Asian Journal of Applied Sciences (ISSN: 2321 – 0893)
Volume 04 – Issue 01, February 2016

Enhancement of Micronutrient in Crops through Farming System: A Review

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ABSTRACT - ***Micronutrient deficiency is a significant problem worldwide because three billion people suffer from malnutrition. The reasons for this is the lack of available micronutrients in soil to crops and the small amounts of nutrients from soil that are transported to edible parts such as leaves or grains - particularly zinc and iron. Some approaches have been developed including the application of organic matter, foliar application of fertilizer and agricultural practices such as irrigation to increase the availability of micronutrients. These approaches have slightly increased the availability of micronutrients in the soil and the ability of crops to absorb micronutrients. This review summarizes the main challenges of micronutrients deficiency and provides recommendations to manage this worldwide agricultural dilemma.***

Keywords - micronutrient, agricultural practices

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1. INTRODUCTION

Approximately 3 billion people worldwide are nutrient deficient because of inadequate nutrients in their diet [1,2]. This problem can be caused by many factors, particularly farming systems and nutrient availabilities. First factor is cropping practices status and behavior of micronutrients in the soil. For example, fallow soil has higher concentration of Zn (zinc) and Cu (copper) than cultivated soil because in cultivated areas these micronutrient are taken, transported and harvested from soil to crops [3,4]. Second, an interaction between macronutrients and micronutrients in soil also influences the capability of crops to uptake micronutrients [5]. For instance, the application of phosphorus fertilization affects the decreasing amount of available Zn and Cu [6]. Third, Zn, Fe (iron) and Mn (mangan) concentration increases when there is an application of organic matter on soil, demonstrating the importance of organic matter in micronutrient availability [3,7]. In addition, Mo (molybdenum) increases as the soil pH rises but Zn, Cu and B (boron) reduce as the soil pH rises, illustrating the importance of soil pH [8]. Finally, the capabilities of plants to distribute micronutrients are varied among plant parts [9,10]. For instance, foliar application of biomin Zn was higher than root application at just over 60 and almost 120 mg zinc per kg of shoot dry weight, respectively [10].

There were two objectives for this literature review. First, the aim was to identify the most crucial micronutrient deficiency in soil and crops; the second was to increase the availability of micronutrients to crops and enhance the concentration of micronutrients in edible parts.

2. MICRONUTRIENT AS CATION FORMS IN SOIL

Micronutrients are available in soil as forms of complex and free ions in soil solution [11,12,13,14]. In acid soil, the low levels of iron and mangan are stable but the amount of copper and zinc are mostly unstable, except if there is an unusually high activity of copper and zinc in the soil solution [13].

Micronutrients in soil are available to plants when there are labile micronutrient cations in the soil solution. This labile micronutrient contains specific and non-specific absorbed cations, and complex and free cations in soil solutions [14]. However, the labile form in soil is unstable and changes. For instance, the application of zinc in the glasshouse positively correlated to an increased corn dry weight, but the effect of zinc application does not affect corn dry weight in field experiments, which may be due to the difference of soil pH and cation formation between glasshouse and field experiments [15].

3. WATER SOLUTION

Water dilutes most nutrients and makes them available to crops. In wheat for example, the comparison between well-irrigated and non-irrigated farming shows that well-irrigated farms significantly increase zinc, iron, and mangan in grains [16]. In wet soil, zinc, iron, and mangan are available due to hydrous oxides which control the availability of those nutrients in soil, whereas in a dry environment they are formed to more crystalline and stable structures which can be immobile and unavailable to crops [17,18]. Tack et al. (2006) added that organic matter associated with microbial and biological activity is able to keep water content in the environment after irrigation, rain or even flooding. This water is used by microbial as media to degrade organic matter to plant-available nutrients. Therefore, water content can increase nutrient availability in soil.

4. MICRONUTRIENT AVAILABILITY TO CROPS

Soil is considered nutrient deficient when the addition of nutrients in the soil increases plant growth, although the quantity of added nutrients may be very small compared to the amount of nutrients in the soil. The totals of absorbed nutrients are correlated to a concentration of crop nutrient and yield. Nevertheless, the concentration of nutrients among crops is varied; therefore, some nutrients might be deficient for particular crops but not for others (Table 1). In most crops, the amount of micronutrients can be categorized as deficient if there are less than 4-5, 12, 80, 200 and 1 mg per kg soil for kobalt, copper, zinc, mangan and molybdenum, respectively [19]. Some crops such as rye are more tolerant to micronutrient deficiency but it seems that most main crops are nutrient deficient, especially iron and zinc (Table 1). Consequently, the following explanation will discuss both micronutrients (zinc and iron):

