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Correlation analysis of texture, physico-chemical properties and nutrient availability in red cotton-growing soils of Nagarkurnool District

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Abstract

Understanding the relationships among soil texture, physico-chemical properties, and nutrient availability is essential for sustainable cotton production. This study evaluated these interactions in irrigated and rainfed red cotton-growing soils of Nagarkurnool district, Telangana. A total of 120 soil samples were collected from shallow and deep soils at surface (0–15 cm) and sub-surface depths during the 2023 kharif season. Soils were analyzed for texture, pH, electrical conductivity (EC), organic carbon (OC), available N, P₂O₅, K₂O, and DTPA-extractable Zn, Fe, Mn, and Cu. Correlation analysis revealed that clay content strongly influenced micronutrient availability, showing significant positive correlations with Zn, Fe, Mn, and Cu across most soil groups. Soil pH exhibited significant negative correlations with micronutrients, indicating reduced availability under alkaline conditions. Organic carbon showed a strong positive relationship with available nitrogen and a moderate association with phosphorus. Micronutrients were also strongly inter-correlated, suggesting co-variation under similar soil conditions. The study highlights the importance of texture, soil reaction, and organic matter in governing nutrient availability in red cotton-growing soils.

Keywords: Shallow, deep, irrigated, rainfed, surface, sub-surface

Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most important commercial crops in India and plays a vital role in the agrarian economy, particularly in semi-arid regions. Soil fertility and nutrient availability are critical determinants of cotton productivity, as the crop has a long growth duration and high nutrient demand. In cotton-based production systems, imbalanced fertilization, continuous cropping and limited organic matter inputs often lead to depletion of essential nutrients and deterioration of soil health, thereby affecting yield sustainability (Fageria *et al.*, 2011)^[5].

Soil texture, physico-chemical properties, and nutrient status are closely interrelated and collectively govern nutrient availability to plants. Among textural fractions, clay plays a major role in nutrient retention due to its higher surface area and cation exchange capacity, particularly for micronutrients such as zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) (Alloway, 2008; Kumar *et al.*, 2016)^[1, 10]. Conversely, sandy soils are generally poor in nutrient-holding capacity and are more prone to nutrient losses through leaching (Schapel *et al.*, 2023)^[19]. Soil reaction (pH) is another key factor influencing nutrient solubility, especially micronutrients, whose availability sharply declines under alkaline conditions due to precipitation and adsorption reactions (Gondal *et al.*, 2021)^[6].

Organic carbon (OC) serves as an important indicator of soil fertility and is strongly associated with nutrient cycling processes. Soil organic matter contributes to the supply of available nitrogen through mineralization and also influences phosphorus availability by forming organic complexes that reduce fixation (Celi *et al.*, 2022)^[3]. Electrical conductivity (EC), though primarily indicative of soluble salt content, may indirectly influence nutrient uptake by affecting soil structure and root activity under irrigated conditions (Chen *et al.*, 2009)^[4].

Black soils and red soils are the dominant soil groups supporting cotton cultivation in southern India. Black soils are characterized by high clay content, shrink–swell properties, and relatively high nutrient reserves, but often suffer from micronutrient deficiencies due to alkaline reaction and calcium carbonate accumulation (Satyavathi and Reddy, 2004; Shukla and Behera, 2017) [17, 19]. Red soils, on the other hand, are generally lighter in texture, low in organic matter, and prone to nutrient depletion, making nutrient management more challenging under rainfed conditions (Jatav *et al.*, 2020) [9].

Correlation analysis is a useful statistical tool for understanding the interrelationships among soil properties and identifying the dominant factors controlling nutrient availability. Such analyses help in diagnosing nutrient constraints, understanding nutrient interactions, and developing site-specific soil fertility management strategies (Singh *et al.*, 2015; Negash and Mohammed, 2014) [20, 13]. Despite the importance of cotton in Telangana, systematic information on the interrelationships among texture, physico-chemical properties, and nutrient availability across different soil types, depths, and moisture regimes remains limited. Therefore, the present study was undertaken to evaluate the relationships among texture, physico-chemical, and chemical properties of irrigated and rainfed cotton-growing red soils of Nagarkurnool district. Understanding these interactions will aid in identifying key soil factors governing nutrient availability and provide a scientific basis for improving nutrient management practices for sustainable cotton production in the region.

