Research article

Evaluation of Soil Micronutrients Across Selected Land Use Types in Chembe Enclave Village, Lake Malawi National Park

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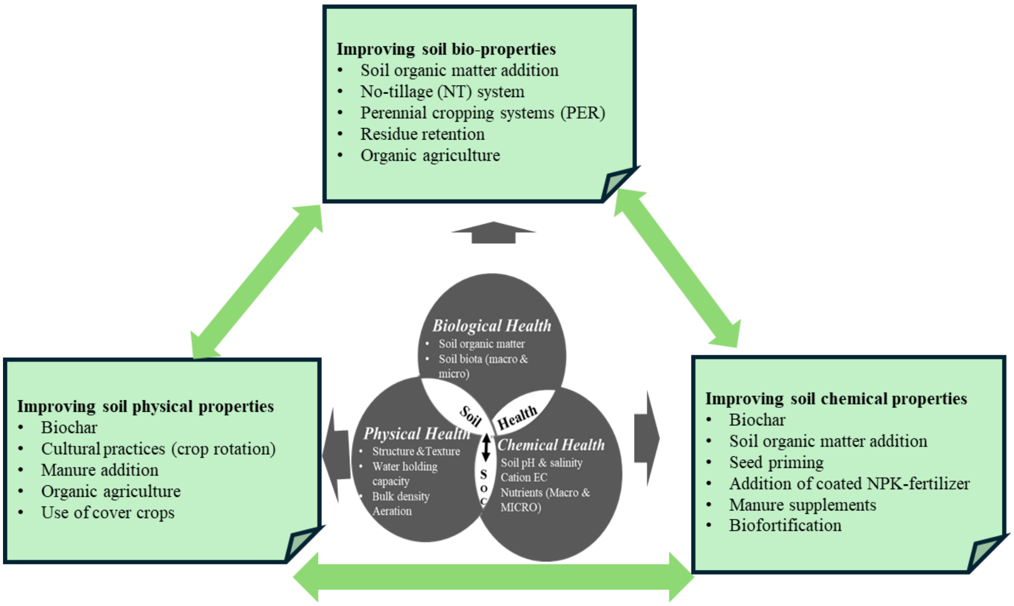
Abstract Knowledge and management of soil micronutrients are vital for maximizing crop production, ecosystem health, functionality, and sustainability. This is especially relevant for the soils of Chembe enclave village, located within Lake Malawi National Park (LMNP), a world heritage site. This study obtained micronutrient baseline data for soils across various land use types and provides benchmark data for long-term monitoring and management. Local soil was measured for the concentration of a panel of micronutrients using Atomic Absorption Spectrometry (AAS) after acid block digestion with a mixture of concentrated nitric acid (70% HNO_3) and Hydrogen peroxide (30% H_2O_2). Measured micronutrients included zinc (Zn), manganese (Mn), copper (Cu), iron (Fe), and selenium (Se). Soil samples were obtained from five different land use types, including community gardens, farmland, Dambo, bare land, and forest land at depths of 0-5 cm and 5 -20 cm. Results indicated that land use type and soil depth are essential factors impacting micronutrient concentrations. Mean soil Zn and Mn concentrations were significantly higher in the community garden (1.51 and 663 mg/kg, respectively) in the topsoil compared to the rest of the land use types (p<0.0001). On the other hand, topsoil from the forest had significantly higher levels of Cu and Fe (3.7 and 329 mg/kg respectively). The maize farmland had the highest concentrations of Se (0.28 mg/kg), while the Dambo and the community garden had the lowest levels (0.01 mg/ kg). These findings suggest that micronutrient levels are tightly linked to land use type and soil depth. Further research should investigate the impacts of micronutrient levels and changes on crop productivity and broader ecosystem-wide implications at multiple scales from the enclave village, across LMNP, and the region as a whole.