Table 1: Micronutrient deficiency in various crops

Crop	Sensitive to Deficiency	References
Bean	Fe and Zn	Martens and Westermann, 1991 [20]
Citrus	Fe, Zn, Mn, Cu, B, Cl and Mo	Wutcher and Smith, 1993 [21]
Cotton	Mn, Zn, Fe and B	Cassman, 1993 [22]
Rye	-	Martens and Westermann, 1991 [20]
Sugarcane	Fe, Zn, Mn, Cu, B, Cl, Mo, and Si	Gascho et al., 1993 [23]
Wheat	Zn, Cu, Fe, Mn, and B	Asad and Rafique, 2002 [24]

4.1 Zinc (Zn)

Zinc is one of the essential elements for plant health and growth. Most areas in Africa, Asia, America and developed countries are Zn deficient which accounts for 30% of total areas in the world [25]. The total zinc concentration in soil is varied among countries; Australia has the lowest zinc availability at less than 2 mg per kg soil (Table 2). If plants suffer from zinc deficiency, their leaves will show symptoms such as chlorosis, necrotic spots, bronzing, resetting, stunting, dwarf and malformed leaves [25]. However, there are various methods to increase zinc nutrients in soil in order to be accessible for crops such as the application of livestock manures, sewage sludges, superphosphate and foliar application as follows:

Table 2: Zn concentration in various countries

Country	The range of Zn concentration (mg per kg)	References
Australia	<2 – 180	Bertrand et al., 2002 [26]
Germany	27 – 76	Gorny et al., 2000 [27]
Poland	37 – 75	Kabata-Pendias, 2010 [28]

4.1.1 Livestock manure and sewage sludge

Livestock manures used in agricultural practices because it contains high levels of zinc. In Wales and England, for example, it was estimated that more than 2,000 ton of zinc from livestock manure is spread on agricultural farms each year and it accounted for 40% of total agricultural areas [29]. This illustrates that livestock manure is a significant input in increasing the zinc availability in the UK.

Sewage sludge is recognized as a source of zinc which can provide approximately 108 – 14,900 mg zinc per kg sewage sludge [30]. In the United Kingdom, zinc concentration in sewage sludge is reasonably high, ranging from 454 mg per kg to 643 mg per kg compared to other sewage which has less than 400 mg zinc per kg [25].

4.1.2 Superphosphate

The fertilizer superphosphate is a resource that provides zinc in soil, containing 600 mg zinc per kg superphosphate [25,31]. Nevertheless, some areas such as South Australia did not apply adequate amounts of superphosphate in the 1980 on fields which resulted in the reduction of areas with sufficient zinc [32]. Therefore, an application of superphosphate is recommended in order to increase zinc availability.

However, the ability of crops to absorb zinc differs among crops and genotypes. For instance, in the comparison of six crops (oat, barley, triticale, rye, durum and bread wheat), rye was the most tolerant and durum wheat was the most susceptible to zinc deficiency [9]. Moreover, rye has a higher shoot dry weight and ability to grow in acid and alkaline soils than other crops [33]. In bread wheat, genotype Dagdas-94 has almost 15% higher capability to absorb zinc from soil than BDME-10 [9]. Therefore, other applications such as foliar are needed to increase zinc absorbance to the crops.

4.1.3 Foliar application

The foliar application can increase protein content, zinc content in seeds and plant defence system to reduce the effect of tan spot on wheat and yield on guava [9,34,35,36,37]. However, the foliar application of zinc reduced the production of dry weight such as tomatoes [37,38]. Perhaps, the amount and frequency of zinc application on tomatoes was higher than was required because in this trial, the zinc application on tomatoes was carried out twice a week starting from one week after transplantation, whereas in wheat the application was only done once when it was on the booting stage [36,38]. Therefore, timing of foliar application of zinc is important in order to achieve significant effects.

4.2 Iron (Fe)

It has been estimated that approximately 30% of the world's population are iron deficient [39]. This is important because iron deficiency results in anemia due to a reduction in the circulating hemoglobin and myoglobin. This may result in poor health during pregnancy, poor mental development in infants, a decrease of immune function and working performance [40,41,42,43,44].

In soil, iron is mainly in the form of ferric, Fe^{3+}, and ferrous, Fe^{2+}. Ferrous is predominantly found as a primary mineral and is converted to ferric through weathering conditions which make it available for crops. However, the availability of ferric in soil is also influenced by pH and concentration of other nutrients. If ferric is found in acid soil (below 6.0), the concentration is high and tends to be toxic [45]. Moreover, if the concentration of copper, zinc and phosphorus are too high, plants cannot absorb iron although it is on neutral pH or mildly acid. As a result, it is important to balance the amount of nutrients in soil so as to be available for crops rather than bonding in the soil.

Farmers have tried to improve iron nutrient availability in soil through fertilisers but most inorganic iron is inaccessible. For example, when $FeSO_4$ is applied in calcareous soil, iron becomes inaccessible for plants because $FeSO_4$ will react with $CaCO_3$ to form Fe oxides; therefore, plants cannot uptake iron from the soil [46]. Even though Fe chelates such as Fe-EDTA or Fe-EDDHA showed a better outcome than $FeSO_4$, these manufactured fertilizers are unaffordable for farmers and sometimes fertiliser application does not give a significant result [47]. Therefore, a suggestion is to raise iron contents through organic biofortification and fertilizer application on leaves.

