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Review Article

Review Paper on Effect of Micronutrients for Crop Production

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Abstract:

Micronutrients are essentially as important as macronutrients to have better growth, yield and quality in plants. There requirement by plants is in trace amounts. Boron, iron, copper, zinc, manganese, magnesium and molybdenum constitute main micronutrients required by different crops in variable quantities. The requirement of micronutrients is partly met from the soil or through chemical fertilizer or through other sources. Various physical and metabolic functions are governed by these mineral nutrients. Boron is particularly essential in pollen germination, copper plays major role in photosynthesis and increases sugar content in fruits, chlorophyll synthesis and phosphorus availability is enhanced by manganese, iron acts as an oxygen carrier and promotes chlorophyll formation, while, zinc aids plant growth hormones and enzyme system. Yield and quality of agricultural products increased with micronutrients application, therefore human and animal health is protected with feed of enrichment plant materials. Each essential element only when can perform its role in plant nutrition properly that other necessary elements are available in balanced ratios for plant. therefore in the plant manganese plays an important role on oxidation and reduction processes, as electron transport in photosynthesis. Manganese deficiency has very serious effects on non-structural carbohydrates, and roots carbohydrates especially. Crops quality and quantity decreased due to manganese deficiency, and this is due to low fertility of pollen and low in carbohydrates during grain filling. In the xylem routes zinc is transmitted to divalent form or with organic acids bond. In the phloem sap zinc makes up complex with organic acids with low molecular weight, and increases its concentration. Zinc deficiency can be seen in eroded, calcareous and weathering acidic soils. Zinc deficiency is often accompanied with iron deficiency in calcareous soils. Iron in the soil is the fourth abundant element on earth, but its amount was low or not available for the plants and microorganisms needs, due to low solubility of minerals containing iron in many places the world, especially in arid region with alkaline soils.

Key words: micronutrients; crops; zinc; manganese; iron; cupper deficiency

Introduction

A micronutrient can be defined as an element essential for all higher plants where the requirement and accumulation are small, usually measured in milligrams per kilogram of soil or biomass or in grams per hectare. Trace elements are elements, including micronutrients that are present in small amounts in soil, water, air or organisms such as microorganisms, plants, animals or humans [3].

Micronutrients are essential elements that are used by plants in small quantities. Yield and quality of agricultural products increased with micronutrients application, therefore human and animal health is protected with feed of enrichment plant materials. Each essential element only when can perform its role in plant nutrition properly that other necessary elements are available imbalanced ratios for plant. Divalent manganese ions (Mn^{2+}) is converted to Mn^{3+} or Mn^{4+} easily, therefore in the plant manganese plays an important role on oxidation and reduction processes, as electron transport in photosynthesis. Moreover manganese acts as an activator of many enzymes, (more than 35 different enzymes). Manganese has important role on activates several enzymes which involve to oxidation reactions, carboxylation, carbohydrates metabolism, phosphorus reactions and citric acid cycle. Of the most important these enzymes, protein-manganese in Photosystem II and superoxide dismutase can be pointed. There is more than 90% of superoxide dismutase in chloroplasts which about 4 to 5 percent of it is in mitochondria 2010 Manganese (Mn^{2+}) [41,45,62]. In terms of biochemical functions is similar to magnesium (Mg^{2+}), both ions connects ATP with complexes enzymes (phosphor transferase· and phosphokinase). Dehydrogenase and Decarboxylase in the Krebs cycle (TCA) are also activated by Mn^{2+} [6, 36].

Manganese plays an important role in chlorophyll production and its presence is essential in Photo system II, also involved in cell division and plant growth. RNA polymerase is activated by manganese. Manganese has an effective role in lipids metabolism, and due to effective role of manganese in the nitrate reduction enzymes, nitrate will accumulation in leaves which are facing with manganese deficiency. Moreover amount of lignin in the plant will decline due to manganese deficiency, that this reduction is more severe in the roots, this matter is very important especially to reduction resistance the roots of plants to fungi infecting [6,45]. Fertilizers are necessary for enhancing productivity in crops especially in wheat, rising use macronutrients and low use micronutrients leading to an imbalance of soil chemical. A staple fertilization program with macronutrients and micronutrients in plant nutrition is very essential in the high production of yield with good quality products, so there is a need balance use of fertilizers and agronomic procedures are needed to increase yield of this crop. The function of macronutrients and micronutrients is vital in crop nutrition for improved yield and quality [59].

