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Review Paper

Critical Role of Micronutrient in Crop Production: A Review

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***Abstract*— In developing countries, crop production and productivity face significant problems, among which soil nutrient availability is crucial. While primary plant nutrients nitrogen (N), phosphorus (P), and potassium (K) have been given considerable attention, in the other case; deficiency of micronutrients and secondary nutrients is becoming more widely acknowledged as a major limiting factor for obtaining optimal crop yields and nutritional quality. This review highlights information on the importance of micronutrients (B, Cl, Cu, Fe, Mn, Mo, Ni, Zn) in agriculture crop production, focusing on the growing prevalence of deficiencies due to continuous cropping, soil erosion, nutrient leaching, and unbalanced nutrient application in the cropping system. Particularly focus is given to the situation in Ethiopia and Sub-Saharan Africa, where multi-nutrient deficiencies are widespread in soil degraded, its impacts not only reduction of crop yields but also contributing to human malnutrition through poor crop dietary quality. Based on the evidence provided, addressing micronutrient limitations, crop yields can be greatly increased, nutrient use efficiency can be improved, and human health problems associated with micronutrient deficiency may be mitigated by using balanced nutrient management systems that combine macro- and micronutrients. The review provided the need for increasing research, targeted soil fertility improvements, and policy focus on micronutrients to ensure sustainable crop productivity and food security.**

Keywords*— Macronutrient, micronutrients, nutrient deficiency, nutrient leaching, secondary nutrient

I. Introduction

A key component of food security is achieving balanced agricultural productivity, especially in emerging nations where agriculture serves as the foundation of many economies. However, numerous difficulties hinder advancement, with the unavailability of necessary crop nutrients in appropriate amounts and forms being a critical challenge [1]. For optimum growth, development, and yield enhancements, plants need a particular ratio of macro and micronutrients at critical times [2].

Historically, the drive for improved agricultural production led to increased use of essential macronutrients like nitrogen (N), phosphorus (P), and potassium (K); although initially effective, this strategy often neglects other important crucial secondary and micronutrients and has resulted in unbalanced nutrient application. This imbalance has accelerated the soil fertility decline, leading to emergent deficiencies not only of primary nutrients but increasingly of secondary nutrients like sulfur (S), calcium (Ca), magnesium (Mg) and micronutrients boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn) [3;4;5]. Replenishment of these trace essential plant nutrients is crucial under intensive agricultural systems to prevent yield decline.

The consequence deficiency of essential micronutrients is a dual problem, impacting both crop production and human nutrition. The deficiency of soil essential plant nutrients leads to reduced crop productivity and low nutritional quality of the harvested product, which can therefore have a detrimental impact on human health, especially in populations that depend on staple crops [6]. This issue is particularly very serious in Sub-Saharan Africa (SSA), where numerous nutritional deficiencies (primary, secondary, and tertiary) impact sizable tracks of arable land [7; 8]. The dependence on food crops like maize, sorghum, and cassava, which are mostly inherently low in micronutrients, exacerbates the prevalence of micronutrient malnutrition (hidden hunger), especially among vulnerable groups commonly women and children [9].

Ethiopia also critically faced these challenges. The country suffers from high rates of soil degradation due to rain [10; 11]. Decades of below-optimal and unbalanced fertilizers focused primarily on only N and P have led to significant nutrient mining, contributing to declining fertilizer productivity [12; 13]. Different scholars and national soil inventories confirm that besides N and P, deficiencies of other essential nutrients like sulfur (S), boron (B), and zinc (Zn) are widespread across agro-ecology, with potassium (K), copper (Cu), manganese (Mn), and iron (Fe) their deficiencies also emerging in specific areas [12; 13; 14;15;16]. These deficiencies hinder observed crop productivity despite the continued use of N and P fertilizers based on blanket recommendations along wider agroecology.

