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Management strategies to enhance micronutrient efficiency in semi-arid tropics

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Abstract
Micronutrients are necessary substances that plants only use in trace amounts it has an impact on photosynthesis as well as other critical plant functions like respiration, protein synthesis, and reproduction. The application of micronutrients increased agricultural product yield and quality, protecting human and animal health through the use of feed enriched with plant materials. The availability of other necessary elements in balanced ratios for plants depends on each essential element performing its function in plant nutrition appropriately. When present in sufficient amounts, these tracer elements improve the physiological, biochemical, and metabolic traits of healthy plant growth, whereas their absence encourages abnormal plant growth. Due to intensive cropping, erosion-related topsoil loss, leaching-related micronutrient losses, and liming of acid soils, the incidence of micronutrient deficiencies in crops has significantly increased in recent years. It is very essential to maintain micronutrient concentration in soil to sustain the production and productivity of the semi-arid tropics.

Keywords: Micronutrients, foliar application, chelates, nano encapsulation, biofertilizers

Introduction

Indian agriculture during the past 50 years has achieved a fourfold growth in food Production by adopting modern agricultural practices. The availability of fertilizer-responsive, high-yielding varieties (HYV) of rice, wheat and maize has made it possible to produce 15-20 t ha^{-1} $year^{-1}$ of biomass dry matter. Initially, this became possible by using nitrogenous (N) fertilisers alone, as the soil could provide all other essential nutrients needed by plants. However, within a few years, the nutrient reserves in soil were gradually exhausted and it was no longer possible to sustain higher yields even by applying both N and phosphorus (P).

Utilising chemical fertilisers significantly increased crop productivity after the green revolution. During this time, nitrogen (N) consumption multiplied by more than nine. In 2022, agriculture consumed 113.3, 48.1, and 39.2 Mt of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), respectively. As a result, productivity and production of food grains have increased globally over the past six decades by 3.4 and 2.25 times, respectively. The cultivated soil, however, has become infertile and unproductive as a result of long-term imbalance and overuse, and production costs have increased (30% of the total cost of agricultural output). Crop yields, factor productivity, and soil fertility are all being decreased by a variety of poor farming techniques and the choice of low-performing cultivars. Therefore, it is crucial to choose more nutrient-responsive cultivars using effective nutrient management in order to improve nutrient dynamics and sustain production (Kumar *et al.*, 2018) [15].

Micro nutrients play a vital role in growth and development of plants and occupy an important portion by virtue of their essentiality in increasing crop yields (Zenda *et al*., 2015, Shukla *et al.*, 2017) [27]. They not only increase the yield but also the quality and shelf life of the produce. A large portion of Indian soil has a micronutrient deficit due to imbalanced fertilisation and intensive cropping. In India, 49% of soils may be deficient in zinc (Zn), 12% in iron (Fe), 5% in manganese (Mn), 3% in copper (Cu), 33% in boron (B), and 11% in molybdenum (Mo), according to ananalysis of soil and plant samples. Micronutrients are necessary substances that plants use sparingly. Crop uptake is typically less than one pound per acre for micronutrients. Despite this low requirement, if micronutrients are lacking, critical plant functions are restricted, leading to abnormal plant growth and lower yield. In such circumstances, costly, high-demand crop inputs like nitrogen and water may be wasted (Dubey *et al.*, 2015) [5]. Micronutrients improve the enzymatic system of plants, which increases plant productivity, leaf area, and grain yield. These micronutrients are affected by factors like organic matter, soil pH, lime content, soil salinity, and others that were previously ignored by other studies

(Bozorgi *et al.*, 2011) [2]. Micro nutrients levels in soil have decreased as a result of continuous use of crop varieties with high yields and the absence of organic manures containing these nutrients, which are necessary for healthy plant growth and yield (Lata *et al.*, 2018) [17]. Growers are examining all potential obstacles to the production of top grain, including micronutrient deficiencies, as a result of higher yields, higher commodity prices, and higher input costs. The soil will no longer be fertile if immediate action is not taken to replenish the micronutrient reserves. Therefore, addressing the micronutrient imbalance and increasing productivity are crucial.

