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Micronutrient Fertilizers

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Abstract: This paper deals with the importance of different micronutrient fertilizers regarding the growth and development of plants. There are a few micronutrients, which are very essential for the growth of plants. A shortage of these nutrients will create deficiency symptoms in plants, which ultimately reduce their growth.

Key words: Micronutrient fertilizers, Fe, Mn, Zn, Cu, B, Mo, plant growth.

Introduction

Increasing interest is being directed towards the use of micronutrients as a mean of increasing efficiency of plant production and improving returns to the farmers. The essential elements included in the class of plant nutrients known as micronutrients includes iron, manganese, zinc, copper, boron, molybdenum and chlorine. These nutrients, required by most plants in small amounts are not less important in plant growth than the other essential plant nutrients (Alam, 1992; Alam, 1999; Shuman, 1999).

Many of the micronutrients, copper, iron, zinc, manganese and molybdenum are important components of enzyme systems and serve to catalyze biological reactions. Copper and iron play important roles in energy production in plants. Iron exerts a strong influence on chlorophyll production without which photosynthesis would not be possible. Zinc is necessary for the production of the amino acid tryptophan and the eventual formation of growth regulators. Molybdenum is essential for the utilization of nitrogen and the incorporation of nitrogen into proteins. Boron aids in sugar translocation and affects water retention by certain plant parts. Chlorine, the most recently recognized micronutrient, has an important role in the chemical processes of photosynthesis. Effects of micronutrients are most often measured in terms of yields but additional effects such as advanced maturity may be equally important in efficient crop production (Alam, 1992; Bould *et al.*, 1984).

Determining crop needs: Micronutrient needs are no guessing matter. Deficiencies of the elements can produce serious losses in yield as well as crop quality. Micronutrient deficiencies cannot be economically determined by mere examination of the crop for classical deficiency symptoms. By then the damage is usually done and the crop will frequently not return to its original yield potential. Reliable methods for the detection of micronutrient needs include both soil and plant tissue analysis. Soil analyses are most important in determining the possibility of micronutrient deficiencies before the crop is established. Plant tissue analysis can aid in diagnosing the suspected deficiency and in the case of some perennial crops, can warn of low levels of nutrients in time to allow the application before irreparable damage. Remember when using tissue analyses, however, that the interpretation of the results requires some training and expertise since the levels in the plant can change with time.

Interpretation must be conducted in relation to the stage of plant development (Thomas, 1986). Micronutrient deficiencies have frequently been associated with land shaping and severe erosion. Micronutrients are naturally concentrated in the soils organic matter by the process of native plant growth. Since most of the surface soil is removed by leveling for irrigation, construction of terraces, or by erosion, the subsoil which is low in organic matter and micronutrients, is exposed.

Exposure of the subsoil in some areas brings on micronutrient problems due to the high pH and calcareous nature of the subsoil. Organic soils also are troubled with micronutrient deficiencies. Copper, manganese and zinc deficiencies are fairly common on these soils. These deficiencies arise either from a natural shortage of these nutrients or as a result of reactions of the organic matter with the micronutrients to produce an unavailable complex (Alam, 1984; Alam, *et al.*, 1999; Devi *et al.*, 1999).

Micronutrient deficiencies can occur from the application of other nutrients. Heavy applications of phosphorus have produced deficiencies of copper, iron and zinc in some soils. In such cases, the micronutrients which are affected by heavy P application are usually in short supply to begin with.

In such cases, the absorption of the micronutrients is apparently hindered by phosphorus. An application of one micronutrient may occasionally induce deficiency of another. Heavy applications of zinc in some areas have depressed the uptake of iron by pecan trees, heavy copper treatments in other instances have interfered with the normal plant absorption of both iron and phosphorus by citrus. Obviously balance and judicious use of both micronutrients and macronutrients (major elements) is essential to avoid deficiencies as well as toxicities (Alam *et al.*, 1999; Martens and Westermann, 1991).

