



# Spatial Heterogeneity of Soil Micronutrients in Shivalik Foothill Zone of Himachal Pradesh: A Cross-Site Investigation of Soil Fertility

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## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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## ABSTRACT

Agricultural soils are subjected to constant management practices which influences their nutrient status. Further, micronutrients play a crucial role in determining optimal crop growth and yield for majority of the commercial crop roster. Keeping this under consideration, an investigation was

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carried out for micronutrient status of soils of Indora block of district Kangra, Himachal Pradesh. Ninety-nine representative soil samples (0-20cm) were collected from the farms primarily growing cauliflower in 400m<sup>2</sup> area (minimum). The profile samples were analyzed for DTPA micronutrients by method Atomic Absorption Spectrophotometer (AAS) which was found to be sufficient in Cu and Fe. However, for DTPA-extractable Zn and Mn it varies from 1.12 to 4.30 and 2.04 to 7.20 mg kg<sup>-1</sup>. These findings emphasize the importance of soil testing and site-specific nutrient management to address potential deficiencies, optimization of crop productivity in the region and promote policy making protocols for the local farming community.

*Keywords: Micronutrients; spatial variability; soil fertility; nutrient status; sustainability; soil survey.*

## 1. INTRODUCTION

Micronutrients are essential trace elements that plants require in very small amounts, but they play a significant role in increasing crop growth, yield, and quality. When properly applied, micronutrients not only help in boosting agricultural productivity but also improve the nutritional quality of food and feed, which is important for human and animal health. Yield and quality of the crop can decrease if the supply of any one of these elements is inadequate, but crop species and cultivars vary considerably in their susceptibility to deficiencies (Shukla et al., 2019).

Micronutrient deficiency has become a major concern globally. One of the main reasons is intensive farming, continuous cropping, and reduced use of organic amendments by the farming communities. These practices have led to a gradual decline in micronutrient levels in the soil (Sharma and Chaudhary, 2007). In India most of the soils are already low in fertility, especially in terms of micronutrients. Years of continuous cultivation without adequate micronutrient management and the heavy reliance on chemical fertilizers that provide only major nutrients like nitrogen (N), phosphorus (P), and potassium (K) have further deteriorated the soil condition and have depleted the soil micronutrient content and which ultimately adversely affects the crop growth (Sharma et al., 2023).

Thus, large areas of Indian agricultural land now exhibit deficiencies of important micronutrients such as zinc (Zn), iron (Fe), and boron (B). This not only affects crop production but also reduces the nutritional value of the food via depreciated bio-assimilation, thereby impacting the health of people and animals who depend on certain staple crops. Therefore, proper micronutrient management based on the crop type, soil condition, severity of deficiency, source, method,

timing, rate, and frequency of application is essential for sustainable agricultural production and maintaining long-term soil and human health (Rahman et al., 2020). Productivity, stability and sustainability in many Indian soils have been affected by deficiency of micronutrients which may be either by primary (due to their low total contents) or secondary (caused by soil factors reducing their availability to plants) causes. Besides soil characteristics, the availability of micronutrients to plants is also influenced by their distribution within the soil profile (Singh et al. 1989). However, long-term integrated practices which utilize organic amendments with a practically sound outlook can promote effective nutrient management prospects (Singh et al., 2024). Furthermore, deeper understanding of micronutrient dynamics is essential for global agricultural sustainability and local resilience pertaining to the uplifting of farming communities (Garima and Nidhi, 2025). Therefore, it is important to study how agricultural management practices affect the availability of micronutrients and their accumulation in commonly consumed food crops.

Considering the aforementioned status and condition of the micronutrient mediated agricultural fertility domain the present study was conducted to evaluate the micronutrient status (Zinc, Copper, Iron and Manganese) of agricultural sites at block level (Indora, H.P., India) and execute subsequent descriptive statistical analysis.