Micronutrients such as Fe and B have essential roles in plant's life cycle and very essential for normal growth plants [17, 39]. Iron is most important for the respiration and photosynthesis processes. Iron is play responsibility in many plant functions. These functions include chlorophyll development, energy transfer, an ingredient of sure enzymes and proteins, and involved in nitrogen fixation. It plays an essential role in nucleic acid metabolism [16,26,54,60]. Boron is a micronutrient required for all plant nutrition. Boron involves at least 16 functions in plants. These functions include cell wall formation, membrane integrity, cell wall syntheses, carbohydrate metabolism, calcium uptake, flowering, RNA metabolism, respiration, indole acetic acid, (IAA) metabolism, membranes, root growth, pollination and may help in the translocation of sugar [9,50,53,60].

Micronutrient deficiency is severing problem in soil and plants worldwide (Imtiaz et al., 2010) while appropriate quality of micronutrients is necessary for better growth, better flowering, higher fruit set, higher yield, quality and post-harvest life of horticultural products [55,56,64,65] while its deficiency leads in lowering the productivity [29,73].

Micronutrients, especially Fe and B either solitary or association with other micronutrients, applied by foliar spraying significantly enhanced growth and increased yield, yield components and grain quality of wheat crop. Ziaeian and Malakouti (2001) found that Fe, Mn, Zn and Cu fertilization significantly increased grain yield, straw yield, 1000-grain weight, and the number of grains per spikelet. Also showed that application of Fe significantly increased the concentration and total uptake of Fe in grain, flag leaves grain protein contents as well [74]. Asad and Rafique (2002) found that application micronutrients increased wheat dry matter, grain yield, and straw yield significantly over an unfertilized control [7]. Foliar application of micronutrients (Fe, Mn, Zn, Cu and B) at different growth stages of wheat increased plants height, grains per spike, 1000-grain weight, biological yield, harvest index, straw and grain yield [30]. Ali (2012) reported that foliar application of Fe at different growth stages enhanced plant height, spike length, 1000-grain weight, grain weight per spike, grain yield, grain protein content and protein yield of wheat plant in both growing seasons as compared to control [1]. Rawashdeh and Sala (2013) reported that foliar application of Fe and B significantly increased plant height, number of tillers and root depth as compared to control treatment (no Fe and B application) [57]. Gomaa et al. (2015) found that the foliar application of mixture nutrients (Zn+Fe) gave the highest grain and yield components and quality of wheat grain [21]. Foliar application of B and Zn had positive effect on yield and yield components of wheat [2, 42]. Raza et al. (2014) reported that foliar application of B was significant affected on grain yield, number of grains per spike and 1000-grain eight [58].

Micronutrient elements such as Zn, Fe, Bo, Mo, Cu, Mn, Cl and Ni are known to be essential for plant growth. Others such as selenium (Se) and Co, which are needed in specific cases, are commonly referred to as beneficial elements. For instance, Co is required by bacteria that fix nitrogen in legumes. Zinc (Zn) and iron (Fe) are some of the most important micronutrient essential for plant growth. Muthukumararaja et.al 2012, Kumar, et.al 2012 Zinc is a major metal component and activator of several enzymes involved in metabolic activities and biochemical pathways [23,28,31,48]. It is a functional, structural or regulatory co-factor of a large number of enzymes [23]. It is required in a large number of enzymes and plays an essential role in DNA transcription [31]. Other functions of zinc include: catalyzing the process of oxidation in plant cell and is vital for the transformation of carbohydrates; and influencing the formation of chlorophyll and auxins, the growth promoting compounds [35]. On the other hand, Fe in a constituent of enzyme system which brings about oxidation-reduction reactions in the plant, it regulates respiration, photosynthesis, reduction of nitrates and sulphates [35]. These reactions are essential to plant development and reproduction. It should be noted that as the case with other plant micronutrients Zn and Fe limit plant growth when they are present both in low concentrations and in excessive concentrations due to deficiency and toxicity respectively [5,12].

