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Review Article

MICRONUTRIENT LIMITATIONS IN CROP PRODUCTION AND STRATEGIES FOR IMPROVEMENT: A REVIEW

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ABSTRACT

Crop productivity in developing countries is hindered by micronutrient deficiency, particularly in the third world, leading to challenges in achieving higher yields. The unbalanced use of fertilizers for higher agricultural production has resulted in soil fertility exhaustion and imbalances in major, secondary, and micronutrients. The intensified cultivation, erosion, and loss of micronutrients through various processes have led to an escalation in crop micronutrient insufficiencies, impacting both crop productivity and human nutrition. African soils, including those in Ethiopia, suffer from multiple nutrient deficiencies, affecting staple crops and leading to poor nutritional quality in diets. In Ethiopian soils, there is a widespread occurrence of micronutrient deficiencies, specifically in zinc, boron, and copper, which adversely impact the productivity of crops. The introduction of mineral fertilizers in Ethiopia in the 1970s has not addressed micronutrient deficiencies adequately. The review emphasizes the importance of micronutrients in global crop production and their role in addressing hunger and malnutrition. The limited use of micronutrients in developing countries contrasts with their significance in improving crop yield and quality. Micronutrient deficiencies can have severe consequences on plant growth, yield, and human health. The review concludes by stressing the significance of addressing micronutrient deficiencies for optimal crop production and human nutrition. The goal of the review is to present a comprehensive understanding of the significance of micronutrients for crop production.

KEYWORDS: Crop production; fertilizer management; micronutrient deficiency; nutrient imbalance; soil fertility.

1. INTRODUCTION

1.1 General Background

"Crop productivity in the developing world encounters various challenges. A significant limitation to crop productivity in third-world countries is the inadequate availability of essential crop nutrients in the right quantities and forms".[1] For optimal growth and development, plants require specific nutrients in precise amounts and forms at specific times. Both macro and micronutrients play vital roles in crop nutrition, significantly influencing the attainment of higher yields.[2] "The pursuit of increased agricultural production without a balanced approach to fertilizer application has resulted in issues related to soil fertility depletion and imbalances in plant nutrients, affecting not only major nutrients but also secondary and micronutrients. It is evident that deficiencies in secondary and trace elements will manifest if timely replenishment is not practiced in intensive agriculture".[3,4,5]

Micronutrient deficiency poses a dual challenge for both crop production and human nutrition. The inadequacy of micronutrients in soil limits both the productivity and nutritional quality of crops, thereby impacting human health.[6] "Numerous African soils grapple with deficiencies in various nutrients, including macronutrients such as N, P, K, secondary nutrients like S, Ca, and Mg, as well as micronutrients such as Zn, Fe, Cu, Mn, and B".[7] "The severity of soil micronutrient deficiencies is particularly pronounced in sub-Saharan Africa, where 75% of arable land faces significant fertility issues".[8] "This scarcity of micronutrients not only leads to reduced crop yields but also diminishes the nutritional quality of harvested crops. Diets in sub-Saharan Africa, particularly among economically disadvantaged populations, tend to be low in diversity, relying heavily on staple crops like maize, sorghum, millet, cassava, rice, and sweet potato. These diets, lacking in mineral micronutrients and vitamins, contribute to widespread micronutrient deficiencies in these populations. The chronic insufficiency of micronutrients can give rise to severe, albeit often hidden, health problems, especially among women and young children".[9]

Ethiopia is particularly susceptible to soil degradation, facing the highest rate of erosion by rainwater in Africa.[10,11] "The country experiences nutrient mining due to suboptimal fertilizer usage on one hand and imbalanced fertilizer applications on the other, contributing to the emergence of multi-nutrient deficiencies in Ethiopian soils. This, in turn has been linked to the decline in fertilizer factor productivity observed in the recent past".[12,13] "Various research reports highlight the depletion of nutrients such as K, S, Ca, Mg, and all micronutrients except Fe, with deficiency symptoms appearing on major crops in different regions of the country".[12,13] "National soil inventory data also disclosed widespread deficiencies in sulfur, boron, and zinc, in addition to nitrogen and phosphorus, while some soils exhibit shortages in potassium, copper, manganese, and iron" (Ethiosis, 2013).[14,15] These deficiencies pose potential constraints to crop productivity, despite the continued use of N and P fertilizers according to blanket recommendations.