Research has shown that different crop species have different micronutrient requirements just as they do for other elements. Corn is much more susceptible to zinc deficiency than is grain sorghum. Grain sorghum, on the other hand, is much more susceptible to iron shortage than corn. Studies have also shown that varieties within a species differ in their ability to absorb and translocate the various nutrients. Apparently the genetics of a plant is connected to its requirements for certain nutrients. Once a micronutrient deficiency has been determined, use the correct nutrient to correct it.

Some important fertilizers of different micronutrients are presented in Tables 1-6 (Shuman, 1999).

Iron: Iron fulfils a number of essential functions in plant and a deficiency has far reaching effects on intermediary metabolism. Iron is an activator of certain enzymes such as aconitase, catalase, peroxidase, ferredoxin, cytochromes. It is involved in the formation of chlorophyll and of chloroplastic protein. Chlorophyll synthesis is affected at a very early stage of deficiency and most of the iron is found in chloroplasts (50-80 %). Iron is taken up by the plants mostly in divalent form (Fe^{+2}) (Alam, 1986; Boxma, 1981).

The first symptom of iron deficiency is the chlorosis yellowing of the young leaves. This reflects the immobility of Fe in plants and primary need in chlorophyll synthesis. Iron deficiency has been encountered on calcareous soils (Morris *et al.*, 1990). Field beans, corn, grain, sorghum, fruit trees, grasses,

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Table 1: Some important Fe fertilizers used in soil.

Source	Formula	% Fe (approx)
Ferrous sulfate	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	19
Ferric sulfate	$\text{Fe}_2(\text{SO}_4)_3 \cdot 4\text{H}_2\text{O}$	23
Ferrous oxide	FeO	77
Ferric oxide	Fe_2O_3	69
Ferrous ammonium phosphate	$\text{Fe}(\text{NH}_4)\text{PO}_4 \cdot \text{H}_2\text{O}$	29
Ferrous ammonium sulfate	$(\text{NH}_4)_2\text{SO}_4 \cdot \text{FeSO}_4 \cdot 6\text{H}_2\text{O}$	14
Iron frits	varies	Varies
Iron ammonium polyphosphate	$\text{Fe}(\text{NH}_4)\text{HP}_2\text{O}_7$	22
Iron chelates	NaFeEDTA	5-14
	NaFeHEDTA	5-9
	NaFeEDDHA	6
	NaFeDTPA	10
Iron polyflavonoids	-----	9 - 10
Lignin sulfonates	-----	5 - 8
Iron methoxyphenylpropane	FeMPP	5

Table 2: Some important Mn fertilizers used in soil.

Name	Chemical-symbols	% Mn (approx.)
Manganese sulfate	$\text{MnSO}_4 \cdot 3\text{H}_2\text{O}$	26-28
Manganese oxide	MnO	41-68
Manganese methoxyphenylpropane	MnMPP	10-12
Manganese chelate	MnEDTA	12
Manganese carbonate	MnCO_3	31
Manganese chloride	MnCl_2	16.8
Manganese oxide	MnO_2	63
Manganese frits	-----	10-25

Table 3: Some important Zn fertilizers used in soil.

Source	Formula	% Zn (approx.)
Zinc sulfate monohydrate	$\text{ZnSO}_4 \cdot \text{H}_2\text{O}$	35
Zinc sulfate heptahydrate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	23
Basic zinc sulfate	$\text{ZnSO}_4 \cdot 4\text{Zn}(\text{OH})_2$	55
Zinc oxide	ZnO	78
Zinc carbonate	ZnCO_3	52
Zinc sulfide	ZnS	67
Zinc frits	(silicates)	varies
Zinc phosphate	$\text{Zn}_3(\text{PO}_4)_2$	51
Zinc chelates	Na_2ZnEDTA	14
	NaZnNTA	13
	NaZnHEDTA	9
Zinc polyflavonoid	-----	10
Zinc lignin sulfonate	-----	5

Table 4: Some Cu compounds used for soil and foliar applications.