The problem of essential micronutrient deficiencies in crop production is rising globally due to factors like modern intensive cropping systems, loss of nutrient-rich surface soil via erosion, nutrient leach, and the high nutrient demands of modern crop varieties. Even though, the rate of application for micronutrients is typically low (0.2 to 100 kg ha^{-1}) their absences are crucial in crop production system [4]. Integrating nutrient management of macronutrients with micronutrients, ensures more uniform application and promotes balanced plant nutrition, which is essential for sustainable high crop yields [17]. Deficiency of any essential crop nutrient, including micronutrients often involved in crop enzymatic systems, can lead to abnormal crop growth and consequently complete total crop failure. In Ethiopia, where systematic micronutrient application is rare and information on soil fertility status is limited, understanding these dynamics is very important. The objectives of this review were to consolidate existing nutrient management practices on the importance of micronutrients, identify information gaps, and highlight the impact of deficiencies, thereby informing future research and agronomic practices for optimizing sustainable crop production.

II. Role of Micronutrients in Crop Production and Deficiencies Worldwide

The necessity of addressing global hunger and malnutrition requires sustainable agricultural productivity, heavily dependent on maintaining soil fertility and balancing plant nutrition [18;19], while the contribution of synthetic fertilizers containing primary nutrients like N, P, and K to the modern food supply is unquestionable, future grain productivity will increasingly dependent on more balanced nutrient application.

The importance of micronutrients, though required even in trace amounts, is essential for the healthy crop growth and reproduction of plants. The recognition of essential micronutrients include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn) [20]. An element is essential if the plant cannot complete its life cycle without it, its action is specific and irreplaceable by others, and it is directly involved in the plant metabolism process. Despite their essentiality, the use of essential micronutrient nutrients lags significantly behind macronutrients (NPK), particularly in developing countries, often being very limited or nonexistent [21].

Different scholars consistently demonstrate the positive results of including micronutrients in fertilization programs. The application of different micronutrients showed that Zn, Cu, Fe, Mn, and B combined within macronutrients significantly increased the dry biomass, grain yield, and other yield components for example it improved grain yields per ear, thousand-grain weight of wheat compared to the control plots [21] (Tables 1). Blending (NPSB) secondary and micronutrients with primary nutrients N and P increased maize grain yield and biomass [23] and fresh turmeric rhizome [24]. This highlights that addressing the deficiency of micronutrients can unlock yield potential often constrained even when only macronutrients are supplied.

TABLE I. Effects of Micronutrients on Wheat Dry Biomass, Grain Yield, 1000 Grain Weight, Tiller Numbers, and Plant Height

Treatments			*Micronutrient kg/ha*	**Dry Matter kg/ha**	**Grain Yield kg/ha**	**1000 grains weight (g)**	**tiller numbers per m2 (g)**	**plant heights (cm)**
N	***P2O5***	***K2O***						
0	0	0	-	8458c	2292d	35.9cd	102	35.6d
100	75	50	-	13125c	3542d	36.6c	128	44.7abc
100	75	50	Zn, Mn, Fe, Cu, B	14167a	3958a	48.1a	115	44.5abc
100	75	50	Zn, Mn, Fe, Cu, (-B)	11192c	2750d	36.6c	117	44.7abc
100	75	50	Zn, Mn, Fe, B, (-Cu)	13958b	3750ab	39.3b	117	46.5a
100	75	50	Zn, Mn, Cu, B, (-Fe)	13167b	3750ab	39.8b	115	42.9c
100	75	50	Zn, Fe, Cu, B, (-Mn)	12208ab	3750ab	40.4b	111	43.6bc
100	75	50	Fe, Cu,B, (-Zn)	13750a	3583abc	42.7b	117	46.25a
100	75	60	Zarzameen	13125a	3958a	43.3ab	117	45.5ab

Means followed by similar letter (a) do not differ significantly from each other at 5%level of significance. Source: [22].

A. *Uses of Micronutrients in Tropical Agriculture*

Tropical agricultural systems are very diverse, in both climates and soil resources. The most stable food crops like maize, sorghum, rice, millet, cassava, pulses and groundnuts and important commercial crops such as coffee, tea, cotton, sugarcane, cocoa, oil palm, bananas are grown in wider agro-ecology of tropic. Many of these crops, particularly high potential yielding improved varieties, show micronutrient deficiencies and respond positively to their application.