1.2 Objective

The objective of this paper is to review studies conducted on micronutrient limitations in crop production and strategies for improvement.

2. LITERATURE REVIEW

2.1 Micronutrient Constraint to Crop Yield

2.2.1 Importance of micronutrient in global crop production

"The pressing need to tackle the challenge posed by a rapidly growing global population, especially by eradicating hunger and malnutrition in underdeveloped nations, emphasizes the necessity for implementing policies that promote sustainable agricultural productivity while safeguarding the environment and natural resources. The pivotal role of soil fertility and mineral nutrition, coupled with advancements in crop varieties and enhanced water availability, is crucial in securing adequate nutrition"[16] and confronting the substantial challenges humanity faces in addressing these issues.[17]

A significant portion of the global food production is currently credited to the utilization of chemical fertilizers (Stewart *et al*., 2005). "Enhanced crop varieties and improved crop management also contribute to this outcome. However, future advancements in food production are anticipated to rely even more on fertilizer inputs, with nitrogen (N), phosphorus (P), and, to a lesser extent, potassium (K) playing crucial roles. The deficiencies of these key nutrients in soil are now comprehensively understood and predominantly addressed in contemporary commercial agriculture through the regular application of fertilizers. Micronutrient constant are currently the problem in crop production. The combined use of macronutrients and micronutrients increases dry matter, grain yield, yield component and wheat straw".[18]

Table 1: Influence of micronutrients on the wheat crop's yield.

Treatments				Micronutrients	Dry Matter	Grain Yield	Straw Yield
N	P_2O_5	K_2O	kgh^{-1}	$kg\ h^{-1}$	$kg\ h^{-1}$		
Ti	100	0	0	-	8458 c	2292 d	5939 b
T2	100	75	50	Zn, Mn, Fe, Cu, B	13125 c	3542 d	8208 a
T3	100	76	50	Zn, Mn, Fe, Cu, (-B)	14167 a	3958 a	10208 a
T4	100	75	50	Zn, Mn, Fe, Cu, (-B)	11192 c	2750 d	7166 a
T5	100	75	50	Zn, Mn, Fe, B, (-Cu)	13958 b	3750 ab	9166 a
T6	100	75	50	Zn, Mn, Cu, B, (-Fe)	13167 b	3750 ab	9166 a
T7	100	76	50	Zn, Fe, Cu, (Eli-Mn)	12208 ab	3750 ab	8333 a
T8	100	75	50	Zn, Fe,Cu.13(-In)	13750 a	3583 abc	8750 a
T9	100	75	60	Zarzameen	13125 a	3958 a	10208 a

Source: [18]

Table 2: The impact of micronutrient supplementation on the average yield of potatoes and sugar beets (measured in kg per hectare) is being assessed.

Potato field location	Treatments		Yield increase (%)	Sugar beet field location	Treatments		Yield increase (%)
	NPK	NPK+Micronutrient			NPK	NPK+Micronutrient	
Semnan	29,000	32,000	10	Fars	6497	6561	1
Hamadan	41,500	46,500	12	Khorasan	4230	4545	7
Kerman	13,900	17,500	26	Arak	9858	10,635	8
Karaj	16,900	22,100	31	Karaj	6450	7500	16
Ardabil	35,500	36,700	3				
Mean	27,360	30,960	16	**Mean**	6759	7310	8

Sources: [19]

Groups with similar letters (a) for means are statistically indistinguishable from each other at a 5% significance level. The application rates for micronutrients were 4 kg Zn, 2 kg Cu, 5 kg Fe, 32 kg Mn, 1 kg B, and 1 kg Zarzmeen per hectare.

Apart from the nine primary nutrients, there are eight micronutrients crucial for the robust growth and reproductive health of higher plants, namely boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).[19] Broadly, although the application of N, P, and K fertilizers has seen a rise in developing countries over the past decades (IFA, 2011), "the utilization of micronutrients is considerably restricted and, in numerous instances, nonexistent". "For a trace element to be essential for either plants or animals (that means a micronutrient), it needs to satisfy three criteria; the organism cannot grow and reproduce normally without the element, its action must be specific and unable to be replaced by any other element and its action must be direct" (Arnon and Stout, 1939).