Micronutrients

Out of 17 nutrients established as essential for plant growth, eight are required in small quantities and therefor called micro nutrients, also known as oligo nutrients, trace elements.
They are

- Boron, (B)
- Chlorine (Cl)
- Copper (Cu)
- Iron (Fe)
- Manganese (Mn)
- Molybdenum (Mo)
- Zinc (Zn)
- Nickel (Ni)

Why deficient?

- Indiscriminate use of macronutrients
- Leaching from sandy soil
- Over liming
- Addition of high rates of phosphorous
- Soil compaction
- Use of sensitive crop varieties
- Cropping intensity and system
- Management and cultivation practices

Importance

Boron

- Essential of germination of pollen grains and growth of pollen tubes
- Essential for seed and cell wall formation
- Promotes maturity
- Necessary for sugar translocation
- Affects nitrogen and carbohydrate

Zinc

- Aids plant growth hormones and enzyme system
- Necessary for chlorophyll production
- Necessary for carbohydrate formation
- Necessary for starch formation
- Aids in seed formation

Iron

- Promotes formation of chlorophyll
- Acts as an oxygen carrier
- Reactions involving cell division and growth

Manganese

- Functions as a part of certain enzyme systems
- Aids in chlorophyll synthesis
- Increases the availability of P and Ca

Molybdenum

- Required to form the enzyme "nitrate reductase" which reduces nitrates to ammonium in plant
- Aids in the formation of nodules help for biological nitrogen fixation.

Copper

- Catalyzes several plant processes · Major function in reproductive stages
- Indirect role in chlorophyll production. Increases sugar content
- Improves flavour of fruits and vegetables

Chlorine

- Interferes with P uptake
- Enhances maturity of small grains
- Increase the disease resistance
- Help in the photolysis

Nickel

- Regulate the N metabolism.
- Essential for hydrogenase grain filling and seed viability

Table 1: Micronutrient deficiencies in different states

Name of State	Percent samples deficient					
	Zn	Cu	Fe	Mn	B	Mo
Andhra Pradesh	49.4	<1	3	1	-	-
Assam	34	<1	2	20	-	-
Bihar & Jharkhand	54	3	6	2	38	-
Gujarat	24	40	8	4	2	10
Haryana	60	2	20	4	0	28
Karnataka	72.8	5	35	17	32	-
Kerala	34	31	<1	0	-	-
Madhya Pradesh & Chhattisgarh	44	<1	>	1	22	18
Maharashtra	86	0	24	0	-	-
Orissa	54	-	0	0	60	80
Punjab	48	1	14	-	13	-
Rajasthan	21	-	-	-	-	-
Tamil Nadu	58.4	6	17	6	21	-
Uttar Pradesh	45.7	1	6	3	24	-
West Bengal	36	0	0	3	68	-

Table 2: Crops sensitive to micro nutrient deficiency

Boron	Copper	Iron	Manganese	Zinc
Alfalfa	Corn	Sorghum	Wheat	Sorghum
Clover	Onion	Soybean	Oat	Corn
cotton	Tomato	Bean	Corn	Dry bean
sugar beat	alfalfa	Dry bean	soybean	cotton

Micro nutrient fertilizer sources

1. Inorganic products
2. Synthetic chelates
3. Natural organic complexes
4. Fritted glass products (frits).

Inorganic Sources

Oxides, carbonates, and metallic salts like sulphates, chlorides, and nitrates are examples of inorganic sources. The sulphates, which are available in crystalline or granular form, are the most popular metallic salts. Polyphosphate starter fertilisers also use an ammoniated $ZnSO_4$ solution. Additionally widely used are the fine powders and granular forms of manganese and zinc oxides, which are also offered for sale. Because they are insoluble in water, oxides like ZnO and MnO have relatively low immediate effectiveness for crops. Also, the available divalent form of manganese in MnO will oxidize to the unavailable tetravalent form of manganese, so there is very little residual availability of manganese fertilizers for efficient Fertilizer use manual - micronutrients succeeding crops. Thus, agronomic effectiveness of granular MnO may be rather low. Although inorganic sources are typically the least expensive per unit of micronutrients, they aren't always the best for crops.