## 2. MATERIALS AND METHODS

### 2.1 Location and Climatic Condition

The geographical setting of Kangra district lies within the coordinates of 31° 21' to 32° 59' N latitude and 75° 47' to 77° 45'E longitude. This district is positioned on the southern slopes of the Himalayan Mountain range. The altitude in Kangra district varies significantly, ranging from

**Table 1. Critical limit for available micronutrients (Lindsay and Norvell, 1978)**

Availability	Micronutrients (mg kg <sup>-1</sup> )			
	Cu	Fe	Zn	Mn
Low	0.1-0.3	2-4	0.5-1	0.5-1.2
Medium	0.3-0.8	4-6	1-3	1.2-3.5
High	0.8-3	6-10	3-5	3.5-6
Very High	>3	>10	>5	>6

approximately 500 to 5000 meters above sea level. The total geographical area of Kangra district is 5,739 sq km, which is 10.31 per cent of the total area of the state. The average annual rainfall of district is 1751 mm.

## 2.2 Study Area

Ninety-nine representative soil samples were collected at a depth of 0-20 cm from ninety-nine locations of Indora block of the farmers who were growing megha variety of cauliflower in more than 400m<sup>2</sup> land. Soil samples thus collected during August - October (2022) before transplantation of the crop, were air dried and passed through 2 mm sieve and stored in small muslin cloth bags for further analysis.

## 2.3 Sample Analysis

Micronutrient concentrations in soil were determined by combining 10 g of air-dried soil with 20 ml of an extractant solution composed of 0.005M DTPA (Diethylenetriaminepentaacetic acid), 0.1M triethanolamine, and 0.01M calcium chloride, buffered at pH 7.3. The mixture was shaken for two hours to facilitate the extraction of plant-available zinc, iron, manganese, and copper. Following filtration, the concentrations of these micronutrients in the filtrate were quantified using atomic absorption spectrophotometry (novAA-350, Analytik Jena), allowing for an accurate assessment of their availability in the soil. (Lindsay and Norvell, 1978).

## 3. RESULTS AND DISCUSSION

Table 2. exhibits the assessed DTPA-extractable Copper, Iron, Zinc and Manganese levels of soil samples collected from the selected sites. The highest Copper content was detected at S10 (3.11 mg kg<sup>-1</sup>) and lowest Copper content was expressed by S3 (0.85 mg kg<sup>-1</sup>). Copper serves as a crucial component in processes such as hormone signalling, electron transport, Mitochondrial respiration and forms structural element in regulatory proteins (Rahman et al., 2020). Copper acts as driving factor for crop

growth by directly influencing tillering and pollen viability of crops (Das, 2014). Primary anthropogenic sources of Copper addition to agricultural soils includes: Copper-rich fungicide, treated sewage sludge and liquid pig feed manure application (Panagos et al., 2018). Also, Copper concentration of agricultural soils positively correlates with degree of precipitation within the region and the age of the farming site, while it is inversely proportional to the increase in soil organic matter content (Neeman et al., 2024). Further, the highest and lowest Iron content was recorded from sites S76 (38.89 mg kg<sup>-1</sup>) and S18 (20.11 mg kg<sup>-1</sup>), respectively. Within plant physiology, Iron plays a crucial role in chlorophyll biosynthesis, photosynthesis, chloroplast development and cellular respiration (Kim and Guerinot, 2007; Gill and Tuteja, 2011). Moreover, inadequate Iron supply can lead to Iron deficiency in plants resulting in interveinal chlorosis in leaves which subsequently compounds to crop yield losses (Lan et al., 2011). Direct Iron addition to agricultural soils can be executed via addition of compound Iron fertilizers (CF) and sulphate iron (FeSO<sub>4</sub>). Iron can readily form exchangeable carbon-bound and Manganese-bound compounds which dictate iron availability within the soil matrix (Liu, 2002). Furthermore, the highest and lowest Zinc levels were exhibited by S76 (4.3 mg kg<sup>-1</sup>) and S18 (1.21 mg kg<sup>-1</sup>), respectively. Zinc influences processes such as stomatal function, cell membrane stabilization, water uptake and seed germination (Hassan et al., 2020). To a restricted degree, enzyme activation, gene expression, signal transduction and plant defence are also regulated by Zinc (Khan, 2022). Zinc sorption is higher in alkaline soil compared to acidic soils (Fan et al., 2018). Application of chelates such as Zn-EDTA and Zn-EDDS can enhance Zinc availability in pre-dominantly deficient soils and have a lower ecological impact due to their biodegradable properties (Belyukova et al., 2023). Zinc is one of the defining nutritional factors determining the yield and quality of cauliflower crop as it enhances metabolism and improves pathogen resistance (Parveen et al., 2022). The combined application of Fe and Zn