Materials and Methods

Cotton-growing soils in the study area were categorized into eight groups based on soil depth (shallow <50 cm; deep >1 m), management system (irrigated or rainfed), and sampling depth (surface or subsurface). A preliminary survey guided the random selection of 120 representative farmer fields in key cotton-producing areas of Nagarkurnool district. Fifteen fields per category were sampled at two depths, yielding 120 total soil samples (Table 1). Sampling occurred during the 2023 kharif season before cotton planting, with surface (0–15 cm) samples collected via the standard zigzag method to account for field heterogeneity.

Table 1: Details of soil sampling

Soil Depth	Shallow soils (up to 50 cm depth)		Deep soils (> 1 m depth)	
	Irrigated	Rainfed	Irrigated	Rainfed
Surface	15	15	15	15
Sub surface	15	15	15	15
Total	30	30	30	30

Soil samples were air-dried, lightly crushed, and sieved through a 2 mm mesh prior to analysis. Samples were stored in labeled plastic bags to avoid cross-contamination and analyzed using established protocols. Physicochemical properties included pH and EC measured in 1:2.5 soil-water suspensions with calibrated digital meters (Jackson, 1973) [8]. Organic carbon was quantified by the Walkley-Black wet digestion technique (Walkley and Black, 1934) [23]. Available N was assessed via alkaline permanganate distillation (Subbiah and Asija, 1956) [21], P by Olsen's method (Olsen *et al.*, 1954) [14], and K by neutral 1 N ammonium acetate extraction. DTPA-extractable micronutrients (Fe, Cu, Zn, Mn) were determined using atomic absorption spectrophotometry (Lindsay and Norvell, 1978) [11].

Results and Discussion

Correlation analysis in red soils

Irrigated deep red soils (sub-surface)

The correlation analysis among texture, physico-chemical, and chemical properties (Table 2) showed several significant relationships. Sand was negatively correlated with clay ($r = -0.683^{**}$), while soil pH showed a significant negative correlation with clay ($r = -0.537^{*}$). Electrical conductivity was strongly and positively correlated with silt ($r = 0.889^{**}$). Organic carbon exhibited a highly significant positive correlation with available nitrogen ($r = 0.710^{**}$), but showed no significant association with texture or pH. Available phosphorus was positively correlated with sand ($r = 1.000^{**}$) and negatively correlated with clay ($r = -0.683^{**}$), whereas available potassium showed no significant relationships. Among micronutrients, Zn, Mn, Fe, and Cu were strongly and positively correlated with clay ($r = 0.786^{**}$, 0.730^{**} , 0.865^{**} , and 0.929^{**} , respectively) and showed highly significant negative correlations with soil pH. Strong positive inter-correlations were observed among micronutrients, particularly between Fe and Cu ($r = 0.957^{**}$) and Zn with Mn, Fe, and Cu, indicating close associations in their availability.

Table 2: Simple correlation amongst texture, physico-chemical and chemical properties of irrigated deep red surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P ₂ O ₅	K ₂ O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.501 ^{NS}	1.000											
Clay	-0.683 ^{**}	-0.290 ^{NS}	1.000										
pH	0.404 ^{NS}	0.105 ^{NS}	-0.537 [*]	1.000									
EC	-0.326 ^{NS}	0.889 ^{**}	-0.389 ^{NS}	0.289 ^{NS}	1.000								
OC	-0.090 ^{NS}	0.362 ^{NS}	-0.206 ^{NS}	0.427 ^{NS}	0.399 ^{NS}	1.000							
N	0.125 ^{NS}	0.144 ^{NS}	-0.261 ^{NS}	0.386 ^{NS}	0.379 ^{NS}	0.710 ^{**}	1.000						
P ₂ O ₅	1.000 ^{**}	-0.501 ^{NS}	-0.683 ^{**}	0.404 ^{NS}	-0.326 ^{NS}	-0.090 ^{NS}	0.125 ^{NS}	1.000					
K ₂ O	-0.393 ^{NS}	0.285 ^{NS}	0.198 ^{NS}	-0.097 ^{NS}	0.163 ^{NS}	0.243 ^{NS}	-0.098 ^{NS}	-0.393 ^{NS}	1.000				
Zn	-0.555 [*]	-0.204 ^{NS}	0.786 ^{**}	-0.805 ^{**}	-0.417 ^{NS}	-0.220 ^{NS}	-0.352 ^{NS}	-0.555 [*]	0.130 ^{NS}	1.000			
Mn	-0.437 ^{NS}	-0.291 ^{NS}	0.730 ^{**}	-0.923 ^{**}	-0.387 ^{NS}	-0.349 ^{NS}	-0.215 ^{NS}	-0.437 ^{NS}	0.023 ^{NS}	0.839 ^{**}	1.000		
Fe	-0.633 [*]	-0.196 ^{NS}	0.865 ^{**}	-0.819 ^{**}	-0.412 ^{NS}	-0.439 ^{NS}	-0.461 ^{NS}	-0.633 [*]	0.183 ^{NS}	0.863 ^{**}	0.854 ^{**}	1.000	
Cu	-0.642 ^{**}	-0.258 ^{NS}	0.929 ^{**}	-0.769 ^{**}	-0.420 ^{NS}	-0.343 ^{NS}	-0.389 ^{NS}	-0.642 ^{**}	0.174 ^{NS}	0.905 ^{**}	0.867 ^{**}	0.957 ^{**}	1.000

