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Nutrients and Crop Production

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ABSTRACT

The rapid increase in population pressurized the food security concerns, and these may be solved by using sustainable crop production. Sustainable crop production requires 18 essential elements known as nutrients. Plant growth and development for more yield require nutrients, which can be categorized into three groups, i.e. basic, macro and micronutrients, according to crop demand. These nutrients are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), zinc (Zn), copper (Cu), nickel (Ni), iron (Fe), chlorine (Cl), molybdenum (Mo), manganese (Mn), cobalt (Co) and Boron (B). These are the keys to crop production and the sustainability of soil systems to maintain the ecosystem. Many of them are required for normal biochemical processes and to improve the crop defense against diseases and pests, and finally, they play a key in completing the plant life cycle. More gain in crop production without suitable application of nutrients to the soil body leads to many problems in the soil system, and low fertility is one of them. More production or Intensive cultivation deteriorates the soil health; that's why the balanced application of nutrients must be in consideration to attain maximum production to feed the population. This review refines the knowledge of readers about the role, importance, deficiency, application and toxicity of nutrients for crop production.

Keywords: *Food security, sustainable production, biochemical processes, defence, production,*

INTRODUCTION

The increasing population demands more food production, and the world is already facing various problems in getting sufficient amounts of available food without deteriorating valuable resources such as soil. Many countries face nutrient-deficient conditions, and one-third of the world's population is affected by micronutrient-deficient conditions known to be "hidden hunger" (FAO, 2013; & Saeed et al., 2020). Now, hidden hunger is seriously threatening the human population. Developing nations are currently facing the deficiency of many elements, such as nutrient-deficient crops sorghum and maize in Africa while wheat and rice in Asia (Fang et al., 2008).

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Justus Von Liebig (1803-1873) was a pioneer in scattering information about crops' mineral nutrition. His study revealed that individual minerals might be limiting factors for plant growth (Sinclair & Park, 1993). More than 100 elements are components of the plant body, but 17 elements are proven to be essential for the completion of the plant life cycle, and human being's welfare requires 22 elements (Welch & Graham, 2004; Graham et al., 2007; & Toor et al., 2021).

Essential elements (18) are classified into two groups (macro and micro) on the basis of quantity required by the plants. Macronutrients required by the plants in higher concentrations, while micronutrients required in small amounts and micronutrients are also known to be minor are trace elements. Macronutrients group include total nine elements such as carbon (C), hydrogen (H), oxygen (O), nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg) and sulfur (S) while in micronutrient group such as iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), boron (B), cobalt (Co), molybdenum (Mo), chlorine (Cl), and nical (Ni) (Brady & Weil, 2008; & Toor et al., 2021).

The productivity of crops depends on the availability of nutrients and nutrient availability enhanced by the application of fertilizers. On the other hand, excessive use of fertilizer may cause the introduction of heavy metals to soil system later they deteriorating the soil quality and normal plant growth (Ali et al., 2022c) and also Wasaya et al. (2019) reviewed that imbalance nutrition considered as the main hindrance towards sustainable crop production. Acosta-Durán et al. (2007) studied that plant nutrition depends on the availability of macro and micronutrients and their uptake by the plants that are enclosed in the soil body. Fageria (2001) showed that many researchers study the effect of a single nutrient on plant growth while all other remaining factors are negligible; on the other hand, researchers studied multi-nutrient interaction with crops, which results in additional nutrients causing the immersion of the main nutrient, effect on crop growth.

The productivity and quality of agricultural products depend on plant nutrition, and crop production must remain the soil nutrient at a sufficient level. Fertilizer addition is a way, but excessive use causes the addition of heavy metals to the soil body. Savci (2012) showed that excessive fertilizer use causes nitrate accumulation, eutrophication of water resources and unnecessary phosphorus application, which badly affects the water quality. According to Byrnes and Bumb (1998), the world population grow from 6 billion to 10 billion by 2050. Micronutrient deficiencies are widespread in well-developed countries, and more than 3milion people are facing iron and zinc deficiency (Graham et al., 2001).

This review will discuss the recent information concerning nutrients and their use in sustainable agriculture for plant growth.

Macronutrients, classification and their importance

The plants require Such elements in large quantity, and their availability or deficiency directly influences the plant growth. This nutrient can be classified into three categories;

a) Basic nutrients
b) Primary nutrients and
c) Secondary

Basic nutrients

Carbon, hydrogen and oxygen are three considerable nutrients taken up by plants through air and water.

Primary and secondary nutrients

While others obtained only by roots are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). These primary and secondary nutrients play significant role in various valuable activities in the entire plant life cycle and protect plants from biotic and abiotic stresses, which include drought, salinity, temperature ultraviolet radiations, insect pest attacks and diseases (Rowley et al., 2012; & Morgan & Connolly, 2013).

Nitrogen:

Nitrogen is the first and most important primary nutrient, which is present in tasteless and colourless gas, which makes up about

78.09% of the total earth's atmosphere by quantity, total plant protein 16% and plant dry matter about 1.5-2.0% (Alvarez et al., 2012). Plants take nitrogen from various sources like water, rain, air and fertilization in its various forms such as ammonia, amino acid, nitrate and nitrite, and sometimes it is available in its molecular form (N_2) directly (Khajuria & Kanae, 2013). Nitrogen is a key factor for crop production. It is an essential component of all proteins and enzymes (Street & Kidder, 1997), an essential constituent of chlorophyll (Nursu'aidah et al., 2014) and metabolic processes in energy transformation, so it is required in enough amounts. It increases vegetative growth, plays a role in the synthesis of starch and protein, and gives a dark color to crop plants. In four major agronomic crops, wheat, cotton, rice and sugarcane, nitrogen enhances productivity and quality of food.

In wheat vegetative growth, shoot length, plant height, number of tillers, number of spikelets per spike, length of the spike, grain per spike, spike length, root length and thousand-grain weight is enhanced by increasing nitrogen supply. Leghari et al. (2016) concluded that rice N at 120kg ha^{-1} showed encouraging results in vegetative growth, dry weight, filled grains, straw yield, number of tillers, harvest index, biological yield and grain yield 4.66 $tons^{-1}$ha and in sugarcane crop cane weight increases as well as with vegetative growth. Chen et al. (2019) found that cotton N application at 100kg ha^{-1} produces more monopodial branches, which at least produce more than 100 seed weight and average boll weight.

Nitrogen deficiency causes chlorosis or yellowing, stunted plant growth, and necrosis starts at the tip of leaves and moves toward midrib. As a result, leaves start falling down. In tomato, the color of the stem becomes purple, flower buds start yellowing, and flowering dropping increase. Nitrogen toxicity causes disturbance in normal photosynthesis, respiration, carbohydrate formation process, activity of enzymes and normal water uptake process (Goyal & Huffaker, 1984).

