Relationship between essential minerals and toxic trace elements of major paddy growing soils in Sri Lanka

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1. Introduction

Mineral elements are important to develop physical structures, and maintain physiological and biochemical activities in plants. In agriculture, mineral elements can be classified as macronutrients, micronutrients and toxic trace elements (Moustakas, 2021). Macronutrients such as potassium (K) and calcium (Ca) are required in higher quantities for essential plant functions while micronutrients such as zinc (Zn) and molybdenum (Mo) are required in relatively lower quantities. However, all these elements are equally important for plant health (Nieder et al., 2018). In order to sustain soil fertility, these elements are supplemented by adding inorganic or/and organic fertilizers (Uchida, 2000). However, excessive or imbalanced use of fertilizers in agriculture not only stagnates crop yields, it can also create negative impacts on the environment. Moreover, the accumulation of toxic trace elements in soil causes adverse impacts to agriculture (Ong et al., 2007). Therefore, the knowledge on the current level of accumulation of essential and toxic trace elements (*i.e.*, Ca, K, Fe, Zn, Cu, Mn, Mo, As, Cd, Pb) in soils is crucial for sustainable soil nutrient management and crop production. As rice is the most important crop, covering the highest land extent used by a crop in Sri Lanka, the aim of this study was to determine the concentrations of selected essential mineral and toxic trace elements in paddy growing soils and the relationship between those elements.

2. Materials and Methods

2.1 Collection and processing of soil samples

Two hundred paddy soil samples were collected representing three climatic zones [Dry Zone (DZ)=145, Wet Zone (WZ)=18, Intermediate Zone (IZ)= 32] and major soil types (18 Soil types) used for rice cultivation using stratified random sampling approach as described in Kadupitiya et al. (2021). Each sample represented top 0-15 cm soil layer. Those samples were air dried, debris were removed, homogenized by breaking large particles manually and sieved using 2 mm sieve.

2.2 Metal concentration detection through ICP-MS (Inductively Coupled Plasma-Mass Spectrometry)

Four grams of soil was extracted with 40 mL of 0.01 M $CaCl_2$ solution at room temperature. Then it was shaken for two hours. After shaking, it was centrifuged for four minutes at 3600 rpm. Supernatant (35 mL) was collected and acidified using 0.5 mL conc. HNO_3. Then 6 mL of solution was filtered using 0.45 µm micro filter. Then 1 mL of solution was pipetted out and it was diluted with 6 mL of distilled water. Then solutions were subjected to ICP-MS analysis to determine the concentrations of essential mineral elements (*i.e.*, Ca, K, Fe, Zn, Cu, Mn, Mo) and toxic trace elements (*i.e.*, As, Cd, Pb). Blanks without soil samples, laboratory and manufacturer standards were used to check the consistency and ensure the quality across batches and samples.

2.3 Statistical Analysis

The mean, minimum and maximum element concentrations were determined using descriptive statistics. Strengths of the relationships between elements (paired comparisons) were determined using Pearson's linear correlation coefficient (*r*). Element concentrations among soil groups and climatic zones were compared using analysis of variance (ANOVA). All the interpretations are made at α=0.05.

3. Results and Discussion

3.1 Variation of element concentrations

The highest mean element concentration in soil samples was recoded in Ca followed by K, Mn and Fe (Table 1). Relatively lower concentrations of Zn, As, Mo and Pb were reported in soil samples than those of Ca, K and Fe. The ICP-MS technique didn't detect the Cu, Zn, As, Mo and Pb in some soil samples.