Synthetic chelates

These sources are created by coordinately bonding a metal with a chelating agent. The availability of the micronutrient metals copper, iron, manganese, and zinc to plants depends on the stability of the metal-chelate bond. An efficient chelate is one that maintains the applied micronutrient in chelated form by having a very low rate of substitution for other cations in the soil. In comparison to inorganic sources, soil-applied chelates maybe two to five times more effective for crops per unit of micronutrient, but their costs per unit of micronutrient may be five to 100 times higher. Because there are various chelate types available, relative effectiveness values vary depending on the chelate and inorganic product sources being compared.

Natural organic complexes

These complexes are created by combining some organic waste products from the wood pulp industry or other related industries with metallic salts. These complexes come in a variety of forms, including lignosulfonates, polyflavonoids, and phenols. Uncertainty exists regarding the types of chemical bonds that metals form with organic components. Other types of chemical bonds might also be present, in addition, to coordinate bonds like those found in chelates. Natural organic complexes are less expensive per micronutrient unit, but they typically perform less well than synthetic chelates. Additionally, soil microorganisms can decompose more easily. These sources work better when mixed with fluid fertilizers and applied as foliar sprays.

Frits

Products made of fritted glass in which changes in matrix composition and particle size affect solubility. Micronutrient concentrations range from 2 to 25%, and a fritted product may contain more than one micronutrient. Fritted micronutrients are typically only applied to sandy soils where leaching occurs in high-rainfall areas. Instead of treating severe micronutrient deficiencies, this class of materials is better suited for maintenance programmes.

Factors affecting micro nutrient availability

Soil pH

One of the most significant soil characteristics that influence the availability of nutrients is soil pH. With the exception of Mo, micronutrient availability decreases as pH rises. The availability of micronutrients is typically lower in calcareous and saline-alkaline soils with very high pH levels.

Organic matter

Micronutrient availability may be lessened in soils with low levels of organic matter (less than 2.0%). Micronutrient availability is frequently low in soils with very high levels of organic matter (greater than 30% organic matter to a depth of 30 cm).

Soil texture

Sandier soils do a much poorer job of holding water and nutrients than clays and organic soils. The sandy soil will lose its nutrients due to leaching. Higher clay content (fine texture) soils are less likely to lack plant-available micronutrients. Micronutrient deficiencies are more likely to occur in sandy soils (course texture).

Parent material and climate

Soils developed on flood plain alluvium largely from siliceous sandstone exhibited strikingly lower concentrations of Zn, Cu, Mn and Fe. The availability of nutrients in the soil will decrease if they come from simple parent material.

Methods to improve micro nutrient efficiency

Foliar application

It can supply nutrients to plants at crucial junctures in their development, quick response as compared to soil application. The amount of nutrients that plants need exceeds their normal capacity to absorb them. A high nutrient requirement growth stage was applied without the use of soil directly to the leaf surface, preventing losses or fixation. Although they cannot completely replace soil application, they can supplement soil fertilization. The nutrient enters the cells after penetrating the leaf or stomatal cuticle. In contrast to soil application, crop response happens quickly. Depending on the nutrients, the concentration ranges from 0.1% to 1.2%. Spreading stickers are used to increase the adherence of the micronutrient source to the foliage.

The advantages of foliar sprays are

- Application rates are much lower than for soil application.
- Uniform application is easily obtained
- Response to the applied nutrient is almost immediate so deficiencies can be corrected during the growing season.
- Leaching losses are nil.
- Little residual effect.
- Quick absorption compared to soil application.

Table 3: micronutrient fertilizer concentration for foliar spray

Element	Fertilizer	Concentration
Zinc	Zinc sulphate	0.5 %
Iron	Ferrous sulphate	1.0 %
Manganese	Manganese sulphate	0.2 %
Copper	Copper sulphate	0.2 %
Boron	Boric acid / Solubor / Agribor	0.2 %
Molybdenum	Sodium molybdate or Ammonium molybdate	0.05 %

