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Status of Micronutrients in Rice Growing Alluvial Soils of Delta Area of Krishna District, Andhra Pradesh, India

K Hema [a++*], M.V.S. Naidu [b#], B.P. Bhaskar [c], K.V. Naga Madhuri [d†], V. Ramamurthy [e‡] and P. Lavanya Kumari [f^]

[a] Department of Soil Science and Agricultural Chemistry, Agricultural College, Bapatla, Acharya N.G. Ranga Agricultural University, Lam, Guntur 522034, Andhra Pradesh, India.
[b] Department of Soil Science & Agricultural Chemistry, S.V. Agricultural College, Tirupati, Acharya N.G. Ranga Agricultural University, Lam, Guntur 522034, Andhra Pradesh, India.
[c] Department of Soil Science, ICAR-NBSS & LUP Regional Centre, Hebbal, Bangalore 560024, Karnataka, India.
[d] IFT, Regional Agricultural Research Station, ANGRAU, Tirupati 517502, Andhra Pradesh, India.
[e] ICAR- NBSS & LUP, Regional Centre, Bengalore, India.
[f] Department of Statistics & Computer Applications, Agricultural College, Acharya N.G. Ranga Agricultural University, Tirupati 517502, Andhra Pradesh, India.

Authors' contributions

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

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[++] *Associate Professor (Soil Science);*
[#] *Professor & Head;*
[†] *Principal Scientist (Soil Science) & Head;*
[‡] *Principal Scientist (Agronomy) & Head;*
[^] *Assistant Professor (Statistics);*
**Corresponding author: E-mail: hemakandru@angrau.ac.in;*

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ABSTRACT

An investigation was carried out to study the micronutrient status of rice-growing soils of the delta area of Krishna district in Andhra Pradesh to know the potential of these soils to supply micronutrients to rice crops. For this, six profiles *viz.,* Vemulamada (P1), Kothapalli (P2), Velivelu (P3), Nangegadda (P4), Penamaluru (P5), and Ganguru (P6) were studied covering the major cereal-maize/ cereal- pulse growing areas. The soils were near neutral to strongly alkaline in reaction, non-saline, and low in organic carbon content. The weighted average of DTPA extractable zinc, copper, iron, and manganese ranged from 0.71 mg kg^{-1} (P6) – 1.65 mg kg^{-1} (P2), 1.50 mg kg^{-1} (P2) – 3.38 mg kg^{-1} (P3), 4.35 mg kg^{-1} (P1)- 5.62 mg kg^{-1} (P5) and 5.6 mg kg^{-1} (P4) to 11.95 mg kg^{-1} (P6) respectively. A mixed trend is observed across horizons in all profiles. DTPA-Fe exhibited low variability while the other micronutrients displayed higher variability. The DTPA extractable Zn was found to be deficient whereas DTPA extractable Cu and Mn were found to be sufficient. The available Mn was decreased with increasing depth in most of the profiles. All the micronutrient are positive correlation with organic carbon content.

Keywords: Cereal; correlation; descriptive micronutrients; statistical analysis.

1. INTRODUCTION

Alluvial soils are a crucial element in river, lake, and coastal-related ecosystems. Due to their specific genesis, they can occur in all climatic zones of the world (Driessen et al*.,* 2001). Despite some common features (e.g. stratification of the material, the influence of groundwater), the high differentiation of the pedogenic properties of these soils makes them a very diverse group (e.g. Holmes & Hearn, 1942; Sheremet, 2006; Schaetzl & Anderson, 2005). Nevertheless, these soils are still often treated by many researchers as homogenous clusters in which lithogenesis plays a major role. Such a lithogenetic approach, which is treating alluvial soils as one unit without taking into account pedogenic transformations, can be found in many publications on various study aspects, e.g.: clay minerals (Cieśla et al*.,* 1988), water retention (Hewelke et al*.,* 2018), soil contamination (Cappuyns & Swennen, 2007), anthropogenic changes (Kanno et al*.,* 1965), and identification of geotechnical parameters (Yilmaz & Karacan, 1997; Młynarek et al*.,* 2012). One of the reasons for this is that in many older versions of classification systems – including international ones – most of the pedons developed from alluvial materials were put into main unit.