1.1. Objectives

After reading this review, the reader should:

- ✓ Know the names of the micronutrients
- ✓ Understand how to diagnose and correct micronutrient Deficiencies

Table : Crop quality characteristics improvements by some micronutrients application in various crops

Crop	Quality characteristic	Nutrient element	Referen
Groundnut (*Arachis hypogaea* L.)	Protein content; oil content	Zn	Nadaf et.al 2013
Rice (*Oryza sativa* L.)	Amino acid content; protein content; grain Zn and Fe content	Zn; Fe	Yuan L, et.al 2012
Pomegranate (*Punica granate* L. Cv 'Ghojagh')	Fruit weight; fruit diameter	Zn;	Hasani M, et al 2012
Cotton (*Gossypium hirsutum* L.)	Ginning percentage; spinning consistency index (SCI)	Zn	Efe L and E Yapuzi 2011
Chilli	Ascorbic acid concentration	Cu	Gangamrutha GV2008
Sweet pepper	Protein, total carbohydrate content, ascorbic acid content	Co	Gad N and NMK Hassan 2013

2. Literature Review

Micronutrient deficiency is severing problem in soil and plants worldwide (Imtiaz, et al., 2010) while appropriate quality of micronutrients is necessary for better growth, better flowering, higher fruit set, higher yield, quality and post-harvest life of horticultural products [27,55,56,64,65] while its deficiency leads in lowering the productivity [73]. Beside major plant nutrients there is eight essential nutrients which is required by plants in very small quantity, known as micronutrients viz., copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), zinc (Zn), boron (B), and chlorine (Cl). Still, other elements like selenium (Se), silicon (Si), and sodium (Na) are regarded as nonessential, although they have been found to enhance growth and confirm other benefits to plants (Datnoff et al., 2007; Marschner 2012). Dependent on the enzyme, Fe, Mn, Zn, Cu, Ni, Mo, and Cl all participate in the functioning of different enzymes, including DNA/RNA polymerases, N-metabolizing enzymes, superoxide dismutases, catalases, dehydrogenases, oxidases, ATPases and numerous other enzymes involved in redox processes (Broadley et al., 2012).

Boron is important micro nutrient required for good quality and high yield of crops (Dale and Krystyna, 1998, Mahmoud M. Shaaban 2010). It involved in the synthesis and integrity of cell wall, cell wall lignification, metabolism of RNA, carbohydrate, phenol and Indole Accetic Acid (IAA), respiration and cell membrane integrity [53]. Boron is exclusive as a substance in this the brink between deficiency and toxicity is narrows (Mortvedt et al., 1991). Boron Deficiency found to affect plant growth and reduced yield (Dell and Huang, 1997, Carpena et al., 2000) better growth and yield was obtained when crops were supplied with Boron (Oyinlola, 2005, Shaaban et al., 2004). Single foliar boron application is effective in increasing B concentration in flower buds, higher B concentrations, however, can improve fruit set in sweet cherry, so the possible positive effects can easily cover the costs. Nutrition with boron can be more useful especially when fruit set is low and can be in function of controlling tree vigor (Valentina Usenik and Franci Stampar, 2007). Flower clusters have a high demand for boron (B) during blossoming if fruit set is to be fully effective (Hanson and Proebsling, 1996). Application of B sprays is often used to ensure that sufficient amounts of B are available for flower fertilization, fruit set, and early fruit let development (Peryea, 1992; Zude et al., 1998; Hanson et al., 1985; Stover et al., 1999; Nyomora et al., 1999; Štampar et al., 1999; Solar et al., 2001). Flower buds are a preferential sink for B mobilization after foliar application (Sanches and Righetti, 2005) [29].

Zinc (Zn) is another important essential micronutrient which helps in the formation of tryptophan, a precursor of IAA responsible for growth stimulation (Mallick and Muthukrishnan, 1979) and plays a vital role in synthesis of carbonic anhydrase enzyme which helps in transport of CO2 in photosynthesis (Alloway, 2008) and directly or indirectly required by several enzyme systems and synthesis of auxin [4]. Magnesium is the metallic constituent of chlorophyll and regulates the uptake of other nutrients [29,56]. Iron increases photosynthesis and carbohydrate synthesis and in reproductive growth of fruit in organs of the plant acts as a strong sink (Sohrab et al., 2013).

The nutrients required in large quantity are supplied through soil application (Fageria et al., 2009) but nutrients needed in lower quantity can be better absorbed through foliar spray (Girma et al., 2007) [17]. Best timing for foliar sprays should be one or more of the followings; i) at a new flush, ii) after fruit harvesting, iii) preanthesis/2-3 weeks prior to fruit bud differentiation, iv) at full bloom, and v) at the small fruit formation stage [29].

