MICRONUTRIENTS IN CULTIVATION OF PLANT: A REVIEW

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Abstract— Micronutrients zinc, iron, manganese, boron, chlorine, copper, and molybdenum are very important for optimum growth and yield of plant. This review will be discussing the function of each micronutrient, the effect of deficiency and toxicity of each of the micronutrient on plants, the optimum concentration of micronutrients required by plants, the method of application of micronutrients, micronutrients economics and recommended application rates and the characteristics of soil that affects the availability and uptake of micronutrients by plants. The objectives of this review are to identify micronutrients required by plants and to evaluate the performance of micronutrients required by plants.

Keywords— *Growth, micronutrients, plants, review, yield*

I. INTRODUCTION

Plant can be defined as as an extensive collection of multicellular eukaryotic organisms belonging to the Kingdom Plantae inclusive of the vascular plants as well as bryophytes characterized by their existence of cell wall, immobile and sexual reproduction through alternation of generations between a diploid stage and haploid stage in their life cycle. They can be further broken down into non-vascular plant that lack conducting tissues such as *anthocerotophyta* (hornworts), *bryophyta* (mosses), *chlorophyta* (fresh water algae) and *hepatophyta* (liverworts) and vascular plant that can circulate fluids in their bodies and they can be further divided into vascular plants reproduce with spores and vascular plants reproduce with seed (Dictionary, 2016; Infoplease, 2016). In order for plants to optimum growth and yield, they need about 20 different kind of nutrients which can be divided into macronutrients consisting of nitrogen, phosphorus, potassium, sulphur, calcium and magnesium that are needed in large amount and micronutrients consisting of chlorine (Cl), cobalt (Co), manganese (Mn) boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), silicon (Si), vanadium (V), sodium (Na), and iron (Fe) that are required in small amount mostly at concentration below 100 ppm. It is very uncommon for plants to have insufficient amount of cobalt (Co), vanadium (V), sodium (Na), and silicon (Si) thus this review will focus on reviewing 7 type of micronutrients that can be manipulated by agronomists which are zinc (Zn), iron (Fe), manganese (Mn), boron (B), chlorine (Cl), copper (Cu), and molybdenum (Mo) (Lohry & Si, 2007).

Zinc is a very important micronutrients required by plants and is essential for normal, healthy growth and reproduction of plants and is taken up from soil solution by plants in the form of divalent cation (Zn^{2+}) that does not go through valence changes thus does not have redox activity in plants (Lohry & Si, 2007; Tavakoli et al., 2014). Zinc possess a crucial role in plant metabolism where it influence the activities of enzymes, for instance, alkaline phosphate, alcohol dehydrogenase, ribonucleic acid (RNA) polymerase, carbonic anhydrase superoxide dismutase zinc-copper, phosphatides lipase, carboxypeptidase, dehydrogenase and aldolase (Hafeez, Khanif, & Saleem, 2013; Sharma, Patni, Shankhdhar, & Shankhdhar, 2013; Tavakoli et al., 2014), synthesizing protein, ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), required in synthesizing of tryptophan which is a precursor of indole acetic acid (IAA) and prerequisite for the formation of auxin, have an active role in metabolism of nitrogen and starch, in the Zn-finger transcription factors, enhance plant resistance to fungal disease and is needed to maintain structural orientation of macromolecules and ion transport system in plants (Chaudhary, Mishra, Bola, Nagar, & Chaudhary, 2015; Hafeez et al., 2013; Kobraee, NoorMohamadi, HeidariSharifabad, DarvishKajori, & Delkhosh, 2011; Tavakoli et al., 2014).

Chlorine is an important micronutrient required by higher plant and is essential for stomatal regulation, water-splitting reaction of photosystem II (PS II), as a bridging ligand in order to stabilize the oxidised form of manganese or as a structural component of correlating polypeptides and is important in photosynthesis of plants due to its accumulation in chloroplast (Chen, He, Yang, Mishra, & Stoffella, 2010).

Boron is a crucial element in organic chemistry due to its one-of-a kind features and has a wide range of application in synthesis of organic compounds and is crucial in plants for its structural role in cell wall development, cell division, structural and functional integrity of plasma membrane, phenol metabolism, nitrogen fixation as well as for the growth and development of vascular plants, diatoms species of marine algal flagellates and for healthy reproductive growth of plant (Ahmad, Niaz, Kanwal, & Rasheed, 2009; Miwa & Fujiwara, 2010).

Manganese biogeochemistry is complicated due to its presence as various forms of oxidation states such as 0, II, III, IV, VI and VII while in biological system, it exists in the oxidation forms of II, III, and IV (Millaleo, Reyes-Díaz, Ivanov, Mora, & Alberdi, 2010). Manganese most important function is its role in photosynthesis which is its involvement in water-splitting system of photosystem II (PSII). Other than that, manganese has a crucial role in ATP synthesis in RuBP carboxylase reaction, biosynthesis of fatty acids, acyl lipids and proteins, as an activator and co-factor of numerous enzymes in plants such as Mn-superoxide dismutase, Mn-catalase, pyruvate carboxylase and phosphor-enolpyruvate carboxykinase as well as in the biosynthesis of chlorophyll , aromatic amino acid (tyrosine) and secondary products, lignin and flavonoids, in biosynthetic pathways of isoprenoids and assimilation of nitration and in plant's defence against oxidative stress (Millaleo et al., 2010; Schmidt, Jensen, & Husted, 2016).

Copper (Cu) is an important micronutrients for plant's physiological processes due to its ability to exist in several oxidation states such as Cu^{2+} and Cu^{+}. Its presence is important in Major regions in plants such as the cytosol, the endoplasmic reticulum (ER), the mitochondrial inner membrane, the chloroplast stroma, the apoplast and the thylakoid lumen, triggers the oxygen-evolution action of PSII, important cofactor of various oxidases such as mitochondrial cytochrome c oxidase, able to bind ethylene and has a role in a molybdenum cofactor synthesis (Yruela, 2005).

Molybdenum (Mo) is known as a transition metal that exists in the lithosphere at moderate amount of 1.2 mg/kg and is among the most limited trace elements in biological system and occurs in several oxidation states which are 0, I, II, III, IV, V, and VI and the most abundant form of Mo found in soils is with the oxidation states VI (Bittner, 2014; Kaiser, Gridley, Brady, Phillips, & Tyerman, 2005). In plants, molybdenum is required for chemical changes that relate to nitrogen nutrition which allow the plant to utilize nitrates taken up from soil for non-legumes plant. Mo has two role in legumes plant, first, Mo is required to break down nitrates taken up from soil and secondly, it aids in atmospheric nitrogen fixation by root nodules bacteria and it required in larger amount for nitrogen fixation than the utilization of nitrates (Weir, 1984).

The objectives of this review are to identify micronutrients required by plants and to evaluate the performance of micronutrients required by plants. Criteria that are involved in this review include the effects of micronutrients on plants involving its toxicity and deficiency, method of application of micronutrient, soil characteristics that influence the availability of micronutrients, economics of micronutrients and micronutrient requirement of plant.