Phosphorus:

Phosphorus is the second most important primary nutrient after nitrogen, so it is an essential component in plant growth and development. Its availability in soil is very low, so organic phosphate is exogenously used to obtain high crop yield (Huang et al., 2011). Jia et al. (2011) proposed that Phosphate transporters are involved in the translocation and uptake of inorganic (pi) form from the soil, and in rice, the OsPht1 PT gene from the Pht1 family does phosphorus homeostasis. Plants uptake phosphorus in the form of PO_4^-, $H_2PO_4^-$ and HPO_4^{2-} through mass flow and diffusion action.

In cell membranes of plants, phosphate is abundantly present and an essential component of most organic compounds which is the main constituent of nucleic acid, proteins, ATP, enzymes, sugar phosphate, DNA, RNA and phospholipid (Brown & Weselby, 2010). Phosphorus is an essential component of photosynthetic activities which are directly involved in the creation of starch, oil, and sugar, convert solar energy into chemical energy, proper plant maturation, improving water use efficiency and protecting the plant from harsh winter conditions (Zewdie & Reta, 2021). It plays a role in cell division, seed, and fruit development and helps roots to move down to get nutrients and water. In sugarcane early shoot, root development, tillering, productivity, internode length, quality and yield increase. Ahmad et al. (2009) concluded that by addition of phosphorus growth and yield parameter of cotton, which include a number of bolls per plant, the weight of balls and seed cotton yield increases while quality components (percentage of lint, fiber strength, fiber length) also increases from 2 to 5%. In agronomic crops like wheat and maize, phosphorus improved quality in different ways, which included increased drought resistance, better feed value, improved winter survivability, high marketable yield, high sugar content and less disease loss (KOW & Nabwami, 2015).

In the leaves of crop plants, due to a deficiency of phosphorus, a decline in cell elongation and cell division is recognized (Kavanova et al., 2006). Takagi et al. (2020) concluded that phosphorus toxicity in plants causes activation of the phytic acid pathway in leaves with limitation of photosynthesis activities and results in Cu/Zn-SOD activities.

Potassium:

Potassium is an essential nutrient absorbed by plants in larger amounts than any other nutrient except nitrogen (Roy et al., 2006). Potassium is not incorporated into the structure of organic compounds like many other nutrients, phosphorus and nitrogen; many cellular enzymes are activated by potassium because it presents in ionic form (K^+) in the solution (Nijira & Nabwami, 2015). In the vascular region of the cell, its concentration is 20 mM, while in cytosol, its highest concentration is available, which is 30-50 mM (Fernando et al., 1992). Its nature is mobile in plants and present in younger parts. Jiang et al. (2018) reviewed that potassium plays a vital role in physiological processes like ATP formation, water and nutrient uptake, and growth under harsh environments, so it enhances the crop's yield and quality. Potassium is responsible for the activation of biosynthesis of NADPH (nicotinamide adenine dinucleotide phosphate), which is a key factor in photosynthesis (Pfluger & Mengel, 1972).

Different metabolic processes, activation of enzymes, photosynthesis, synthesis of amino acid and protein, movement of sugar and starch through the plant parts, cell division, and elongation take place. Opening and closing of stomata is dependent on k ions because their movement checks the loss of water, which protects the plant from drought risk. Wakeel et al. (2011) observed that potassium is associated during the entire protein synthesis process, mainly from the binding of transfer RNA to ribosomes. Among all plant nutrients, potassium has the strongest influence on quality attributes like human health-associated bioactive compounds (beta carotene and ascorbic acid) or phytonutrients, consumer preference and fruit marketability (Lester et al., 2010). Oil and protein content is increased, improving cereals' nutritive value and resistance to injury during storage. Recent studies have shown that the yield of rice, wheat and sugarcane increases with the application of potassium.

Initially, potassium deficiency causes growth reduction. Later on, chlorosis and necrosis occur (Mengel & Kirkby, 2001). Small whitish-yellow coloured necrotic spots also develop along the leaf margin, and this chlorosis along the margin towards the base of the leaf usually leaves the midrib alive and green (McCauley et al., 2009). Xu et al. (2020) studied that the toxicity of potassium causes hindrance in root growth and disturbances in the supply and distribution of photosynthesis products with a lowering in the (^{13}C) carbon assimilation in leaves. Photochemical efficiency and electron transfer efficiency of photosystem II (PSII) reaction centre (Zhang et al., 2009; & Pettigrew, 2008).

Calcium:

Calcium is the fifth most abundant element on earth's crust and the fifth most important liquefied ion in the ocean (Krebs et al., 2006). Calcium is an essential plant nutrient. It is required in the form of (Ca2+) which play an important role in the middle lamella (ca-pectates) of the cell wall, cell membrane, activation of several critical enzymes, membrane permeability and cell division and elongation (Brady et al., 2008). Calcium enters through roots from soil solution into plant body, and foliar application of calcium improved quality characteristics such as fruit's calcium content, which increased from 50-150 mg/kg (Lanauskas & Kvikliene, 2006). It is less mobile, so its effect on crop quality is easily noted with foliar application. Calcium boosts nutrient uptake, strengthens the cell wall, promotes root system development, and improves plant tissue resistance (Berridge et al., 2000). Kudla et al. (2010) noticed that calcium has many advantageous signalling channels, such as Ca^{2+} - ATPase's, $Ca^{2+/}H^+$ antiporters, which protect plants from various biotic and abiotic stresses where channels of porous calcium ion are accountable for drought stress signal transduction. In tobacco, under NaCl stress, the HSP gene successfully expressed a calcium signalling pathway (Li et al., 2014). Many transcription factors like SR/CAMTA perform a greater role in various stress, including pathogen stress, drought, cold, wounding, and auxin, MeJA and ethylene. (Yang et al., 2013).

Calcium deficiency causes younger leaves to become yellow and dark abnormally into dark green. Leaf tips often become dry or brittle, and the plant will die. Stems result in weak, and germination is poor (McCauley et al., 2009).

Magnesium:

Magnesium is another secondary nutrient element. It Is the eighth most abundant element on earth's crust and ninth in the universe, and it is a very common element of all living beings (Luft, 2012). Its concentration is about 0.2-0.4% of plant dry matter in plants, and its requirement is 1.5-3.5 g per kg in vegetative parts (Chen & Ma, 2013). It is a component of chlorophyll, photosynthesis, a component of ribosomes, and carbohydrate metabolism, and it's an active component of the electron transport chain during the entire process. Mg has a significant role (Ding et al., 2008). Waraich et al. (2012). I was reported that when magnesium content is present at the appropriate level in pepper, mulberry, bean and maize, the content of antioxidant molecules and action of antioxidant enzymes increases. Magnesium is required by many enzymes and enzymatic activities, carboxylase, and adenosine triphosphate and plays an important role in the central atom in the structure porphyrin of the chlorophyll molecule (Grusak, 2001).

