

## AVAILABILITY OF MICROELEMENTS SUCH AS Zn, Fe, Mn, Cu AND IMPACT ON YIELD

<https://zenodo.org/10.5281/zenodo.19043072>

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### **Abstract**

This study systematically analyzes the soil occurrence forms of zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu), their mechanisms of plant uptake, and their physiological effects on crop productivity. Based on contemporary scientific literature, the roles of these micronutrients in enzymatic processes, photosynthesis, redox reactions, and phytohormone biosynthesis are substantiated. The findings indicate that both deficiency and excess of micronutrients disrupt plant metabolic processes, leading to reduced yield quantity and quality. Soil pH, carbonate content, and organic matter reserves are identified as key determinants regulating micronutrient bioavailability in agroecosystems.

### **Keywords**

micronutrients, zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), bioavailability, enzymatic activity, crop productivity

### **Annotatsiya**

Mazkur maqolada rux (Zn), temir (Fe), marganets (Mn) va mis (Cu) mikroelementlarining tuproqdagi mavjud shakllari, ularning o'simlik tomonidan o'zlashtirilish mexanizmlari hamda hosildorlikka ko'rsatadigan fiziologik ta'siri tizimli ravishda tahlil qilindi. Ushbu elementlar fermentativ jarayonlar, fotosintez, oksidlanish-qaytarilish reaksiyalari va gormonlar biosintezida muhim rol o'ynashi ilmiy adabiyotlar asosida asoslab berildi. Tadqiqotlar shuni ko'rsatadiki, mikroelementlar yetishmovchiligi yoki ortiqchaligi o'simlikning metabolik jarayonlariga ta'sir qilib, hosil sifati va miqdorining pasayishiga olib keladi. Tuproqning pH darajasi, karbonat miqdori va organik modda zaxirasi mikroelementlar biokirishuvchanligini belgilovchi asosiy omillar sifatida baholandi.

### **kalit so'zlar**

mikroelementlar, rux (Zn), temir (Fe), marganets (Mn), mis (Cu), biokirishuvchanlik, fermentativ faollik, hosildorlik

### **Аннотация**

В данной статье системно проанализированы формы присутствия микроэлементов цинка (Zn), железа (Fe), марганца (Mn) и меди (Cu) в почве, механизмы их усвоения растениями, а также их физиологическое влияние на продуктивность сельскохозяйственных культур. На основе современных научных источников обоснована роль указанных элементов в ферментативных процессах, фотосинтезе, окислительно-восстановительных реакциях и биосинтезе фитогормонов. Результаты исследований свидетельствуют о том, что как дефицит, так и избыток микроэлементов приводит к нарушению метаболических процессов растений, снижению урожайности и ухудшению качества продукции. Установлено, что уровень pH почвы, содержание карбонатов и запас органического вещества являются ключевыми факторами, определяющими биодоступность микроэлементов.

### **Ключевые слова**

микроэлементы, цинк (Zn), железо (Fe), марганец (Mn), медь (Cu), биодоступность, ферментативная активность, урожайность

Improving productivity and ensuring food security are pressing issues in modern agricultural systems. However, in the process of achieving high yields, primary attention is often given to supplying macronutrients, such as nitrogen, phosphorus and potassium, while the importance of microelements is not sufficiently recognized. Whereas microelements such as zinc (Zn), iron (Fe), manganese (Mn), copper (Cu) are required in small quantities in plants, they are integral part of metabolic and enzymatic processes. These elements regulate oxidation-reduction reactions, ensure stability of photosynthesis, participate in protein synthesis and hormone formation.

In recent years, micronutrient deficiency has become more common due to intensive agriculture, an unbalanced fertilization system, soil degradation in numerous regions. The availability of soluble and bioavailable forms of the present elements for plants decreases especially in calcareous and alkaline soils, consequently, their assimilation are constrained. Under such conditions, plants develop physiological disorders, chlorosis symptoms and reduced growth, which negatively affect both the quantity and quality of yield.

From this perspective, investigating the availability of micronutrients in the soil, their available forms and uptake mechanisms is considered an agronomically

important scientific issue. Maintaining microelement balance not only increases crop yield but also improves the nutritional value of crop products. This article systematically analyzes the role of Zn, Fe, Mn and Cu microelements in agroecosystems, their physiological importance and, their effects on crop productivity.

A more effective scientific approach is to explain the effect of Zn, Fe, Mn, and Cu micronutrients on yield not in isolation, but within the framework of the “soil-rhizosphere-plant physiology-yield” system, because on the one hand, these elements control enzymatic-metabolic processes, and on the other hand, their bioavailability is strictly determined by soil chemistry and rhizosphere biology. Therefore, the issue of micronutrient supply is often determined more to the “mobile and bioavailable form of element” than to the “presence of the element in the soil”; especially the conversion of Zn, Fe, Mn into inactive forms commonly occurs in calcareous and alkaline soils.