2.2.2 Importance of micronutrient in tropical crop production

The tropics exhibit significant diversity in both climate and soil resources while a variety of crops are cultivated in the tropics, certain ones play a crucial role in food production. Notably, sorghum, millet, wheat, pulses (such as cowpeas, pigeon peas, chickpeas, and beans), and groundnuts are more prevalent in dry semiarid tropics, while others thrive in wet dry to humid tropics. Besides these essential food crops, the tropical economy also relies on several significant commercial crops like sugarcane, cotton, coffee, tea, cocoa, coconut, oil palm, and bananas.

Recognizing the micronutrient needs of these crops is vital, as they commonly exhibit deficiencies and demand increased fertilizer usage, including micronutrients, due to their economic importance. The application of micronutrients, whether through soil application, foliar spray, or seed treatment, has been shown to enhance grain yield, improve quality, and boost macronutrient use efficiency, as supported by studies like those conducted by John *et al*. (2000), Malakouti[20] and Asefa et al.[20]

"Recently, the role of micronutrients in plants show multiple advantages arise, encompassing the stimulation of growth and yield, improvement of nutritional quality in produce, reinforcement of resistance or tolerance to pests and diseases, and alleviation of drought impacts" (Dimkpa and Bindraban, 2016). "Notably, within the spectrum of micronutrients, the pivotal roles of zinc (Zn), copper (Cu), and boron (B) in influencing crop responses to drought stress stand out. Zinc activates numerous enzymes that regulate a plant's response to water stress. Additionally, serving as a structural component, zinc plays a crucial role in maintaining the integrity of biological membranes, particularly essential for effective water absorption and utilization during periods of drought stress".[21]

Table 3: Impact of varied copper application levels on wheat's grain yield characteristics, straw production, and harvest index.

Cu applied $Mgkg^{-1}$	Length of main ear (cm)	No. of ears per plant	No. of grains per ear	Grain yield g/plot	Straw yield g/plot	100 grains wt.(g)
0	6.6	2.1	12.7	3.88	6.92	32.58
0.5	7.7	1.9	16.7	4.48	6.64	35.02
1	8.5	2.3	12.9	4.64	6.68	41.35
1.5	9.5	1.9	20	6.32	6.92	35.85
2	7.8	1.7	18.5	4.44	6.44	33.85
2.5	7.1	1.6	17.3	3.8	5.84	33.93
SE (d) ±	0.9	-	2.6	0.98	-	1.54
CD (0.05)	1.9	NS	5.5	2.06	NS	3.24