can lead to a synergistic effect, where the presence of one micronutrient enhances the uptake and utilization of the other. This is particularly evident in soils that are deficient in both elements, where their co-application mobilizes native nutrients and increases their bioavailability to plants (Choudhary et al., 2015). Lastly, the highest and lowest Manganese concentration was detected at S76 (7.2 mg kg<sup>-1</sup>) and S73 (2.04 mg kg<sup>-1</sup>), respectively. Manganese primarily plays a significant role in oxidation and reduction processes in plants (electron transport during photosynthesis) and is an essential component of Photosystem-II (Mousavi et al.,

2011). Manganese fertilization can improve crop yield by augmenting photosynthetic efficiency of the plant (Mousavi et al., 2007). Improved photosynthetic efficiency positively correlates to the biomass accumulation capacity of the plant which directly influences the overall yield. Commercial sources for addition of Manganese to agricultural platforms include: Manganese sulphate, Manganese oxide and organic amendments (Rashed et al., 2019). Moreover, microbial interactions have proved to increase the availability of innate soil Manganese via causing reduction system pH and organic acid production (Khoshru et al., 2023).

**Table 2. Status of DTPA-extractable Copper, Iron, Zinc and Manganese of selected sites of Indora block, H.P**

Sample No.	Village	DTPA-extractable Cu (mg kg <sup>-1</sup> )	DTPA-extractable Fe (mg kg <sup>-1</sup> )	DTPA-extractable Zn (mg kg <sup>-1</sup> )	DTPA-extractable Mn (mg kg <sup>-1</sup> )
S1.	Sargotran	0.92	23.38	1.30	2.25
S2.	Sargotran	1.10	25.38	1.35	2.32
S3.	Sargotran	0.85	20.32	1.28	2.35
S4.	Pandohar	1.65	32.56	2.55	3.24
S5.	Pandohar	1.38	28.95	1.66	2.91
S6.	Pandohar	1.25	27.75	1.58	2.85
S7.	Badukhar	1.47	29.65	1.78	3.00
S8.	Badukhar	1.00	24.41	1.38	2.30
S9.	Badukhar	1.40	30.12	2.20	3.05
S10.	Samoon	1.98	32.22	2.51	3.11
S11.	Samoon	1.53	31.25	2.19	2.37
S12.	Baleer	0.89	21.12	1.40	2.55
S13.	Baleer	1.34	26.65	1.51	2.62
S14.	Tamladar	1.47	31.22	2.26	2.38
S15.	Madoli	2.00	33.74	2.85	2.74
S16.	Madoli	0.97	24.10	1.32	2.17
S17.	Tajwan	2.11	30.95	2.18	2.32
S18.	Tajwan	0.88	20.11	1.21	2.10
S19.	Tajwan	2.85	35.56	3.55	5.52
S20.	Lehrian	2.45	34.14	3.21	5.35
S21.	Lehrian	2.15	28.68	2.00	2.52
S22.	Sanaur	0.92	22.45	1.51	2.80
S23.	Sanaur	0.90	22.40	1.41	2.23
S24.	Sanaur	1.45	31.12	2.23	2.65
S25.	Paral	0.95	21.44	1.38	2.11
S26.	Kursan	1.11	28.47	2.14	2.34
S27.	Kursan	2.48	33.12	2.61	3.12
S28.	Kursan	2.24	30.25	2.15	3.45
S29.	Chanour	1.65	28.21	1.89	3.64
S30.	Chanour	1.13	27.49	1.77	2.19
S31.	Chanour	1.69	29.00	2.18	2.66
S32.	Ghurohan	1.29	28.88	2.16	2.68
S33.	Ghurohan	1.38	30.20	2.06	2.41
S34.	Dagla	2.39	35.65	3.35	5.45