Source	Formula	% Cu (approx.)
Copper (ic) sulfate pentahydrate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	25
Copper (ic) sulfate monohydrate	$\text{CuSO}_4 \cdot \text{H}_2\text{O}$	35
Basic copper (ic) sulfates	$\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2$ (genera formula)	13 - 53
Malachite	$\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$	57
Azurite	$2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$	55
Cuprous oxide	Cu_2O	89
Cupric oxide	CuO	75
Chalcopyrite	CuFeS_2	35
Chalcostie	Cu_2S	80
Copper (ic) acetate	$\text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 2\text{H}_2\text{O}$	32
Copper (ic) axalate	$\text{CuC}_2\text{O}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$	40
Copper (ic) ammonium phosphate	$\text{Cu}(\text{NH}_4)\text{PO}_4 \cdot \text{H}_2\text{O}$	32
Copper - S fusions	$\text{CuC}_2\text{O}_4 \cdot \text{S}$	Varies
Copper chelates	Na_2CuEDTA	13
	NaCuHEDTA	9
Copper polyflavonoids	-----	5 - 6.7

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Table 5: Commonly used B fertilizers.

Source	Formula	% B (approx.)
Borax	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	11
Sodium pentaborate	$\text{Na}_2\text{B}_{10}\text{O}_{16} \cdot 10\text{H}_2\text{O}$	18
Sodium tetraborate:		
Fertilizer borate - 46	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$	14
Fertilizer borate - 65	$\text{Na}_2\text{B}_4\text{O}_7$	20
Solubor	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$	20
	$\text{Na}_2\text{B}_{10}\text{O}_{16} \cdot 10\text{H}_2\text{O}$	
Boric acid	H_3BO_3	17
Colemanite	$\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$	10
Boron frits	-----	2-6

Table 6: Commonly used Mo fertilizers.

Source	Formula	% Mo (approx.)
Sodium molybdate	$\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$	39
Ammonium molybdate	$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$	54
Molybdenum trioxide	MoO_3	66
Molybdenum sulfide	MoS_2	60
Molybdenum frits	-----	2-3

legumes, rice, nut trees, tomatoes and vegetables have been reported to suffer from Iron deficiency problems. Iron chlorosis is commonly seen in calcareous soils that covers 30 % of the earth crust. The disorder is due to deficiency of active Fe in the leaves and induces imbalance in the metabolic processes. Iron deficiency directly affects the photosynthetic mechanism causing a dramatic reduction in crop yield. Interveneal areas of the leaves become chlorotic and veins usually remain green. Deficiency is common in alkaline soil (lime induced chlorosis) due to immobilization (Cummings and Xie, 1995). In general, when iron values are 50 ppm or less in the dry matter, deficiency is likely to occur, the sufficiency range seems to be from 10-250 ppm Fe. Iron compounds generally become unavailable in alkaline soils, so foliar application of Fe compounds is generally beneficial.

Manganese: Manganese is an essential plant nutrient (Alam, 1985). It is a constituent of pyruvate carboxylase and a number of enzymes concerned with the metabolism of N, synthesis of chlorophyll and physiological reactions in plants and such enzymes are nitrate reductase, malic dehydrogenase and oxalo-succinic decarboxylase. It is involved in the plant's respiratory process and controls the redox potential in plant cells during the phases of light and darkness. It can replace Co^{++} or Mg^{++} under certain cases. Manganese deficiency symptoms are first seen on the new leaves. Chlorosis occurs between the veins of young leaves, characterized by the appearance of chlorotic and necrotic spots in the interveneal areas (Martens and Westermann, 1991). The normal contents of Mn in plants range from 50-200 ppm on dry weight basis. Values less than 25 ppm in plant leaves are usually deficient and those over 400 ppm are considered excessive. Other symptoms are grey speck of rats, pahala blight of sugarcane, speckle yellow of sugarbeet and marsh spot of peas.

Plants take up Mn in bivalent (Mn^{++}) form. Total Mn content of soil vary from a trace to as high as 10 % or even more. However, the total Mn contents of soil between 200-300 ppm are the most common. The critical level is ranged from 1-2 ppm. Soil application of MnSO_4 on calcareous soils ranged from 5-10 kg/ha for crop plants. In foliar spray, 0.5 kg Mn/ha may be used in combination with other trace elements.