In a study on the impact of foliar micronutrient application on wheat yield, Khan *et al*. (2010) [13] found that applications of the shelter (Zn 2%, Fe 1%, B 2%, Mn 1%) at tillering booting jointing and ear head formation resulted in higher yield and economics than other treatments. Wheat plants' height, grains per spike, 1000-grain weight, biological yield, harvest index, straw yield, and grain yield were all improved by foliar applications of micronutrient mixture shelter at different growth stages. The improved yield components are the primary cause of this increased grain yield. Therefore, an increase in grain size and number of grains per spike may have a direct impact on producing the highest grain yield. The increased grain yield is thought to be the cause of the rise in BC ratio brought on by the foliar application of Shelter at four growth stages. Rawashdeh *et al*. (2015) [25] and Ahmad *et al*. (2010) [11] also recorded similar results in canola with foliar applications of Fe and Zn in comparison to soil application. Foliar sprays have several advantages over soil applications, including lower application rates, easier uniform application, almost immediate response to applied nutrients, and the ability to correct deficiencies during the growing season.

The main effects of Zn, Mn, and Fe addition and its application methods on maize yield and its constituent parts were studied by Hythum *et al*. in 2012 [9]. The combined application of Zn+Mn+Fe results in the highest yield components and grain yield among the various micronutrient applications. Compared to the soaking and coating methods, micronutrient foliar application produced the highest grain and straw yield. These results could be attributed to micronutrients' participation in a number of physiological and biochemical processes that lead to increased dry matter production. The biological, grain, and straw yields were improved by multiple foliar applications of a micronutrient mixture beginning at tillering.

Gavisiddappa *et al*. (2013) [7] investigated how seed quality and economics of the KBSH-53 sunflower hybrid were affected by the application of micronutrients and a growth regulator (TIBA). In comparison to soil application of boron, foliar application of boron in the form of TIBA at the ray floret initiation stage produced the highest yield. Foliar application of boron increases flowering and pollination rates, which in turn increases seed setting and oil yield.

Nadim *et al*. (2012) [22] studied response of wheat to different micronutrients and their application methods. Compared to side dressing and soil application, foliar spray has demonstrated a higher grain yield among the various techniques. When micronutrients are fed through the leaves, there is a greater increase in absorption and translocation than when they are applied through the soil. This results in the development of higher growth and yield attributes, which results in the production of higher yields.

Application with mixed fertilizers

As micronutrient carriers, NPK fertilizers in both granular and fluid forms are frequently used. Distributes more evenly when using standard application equipment. Eliminating a separate application also lowers costs. They are mainly four types,

Incorporation during manufacture

During the manufacturing process, the micro nutrients are combined with the major fertilizers. They cause the micronutrients in granular NPK fertilizers to be distributed uniformly.

Bulk blending with granular fertilizers

There are fertilizer grades available that will deliver the recommended micronutrient levels for a specific field at the typical fertiliser application rates. During the blending process and during subsequent handling, nutrients may separate. By carefully balancing the particle sizes of the blend's NPK components and micronutrient sources, it can be reduced.

Coating granular fertilizers

Granular NPK fertilizers can be coated with powdered micronutrients to reduce the likelihood of segregation. It is not frequently used because coating adds additional costs.

Fluid fertilizers

For row crops, clear liquids are frequently used as starter fertilizers, and these liquids make it simple to apply some micronutrients, particularly zinc sources. With nitrogen solutions like UAN, micronutrients can also be applied.

Field research on the impact of various micronutrient treatments on rice growth and yield in saline soil conditions was conducted by Zayed *et al*. (2011) [26]. Micronutrient application significantly increased rice grain yield, straw yield, harvest index and yield components; panicle numbers, panicle weight, filled grains/panicle, and 1000-grain weight compared to other treatments. Because of the ion imbalance and uptake issues that resulted from the saline soil condition, foliar application may be preferable to soil application. Comparing the combined application of Fe+ Zn+ Mn to the individual application of the micronutrients, it was found that the combined application produced a higher yield. The combined application of micronutrients also increases their solubility in the soil and makes them more available to the soils, while controlling their release.

In a field experiment, Ali *et al*. (2013) examined the potential effects of various concentrations of macro and micronutrients applied as a foliar spray on tomato vegetative growth, flowering, and yield. They found that mixed applications of nitrogen and the other two micronutrients recorded the highest yield-contributing parameters as opposed to individual applications. This could be as a result of variations in the overall number of tomato plants per plot and variations in the environment. In addition, the increased tomato vegetative growth and improved nutrient uptake as a result of foliar nitrogen application had a supplemental effect on the boron and zinc, which in turn led to an increased assimilation rate and the accumulation of biosynthesis as a result of the optimal availability of some necessary nutrients.