Sample No.	Village	DTPA-extractable Cu (mg kg <sup>-1</sup> )	DTPA-extractable Fe (mg kg <sup>-1</sup> )	DTPA-extractable Zn (mg kg <sup>-1</sup> )	DTPA-extractable Mn (mg kg <sup>-1</sup> )
S35.	Dagla	0.87	21.12	1.37	2.34
S36.	Dagla	1.24	28.64	2.31	3.64
S37.	Manwal jattan	1.33	30.01	2.44	3.58
S38.	Manwal jattan	2.09	32.44	2.54	3.57
S39.	Surdwan	1.11	25.48	1.40	2.42
S40.	Surdwan	0.98	22.36	1.38	2.34
S41.	Mijhli band	2.58	33.58	2.66	3.55
S42.	Thakurdwara	2.68	33.74	2.71	4.21
S43.	Thakurdwara	1.57	29.98	2.54	3.66
S44.	Mand miami	0.89	21.14	2.12	3.22
S45.	Mand miami	3.01	38.14	3.85	5.65
S46.	Ghoran	2.95	37.89	3.77	3.88
S47.	Ghoran	1.84	30.27	2.45	2.69
S48.	Ghoran	1.39	28.86	2.23	2.44
S49.	Ghoran	0.99	22.23	2.02	2.36
S50.	Bhapu	3.00	38.05	3.87	2.65
S51.	Bhapu	2.27	31.16	2.68	2.37
S52.	Bhapu	2.55	32.23	2.74	2.66
S53.	Bhapu	1.69	29.65	2.39	3.44
S54.	Bhapu	1.84	29.89	2.52	3.65
S55.	Mangwal	0.85	21.54	1.36	2.14
S56.	Mangwal	1.95	30.14	2.66	3.68
S57.	Mangwal	2.00	30.54	2.71	3.00
S58.	Indora	3.05	37.45	4.00	6.32
S59.	Indora	2.33	36.65	3.66	5.52
S60.	Indora	1.54	28.74	2.68	5.12
S61.	Indora	1.00	27.47	2.54	4.11
S62.	Indora	1.29	28.24	2.39	3.54
S63.	Indpur	3.01	37.40	4.11	6.34
S64.	Indpur	2.56	31.47	2.70	3.65
S65.	Indpur	2.74	32.22	2.58	2.11
S66.	Thath	2.91	37.74	4.00	6.11
S67.	Thath	0.88	25.21	1.50	2.34
S68.	Thath	3.00	38.78	4.24	6.54
S69.	Thath	0.89	24.44	1.48	2.44
S70.	Haler	0.92	22.24	1.28	2.30
S71.	Haler	2.02	30.21	2.19	3.57
S72.	Haler	1.68	29.74	2.25	3.61
S73.	Raja khasa	0.99	20.54	1.50	2.04
S74.	Gharoh	1.78	28.85	1.66	2.45
S75.	Gharoh	2.32	31.12	2.68	4.12
S76.	Gharoh	3.11	38.89	4.30	7.20
S77.	Gharoh	1.87	29.16	2.35	2.66
S78.	Gharoh	2.65	32.25	2.45	2.45
S79.	Gharoh	2.85	33.54	2.55	3.56
S80.	Purani gangath	0.95	21.14	1.73	2.24
S81.	Purani gangath	0.88	21.03	1.68	2.31
S82.	Purani gangath	1.86	29.85	2.47	2.45
S83.	Purani gangath	3.00	38.25	4.28	7.15
S84.	Purani gangath	2.05	32.34	2.87	2.74
S85.	Khadoli	2.55	33.87	3.05	5.22