** star and * star denote significant correlation (2-tailed) at 0.01 level and 0.05 level, respectively

Irrigated deep red soils (sub-surface)

The correlation analysis of irrigated deep red sub-surface cotton-growing soils of Nagarkurnool district revealed several significant relationships among texture, physico-chemical, and chemical properties (Table 3). Clay content was positively and significantly correlated with micronutrients, particularly Zn ($r = 0.783$), Fe ($r = 0.698$), and Cu ($r = 0.877^{**}$). Soil pH showed a

significant negative correlation with clay ($r = -0.515$) and exhibited strong negative correlations with Zn ($r = -0.799$), Fe ($r = -0.789$), and Cu ($r = -0.741$). Electrical conductivity (EC) was positively correlated with silt ($r = 0.516$) and pH ($r = 0.526$), but negatively correlated with clay ($r = -0.570$), indicating an inverse relationship between salinity and finer soil fractions.

Table 3: Simple correlation amongst texture, physico-chemical and chemical properties of irrigated deep red sub surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P ₂ O ₅	K ₂ O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.382 ^{NS}	1.000											
Clay	-0.576*	-0.535*	1.000										
pH	0.154 ^{NS}	0.423 ^{NS}	-0.515*	1.000									
EC	0.124 ^{NS}	0.516*	-0.570*	0.526*	1.000								
OC	0.021 ^{NS}	-0.335 ^{NS}	0.279 ^{NS}	-0.217 ^{NS}	-0.237 ^{NS}	1.000							
N	0.386 ^{NS}	-0.387 ^{NS}	-0.009 ^{NS}	-0.158 ^{NS}	-0.300 ^{NS}	0.512 ^{NS}							
P ₂ O ₅	0.051 ^{NS}	-0.218 ^{NS}	0.149 ^{NS}	0.030 ^{NS}	-0.348 ^{NS}	0.428 ^{NS}	0.129 ^{NS}	1.000					
K ₂ O	0.319 ^{NS}	0.079 ^{NS}	-0.361 ^{NS}	0.163 ^{NS}	0.466 ^{NS}	-0.473 ^{NS}	-0.357 ^{NS}	-0.581*	1.000				
Zn	-0.422 ^{NS}	-0.450 ^{NS}	0.783**	-0.799**	-0.406 ^{NS}	0.149 ^{NS}	-0.027 ^{NS}	-0.130 ^{NS}	-0.026 ^{NS}	1.000			
Mn	-0.197 ^{NS}	-0.103 ^{NS}	0.277 ^{NS}	-0.161 ^{NS}	-0.369 ^{NS}	0.114 ^{NS}	0.039 ^{NS}	0.454 ^{NS}	-0.307 ^{NS}	0.078 ^{NS}			
Fe	-0.265 ^{NS}	-0.517*	0.698**	-0.789**	-0.341 ^{NS}	-0.014 ^{NS}	-0.146 ^{NS}	-0.191 ^{NS}	0.124 ^{NS}	0.886**	0.188 ^{NS}	1.000	1.000
Cu	-0.425 ^{NS}	-0.552*	0.877**	-0.741**	-0.453 ^{NS}	0.152 ^{NS}	-0.016 ^{NS}	-0.173 ^{NS}	-0.063 ^{NS}	0.916**	0.102 ^{NS}	0.878**	1

** star and * star denote significant correlation (2-tailed) at 0.01 level and 0.05 level, respectively

Rainfed deep red soils (surface)