First of all, zinc (Zn) is involved in the activity of many enzymes essential for plant growth and crop formation, as well as regulating gene expression and protein synthesis. Zn deficiency inhibits meristem activity, restricting cell division and elongation; as a result, leaf blade size decrease, shortening of internodes, decrease in vegetative biomass accumulation are observed. This condition reduces the stability of the photosynthetic apparatus and the flow of assimilates, thereby decreasing the amount of plastic substances allocated to the yield. Zinc uptake is particularly restricted in calcareous soils due to its binding with phosphates and  $\text{CaCO}_3$  as well as sorption processes; thus, Zn fertilizers and bioavailable forms (e.g., suitable formula or seed/foiar application) have been reported in numerous scientific studies to significantly improve yield and quality in cereal crops.

Physiological limitations associated with zinc are often observed simultaneously with processes related to iron (Fe), since in alkaline-calcareous soil the solubility of Fe is declined sharply and the symptoms of “iron chlorosis” in plants are intensified. Although, Fe is not integral component of the chlorophyll molecule, it is necessary for chlorophyll biosynthesis, the electron transport chain, redox enzymes (e.g., heme proteins), and it maintains photosynthetic efficiency.  $\text{Fe}^{3+}$  precipitates as hydroxides/ oxides under conditions of high bicarbonate concentration and high pH, and uptake through plant roots is limited; as a result, chlorosis in young leaves, reduced photosynthetic efficiency, and a decline in both quantity and quality are observed. The practical effectiveness of chelated Fe (e.g., EDDHA-type) in mitigating this problem, considering Strategy I/ Strategy II iron uptake mechanisms, has been demonstrated in numerous experiments.

Closely associated with the iron problem, the problem of manganese (Mn) also becomes significant under the same soil conditions, since Mn is also oxidized in high pH and oxidizing environments, shifting to less soluble, plant-unavailable forms. One of the key biological functions of Mn is its involvement in the water-splitting complex of Photosystem II, a process that is fundamental for the stability of electron flow and energy metabolism in photosynthesis. The energetic stages of photosynthesis are disrupted under conditions of Mn deficiency, and symptoms such as spotted chlorosis, necrotic lesions, stress on the antioxidant system, and decreased biomass are observed. Therefore, yield decline when Mn supply deteriorates is interpreted not only as a “nutrition” problem but also as a direct limitation of photosynthetic energy production.

Copper occupies a special place in this chain: it plays a crucial role in the photosynthetic and respiratory electron transport systems, in the activity of oxidases and in cell wall strength through enzymes that control lignin biosynthesis. Cu deficiency is more pronounced during the reproductive stage than during vegetative growth: anther and pollen function, the processes of flowering and seed set are disrupted, reducing grain yields. However, excess Cu promotes the generation of reactive oxygen species (ROS), due to redox activity, restricting root growth and leading to toxicity; that is, the requirement for an “optimal range” of this element is stricter than for many other elements. Therefore, management in agroecosystems is not only associated with increasing yields, but also with limiting the risk of toxic accumulation.

The real impact of the above four micronutrients on yield ultimately comes down to the issue of bioavailability which is controlled by soil factors. The pH parameter of soil and carbonate content enhance the precipitation of Fe and Mn as hydroxides/oxides, and the binding of Zn to  $\text{CaCO}_3$  and phosphates; organic matter can mobilize elements through chelation and complexation under some conditions, and strongly bind elements such as Cu under other conditions. Therefore, in practical agro-chemistry, the management of Zn, Fe, Mn and Cu should be based not on their total content, but on the plant - available fraction determined by extractants such as DTPA, which represents a scientifically and practically sound approach.

Analyses show that the microelements zinc (Zn), iron (Fe), manganese (Mn), copper (Cu) are important regulators that ensure the uninterrupted progression of enzymatic, metabolic, and physiological processes in plants. Every one of them performs specific functions in photosynthesis, protein synthesis, oxidation-reduction reactions and generative development stages. Therefore, the availability

level of micronutrients has direct effect on plant growth rate, biomass accumulation, and final yield parameters.

However, the real impact of micronutrients on productivity depends on their total content in the soil, but on their bioavailable form. Soil pH, carbonate content, organic matter levels, and moisture conditions can restrict the mobility of Zn, Fe, and Mn, while under certain conditions promoting the toxic accumulation of Cu. Especially in calcareous and alkaline soils, the transformation of micronutrients into inactive forms leads to physiological deficiencies in plants, manifested by reduced photosynthetic efficiency, the development of chlorosis symptoms and impaired generative development.

Thus, the microelement balance represents an integral component of agroecosystem stability and sustainable productivity. To obtain high-quality yields, it is necessary to implement a management system based on soil agrochemical analysis, determine the plant-available fraction of micronutrients, and optimize fertilization on a scientific basis. Balancing micronutrient supply through an integrated approach not only increases productivity but also improves the nutritional value of agricultural products.

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