Source: (Kumar, 2007)
**Significant at p = 0.05, NS: non-significant*

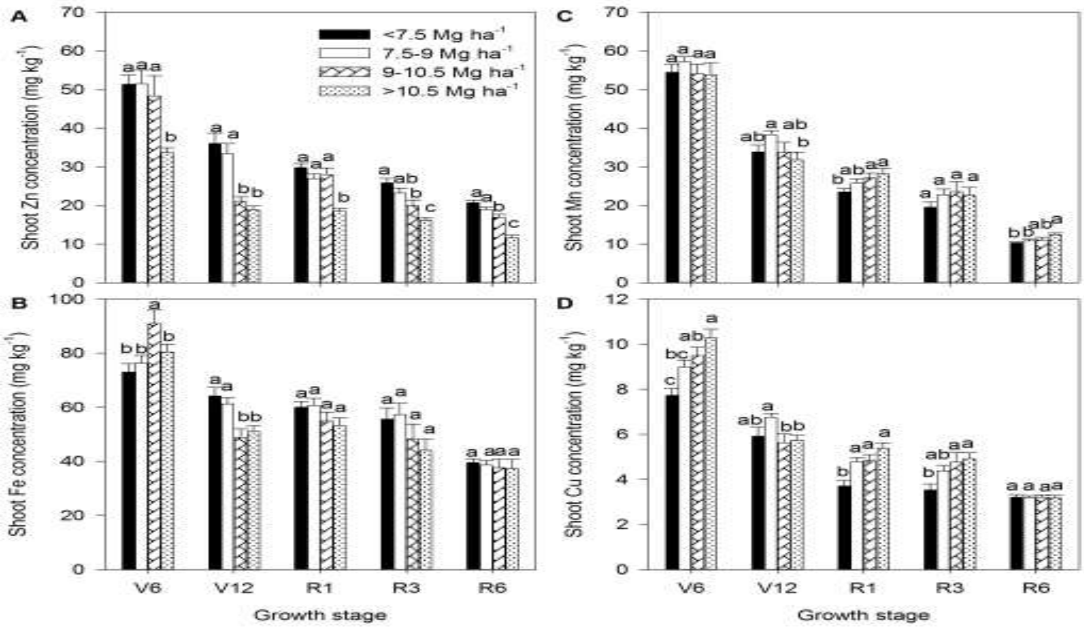

Fig. 1: Fluctuations in the zinc concentration in plant shoots.

Source: [22]

Table 4: The impact of adding secondary and micronutrients on cereal yield in different African nations.

Crop	Country	Number of sites	Yield with NP (K) only	Yield with NP(K) and with secondary/micronutrients	Yield increase ±95% confidence interval	Additional nutrients
			tha-1			
Maize	Ethiopia	9	5.60	6.72	1.12±0.84	S, Zn, B
Wheat	Ethiopia	43	3.99	5.28	1.29±0.25	S, Zn, B, Cu
Maize	Burundi	44	3.11	5.27	2.16±0.29	Dolomite, S, Zn, B,Cu
Rice	Burundi	168	4.89	6.89	2.00±0.12	S,Zn,B,Cu
Maize	Mozambique	17	2.99	4.18	1.19±0.10	Mg,S,Zn,B
Wheat	Rwanda	40	4.14	5.64	1.50±0.25	K,S,Zn,B,Cu
Rice (paddy)	Rwanda	20	4.32	5.89	1.57±0.31	S,Zn,B,Cu

Source: [23]

At various growth stages, namely V6 (six-leaf stage), V12 (12-leaf stage), R1 (silk emerging), R3 (milk stage), and R6 (physiological maturity), the concentrations of iron (Fe) in shoots (A), manganese (Mn) in shoots (B), and copper (Cu) in shoots (C) for summer maize were examined. These analyses were conducted across distinct grain yield ranges. Table 2 provides the corresponding number of observations, and the standard error of the mean is represented by the bars. Significantly different bars, indicated by distinct lowercase letters, were observed at various yield ranges (P=0.05).

The application of secondary and micronutrients can exert substantial impacts on crop yields in sub-Saharan Africa, as depicted in Table 6. However, this aspect has not garnered as much attention as the macronutrients N, P, and K. This is evident in the predominant focus of most fertilizer subsidy programs on NPK fertilizers. This emphasis may stem, at least in part, from a prevalent belief that addressing other nutrients is unnecessary while the continent is still grappling with the adoption of macronutrient fertilizers. Contrary to this perception, it is more likely that, in the presence of deficiencies in secondary and micronutrients, the response to NPK fertilizers may be constrained. Given that secondary and micronutrients are required in smaller quantities, rectifying these deficiencies could enhance the return on fertilizer investment for farmers, a crucial factor in promoting adoption. A notable limitation in much of the research on secondary and micronutrient deficiencies in sub-Saharan Africa is the tendency to investigate these nutrients individually rather than in combination. In reality, multiple deficiencies in secondary and micronutrients are commonplace in many regions of sub-Saharan Africa.

Secondary and micronutrients, including Ca, Mg, S, Zn, Cu, Mn, Fe, B, and Mo, often limit crop growth especially in soils are continuously cropped without returning these nutrients. Most of the commonly applied fertilizer in SSA contains mainly N, P, and/or K, which do not replenish Secondary and micronutrients. Nutrient depletion can be further aggravated by soil acidification, which interferes with the availability of specific nutrients. The considerable extent of secondary and micronutrient deficiencies in SSA is gradually becoming apparent.