II. METHODOLOGY

For this research, 5 criteria are used in order differentiate the micronutrients. The criteria chosen are characteristics of soil, the economics of the micronutrients, the effects that the micronutrients have on plants, application method to apply micronutrients on plants and the micronutrients required by different type of plants.

1. Characteristics of Soil

Micronutrients availability in soils differs according to soil characteristics. The soil characteristics that will be evaluated are soil pH, soil texture, soil moisture and temperature as well as the interaction of micronutrients with other element of the soil. A summary table will be constructed to categorize the availability of each micronutrient and the soil characteristics as well as the soil type classification.

2. Method of Application of Micronutrients

There are three most common type of applying fertilizers are using soil application either by broadcasting or band, foliar fertilization and seed treatment. Each of the method has its own advantages and disadvantages and the suitability of the application method for each micronutrient will be discussed.

3. Economics of micronutrients

Each micronutrient has its own recommended application rates. Those rates will be stated and the cost of micronutrient fertilization using the recommended rates will be calculated.

4. Effect of Micronutrients on Plant

The effect of micronutrients on plants will include toxicity and deficiency characteristics and symptoms that occur in plants as well as some pictures to provide a clearer image.

5. Micronutrients Requirement of Plant

Plants required a certain range of micronutrient concentration that is sufficient for the growth and to obtain optimum yield. Exceeding the concentration will lead to toxicity while not having enough of the concentration will cause deficiency. In this section, the sufficiency concentration for several plants will be identified.

III. RESULTS AND DISCUSSION

A. Characteristics of Soil

Micronutrients availability in soils is dependent of several factors such as soil pH, content of organic matter in soils, texture of soils that can contribute to leaching and decrease of organic matter content, water content in soils, interaction between the micronutrients and temperature (Voss, 1998).

Soil pH can be defined as the relative measure of hydrogen ion (H^+) in soil. For pH less than 7, the soil is acidic, pH 7, soil is neutral while pH more than 7, the soil is alkaline (Manjula, 2009). Soil pH affects various properties of micronutrients in soils such as its solubility, concentration, ionic forms, mobility of micronutrients in soil and the uptake of micronutrients by plants (Fageria, Baligar, & Clark, 2002). At high pH whereby the soil is alkaline, the availability of micronutrients iron, manganese, copper, zinc and boron decreases while for molybdenum, it is the only micronutrients where its availability is enhanced due to high pH (Voss, 1998). Optimum boron availability is at pH 5.5 to 7.5 while chlorine is only lightly bound in acid to neutral soils and is negligible at pH 7. Absorption of copper increases when pH is increase from 4 to 7. As for iron, its solubility decreases by approximately 1000 fold when soil pH is increase from pH 4 to pH 9 (Fageria et al., 2002). The range of optimum soil pH for most fruits and vegetables are between pH 6 – pH 7, for potato is between pH 4.5 to pH 5.5 and for blueberry, rhododendron and azalea are between pH 4.3 to pH 5.3 (Manjula, 2009).

The second factor that affects the availability of micronutrients in soil is the texture of soils. Soil texture can be describe as the percentage of sand, silt and clay particles that compose the mineral part of the soil. Loam soil is the mixture of sand, silt and clay particles. Each of these textural classes adds different properties to the soil such as sand add porosity to soil, silts add body to the soil while clay adds physical and chemical properties that can affect the uptake of nutrients by soils via adsorption through soil particles (Manjula, 2009). Micronutrients availability in soils are considerably affected by soil texture. A coarse textured soils such as sandy soils mostly does not contain sufficient amount of micronutrients for plant while fine textured soils such as clay soils have less potential to be deficient in micronutrients due to the fact that clay and organic soils have better retention of water and nutrients than sandy soils. Leaching in sandy soils occurs when water is drains from sandy soils along with micronutrients in the soil thus contributing to the unavailability of micronutrients. Moreover, mineral soils with low organic matter and severely leached acid soils are also very likely to be deficient in micronutrients. For severely leached acid soils, its parent materials are already deficient in micronutrients coupled acid leaching which further remove more micronutrients in the soil (Kumar, Choudhary, Pooniya, Suri, & Singh, 2016).

Soil moisture and temperature are also factors that can affect the availability of micronutrients in soils. At low temperature at moisture content, the micronutrients availability in soils decreases due to decrease root activity, decreased rates of dissolution and diffusion of micronutrients. Other than that, soil moisture content are also affected by mineralisation of micronutrients from soil organic matter (Almendros, Gonzalez, & Alvarez, 2013). Micronutrients zinc and copper availability tend to increase with increase of soil temperature while micronutrient manganese availability tends to decrease with increasing soil temperature and as for micronutrient boron, its availability differs according to species (Kumar et al., 2016).

The final factor that affect the micronutrients availability in soil is the interaction between the micronutrients and also with other elements present in the soil. High concentration of one micronutrients can influence the level of other micronutrients via a process called antagonism such as high level of iron causes manganese and zinc deficiencies in plant and while high concentration of zinc added to soil will cause copper deficiency in cereal crops thus proving copper and zinc has antagonistic effects to each other. Increased level of copper in soil induce iron chlorosis in citrus crops while addition of iron fertilizer to soil cancel out the toxic effect of copper. There are also micronutrients that show both beneficial and detrimental effect to each other such as molybdenum is able to enhance the deficiency of iron in plants as a result of the formation of iron molybdate precipitate in the roots although molybdenum application coupled with high doses of iron is also known to enhances crop yield (Kumar et al., 2016). Table 1 shows the soil characteristics in which micronutrients availability is low and its major soil group.

Table 1 Soil characteristics in which micronutrients availability is low and its major soil group (Alloway, 2008; Kaiser et al., 2005; Penney, 2004; Shaaban, 2010; Tariq & Mott, 2007; Voss, 1998).

Micronutrients	Soil Characteristics	Soil Classification System (Using Soil Taxonomy and World Reference Base for Soil Resources)
Zinc	• Highly weathered and leached tropical soil with low pH • Sandy soil with low organic content • Saline soils • Calcareous soil with high pH • Organic soil (peat and muck) • Prolonged period of waterlogging (paddy field soil)	Sandy soil : Arenosols, Leptosols, Regosols, Podzols and Ferralsols Saline soil: Solonchaks and Solonetz Calcerous soil: Calcisols, Leptosols, Rendzinas and Cambisols Organic soil: Histosols, Chernozems, Kastanozems, Phaeozems, Podzols, Rendzinas (Rendic Leptosols and Calcisols) Umbrisols, Cambiols, Fluvisols and Gleysols
Manganese	• Heavily weathered tropical and sandy soil • Organic soil with pH more than 6 (peat soils) • Mineral soils with pH above 6.5 ○ Calcareous ○ Heavily limed acid Soil.	
Iron	• Calcareous • Neutral to alkaline soils • Soils with less than 2% organic matter • High pH of more than 8	Calcerous soil: Calcisols, Leptosols, Rendzinas and Cambisols
Boron	• Alkaline, heavily limed soil with pH 7.0 and above • Highly leached sandy soil • Coarse textured soil	Sandy soil: Podzols Deserts soil : Aridisols
Chlorine	• Highly leached sandy textured soil • Soils far from sea	Arenosols, Ferralsols, and Acrisols
Copper	• Highly leached sandy soil • Calcareous and high pH soil • Saline soils • Soil with high organic content	Highly leached sandy soil : Arenosols, Ferralsols, Acrisols Calcareous soils: Calcisols, Rendzinas Saline soils : Solonchaks Soil with high organic content : Histosols and Podzols
Molybdenum	• Acidic soils of pH less than 5.5 • Sandy soils	Sandy soil : Arenosols, Leptosols, Regosols, Podzols and Ferralsols