Application of micronutrient (molybdenum) showed significant increases in the seed and straw yield of cluster beans as the rate increased (Fig 1).

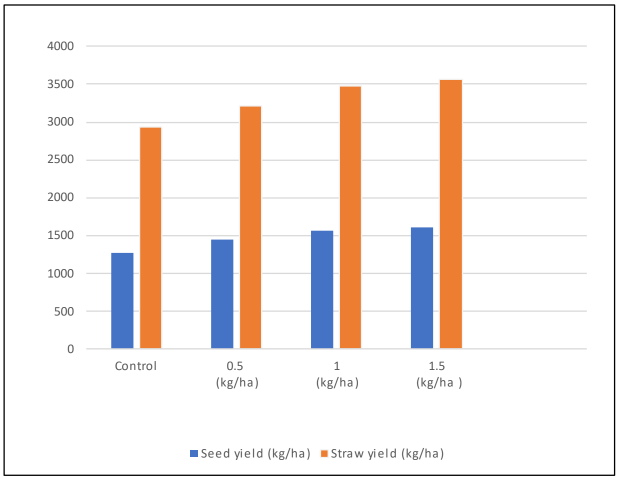

Fig. 1. Effect of molybdenum application on seed and straw yield of cluster bean

Different application techniques can be used to address micronutrient deficiencies. For even dispersion, soil application often broadcast, occasionally banded is widely combined with NPK fertilizers [4]. Although seed treatments can give the budding seedling nutrients, foliar sprays provide quick correction, especially during crucial growth stages [20]. These include stimulating overall growth and yield improvements, enhancing the nutritional quality of the product, increasing plant resistance, reducing abiotic stresses including drought, and increasing tolerance to pests and disease [25]. Different studies have shown significant yield improvements in potatoes and sugar beet with application of micronutrient (Tables III).

TABLE II. EFFECTS OF APPLICATION OF MICRONUTRIENTS ON YIELD IMPROVEMENT OF POTATO AND SUGAR BEET (KG/HA)

Location of Potato Field	Treatments		Yield Increments (%)	Location of Sugar beet Field	Treatments		Yield Increments (%)
	NPK	*NPK+ Micronutrients*			NPK	NPK+ Micronutrients	
Semnan	29,000	32000	10	Fars	6497	6561	1
Hamadan	41,500	465000	12	Khorasan	4230	4545	7
Kerman	13900	17500	26	Arak	9858	10635	8
Karaj	16900	22100	31	Karaj	6450	7500	16
Ardabil	35500	36700	3				
Mean	27.36	30960	16	mean	6759	7310	8

Source: [25]

Likewise, micronutrients play specific vital roles in crop stress tolerance. For example, zinc is essential for maintaining the integrity of biological membranes and activating enzymes involved in plant responses to water stress [27]. At optimum rates, copper has also been demonstrated to have a positive impact on wheat grain yield attributes (Table III). Understanding the micronutrient uptake and concentration in plant tissues throughout the growth cycle is also important for balancing nutrient application strategies.

TABLE III. EFFECT OF GRADED LEVELS OF COPPER APPLICATION ON WHEAT EAR LENGTH, NUMBER EAR PER PLANT, NUMBER OF GRAIN PER EAR, GRAIN YIELD G/PLOT, STRAW YIELD G/PLOT, 1000 GRAINS WEIGHT AND HARVEST INDEX (%)

Cu applied mg/kg	Length of main ear cm	No. of ears per plant	No. of grains per ear	Grain yield g/plot	Straw yield g/plot	1000 grains wt.g	Harvest index (%)
0	6.6	2.1	12.7	3.88	6.92	32.58	35.92
0.5	7.7	1.9	16.7	4.48	6.64	35.02	40.29
1	8.5	2.3	12.9	4.46	6.68	38.62*	40.99*
1.5	9.5	1.9	20*	6.32*	6.92	41.35*	47.73*
2	7.8	1.7	18.5*	4.44	6.44	35.85*	40.81
2.5	7.1	1.6	17.3	3.8	5.84	33.93	39.42
SE (d) ±	0.9	-	2.6	0.98	-	1.54	2.39
CD (p=0.05)	1.9	Ns	5.5	2.06	Ns	3.24	5.03