Due to restricted mobility of iron, zinc and boron in plant tissues and keeping in view plant physiology, the authors are of the view that as orchard crops try to accumulate maximum amounts of essential nutrients before flower formation so micronutrients foliar sprays should be made preferably after fruit harvest and before flower formation in addition to recommended deficiency doses already applied through soil [29].

Foliar sprays can prevent or correct a problem with relatively small amounts absorbed by the foliage but at the same time, it has also been recognized that root uptake must be maximized in order to obtain the most benefit from foliar sprays. For details about different aspects of foliar nutrition, readers may refer to various reviews (Haynes and Goh, 1977; Slowik and Swietlik, 1978; Kannan, 1980).

Mineral nutrients enter into leaves in three steps (Frank, 1967) involving: (1) penetration through the cuticle and epidermal walls; (2) adsorption on the surface of the plasma lemma, and (3) passage through the plasma lemma into the cytoplasm. Discontinuities and cracks in the epicuticular waxes, however, open a pathway for penetration of leaf-applied nutrients [29].

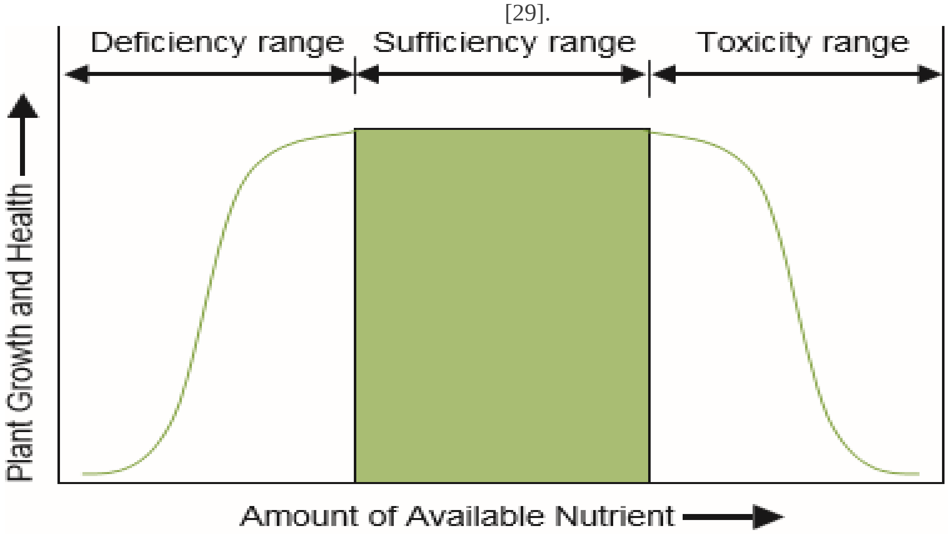

Figure 2. *Relationship between plant growth and health and amount of nutrient available (Brady and Weil, 1999)*

2.1. Manganese (Mn)

2.1.1. Manganese (Mn) Deficiency:

Manganese deficiency has very serious effects on non-structural carbohydrates, and roots carbohydrates especially. Crops quality and quantity decreased due to manganese deficiency, and this is due to low fertility of pollen and low in carbohydrates during grain filling. Manganese deficiency is similar to magnesium deficiency, because there comes yellow in both inter costal. Manganese deficiency symptoms first appear on younger leaves; because dynamics of these elements in different plant tissues is limited (manganese isn't a mobile element); but the magnesium deficiency symptoms is seen in older leaves primarily [29,33,36,63,69].

In dicot plants manganese deficiencies often are known with small yellow spots on leaves, also manganese deficiency symptoms in monocot plants appears as tape and gray-green spots on base of leaves. The major symptom of deficiency is a reduction in the efficiency of photosynthesis leading to a general decline in dry matter productivity and yield. Occurrence and intensity of manganese deficiency is depend to seasonal conditions, as manganese deficiency will be more severe in the cold and wet seasons, due to reduced roots metabolic activity in manganese uptake. Manganese concentrations in plant tissues have been determined 50 to 150 ppm. Manganese critical levels in plant tissues depending on the cultivar, species and environmental conditions and has been reported between 10 to 50 micrograms per gram for dry matter [33,36,40,47].

2.2. Zinc (Zn):

Zinc uptake of soil solution in divalent cations form (Zn2+); in calcareous soils with high pH zinc uptake may be a valence ion form. In the xylem routes zinc is transmitted to divalent form or with organic acids bond [33].