B. Application Method

Fertilization using micronutrient fertilizers are done to correct deficiencies of micronutrients in plant and also to supply adequate micronutrients to obtain optimum yield of plants. There are three general method of applying micronutrient fertilizer which are soil application, foliar spray and seed treatment. Soil application includes broadcasting and banding method. In broadcasting method, micronutrient fertilizer at a recommended rate is spread over the plants' growing area and left to enter into the soil or using a cultivator to incorporate the fertilizer into the soil and is best used for a field are that is huge, with limited time and labour as well as when it is crucial to have a uniform distribution of soil amendment while banding is a method of applying small amount of micronutrient fertilizer as a plant start which can boost early plant growth and maximize yield. Placement of band fertilizer should be done in careful manner since applying it to close to seed or plant or in excessive amount could lead to decrease in germination rate, burning of seedling roots as well as loss of stand (Savoy, 2015).

Foliar application as foliar spray are used when the condition of soil limit the availability of micronutrients applied through soil application, there is a possibility of huge loss of soil applied micronutrients and when there is an interaction between the plant internal demand and environmental condition that limit micronutrient delivery to important plant organs during plant growth (Fernández, Sotiropoulos, & Brown, 2013). Advantages of foliar spray include lower application rates compared to soil application, uniform distribution can be obtained easily, the response of the applied micronutrient is very quick thus micronutrient deficiencies in plant can be easily corrected during the growing phase and spray trials can be used as an easy method to diagnose suspected deficiencies while its disadvantages include small plant have high nutrient demand but the leaf area is too small for foliar absorption, excessive concentration can lead to leaf burn, can cause some residual effects and plants might need more than one spray application causing extra application expenses (Mortvedt, 1985).

Seed treatment includes seed priming and seed coating. Primed seed is known to germinate quicker, have better synchronized germination due to decrease inhibition time and build-up of metabolites that increase germination (Farooq, Wahid, & Siddique, 2012) while seed coating involves covering the natural seed coat by applying finely ground solids or liquid that contain dissolved or suspended solids including pelleting. For seed coating, beneficial materials are attached around the seed aided by sticky materials while seed pelleting involves adding inert material to change shape, size and surface area of seed for precision planting as well as making irregular shaped seed smooth and making small seed larger. Factors that determine the success and effectiveness of micronutrient seed coating include types of nutrient used, coating material, types of soil, moisture and fertility status and ratio of nutrient to seed (Halmer, 2006).

Zinc micronutrient are applied to plants using foliar spray and soil application involving broadcasting and band. For foliar application of zinc, zinc in the form of chelates are more commonly use since it is compatible with various herbicide and fungicide formulation although it is quite expensive compared to inorganic compounds. Among chelates form of zinc, $ZnSO_4$.DPTA is discovered to be the most effective zinc chelates sources for the growth and yield of maize (Tahir, Fiaz, Nadeem, Khalid, & Ali, 2009). Zinc sulphate, $ZnSO_4$ can also be used as foliar spray but it has a high probability of scorching the plant if neutraliser are not added or if the solution is made of hard water and using foliar spray is the best method to decrease deficiencies of zinc micronutrient in plant due to its ease of absorption via leaves and is the best and quickest method to improve zinc deficiencies under rain-fed condition while applying $ZnSO_4$ by broadcasting is known to be as effective as root dipping of rice plants in 1% ZnO suspension and is the most commonly used method as well as the cheapest method to supply zinc to transplanted rice (Alloway, 2008; Mortvedt, 1985; Wasaya et al., 2017).

Iron micronutrient can be applied to plant by both soil application and foliar application. For citrus, soil application is more preferable than foliar application when correcting iron deficiencies due to its ineffectiveness and the probability of having fruit and leaf burn. When applying iron using soil application, the use of iron chelates are recommended although different types of iron chelates have different effective pH range while the use of iron sulphate, $FeSO_4$ in acid or alkaline soil is not recommended since it does not provide enough available iron due to its ability to quickly change into iron oxide (Obreza, 2002). In China, acid ferrous sulphate is used as fertilizer on high pH soils as well as for seed treatment involving soaking of soya bean seeds (Alloway, 2008).

Manganese can be applied to soil using soil application method, foliar spray and seed treatment method. Foliar spray is commonly applied to plant using $MnSO_4$ and is effective for plant such as small grain cereal cultivated in calcareous and alkaline soils. It is more effective to apply multiple foliar spray of $MnSO_4$ rather than a single application on soybean and some reports show that soybean plant that has been sprayed with $MnSO_4$ at early growth stage and at late growth stage had higher yield compared to soybean plant that has a single application (Alley et al., 1978; Fageria et al., 2002). Similar findings to soybean have been found on corn although soil critical level for corn is lower than soybean. The foliar application to correct manganese deficiencies in corn has to done as soon as symptoms appear and has to be repeated under severe deficient conditions. For foliar application, both organic and inorganic sources are equally effective (Mascagni, 1984). For soil application, it is sufficient to apply $MnSO_4$, MnO and manganese frits to correct manganese deficiency except for manganese chelates due to its quick loss from soil and instability of manganese chelates in soil (Bligh, 1987). Broadcasting and banding of $MnSO_4$ can be used to achieve optimum yield of soybean as well as to treat manganese deficiencies in soybean. Research has shown that placing manganese in band with rows of soybean seed is able to increase yield on soils that has insufficient manganese and its effectiveness can be increased by combining manganese with acid-forming macronutrients fertilizers in high pH to neutral type soils and the highest seed oil yield and the greatest seed protein yield of soybean were obtained by soil application of manganese (Alley et al., 1978; Fageria et al., 2002; Yasari & Vahedi, 2012). Seed treatment with manganese is observed to be the most effective fertilizing method for wheat (Alloway, 2008).