The vast agricultural potential of alluvial soils, combined with the appealing landscapes of river valleys, has led to extensive transformations in these areas. This often includes river canalization and soil drainage efforts. Such regulation projects have successfully reduced flooding and stabilized groundwater levels, resulting in notable environmental shifts. Consequently, there is an increasing need for precise, scientific, and landscape scale soil data in agricultural regions. This data is crucial for addressing emerging challenges and ensuring sustainable land use for both current and future generations. Soil information plays a vital role in research and decision-making across various fields. It aids farmers in making informed choices about fertilizer application rates, supports biophysical modeling of the global carbon cycle, and informs high-level policy decisions (Tagore et al*.,* 2014). Understanding the variability of soil properties at the Pedon scale is essential for environmental assessment and is a key factor in determining agricultural productivity. It also influences the efficiency of farm inputs, crop yields, and the effectiveness of field research trials (Rizvi et al*.,* 2015). However, many areas have implemented blanket soil management recommendations that overlook the complexities and variability of soils, rendering them inadequate for farmers' advisory services. This highlights the necessity for soil testing to ensure balanced nutrition and maintain soil health.

Many researchers have extensively studied the relationship of trace elements to problems of soil fertility and plant nutrients. It has also been shown that However, DTPA extractable microelements in exchange sites are important in reducing the sufficient levels for plant growth (Martens & Lindsay,1980 and Mengel and Kirkby,1979). These concerns make it necessary to know their levels in soils, and to do this sensitive, precise, accurate and easy to use analytical methods must be developed. The aim of this research was to determine background levels of DTPA extractable Fe, Mn, Zn and Cu with some important properties of rice growing soils of Krishna delta area in Andhra Pradesh.

2. MATERIALS AND METHODS

The study area is the Krishna River which is a key river basin in Peninsular India, commonly known as the "rice bowl" of Andhra Pradesh. It lies in between longitudes of 80° 35' and 81° 05' East, and latitudes of 15° 40' and 16° 30' North, covering a drainage area of about 2,59,000 square kilometers. The river has an average yearly water flow of 78 billion cubic meters. The area is at risk of frequent cyclones that can cause higher waves and occasional storm surges, sometimes traveling several kilometers inland on a very gentle slope of about less than one percent. The geology of the Krishna basin mainly consists of marine sand and alluvium. The landforms in this study area include gently sloping alluvial plains, flatlands and coastal regions that experience little erosion and have generally well-drained soils. The sea plains have quick runoff, while the flat fluvial areas show very slow runoff. The flat lands are often used for double cropping. In the Krishna delta, the cropping patterns include combinations of cereal-cereal, cereal-pulse and cereal-cereal-fallow with smaller portions reserved for vegetables, bananas and turmeric. Hence, the area qualifies for 'iso-hyperthermic' temperature regime. The soil moisture control section is dry for more than 90 cumulative days or 45 consecutive days in four months following summer solstice. So it qualifies for ustic soil moisture regime. The natural vegetation includes grasses, *Prosopis juliflora, Parthenium* sp., *Tridax* sp., mango (*Mangifera indica*) and *neem* (*Azadirachta indica*) *etc.,* The soils were developed from basaltic alluvium parent materials. The soil texture varied from clay to-sandy clay loam. The pH of soils is slight alkaline in nature, non-saline in electrical conductivity and low in organic carbon content.

A total of six soil profile samples were collected from five mandals in Krishna district: Movva, Ghatasala, Challapalli, Nagayalanka, and Penamaluru. The sample locations were situated 27 to 50 km from the Machilipatnam sea coast and at elevations of 6 to 27 meters. The profiles were selected according to drainage evident from the textural classes. The initial on field inspection of texture was done through feel method. The soil samples collected horizon-wise were tested for available micronutrients and were estimated using standard procedures as described by Lindsay & Norvell (1978).