In a study on the effects of foliar application of macro and micronutrients on the growth, yield, and quality of greengram, Muthal *et al*. (2016) [21] recorded that urea with boron and DAP applied at flowering produced the highest grain yield, straw yield, and protein content. The higher growth and yield attributes may have had a cumulative and synergistic effect on this, which may have ultimately resulted in a higher grain yield. This may be attributed to ideal physiological conditions throughout the crop's growth. Additionally, supplementing nutrients through foliage with DAP and micronutrients at different growth stages of the crop increased grain yield by ensuring prompt delivery of mineral nutrients to the site of photosynthesis, translocated assimilates more efficiently to the developing pods, and further assisted for proper grain filling up resulting in higher grain yield.

Nutrient interaction

The supply of one nutrient affects the absorption and utilization of other nutrients Interaction occur between the ions

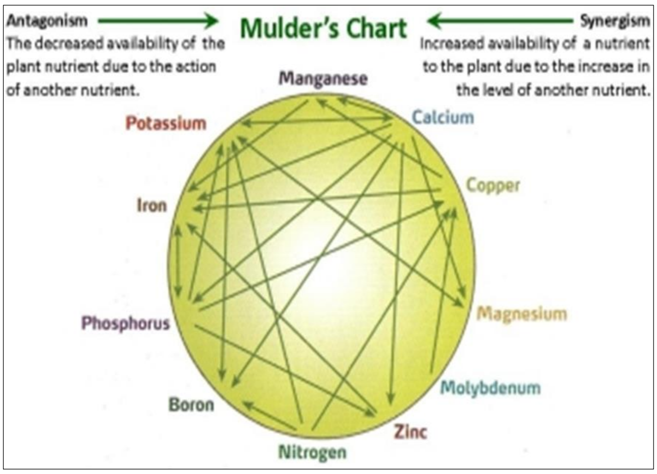
A) Due to formation of precipitate and complex

B) Similar chemical properties

They compete for a site of absorption, adsorption and transport and function of plant root surface. They are measured in term of growth response and change in concentration of nutrition. Interaction modifies nutrient composition.

Antagonistic: Decrease in the availability of one plant nutrient due to the action of another nutrient.

Synergetic: Increase in the availability of the one plant nutrient due to the action of the nutrient.



Jamil *et al*. (2015) [11] studied growth and yield of fodder maize influenced by nitrogen and zinc interaction. Significantly higher growth and yield were noticed in combined application of nitrogen and Zn compared to other treatments. Nitrogen has a synergetic effect on the Zn nutrient nitrogen uptake of both nitrogen and Zn is increased various growth processes like photosynthesis, nitrogen metabolism, protein synthesis, hormone production and regulation of auxin concentration in the plants. These resulted in taller plants, increase in the of leaves, leaf-to-stem ratio and dry matter production which might have reflected in terms of higher green fodder yields.

Klikocka *et al*. (2011) [14] studied the effect of sulphur kind and dose on content and uptake of micro-nutrients by potato tubers**.** The upake of micronutrients is increased with the application of sulphur in the soil. The elemental sulphur application had a higher nutrient content than the sulphate form among the various sources of application. Utilizing S reduces run-off and leaching losses, resulting in long-lasting residual effects on the S nutrition of the succeeding crop. In alkaline calcareous soils, the biochemical oxidation of S results in the production of H_2SO_4, which lowers soil pH and solubilizes $CaCO_3$ to improve soil conditions for plant growth, including the availability of plant nutrients.

In a study conducted by Dash *et al*. (2014) in the *inceptisol* of coastal Odisha, to examine the effects of nitrogen, phosphorus, potassium, sulphur, boron, and zinc on rice yield and nutrient uptake. They discovered that mixed applications of macro and micronutrients resulted in higher grain yield. The productivity of crops and returns from farmers' fertilizer investments are significantly impacted by these interaction effects. Two or more nutrients may interact in a positive (synergistic), negative (antagonistic), or even absent way (additive effect). Due to the ability to maximize returns from positive interaction and also to minimise losses from antagonistic effects, both positive and negative ones are crucial. The interaction between N and P is frequently synergistic, intermittently additive, and occasionally antagonistic. In alluvial, black, red, and lateritic soils of India, K application increased grain N content and rice K uptake.