4.2.1 Microbial activity and crop management of iron

The microbial activity in rhizosphere and non rhizosphere soil are significantly different because there is a constant supply of carbon from root-tip growth in rhizosphere [48]. When plants suffer from iron deficiency they produce phenolic compounds which are exuded from root tips to rhizosphere and this compound triggers a microbial community. These favourable microbes produce ferric as they return to the plants, making iron available. Some plants such as sub clover are able to produce the phenolic compound which improves siderophore-secreting microbes in rhizosphere [49]. In addition, the application of some microbes including Pseudomonas, Acinetobacter and *Rhizobium leguminosarum* bv. trifolii E11 in soil showed an increasing iron uptake in various crops [50,51,52]. Therefore, this suggests that microbes in rhizosphere and the capability of particular crops to produce phenolic compounds in root tips are essential to improve iron availability to plants.

Iron deficiency is widespread and is mainly affected by soil water content. The research indicated that iron deficiency could be controlled by managing soil water content in particular crops such as lupins (*Lupinus pilosus*) and peanuts (*Arachis hypogaea*) [53,54] (Table 3). Chlorosis easily performs when these crops are on saturated soil indicating that crops are iron deficient. Zou et al. (2008) added that as the soil water content increases, the amount of HCO_3 in peanut rhizosphere rises. This high level of HCO_3 might play a role in the availability of iron in acid soil. Therefore, water management is important in order to achieve a sufficient amount of iron to crops, particularly peanuts and lupinus. In addition, the capability of peanuts to recover from excess water was shown by the decreasing amount of chlorosis in younger leaves [53].

Table 3: The effects of soil moisture (% of soil capacity) to iron absorption according to Zou et al. (2008) and Brand et al. (2000) for lupinus and peanuts, respectively, at 35 days after sowing in calcareous soil

Soil moisture (%)	Iron concentration in young leaves (mg/kg)	
	Lupinus	Peanut
50	31.2	20.4
80	28.6	15.5
100	21.3	20.1

4.2.2 Foliar application

Foliar application of iron is another possible method of increasing the micronutrient content in edible parts because of its accessibility to transport in plant tissue. In grain crops such as corn and wheat, foliar application is one of the most effective techniques to increase micronutrient content in plants when they are growing with an unfavourable condition such as iron deficiency [10,55]. This result is also supported by Zuo and Zhang (2011) whose research suggested that an application of $FeSO_4$ or Fe-chelates is more efficient through foliar application than soil application. They claim that this is because iron is mostly bonded to soil particles and only small amounts are available, whereas in leaf application the micronutrients are directly available for crops. Moreover, Zuo and Zhang (2011) added that foliar application can help crops recover from cholorosis in peanuts, beans, rice and sorghum. With rice, the concentration of iron was higher at 37.1% compared to crops without foliar application; and in polished rice, the content of iron was more than double compared to the control [56]. However, $FeSO_4$ is rarely applied in grain crops including sorghum and corn because a spray application often needs to be applied frequently during plant growth. Additionally, iron application often influences crop quantity rather than quality, so farmers tend not to apply this technique because they cannot get a premium price although the investment costs are high. Additionally, some crops such as wheat do not transport adequate amount of iron from leaves to edible parts [57,58].

5. CONCLUSION

Micronutrients are important in keeping humans healthy but many micronutrients such as zinc and iron are lacking in the human diet. One of the reasons is because approximately 30% of total areas worldwide are zinc and iron deficient. To solve this problem, many agricultural techniques such as foliar application, adding fertiliser and organic matter in soil have been applied but the content of micronutrients in edible parts are still lower than is required. Therefore, it is suggested that agricultural practices - the application of organic matters in order to improve micronutrient availability and transportability to edible parts - need to consider many aspects such as soil pH, nutrient contents in soil, time of application, soil moisture and type of fertiliser.

6. FUTURE WORK

Looking to the future it is important to confirm the findings that zinc and iron are the most micronutrient deficient worldwide. It is also found that increasing micronutrients through agricultural practices can influence on low yield and biomass. Furthermore, the concentration of both micronutrients in edible parts is still low. Therefore, it is important to increase the concentration of micronutrients, particularly in edible parts, and yield by combining agricultural practices and breeding programs. First is by identifying recommended cultivars which have high yield and tolerance to micronutrient deficient. Following this, modification of agricultural practices such as foliar and/or trunk applications of fertiliser will be applied on the recommended cultivars. As a consequence, it will be possible to have tolerant cultivars with high yield and responsive to agricultural practices.

7. ACKNOWLEDGEMENT

Associated Bachelor of Bogor Agricultural University is greatly acknowledged for its part-funding during the publication process.

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