2.1 DTPA – Zinc (Zn)

Six profiles were assessed for zinc levels. The weighted mean for Zn is 1.65 mg kg^{-1} in P2 and 0.69 mg kg^{-1} in P6. The top layers have zinc values below the critical limit of 0.4 mg kg^{-1} but show gradual increases in the endogenetic slicken-sided horizons of P1. P2 has an irregular distribution of values, ranging from 1.53 mg kg^{-1} in the C horizon to 1.71 mg kg^{-1} in the B horizons (Table 2). In the Velivelu soil (P3), DTPA Zn levels drop significantly below 0.8 mg/kg in the lithologically inconsistent layers of the Bss horizon at depths of 0.8 to 1.5 m. For P4, DTPA-Zn increases with depth, ranging from 0.14 mg kg^{-1} to 1.33 mg kg^{-1} in the Bss horizons. This soil maintains a weighted mean of 0.96 mg kg^{-1}, which is below the critical value of up to 0.8 m. The Penamaluru soil (P5) exhibits an irregular DTPA-Zn distribution, with a weighted mean of 0.87 mg kg^{-1}. The endogenic layers Bw2, Bw4, and Bw5 have less than 0.29 mg kg^{-1} of DTPA-Zn. The Ganguru soil (P6) has a weighted mean of 0.67 mg kg^{-1}, also below the critical level. The cambic B horizons, between 0.20 and 1.10 m, show zinc values from 0.71 to 1.48 mg kg^{-1}, but the BW4 horizon has a very low level of 0.09 mg kg^{-1}. The results also with the results of (Singh, 1998). The amount of zinc varied irregularly with depth, indicating that zinc does not move easily in soils and tends to stick to clay particles. There was a strong positive correlation between zinc and organic carbon, suggesting that organic carbon is a key factor in predicting zinc availability (Aseefa Meena, 2022).

2.2 DTPA Available Zn (mg kg^{-1}) = 5.7567 + 19.9517 OC (%)

The Available zinc (mg kg^{-1}) value is 5.7567 ± 19.95 (Organic carbon %) with an R^2 of 0.36 and F value of 20.48. $R^2 = 0.36$ indicates that 36.3% of the variability of DTPA Zn (mg kg^{-1}) is explained by organic carbon percentage depicted in Fig. 1. Correlation (R) equals 0.60 indicates that a strong direct relationship between OC% and DTPA Zn (mg kg^{-1}).

2.3 DTPA -Copper (Cu)

The weighted mean concentration of DTPA-Cu is 3.38 mg kg^{-1} at P2, which is higher than 2.87 mg kg^{-1} at P6, 2.45 mg kg^{-1} at P4, 2.28 mg kg^{-1} at P5, 2.20 mg kg^{-1} at P1, and 1.5 mg/kg at P3. The DTPA-Cu levels decrease from 9.58 mg kg^{-1} in the Ap horizon to 0.3 mg kg^{-1} in Bss4, and from 7.35 mg kg^{-1} to 0.20 mg kg^{-1} in P2. Similar trends in soil depth are observed, but the levels remain above critical limits (Table 1). As noted by Barona, et al., (1999), the significant correlation of copper with organic carbon indicates its enhanced extractability from soils rich in organic carbon, while a negative correlation with pH was also observed.

2.4 DTPA Available Cu (mg kg^{-1}) = 0.6919 + 7.5209 OC (9%)

The Available copper (mg kg^{-1}) value is 0.6919 ± 7.5209 with R^2 of 0.44 and (F) value of 28.57 for degrees of freedom 1 and 36. R- square value of 0.44 indicates that 44.4% of the variability (Fig. 2) of DTPA Cu (mg kg^{-1}) is explained by OC percentage, depicted in Fig. 2. Correlation 'R' value 0.6664 means there is a strong direct relationship between OC% and DTPA Cu (mg kg^{-1}).