Source: [26]

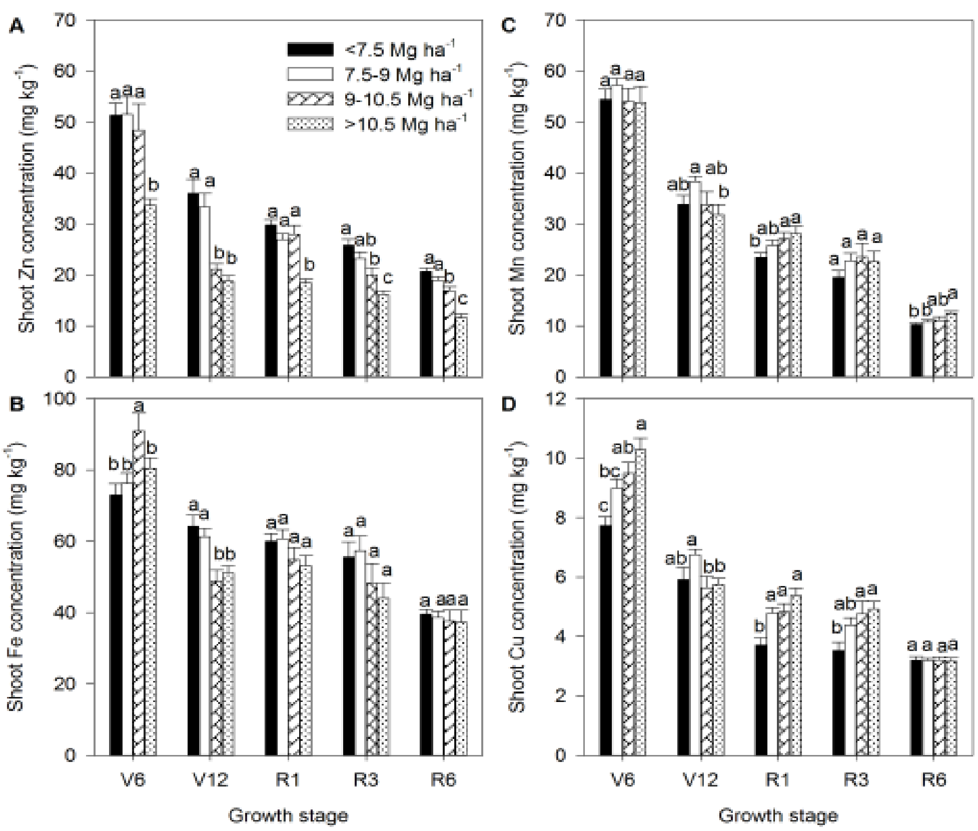

Fig. 2. Dynamics of shoot Zn concentratio

(A) shoot Fe concentration (B), shoot Mn concentration (C) and shoot Cu concentration (D) of summer maize at V6 (six-leaf stage), V12 (12-leaf stage), R1 (silk emerging), R3 (milk stage) and R6 (physiological maturity) stages, respectively, with different grain yield ranges. The number of observations was shown in Table S2.The bars represent the standard error of the mean. Bars with different lowercase letters are significantly different at different yield ranges (P= 0.05) [28].

In Sub-Saharan Africa, the applications of secondary and micronutrients has demonstrated significant positive effects on cereal grain yields (Table IV). However, their adoption is often ignored, partly due to the focus on the primary nutrient content of fertilizers in subsidy programs and a misconception that addressing NPK deficiencies must precede attention to other nutrients. On the other hand, existing secondary and micronutrient deficiencies can limit the crop's response to applied NPK fertilizers. Overcoming these deficiencies can provide farmers with significant returns on their investment, even though they only require small amounts of fertilizer [21]. The prevalence of multiple deficiencies, rather than single nutrient issues, is common in SSA soils, often increased by soil acidification and affecting nutrient availability.

TABLE IV. CEREAL YIELD RESPONSE IN VARIOUS AFRICAN COUNTRIES DUE TO SECONDARY AND MICRONUTRIENT ADDITIONS.

