molybdenum deficiency similar presentation to iron deficiency) due to presence in two other enzymes (xanthine oxidase or xanthine dehydrogenase)

Cobalt (Co)
- Essential for nitrogen fixation (legumes and the root nodules of nonlegumes) though several enzymes
- Found in Vitamin B12 – important for ruminant animals

Chloride (Cl)
- Essential for photosynthesis (in combination with manganese) and enzyme activation
- Plays a role in regulation of water uptake on salt affected soils (cell turgor)
- Works with potassium for stomatal regulation

Selenium (Se)
- Not essential to plants but is essential to animals. Nutritional disorders (muscular dystrophy, white muscle etc.) are common in animals with Se deficient diets
- Some Cruciferae, such as black mustard, accumulate large amounts of selenium
- New evidence suggests that Se has a positive effect on plant growth and stress tolerance (mechanisms unknown)

Silicon (Si)

- Assists in drought tolerance (lowers water loss by cuticular transpiration)
- Assists in remediation of toxic effects of high soil phosphorous, manganese, iron and aluminium
- Role in improving plant disease resistance (silification of the endodermis works as a mechanical barrier to pathogens and parasites), stalk strength (mechanical stability) and resistance of lodging, increased P availability and reduced transpiration
- Possible role in UV protection
- Increases physiological availability of zinc in plants

[11, 12, 13]

ROLE OF NUTRIENTS IN HUMANS

Sulphur (S)

- Sulphur is integrated into many molecules including amino acids, proteins, enzymes and vitamins.
- Sulphur-containing amino acids (SAAs) play an important role in multiple physiological pathways. In humans, sulphur is critical to the amino acids methionine and cysteine. Methionine cannot be synthesized by humans and must come from a dietary source. It is most abundant in animal sources. Cysteine is important part of a large number of metabolic intermediates and is synthesised by the human body. Some of these SAAs provide sulphates for molecules that are important to cartilage and collagen health, brain and organ function.
- Sulphur plays a major role in connective tissue in skin, tendons and ligaments. It assists in giving connective tissue the strong yet flexible characteristic. Extracellular matrix proteins, which are highly sulphonated, provide strength and cushioning and retain moisture.
- In the liver, sulphur is a component of glutathione, assisting in detoxification. It also works together with other molecules and micronutrients in the liver to synthesize prostaglandins and assist the antioxidant cascade.
- Sulphur is also involved in the stress response and in exercise recovery. Sulphur has an anti-inflammatory function and as an anti-oxidant, sulphur reduces the production of reactive oxygen and nitrogen species. [14]

Calcium (Ca)

- Calcium is present throughout the body with bones and teeth containing the most calcium, but it is also present in nerve cells, body tissues, blood and other body fluids. It plays a role in the hardness of bones and teeth. It is part of blood clotting, sending and receiving nerve signals, the contraction and relaxation of muscles (including the heart), and the release of hormones and other chemicals. [15][16][17]
- Calcium combines with phosphorous to strengthen teeth and bones to resist breaks and decay. [16]
- Helps to regulate blood pressure, with an association between high blood pressure and low calcium. [16]
- Calcium has a possible role in reducing the risk of colon cancer. Calcium binds to fat and bile acids in the large intestine, which reduces possible tissue harm. It also prevents excessive growth of tissue in the intestines and thus reduces the risk of cancer development. [16]

Magnesium (Mg)

- Magnesium is needed for more than 300 biochemical reactions (as a cofactor to enzymes) in the body. It helps to maintain normal nerve and muscle function, supports a healthy immune system, keeps the heartbeat steady, and helps bones remain strong. It also helps adjust blood glucose levels and protein synthesis. [18][19]
- Magnesium is required for energy production through oxidative phosphorylation (ATP formation) and glycolysis (breaking down of glucose). [18][19]
- It is required for the synthesis of DNA, RNA and the antioxidant glutathione.
- Nerve impulse conduction, muscle contraction and normal heart rhythm are achieved through the active transport of calcium and potassium across cell membranes in which magnesium assists. [18][19]

Zinc (Zn)

- Zinc is found in cells throughout the body and is present in over 300 enzymes. It is needed for the immune system (massively boosts the immune system and reduces cold symptoms), plays a role in cell division, cell growth, genetic expression, wound healing, and the degradation and synthesis of carbohydrates, lipids, proteins and nucleic acids and the metabolism of other micronutrients.
- Zinc is also needed for the senses of smell and taste through a zinc dependent enzyme.
- It enhances the action of insulin in controlling blood sugar levels.
- Zinc stabilises the molecular structure of cellular components and membranes and contributes in this way to the maintenance of cell and organ integrity. [20][21]

Iron (Fe)

