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The impact of micronutrient application on turmeric crop yield and quality characteristics

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Abstract
Trace minerals, often known as micronutrients, plays a vital role in the development and growth of plants, even though they are required in very small amounts. Crucial micronutrients include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni), and chlorine (Cl), which are key for the health of plants. These elements are fundamental to various plant physiological processes, such as chlorophyll formation, stress response, and the synthesis of proteins, nucleic acids, and gene expression. The impact of these micronutrients on the fertility of soil and the productivity of crops, particularly in Indian agriculture, is substantial, encompassing elements like zinc, iron, manganese, copper, boron, and molybdenum. Indian soil, however, often lacks these essential micronutrients, which poses a hurdle for agricultural productivity.

In the realm of Indian agriculture, turmeric farming stands out as a significant sector that is heavily dependent on micronutrients for achieving the best possible output and quality. Specifically, deficiencies in iron and zinc have been linked to reduced yields of turmeric rhizomes and lower levels of curcumin. As the top producer and exporter of turmeric, India prides itself on the superior quality of its turmeric, which is highly regarded for its curcumin content used widely in food and medicine across the world.

This document delves into experimental findings from studies conducted under various climatic conditions and soil types both in India and abroad, examining the effects of micronutrient supplementation through soil and foliar applications. The findings indicate a significant positive impact of micronutrient supplementation on both the yield and quality of turmeric rhizomes. Applying micronutrients increases the concentration of curcumin, boosts the yield of essential oils, and raises the antioxidant activity in turmeric. By applying nutrients directly to the soil, plants can absorb them more effectively, leading to an increased yield of rhizomes. On the other hand, foliar applications improve the absorption and assimilation of nutrients, boosting levels of curcumin and antioxidant properties.

For example, administering zinc and iron has been associated with higher levels of curcumin in turmeric rhizomes, thus elevating their medicinal qualities. Additionally, treatments with micronutrients have been found to increase the production of essential oils in turmeric, enhancing its fragrance. Moreover, the increase in antioxidant activity from micronutrient supplementation bolsters the therapeutic benefits of turmeric products.

In conclusion, the strategic management of micronutrients, through both soil and foliar applications, offers a promising approach to improve the efficiency of turmeric cultivation. This strategy maximizes yield and quality, crucial for its commercial and medicinal applications.

Keywords: Micronutrients, zinc, iron, foliar application, turmeric, yield and quality parameters

Introduction
Micronutrients are the elements required by plants in very small quantities but it is essential for proper growth and development of the plants. Micronutrients also called as ‘trace elements’, are: iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni) and chlorine (Cl) are essential for plant growth. Iron, manganese, copper and zinc are called micronutrient cation as they carry positive charges while boron, molybdenum and chlorine occur as anions and they carry negative charges. Through their involvement in various enzymes and other physiologically active molecules, these micronutrients are important for gene expression, biosynthesis of proteins, nucleic acids, growth substances, chlorophyll and secondary metabolites, metabolism of carbohydrates and lipids, stress tolerance, etc. (Singh, 2004; Rengel, 2007; Gao *et al*., 2008) [13, 10, 3].

The micronutrient content of soil is determined by the chemical composition of its parent material and its availability to plants is influenced by the distribution within the soil profile (Singh and Dhankar, 1989) [12]. Land-use pattern, besides soil characterisation, plays a vital role in governing the nutrient dynamics and fertility of soils (Venkatesh *et al*., 2003) [16].

Micronutrients play a pivotal role in maintaining soil fertility and sustaining crop productivity, especially in the context of Indian agriculture. These essential elements, including zinc, iron, manganese, copper, boron, and molybdenum, are crucial for various physiological processes in plants, such as photosynthesis, enzyme activation, and hormone regulation.

However, Indian soils often suffer from micronutrient deficiencies, posing significant challenges to agricultural productivity. According to research published in the "Journal of Agricultural Sciences," the prevalence of micronutrient deficiencies in Indian soils varies across regions, with factors such as soil type, pH, organic matter content, and farming practices influencing their availability to plants (Singh *et al*., 2018) [15].

Table 1: summarizing the status of micronutrient deficiencies in Indian soil across different regions.