Zinc: Zinc is an essential element needed in balanced amount

for normal growth of plants. The element has functions in biosynthesis of tryptophane and indole acetic acid and acts as an activator of a number of enzymes. A few enzymes in which the Zn is associated are: carbonic anhydrase, ribonuclease, alcohol dehydrogenase, pyridine nucleotide dehydrogenase, glutamic dehydrogenase, L-lactic acid dehydrogenase, D-glyceraldehyde-3-phosphate dehydrogenase, malic dehydrogenase, D-lactic dehydrogenase, D-lactic cytochrome, reductase and aldolase. Zinc also plays an important role in nucleic acid and protein synthesis and assists the utilization of P and N in plants and is involved in auxin plant hormone production. In the deficiency of Zn, plants do not grow properly well due to reduction in enzyme activities. The auxin depression due to Zn deficiency has been studied since 1940 by a large number of research workers and at approximately the same time the depression of protein content due to Zn deficiency was revealed (Alam *et al.*, 1999).

The source of zinc generally consist of inorganic fertilizer, especially in the form of zinc sulphate. Other forms added include organic sources such as lignosulfonate and EDTA. Zinc availability to plant from different fertilizer sources depend greatly on soil pH, which governs the solubility of Zn generally influencing the Zn release from soil colloidal surface. The pH value of soil has the most important influence on Zn availability. With increasing soil pH the solubility of Zn in soils decrease and above pH 6.5 the decreased seemed to be significant. Thus Zn tends to be less available in alkaline soils than in acid soils. The optimum pH for availability of Zn is between pH 5.6 and 6.5. Organic matter of the soils also play an important role in the availability of Zn for the growth of plants. Zinc availability is usually higher in fine-textured soils with higher clay contents and with higher organic matter contents. At high pH values, organic matter facilitates the formation of chemical complexes that tie up the Zn and becomes to a great extent unavailable.

Reduction in the availability of Zn is associated with high pH (Martens and Westermann, 1991). It may be immobilized similar to Cu by organic matter. Soils with increasing CaCO_3 content show a decrease in Zn availability to plants. Soil Fe oxides can affect Zn availability. There is an interaction between P and Zn availability, which is usually attributed to plant effects (Alam *et al.*, 1999). Zinc deficiency was induced by high P rates and high pH and the magnitude of the yield

decrease corresponds well with the intensity of deficiency symptoms. Submerged soils tend to develop Zn deficiency, because the concentration of Zn in soil solution decreases. The decrease is the fastest in alkaline and calcareous soils. Soils with a high content of available and water soluble P tend to have low concentration of water soluble Zn, regardless of pH or the content of total or available Zn (Alam *et al.*, 2001). Zinc deficiency has been detected in most of the alkaline calcareous soils of Pakistan. Up to 85 % of the soils were found to be either deficient or within the marginal range of Zn. Zn is usually present in the concentration range 10-300 ppm, and occurs in a number of different minerals, on exchange sites of clay minerals and organic matter or adsorbed on solid surface. Zinc interacts with soil organic matter and both soluble and insoluble Zn organic complexes are formed. The levels of Zn in plant materials are low and the Zn requirement of plants is correspondingly small. The form in which Zn is translated from roots to shoots is generally of Zn^{++} . Zinc accumulates in root tissue especially Zn supply is high. Plants suffering from Zn-def often show chlorosis in the interveinal areas of the older leaves starting from tips and margins. Mottle leaf of citrus, little leaf or rosette appearance due to effect on IAA synthesis, bronzing of tung trees, and white bud of maize.

Copper: It is known to be associated with enzymes, such as cytochrome oxidase, ascorbic acid oxidase, phenolase, lactase and polyphenol oxidase. It generally promotes the formation of vitamin-A in plants. The normal range of Cu in many plants is usually from 5-20 ppm. When the Cu concentration in plants is less than 4 ppm, then deficiencies are likely to occur. The characteristic symptoms of Cu deficiency in crop first appear in the leaf tips. The leaf tips become white and the leaves are narrow and twisted. Top leaves develop necrotic spots and brown areas, followed by withering and death of short tips. Copper deficiencies are usually corrected by soil application of Cu inorganic fertilizers (Alam, 1983; Martens and Westermann, 1991; Reed *et al.*, 1993).