2.5 DTPA- Iron (Fe)

The weighted mean for DTPA-Fe is classified as marginal, as noted by Singh in 1998. Values range from 5.62 mg kg^{-1} at P5 to 4.35 mg kg^{-1} at P1. A noticeable decline in DTPA-Fe with depth occurs at P1, dropping from 5.39 mg kg^{-1} to 3.31 mg kg^{-1}, and in the Bw horizons of P6, which decrease from 5.70 mgkg^{-1} to 3.77 mg kg^{-1}. Other soil types display lower DTPA-Fe levels in cambic horizons, exhibiting irregular patterns. Conversely, the moderate correlation between Fe and organic carbon (OC) indicates a significant bonding effect between Fe and organic matter (OM), likely due to the formation of chelates known as siderophores, which enhance Fe solubility. Najafi-Ghiri et al., (2013) linked this relationship to the exchange capacity of OM for Fe, the chelating properties of organic compounds, and the acidifying effects of OM. A positive correlation between Fe and OC may suggest that OC serves as a vital source of this nutrient in cultivated soils (Fig. 3).

2.6 DTPA-Manganese (Mn)

The DTPA-Mn profile at Vemulamanda (P1) shows uneven trends but maintains levels above 4 mg kg^{-1} at most depths, except in Bss4, where it drops below 4 mg kg^{-1}, indicating marginal levels (Singh 1998). DTPA-Mn concentrations range from 9.95 mg/kg in Bss1 to 10.91 mg/kg in the Ap horizon, with a weighted average of 7.91 mg kg^{-1}. The weighted means for all profiles are as follows: 11.95 mg kg^{-1} (P6), 10.96 mg kg^{-1} (P3-Velivelu), 8.83 mg kg^{-1} (P5), 8.14 mg kg^{-1} (P2), 7.91 mg kg^{-1} (P1), and 5.57 mg kg^{-1} (P4). A gradual decline in DTPA-Mn is observed in P2, from 12.0 mg kg^{-1} in the Ap horizon to 4.56 mg/kg in the C horizon. Similar patterns occur in P3, P4, and P5, with slight variations in depth for P6. The moderate correlation of DTPA-Mn with OC is due to higher adsorption and retention of Mn by finer fractions and conversion of Mn to its water-insoluble oxide forms in alluvial plains where flooding frequency is high under alkaline pH conditions. This result is contrary to the findings of. Sharma et al., (2005) but in agreement with the findings of the hydric soils of Majuli Island (Bhaskar et al., 2017).

2.7 DTPA Available Mn (mg kg^{-1}) = 5.5712 + 12.1795 (OC%)

The Available manganese mg kg^{-1} value is 5.5712 ± 12.1795 with R^2 value is 0.42 indicating (Fig. 4) that the variability of DTPA Mn (mg kg^{-1}) is explained by OC%, depicted in Fig. 4. Correlation (R) value 0.6486 means there is a strong positive relationship between OC (%) and DTPA Mn (mg kg^{-1}).

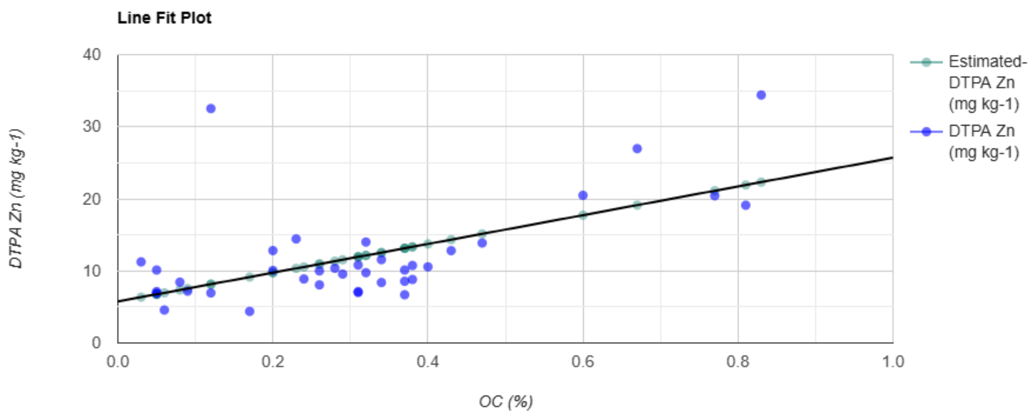

Fig. 1. The simple linear regression model between DTPA available Zinc (mg kg^{-1}) and Organic Carbon (%)