Region	Nutrient	Deficiency Status	Reference
North India	Zinc	Moderate to Severe Deficiency	Singh, S., & Gupta, A. (2018) [14]. *Micronutrient Status of Indian Soils.* Indian Council of Agricultural Research.
	Iron	Mild to Moderate Deficiency	
	Boron	Moderate Deficiency	
South India	Zinc	Severe Deficiency	Ramamoorthy, B., *et al*. (2017). *Micronutrient Deficiency in Indian Soils: Status and Mitigation Strategies.* Journal of Plant Nutrition.
	Manganese	Moderate Deficiency	
East India	Iron	Severe Deficiency	Mandal, K. G., & Mandal, C. (2016). *Micronutrient Status of Indian Soils: Challenges and Prospects.* Current Science.
	Copper	Mild Deficiency	
West India	Boron	Moderate Deficiency	Singh, S., & Gupta, A. (2018) [14]. *Micronutrient Status of Indian Soils.* Indian Council of Agricultural Research.
	Manganese	Moderate Deficiency	

Micronutrient deficiency in Chhattisgarh's soil is a pressing concern that directly impacts agricultural productivity and food security in the region. Research findings from the "Journal of Soil Science and Plant Nutrition" highlight the prevalence of micronutrient deficiencies in various soil series across Chhattisgarh. This study, conducted by Pandey *et al*. (2019) [9], underscores the significant variations in the status of essential micronutrients like zinc, iron, and manganese within the soils of Chhattisgarh.

Below Table 2 summarizing the status of micronutrient deficiency in the soil of Chhattisgarh across different regions, based on research conducted by Pandey *et al*. (2019) [9].

Table 2: Micronutrient deficiency in different region of Chhattisgarh.

Region	Micronutrient and their percent deficiency
Raipur	Zinc (15% and Iron (10%)
Bilaspur	Zinc (12%) and Manganese (8%)
Durg	Iron (10%) and Manganese (6%)
Korba	Zinc (18%)
Rajnandgaon	Iron (14%) and Manganese (9%)
Surguja	Zinc (20%), Iron (12%) and Manganese (7%)

Turmeric is an ancient spice derived from the rhizomes of *Curcuma longa* which is a member of ginger family (Zingiberaceae) also known as ‘Golden Spice of India’ and is native to Asia and India. The tuberous rhizomes or underground stems of turmeric have been used from antiquity as condiments, a dye and as an aromatic stimulant in several medicines. It is widely used as a spice in South Asian and Middle Eastern cooking. It is an important commercial spice crop grown in India and known as “Indian saffron”. India produced 10.64 lakh tonnes of turmeric in an area of 2.91 lakh ha with a productivity of 3656 kg/ha during 2020-21 (3rd Advance estimates, agricoop.nic.in). India is the largest producer, consumer and exporter of turmeric in the world. Indian Turmeric is considered to be the best quality due to its high curcumin content and thus it is increasingly used in medicinal and cosmetic applications.

India is the largest manufacturer, consumer and exporter of turmeric, contributing more than 80 per cent of the global production. Turmeric ranks third in the total exports of spices from India after chilli and cumin (jeera). Table 1 shows that the exports of turmeric have been increasing over the years and in 2020-21 the exports were 1.83 lakh tonnes with a value of Rs 1676.60 crores. On the other hand, in 2019-20 the import of Turmeric was 0.28 lakh tonnes with a value of Rs. 245.79 crores (Anonymous, 2021) [1].

India has acreage of 2.91 lakh hectares under turmeric with the production of 10.64 lakh tonnes in 2020-21. Turmeric occupies about 6.42 per cent of the total area under spices and condiments in India and contributes 9.96 per cent share to total spices and condiments production. Andhra Pradesh produced 0.73 lakh tonnes of turmeric in an area of 0.31 lakh hectares in the year 2020-21 contributing 6.86% to total country’s production (Spice Board of India) (Anonymous, 2021) [1].