McCauley et al. (2009) described the symptoms of magnesium deficiency include interveinal chlorosis and leaf margins becoming yellow or reddish-purple while midrib remains green. Deficiencies can be corrected by applying magnesium fertilizer in adequate amounts.

Sulphur

Sulphur is one of the essential secondary elements required by the plants in suitable concentration for normal growth and reproduction. Sulphur is required by plants for the formation of chlorophyll, amino acids (cysteine, cystine, methionine), protein and activation of enzymes involved in the many metabolic processes. It also increases the N, K, and P uptake, defence against various stresses, and increases starch content in tubers, as a result, helps in crop productivity (Hawkesford et al., 2012). Sufficient supply of this nutrient helps in biological nitrogen fixation. Sulphur-deficient plants have short or spindly stems and yellowing of the younger or newly growing leaves. Canola-deficient plants showed upward curling, purpling of leaves, and delayed and prolonged flowering with smaller pods or few flowers (Malhi et al., 2005). A combination of sulphur-containing fertilizers with other nutrients can correct nutrient deficiency. These fertilizers are such as ammonium sulphate and potassium sulphate fertilizers (Yoshida & Choudhry, 1979). Sulphur toxicity causes yellowing or chlorosis of the whole leaf surface, and toxicity symptoms appear on older leaves.

Table1. Conclusive table of macronutrients, their form of uptake, and mobility in soil and plant systems with references

Nutrients	Uptake form	Mobility in Plants	Mobility in Soil	References
Carbon (C)	CO_2, $H_2CO_3^-$	-	-	-
Hydrogen (H)	H^+, OH^-, H_2O	-	-	-
Oxygen (O)	O_2	-	-	-
Nitrogen (N)	NH_4^+, NO_3^-	Mobile	Mobile as NO_3^-, Immobile as NH_4^+	Zhang et al., 2019
Phosphorus (P)	HPO_4^{2-}, $H_2PO_4^-$	Somewhat Mobile	Immobile	Hasan et al., 2016
Potassium (K)	K^+	Very mobile	Somewhat mobile	Xu et al., 2020
Calcium (Ca)	Ca^{2+}	Immobile	Somewhat mobile	Pj, 2003
Magnesium (Mg)	Mg^{2+}	Somewhat Mobile	Immobile	Guo et al. 2016
Sulphur (S)	SO_4^-	Mobile	Mobile	Davidian and Kopriva, 2010

Micronutrients

Elements required in trace quantity or small amounts are known to be micronutrients. These essential nutrients are such as iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), cobalt (Co) and medical (Ni). These nutrients are required in trace quantity but essential as macronutrients, and they perform multifunctions in crop plants. Micronutrient functions and their role in the management of plant disease are described in the following manners;

Iron

It is the second most abundant metal in the earth's crust after aluminium and is a component of many proteins (i.e. heme protein and Fe-S protein) and Fe-requiring enzymes (Broadley et al., 2012). Plants uptake iron by the two strategies. Through strategy **I,** non-graminaceous species release phenolic compounds and organic acids to increase Fe+3 concentration, which reduces to Fe+2 by ferric reductase, while strategy **II** graminaceous like grasses and cereals that chelates Fe+3 in the rhizosphere by phytosiderophores whose complex is taken up by the roots (Ali et al., 2022).

Plants require iron for chlorophyll synthesis, maintenance of chloroplast structure, and their functions and is also involved in DNA synthesis, respiration and photosynthetic activities. Furthermore, many metabolic pathways are activated by iron and prosthetic group constituents of many enzymes (Rout & Sahoo, 2015). Kim and Rees (1992) found that, as a critical component of protein and enzymes, iron is involved in many biological processes such as photosynthesis, chlorophyll formation, nitrogen fixation, respiration, uptake mechanism and DNA synthesis through the action of ribonucleotide reductase (Reichard, 1993).

Zinc

Zinc is considered an essential bio-element for crop growth, development and reproduction. Cereal crops grow in deficient soils, resulting in many times lower grains. Ali et al. (2021) reviewed that micronutrient deficiency generally zinc occurs in the soil due to crop intensification, and that lead to the degradation of micronutrients in soil and plant system. Rudani et al. (2018) reviewed that zinc plays a critical role in the defence against plant diseases, cell membrane integrity, protein synthesis, and pollen formation, and enhances the level of chlorophyll and antioxidants in plant tissue.

Zinc deficiency shows various types of symptoms such as chlorosis, necrotic spots, stunting of plants, resetting of leaves, bronzing of leaves and malformed leaves. Symptoms of deficiency first appear on the younger leaves because zinc is immobile in the plant system, and in the case of wheat, a reduction in grain yield and nutritional quality was observed (Rudani et al., 2018). Deficiency can be corrected by using zinc-containing fertilizers (ZnSO4). Increasing fertilizer increases the rate of availability of zinc to plant systems, but this is not an economical approach to overcome the deficiency (Ali et al., 2021).

Boron

Boron is taken up by the plant roots in the form of boric acid $(H_3BO_3)^o$ and/or borate $[B(OH)4]^{-1}$ (Jiao et al., 2005). Boron amount and availability to plants is affected by the soil pH, texture, soil moisture or temperature, $CaCO_3$ and organic matter contents. Cellulose synthesis is also affected by boron deficiency. Dridine diphosphate glucose (UDPG)- the deficiency also inhibits pyrophosphorylase and causes a decrease in UDPG responsible for cellulose synthesis (Shaaban, 2010). Camacho-Cristóbal et al. (2008) showed that boron deficiency causes a rapid reduction in the expression of several AGP genes in Arabidopsis roots.

Many researchers reported that boron deficiency on shoots caused crinkle, stunted, and upwards cupping of leaves, aborted growing tips, decreased leaf expression, fast-growing axillary shoots, yellow and red veins on terminal shoots, dead terminal shoots and at last, dieback of the shoots (Brown & Hu, 1996; & Jiao et al., 2005). It was also reported that boron-deficient plants resulted in flattened or misshapen fruits, internal cork russet and cracking in apples, drought spots, premature ripening, low seed count, and increased fruit drop (Brown & Hu, 1996).