2.2.3 Importance of micronutrient in Ethiopia crop production

The worldwide study provided data on micronutrient concentrations in selected soils of Africa.[25] It illustrated that copper, zinc and molybdenum deficiencies are common in many coarse textured, acid soils of Ethiopia, Ghana, Malawi, Nigeria, Sierra Leone, Tanzania, and Zambia. The use of fertilizers that contain multi nutrients is of great importance to ensure the supply of all or most of the nutrients required by crops.

"Experience in Malawi provides a striking example of how N fertilizer efficiency for maize can be raised by providing appropriate micronutrients on a location specific basis. A study in Malawi revealed that application of N, P, K, S, Zn and B, increased maize yields by 40% over the use of only recommended amounts of N and P" (John *et al*., 2000). "A Greenhouse assessment of micronutrient deficiency (Fe, Cu, Zn, B and Mo) in some Nitisols of Western Ethiopia on maize shows a significance yield reduction".[26] "Micronutrients are important for crop growth, production and their deficiency and toxicity affect crop yield. However, the up dated information about their status and spatial distribution in Ethiopian soils is scarce. Therefore, fertilizer recommendation for crops in the country has until recently focused on nitrogen and phosphorus macronutrients only. But many studies have revealed the deficiency of some micronutrients in soils of different parts of Ethiopia" (EthioSIS, 2013).[14,15,27]

"Deficiencies of micronutrients have emerged as a new problem to crop productivity in Ethiopia" [28]. Some preliminary results from recent EthioSIS survey also indicated that boron, zinc and copper are deficient micronutrients in most Ethiopian soils. Studies on response of crops to micronutrients in Ethiopia are rather limited. However, both response and lack of response of crops to micronutrient fertilizer applications were reported. Crops often vary in their response to micronutrients and sensitiveness to micronutrient deficiencies. Another important of micronutrient combination with micronutrients NPK fertilizers is to improve nutrient concentration and uptake and enhanced yield [21] and economical return also significant results (Table 9).

2.2.4 Impact of micronutrient deficiency in crop production

Increased productivity has significantly increased the need for soil nutrients. While conventional fertilization practices aimed to meet major element requirements (NPK), micronutrients absorbed by plants were generally not supplemented. In rice, micronutrient problems have been observed in food crops. The impact of micronutrient deficiencies on agricultural production is often measured in terms of yield losses. Micronutrient deficiencies can significantly affect crop yield and quality, as well as the health of domestic animals and humans.[30,31,32] Due to the increase in grain yield and efficiency in the use of mineral fertilizers, it can be assumed that the use of fertilizers enriched with micronutrients brings significant economic benefits to farmers. Fertilizer efficiency (FUE) for various crops can be increased through the use of micronutrients (Table 5). Micronutrients (Fe, Zn, Cu and B) or a combination of Fe + Zn + Cu + B for NPK fertilizers increase grain yield. The highest yield was achieved after adding all trace elements to the NPK fertilizer [33]. Boron deficiency in rice can only manifest itself in reduced grain yield due to flower sterility and can be incorrectly attributed to poor environmental conditions during flowering.[34]

Table 5: The impact of lime, a combination of fertilizers, and compost on the thousand seed weight, harvest index, grain yield, straw yield, biological yield, and straw yield of barley were investigated in Wolmera district, West Showa, Ethiopia.

Treatments	Thousand seed weight (g)	Harvest Index (%)	Grain yield (kg ha^{-1})	Biomass Yield (kgha^{-1})	Straw yield (kg ha^{-1})
Control	10^{c}	38^{c}	1318^{c}	3433^{c}	2116^{b}
5 t compost ha^{-1}	37^{b}	39^{c}	1617^{c}	4173^{c}	2556^{b}
611kg lime ha^{-1}	36^{b}	37^{c}	1683^{c}	4483^{c}	2801^{b}
611kg lime + 5 t compost ha^{-1}	37^{b}	40^{bc}	1745^{c}	4267^{c}	2522^{b}
150kgDAP + 100 kg KCL + 72 kg N kg ha^{-1}	38^{b}	43^{abc}	3811^{b}	8917^{b}	5106^{a}
150 kg NPSB +100 kg KCL + 72 kg N ha^{-1}	37^{b}	42^{abc}	1670^{c}	3967^{c}	2296^{b}
611 kg lime +lime + 150 kg NPSB + 100 KG KCL +72 KG N ha^{-1}	38^{b}	45^{ab}	4414^{ab}	9820^{ab}	5406^{a}
611 kg lime +5 t compost + 150 kg NPSB + 100 KG KCL + 72 kg N ha^{-1}	44^{a}	47^{a}	5386^{a}	11500^{a}	6114^{a}