Boron micronutrient can be added to the soil by mixing it with other types of fertilizer, foliar sprays, soil treatment such as banded and broadcasted and seed treatment. Mixing boron micronutrient with other types of fertilizer will produce “boronated fertilizers” that is commonly used in areas with high rainfall where leaching is frequent and low risk boron accumulation to harmful level and should not be applied in the row of soybean and corn as well as drill in for oat due to its toxic concentration and might lead to serious injury as well as mixed with various phosphate or potash applied to soil (Alloway, 2008; Kelling, 1999). In Columbia, foliar application is recommended for cultivation of beans on moderately deficient soils but less effective for cotton in Nigeria while some research found that foliar application of boron can increase number of fruits sets and production of prune and sour cherry and number of pods on branches of soybeans although some research also show that foliar application of boron on soybean during growth phase does not affect soybean yield but its application to soil before planting of soybean shows an increase of 17 % number of pods per branch as well as 39% number of branch pod per plant and while another research shows that foliar application of boron did not seed yield of soybean at any rate or application stage (Freeborn, Holshouser, Alley, Powell, & Orcutt, 2001; E. Hanson, Chaplin, & Breen, 1985; E. J. Hanson, 1991; Mortvedt, 1985; Reinbott & Blevins, 1995; Schon & Blevins, 1990). For soil application, boron can be broadcasted before planting of corn, beans or oats although higher rates are required for broadcast compared to banded or foliar sprays (Fageria et al., 2002; Kelling, 1999). Broadcasting of boron are applied to establish and maintain alfalfa and various non-row crops while band application of boron can lead to enhanced efficiency of applied boron. For rutabaga plant, band application is more suitable than broadcast since banding produce increased concentration of boron in leaves (Barker & Pilbeam, 2007). Soil application using Borax to rice prior to planting also produce a higher yield compared to foliar application (David, Gene, & Andy, 2005). Boron fertilizer in India are applied using broadcasting and is cultivated into soil prior to seedling or by band application while in China, for oil seed rape and cotton, boron fertilizer are administered either to the soil, seed or the foliage (Alloway, 2008).

There is a lack of research done on the method of application of chlorine fertilizer although there are various research that shows the application of chlorine fertilizers are able to increase yield of various types of plants. Chlorine micronutrient fertilizer are mostly applied through broadcast application since it is safer than band application that could have a risk of salt injury (Barker & Pilbeam, 2007). On the other hand, application of chlorine fertilizer in the form of KCl or $CaCl_2$ using side band application was discovered to increase the seed yield of annual canarygrass (*Phalaris canariensis L.*) by 24% (May et al., 2012). Apart from broadcast and band application, chlorine can also be applied prior to planting although for winter wheat, broadcast application of chlorine fertilizer is more preferable due to leaching during the winter (RE Lamond, Roberson, & Rector, 1999).

Copper fertilization can be done using soil application involving broadcasting and band, foliar treatment and mixed with phosphatic fertilizer which is commonly done in Australia (Alloway, 2008). Band application of copper requires lower rates than broadcasting using $CuSO_4$ to correct copper deficiencies. Soil application using $CuSO_4$ is more preferable than using CuO since $CuSO_4$ is more effective when correcting copper deficiencies and re-applying of copper is needed if deficiencies continues while foliar application of copper are only used as emergency measures (Fageria et al., 2002). Foliar application are normally applied in the form of $CuSO_4$, CuO and copper chelates and known to cause leaf burn to plant although this injury can be minimized by keeping the application rates low but second foliar application might be required. An experiment studying the effect copper application on wheat revealed that copper application using broadcasting and soil incorporation using $CuSO_4.5H_2O$ produce maximum grain yield of wheat during all stages of wheat growth and in deficient and sufficient copper level in soil while foliar application only produce significant increase in grain yield in 7 out of 10 trials. Early application of foliar copper is not preferable since it is ineffective in correcting copper deficiency due to area of leaf exposed to foliar spray is small while another experiment involving wheat shows that a single copper spray does not produce any significant increase in the content of copper in wheat grain and although some varsities of wheat show 20% increase in yield, it is accompanied by a decrease of 11 to 12% copper content in wheat grain due to dilution effect (Karamanos, Pomarenski, Goh, & A Flore, 2004; Korzeniowska & Stanisławska-Glubiak, 2011). At the Canadian Great Plains, soil application by surface broadcast followed by inclusion of copper in granular form was usually enough at inhibiting deficiency of copper in wheat on soils with low level of copper as well as enhancing seed yield and quality although it was later discovered that surface spray broadcast application followed by inclusion of copper solution fertilizer was better at inhibiting copper deficiency as well as enhancing seed yield of wheat (Malhi & Karamanos). In cultivation of rapeseed in Poland, both soil application and foliar application show significant effect to yield and oil content of rapeseed with best result obtained using foliar application of copper sulphate solution (0.2%) during the budding phase of rapeseed (Sienkiewicz-Cholewa, 2008).

Molybdenum fertilizer can be applied to plant and soil by soil application, foliar application and seed treatment and also added to superphosphate fertilizer in Australia as well as applied with copper and zinc fertilizer for gravely soil, acidic and sandy soil from Western Australia. Soil application of molybdenum can be done using either broadcast or band as well as using basal application which is a broadcasting method that is done at planting or sowing and is usually done on calcareous soils for peanut plant (Alloway, 2008). Soil application of molybdenum usually use sodium molybdate and ammonium molybdate which are soluble sources of molybdenum and spray them onto soil surface prior to tilling for a more uniform coverage although this method is rarely used (Barker & Pilbeam, 2007). Plants only require molybdenum is small amount thus evenly distributing such amount is a challenge for direct granular molybdenum soil application therefore it is recommended to solubilize molybdenum fertilizer in water before spraying in directly to soil (Mahler & Bull, 1982). An experiment using Nantes carrots (*Daucus carota L. 'Sativa D.C.'*), onions (*Allium cepa L. 'Autumn spice'*), cauliflower (*Brassica oleracea L. botrytis 'Primosnow'*), and red clover (*Trifulium pratense L. 'Lakeland'*) in both greenhouse and field experiment shows significant increase in yield of onions, cauliflower and red clover during the greenhouse experiment and a slight increase in yield of carrots during the field experiment when molybdenum fertilization is added to soil. It was also observed that soil application using molybdenum solution was better at increasing level of molybdenum in leaves than soil application using granular form of molybdenum (Umesh C Gupta, Leblanc, & Chipman, 1990). Foliar fertilization of molybdenum also uses sources such as sodium molybdate and ammonium molybdate due to their high solubility in water and should be applied during plant's early development stage and is more effective than soil application of molybdenum. Wetting agents should be added to the foliar spray solution to obtain better coverage on foliage of crops (Barker & Pilbeam, 2007; Fageria et al., 2002). In potatoes, foliar application of molybdenum using sodium molybdate result in significant increase in leaf nitrate reductase activity as well as increase in the amount of molybdenum level in potato tuber and decrease in toxicants in potatoes compared to soil application by banding (Mondy & Munshi, 1993). A research done in Brazil showed that foliar application of molybdenum in common beans significantly increased nitrogenase activity and able to prolong the period of high nitrate reductase activity as well as increase in total shoot of nitrogen independently of inoculation with selected strains of *Rhizobium* (Vieira, Cardoso, Vieira, & Cassini, 1998). In experiment involving sunflower, foliar application of molybdenum resulted in a significant increase in sunflower biomass production and content of dry matter. It was also discovered that foliar application of molybdenum during the beginning of vegetation stage and during development stage of sunflower enhance the achenes yield. Moreover, oil production of sunflower was also enhanced as a result of increased yield and stabilised oil content (Škarpa, Kunzova, & Zukalova, 2013). Another study shows that apart from increasing achene yield, foliar application of molybdenum on sunflower also increases achene mass by 40% as well as improving the nitrogen nutrition is sunflower (Steiner & Zoz, 2015). Another method of applying molybdenum to plant is by seed treatment preferably using seed coating method. This method is very effective for preventing molybdenum deficiency in plants cultivated on soils with insufficient level of molybdenum as it is able to provide uniform application and amount of molybdenum coated onto the seed is enough for optimum plant growth (Barker & Pilbeam, 2007). This method is recommended for small farmers as it is cheap, simple, spraying equipment is not needed and is tolerance towards unexpected rain and wind (Haque, 1987). An experiment with cauliflower shows that seed pelleting is able to correct molybdenum deficiency at a lower molybdenum rate than foliar application. According to the experiment, the advantages of seed pelleting of cauliflower include as a practical method for direct seeded crops and risk of build-up of undesirable molybdenum level in soil can be decrease due to low amount of molybdenum needed during coating of seed (Scheffer & Wilson, 1987). On another experiment, it was discovered that rhizobial seed-coat inoculants enriched with molybdenum had significantly enhanced plant heights, dry weights, number of root nodule, nodule weight and nitrogenase activity of alfalfa (Zhou, Deng, Zhang, Cobb, & Zhang, 2017).