Laharia *et al*. (2015) [16] studied interaction of P and Zn on nutrient uptake and nutrient efficiency of soybean. Nutrient recovery and nutrient use efficiency of the soybean are both improved by the use of Zn fertilizer. The micronutrients zinc and boron, which are involved in nitrogen fixation and translocation into plant parts, may have contributed to higher dry matter production, which in turn may have led to an increase in the uptake of major nutrients. Zinc and boron's stimulatory effects on nitrogen uptake may also be a factor in the increased nitrogen absorption. The solubilisation of native phosphorus by organic acids in addition to fertiliser application may be the cause of the higher P uptake, which ultimately led to improved root growth and increased physiological activity of roots to absorb more phosphorus. Better plant growth that results in higher nutrient uptake as well as the stimulatory effects of B and Zn on potassium absorption may be the cause of the increased K uptake.

A sufficient supply of Zn might not have a negative impact on how well maize plants absorb P. NUE was also strongly genotype dependent. It was found that adding P and Zn to calcareous soils that were deficient in Zn and P increased each other's effectiveness. This may be a result of the improved metabolism, which could improve nutrient uptake and assimilation by plants. For optimal plant growth and NUE, balanced P and Zn nutrition in nutrient-deficient calcareous soils is essential. \

Chelates

Chelates are organo metalic complexes with 2 or more sites capable of bonding to metal. These include natural products released by plants or components of soil humus and also synthetic chelates amendments. They increase the solubility and availability of micronutrients by increasing the solution concentration. They depend on relative stability constant-the greater the tendency for formation of chelate forms the greater the solubility of the chelate metal. It can be applied as foliar or banded.

Mudlagiri *et al*. (2015) [20] investigated how soil applications of micronutrients and the chelating agent citric acid affected the mineral nutrients in soybean seeds and found that the application of the micronutrients with the chelating agent in the form of citric acid significantly increased the soil's concentration of micronutrients. The direct and indirect effects of mineral treatments on increasing the minerals applied as well as on other minerals in the leaves and seeds, with the exception of $MnCl_2$, have increased the minerals applied. This may be because of the nature of Fe immobility or because of the inhibiting effects of CA. Additionally, Mn, Cu, Zn, Mo, and B had a synergistic effect on a number of micro and macronutrients in leaves and seeds when combined with a chelating agent.

Okra's growth and productivity were studied by Datir *et al*. (2010) [4] in relation to the effect of organically chelated micronutrients. With an increase in concentration, yield components increased. The application of micronutrients increased yield, which can be attributed to improved photosynthesis activity, increased carbohydrate production and accumulation, favourable effects on vegetative growth and retention of flowers and fruits, and an increase in the number of fruits per plant. The greater accumulation of photosynthates by the fruits and vegetative parts of the okra plant may also be responsible for the increased dry matter production. The findings of this study have shed light on the use of chelated micronutrients in organic farming as well as in the immediate correction of micronutrient deficiencies in fruit, vegetables, and other plant-based foods.

Microencapsulation and low-solubility products

Micro encapsulation on micro nutrient produces tiny capsules (micrometre diameter) that have several nutritional. The capsulation of commercial fertilizers uses polymer films to protect the nutrients from rapid stabilization reactions in soil and control their release into the soil solution during plant growth. Nutrient release of coated fertilizers micronutrients occur according to soil moisture content and temperature ph and ionic content. The nutrient release mechanisms are based on either direct diffusion through a polymer film or by decreasing the rate of product hydrolysis. Properties and structure of polymer together with the architecture of microcapsules influence the release of encapsulated micro nutrient fertilizers.

Advantages

- Enhancement of the contact surface for absorption and thus increases the bioavailability.
- Low cost of production.
- Biodegradability and biocompatibility with food and the environment.