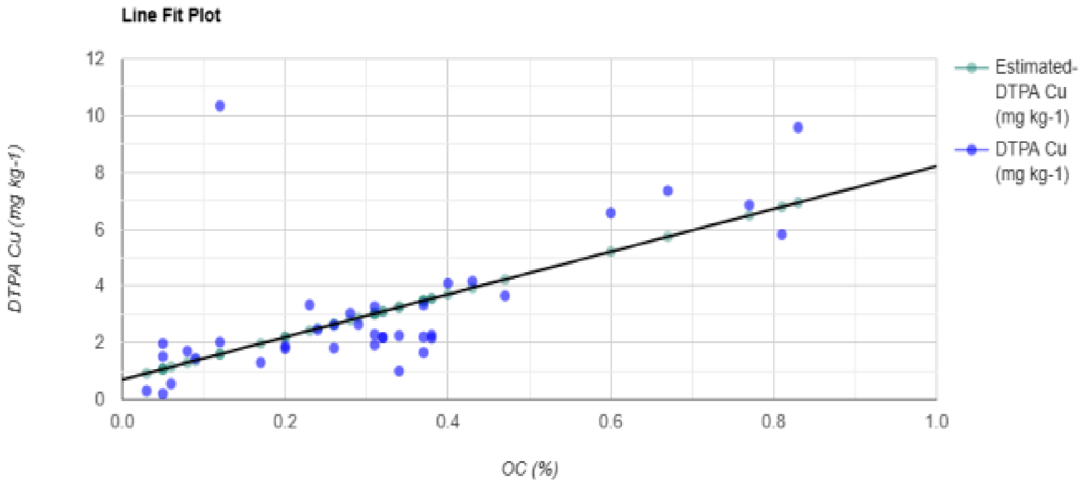

Fig. 2. The simple linear regression model between DTPA available Copper (mg kg^{-1}) and Organic Carbon (%)

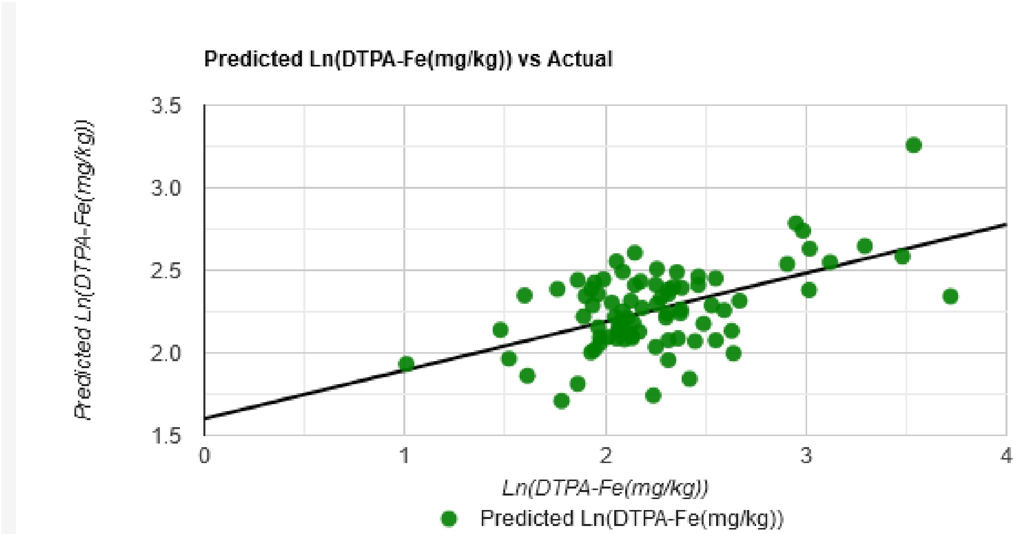

Fig. 3. Simple linear regression model between actual Ln DTPA Fe and predicted Ln DTPA Fe