C. *Economics of Micronutrients*

Micronutrients are added to soils in the form of micronutrients fertilizers. This section explains about the economics of each micronutrients including its rates of application and price of the micronutrients fertilizers.

Table 2: Price of fertilizers containing micronutrients (Alibaba, 2016)

Micronutrients	Price, RM (per kg)
Zinc	2.84
Iron	0.40
Manganese	2.04
Boron	2.76
Chlorine	1.80
Copper	9.20
Molybdenum	31.32

Copper micronutrients is usually applied to soil and plant in the form of copper sulphate pentahydrate ($CuSO_4.5H_2O$), copper sulphate monohydrate ($CuSO_4.H_2O$), copper oxychloride ($3Cu(OH)_2.CuCl_2.4H_2O$), copper sulphate ($CuSO_4.5H_2O$), copper EDTA chelate (Na_2EDTA) and cupric oxide (CuO) although $CuSO_4.5H_2O$ is the most commonly used copper fertilizer due to its low cost and high water solubility (Barker & Pilbeam, 2007; R. K. Gupta, 2013). Copper micronutrients are generally applied to soil at a rate of 1.4 to 2.8 kg copper per acre although sometimes it is also applied at a range of 1.8kg to 5.9 kg copper per acre according to soil and crops and due to immobility of copper in soil the recommended rates are enough for 5 to 8 years according to soil and plant (Voss, 1998). It is also recommended to apply 0.025% of $CuSO_4.5H_2O$ foliar spray solution, seed soaking using 0.25% $CuSO_4.5H_2O$ solution and for rice and soil application, 1.5 – 2 kg $CuSO_4.5H_2O$ per hectare once in 4-8 years (R. K. Gupta, 2013). Furthermore, application of 0.5-1 kg of $CuSO_4$ in 500L of water for used as foliar spray is also recommended (Fageria et al., 2002). In Europe, 2-5 tonnes per hectare of $CuSO_4$ are applied to soil at interval of 5 to 15 years while application of copper as ($3Cu(OH)_2.CuCl_2.4H_2O$) is applied at rates of 10 kg per hectare and ($3Cu(OH)_2.CuCl_2.4H_2O$ as foliar treatment are also applied at rates of 0.5 to 2.2 kg per hectare or application of Cu EDTA at rate of 100g per hectare. In Brazil, copper are applied using broadcast or banded at rate of 1-2 kg per hectare or as foliar spray using 0.1 - 0.2% of copper sulphate solution in 400 L water per hectare (Alloway, 2008). At the highest application of copper fertilizer at 5.9 kg per acre, the cost of fertilization using copper micronutrient is RM54.28 for every 5 to 8 years.

Iron micronutrient is usually applied to plant and soil in the forms of iron chelates such as Fe EDDHA, Fe DTPA, Fe EDTA, ferrous sulphate $FeSO_4.7H_2O$ and ferrous ammonium sulphate $(NH_4)_2SO_4.FeSO_4.6H_2O$ (Alloway, 2008; R. K. Gupta, 2013). In India, the most commonly used iron fertilizer is ferrous sulphate and is applied as soil application at rates of 50 kg per hectare every 3 years to crops such as wheat and rice or applied every year at rates of 15 kg per hectare. Foliar spray is applied at rates of 1% solution, 2-3 times weekly interval is more effective for rice, wheats or pulse crops while in Brazil, iron salts are used as foliar sprays in the from solution at rates of 1-2% $FeSO_4.7H_2O$ in 400 L water per hectare or using $FeSO_4$ as foliar sprays at rates of 3-6 kg per 500 L water (Alloway, 2008; Fageria et al., 2002; R. K. Gupta, 2013). Using fertilization recommendation in India, applying 50 kg per hectare every 3 years will cost RM 20.00 while applying 15 kg per hectare every year will cost RM6 or RM18 for 3 years.

Manganese micronutrient is usually applied to plant and soil in the form of manganese sulphate, $MnSO_4$, manganese EDTA chelate, Mn EDTA, manganese chloride, $MnCl_2$ and manganese oxide, MnO (R. K. Gupta, 2013; Voss, 1998). In India, manganese is applied as foliar spray in the form of $MnSO_4.H_2O$ at rates of 0.5% for tillering in rice and initiation of crown root in wheat (R. K. Gupta, 2013). For highest soybean yield, manganese in the form of manganese sulphate, $MnSO_4$ is applied at rates of 2.2 kg per hectare as foliar spray, 5.6 kg per hectare as banded and 11-22 kg per hectare as broadcasting according to soil pH (Mortvedt, 1985). For foliar application using manganese chelate, recommended rate is 0.05 – 0.07 kg per acre and not more than 0.1 kg per acre since it might be phytotoxic while using manganese sulphate as foliar spray, the recommended rate is between 0.3 to 0.5 kg per acre (Voss, 1998). Foliar spray at rates of 1-2 kg per 500 L water using manganese sulphate is also recommended (Fageria et al., 2002). There are evidence that foliar application using 2.2 kg manganese per hectare increased the grain yield of soybean (Alley et al., 1978). Manganese applied as soil application are usually applied at rates of 1.4 to 2.3 kg per acre using manganese sulphate or manganese oxide and if using manganese chelate, 0.2 kg to 0.4 kg per acre is applied (Voss, 1998). Soil application in Brazil are applied at rates between 5 to 50 kg manganese per hectare using broadcasting method for larger amount and banding method for smaller amount while foliar application uses 0.1-0.2% $MnSO_4.H_2O$ in 400 L of water. In UK, crops with manganese deficiency are treated with $MnSO_4$ in the form of foliar spray at a rate of 5 kg per hectare (Alloway, 2008). Using soil application of manganese sulphate or manganese oxide at a rate of 2.3 kg per acre, the cost of fertilization is RM4.70. For broadcasting method of using 50 kg per hectare, the cost of manganese fertilization is RM102.00 while using banding at rate of 5 kg per hectare, the cost is RM10.20.