Sample No.	Village	DTPA-extractable Cu (mg kg <sup>-1</sup> )	DTPA-extractable Fe (mg kg <sup>-1</sup> )	DTPA-extractable Zn (mg kg <sup>-1</sup> )	DTPA-extractable Mn (mg kg <sup>-1</sup> )
S86.	Khadoli	1.55	28.89	2.51	2.35
S87.	Khadoli	1.95	30.25	2.65	2.36
S88.	Khadoli	0.94	22.36	1.50	2.10
S89.	Rohan	1.15	24.35	1.80	2.11
S90.	Rohan	1.58	24.33	1.84	2.25
S91.	Rohan	2.70	34.12	3.21	5.32
S92.	Taloti	2.66	33.66	3.10	4.25
S93.	Taloti	2.11	32.21	2.89	3.66
S94.	Indorian	2.65	34.45	4.01	5.85
S95.	Indorian	1.60	28.74	2.74	2.85
S96.	Tappa	1.65	29.02	2.80	2.96
S97.	Tappa	1.45	28.88	2.85	2.88
S98.	Gangwal	2.35	35.87	4.14	6.45
S99.	Gangwal	2.95	36.22	4.21	7.11

\*DTPA: Diethylenetriaminepentaacetic acid.

**Table 3. Descriptive statistical measures of soil micronutrients**

Statistical property	DTPA-extractable Cu	DTPA-extractable Fe	DTPA-extractable Zn	DTPA-extractable Mn
Range	0.85 - 3.11	20.11 - 38.89	1.21 - 4.3	2.04 - 7.2
Mean	1.79	29.52	2.43	3.37
SE±	0.07	0.5	0.08	0.14
C.V.(%)	39.65	16.91	34.26	40.32

\* DTPA: Diethylenetriaminepentaacetic acid; SE±: Standard error; C.V.(%): Coefficient of variation.

### 3.1 DTPA-Extractable Copper

The data presented in Table 3 reveal that the DTPA-extractable copper content ranged from 0.85 to 3.11 mg kg<sup>-1</sup> with mean value of 1.79 mg kg<sup>-1</sup>. The per cent distribution of DTPA-extractable copper content shows that 100 per cent of the soil samples were found to be in high category. Mahajan *et al.* (2007) also reported high levels of DTPA-extractable Cu in the soils of Himachal Pradesh. Comparatively higher copper content may be due to higher organic carbon because Cu forms Cu-humus complex of relatively high stability with humus that decreases its susceptibility to fixation or precipitation in the soil. The results are in the line with those of Thakur and Bhandari (1986), Mahajan (2001) and Sharma and Kanwar (2010).