- Iron is vital for all living organisms because it is essential for multiple metabolic processes, including oxygen transport, DNA synthesis, and electron transport.
- Iron forms part of the haemoglobin structure of red blood cells which carry oxygen to tissues from the lungs. [22]
- It is present in muscles as myoglobin, similar to haemoglobin, and stores oxygen in muscle tissue. [23]
- Iron is a transport medium for electrons within cells and as an integrated part of important enzyme systems in various tissues. Several iron-containing enzymes, the cytochromes, act as electron carriers within the cell and their structures do not permit reversible loading and unloading of oxygen. Their role in the oxidative metabolism is to transfer energy within the cell and specifically in the mitochondria. [23]
- Other functions for the iron-containing enzymes include the synthesis of steroid hormones and bile acids, detoxification of foreign substances in the liver, and signal controlling in some neurotransmitters (dopamine and serotonin) in the brain. [23]

Copper (Cu)

- Involved in numerous biological processes including antioxidant defense, neuropeptide synthesis, immune function, adequate growth, cardiovascular integrity, lung elasticity (connective tissue maturation), neovascularisation, neuroendocrine function, energy production and iron metabolism. This is due to copper-containing enzymes. [24][25][26]
- Copper is an essential cofactor for oxidation-reduction reactions involving copper-containing oxidases used in the mitochondria to produce energy. [26]
- Copper is essential to connective tissue formation in collagen and elastin (both give tissue strength and flexibility). [26]
- In the central nervous system, copper is essential to neurotransmitters (messengers) and myelin (signal conductors on the nerve). [26]
- Copper is also essential to melanin formation which is the pigment found in skin, hair and eyes. [26]
- Copper seems to regulate gene expression. By increasing the intracellular oxidative stress, copper activates a response that leads to the expression of genes involved in detoxification of reactive oxygen species. [26]

Manganese (Mn)

- Manganese is a cofactor and activator in many enzymes and is involved in amino acid, cholesterol, glucose and carbohydrate metabolism, reactive oxygen species scavenging, bone formation, reproduction and immune response. [27][28]
- Manganese also plays a role in blood clotting and hemostasis together with Vitamin K. [27]
- Manganese forms part of an antioxidant enzyme in the mitochondria. [28]
- Manganese is needed as an enzyme cofactor needed for proteoglycans which are essential for the formation of healthy cartilage and bone. [28]
- In wound healing, manganese is essential for collagen formation necessary for healing as well as other processes necessary for healing. [28]

Nickel (Ni)

- Nickel is found in nucleic acids, particularly RNA, and may be involved in protein structure or function.
- It is involved in iron absorption, adrenaline metabolism, hormones, lipids, cell membranes, improves bone strength and may play a role in red blood cells. [29]

Boron (B) • Boron has a variety of functions in the human body. It is essential for the growth and maintenance of bone, greatly improves wound healing, it beneficially affects the body's use of estrogen, testosterone and vitamin D, it boosts magnesium absorption, reduces levels of inflammatory biomarkers, raises levels of antioxidant enzymes, protects against pesticide induced oxidative stress and heavy-metal toxicity, improves the brains electrical activity, cognitive performance and short-term memory for older people, it influences the formation and activity of key biomolecules such as nicotinamide adenine dinucleotide (NAD^+), it has demonstrated preventive and therapeutic effects in a number of cancers such as prostate, cervical, and lung cancers and multiple lymphoma and non-Hodgkin's lymphoma and may help ameliorate the adverse effects of traditional chemotherapeutic agents. [30]
Molybdenum (Mo) • Molybdenum functions as a cofactor for at least four enzymes: sulfite oxidase (degradation of sulfur amino acids, cysteine and methionine), xanthine oxidase (catalyzes the oxidation of purines to uric acid), aldehyde oxidase (metabolism of various nitrogen compounds) and mitochondrial amidoxime reducing component (portion of an enzyme system that could play a role in detoxification in the liver and kidneys). [31][32]
Cobalt (Co) • Cobalt is a necessary component of Vitamin B12 and a fundamental coenzyme of cell mitosis (cell division). • Cobalt is very important for forming amino acids and some proteins to create myelin sheath in nerve cells and plays a role in creating neurotransmitters. • It stimulates the synthesis of erythropoietin which is connected with the formation of erythrocytes (red blood cells) in bone marrow. [33]
Chloride (Cl) • Chloride is one of the most important electrolytes in the blood. It helps keep the amount of fluid inside and outside cells in balance as a primary anion in extracellular fluid. It also helps maintain proper blood volume, blood pressure, and pH of body fluids. [34][35] • It plays a role in regulating fluid secretions, such as pancreatic juice into the small intestine and the flow of water into mucus. [35] • Hydrochloric acid is formed from chloride and aids digestion and prevents growth of unwanted microbes in the stomach. [35] • Red blood cells use chloride anions to remove carbon dioxide from the body. [35]