Crop	Country	Number of Sites	Yield with NPK only kg/ha	Yield with NPK secondary nutrient kg/ha	Yield increase (%)	Applied nutrients
Maize	Ethiopia	9	5600	6720	11.2	S, Zn, B
wheat	Ethiopia	43	3990	5280	12.9	S, Zn, B, Cu
maize	Burundi	44	3110	5270	21.6	S, Zn, B
Rice	Burundi	168	4890	6890	20	S, Zn, B
maize	Mozambique	17	2990	4180	11.9	S, Zn, B
wheat	Rwanda	40	4140	5640	15	S, Zn, B
Rice	Rwanda	20	4320	5890	15.7	S, Zn, B

Source: [21]

B. Importance of micronutrient for crop production in Ethiopia

Early global studies revealed that the coarse-textured, acidic soils found in some regions of Ethiopia most likely have deficiencies in Cu, Zn, and Mo [29]. The more recent and targeted study, by the Ethiopian Soil Information System (EthioSIS) surveys and other studies, has provided tangible evidence of widespread deficiencies of sulfur (S), boron (B), and zinc (Zn), along with localized deficiencies of potassium (K), copper (Cu), manganese (Mn), and iron (Fe) across different agro-ecology [14; 15; 16; 30]. This suggests that depending only on N and P fertilization is insufficient for agricultural production.

Furthermore, the soil fertility status of Ethiopia is limited due to supporting findings. Some greenhouse studies showed significant maize grain yield reductions on nitisols from Western Ethiopia when micronutrients like Fe, Cu, Zn, B, and Mo were applied [31]. Field studies evaluating the response of major crops like teff and barley to blended fertilizers containing N, P, K, S, and micronutrients Zn and B have demonstrated significant improvements in yield components, overall grain and straw yield, nutrient uptake, and nutrient use efficiencies compared to previously recommended N and P fertilizer applications or control plots [32; 33].

According to a study by Woubsh et al. [34], barley yields were significantly increased when lime was combined with micronutrient content blended fertilizer and compost (Table V). Significant reports on teff yield increases with blended fertilizers containing micronutrient; which also proved economically viable based on partial budget analysis [32](Table VI). Balanced nutrient application of micronutrients enhanced total nutrient uptake and improved agronomic use efficiency (AE), apparent recovery efficiency (ARE), and physiological nutrient efficiency (PNE) for teff compared to treatments omission of certain nutrients [33]. These studies collectively emphasize the necessity and importance of combining secondary and micronutrients into fertilizer recommendations in Ethiopia.

TABLE V. EFFECTS OF LIME, BLENDED FERTILIZER AND COMPOST ON THOUSAND SEED WEIGHT, HARVEST INDEX, GRAIN YIELD, STRAW YIELD, BIOLOGICAL YIELD AND STRAW YIELD OF BARLEY IN WOLMERA DISTRICT WEST SHOWA, ETHIOPIA

Treatments	100 seed weight gm	Grain Yield kg/ha	Biomass yield kg/ha	Straw Yield kg/ha	Harvest Index (5%)
Control	10c	1318c	3433c	2116 b	38c
5 t compost/ha	37b	1617c	4173c	2556 b	39c
611 kg lime/ha	36b	1683c	4483c	2801 b	37c
611 kg/ha lime + 5 t compost /ha	37b	1745c	4267c	2522 b	40bc
150 kg DAP + 100 kg KCl+ 72 kg N/ha	38b	3811b	8917	5106 a	43abc
150 kg NPSB +100 kg KCl + kg N/ha	37b	1670c	3967c	2296 b	42abc
611 kg lime + 150 kg NPSB+ 100kg KCl+72kg N/ha	38a	4414ab	9820ab	5406 a	45ab
611 kg lime + 5t compost + 150kg NPSB+100 kg KCl/ha +72kg N/ha	44a	5386a	11500a	6114 a	47a
611 kg lime + 2.5t compost + 75kg NPSB+50 kg KCl/ha +36kg N/ha	42a	4800ab	10767ab	5967	44ab
LSD (5%)	5	1099.7	2467.9	1465.3	0.05
CV (%)	2.25	13.08	12.66	13.21	4.43