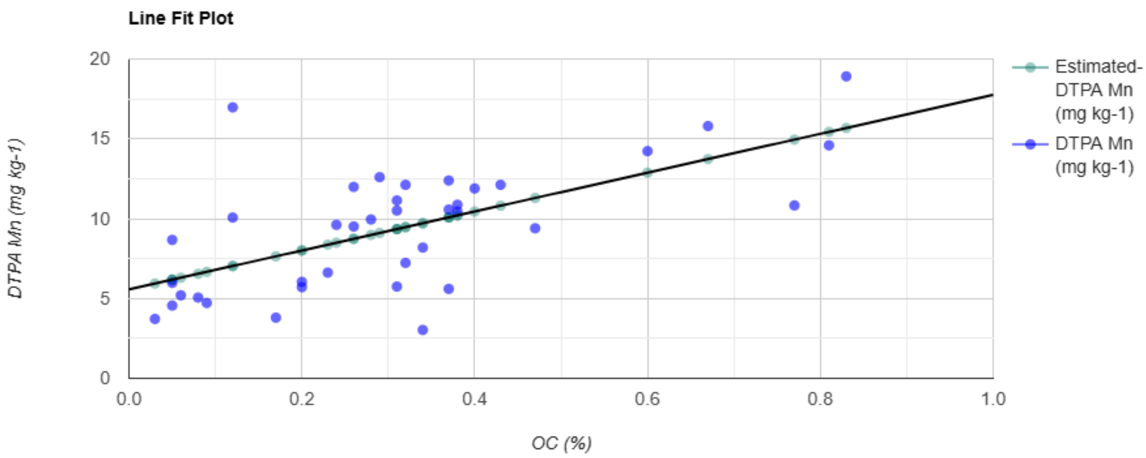

Fig. 4. The simple linear regression model between DTPA available Manganese (mg kg^{-1}) and Organic Carbon (%)

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistics

The data collected and pooled analysis underwent descriptive statistical evaluation, with the findings summarized in Table 3. The mean concentrations were recorded as 1.14±0.58 mg kg^{-1} for DTPA-Zn, 2.67±1.66 mg kg^{-1}for DTPA-Cu, 5.04±0.83 mg kg^{-1} for DTPA-Fe, and 8.96±3.34 mg kg^{-1} for DTPA-Mn. These figures suggest sufficient levels following the critical thresholds established by Katyal & Rattan (2003). DTPA-Fe exhibited low variability, reflected by a coefficient of variation (CV) of 16.46%, while the other micronutrients displayed higher variability. The normality test indicated significance for DTPA-Zn, with a D value of and a p-value of 0.001, characterized by negative skewness and mesokurtic distribution.

Table. 1. Critical levels of deficiency of micronutrients in soils usually adopted in India for delineation purposes

Nutrient	Extractant	Critical level (mg kg^{-1})
Zn	DTPA	0.4-1.2 (0.6)
Fe	DTPA	2.5-4.5
	Ammonium acetate	2.0
Cu	DTPA or Ammonium acetate	0.2
Mn	DTPA	2.0
B	Hot water	0.5
Mo	Ammonium oxalate	0.2
S	0.15 % $CaCl_2$ $2H_2O$	10

Katyal and Rattan, 2003; Tandon, 1999

Table 2. Horizon wise descriptive statistics for DTPA extractable micronutrients (mg kg^{-1}) in soils of Krishna Basin

Statistical parameters	DTPA extractable micronutrients (mg kg^{-1})			
	Zn	Cu	Fe	Mn
Mean	1.14	2.67	5.04	8.96
SD	0.58	1.66	0.83	3.34
CV	50.08	62.17	16.46	37.27
Kurtosis	-1.20	1.85	-0.74	-0.73
Skewness	-1.48	1.40	-0.36	0.44
p-Value	0.001	0.00	0.068	0.09
D- Value	0.00014	0.00	0.08	0.11