Table 01. Element concentrations in the soil samples tested (mean± stderr, n=200)

Mineral elements	mg kg^{-1}		
	Mean	Minimum	Maximum
Potassium (K)	57.57 ± 5.35	4.13	786.08
Calcium (Ca)	720.40 ± 37.70	4.95	1984.10
Manganese (Mn)	17.13 ± 1.63	0.11	143.59
Iron (Fe)	11.72± 0.79	0.26	55.78
Copper (Cu)	0.05 ± 0.00	0	0.26
Zinc (Zn)	0.32 ± 0.04	0	3.16
Arsenic (As)	0.02± 0.00	0	0.10
Molybdenum (Mo)	0.10± 0.02	0	2.51
Lead (Pb)	0.06± 0.01	0	0.79

3.2 Difference among climatic zones

There were significant differences in element concentrations in soil samples collected from three climatic zones ($P<0.05$). Wet Zone (WZ) soils contained higher concentrations of Ca (1226 mg kg^{-1}) and Fe (23 mg kg^{-1}) compared to that of the Dry Zone (DZ) and Intermediate Zone (IZ) soils ($P<0.05$). The concentrations of other detected elements in soil samples collected from three climatic zones were similar ($P>0.05$).

3.3 Difference among soil groups

When compared different soils groups, Red-Yellow Podzolic soils with soft or hard laterite (RYP), Bog and Half-Bog soils (BHB) and Rock Knob Plain (RKP) soils recorded higher Ca concentration than other soil groups (> 1000 mg kg^{-1}). RYP, BHB, Red-Yellow Podzolic soils; steeply dissected, hilly and rolling terrain (RYP-SD R) soils recorded higher Fe concentration than other soil groups (> 20 mg kg^{-1}). Solodized Solonetz and Solonchaks (SSS) soil had higher As and Mo concentration, while Calcic Red-Yellow Latosols (CRYL) soil had higher Cu concentration. Concentrations of K, Mn, Zn and Pb among the soil groups were similar ($P>0.05$).

3.4 Relationships between elements

There were significant correlations between elements. Out of which the correlation between Cu and Mn was the strongest ($r=0.477$, $P<0.001$) (Fig. 1).

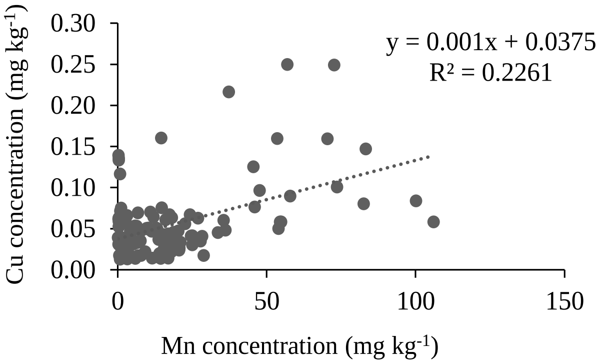

Figure 1. Correlation between Cu and Mn concentration in selected paddy soil

ICP-MS technique is widely used to detect multiple elements in soil samples. Moreover, 0.01 M $CaCl_2$ is widely used as a universal extractant of mineral elements in soil samples. Due to the weak molarity and strength, 0.01 M $CaCl_2$ solution reflects the soil solution concentrations of mineral elements *(Van Erp, 2002)*. As this reflects the rhizosphere element concentration, the values and correlations studied in this research represent the concentrations of different elements available for plant roots, and thus have a direct biological relevance. The concentrations of elements in Sri Lankan paddy soil samples varied due to numerous factors such as the differences in parental materials and geology, and the cropping systems and agronomic practices adopted by the farmers. Irrespective of the soil groups, presence of macronutrients were the highest, followed by micronutrients and toxic trace elements. Taking up of both toxic and essential trace elements depend on their accumulation and cycling in soil. Therefore, keeping a balance between these elements is important to ensure crop yield in terms of both quantity and quality (Rajmohan et al., 2007). In these soils, small quantities of heavy metals (*e.g.*, Pb; 0-0.8 mg kg^{-1}) and metalloids (*e.g.*, As; 0-0.1 mg kg^{-1}) were detected.

4. Conclusions

The concentrations of mineral elements determined in Sri Lankan paddy soils samples were in order of Ca>K>Mn>Fe>Zn>Mo>Pb>Cu>As. WZ soils recorded higher Ca and Fe concentrations than those reported in other zones. RYP and BHB soil recorded relatively higher Ca and Fe concentrations. This knowledge is important when designing sustainable nutrient management in Sri Lankan rice fields.

5. References

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