In rainfed deep red surface soils, (table 4) clay content exhibited positive correlations with Zn ($r = 0.649^{**}$), Mn ($r = 0.479$), Fe ($r = 0.068$) and Cu ($r = 0.807^{**}$). Soil pH showed a significant positive correlation with available P₂O₅ ($r = 0.567^{*}$), but was negatively correlated with Zn ($r = -0.722^{**}$), Mn ($r = -$

0.732**), Fe ($r = -0.556^{*}$) and Cu ($r = -0.586^{*}$). Organic carbon (OC) exhibited a very strong positive correlation with available nitrogen ($r = 0.941^{**}$) and a moderate positive correlation with P₂O₅ ($r = 0.534^{*}$). Available nitrogen was also moderately correlated with P₂O₅ ($r = 0.632^{*}$).

Table 4: Simple correlation amongst texture, physico-chemical and chemical properties of rainfed deep red surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P ₂ O ₅	K ₂ O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.46	1.000											
Clay	-0.71**	-0.298	1.000										
pH	-0.253	0.482	-0.11	1.000									
EC	-0.436	0.323	0.213	0.54*	1.000								
OC	0.059	0.01	-0.072	0.09	0.151	1.000							
N	0.045	0.057	-0.094	0.12	0.234	0.941**	1.000						
P ₂ O ₅	0.032	0.471	-0.407	0.567*	0.171	0.534*	0.632*	1.000					
K ₂ O	0.372	-0.308	-0.155	-0.172	0.04	-0.06	0.031	-0.031	1.000				
Zn	-0.279	-0.44	0.649**	-0.722**	-0.256	0.036	0.017	-0.562*	0.049	1.000			
Mn	-0.223	-0.301	0.479	-0.732**	-0.309	-0.015	-0.116	-0.609*	-0.378	0.764**	1.000		
Fe	0.203	-0.362	0.068	-0.556*	-0.407	0.162	0.056	-0.362	-0.059	0.619**	0.471	1.000	
Cu	-0.504	-0.334	0.807**	-0.586*	-0.164	0.066	0.001	-0.491	-0.175	0.899**	0.842**	0.39	1.000

** star and * star denote significant correlation (2-tailed) at 0.01 level and 0.05 level, respectively

Rainfed deep red soils (sub-surface)

In rainfed deep red sub-surface soils (Table 5), clay showed positive but non-significant associations with most nutrients and micronutrients. Zinc and Cu exhibited moderate positive correlations with clay ($r = 0.363$ and 0.362 , respectively), indicating reduced influence of texture with depth. Soil pH displayed consistent and significant negative correlations with

Zn ($r = -0.693^{**}$), Mn ($r = -0.599^{*}$), Fe ($r = -0.557^{*}$) and Cu ($r = -0.550^{*}$). Organic carbon was significantly correlated with available N ($r = 0.549^{*}$) and P₂O₅ ($r = 0.584^{*}$). Among micronutrients, strong positive interrelationships were observed, particularly between Zn and Cu ($r = 0.897^{**}$), and moderate correlations of Zn with Mn ($r = 0.673^{**}$) and Fe ($r = 0.633^{*}$).

Table 5: Simple correlation amongst texture, physico-chemical and chemical properties of rainfed deep red sub surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P ₂ O ₅	K ₂ O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.65**	1.000											
Clay	-0.897***	0.248	1.000										
pH	-0.28	0.395	0.127	1.000									
EC	-0.468	0.521*	0.294	0.516*	1.000								
OC	0.324	-0.036	-0.392	-0.157	-0.065	1.000							
N	-0.03	-0.024	0.053	0.156	-0.217	0.549*	1.000						
P ₂ O ₅	0.249	0.085	-0.366	0.224	0.098	0.584*	0.468	1.000					
K ₂ O	-0.409	0.259	0.371	-0.295	0.305	0.143	-0.119	-0.152	1.000				
Zn	-0.247	-0.084	0.363	-0.693**	-0.301	-0.037	-0.031	-0.413	0.325	1.000			
Mn	0.002	-0.338	0.194	-0.599*	-0.366	-0.002	0.198	-0.078	-0.184	0.673**	1.000		
Fe	0.019	-0.184	0.083	-0.557*	-0.456	-0.106	0.14	-0.296	-0.084	0.633*	0.812*	1.000	
Cu	-0.214	-0.154	0.362	-0.55*	-0.147	0.02	-0.112	-0.278	0.155	0.897**	0.661**	0.461	1.000