Selenium (Se)

- Selenium is a constituent of more than two dozen selenoproteins that play critical roles in reproduction, thyroid hormone metabolism, DNA synthesis, protection from oxidative damage and infection and the modulation of growth and development. [36][37][38]
- Selenium-containing enzymes control oxygen-containing metabolites. These metabolites are essential for maintaining cell-mediated immunity against infections. During stress, infection, or tissue injury, selenoenzymes may protect against the damaging effects of hydrogen peroxide or oxygen-rich free radicals. It is also involved in the protection of cell membranes against oxidative damage and is involved in disposal of the products of oxidative metabolism. The antioxidant effect of selenium can prevent the oxidation of LDL cholesterol, reduce inflammation and reduce the amount of sulphur in tissue. [37][38]
- Selenium is essential to normal thyroid function. [37][38]
- Selenoproteins form a component of the mitochondrial capsule of sperm cells, damage to which may account for the development of sperm abnormalities. [37]
- Selenium reduces some toxic elements, such as mercury toxicity, by inhibiting their absorption by forming insoluble compounds. [38]

Silicon (Si)

- Silicon has been indicated in promoting bone health and strength as well as connective tissue through synthesis of collagen and glycosaminoglycans.
- Silica binds to aluminum and can help to prevent the neurodegenerative effects of aluminium.
- It increases the absorption and use of other mineral elements such as magnesium and copper.
- It promotes the immune and inflammatory response because it plays a role in regulating the cell cycle of lymphocytes (white blood cells).
- Silica also plays a role in signal transduction (cellular signals). [29]

REFERENCES

1. Ritchie, H. and Roser, M. (2017). Micronutrient Deficiency. [Online] Available at: https://ourworldindata.org/micronutrient-deficiency [Accessed 16 March 2020].
2. Henao, J. and Baanante, C. (1999). Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands of Africa. Muscle Shoals: International Fertilizer Development Center (IFDC).
3. Jones, D., Cross, P., Withers, P., DeLuca, T., Robinson, D., Quilliam, R., Harris, I., Chadwick, D. and Edward-Jones, G. (2013). The UK National Ecosystem Assessment Nutrient stripping: the global disparity between food security and soil nutrient stocks. Journal of Applied Ecology 50 (851–862).
4. Lyne, J. and Barak, P. (2000). Are Depleted Soils Causing a Reduction in the Mineral Content of Food Crops? [0nline] https://soils.wisc.edu/facstaff/barak/poster_gallery/minneapolis2000a/
5. Dalal, R. and Probert, M. Chapter 4 Soil Nutrient Depletion. Sustainable crop production.
6. Davis, D., Epp, M. and Riordan, H. (2004). Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999. Journal of the American College of Nutrition, 23(6), pp. 669–682.
7. McCance, R. and Widdowson, E. (2000). A Study on the Mineral Depletion of the Foods Available to us as a Nation Over the Period 1940 To 1991. Ministry of Agriculture Fisheries and Foods and the Royal Society of Chemistry.
8. Thomas, D. (2007). The Mineral Depletion of Foods Available to us as a Nation (1940–2002) – A Review of the 6th Edition of McCance and Widdowson. Nutrition and Health. 19, pp. 21–55.
9. Udo de Haes, H., Voortman, R., Bastein, T., Bussink, D., Rougoor, C. and van der Weijden, W. (2012). Scarcity of Micronutrients in Soil, Feed, Food, and Mineral Reserves Urgency and Policy Options. Report and advisory memorandum for the Dutch Minister of Agriculture and Foreign Trade; Platform for Agriculture, Innovation & Society.
10. Marles, R. (2017). Mineral nutrient composition of vegetables, fruits and grains: The context of reports of apparent historical declines. Journal of Food Composition and Analysis, (56), pp. 93–103
11. Marschner, H. (2006). Mineral Nutrition of Higher Plants. 2nd ed. London: Academic Press
12. Brady, N. and Weil, R. (2008). The Nature and Properties of Soil. 14th ed. New Jersey: Pearson Prentice Hall
13. Havlin, J., Beaton, J., Tisdale, S. and Nelson, W. (2005). Soil Fertility and Fertilizers an Introduction to Nutrient Management. 7th ed. New Jersey: Pearson Prentice Hall
14. Hewlings, S. and Kalman, D. (2019). Sulfur in Human Health [Online] Available at: https://www.ecronicon.com/ecnu/pdf/ECNU-14-00660.pdf
15. medlineplus.gov, (2020). Calcium in Diet. [Online] Available at: https://medlineplus.gov/ency/article/002412.htm [Accessed 16 Apr. 2020]
16. und.edu, (2020). The University of North Dakota Fact Sheet Calcium. [Online] Available at: https://und.edu/student-life/dining/_files/docs/fact-sheets/calcium.pdf [Accessed 16 Apr. 2020]
17. Beto, J. (2015). The Role of Calcium in Human Aging. Clinical Nutrition Research. 4, pp. 1-8
18. medlineplus.gov, (2020). Magnesium in Diet. [Online] Available at: https://medlineplus.gov/ency/article/002423.htm [Accessed 16 Apr. 2020]
19. nih.gov, (2020). Magnesium Fact Sheet for Health Professionals. [Online] Available at: https://ods.od.nih.gov/factsheets/Magnesium-HealthProfessional/ [Accessed 16 Apr. 2020]
20. medlineplus.gov, (2020). Zinc in Diet. [Online] Available at: https://medlineplus.gov/ency/article/002416.htm [Accessed 16 Apr. 2020]
21. fao.org, (2020). Zinc. [Online] Available at: http://www.fao.org/3/y2809e/y2809e0m.htm [Accessed 16 Apr. 2020]