611 kg lime + 2.5 t compost +75 kg NPSB +50 kg KCL + 36 kg N ha^{-1}	42a	44ab	4800ab	10767ab	5967a
LSD (5%)	2	0.05	1099.7	2467.9	1465.3
CV (%)	2.25	4.43	13.08	12.66	13.21

Source: (Woubsh et al., 2017)
Means within a column followed by the same letter are not significantly different at 5% probability level

Table 6: Response of teff to application of different fertilizers.

Treatments	Grain yield (kg/ha)	Biomass (t/ha)	Straw yield (t/ha)	No. of tillers
64kgN+30kg p/ha (recommended amount of NP)	**1187.0bc**	**4.39b**	**3.27b**	**6.83ab**
28kgN+18kgP+25kgK+13kgS+2.4kgZn+1kgB/ha	1081.3c	4.32b	3.20b	6.70ab
46kgN+20kgP+16kgS+2.6kgZn/ha	1243.3bc	5.01ab	3.83ab	6.17b
64kgN+18kgP+25kgK+13kgS+2.4kgZn+1kgB/ha	1365.4ab	5.83a	4.50a	7.17a
28kgN+30kgP+25kgK+13kgS+2.4kgZn+1kgB/ha	1207.4ab	4.69ab	3.52ab	7.30a
64kgN+30kgP+25kgK+13kgS+2.4kgZn+1kgB/ha	1502.5a	5.46ab	4.13ab	6.83ab
64kgN+20kgP+16kgS+2.6kgZn/ha	1280.8abc	4.69ab	3.43b	6.03ab
CV (%)	15.46	19.82	24.25	10.26
LSD 5%	232.44	1.15	1.06	0.82

Source: [29]
Means within a column followed by the same letter are not significantly different at 5% probability level.
Zn Application Methods

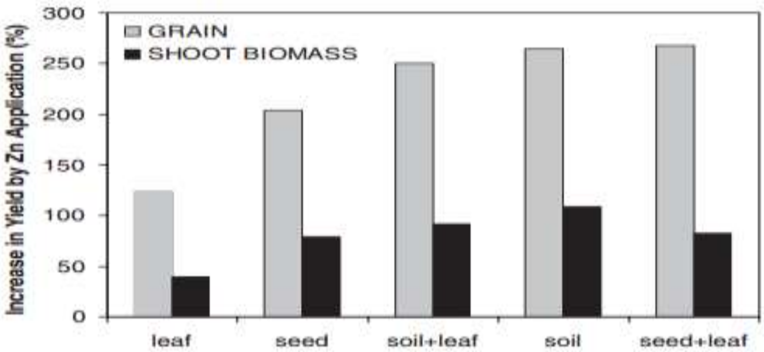

Fig. 2: Increases in grain and whole shoot biomass production by different Zn application methods.
Source: [19]

Table 7: Evaluating teff production involves examining partial budgets, marginal rates of return, and conducting dominance analysis on fertilizers.