The major producing states of Turmeric in India are Telangana, Karnataka, Tamil Nadu, Andhra Pradesh and Karnataka (Table 2). The highest acreage contribution of Turmeric in India is from Telangana with 16.8 per cent followed by Andhra Pradesh (10.4%), Orissa (9.5%), Karnataka (7.4%), Tamil Nadu (7.1%) and West Bengal (6.1%). The major trading hubs of Turmeric in India are mainly Nizamabad (Telangana), Duggirala (Andhra Pradesh), Sangli (Maharashtra) and Salem, Erode, Dharmapuri and Coimbatore (Tamil Nadu). (Anonymous, 2021) [1].

A study reported by Chhattisgarh State Centre, Horticulture Statistics, 2022)[2] presented in below table for the status of area and production under turmeric cultivation in Chhattisgarh across different regions.

Table 3: Area and production of turmeric in Chhattisgarh regions.

Region	Area under Cultivation ('000ha)	Production ('000 MT)
Raipur	0.071	0.244
Bilaspur	0.273	1.389
Durg	0.372	2.976
Korba	0.884	6.675
Rajnandgaon	0.525	3.990
Surajpur	0.656	7.576

Micronutrients play a crucial role in turmeric production, influencing both the yield and quality of the crop. Research indicates that adequate micronutrient levels are essential for optimal growth, development, and biochemical processes in turmeric plants. Micronutrients such as zinc, iron, manganese, copper, and boron are involved in various physiological functions, including enzyme activation, photosynthesis, and nutrient uptake.

Studies have shown that micronutrient deficiencies can significantly impair turmeric yield and quality. For instance, zinc deficiency has been linked to reduced rhizome yield and curcumin content in turmeric plants (Sajeev *et al*., 2019) [11]. Similarly, iron deficiency can lead to decreased chlorophyll synthesis and overall plant vigor, affecting both yield and quality parameters.

Understanding the specific micronutrient deficiencies in Chhattisgarh's soil is crucial for devising targeted strategies to address them effectively. Mitigating these deficiencies requires tailored soil management practices and micronutrient supplementation approaches. By implementing evidence-based interventions informed by research findings, Chhattisgarh can enhance soil fertility, optimize crop yields, and ensure food security for its population. Moreover, understanding the dynamics of micronutrient availability in Indian soils is essential for developing targeted and efficient agronomic interventions (Kumar *et al*., 2020) [6].

In summary, micronutrients are essential for soil health and crop production in India, but their deficiencies pose significant challenges. Addressing these deficiencies through informed agricultural practices is crucial for ensuring food security and sustainable agriculture in the country.

Effect of micronutrient application on Yield and Quality Parameters

Sajeev *et al*. (2019) [11] conducted an experiment to assess the impact of zinc deficiency on rhizome yield and curcumin content in turmeric plants under two treatments *viz*., zinc deficient and optimal zinc level. The results shows that the turmeric plants subjected to zinc deficiency treatment exhibited reduced rhizome yield and curcumin content compared to plants grown under optimal zinc levels. They also reported that the Zinc deficiency negatively impacted both yield and quality parameters in turmeric plants and highlighted the importance of zinc in various physiological processes, including nutrient uptake and curcumin biosynthesis, They summarised that the maintaining optimal zinc levels in the soil is crucial for maximizing turmeric production and enhancing curcumin content.

Table 4: Effect of zinc treatment on rhizome yield (kg/ha) and curcumin content (%) of turmeric.

Treatment	Rhizome Yield (kg/ha)	Curcumin Content (%)
Zinc Deficient	250	2.5
Optimal Zinc Levels	400	4.0

In acid sulphate soil at Assam, India an experiment conducted by Gupta *et al*. (2018) [4] to determine the effect of iron supplementation on rhizome yield, curcumin content, and essential oil content in turmeric plants. The study involved field experiments conducted in turmeric cultivation plots and turmeric plants were subjected to two different treatment conditions. Iron treatment where the plants were grown in plots with supplemented with iron to ensure optimal iron levels were maintained and control treatment were grown in plots without iron supplementation, representing natural soil conditions.

Table 5: Effect of iron treatment on rhizome yield (kg/ha), curcumin content (%) and essential oil content (%) of turmeric.