Keywords micronutrient, crop production, ecosystem, soil management, land use

INTRODUCTION

Agriculture in protected areas can benefit from healthy soils that ensure good crop productivity on limited land resources. Macro- and micronutrients are crucial components of healthy soils. Micronutrients are essential plant nutrients found in trace amounts within plant tissues that play an indispensable role in plant growth and development. Some micronutrients are considered essential nutrients as without them, plants cannot complete their life cycle (Fageria et al., 2002) leading to compromised plant nutrition, declines in plant productivity, or total crop failure. Essential micronutrients include boron (B), Cu, Fe, Mn, molybdenum (Mo), and Zn (Fageria et al., 2002). In plants, micronutrients function in carbohydrate metabolism, biosynthesis of proteins and amino acids, and help plants respond to water stress (Dhaliwal et al., 2022) among other functions. Deficiency in such micronutrients is manifested as stunted growth, leaf distortions, interveinal chlorosis of young leaves, and restricted flower formation (Uchida, 2000) with a consequence of low yield. Different agricultural strategies have been deployed to improve soil's physical, chemical, and biological health and to curb soil micronutrient deficiency. Micronutrient fertilization has gained interest among agricultural communities for various reasons, including soil erosion and long-term cropping, which result in the removal of micronutrients from soils. Furthermore, increasing crop yields generally leads to correspondingly increased micronutrient removal rates. Furthermore, the widespread replacement of micronutrient-rich compost or manure with inorganic fertilizers has reduced micronutrient addition to the soils (Sharma et al., 2018). While micronutrient improvement has largely been focused on soil chemistry, improvements in physical and biological aspects of soil health are equally important as they impact micronutrient availability to plants (Fig. 1). Thus, a holistic approach that considers soil chemical, physical, and biological aspects has significant potential to maximize crop productivity. Although soil health improvements and impacts are deeply intertwined and integrated, knowledge of specific soil deficiencies is fundamental and can help guide informed agronomic and environmental interventions for sustainability.

In Lake Malawi National Park, a world heritage site with multiple complex ecosystems located close to each other, it is vital to understand soil micronutrient profiles and their flows in time and space to adequately determine and direct appropriate soil improvement strategies to ecosystems where such efforts are required the most.



Modified after (Reicosky, 2018) and (Thapa et al., 2021).

Fig. 1 Three facets of soil health and the diversity of different approaches to improving soil health for micronutrient improvement

OBJECTIVE

This work aims to determine baseline micronutrient distribution in five different land-use ecosystems to help guide and prioritize areas for soil improvement. Specifically, the study seeks to determine micronutrient concentrations in soil profiles of the Chembe enclave village and assess the comparative adequacy of Chembe's soil micronutrient composition for agricultural productivity. This assessment will help inform soil management strategies and the selection of appropriate crop species for use in agriculture.

METHODOLOGY

Study Site

The study was conducted in the Chembe enclave village of Lake Malawi National Park (LMNP). The area is in Mangochi District, Southern Malawi, and is situated between 34.8508°- 34.8680° E and 14.0152° –14.0458° S at an altitude of 490 m.a.s.l. LMNP has multiple enclave villages, with Chembe as the largest village. Chembe's climate is tropical with two distinct seasons: the dry season from May to October and the wet season from December to March. The average annual rainfall is 559 mm annually. The underlying soil type is Cambisols.

Soil Sampling and Micronutrient Determination

Surface soil samples were obtained in August 2022 from five randomly assigned sampling stations in each land use type. Each soil sample was scraped from a pit dug at two depth intervals of 0-5 cm and 5-20 cm as described by Osterholz et al. (2020). Five samples were collected from each of the five land use types (community garden, farmland, Dambo wetlands, bare land, and forest land). Soil samples from the forest land were included as a control in this study. Each sample was composited and pushed through a 4 mm sieve to remove roots and rocks larger than 4 mm. The soil samples were then oven-dried at 60°C until a constant weight. The composite samples, two from each depth variate of the five land use types were then set aside for soil analyses. The oven-dried composite samples were subsequently ground to less than 250 µm using an IKA mill (A 10 Basic, IKA Japan, Osaka). After grinding, soil samples weighing 0.10 g were mixed with 2.5 mL of concentrated HNO_3 (70%) in glass digest tubes and left overnight. A reference sample NCS DC73319 (0.10 g) was included for comparison. Next, 2.5 mL of hydrogen peroxide (H_2O_2) was added to each sample after which the samples were digested using a bloc digestion system. The digests were made up to 10 mL in a 15 mL centrifuge tube. Exactly 1.0 mL of the sample extract was diluted with 9 mL (v/v) of ultra-pure water in another 15 mL centrifuge tube to make 10 mL of sample solution. The concentrations of micronutrients in the resulting filtrates were analyzed using an Agilent Atomic Absorption Spectrometer – Agilent 240 FS AA (Agilent, Santa Clara, California).