Treatment	Straw yield	Av. yield	Adj. yield	TCTV (ETB/ha)	Revenues (ETB/ha)	NB (ETB/ha)	MRR (%)
46kgN+20kgP+16kgS+2.6kgZn/ha	3.83	1243	1119.1	3082.82	21674.3	18591.5	
64kgN+30kgp/ha(recommended)	3.27	1187	1068.2	3174.26	20533.8	17359.6	D
28kgN+18kgP+25kgK+13kgS+2.4kg Zn+1kgB/ha	3.22	1081	973.17	3381.82	18803.8	15422	D
64kgN+20kgP+16kgS+2.6kgZn/ha	3.42	1281	1152.8	3538.29	22116.6	18578.4	D
64kgN+18kgP+25kgK+13kgS+2.4kg Zn+1kgB/ha	4.52	1365	1228.9	4166.6	23926.2	19759.6	
28kgN+30kgP+25kgK+13kgS+2.4kg Zn+1kgB/ha	3.52	1207	1086.7	4251.65	20969.3	16717.6	D
64kgN+30kgP+25kgK+13kgS+2.4kg Zn+1kgB/ha	4.14	1503	1352.3	5036.43	25995.2	20958.7	

Source: [29]

Yield adjustment=10%, Field price of teff = 18/kg, MRR= marginal rate of return, MARR=100%, BF= blended fertilizer, Av.yield= average yield, Adj.yield=adjusted yield, TCTV= total cost that vary, NB=net benefit, D= dominated treatments, ETB=Ethiopian Birr

Table 8: The effect of balanced fertilization on grain yield (kg /ha) and thousand kernel weight index.

	Grain yield (kg ha-1)				Weight of a thousand seeds(g)			
Region	control	Balanced fertilization	Change (%)	C.V. (%)	Control	Balanced fertilization	Change (%)***	C.V. (%)
Fars	3904	4476	14.5**	17.29	37.73	36.75	-2.6ns	61.12
Hamadan	5496	6418	16.8**	7.63	36.07	37.21	+3.2**	2.38
Illam	4428	4565	3.1	6.50%	36.36	36.86	+1.4**	1.41
Esfahan	5843	6287	7.6**	11.50	40.97	42.26	+3.2**	7.05
Khuzestan	2546	2555	0.4	9.52ns	34.91	34.71	0.6ns	4.30
Tehran	4480	4835	7.9**	10.19	47.33	47.22	-0.2**	1.63
Zabol	2800	2877	2.8	22.69ns	37.87	37.73	-0.4ns	10.22
Semnan	4705	4448	-5.5	12.99ns	43.87	41.88	-4.5*	6.69
Yard	3698	4500	21.7**	13.52	40.61	40.97	0.9	5.16
Veramin	5200	5925	14.0**	3.73	40.87	39.87	-2.5ns	4.74
Kordestan	5023	5387	7.3**	9.81	33.31	33.99	2.0ns	5.43
Average	4353	4640	6.6**	10.77	38.49	38.94	1.2**	5.51

Source: [20]

**Significant differences at the 5% level. **Significant differences at the 1% level. ***The main cause of the decrease in the thousand kernel weight index in the field studies was the existence of some growth-limiting factors in some of the provinces, such as soil salinity.*
ns: no significant differences between treatments.

Table 9: Amount of micronutrients removed by major intensified production systems in India.

Cropping system	Total grain yield (t ha-1)	Nutrients removal (g ha-1)					
		Zn	Fe	Mn	Cu	B	Mo
Rice-rice	8.0	320	1224	2200	144	120	16
Rice-wheat	8.0	384	3108	2980	168	125	16
Maize-wheat	8.0	744	7296	1560	616	-	-
Soyabean-wheat	6.5	416	3364	488	710	-	-
Pigeonpea-wheat	6.0	287	4356	493	148	-	-

Source: Takkar, 1996 cited by Reg et al. (2005)

Table 10: Shoot dry weight, grain yield, number of panicles, grain harvest index (GHI), (across two Zn levels) and Zn harvest index (ZnHI) of 10 upland rice genotypes.