Molybdenum micronutrient is applied to plants and soil in the form of ammonium molybdate, $(NH_4)_6Mo_7O_{24}.4H_2O$, sodium molybdate, $Na_2MoO_4.2H_2O$ and molybdenum trioxide, MoO_3. For soil application of molybdenum, rates of 50-100 g per hectare are sufficient for agronomics crops while for vegetables crops, 400 g per hectare are required. For foliar application of molybdenum at beginning of plant development, rates of 0.025 to 0.1% solution of $Na_2MoO_4.2H_2O$ and $(NH_4)_6Mo_7O_{24}.4H_2O$ (approximately 200 g per hectare) is suggested. For seed treatment, the suggested rates are between 7 to 100 g molybdenum per hectare (Barker & Pilbeam, 2007). In India, 2 to 4 kg per hectare of $Na_2MoO_4.2H_2O$ or 2 to 3 kg per hectare of $(NH_4)_6Mo_7O_{24}.4H_2O$ are applied at planting stage or seed treatment is done using 10 to 20 g $Na_2MoO_4.2H_2O$ per 25 kg of seed. Foliar spray can also be applied using ammonium molybdate solution at rates of 0.1% to 0.3% for 2 to 3 times at 10 days interval (Voss, 1998). For crops such as clovers and lucerne, it is recommended to apply 75 g per hectare of MoO_3 or equivalent amount of $Na_2MoO_4.2H_2O$ or $(NH_4)_6Mo_7O_{24}.4H_2O$ mixed with superphoste while for vegetable crops, $(NH_4)_6Mo_7O_{24}.4H_2O$ or $Na_2MoO_4.2H_2O$ at rates of 1 kg per hectare are mixed with fertilizers. For crops such as cauliflower, broccoli, cabbage and tomato, seedbed application are done at rates of 40g per 50 L water using $Na_2MoO_4.2H_2O$ or $(NH_4)_6Mo_7O_{24}.4H_2O$ for one or two weeks before transplanting and for growing crops, field application using 50g in 100L water of $(NH_4)_6Mo_7O_{24}.4H_2O$ or $Na_2MoO_4.2H_2O$ is recommended (Dear & Weir, 2004; Weir, 1984). The cost for agronomic crops using soil application at the rate of 100 g per hectare is RM3.13 while for vegetable crops at the rate of 400 g per hectare, the cost of molybdenum fertilization is RM12.53.

Zinc micronutrient is usually applied to soil and plant in the form of zinc EDTA chelate, zinc sulphate monohydrate, $ZnSO_4.H_2O$, zinc sulphate heptahydrate, $ZnSO_4.7H_2O$ and zinc oxide, ZnO (R. K. Gupta, 2013; Voss, 1998). For broadcast application, the common recommended rates of inorganic zinc are between 1.8 – 4.5kg per acre while for banded application, the recommendation rates are between 0.9 – 2.3 kg per acre (Voss, 1998). In India, recommended rates for soil application using $ZnSO_4.7H_2O$ are between 25 to 60 kg per hectare applied once every two years. It is also recommended to apply $ZnSO_4$ every year at a rate of 10 kg per hectare. For foliar application, the recommendation rate is using 0.5% solution of $ZnSO_4.7H_2O$ after 15 days of rice transplanting or 30 days of wheat planting and should be repeated after 15 days (R. K. Gupta, 2013). In Nigeria, application of ZnEDTA at rates of 1-2kg per hectare is require for highest yield of maize while in Brazil, maize planted on Cerrado soils requires 3-9 kg of $ZnSO_4$ per hectare. In Columbia, cassava crops require up to 20 kg per hectare $ZnSO_4$ for maximum yields (Mortvedt, 1985). In South Australia, soil application of 9 to 22 kg of zinc per hectare were discovered to have useful effects on calcareous soils for approximately 10 years. In South America, 30 to 50 kg of $ZnSO_4.7H_2O$ per hectare are used as top dressing for both upland and lowland rice while in India, for wheat and rice, the application rate using $ZnSO_4.7H_2O$ is 11 kg per hectare, for maize, soybean and sugarcane, application rate is 5.5 kg per hectare and for peanuts, soya beans and other crops, recommended rate is 2.5 kg per hectare (Alloway, 2008). Using the common broadcasting rate of 4.5 kg per acre, the cost of zinc fertilization is RM12.78 while using banded method at 2.3 kg per acre, the cost is RM6.53.

Boron micronutrient is usually applied to soil and plant in the form of Borax also known as disodium tetraborate decahydrate, $Na_2B_4O_7.10H_2O$, boric acid, H_3BO_3 and Solubor, $Na_2B_8O_{13}.4H_2O$. For boron application, the recommended rates depending on requirements by crops and application method are between 0.25 to 3 kg per hectare and to obtain cotton maximum yield, it requires foliar spray at a rate of 0.5 kg per hectare or soil application of less than 0.3 kg per hectare (Barker & Pilbeam, 2007). In India, boron is applied as Borax using broadcasting method at a rate of 10 kg per hectare for crops such as rice, wheat and pulses and also as foliar spray 15 days after crops planting and at flower initiation stage at a rate of 0.5% Borax solution (R. K. Gupta, 2013). For broadcasting method, optimum application rate for alfalfa using $Na_2B_4O_7$ is 2.24 kg per hectare, for grapes using Solubor at 0.76 kg per hectare, for pine tree using $Na_2B_40_7.10H_2O$ at 5.7 kg per hectare, for rapeseed using H_3BO_3 at 1.4 kg per hectare, for soybean using $Na_2B_4O_7.5H_2O$ at 1.12 kg per hectare, for strawberry using $Na_2B_4O_7$ at 1.12 kg per hectare and table beet using Solubor at 3.4 kg per hectare while for banded method, optimum application rate for cole crops using $Na_2B_4O_7$ is 0.45 kg per hectare and for sugarbeet using Solubor at 2.2 kg per hectare (Martens & Westermann, 1991). Soil application at rates of 0.7 kg to 1.4 kg per acre is recommended for very responsive specialty crops while for medium responsive specialty crops, 0.2 kg to 0.45 kg per acre is recommended (Voss, 1998). Another recommended boron application is 0.5 to 1.36 kg per acre (1.0 to 3.0 lb per acre) depending on types of crops (Urvi C Gupta & Solanki, 2013). Using the recommended rate of boron fertilization at 3 kg per hectare, the cost gained will be RM 8.28.

Sources used as chlorine fertilizers are obtained from potassium chloride, KCl, sodium chloride, NaCl, ammonium chloride, NH_4Cl, calcium chloride, $CaCl_2$ and magnesium chloride, $MgCl_2$ and the most widely used chlorine fertilizer is KCl (Barker & Pilbeam, 2007). It is recommended to apply actual chlorine at a rate of 4.5 to 9 kg per acre when chlorine soil level is low (R Lamond & Leikam, 2002). In Argentina, the application of chlorine fertilizer has been reported to increase the grain yield of wheat (Triticum aestivum L.) when chlorine fertilizer is applied at a rate of 253 kg per hectare (Díaz-Zorita, Duarte, & Barraco, 2004). Using application of chlorine fertilizer in Argentina as a reference, chlorine fertilization at a rate of 253 kg per hectare will cost RM455.40.