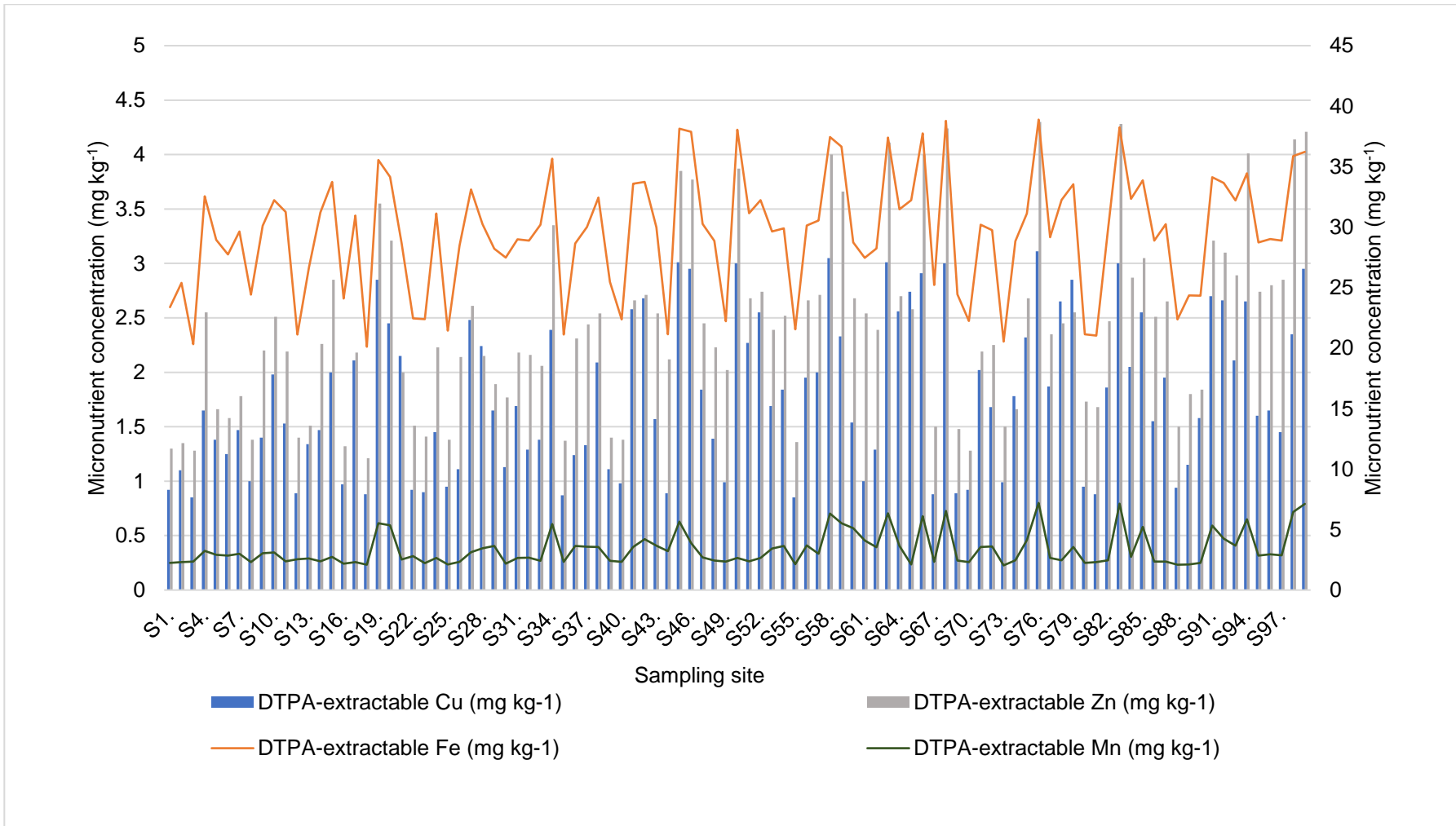
### 3.2 DTPA-Extractable IRON

Table 3 further reveals that the DTPA-extractable Fe content ranged from 20.11 to 38.89 mg kg<sup>-1</sup> with mean value of 29.52 mg kg<sup>-1</sup>. The percentage distribution of DTPA-extractable Fe content shows that 100 per cent of the soil samples were found to be in very high category

which may be attributed to neutral to slightly alkaline soil reaction beside presence of gypsiferous and ferruginous parent materials containing hematite and limonite minerals (Wadia, 1966). Mahajan *et al.* (2007) also found that the soils of North West Himalayas were high in DTPA-extractable Fe content. Chander *et al.* (2014) and Kakar *et al.* (2018) reported that the soils of different zones of Himachal Pradesh were high in DTPA-extractable iron content.