Statistical Analyses

Measured soil micronutrient concentrations were compared with various soil guidelines. Data were analyzed using XLSTAT Software and Excel for Windows 11. Graphics were prepared using Excel and R software packages.

RESULTS AND DISCUSSION

Nutrient Distribution Along a Soil Profile

Study data demonstrates that the top 0-5 cm soils contained high concentrations of Fe, Mn, and Zn. On the other hand, Se concentration in Dambo and garden land use types was comparatively low.

Explaining the distribution differences of micronutrients along soil gradients can be challenging. For instance, Franzluebbers and Hons (1996), found that no-tillage (NT) and conventional cultivation (CT) systems affected nutrient distribution differently at various soil depths. Further, plant growth in an ecosystem has been found to determine the distribution of limiting elements in topsoil via plants' relative biomass allocation and cycling rates along with root distribution and root depth within soils. The observed low levels of Se and Cu in the 0-5 cm depth could be explained by leaching due to the type of crops grown as found elsewhere (Kao et al., 2023) and consistent water supply in gardens and Dambos.

The results indicate that soils from Dambo and garden land use types had low Se levels in the 0-5 cm layer. The observation can be attributed to several factors. Firstly, Dambo and garden land use types are mostly associated with higher water availability. Dambo areas experience high water levels during the rainy season due to their topographical characteristics. On the other hand, irrigation increases garden soil water levels across seasons. Thus, Se and Cu can easily be leached from the topsoil to deeper layers by water movement in the two land use types. Secondly, the shallow-rooted plants in the Dambo area and the vegetables that are frequently cultivated and harvested in the garden absorb Cu and Se from the topsoil, which can deplete the Se and Cu concentrations in the 0-5 cm layer. Thirdly, soil pH and Redox conditions can also influence Cu and Se availability in Dambo and garden soils. The pH and redox conditions in the topsoil affect the solubility and mobility of Se and Cu. Through decomposition and microbial activities at the topsoil, the pH can vary to alkaline conditions. Se is more mobile in alkaline conditions which can lead to its leaching. This is an interesting area that will require further future research.