D. Effects of Micronutrients on Plant

Since zinc is vital for nitrogen metabolism in plant, zinc deficiency can cause a decrease in protein synthesis in plants.

Other than that, zinc deficiency will affect the root system which in turn will affect nutrients and water absorption from soils which will result in decrease growth and yield of plants. Plants with zinc deficiency will exhibit several symptoms such as shorter stem length and internodes as well as rosetting of terminal leaves, decreased in fruit bud formation resulting in decreased in yield of plant, mottled leaves and interveinal chlorosis and have a short and thin stems with patchy appearance (Hafeez et al., 2013; Lohry & Si, 2007; Tavakoli et al., 2014). At high concentration, zinc is known to inhibit growth of plant, it can induce oxidative damage to plants, change the mitotic activity of plants thus affecting the membrane permeability and integrity and eventually kills the cells of the plant (Zahra & Latifeh, 2013).

Symptoms of iron deficiency include interveinal chlorosis in young leaves in which the space between the leaf veins turns pale yellow or white as well as its growth becomes stunted as well as the formation of filaments root and swelling at the root tip then afterwards root growth is reduced. Since iron has a crucial role in chloroplasts, thus chloroplast is the main targets of iron deficiency causing a decreased in photosynthetic activity as well as plastidic pigments and proteins (Eskandari, 2011; Rout & Sahoo, 2015; Tavakoli et al., 2014). Common symptoms of iron toxicity that can be observed are plant tissues turning brown, black and soft roots, root flaccidity, root branching decrease, more shoot die-back and mottling of leaves (Tavakoli et al., 2014).

Chloroplast is severely affected by manganese deficiency that result in severe damage to the structure of chloroplasts as well as decrease in net photosynthesis and amount of chlorophyll. Besides that, manganese deficiency cause significant effects to non-structural carbohydrate especially root carbohydrates as well as causing poor fertility of pollen resulting in decreased crops quality and quantity and also decrease in carbohydrates during grain filling. The symptoms of deficiency of manganese in dicot plants is usually associated with yellow spots on leaves while symptoms of manganese deficiency in monocot plants is associated with appearance of tape and green-gray spots in the leaves. The main symptoms of manganese deficiency is the decrease in photosynthesis efficiency resulting in decrease in dry matter productivity and yield. Some of the common symptoms of manganese toxicity occurs on mature leaves as brown spots and chlorotic dots at tips of younger leaves which appear more on less light intensity than in high light intensity. Toxicity due to manganese will starts with chlorotic in the older leaves then proceed to the younger leaves and also started at the border of the leaves proceed to the areas between the leaves while the leaves necrosis will spread with higher toxicity. Size of cell is more affected by toxicity due to manganese than number of cells. Irregular distribution of chlorophyll and starch granules accumulation in chloroplasts are also signs of manganese deficiency (Mousavi, Shahsavari, & Rezaei, 2011).

Boron deficiency can kill the tips of growing vegetative and the lateral shoots growth will be directly affected by the death of terminal buds where the tips would be deformed or die resulting in a rosette on the plant called "witches broom". The leaves will become thick with coppery texture, become curled and brittle as well as the young leaves growth is inhibited. Boron deficiency will also cause the tissue of the plants to break down prematurely resulting in brown flecks, necrotic spots, cracking and corky region in fruits and tubers. Insufficient boron nutrition will also affect flowering and fruiting process due to pollen germination and pollen tube development being retarded as well as decrease fertility and slowing down fruit development. Deficiency in boron will cause harmful effects which may result in cell death or disintegration of internal tissues as well abnormalities such as distorted, cracked or hollow stems (Urvi C Gupta & Solanki, 2013). Various effects can be caused by boron toxicity on processes in vascular plants such as altered metabolism, decrease root cell division, decrease leaf chlorophyll contents and photosynthetic rates as well as low lignin and suberin levels. Accumulation of boron starts at the leaf base and proceed to the tip of plants resulting in common toxicity symptoms such as marginal or tip chlorosis or both and necrosis (Camacho-Cristóbal, Rexach, & González-Fontes, 2008).

The common symptoms of chlorine deficiency include wilting of leaves mostly at the leaf margins and as the deficiency worsen, the younge(Chen et al., 2010; White & Broadley, 2001)st leaves would curl followed by shrivelling and necrosis. Other than cell division, cell extension is also affected by insufficient chlorine in plant whereby in roots, subapical swelling will occur accompanied by increased short lateral formation that will result in a stubby appearance of the roots (Chen et al., 2010). When high concentration of external chlorine is applied to plants exceeding their respective critical limits, negative effects such as decrease in crops yield and in the quality of the crops (Chen et al., 2010).

Plants with copper deficiency exhibit an alteration a series of gene expression and activation of morphological changes like in root and leaf structure. The common symptoms shows at young leaves tips first then proceed downwards along the margins of the leaf and may also be twisted or deformed as well as exhibits signs of chlorosis and necrosis. Other than that, copper deficiency will also cause the reduction of photosystem I (PSI) electron transport resulting from reduced plastocyanin formation, decline in activity of phosystem II, chloroplasts thylakoid membranes disintegrates, pigment content is reduced, decrease in synthesis of plastoquinone and reduction in the content of unsaturated C18 fatty acids as well as alteration in the thylakoid membranes and ambient of PSII acceptor side (Yruela, 2005). Some of copper toxicity symptoms shown by plant are chlorophyll content in plant decreases and there is changes in the structure of chloroplast and composition of thylakoid membrane as well as reduction in biomass and chlorotic symptoms occurs. There is also the deterioration of grana stacking and stroma lamellae, high number and bigger size of plastoglobuli and changes in the intrathylakoidal inclusion's appearance. Moreover, low photochemical activity due to copper toxicity also caused the structure and composition of thylakoid membranes to change. In addition, high level of copper can cause oxidative stress in plants leading to an increase of antioxidant responses resulting from additional production of very toxic oxygen free radicals which can cause alteration in the activity and content of several components of the anti-oxidative pathways. Other effects of copper toxicity include reduction of function of oxidation site of PSII, cluster of Mn as well as the extrinsic protein of oxygen-evolving-complex together with acceptor side that interact with non-heminic Fe^{2+} and cytochrome are affected and reduced the level of photoreduce cytochrome and the rate of photoreduction and also alter the initial S-state distribution of oxygen-evolving complex and increase Chl_z^+ radical formation that can result in fluorescence quenching in PSII. High level of copper also lead to photoinhibition due to PSII electron transport functional reduction and structural impairment of PSII reaction centre (Yruela, 2005).