It was also found that wheat grain yield has been increased by the application of Boron (Halder et al., 2007), sunflower yield has been reduced by deficiency (Blamey et al., 1997), and an increase in tomato yield was observed (Oyinlola, 2005), maize, rice, soybean, and sugar beet have also observed positive impacts on grain yield (Li & Liang, 1997). It was generally accepted that Boron has a narrow range between deficiency and toxicity in plants (Manscher, 1995). Toxicity causes inhibition of cell division and elongation, disruption in metabolic processes and disruption of cell walls (Reid et al., 2004; & Stangoulis & Reid, 2002).

Chlorine

Essential element for several physiological functions in plants, especially stomatal opening and closing. Plants uptake chlorine in the Cl- and some plants have the ability to uptake some metal-Cl complex such as CdCl+ but in minimal percentage (Weggler et al., 2004). Li et al. (2002) described that chlorine accumulates more in elder leaves than in younger ones due to its characteristics of immobility.

Marscher (2011) described chlorine as essential for stomatal functioning in *Allium cepa*. Various studies show that chlorine is essential for water splitting reaction or Hill reaction in photosystem II (Chen et al., 2010). Hang and Guorui (1993) reported that chlorine affects uptakes and utilization of nitrogen (N), phosphorus (P), potassium (K), manganese (Mn), silicon (Si), sulphur (S), zinc (Zn), magnesium (Mg), iron (Fe), copper (Cu), in higher plants. Wang et al. (1990) suggested that Cl affects phosphorus (P) level intake once the Cl is above 400mg/kg.

The studied literature supported that Cl enhances plant resistance against diseases requiring a large amount of Cl. Many diseases in crop suppressed by Cl at their level of macronutrients, these include corn (*Zea mays* L.) stalk rot, *Gibberella zeae* (Warren et al., 1975), or *Gibberella fujikuroi* (Younts & Musgrave, 1958), stripe rust of wheat (Taylor et al., 1983), and downy mildew (*Sclerophthora macrospora*) of millet (*Pennissetum typhoids* L.) (Hedge & Karande, 1978).

Diaz-Zorita et al. (2004) reported that wheat grains yield was enhanced by the application of Cl @ 253 kg/ha^{-1}, and this study indicated that wheat and barley were more responsive to KCl fertilization than oats. Randle (2004) studied that onion required an amount of chloride, which was verified from this vegetable's epidermal layer colour. Many studies showed that chlorine fertilizer can obtain rice, wheat, rape, Chinese cabbage and asparagus increasing yield (Li et al., 1989; & Chen et al., 2010). Smith et al. (1987) described that leaves and roots, besides cell division and cell extension, are particularly impaired in Cl-deficient plants. Higher amounts of Cl in plants and soil systems pose salinity stress to plants. The deficiency of Cl could be corrected by the application of fertilizers (KCl) in adequate amounts.

Copper

As essential redox-active metal involved in the many physiological functions or processes in plants and under physiological conditions, Cu exists as Cu^{2+} and Cu^{+}. Gad and Hasan (2013) described that Cu is an essential heavy metal that actively participates in photosynthesis. Soil is one of the most vital natural sources, and its quality could deteriorate due to many factors, such as excess copper (Cu) and other heavy metals added by the long-term use of the wastewater (Ali et al., 2022a, 2022b). Also act as cofactors for various enzymes such as Cu/Zn superoxide dismutase (SOD), amino oxidase, laccase, cytochrome c oxidase, plastocyanin, and polyphenol oxidase. At the cellular level, Cu plays a key role in the signalling of transcription and protein trafficking machinery, mobilization of iron and oxidative phosphorylation (Yruela, 2005). Many reviews showed that Cu acts as a structural element in regulatory protein and participates in photosynthetic electron transport, respiration in mitochondria, response to oxidative stress, metabolism in the cell wall, and signalling of hormones (Marschner, 1995; & Raven et al., 1999).

Essential elements are necessary to maintain a a low level in plant tissues, and plants find a variable supplies of Cu in the soil solution ranging from 10^{-6} to 10^{-9} M, but plants need to solubilize this metal. Baker and Senef (1995) concluded that the average content of Cu in plant tissue is 10µg.g^{-1} dry weight. No specific transporter involved in Cu uptake from the environment has been characterized to uptake, but there was evidence that Cu is reduced.

Cu deficiency symptoms first appear on the tips of the younger leaves and extend towards the leaf margin. Marschner (1995) showed that leaves may also be twisted or malformed and show chlorosis, even necrosis. Cu deficiency was found to reduce photosystem I (PSI) electron transport due to decreased formation of plastocyanin and also a decrease in efficiency of photosystem II (PSII) activity due to Cu deficient chloroplast (Shikanai et al., 2003; & Dropa & Horváth, 1990). Excessive accumulation of Cu causes oxidative stress in plants and subsequently increases in antioxidative in plants due to increased production responses of highly toxic oxygen free radicals. Both photosystem II (PSII) sides were suggested as the main targets of Cu toxic action, and many researchers suggested reduced chlorophyll contents in plant leaves grown at higher concentrations (Yruela, 2005).

Manganese

One of the main micronutrients that has an important role in plants is a component of enzymes involved in photosynthesis and plant physiological processes. Uptake by the plants in divalent ion (Mn^{2+}) and considered an important antioxidant structure that protects plant cells by deactivating free radicals which can destroy plant tissues. As a vital role in photosynthesis, Mn is considered as a structural component of the photosystem II (PSII) water splitting protein. Mn served as electron storage and delivery to the centre of the chlorophyll reaction (Diedrick, 2010; & Millaleo et al., 2010).

Total Mn in soil ranges from 20 to 3000 ppm and averages 600 ppm. Mn occurs as exchangeable manganese, manganese oxides, organic manganese, and a component of Ferro-manganese silicate mineral. Divalent ions of manganese (Mn^{2+}) are absorbed by clay minerals and organic colloids and divalent ions concerned with plant uptake (Mousavi et al., 2011). Mn deficiency first appears on younger leaves due to immobility in plant systems, but magnesium deficiency first appears on older leaves (Sharma et al., 1991; & Longnecker et al., 1991). Mn deficiency symptoms are similar to Mg because there comes yellow in both intercostal, reduction in overall chlorophyll contents and amount of photosynthesis due to chlorophyll deficiency (Ndakidemi et al., 2011; & Polle et al., 1992). Manganese deficiency has a very serious effect on non-carbohydrates (root carbohydrates especially), and a major deficiency is in the reduction in the efficiency of photosynthesis that leads to a reduction in dry matter productivity and yield (Mousavi et al., 2011).

Mn toxicity varies with plant species and environmental conditions. Brown spots on mature leaves and chlorotic dots at the tips of the younger leaves due to toxicity. To deal with deficiency, the use of Mn containing fertilizer is the best solution, and Mn toxicity can be eliminated with a high amount of magnesium (Rezai & Farbodnia, 2008; & Wu, 1994).