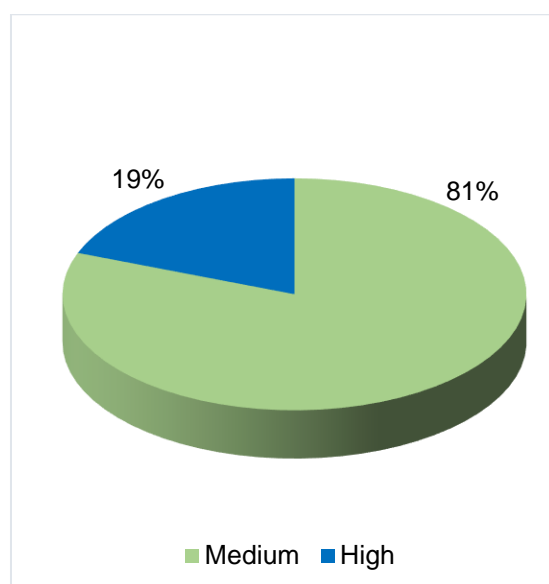
### 3.3 DTPA-Extractable ZINC

The data in Table 3 reveals that the DTPA-extractable Zn ranged from 1.21 to 4.3 mg kg<sup>-1</sup> with mean value of 2.43 mg kg<sup>-1</sup>. The percentage distribution of DTPA-extractable Zn content is illustrated in Fig. 2 which shows that 81.00 per cent of the soil samples were found to be in medium category while 19.00 per cent were found to be in high category. Thakur and Bhandari (1986) reported that DTPA extractable Zn varied from 0.56 to 6.76 ppm in Sapruon valley of Himachal Pradesh, while Mahajan (2001) found high levels of zinc in Mandi district soils.

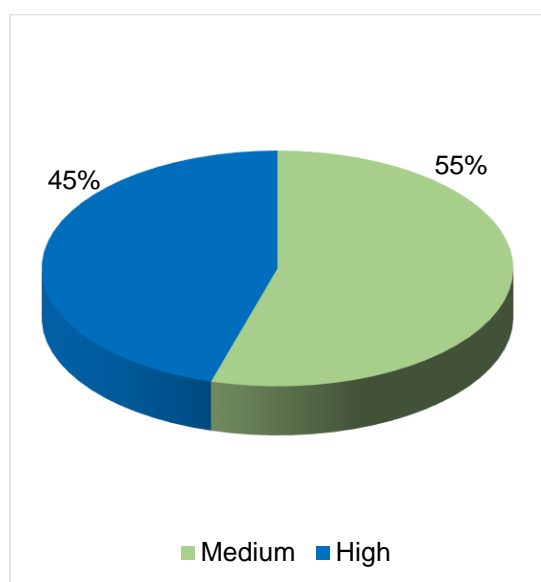


**Fig. 1. Site-wise micronutrient status of Indora block, H.P**

*\*DTPA: Diethylenetriaminepentaacetic acid*



**Fig. 2. DTPA-extractable Zinc percentage distribution**



**Fig. 3. DTPA-extractable Manganese percentage distribution**

### 3.4 DTPA-Extractable Manganese

A perusal of data in Table 3 reveals that the DTPA-extractable Mn content ranged from 2.04 to 7.2 mg kg<sup>-1</sup> with mean value of 3.37 mg kg<sup>-1</sup>. The percentage distribution of DTPA-extractable Mn is illustrated in Fig. 3 which shows that 55.00 per cent of the soil samples were in medium category while, the remaining 45.00 per cent were in high category. Similar values of DTPA extractable Mn were also observed by Behera and Shukla (2013), Dixit (2021) and Kumar *et al.* (2022) in soils of Himachal Pradesh.

### 4. CONCLUSION

India is facing reduced crop yields and lower micronutrient levels in food due to the intensive farming and modern cropping practices with high yielding crop cultivars and unbalanced fertilizer application which ultimately results in widespread deficiency of micronutrients. While, Zn deficiency has declined in soils of the country because of regular and more use of Zn fertilizer whereas deficiency of Fe and Mn increased slightly which can be overcome by spraying of suitable chemicals at recommended levels by foliar

application which reduce the deficiency of these nutrients in the soil. Therefore, the information obtained by this study about micronutrients status would be useful for the farmers in developing nutrient management techniques for better and long-term soil health sustainability.

#### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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