Nano encapsulated micronutrients

Mesoporous silica and aluminosilicates have important properties such as highly ordered channels with accessible large porosity, large surface areas, and active sites for adsorption and ionic exchange and catalysis. As nutrient delivery system mesoporous silica and aluminosilicates appear to have the potential for delivering micronutrient in soil or plants. In soil mesoporous material of silicates also reduces the rate of release of micronutrients in plants. A nano-sized Mn-carbonates hollow core-shell loaded with $Znso_4$ regulated Zn release in solution, more slowly than the Znso4 salt, satisfying plant root demand through the process of dissolution and ion exchange reactions.

Pourjafa *et al*. (2016) [24] studied the effect of foliar application of nano iron and manganese chelated on the yield and yield component of canola. The biological yield and harvest index of canola increased with the application of nano-encapsulated Fe and Mn fertilizers. The highest yield was recorded with the application of lower dose of micronutrients. This might be due to micro and nano encapsulated micronutrients increasing cell metabolism, photosynthesis, respiration, enzymes activity which leads to the production of higher dry matter results higher biological yield as well as nutrient uptake compared to other treatments.

Mele *et al*. (2014) [18] investigated the impact of liquid nanotechnology fertilizers on cucumber plant growth and yield. The findings of this study demonstrated that the treatment of cucumber plants with nanotechnology liquid fertilizer (Ferbanat and Nanonat) increased plant yield and growth metrics in comparison to the control. The nutrients that are accessible to plants are contained in nanomaterials (nanotubes or nanoporous materials), covered with a thin polymer film for protection, or added as nanoscale particles or emulsions. Because of their small size and ease of absorption through foliage, nano-chelated fertilizers have the potential to be excellent alternatives to soluble fertilizers and, in the long run, may increase the effectiveness of plant nutrients when there is a water shortage.

Janmohammadi *et al*. (2016) [12] studied impact of nano-chelated micronutrients and biological fertilizers on growth performance and grain yield of maize under deficit irrigation conditions and noticed that yield of the maize increased by application of nano-chelated fertilizers over control. The highest yield is observed in the treatment with complete application of nano fertilizer (containing both B and Zn), they increase the surface area and their by availability increased and nutrient losses reduced. Zn had the most positive impact on the growth and yield of maize among the nano-chelated micronutrients used. Zinc is a crucial micronutrient that participates in numerous key biochemical pathways as a structural component or regulatory co-factor of a variety of different enzymes and proteins. Despite the few studies that have been done on nano fertilizers, it seems that these fertilizers with slow elemental release greatly increase the likelihood of nutrient absorption and minimize environmental losses.

Biofertilizers

Biofertilizers are organic substances that have been transformed by microorganisms or microbial inoculants and are used to supply plants with nutrients. *Rhizobium, Azospirillum, mycorrhizal fungi, cyanobacteria*, or plant-algae symbioses are some examples of microbial inoculants. The definition of "biofertilizers" has been expanded to include things like composts, sludges, and animal manures. Most biofertilizers have been created and used up to this point primarily to provide N and P to plants; little is known about their usefulness for providing micronutrients. However, the chemistry of micronutrients in soils can be significantly influenced by the presence of microorganisms and organic matter supplements. In some cases, this can be done to improve the uptake of micronutrients by plants.

Mohsen *et al*. (2012) [19] investigated the effects of biofertilizer and micronutrients (zinc and iron) on chickpea yield and yield components. The chick pea cultivar that was inoculated with the bio super, which contained PSB and elemental sulphur sulphoxidizing bacteria, produced the freshest weight and seeds per plant compared to the control. Increased supply of N and P to the crop in addition to growth-promoting substances produced by these organisms can be attributed to the cooperative effects of *Azospirillum, Azotobacter, Bacillus subtilis*, and *Pseudomonas fluorescens*, which have been shown to increase growth and yield parameters of chickpea by Biosuper inoculation. Azospirillum seed inoculation of maize could increase root surface area, which would increase absorption of N, P, K, other nutrients, and water, improving aboveground biomass. Increased rates of atmospheric nitrogen fixation can improve vegetative growth and yield by inducing and activating nitrogen-fixing symbiotic bacteria in the roots of pulse crops during seed inoculation. Iron and zinc are essential for healthy growth. Zn is a crucial part of many enzymes and is used in the synthesis of proteins, nucleic acids, and auxin as well as the metabolism of nitrogen. Additionally, iron is crucial for the production of chlorophyll and aids in the absorption of other nutrients. It controls respiration, photosynthesis, nitrogen fixation, and the reduction of nitrates and sulphates. It is a component of chlorophyll. Ganesh *et al*. (2015) [6] found similar results in groundnut, and Gupta *et al*. (2012) [8] in chickpeas.