Nical

Essential micronutrients are considered heavy metals but necessary for plant growth and development (Eskew et al., 1983). It is mostly uptake by the plants in divalent cations (Ni^{2+}) and becomes toxic for plants at higher concentrations. The phytotoxicity of heavy metals is closely related to the production of reactive oxygen species (ROS) in plants (Selmeczi et al., 2004). It has demonstrated that medical and cadmium significantly increase the content of H_2O_2 (Pandolfini et al., 1992) and lipid peroxidation in a few species (Bates et al., 1973). The amount of the nical required by plants in very low concentration and adequately provided by soil, and his deficiency symptoms do not appear in normal conditions; they just stopped the conversion of urea to ammonia in the plant system (Uruc Parlak, 2016)

Several research results showed that decrease in chlorophyll content in the leaves was observed due to their treatments with nical in higher concentration (Pandey & Sharma, 2002; Gajewska et al., 2006; & Severgin & Kozhevnikova, 2006) and that resulted in reduced photosynthetic efficiency of crops. Such chlorosis results from iron and magnesium deficiency and chlorophyll synthesis inhibition (Seregin & Kozhevnikova, 2006). In plants, proline plays a key role in the recovery from environmental stresses, including salinity, drought, and heavy metals toxicity, which induce proline accumulation in plants (Stadtman, 1996). Many results suggested that higher initial levels can cause membrane damage through the production of ROS and interface with chlorophyll metabolism (Uruc Parlak, 2016).

Molybdenum

Element required by plants in trace quantity for the growth and development of many biological organisms, including plants and animals. Molybdenum becomes more soluble and accessible to plants, mainly in its anionic form as MoO^{-}_{4}. Transitional elements in various states vary from zero (0) to VI, and VI is abundantly found in agricultural soils (Kaiser et al., 2005).

Visual symptoms of deficiency develop pale green leaves, at times, necrotic regions at leaf margins, which decrease overall plant growth (Chatterjee & Nautiyal, 2001; & Agarwala et al., 1978). Mo deficiency in maize shortens internodes, decreases leaf areas and, as a result, causes the development of chlorotic leaves (Agarwala, 1978). Alter in phenotypes of maize flowers, delayed emergence of tassels, small anthers, poorly developed stamens, and reduced pollen grain development (Agarwala, 1979).

In contrast with other, micronutrient (Mo) toxicity is rare under normal condition agricultural conditions and in highly contaminated soil, plants have leaves that have been shown yellow colour (Bergmann, 1992; & Gupta, 1977). Miller et al. 1991 stated that consumption of Mo rich fodder or feed results in the molybdenosis and simultaneously induces copper deficiency in animals.

Cobalt

Element recognized as essential as many micronutrients, necessary for nitrogen (N) fixation occurring within the nodules formation of legumes and uptake by the plants in the form of divalent cations (Co_2^{+}).

Co is required in adequate amounts by plants for nitrogen fixation, while leguminous species that grow in Co deficient conditions produce nitrogen deficiency symptoms due to inadequate production of B_{12} synthesis. Co deficiency produces symptoms such as leaf chlorosis and necrosis, growth retardation, and reduced crop yield, resembling N-deficiency in plants (Uchida, 2000). Cobalt-deficient legumes produce smaller plant sizes, pale yellow leaves, and smaller pods than non-deficient plants. To correct the Co deficiency applications, cobalt containing fertilizer ranges from 1.8-1.45g per hectare was reported (Hu et al., 2021). Asati et al. (2016) reported that heavy metal (Co) decreased the rate of seed germination, root length, shoot length and phenolic contents in broad beans (*Vicia faba* L.).

Conclusive table of macronutrients, their form of uptake, and mobility in soil and plant systems with references

Nutrients	Uptake form	Mobility in Plants	Mobility in Soil	References
Iron (Fe)	Fe^{2+}, Fe^{3+}	Immobile	Immobile	Schmidt et al., 2020
Copper (Cu)	Cu^{+}, Cu^{2+}	Immobile	Immobile	Printz et al., 2016
Zinc (Zn)	Zn^{2+}	Immobile	Immobile	Liu et al., 2019
Manganese (Mn)	Mn^{2+}	Immobile	Mobile	Alejandro et al., 2020
Boron (B)	H_3BO_3, BO_3^{-}	Immobile	Very mobile	Shireen et al., 2018
Molybdenum (Mo)	MoO_4^{-}	Immobile	Somewhat mobile	Kaiser et al., 2005
Chlorine (Cl)	Cl^{-}	Mobile	Mobile	White and Broadly, 2001
Cobalt (Co)	Co^{2+}	Immobile	Somewhat mobile	Hu et al., 2021
Nical (Ni)	Ni^{2+}	Mobile	Somewhat mobile	Kumari et al., 2018

CONCLUSION

It could be concluded that all these nutrients are necessary for crop growth and development. Any other essential or non-essential element can't replace the function of other ones. Their deficiency retards the crop growth, while application enhances the growth with the edge of providing resistance against diseases and pests. While on the other hand, toxicity leads to crop death. So, the sustainable application of nutrients resulted in the balancing of soil health and crop production. With a proper application, global food security demand may be reached, which results in the welfare of human beings.

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REFERENCES

Acosta-Durán, C. M., Ocampo, D., Cedillo, E., & Nava, L. M. (2007). Effect of calcium sulphate and biosolids in crop yield peanut (Arachis hypogaea L.). *Agric. Res. 4*(1), 31-38.

Agarwala, S. C., Sharma, C. P., Farooq, S., & Chatterjee, C. (1978). Effect of molybdenum deficiency on the growth and metabolism of corn plants raised in sand culture. *Canadian Journal of Botany*, *56*(16), 1905-1908.

Agarwala, S. C., Chatterjee, C., Sharma, P. N., Sharma, C. P., & Nautiyal, N. (1979). Pollen development in maize plants subjected to molybdenum deficiency. *Canadian Journal of Botany*, *57*(18), 1946-1950.

Alejandro, S., Höller, S., Meier, B., & Peiter, E. (2020). Manganese in plants: from acquisition to subcellular allocation. *Frontiers in Plant Science*, *11*, 300. https://doi.org/10.3389/fpls.2020.00300

Ali, S., Mahmood, T., Ullah, S., Aslam, Z., Nasir, S., Zain, R., & Zain S. (2021). Review: Biofortification of Cereals with Zinc through Agronomic Practices. *International Journal of Agricultural and Applied Sciences, 2*(2), 14-19.

Ali, S., Riaz, A., Shafaat, S., Sidra, Shakoor, K., Sufyan, M., Huzaifa, M., Imtiaz, S., & Ur Rehman, H. (2022). Biofortification of Cereals with Iron through Agronomic Practices, *Curr. Rese. Agri. Far. 3*(5), 11-16.