Genotype	Shoot dry wet. (g pot-1)	Grain yield (g pot-1)	Number of panicles pot-1	GHI	ZnHI	
					Zn_0	Zn_{10}
Bonanca	64.25ab	52.93c	21.00bc	0.45ab	0.60abc	0.25ab
Caipo	89.52de	55.60bc	19.17c	0.38e	0.62ab	0.25ab
Canastra	79.02c	60.47abc	24.00abc	0.43ab	0.64ab	0.35a
Carajas	62.07ab	60.67abc	24.50ab	0.50cd	0.76a	0.32ab
Charisma	70.38a	61.78abcd	26.17ab	0.47ab	0.60abc	0.31ab
CNA8540	66.85ab	68.78d	25.83ab	0.53cd	0.68a	0.37a
CNA8557	79.83c	71.33d	26.83a	0.47ab	0.46bc	0.30ab
Guarani	58.43b	64.92abcd	25.67ab	0.53cd	0.70a	0.22b
Maravilha	83.98ce	60.45abc	27.33a	0.42ab	0.57abc	0.26ab
IR42	96.26d	68.15d	35.83d	0.41ab	0.40c	0.21b
Average F test	75.06	62.51	25.63	0.46	0.60	0.28
Zn level	**	*	NS	NS	**	
Genotype	**	**	**	**	**	
Zn X G	NS	NS	NS	NS	**	
CV (%)	9	12	15	8	12	

Source: [19]

*,**, NS Significant at the 5%, 1% probability levels and non-significant, respectively Means in the same column followed by the same letter are not statistically different at the 5% probability level by the Tukey's test. Several application methods are used for the correction of micronutrient deficiency. The most frequent method is the broadcast application of micronutrient onto soil. Irrespective of the methods used, application of Zn very significantly enhanced grain yield and shoot biomass. The highest increases in grain yield were found with soil, soil + leaf or seed + leaf application methods (Fig 2).

2.2.5 Efficiency of micronutrient

"Crop species have shown varying responses to micronutrient availability. A crop such as cassava, which is native to infertile soils, can grow on soil surprisingly low in available micronutrients, whereas crops such as field beans and sorghum seem to require much higher amounts of available micronutrients. Intensive and multiple cropping, cultivations of crop varieties with heavy nutrient requirement and unbalanced use of chemical fertilizers especially nitrogen and phosphorus fertilizers reduced quality of grain production and the appearance of micronutrient deficiency in crops".[35-39] A rice genotypes differed significantly in relation to shoot dry weight, grain yield, panicle number, grain harvest index and Zn harvest index, when tested under two Zn levels (0 and 10 gm Zn per kg soil).

3. CONCLUSIONS AND RECOMMENDATION

3.1 Conclusions

Worldwide deficiency of micronutrient becomes the constraint for crop production. Micronutrient deficiencies are a problem not only in agricultural production, but also in human nutrition. Soil micronutrient deficiencies limit crop productivity and nutrient quality, which can have an overall negative impact on human health. Many African soils are affected by several nutrient deficiencies, including macronutrients N, P, K, secondary nutrients S, Ca and Mg, and trace elements Zn, Fe, Cu, Mn and B. The occurrence of micronutrient deficiencies in crops increased. In recent years, due to intensive farming, there has been a loss of topsoil through erosion and loss of microelements through leaching. Problems related to micronutrient deficiencies are also exacerbated by the high demand for modern agricultural varieties. A combination of micro and macronutrient fertilizers is important to increase plant grain intake and nutrient use efficiency. In general, a deficiency of microelements leads to significant yield losses and is therefore of great importance for both crop production and human nutrition. Therefore, attention must be paid to microelements in plant production.

3.2 Recommendation

Based on the comprehensive review of studies conducted on micronutrient limitations in crop production and strategies for improvement, we recommend the following key actions:

- Further Research Initiatives: Encourage and support additional research initiatives to deepen our understanding of specific micronutrient deficiencies in various crops and regions. This can help identify tailored solutions for different agricultural contexts.
- Implementation of Innovative Strategies: Advocate for the implementation of innovative strategies identified in the reviewed studies. This may include the use of precision agriculture, agronomic practices, and biofortification to address micronutrient limitations and enhance crop yields.
- Collaboration and Knowledge Sharing: Promote collaboration among researchers, agronomists, policymakers, and farmers to facilitate the exchange of knowledge and experiences related to micronutrient management. This collaborative effort can lead to more effective and practical solutions for improving crop production.
- Educational Outreach: Develop educational programs to raise awareness among farmers about micronutrient deficiencies, their impact on crop health, and the benefits of adopting recommended strategies. Empowering farmers with this knowledge can contribute to the successful implementation of micronutrient improvement measures at the grassroots level.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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