The availability of Cu in soil decreases with increasing soil pH (Mozaffari *et al.*, 1996). Copper is closely associated with organic matter in soils and is the most tightly bound in organic complexes of any of the divalent transition metals. Copper added as fertilizer is in soluble forms, but soon reverts to other forms including adsorbed and associated with organic matter and oxides. The total contents in soil generally vary between 10-200 ppm with an average value of around 50 ppm. Copper is thought to be involved in the oxidation of soluble divalent iron (Fe^{++}) to trivalent iron (Fe^{+++}) state and manganese to manganic salts and soluble sulphide to more insoluble sulphides. Copper is generally taken by plants in bivalent form. The soil organic matter immobilizes Cu in soils (McBride, 1994). Copper compounds such as copper sulphate may be applied to various crops on copper deficient soils at the rate of 2.0-5.0 kg/ha. Copper may become toxic if very frequent spraying of Cu containing fungicides e.g. Boreaux mixture to be used.

Boron: Boron is associated with meristematic activity, auxin, cell division, cell growth and membrane function, protein synthesis, lignin synthesis and pectin metabolism, maintaining correct water relations within the plant, sugar translocation across cell membrane, fruit processes and phenolase inhibition affects water relation of plants (Tandon, 1991; Martens and Westermann, 1991). Much of the B in the plant is located in the cell wall. It is also associated with the uptake of Ca and its

utilization by plants and in its regulation. Boron deficiency is one of the most widespread trace element problems in arable crops.

There are large variations in susceptibility between crops. Cereals and grasses contain only 2-5 mg B kg^{-1} dry matter and very rarely show B deficiency. Boron and sodium tetraborate are the most popular B fertilizers (Guertal *et al.*, 1996).

The most sensitive crops are the root crops, sugar beet, turnips and swedes; others are red beet, carrots, cauliflower, cereal, lucerne, red clover, kale, cabbage, grapes and tomatoes. Many fruit and forest trees and flower crops are also susceptible. Boron has low mobility in the plant, so B deficiency symptoms appear in growing points and reproductive organs. The symptoms are often very severe, and may include death of the growing point and quality losses in harvestable organs. Mild boron deficiency can cause quality problems in susceptible crops, especially root vegetables and flowers, in the absence of visual symptoms in the leaves. When symptoms are visible, it is often too late to obtain a worthwhile response to the application of B, so it is important to apply B before growing susceptible crops on soils low in B. The optimum range of B in leaf tissues of most crops is from 20-100 ppm.

Toxicity may occur when B level in most of the crop plants exceed 25 ppm. Soil B availability to plant decreases with an increase in soil pH, usually brought about by liming. Adding Ca and Mg to soils lowered B uptake by plants, but the decrease was related to soil pH. Soil properties such as organic matter and clay contents and water potential can influence the availability of boron (Datta *et al.*, 1994). Boron deficiency symptoms are of heart rot of sugarbeet, brown rot in turnip, drought spot or corky pit of apples, brown spotting of apricot and browning of cauliflower curd. In tomato, corky patches and uneven ripening and in turnip terminal bud break down, leaves are curled, rotted purplish yellow. In severe cases, the central tissue may break down and root may become hollow. Morphological characters of a plant such as root length, surface area, fineness and intensity of root hair combined to influence strongly the P uptake, because soil P is supplied to plants mainly by diffusion and P diffusion co-efficient remains very low. Boron is taken up by plants in form of borate (BO_3) ion. Its solubility decreases with increase in pH of the growth medium. Boron as sodium tetraborate is the most commonly used B fertilizer in soil. The normal range of B application in the soil is 1-2 kg B/ha of area. Foliar application of boron directly on young developing fruits can be highly beneficial, but is less effective in other cases, because of poor translocation of boron from the leaves. Boric acid and solubor can be used as foliar spray. The concentration of B in a spray used for majority crop is 0.2-0.5 %. For sugar beet, the concentration can be as high as 2.5 percent.