Table 3. DTPA extractable micronutrients (mg kg^{-1}) in soils of Krishna Basin

Profile & horizon	Depth(m)	Zn	Cu	Fe	Mn
Window I					
P1 Vemulamanda					
Ap	0.00 - 0.18	0.11	9.58	5.39	10.91
Bss1	0.18 - 0.40	0.40	3.03	5.15	9.95
Bss2	0.40 - 0.70	1.88	2.29	5.10	10.51
1Bss1	0.70 - 1.00	1.87	2.02	4.73	10.07
1Bss2	1.00 - 1.30	1.81	1.51	4.23	8.67
Bss3	1.30 - 1.50	1.80	0.55	3.61	5.20
Bss4	1.50 - 2.00	1.78	0.30	3.31	3.72

Profile & horizon	Depth(m)	Zn	Cu	Fe	Mn
P2 Kothapalli	**W**	**1.51**	**2.20**	**4.35**	**7.91**
Ap	0.00 - 0.25	1.70	7.35	5.12	12.00
Bss1	0.25 - 0.50	1.69	2.62	6.03	11.99
Bss2	0.50 - 0.90	1.71	2.16	5.98	10.45
Bss3	0.90 - 1.30	1.67	2.25	6.00	8.19
Bss4	1.30 - 1.70	1.64	1.65	5.60	5.60
Bss5	1.70 - 2.10	1.53	0.20	4.62	4.56
P3 Velivelu	**W**	**1.65**	**1.50**	**5.56**	**8.14**
Ap	0.00 - 0.20	1.51	6.57	4.57	14.23
Bss1	0.20 - 0.50	1.51	4.16	6.05	12.12
Bss2	0.50 - 0.80	1.01	4.09	6.07	11.89
1Bss1	0.80 - 1.20	0.72	3.33	5.79	10.57
1Bss2	1.20 – 1.50	0.69	2.46	4.98	9.61
Bss3	1.50 - 2.00+	1.41	1.81	4.28	9.51
P4 Nangagadda	**W**	**1.13**	**3.38**	**5.25**	**10.96**
Ap	0.00 - 0.25	0.14	6.85	5.15	10.83
Bss1	0.25 - 0.50	0.68	3.33	5.31	6.62
Bss2	0.50 - 0.80	0.67	1.88	6.18	5.71
1Bss1	0.80 - 1.05	1.33	1.70	4.50	5.06
1Bss2	1.05 -1.20	1.31	1.44	4.03	4.72
2 Bss1	1.20 - 1.40	1.33	1.30	3.35	3.80
2Bss2	1.40 - 1.80	1.29	1.00	4.80	3.03
P5 Penamaluru	**W**	**0.96**	**2.45**	**4.88**	**5.57**
Ap	0.00 - 0.20	1.30	2.18	5.44	7.23
Bw1	0.20 - 0.60	1.45	3.65	5.13	9.40
Bw2	0.60 - 0.90	0.29	1.97	6.25	5.98
Bw3	0.90 - 1.22	1.86	1.92	6.21	5.75
Bw4	1.22 - 1.55	0.23	1.79	5.81	6.04
Bw5	1.55 - 1.90+	0.18	1.85	5.04	16.97
P6 Ganguru	**W**	**0.87**	**2.28**	**5.62**	**8.83**
Ap	0.00 - 0.20	0.23	5.81	4.90	12.59
Bw1	0.20 - 0.50	0.97	3.26	5.70	11.14
Bw2	0.50 - 0.82	0.71	2.64	5.23	12.60
Bw3	0.82 - 1.10	1.48	2.18	4.18	12.12
Bw4	1.10 - 1.40	0.09	2.27	4.06	10.87
Bw5	1.40 - 1.80	0.59	2.20	3.77	12.39
	W	**0.69**	**2.87**	**4.59**	**11.95**

4. CONCLUSION

The investigation of micronutrient status in rice-growing soils of the Krishna district's delta area revealed near-neutral to strongly alkaline pH and low organic carbon content. Zinc was found to be deficient, while copper and manganese were sufficient for rice crops. Iron exhibited low variability across profiles, indicating a stable supply. Manganese levels decreased with soil depth in most profiles. A positive correlation between micronutrients and organic carbon content suggests that organic matter plays a key role in enhancing nutrient availability. These findings highlight the need for zinc supplementation while copper and manganese are sufficient for optimal rice growth.

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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