Siderophores

Iron, manganese, copper, and zinc are just a few of the metallic soil micronutrients that can become more readily available thanks to certain root exudates that function as metal chelators in the rhizosphere. By creating complexes with soil metals, metal chelators increase the solubility and mobility of metals by releasing metals that are bound to soil particles. These substances have the function of scavenging iron from the environment and supplying the mineral-which is almost always necessary to the microbial cell. In comparison to bulk soil, siderophores are more concentrated in the rhizosphere. When supplied at concentrations comparable to those used for delivery of Fe with synthetic chelating agents like EDTA or EDDHA, it provides Fe to plants. Takeshi *et al*. (2013) studied effect of siderophore in tomatoes and found that inoculation of the tomato plant with siderophore in the form of pyroverine increased the solubility of iron and the chlorotic patch developed is very less in inoculated plant over the control.

Mycorrhizae

Mycorrhizae are naturally occurring interactions between particular soil fungi and plant roots. In these associations, the fungi colonise the root tissue while also acting as extensions of the plant's root system, allowing hyphae to absorb and transport water and other nutrients from the environment. Mycorrhizal plants typically have significantly higher levels of P and a variety of micronutrients, most notably Zn and Cu, according to experiments examining the effects of mycorrhizal inoculation on plant growth. Mycorrhizae have also been demonstrated to take up and transport metals to the roots where they are absorbed and translocated to the plant shoot, which may partly explain this effect's association with mycorrhizal plants' increased vigour.

Organic matter

Organic matter can make Fe, which is primarily present as insoluble Fe (III) oxides, more soluble by changing the soil's redox potential. Fulvic acid produced by the breakdown of organic matter and siderophores created by microorganisms will also aid in enhancing the solubility of Fe and its accessibility to plants. Metals like Cu and Ni are tightly bound by soil organic matter and are less accessible in soils with added organic matter.

Jadhav *et al*. (2014) [10] studied effect of ferrous and zinc nutrient management practices on rice under aerobic condition. The highest grain yield and straw yield of rice s occurred with the application of the OM in the form of FYM 5 t and with the RDF and application of Zn and $Feso_4$ over the control and other treatments. Response to Fe through soil or foliar application might be attributed to deficiency of iron (Fe) in anaerobic condition due to oxidation of available ferrous form to unavailable ferric form in soil. For correction of Fe deficiency, drilling of 0.5 kg of libel Fe into the soil at sowing time or foliar application found promising. Moreover, foliar application of Fe was found better over soil application of Fe as foliar applied Fe is easily translocated acropetally and even retranslocated basipetally.

Patel *et al*. (2010) [23] studied effect of FYM and Fe-Zn-S supplementation on yield and quality of multicut forage sorghum. Application of the organic manure with the fertilized had increased the yield significantly over the control. Application of Fe, Zn and S helped in a significant increase in N content of forage sorghum. Sulphur plays an important role in protein synthesis by being a constituent of S-containing amino acids.

Conclusion

Micronutrients are required in very small quantities by the plant for their function. Since they are involved in various enzymatic activities, their deficiencies causes malfunctioning of the plant activities. The efficiency of NPK's internal utilization was increased by including micronutrients in a balanced fertilization schedule. Therefore, micronutrient management must be carried out for sustainable agricultural production and maintenance of human health, depending on crops, soil types, severity of deficiency, source, method, time, rates, and frequency of application. Micronutrient efficiency in the semi-arid tropics can be increased by practising different management practises such as foliar application, balanced fertilization, biofertilizers, mycorrhizae inoculation, micro and nano encapsulated fertilization etc. Selection of the suitable fertilizer mixers will increase the efficiency of the application and biofertilizers and organic matter will increase the solubility of micronutrients. Chelated and micro-encapsulated fertilizer will control the release of the nutrient and increase the surface area hence the losses of nutrients will be reduced. In future aspects, more field experiments should be conducted to generate information on response, critical limits and their efficient management under field conditions.

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