22. Harper, J. (2020). What is the Role of Iron in Healthy Individuals? [Online] Medscape. Available at: https://www.medscape.com/answers/202333-153081/what-is-the-role-of-iron-in-healthy-individuals [Accessed 16 Apr. 2020]
23. fao.org, (2020). Iron. [Online] Available at: http://www.fao.org/3/Y2809E/y2809e0j.htm [Accessed 16 Apr. 2020]
24. Bost, M., Houdart, S., Oberli, M., Kalonji, E., Huneau, JF. and Margaritis, I. (2016). Dietary copper and human health: Current evidence and unresolved issues. Journal of Trace Elements in Medicine and Biology. 35, pp. 107-115
25. Nih.gov, (2000). Copper in Drinking Water. [Online] Available at: https://www.ncbi.nlm.nih.gov/books/NBK225407/ [Accessed 16 Apr. 2020]
26. Oregonstate.edu, (2014). Copper. [Online] Available at: https://lpi.oregonstate.edu/mic/minerals/copper [Accessed 16 Apr. 2020]
27. Nih.gov, (2020). Manganese. [Online] Available at: https://ods.od.nih.gov/factsheets/Manganese-HealthProfessional/ [Accessed 16 Apr. 2020]
28. Oregonstate.edu, (2010). Manganese. [Online] Available at: https://lpi.oregonstate.edu/mic/minerals/manganese [Accessed 16 Apr. 2020]
29. Kumar, S. and Trivedi, A. (2016). A Review on Role of Nickel in the Biological System. International Journal of Current Microbiology and Applied Sciences. 5(3), pp. 719-727
30. Pizzorno, L. (2015). Nothing Boring About Boron. Integrative Medicine. 14(4), pp. 35–48
31. Novotny, J. (2011). Molybdenum Nutriture in Humans. Journal of Evidence-Based Complementary & Alternative Medicine. 16(3), pp. 164-168
32. Oregonstate.edu, (2013). Molybdenum. [Online] Available at: https://lpi.oregonstate.edu/mic/minerals/molybdenum [Accessed 16 Apr. 2020]
33. Czarnek, K., Terpilowska, S. and Siwicki, A. (2015). Selected aspects of the action of cobalt ions in the human body. Central European Journal of Immunology. 40(2), pp. 236–242
34. uofmhealth.org, (2019). Chloride. [Online] Available at: https://www.uofmhealth.org/health-library/hw6323 [Accessed 16 Apr. 2020]
35. pressbooks-dev.oer. Human Nutrition, Chapter 3: Water and Electrolytes, University of Hawai'I at Manoa Food Science and Human Nutrition Program. [Online] Available at: http://pressbooks-dev.oer.hawaii.edu/humannutrition/chapter/chloride/ [Accessed 16 Apr. 2020]
36. Nih.gov, (2020). Selenium. [Online] Available at: https://ods.od.nih.gov/factsheets/Selenium-HealthProfessional/ [Accessed 16 Apr. 2020]
37. fao.org, (2020). Selenium. [Online] Available at: http://www.fao.org/3/Y2809E/y2809e0l.htm [Accessed 16 Apr. 2020]
38. Toth, R. and Csapo, J. (2018). The role of Selenium in Nutrition – A Review. Acta Univ. Sapientiae, Alimentaria. 11, pp. 128 – 144
39. Farooq, M. and Dietz, K. (2015). Silicon as Versatile Player in Plant and Human Biology: Overlooked and Poorly Understood. Frontiers in Plant Science. [Online] Available at: https://www.frontiersin.org/articles/10.3389/fpls.2015.00994/full (Accessed 16 Apr. 2020]