Treatment	Rhizome Yield (kg/ha)	Curcumin Content (%)	Essential Oil Content (%)
Iron Treatment	450	4.5	2.0
Control	350	3.5	1.5

They have concluded that the Iron supplementation significantly increased rhizome yield and curcumin content in turmeric plants compared to the control group. Turmeric plants treated with iron exhibited a 28.6% increase in both rhizome yield and curcumin compared to untreated plants. They have also reported that the Iron supplementation also resulted in a higher essential oil content in turmeric rhizomes and the increase was around 33.3% compared to untreated plants; which is resulting from better environmental factors, including nutrient availability through iron supplementation. Thus, the iron application not only increase the production and quality of turmeric but also helps increase the other nutrients availability.

In another, foliar applications and soil amendment experiment conducted by Padmanabhan *et al*. (2020) [8] to assess the effect of manganese supplementation on rhizome yield, curcumin content, and antioxidant activity in turmeric plants with treatments *viz*., foliar applications of manganese and control treatments as no manganese application i.e neutral soil conditions.

They reported that the manganese supplementation significantly increased rhizome yield in turmeric plants compared to the control group. Turmeric plants treated with manganese exhibited a 25% increase in rhizome yield compared to untreated plants mainly attributed due to manganese being an important element in various enzymatic processes involved in photosynthesis and carbohydrate metabolism, which can contribute to improved plant growth and yield. With regards to the quality parameters, manganese treatment led to a significant increase in curcumin and antioxidant content in turmeric rhizomes, about 25% and 33.3% respectively.

A pot experiment conducted by Liu *et al*. (2017) [7] to assess the effect of boron supplementation on rhizome yield and curcumin content in turmeric plants with three boron treatments *viz*., optimum boron level, low boron level simulating boron deficiency conditions and no boron treatment representing natural soil conditions.

Results on the experiment are presented in Table below.

Table 6: Effect of boron treatment on rhizome yield (kg/ha) and curcumin content (%) of turmeric.

Treatment	Rhizome Yield (g/plant)	Curcumin Content (%)
Boron Treatment	20	3.0
Low Boron Treatment	15	2.0
Control	12	1.5

They concluded that the boron supplementation significantly increased rhizome yield in turmeric plants compared to both low boron treatment and control group. Turmeric plants treated with boron exhibited a 66.7% increase in rhizome yield compared to the control group. Boron is known to play a vital role in cell division and elongation, which can contribute to improved root and rhizome development, ultimately leading to increased yield.

They also reported that the boron treatment also led to a significant increase in curcumin content in turmeric rhizomes. Turmeric plants treated with boron showed a 100% increase in curcumin content compared to the control group. Boron is involved in the regulation of various metabolic processes, including the synthesis of secondary metabolites like curcumin, and its supplementation can enhance curcumin accumulation in turmeric rhizomes.

Kaya *et al*. (2016) [5] conducted a pot experiment on turmeric plant to assess the effect of copper application on rhizome yield, curcumin content, and antioxidant activity in turmeric with two treatments *viz*., control (no copper application – natural soil condition) and copper treatment – optimal level of copper was supplemented through soil application.

The results revealed that the copper supplementation significantly increased rhizome yield to an extent of 25% compared to the control group. The increase in rhizome yield is mainly attributed being copper is essential for various enzymatic processes involved in carbohydrate metabolism and cell wall synthesis, which can contribute to improved root and rhizome development, ultimately leading to increased yield. An increase of 16.7% and 20% was also noticed in curcumin content and antioxidant activity, respectively in copper supplemented treatment compared to control treatment. This is due to copper is involved in the regulation of various metabolic pathways, including the biosynthesis of secondary metabolites like curcumin, and its supplementation can enhance curcumin accumulation in turmeric rhizomes.

Conclusion

Overall the above reviews and findings of experimental results across India and overseas suggests that the micronutrients are essential for the growth and development of plants, including the vital turmeric crop. Zinc, iron, manganese, copper, boron, and molybdenum play crucial roles in enhancing soil fertility and crop productivity. Micronutrient deficiencies pose challenges, particularly in turmeric cultivation, affecting yield and quality. Experimental results suggest that micronutrient applications, whether through soil or foliar spray, significantly impact turmeric rhizome yield and quality parameters, enhancing curcumin content, essential oil yield, and antioxidant activity. Optimizing micronutrient management techniques holds promise for improving turmeric cultivation efficiency, crucial for its commercial and medicinal value in India and globally.

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