In the phloem sap zinc makes up complex with organic acids with low molecular weight, and increases its concentration. Zinc is in plants only in divalent cation (Zn+2) and does not participate in oxidation and regenerative reactions. The main functions of zinc is tendency to make up tetragonal complexes with nitrogen, oxygen and sulfur, thus zinc have a catalytic, building and activating role in the enzymes. Zinc is main building part of some enzymes and is needed for the plant enzymes formation; in addition, many enzymatic reactions active by zinc [5,34,43,46,71].

Zinc plays an important role in most of the enzymes that they can point to the following: Alcohol dehydrogenase: this enzyme molecule has two atoms of zinc. One of the atoms has a catalytic and other has a building role. Alcohol dehydrogenase enzyme has a catalytic role in regeneration of acetaldehyde to ethanol. In higher plants, ethanol is making in the root tip of meristematic tissue under aerobic conditions, alcohol dehydrogenate enzyme declined by zinc deficiency in plants, as a result root development reduced [22,47]. Carbonic anhydrate: This enzyme has a zinc atom that catalyzes CO_2 hydration. Enzyme activity location is in chloroplasts and cytoplasm and the enzyme activity is dependent to zinc value in the plant [33].

The main functions of this enzyme are: dehydration of carbon dioxide, increasing absorption of carbon dioxide per leaf area unit, increasing in photosynthesis and biomass production. In the plants that are confronted with zinc deficiency activity of this enzyme is stopped [46]. Superoxide dismutase zinc-copper: In this enzymes zinc is connected to copper, it seems that zinc has catalytic and copper has building role. Superoxide dismutase activity decreased in zinc deficiency conditions and is associated with increased free radicals oxygen (super oxide), that it's a toxic substance and have a harmful effect on plants tissues due to lipids per oxidation of membrane and increasing its permeability [36,47]. Also zinc is part of some enzymes structure, such as: Alkaline Phosphatase, phosphatides lipase, Carboxy peptidase, RNA polymerase, Dehydrogenase and Aldolase [52].

2.2.1. The Role of Zinc on Carbohydrates Metabolism:

Zinc is one of the most important elements in the carbohydrates metabolism, most enzymes that play a role in carbohydrates metabolism are activated by zinc. In addition Carbonic anhydrase, Fructose-1, 6-bisphosphate and Aldolase enzymes are activated by zinc. These enzymes are active in the chloroplasts and cytoplasm, six-carbon sugar molecule are separated between chloroplasts and cytoplasm by Fructose-1, 6-bisphosphate and three-carbon sugars molecule in photosynthesis are transported from cytoplasm to chloroplasts by Aldolase. The activity of these enzymes decreased in zinc deficiency condition, in resulting carbohydrate accumulated in plants leaves [47]. Zinc is essential micronutrients for proteins production in plants; also zinc is main composition of ribosome and is essential for their development. Amino acids accumulated in plant tissues and protein synthesis decline by zinc deficit. One of the sites of protein synthesis is pollen tube that amount of zinc in there tip is 150 micrograms per gram of dry matter. In addition zinc will contribute on the pollination by impact on pollen tube formation [33,51].

Metabolism of plant hormones such as auxin (IAA) and tryptophan decreases in zinc deficiency condition, as a result leaf growth stops. In fact, zinc is essential for tryptophan synthesis, which is a prerequisite for auxin formation, therefore amount of auxin decreases by zinc deficiency [36.46]. In some conditions that plant are in zinc deficient, tryptophan may increase in the leaves as a result in impaired of protein synthesis. Zinc is necessary element for maintain living membranes. Zinc may be connected to membrane phospholipids or constituent groups of sulfhydryl or make up tetragonal compounds with residues of Cysteine polypeptide chains and thus, proteins and lipids were protect against oxidation damage 1992 [13,33,36,66].

2.2.2. Zinc Deficiency:

Zinc deficiency can be seen in eroded, calcareous and weathering acidic soils. Zinc deficiency is often accompanied with iron deficiency in calcareous soils. Zinc deficiency in these soils is related to adsorption of solution zinc in the soil by clay and limestone particles. In eroded soils, zinc deficiency is caused by organic matter deficiency. Also zinc deficiency may be related to weather conditions, zinc deficiency increases in cold and wet weather conditions. It may be due to the limited root growth in cool soils, or reduction activity of microorganisms and reduction the release of zinc from organic materials. High concentrations of bicarbonate (HCO_3) prevent of zinc uptake by plants shoot [44].