** star and * star denote significant correlation (2-tailed) at 0.01 level and 0.05 level, respectively

Table 6: Simple correlation amongst texture, physico-chemical and chemical properties of irrigated shallow red surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P ₂ O ₅	K ₂ O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.882**	1.000											
Clay	-0.472 ^{NS}	0.005 ^{NS}	1.000										
pH	-0.031 ^{NS}	0.010 ^{NS}	0.063 ^{NS}	1.000									
EC	-0.242 ^{NS}	0.147 ^{NS}	0.269 ^{NS}	0.474 ^{NS}	1.000								
OC	-0.422 ^{NS}	0.097 ^{NS}	0.741**	0.358 ^{NS}	0.233 ^{NS}	1.000							
N	0.000 ^{NS}	-0.148 ^{NS}	0.324 ^{NS}	0.555*	0.004 ^{NS}	0.745**	1.000						
P ₂ O ₅	-0.176 ^{NS}	0.049 ^{NS}	0.331 ^{NS}	0.489 ^{NS}	0.296 ^{NS}	0.424 ^{NS}	0.416 ^{NS}	1.000					
K ₂ O	-0.467 ^{NS}	0.554*	-0.019 ^{NS}	-0.042 ^{NS}	0.053 ^{NS}	-0.048 ^{NS}	0.064 ^{NS}	-0.127 ^{NS}	1.000				
Zn	-0.192 ^{NS}	-0.117 ^{NS}	0.599*	-0.664**	-0.205 ^{NS}	0.185 ^{NS}	-0.219 ^{NS}	-0.374 ^{NS}	-0.048 ^{NS}	1.000			
Mn	-0.070 ^{NS}	-0.163 ^{NS}	0.429 ^{NS}	-0.657**	-0.441 ^{NS}	0.312 ^{NS}	0.029 ^{NS}	-0.408 ^{NS}	-0.020 ^{NS}	0.820**	1.000		
Fe	-0.131 ^{NS}	-0.120 ^{NS}	0.475 ^{NS}	-0.438 ^{NS}	-0.118 ^{NS}	0.159 ^{NS}	-0.055 ^{NS}	-0.047 ^{NS}	0.046 ^{NS}	0.521*	0.535*	1.000	
Cu	-0.432 ^{NS}	0.018 ^{NS}	0.872**	-0.385 ^{NS}	0.020 ^{NS}	0.510 ^{NS}	0.025 ^{NS}	-0.048 ^{NS}	0.014 ^{NS}	0.858**	0.738**	0.632*	1.000

** star and * star denote significant correlation (2-tailed) at 0.01 level and 0.05 level, respectively

Irrigated shallow red soils (surface)

The correlation analysis of irrigated shallow red surface soils (Table 6) revealed a strong negative correlation between sand and silt ($r = -0.882$), indicating contrasting distribution of textural fractions. Clay showed a significant positive correlation with OC ($r = 0.741$), while OC was strongly correlated with available N ($r = 0.745$). Zinc exhibited a positive correlation with clay ($r = 0.599$) and a strong negative correlation with pH ($r = -0.664$). Manganese showed a similar negative relationship with pH ($r = -0.657$) and a strong positive association with Zn ($r = 0.820$). Copper showed the strongest positive correlation with clay ($r = 0.872$).

Irrigated shallow red soils (sub-surface)

In irrigated shallow red sub-surface soils (Table 7), sand was strongly and negatively correlated with silt ($r = -0.781$ **). Clay exhibited strong positive correlations with Zn ($r = 0.856$ **), Mn ($r = 0.664$ **) and Cu ($r = 0.948$ **). Soil pH did not show significant relationships with texture but was negatively correlated with Mn ($r = -0.707$ **) and Fe ($r = -0.603$ *). Organic carbon showed weak and non-significant correlations with available N and P₂O₅. Available P₂O₅ exhibited negative but non-significant associations with Zn ($r = -0.507$) and Cu ($r = -0.416$). Copper showed the strongest association with clay among all micronutrients.