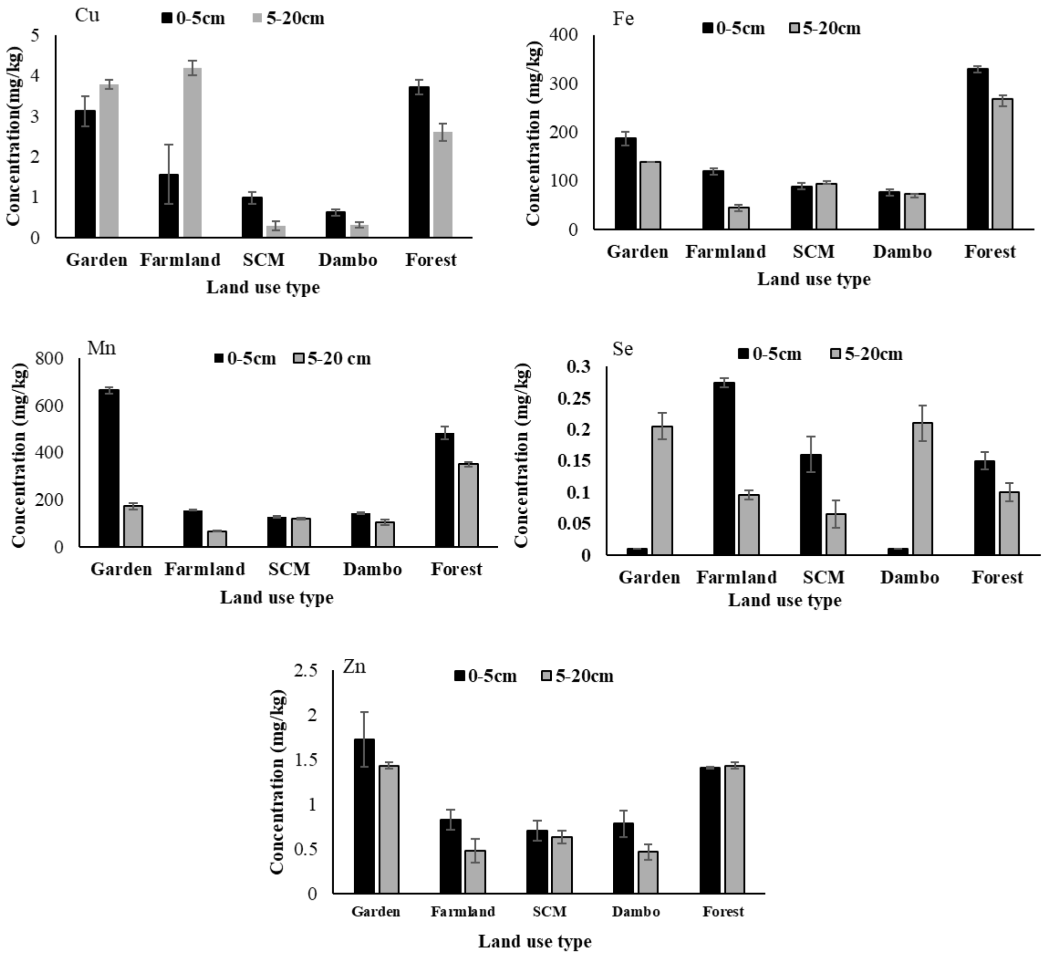


Fig. 2 Micronutrient distribution at 0-5 cm and 5-20 cm soil depths in the five land use types for Chembe enclave village in Lake Malawi National Park

Comparative Nutrient Distribution

Overall, garden and forest soils had higher Zn, Fe, Cu, and Mn concentrations compared to farmland, Dambo, and bare land. On the other hand, Se concentration was higher in farmland (particularly with 0 – 5 cm depth, Fig. 2) compared to the rest of the land use types. For the garden soils, the observed high micronutrient concentration could be explained by soil-improving interventions (manure, compost, and fertilizer supplementations) that have been implemented since the garden was established.

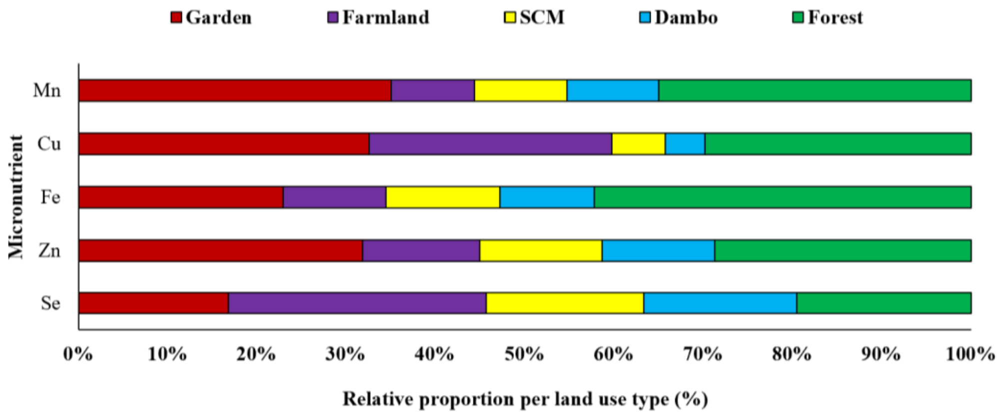


Fig. 3 Relative micronutrient distribution in different land use types

Comparative Micronutrient Adequacy for Chembe Soils

Agriculture serves as a safety net during times of disasters as was evidenced during COVID-19 when vegetable production increased, serving as an economic, and dietary cushion from pandemic impacts. The suboptimal micronutrient levels in farmland and Dambo land call for soil improvement techniques to enhance overall agricultural productivity in land use types in Chembe that registered micronutrient deficiencies.