Molybdenum: The main crops that need Mo fertilization are legumes, where Mo plays an important role in symbiotic N fixation and in the reduction of nitrate. Molybdenum is an essential component of nitrate reductase and nitrogenase, which controls the reduction of inorganic nitrate to ammonium and help in fixing N_2 to NH_3 . It is also associated with aldehyde oxidase and xanthine dehydrogenase in maize roots. Molybdenum is required in the synthesis of ascorbic acid and is implicated in making iron physiologically available within the plant (Gupta and Vyas, 1994). It also involves in P metabolism in plants and reduces ethane to ethylene. It is considered an

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antidote of excess Ca, Mn, Zn, Cu, B and Si in plants. Molybdenum concentration in plants range from less than 0.1 ppm to greater than 300 ppm (Alam, 1999)

Plants usually respond to Mo, if they contain less than 0.1 ppm Mo. High Mo in lungs (15 ppm) can be a problem for cattle, which is known as molybdenosis or teart disease. Molybdenum deficiency resembles N-deficiency and show up as general yellowing and stunting growth. Yellow spot disease of citrus, bean, scald and whiptail of cauliflower are the well-known name associated with Mo deficiency. Molybdenum deficiency symptoms are likely to occur, when leaf Mo concentration are less than 0.2 ppm on a dry-weight basis. In soils with low Mo, soil application of 1 to 2 lbs of sodium molybdate or foliar application of 2 ounces per acre usually provide complete control of deficiencies. The availability of Mo increases as the pH rises, so Mo deficiency is most likely to occur in acid soils, and can often be cured by application of lime. Molybdenum is taken up by plants as MoO_4^{2-} , so behaves in the soil rather like phosphate (PO_4^{3-}). Molybdate is strongly adsorbed by ferric sides and the adsorption is pH dependent. Sodium and ammonium molybdates are the most widely used source of molybdenum.

General Conclusion: The micronutrient fertilizer sources that continue to be used for Fe, Mn, Zn, Cu, B and Mo are sulphates, because of their solubility and widespread availability to farmers. Some of the chelated forms of iron and manganese are also very important, but they are costlier than sulphate fertilizers. For boron the usual source is borate and for Mo, it is sodium molybdate. Soil pH is certainly the one soil property that mostly influences the micronutrient availability or solubility and for all but Mo, the higher the soil pH, the lower is the plant availability of micronutrients. For Mo, liming can

actually prevent deficiencies, since its availability increases with pH. Other soil properties that can be important are organic matter for Cu and oxidation/reduction conditions for Fe and especially for Mn. For future research, the use of soluble organic and inorganic wastes and especially manures can supply micronutrient metals for plant growth.