Source: - [34]

TABLE VI. EFFECTS OF MACRONUTRIENT WITH SECONDARY AND MICRONUTRIENT ON TEFF GRAIN YIELD, BIOMASS, STRAW YIELD AND NUMBER OF TILLERS

Treatments (kg/ha)	Grain Yield kg/ha	Biomass t/ha	Straw Yield t/ha	No. of tillers
64N +30P	1187bc	4.39b	3.27b	6.83ab
28N + 18P+25K+13 S+2.4Zn+ B	1081.3c	4.32b	3.2b	6.70ab
46N + 20P+16K+2.6S	1243.3bc	5.01ab	3.83ab	6.17b
64N + 18P+25K+13S+2.4Zn+1B	1365.4ab	5.83a	4.50a	7.17a
28N + 30P+25K+13S+2.4Zn+B	1207.4bc	4.6b	3.52ab	7.30a
64N + 30P+25K+13S+2.4Zn+1B	1502.5a	5.46ab	4.13ab	6.83ab
64N+ 20P+13S+2.6Zn	1280.8abc	4.69ab	3.43b	6.03b
LSD (5%)	232.44	1.15	1.06	0.82
CV (%)	15.46	19.82	24.25	10.26

Source: [32]

C. Impact of micronutrient deficiency in crop production

Deficiencies of micronutrients directly lead to lower agricultural yields and poorer quality [35; 36; 26]. Increased yield from agriculture eventually places greater demands on soil nutrient stocks, and traditional NPK focused fertilization has generally failed to replace the micronutrients that harvested crops removed (Table VII). This depletion, which mainly shows up as yield loss, might cause deficiency symptoms or hidden hunger in plants. Crop species' sensitivity and effectiveness in absorbing and utilizing micronutrients vary, as do genotypes within species, which may indicate the possibility of breeding more micronutrient-efficient cultivars [20].

TABLE VII. AMOUNT OF MICRONUTRIENTS REMOVED BY MAJOR INTENSIFIED PRODUCTION SYSTEMS

Cropping System	Grain Yield kg/ha	Nutrients removed with harvest g/ha				
		Zn	***Fe***	***Cu***	***B***	***Mo***
Rice-Rice	8000	320	1224	144	120	16
Rice-Wheat	8000	384	2108	168	252	16
Maize-wheat	8000	744	7296	616	-	-
Soybean-wheat	6500	416	3362	710	-	-
Pigeon pea-wheat	6000	287	4356	148	-	-

Source: [20]

Deficiency of boron in rice can result in floret sterility, which significantly lowers grain yield and is sometimes confused with the effects of environmental stress [37]. Additionally, a sufficient supply of micronutrients improves the efficiency with which crops use macronutrients, improving overall crop fertilizer use efficiency and possibly increasing farmers' profits [38; 25].

III. SUMMARY AND CONCLUSIONS

Global crop production is severely and continuously negatively impacted by deficiencies of both macro and micronutrients, which have an especially negative impact on food security and sustainable crop production in underdeveloped countries. Essential micronutrients such as Zn, B, Cu, Fe, and Mn have been depleted in many agricultural lands due to different factors like modern extensive cropping systems, soil erosion, unbalanced fertilization that mainly depends on NPK, and the use of high nutrient-demanding crop varieties.

The advantages of meeting essential micronutrient requirements through balanced fertilization approaches are supported by evidence. When macronutrients and necessary micronutrients are applied together, crop yields, yield components, nutrient uptake, and overall crop nutrient usage efficiency are all continuously improved. In Ethiopia across a range of crops (maize, teff, wheat, barley, potato, and sugar beet) and geographical areas, positive reactions have been reported. Ignoring essential micronutrient limitations will make it more difficult to meet the goals of food security and sustainable development.

Therefore, in feature micronutrients in crop production will be considered into soil fertility and health management strategies is not only advantageous but also necessary to maximize crop yield, enhance food quality, increase farmer profitability, and improve human health

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