In *Brassicaceae* family, insufficient Mo causes young plants to exhibit visual symptoms such as mottling, leaf cupping, and grey tinting and leaves flaccid especially on seeds that becomes dwarfs until it died. In older plants, symptoms exhibit on the young leaves of the plant such as 'whip-tail', leathery leaves and necrosis on meristem. Horticultural plants, cereal and legumes in Mo deficiency establish pale, green leaves sometimes with necrotic at leaf margins together with reduction in overall plant growth. In oat and wheat, symptoms are necrosis on leaves blades with seeds that developed poorly and shrivelled while in maize, Mo deficiency cause shortens internodes, reduction in leaves area and lead to the development of chlorotic leaves. Other than that, Mo deficiency in maize also result in changes of phenotypes in growing flowers, postponed the development of tassels, small anthers, stamens that developed poorly and decrease in pollen grain development. In recent studies, Mo deficiency is proposed as the main cause of bunch development disorder known as *Millerandage* where grapevines bunches grow unevenly with the presence of fully matured berries together with a huge amount of fertilized immature berries and unfertilized swollen green ovaries as well as other symptoms including zigzag-shaped internodes, pale-green leaves, more cupped and flaccid leaves and marginal leaf necrosis. Mo toxicity does not happen easily under most agricultural conditions. In reports which Mo toxicity does occurs, such as in tomato and cauliflower, symptoms shown are anthocyanins accumulated in leaves and becomes purple, while in legumes, the leaves become yellow (Kaiser et al., 2005).

E. Micronutrients Requirement of Plant

Table 3 shows the sufficiency concentration of several plants according to each micronutrients. These concentration need to be achieved by these plant for optimum growth and high yield.

Table 3 Sufficiency concentration of several plants according to each micronutrients (Barker & Pilbeam, 2007; Chen et al., 2010; Hochmuth, 2011; Kelling, 1999; Lohry & Si, 2007; E. Schulte & Kelling, 2004a, 2004b; Shaaban, 2010; Sutradhar, Kaiser, Rosen, & Lamb, 2016; Voss, 1998).

Micronutrients	Plants	Sufficiency level (ppm)
Zinc	Alfalfa	21-70
	Broccoli	20-80
	Cabbage	20-200
	Carrot	25-250
	Potato	20-40
	Soybean	21-80
	Sweet corn	20-100
Iron	Alfalfa	31-250
	Corn	21-250
	Soybeans	51-350
	Sugar beets	51-200
	Vegetable	50-250
	Potatoes	30-300
	Pecan	62-92
Manganese	Alfalfa	31-100
	Onion	21-150
	Potatoes	21-200
	Soybean	21-100
	Corn	20-150
	Wheat	16-200
	Oat	26-200
Boron	Alfalfa	30-80
	Corn	4-25
	Oat	3-40
	Soybean	20-50
	Wheat	6-40
	Cucumber	22-26
	Tomato	22-27
Chlorine	Kiwifruit	2130
	Sugar beets	710
	Coconut and oil palm	2490
Copper	Alfalfa	7.1-30.0
	Corn	5.1-20.0
	Oat	5.1-20.0
	Potato	5.1-30.0
	Soybean	9.1-30.0
	Legumes	1-28
Molybdenum	Alfalfa	0.5-5.0
	Barley	0.09-0.18
	Corn	1.4-7.0
	Oats	0.2-0.3
	Rice	0.4-1.0
	Sunflower	0.25-0.75

The common range of zinc in plant are between 20 to 100 ppm. Zinc level in leaves should not fall below 15 ppm so that zinc deficiency does not occur and should be maintained at 20 ppm for sufficiency level except for pecan where its sufficiency level is 50 ppm. Wheat is a plant that has low sensitivity to zinc deficiency thus needed lower amount of sufficient zinc for healthy growth compared to other plants (Alloway, 2004) Zinc toxicity does not occurs until zinc level exceeded 200 ppm (Plank, 1989).

Normal concentration of iron in plant is approximately 50 ppm and any concentration lower than that in plant leaves, iron deficiency is suspected to occur except for corn and grasses that have low iron requirement with critical level of approximately 20 ppm (Plank, 1989). Iron toxicity rarely occur in plant cultivation except for rice cultivation where toxicity will occur at 500 ppm (Barker & Pilbeam, 2007).

The sufficient level of manganese in plant range from 15 ppm to more than 1000 ppm depending on type of crop. There are not enough data to determine at what concentration manganese toxicity starts but evidence shows that concentration at several hundred ppm in leaf are toxic to a lot of plant especially plants that are sensitive to manganese such as soybeans whereby its growth is affected when manganese concentration is close to 200 ppm. Some plants such as pecan are very tolerant towards manganese where its leaves can contain almost 1000 ppm without any adverse effect (Plank, 1989).

As for boron, its sufficiency in plant vary considerably where its optimum concentration can range from 20 to 100 ppm in plant leaf tissues. Some plants are very sensitive towards boron such as peaches where its toxicity can occur if boron concentration is more than 50 ppm while for corn that has very low boron requirement, toxicity can happen when boron concentration in young leaves is more than 25 ppm (Plank, 1989).

Information about chlorine requirements in plant are limited but through several research it is known that plants generally need a large amount of chlorine mostly in several hundreds of ppm. Some researchers found that the optimum concentration of chlorine in plant for healthy growth is between 70 to 100 ppm while others set the optimum concentration at a range of 200 to 400 ppm. Chlorine toxicity rarely occurs even at several thousands of ppm and some plants such as kiwifruit, sugar beets, coconut and palm oil required very high amount of chlorine for healthy growth (Chen et al., 2010; E. E. Schulte, 2004).

The sufficient range of copper content in plant is between 5 to 30 ppm which is fairly narrow (Plank, 1989). For most vegetative plant section, the critical deficiency concentration for copper ranges between 3 to 5 ppm while in young grains, the critical deficiency concentration is 1.5 ppm (Sonmez, Kaplan, Sonmez, Kaya, & Uz, 2006). High response vegetables to copper are beet, lettuce, onion and spinach while low response vegetables to copper are asparagus, bean, pea and potato (Barker & Pilbeam, 2007).

Molybdenum micronutrient is required inn very low amount by plants compare to other micronutrients. The sufficiency concentration of molybdenum for most plants is within the range of 0.2 to 2 ppm (Barker & Pilbeam, 2007). Legumes plants require more molybdenum than non-legumes plants due to atmospheric nitrogen fixation by symbiotic bacteria. As for its toxicity level, currently, it is not established (Plank, 1989).

IV. Conclusion

This review is a collection of various research done on micronutrients required by plants. From these research, micronutrients iron, zinc, chlorine, manganese, molybdenum, copper and boron has been identified to be of utmost importance to plant. Each of the micronutrients is involve in various functions to ensure plant's optimum growth and yield. The characteristics of soil that influence the micronutrients availability in soil and micronutrients uptake by plant such as soil pH, soil texture, soil moisture and temperature as well as interaction of micronutrients with other nutrients present in soil are identified to ensure the suitability of the soil for plant cultivation. The correct application method of micronutrient either by soil application, foliar application and seed treatment aid in achieving optimum growth as well as preventing excessive accumulation of fertilizer in soil and help prevent leaf burn. Economics of micronutrient is also discussed, providing the recommended application rates and price to aid in cost evaluation. Insufficient and excessive amount of micronutrients in plants cause plant to experience deficiency and toxicity symptoms that ultimately lead to plant death and decrease in yield. Lastly, the optimum concentration of micronutrients required by plant is also discussed so that toxicity and deficiency of micronutrients in plant can be avoided.

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