Zinc deficiency symptoms appear on the young leaves of plants first; because zinc cannot be transferred to younger tissues from older tissue (zinc isn't a mobile element) [33].

Areas between nervure in plants are yellow by zinc deficient. In dicot plants internodes distance and leaf size will be short and in monocot plants, corn especially, bands comes into the main nervure on both sides of leaves in zinc deficient condition. Overall, shoot is more affected than the root growing by zinc deficiency. When zinc deficiency developed, the yield is more affected than dry matter. This may is due to damage to the pollen fertility by zinc deficiency. The plants that zinc amount in their tissues is lower than 20ppm, are encountered with zinc deficit [36,67,71].

2.3. Iron (Fe):

Iron in the soil is the fourth abundant element on earth, but its amount was low or not available for the plants and microorganisms needs, due to low solubility of minerals containing iron in many places the world, especially in arid region with alkaline soils. Iron is an importance element in crops, because it is essential for many important enzymes, including cytochrome that is involved in electron transport chain, synthesize chlorophyll, maintain the structure of chloroplasts, and enzyme activity [16,35,70]. Often iron is found in the form of trivalent ($Fe3+$) in aerobic soils, which has low solubility, and in most cases this is not enough iron to meet the needs of plants. Considering the effect of pH on the solubility of Iron (Fe), in the pH = 7 amount of water soluble iron is about 10-18mol L (moles per liter); while the required concentrations for normal growth of plants is about 10-8mol L. Generally solubility of trivalent iron decreases by increasing PH. Iron deficiency has a powerful effect on chloroplast protein, so that chloroplast protein is reduced significantly by iron deficiency. In conditions of severe iron deficiency, cell division stops and therefore leaf growth decreases.

Iron is needed to produce chlorophyll; hence its deficiency causes chlorosis. For example, iron is used in the active site of glutamyl-t RNA reductase, an enzyme needed for the formation of 5-Aminolevulinic acid which is a precursor of chlorophyll. Iron-deficient fields, when viewed from a distance, exhibit irregularly-shaped yellow areas. Because iron is not translocated in the plant, deficiency symptoms appear on the new growth first. Iron deficiency on individual plants is characterized by yellow leaves with dark green veins (interveinal chlorosis) [33].

On corn and sorghum, this gives the plants a definite striped appearance. If the condition is severe, the whole plant may be affected and turn a very light yellow or even white. In many cases where moderate deficiencies occur early in the season, plants tend to recover later [16,33].

Iron solution concentrations in flooding soils to may be increased several-fold due to low redox potential. In these conditions large amounts of iron may available for plant, and can be toxic to plants. Brown plant tissues, black and soft roots are the iron toxicity symptoms. In addition, at these higher iron (Fe) solution concentrations plants exhibited visual symptoms of possible iron toxicity, including root flaccidity, reduced root branching, increased shoot die-back and mottling of leaves. Plant species in wet regions have mechanisms to oxidize iron in roots area to limit the excessive absorption of iron. Plants in soils aerobic conditions have two strategy-oriented for access to the iron compounds: first siderophore secretion (non-protein amino acid) (This strategy is found in Gramineae family); and second separation iron of soil chelate or restore trivalent iron ($Fe3+$) to bivalent that occurs through the proton leakage (This strategy can be found in other monocotyledon and dicotyledons plants) and [16,33].

2.4. Boron (B):

Boron is mobile in the soil and is subject to leaching, like nitrate and sulphate. Organic matter is the main source of B in western Canadian soils. The vast majority of Saskatchewan soils contain enough organic matter to supply B for crop needs. Boron deficiencies have been suspected in alfalfa and canola on sandy and eroded sandy soils in the Gray soil zone. Boron may be limiting to seed production of alfalfa in these soils. Symptoms that appear in spring under cool and wet conditions tend to go away when soil conditions become warm and drier. Apply B in test strips to confirm economic yield response. Additions of high rates of B on soils where B is not required can result in toxicity and a reduction in yield.

There is a narrow range between deficiency and toxicity, so extreme care must be taken to avoid overlap when B fertilizer is applied [33].