Forest soil, which acted as a control, was found to have all the micronutrients investigated in this study within the optimal ranges (Table 1). Of all micronutrients analyzed, Mn was found to be within the optimum range across all land use types. However, Se was deficient in soils from Dambo and garden land use types. However, soils from the garden had optimal levels of Zn, and Cu in addition to Mn. The relatively fertile garden soils could be attributed to various soil improvement strategies implemented at the start of vegetable production in 2019. Implementation of soil health improvement strategies in the land use types identified as deficient in specific micronutrients is encouraged to enhance the productivity of the marginal land use types.

Table 1 Micronutrient concentrations in topsoil from different land use types in Chembe enclave village

	Concentration in surveyed soil (mg/kg) vs published optimal range						
Micronutrient	Garden	Farm	Bare land	Dambo	Forest	Optimal soil amount	
Se	0.01	0.28	0.16	0.01	0.15	0.1-0.6 (^{d})	(Gupta and Gupta, 2000)
Zn	1.73	0.83	0.71	0.79	1.41	1-900	(Fageria et al., 2002)
Fe	187.00	119.00	88.50	76.00	329.00	200-500,000	(Fageria et al., 2002)
Cu	3.12	1.56	0.99	0.62	3.72	2-250	(Fageria et al., 2002)
Mn	662.50	155.50	125.50	141.00	482.00	7-10,000	(Fageria et al., 2002)

Note: The deficiency range for selenium is indicated by (d).

In general, the 0-5 cm layer had higher micronutrients across all land use types compared to the 5-20 cm layer. The 0-5 cm layer typically has higher organic matter due to plant residues and microbial activity, which can bind micronutrients and make them more available. In addition, Chembe is located in a relatively dry climate area and does not experience very heavy rainfall. This can limit micronutrient leaching to the bottom layers, making them widely distributed with surface run-off, and being more available in surface soils, but less available in the bottom layers.

Garden and Dambo land use types had the least Se concentration in the topsoil as revealed by this study. It is, therefore, necessary to address Se deficiency in the garden and Dambo land use types. Se availability can be improved by ensuring improved soil health. This can be done through the implementation of several interventions which include agronomic biofortification, where Se can be added to the soil or foliar sprays. This strategy can be effective in addressing Se deficiency. Secondly, organic matter addition can also improve Se availability in the garden and Dambo land use types. Incorporating organic matter such as compost or manure and the addition of biochar can improve soil structure and increase the availability of Se. Thirdly, soil pH management also holds the key to Se availability. Adjusting soil pH to optimal levels in the two land use types identified as Se- deficient can enhance Se availability. Fourthly, the use of microbial inoculants can also make Se available from deficient soils. Using beneficial soil microbes that enhance Se availability to plants from otherwise inaccessible forms is an effective strategy for improving Se availability. Finally, crop rotation and crop diversity also hold promise to improve Se availability in degraded soils. Rotating crops and deliberate inclusion of plants that do not mine soil Se heavily (like certain legumes) can help to manage Se levels in the soil.

CONCLUSION

Agriculture is a key enterprise for locals in Chembe enclave village, especially in recent times due to declining fishery productivity in the area. Micronutrients are, on the other hand, a key soil health component due to their importance to plant productivity. At the study site, agriculture is primarily conducted on farmland during the rainy season, and on Dambo land in the dry season, primarily for vegetable production. This study sought to determine the concentration of five micronutrients in the soils of Chembe enclave village collected across five land use types in a benchmark study. Overall, the topsoil layers had greater concentrations of micronutrients compared to the bottom layers across the five land use types. The micronutrient concentrations of Chembe soils as revealed by this study, are generally suboptimal compared to published optimal ranges for crop production. Consequently, there is a need for soil health improvement technologies to be implemented in the area. For instance, Dambo land use type can be improved using tailored strategies such as deploying good water management practices and implementing proper drainage systems that prevent waterlogging and ensure an adequate water supply during dry periods. Furthermore, conservation practices such as the maintenance of vegetation around the Dambo to prevent erosion and protect water quality would help improve Dambo land for vegetable cultivation. Buffer strips and grassed waterways can also mitigate runoff and sedimentation. Finally, regular soil tests to monitor micronutrient levels, pH, and other soil health indicators following the application of necessary amendments that address nutrient deficiencies are recommended in Chembe enclave village and Lake Malawi National Park for ecosystem health, resilience, and sustainability.

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