Ali, S., Ullah, S., Umar, H., Aslam, M. U., Aslam, Z., Akram, M. S., Haider, H., Nasir, S., Hayat, S., & Zain, R. (2022a). Effects of Wastewater use on Soil Physico-chemical Properties and Human Health status, *Ind. J. Pure App. Biosci. 10*(2), 50-56.

Ali, S., Ullah, S., Umar, H., Saghir, A., Nasir, S., Aslam, Z., M. Jabbar, H., ul Aabdeen, Z., & Zain, R. (2022c). Effects of Heavy Metals on Soil Properties and their Biological Remediation, *Ind. J. Pure App. Biosci. 10*(1), 40-46.

Ali, S., Ullah, S., Umar, H., Usama Aslam, M., Saghir, A., Nasir, S., Imran, S., Zain, S., & Zain, R. (2022b). Influence of Slope variation on northern areas on soil physical properties, *Ind. J. Pure App. Biosci. 10*(2), 38-42.

Asati, A., Pichhode, M., & Nikhil, K. (2016). Effect of heavy metals on plants: an overview. *International Journal of Application or Innovation in Engineering & Management*, *5*(3), 56-66.

Bates, L. S., Waldren, R. P., & Teare, I. D. (1973). Rapid determination of free proline for water-stress studies. *Plant and soil*, *39*(1), 205-207.

Bergmann, W. (1992). Nutritional disorders of plants: visual and analytical diagnosis (English, French, Spanish).

Blamey, F. P. C., Asher, C. J., & Edwards, D. G. (1997). Boron toxicity in sunflower. In *Boron in soils and plants* (pp. 145–149). Springer, Dordrecht.

Brady, N. C., & Weil, R. R. (2008). The nature and properties of soils. *Pearson Education, Inc., Upper Saddle River, New Jersey*, 07458. 13, 662–710.

Broadley, M., Brown, P., Cakmak, I., Rengel, Z., & Zhao, F. (2012). Function of nutrients: micronutrients. In *Marschner's mineral nutrition of higher plants* (pp. 191-248). Academic Press.

Broadley, M., Brown, P., Cakmak, I., Rengel, Z., & Zhao, F. (2012). Function of nutrients: micronutrients. In *Marschner's mineral nutrition of higher plants* (pp. 191–248). Academic Press.

Brown, P. H., & Hu, H. (1996). Phloem mobility of Boron is species dependent: evidence for phloem mobility in sorbitol-rich species. *Annals of Botany*, *77*(5), 497-506.

Byrnes, B. H., & Bumb, B. L. (1998). Population growth, food production and nutrient requirements. *J. Crop Prod. 1*(2), 1–27.

Camacho-Cristóbal, J. J., Herrera-Rodríguez, M. B., Beato, V. M., Rexach, J., Navarro-Gochicoa, M. T., Maldonado, J. M., & González-Fontes, A. (2008). The expression of several cell wall-related genes in Arabidopsis roots is down-regulated under boron deficiency. *Environmental and Experimental Botany*, *63*(1-3), 351-358.

Chatterjee, C., & Nautiyal, N. (2001). Molybdenum stress affects the viability and vigour of wheat seeds. *Journal of Plant Nutrition*, *24*(9), 1377-1386.

Chen, W., He, Z. L., Yang, X. E., Mishra, S., & Stoffella, P. J. (2010). Chlorine nutrition of higher plants: progress and perspectives. *Journal of Plant Nutrition*, *33*(7), 943-952.

Davidian, J. C., & Kopriva, S. (2010). Regulation of sulfate uptake and assimilation—the same or not the same? *Molecular Plant*, *3*(2), 314-325.

Díaz-Zorita, M., Duarte, G. A., & Barraco, M. (2004). Effects of chloride fertilization on wheat (Triticum aestivum L.) productivity in the sandy Pampas region, Argentina. *Agronomy Journal*, *96*(3), 839-844.

Diedrick, K. (2010). Manganese fertility in soybean production. *Pioneer Hi-Bred agronomy sciences*, *20*(14), 23-28.

Droppa, M., & Horváth, G. (1990). The role of copper in photosynthesis. *Critical Reviews in Plant Sciences*, *9*(2), 111-123.

Eskew, D. L., Welch, R. M., & Cary, E. E. (1983). Nickel: an essential micronutrient for legumes and possibly all higher plants. *Science*, *222*(4624), 621-623.

Fageria, V. D. (2001). Nutrient interactions in crop plants. *J. Plant Nutr. 24*(8), 1269-1290.

Fang, Y., Wang, L., Xin, Z. H., Zhao, L. Y., An, X. X., & Hu, Q. H. (2008). Effect of foliar application of zinc, selenium, and iron fertilizers on nutrients concentration and yield of rice grain in China. *Journal of Agricultural and Food Chemistry, 56*, 2079–2084.

FAO, (2013). The State of Food and Agriculture, Food and Agriculture Organization. Rome.

Gad, N., & Hassan, N. M. (2013). Role of cobalt and organic fertilizers amendments on tomato production in the newly reclaimed soil. *World Applied Sciences Journal*, *22*(10), 1527-1533.

Graham, R, D., Welch, R. M., Saunders, D. A., Ortiz-Monasterio, I., Bouis, H. E., Bonierbale, M., de Haan, S., Burgos, G., & Thiele, G. (2007). Nutritious subsistence food systems. *Advances in Agronomy 92*, 1–74.

Guo, W., Nazim, H., Liang, Z., & Yang, D. (2016). Magnesium deficiency in plants: An urgent problem. *The Crop Journal*, *4*(2), 83-91.

Gupta, U. C. (1997). Soil and plant factors affecting molybdenum uptake by plants. *Molybdenum in agriculture.*, 71–91.

Halder, N. K., Hossain, M. A., Siddiky, M. A., Nasreen, N., & Ullah, M. H. (2007). Response of wheat varieties to boron application in Calcareous Brown Floodplain Soil at the southern region of Bangladesh. *Journal of Agronomy*, *6*, 21-24.

Hang, Z., & Guorui, M. (1993). The influence of chlorine on the physiological effects of potato (Solanum tuberosum). *Acta Agriculturae Zhejiangensis (China)*.

Hasan, M., Teixeira da Silva, J. A., & Li, X. (2016). Regulation of phosphorus uptake and utilization: transitioning from current knowledge to practical strategies. *Cellular and Molecular Biology Letters*, *21*(1), 1-19.

Hawkesford, M., Horst, W., Kichey, T., Lambers, H., Schjoerring, J., Møller, I. S., & White, P. (2012). Functions of macronutrients. In *Marschner's mineral nutrition of higher plants* (pp. 135-189). Academic Press.