Table 7: Simple correlation amongst texture, physico-chemical and chemical properties of irrigated shallow red sub surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P ₂ O ₅	K ₂ O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.781**	1.000											
Clay	-0.484 ^{NS}	-0.169 ^{NS}	1.000										
pH	0.075 ^{NS}	-0.049 ^{NS}	-0.049 ^{NS}	1.000									
EC	-0.021 ^{NS}	0.010 ^{NS}	0.018 ^{NS}	0.483 ^{NS}	1.000								
OC	-0.202 ^{NS}	0.199 ^{NS}	0.039 ^{NS}	-0.121 ^{NS}	-0.200 ^{NS}	1.000							
N	-0.039 ^{NS}	0.155 ^{NS}	-0.156 ^{NS}	-0.160 ^{NS}	-0.457 ^{NS}	0.398 ^{NS}	1.000						
P ₂ O ₅	0.157 ^{NS}	0.170 ^{NS}	-0.486 ^{NS}	-0.142 ^{NS}	0.033 ^{NS}	0.506 ^{NS}	-0.129 ^{NS}	1.000					
K ₂ O	-0.269 ^{NS}	0.318 ^{NS}	-0.021 ^{NS}	0.044 ^{NS}	0.201 ^{NS}	0.180 ^{NS}	-0.208 ^{NS}	0.280 ^{NS}	1.000				
Zn	-0.244 ^{NS}	-0.336 ^{NS}	0.856**	-0.407 ^{NS}	-0.131 ^{NS}	-0.007 ^{NS}	0.052 ^{NS}	-0.507 ^{NS}	-0.166 ^{NS}	1.000			
Mn	-0.271 ^{NS}	-0.169 ^{NS}	0.664**	-0.707**	-0.365 ^{NS}	0.102 ^{NS}	-0.100 ^{NS}	-0.085 ^{NS}	-0.034 ^{NS}	0.793**	1.000		
Fe	-0.066 ^{NS}	-0.210 ^{NS}	0.398 ^{NS}	-0.603*	-0.263 ^{NS}	0.378 ^{NS}	0.260 ^{NS}	-0.037 ^{NS}	-0.117 ^{NS}	0.643**	0.620*	1.000	
Cu	-0.485 ^{NS}	-0.130 ^{NS}	0.948**	-0.331 ^{NS}	-0.168 ^{NS}	0.111 ^{NS}	-0.025 ^{NS}	-0.416 ^{NS}	-0.007 ^{NS}	0.911**	0.824**	0.551*	1.000

** star and * star denote significant correlation (2-tailed) at 0.01 level and 0.05 level, respectively

Rainfed shallow red soils (surface)

In rainfed shallow red surface soils (Table 8), sand showed strong negative correlations with silt ($r = -0.794^{**}$) and clay ($r = -0.541^{*}$). Clay was significantly and positively correlated with Zn ($r = 0.732^{**}$), Mn ($r = 0.704^{**}$), Fe ($r = 0.580^{*}$) and Cu ($r =$

0.862^{**}). Soil pH exhibited strong negative correlations with Zn ($r = -0.556^{*}$), Mn ($r = -0.672^{**}$), Fe ($r = -0.753^{**}$) and Cu ($r = -0.541^{*}$). Organic carbon was strongly correlated with available N ($r = 0.767^{**}$).

Table 8: Simple correlation amongst texture, physico-chemical and chemical properties of rainfed shallow red surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P ₂ O ₅	K ₂ O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.794 ^{**}	1.000											
Clay	-0.541 [*]	-0.082 ^{NS}	1.000										
pH	0.131 ^{NS}	-0.071 ^{NS}	-0.116 ^{NS}	1.000									
EC	0.248 ^{NS}	-0.070 ^{NS}	-0.311 ^{NS}	0.545 [*]	1.000								
OC	0.098 ^{NS}	0.092 ^{NS}	-0.289 ^{NS}	-0.043 ^{NS}	-0.179 ^{NS}	1.000							
N	0.128 ^{NS}	0.268 ^{NS}	-0.581 [*]	-0.143 ^{NS}	-0.134 ^{NS}	0.767 ^{**}	1.000						
P ₂ O ₅	0.092 ^{NS}	-0.190 ^{NS}	0.111 ^{NS}	0.401 ^{NS}	0.179 ^{NS}	0.083 ^{NS}	-0.163 ^{NS}	1.000					
K ₂ O	-0.028 ^{NS}	0.309 ^{NS}	-0.382 ^{NS}	-0.530 [*]	-0.537 [*]	0.330 ^{NS}	0.549 [*]	-0.525 [*]	1.000				
Zn	-0.425 ^{NS}	-0.026 ^{NS}	0.732 ^{**}	-0.556 [*]	-0.248 ^{NS}	-0.471 ^{NS}	-0.541 [*]	-0.188 ^{NS}	-0.172 ^{NS}	1.000			
Mn	-0.519 [*]	0.107 ^{NS}	0.704 ^{**}	-0.672 ^{**}	-0.655 ^{**}	-0.029 ^{NS}	-0.227 ^{NS}	-0.253 ^{NS}	0.085 ^{NS}	0.758 ^{**}	1.000		
Fe	-0.487 ^{NS}	0.158 ^{NS}	0.580 [*]	-0.753 ^{**}	-0.593 [*]	-0.037 ^{NS}	-0.054 ^{NS}	-0.189 ^{NS}	0.115 ^{NS}	0.799 ^{**}	0.863 ^{**}	1.000	
Cu	-0.517 [*]	-0.011 ^{NS}	0.862 ^{**}	-0.541 [*]	-0.482 ^{NS}	-0.257 ^{NS}	-0.418 ^{NS}	-0.123 ^{NS}	-0.126 ^{NS}	0.881 ^{**}	0.915 ^{**}	0.827 ^{**}	1.000