References

- Alam, S.M., 1983. Effects of copper and phosphorus on growth and nutrient content of rice. *Pak. J. Sci. Ind. Res.*, 26: 370-373.
- Alam, S.M., 1984. Effect of nutrient solution pH and N-sources (NH_4/NO_3) on the growth and elemental content of rice plants. *Agronomie (Paris, France)*, 4: 361-365.
- Alam, S.M., 1985. Effects of iron and manganese on the growth of rice and on the contents of these elements in rice plants. *Agronomie (Paris, France)*, 5: 487-490.
- Alam, S.M., 1986. Effect of iron applied through the leaves or soil on the growth and nutrient content of rice plants. *Acta Agronomica Hungarica (Budapest, Hungary)*, 35: 79-82.
- Alam, S.M., 1992. Trace elements and their physiological functions. *Pak. and Gulf Economist*. (Karachi, Pakistan), January 18-24. 11: 14-16.
- Alam, S.M., 1999. Nutrient uptake by plants under stress condition. In: *Handbook of plant and crop stress*. Ed. M. Pessarakli. Marcel Dekker. Publishers. New York. USA, pp: 285-313.
- Alam, S.M., M.A. Khan, M. Ali and R. Ansari, 1999. Effect of different levels of Zn and P on seedling growth of rice. *J. Sc. & Tech. Univ. Peshawar*, 23: 49-51.
- Alam, S.M., S.S.M. Naqvi and R. Ansari, 1999. Impact of soil pH on nutrient uptake by crop plants. In: *Handbook of plant and crop stress*. Ed. M. Pessarakli. Marcel Dekker. Publishers. New York. USA, pp: 51-60.
- Alam, S.M., M.A. Khan, M. Ali and R. Ansari, 2001. Effect of different levels of Zn and P on seedling growth, chlorophyll and peroxidase contents of rice. *Online J. Biol. Sci.*, 1: 49-51.
- Bould, C., E.J. Hewitt and P. Needham, 1984. *Diagnosis of Mineral Disorders in Plants*. Vol. 1. Principles, Chemical Publications, New York.
- Boxma, R., 1981. Effect of pH on the behaviour of various iron chelates in sphagnum (moss) peat. *Communications in Soil Science and Plant Analysis*, 12: 755-763.
- Cummings, G.A. and H.S. Xie, 1995. Effect of soil pH nitrogen source on the nutrient status in peach: II. Micronutrients. *J. Pl. Nut.*, 18: 553-562.
- Datta, S.P., A. Kumar, R.P. Singh and A.K. Sarkar, 1994. Critical limit of available boron for soybean in acid sedentary soils of Chotanagpur region. *J. Ind. Soc. Soil Sci.*, 42: 93-96.
- Devi, W.L., P.K. Singh and G.A.S. Devi, 1999. Role of boron, molybdenum and zinc on various nitrogenous fractions of cabbage. *J. Vegetable Crop Prod.*, 2: 45-57.
- Guertal, E.A., A.O. Abaye, B.M. Lippert, G.S. Miner and G.J. Ghascho, 1996. Sources of boron for foliar fertilization of cotton and soybean. *Communication in Soil Science and Plant Analysis*, 27: 2815-2828.
- Gupta, P.K. and K.K. Vyas, 1994. Effect of P, Zn and Mo on the yield and quality of soybean. *Legume Res.*, 17: 5-7.
- Martens, D.C. and D.T. Westermann, 1991. Fertilizer applications for correcting micronutrient deficiencies. In *Micronutrients in Agriculture*, eds. J.J. Mortvedt, F.R. Cox, L.M. Shuman, and R.M. Welch, Madison, Wisconsin, USA: Soil Science Society of America, pp: 549-592.
- McBride, M.B., 1994. *Environmental Chemistry of Soils*. New York, USA: Oxford University Press.
- Morris, D.R., R.H. Loepfert and T.J. Moore, 1990. Indigenous soil factors influencing iron chlorosis of soybean in calcareous soils. *Soil Sci. Soc. Amer. J.*, 54: 1329-1336.
- Mozaffari, M., A.K. Alva and E.Q. Chen, 1996. Relation of copper extractable from soil and pH to copper content and growth of two citrus rootstocks. *Soil Sci.*, 161: 786-792.
- Reed, S.T., M.G. Allen, D.C. Martens and J.R. McKenna, 1993. Copper fractions extracted by Mehlich-3 from soils amended with either CuSO_4 or copper rich pig manure. *Commun. Soil Sci. Pl. Anal.*, 24: 827-839.
- Shuman, L.M., 1999. Micronutrient Fertilizers. *J. Crop Prod.*, 1: 165-195.
- Tandon, H.L.S., 1991. *Secondary and Micronutrients in Agriculture Fertilizer Development and Consultation Organization*, New Delhi.
- Thomas, G.W., 1986. Mineral nutrition and fertilizer placement. In *No Tillage and Surface - Tillage Agriculture: The Tillage Revolution*, eds. M.A. Sprague and G.B. Triplett. New York, USA: John Wiley and Sons, pp. 93-148.
- Wallace, A. and E.M. Romney, 1977. Synergistic trace metal effects in plant. *Commun. Soil Sci. Pl. Anal.* 8: 699-707.