Hegde, B. A., & Karande, S. M. (1978). Effect of presowing treatment of sodium chloride on the incidence of green ear disease of Pennisetum typhoides (Burm) Stapf and Hubb. Var. HB3. *Plant and Soil*, *49*(3), 551-559.

Hu, X., Wei, X., Ling, J., & Chen, J. (2021). Cobalt: an essential micronutrient for plant growth? *Frontiers in Plant Science*, 2370.

Hu, X., Wei, X., Ling, J., & Chen, J. (2021). Cobalt: an essential micronutrient for plant growth? *Frontiers in Plant Science*, 2370. https://doi.org/10.3389/fpls.2021.768523

Kaiser, B. N., Gridley, K. L., Ngaire Brady, J., Phillips, T., & Tyerman, S. D. (2005). The role of molybdenum in agricultural plant production. *Annals of Botany*, *96*(5), 745-754.

Kim, J., & Rees, D. C. (1992). Structural models for the metal centres in the nitrogenase molybdenum-iron protein. *Science*, *257*(5077), 1677-1682.

Kumar, O., Singh, S. K., Singh, A. P., Yadav, S. N., & Latare, A. M. (2018). Effect of soil application of nickel on growth, micronutrient concentration and uptake in barley (Hordeum vulgare L.) grown in Inceptisols of Varanasi. *Journal of Plant Nutrition*, *41*(1), 50-66.

Li, T. G., Zhou, Z. D., & Huang, Q. W. (1991). The effects of the applied ammonium chloride on the yield and quality of the vegetables. *Journal of Hunan Agricultural College, pp. 17*, 388–394.

Li, Y., & Liang, H. (1997). Soil Boron Content and the Effects of Boron Application on Yields of Maize, Soybean, Rice and Sugar beet in Heilongjiang Province, PR China. In *Boron in Soils and Plants* (pp. 17-21). Springer, Dordrecht.

Liu, D. Y., Liu, Y. M., Zhang, W., Chen, X. P., & Zou, C. Q. (2019). Zinc uptake, translocation, and remobilization in winter wheat as affected by soil application of Zn fertilizer. *Frontiers in Plant Science*, *10*, 426. https://doi.org/10.3389/fpls.2019.00426

Longnecker, N. E., Graham, R. D., & Card, G. (1991). Effects of manganese deficiency on the pattern of tillering and development of barley (*Hordeum* *vulgare cv Galleon*). *Field Crops Research*, *28*(1-2), 85–102.

Mahey, S., Kumar, R., Sharma, M., Kumar, V., & Bhardwaj, R. (2020). A critical review on toxicity of cobalt and its bioremediation strategies. *SN Applied Sciences*, *2*(7), 1-12.

Malhi, S. S., Schoenau, J. J., & Grant, C. A. (2005). A review of sulphur fertilizer management for optimum yield and quality of canola in the Canadian Great Plains. *Canadian journal of plant science*, *85*(2), 297-307.

Marschner, H. (1995). Mineral nutrition of higher plants Academic Press San Diego. *Mineral nutrition of higher plants. 2nd ed. Academic Press, San Diego, CA.*

Marschner, H. (Ed.). (2011). *Marschner's mineral nutrition of higher plants*. Academic press.

Matres, J. M., Arcillas, E., Cueto-Reaño, M. F., Sallan-Gonzales, R., Trijatmiko, K. R., & Slamet-Loedin, I. (2021). Biofortification of rice grains for increased iron content. *Rice improvement*, 471. https://doi.org/10.1007/978-3-030-66530-2

Millaleo, R., Reyes-Díaz, M., Ivanov, A. G., Mora, M. L., & Alberdi, M. (2010). Manganese as essential and toxic element for plants: transport, accumulation and resistance mechanisms. *Journal of Soil Science and Plant Nutrition*, *10*(4), 470-481.

Miller, E. R., Lei, X., & Ullrey, D. E. (1991). Trace elements in animal nutrition. *Micronutrients in agriculture*, *4*, 593-662.

Mousavi, S. R., Shahsavari, M., & Rezaei, M. (2011). A general overview of manganese (Mn) importance for crop production. *Australian Journal of Basic and Applied Sciences*, *5*(9), 1799-1803.

Ndakidemi, P. A., Bambara, S., & Makoi, J. H. (2011). Micronutrient uptake in common bean ('Phaseolus vulgaris' L.) as affected by Rhizobium inoculation and the supply of molybdenum and lime. *Plant Omics*, *4*(1), 40-52.

Oyinlola, E. Y. (2005). Distribution of Boron and its uptake in the plant parts of two tomato varieties. *Chem. Class J.*, *2*, 77-80.

Pandolfini, T., Gabbrielli, R., & Comparini, C. (1992). Nickel toxicity and peroxidase activity in seedlings of Triticum aestivum L. *Plant, Cell and Environment*, *15*(6), 719-725.

Pettigrew, W. T. (2008). Potassium influences on yield and quality production for maize, wheat, soybean and cotton. *Physiologia Plantarum*, *133*(4), 670–681.

Pj, W. (2003). Calcium in plants. *Annals of Botany*, *92*(4), 487–511.

Polle, A., Chakrabarti, K., Chakrabarti, S., Seifert, F., Schramel, P., & Rennenberg, H. (1992). Antioxidants and manganese deficiency in needles of Norway spruce (Picea abies L.) trees. *Plant Physiology*, *99*(3), 1084-1089.

Printz, B., Lutts, S., Hausman, J. F., & Sergeant, K. (2016). Copper trafficking in plants and its implication on cell wall dynamics. *Frontiers in Plant Science*, *7*, 601. https://doi.org/10.3389/fpls.2016.00601

Randle, W. M. (2004). Chloride Requirements in onion: clarifying a widespread misunderstanding. *Better Crops Plant Food*, *88*(4), 10-11.

Raven, J. A., Evans, M. C., & Korb, R. E. (1999). The role of trace metals in photosynthetic electron transport in O_2-evolving organisms. *Photosynthesis Research*, *60*(2), 111-150.

Reid, R. J., Hayes, J. E., Post, A., Stangoulis, J. C. R., & Graham, R. D. (2004). A critical analysis of the causes of boron toxicity in plants. *Plant, Cell and Environment*, *27*(11), 1405-1414.

Rezai, K., & Farboodnia, T. (2008). The response of pea plant to manganese toxicity in solution culture. *Agric. J.*, *3*(3), 248-251.

Rout, G. R., & Sahoo, S. (2015). Role of iron in plant growth and metabolism. *Reviews in Agricultural Science, 3*, 1–24.

Rudani, L., Vishal, P., & Kalavati, P. (2018). The importance of zinc in plant growth review. *International Research Journal of Natural and Applied Sciences*, *5*(2), 38-48.