2.5. Chloride (Cl)

Chloride is required by the plant for leaf turgor and photosynthesis. Until recently, little information was documented on Cl deficiencies, as symptoms were often misdiagnosed as physiological leaf spot. However, more recent studies have shown Cl deficiencies to exist in Montana, with visual symptoms observed in winter wheat and durum wheat cultivars (Engel et al., 1998) [39]. Plants with insufficient Cl show chlorotic and necrotic spotting along leaves with abrupt boundaries between dead and live tissue (Figure 9). Wilting of leaves at margins and highly branched root systems are also typical Cl deficient symptoms, found mainly in cereal crops [39]. Cl deficiencies are highly cultivar specific and can be easily mistaken for leaf diseases.

2.6. Molybdenum (Mo

Molybdenum is needed for enzyme activity in the plant and for nitrogen fixation in legumes. Due to this interrelationship, Mo deficiency symptoms often resemble N deficiency symptoms with stunted growth and chlorosis occurring in legumes. Other symptoms of Mo deficiency include pale leaves that may be scorched, cupped, or rolled. Leaves may also appear thick or brittle, and will eventually wither, leaving only the midrib.

2.7. Sulfur (S)

As S is an essential constituent of certain amino acids and proteins, S deficiency results in the inhibition of protein and chlorophyll synthesis. S deficiency symptoms can be difficult to diagnose as effects can resemble symptoms of N and Mo deficiencies. In contrast to N or Mo deficiency, however, S deficiency symptoms initially occur in younger leaves, causing them to turn light green to yellow. In later growth, the entire plant may be pale green. There are no characteristic spots or stripes. Additionally, plants deficient in S tend to be spindly and small, and stems are often thin.

2.8. Copper (Cu)

Copper is needed for chlorophyll production, respiration and protein synthesis. Cu deficient plants display chlorosis in younger leaves, stunted growth, delayed maturity (excessively late tillering in grain crops), lodging and, in some cases, melanosis (brown discoloration). In cereals, grain production and fill is often poor, and under severe deficiency, grain heads may not even form (Figure 14). Cu deficient plants are prone to increased disease, specifically ergot (a fungus causing reduced yield and grain quality; Solberg et al., 1999). The onset of disease-caused symptoms may confound the identification of Cu deficient symptoms. Winter and spring wheat are the most sensitive crops to Cu deficiency (Solberg et al., 1999). In the field, Cu deficiency symptoms occur in irregular patches with melanosis being the most obvious symptom, particularly in wheat stands. Similar to Zn deficiency, forage that is deficient in Cu can cause reduced reproductive efficiency in cattle (Paterson, 2002).

2.9. Nickel (Ni)

Nickel is required by plants for proper seed germination and is beneficial for N metabolism in legumes and other plants in which ureides (compounds derived from urea) are important in metabolism (Gerendas et al., 1999). Ni is the metal component in urease, an enzyme that catalyzes the conversion of urea to ammonium (Havlin et al., 1999). Though Ni deficiency symptoms are not well documented and believed to be non-existent in Montana and Wyoming, symptoms include chlorosis and interveinal chlorosis in young leaves that progress to plant tissue necrosis. Other symptoms include poor seed germination and decreased crop yield.

3. Conclusion

From this review, it can be concluded that all nutrient elements focused in this study (N, P, K, S, Ca, Mg, Fe, and Zn) influence crop quality. This is manifested by changes or differences in quality attributes of different crops with different rates of nutrient elements applied or available to various crops. The common quality attributes that are influenced as reported by many authors include protein and carbohydrate content of the sink organs of plants, fruit color, flavor and vitamin related attributes for example Beta-carotene, grain hardness and moisture content at storage of crops such as maize and wheat, potato tuber density and internal color.

Undersupplying and oversupplying of nutrients may lead to reduced crop quality. This can result from the nutrient being a raw material for synthesis of a product but also from its involvement in enzymatic activities, for instance low N (as a raw material) will lead to reduced amount of proteins where as low K will lead to reduced amount of proteins due to reduced activation of enzymes that metabolize carbohydrates for synthesis of amino acids and proteins. Too much NH4-N will suppress uptake of Ca and its functions. On the other hand, low levels of Mg and K will lead to reduced distribution of carbohydrates. It should be noted that nutrients do not work in isolation; therefore balanced nutrition is needed to optimize crop quality.

From this review, it can be noted that apart from crop yields, crop quality is anotherarea that needs to be considered with serious attention as it affects human nutrition and profitability of crop products. It is recommended that research in soil fertility and plantnutrition take a multidisciplinary approach where soil scientists, breeders and human nutrition experts come face to face in planning a research agenda.

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