Saeed, M. S., Saeed, A., & Adnan, M. (2020). Production and Utilization of Single Cell Proteins- An Overview. *Curr. Res. Agri. Farm. 1*(4), 9–12. http://dx.doi.org/10.18782/25827146.117.

Savci, S. (2012). An agricultural pollutant: chemical fertilizer. *Int. J. Environ. Sci. Dev. 3*(1), 77-80.

Schmidt, W., Thomine, S., & Buckhout, T. J. (2020). Iron nutrition and interactions in plants. *Frontiers in Plant Science, 10*, 1670. https://doi.org/10.3389/fpls.2019.01670

Selmeczi, K., Robert, A., Claparols, C., & Meunier, B. (2004). Alkylation of human haemoglobin A0 by the antimalarial drug artemisinin. *FEBS letters*, *556*(1-3), 245-248.

Seregin, I., & Kozhevnikova, A. D. (2006). Physiological role of nickel and its toxic effects on higher plants. *Russian Journal of Plant Physiology*, *53*(2), 257-277.

Shaaban, M. M. (2010). Role of Boron in plant nutrition and human health. *American Journal of Plant Physiology*, *5*(5), 224-240.

Sharma, C. P., Sharma, P. N., Chatterjee, C., & Agarwala, S. C. (1991). Manganese deficiency in maize affects pollen viability. *Plant and Soil*, *138*(1), 139-142.

Shikanai, T., Müller-Moulé, P., Munekage, Y., Niyogi, K. K., & Pilon, M. (2003). PAA1, a P-type ATPase of Arabidopsis, functions in copper transport in chloroplasts. *The Plant Cell*, *15*(6), 1333–1346.

Shireen, F., Nawaz, M. A., Chen, C., Zhang, Q., Zheng, Z., Sohail, H., Sun, J. Cao, H., Huang, Y., & Bie, Z. (2018). Boron: functions and approaches to enhance its availability in plants for sustainable agriculture. *International Journal of Molecular Sciences*, *19*(7), 1856. https://doi.org/10.3390%2Fijms19071856

Sinclair, T. R., & Park, W. I. (1993). Inadequacy of the Liebig limiting-factor paradigm for explaining varying crop yields. *Agronomy Journal*, *85*(3), 742-746.

Smith, G. S., Clark, C. J., & Holland, P. T. (1987). Chlorine requirement of kiwifruit (Actinidia deliciosa). *New Phytologist*, *106*(1), 71-80.

Stadtman, T. C. (1996). Selenocysteine. *Annual review of biochemistry*, *65*(1), 83-100.

Stangoulis, J. C., & Reid, R. J. (2002). Boron toxicity in plants and animals. In *Boron in plant and animal nutrition* (pp. 227-240). Springer, Boston, MA.

Taylor, R. G., Jackson, T. L., Powelson, R. L., & Christensen, N. W. (1983). Chloride, nitrogen form, lime, and planting date effects on take-all root rot of winter wheat. *Plant Disease*, *67*(10), 1116–1120.

Toor, M. D., Adnan, M., ur Rehman, F., Tahir, R., Saeed, M. S., Khan, A. U., & Pareek, V. (2021). Nutrients and Their Importance in Agriculture Crop Production; A Review, *Ind. J. Pure App. Biosci. 9*(1), 1-6.

Uchida, R. (2000). Essential nutrients for plant growth: nutrient functions and deficiency symptoms. *Plant nutrient management in Hawaii's soils*, *4*, 31-55.

Uruç Parlak, K. (2016). Effect of nickel on growth and biochemical characteristics of wheat (Triticum aestivum L.) seedlings. *NJAS: Wageningen Journal of Life Sciences*, *76*(1), 1-5.

Warren, H. L., Huber, D. M., Nelson, D. W., & Mann, O. W. (1975). Stalk Rot Incidence and Yield of Corn as Affected by Inhibiting Nitrification of Fall-applied Ammonium 1. *Agronomy Journal*, *67*(5), 655-660.

Wasaya, A., Affan, M., Yasir, T. A., Sheikh, G. R., Aziz, A., Baloach, A. W., Nawaz, F., & Adnan, M. (2019). Growth and economic return of maize (Zea mays L.) with foliar application of potassium sulphate under rainfed conditions. *J. Enviro Agri 4*(1), 268374.

Weggler, K., McLaughlin, M. J., & Graham, R. D. (2004). Effect of chloride in soil solution on the plant availability of biosolid-borne cadmium. *Journal of Environmental Quality*, *33*(2), 496-504.

Welch, R. M., & Graham, R. D. (2004). Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of Experimental Botany 55*, 353–364.

White, P. J., & Broadley, M. R. (2001). Chloride in soils and its uptake and movement within the plant: a review. *Annals of Botany*, *88*(6), 967–988.

Wu, S. H. (1994). Effect of manganese excess on the soybean plant cultivated under various growth conditions. *Journal of Plant Nutrition*, *17*(6), 991-1003.

Xu, X., Du, X., Wang, F., Sha, J., Chen, Q., Tian, G., Zhu, Z., Ge, S. & Jiang, Y. (2020). Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. *Frontiers in Plant Science*, *11*, 904. https://doi.org/10.3389/fpls.2020.00904.

Xu, X., Du, X., Wang, F., Sha, J., Chen, Q., Tian, G., Zhu, Z., Ge, S, & Jiang, Y. (2020). Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. *Frontiers in Plant Science*, *11*, 904.

Yoshida, S., & Chaudhry, M. R. (1979). Sulfur nutrition of rice. *Soil Science and Plant Nutrition*, *25*(1), 121-134.

Younts, S. E., & Musgrave, R. B. (1958). Chemical Composition, Nutrient Absorption, and Stalk Rot Incidence of Corn as Affected by Chloride in Potassium Fertilizer 1. *Agronomy Journal*, *50*(8), 426-429.

Yruela, I. (2005). Copper in plants. *Brazilian Journal of Plant Physiology*, *17*, 145-156.

Zhang, K., Wu, Y., & Hang, H. (2019). Differential contributions of NO3−/NH4+ to nitrogen use in response to a variable inorganic nitrogen supply in plantlets of two Brassicaceae species in vitro. *Plant Methods*, *15*(1), 1-12.

Zhang, Z., Yang, F., Li, B., Egrinya Eneji, A., Li, J., Duan, L., Wang, B., Li, Z., & Tian, X. (2009). Coronatine-induced lateral-root formation in cotton (Gossypium hirsutum) seedlings under potassium-sufficient and-deficient conditions in relation to auxin. *Journal of Plant Nutrition and Soil Science*, *172*(3), 435-444.