** star and * star denote significant correlation (2-tailed) at 0.01 level and 0.05 level, respectively

Table 9: Simple correlation amongst texture, physico-chemical and chemical properties of rainfed shallow red sub surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P ₂ O ₅	K ₂ O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.922 ^{**}	1.000											
Clay	-0.678 ^{**}	0.340 ^{NS}	1.000										
pH	0.058 ^{NS}	0.051 ^{NS}	-0.238 ^{NS}	1.000									
EC	0.325 ^{NS}	-0.436 ^{NS}	0.039 ^{NS}	-0.150 ^{NS}	1.000								
OC	0.251 ^{NS}	-0.114 ^{NS}	-0.392 ^{NS}	-0.072 ^{NS}	0.061 ^{NS}	1.000							
N	0.053 ^{NS}	-0.031 ^{NS}	-0.070 ^{NS}	-0.075 ^{NS}	0.004 ^{NS}	0.871 ^{**}	1.000						
P ₂ O ₅	0.480 ^{NS}	-0.459 ^{NS}	-0.294 ^{NS}	0.186 ^{NS}	-0.097 ^{NS}	0.422 ^{NS}	0.280 ^{NS}	1.000					
K ₂ O	-0.362 ^{NS}	0.314 ^{NS}	0.282 ^{NS}	-0.349 ^{NS}	-0.352 ^{NS}	0.279 ^{NS}	0.259 ^{NS}	0.079 ^{NS}	1.000				
Zn	-0.342 ^{NS}	0.244 ^{NS}	0.368 ^{NS}	-0.714 ^{**}	0.162 ^{NS}	-0.096 ^{NS}	-0.158 ^{NS}	-0.292 ^{NS}	0.196 ^{NS}	1.000			
Mn	-0.296 ^{NS}	0.264 ^{NS}	0.218 ^{NS}	-0.611 [*]	-0.102 ^{NS}	-0.058 ^{NS}	-0.187 ^{NS}	-0.143 ^{NS}	0.376 ^{NS}	0.765 ^{**}	1.000		
Fe	-0.140 ^{NS}	0.145 ^{NS}	0.064 ^{NS}	-0.703 ^{**}	-0.035 ^{NS}	0.056 ^{NS}	-0.039 ^{NS}	-0.118 ^{NS}	0.169 ^{NS}	0.843 ^{**}	0.838 ^{**}	1.000	
Cu	-0.283 ^{NS}	0.174 ^{NS}	0.356 ^{NS}	-0.698 ^{**}	-0.032 ^{NS}	-0.237 ^{NS}	-0.259 ^{NS}	-0.270 ^{NS}	0.185 ^{NS}	0.824 ^{**}	0.932 ^{**}	0.840 ^{**}	1.000

** star and * star denote significant correlation (2-tailed) at 0.01 level and 0.05 level, respectively

Rainfed shallow red soils (sub-surface)

The correlation analysis of rainfed shallow red sub-surface soils (Table 9) revealed highly significant negative correlations of sand with silt ($r = -0.922^{**}$) and clay ($r = -0.678^{**}$). Soil pH showed strong negative correlations with Zn ($r = -0.714^{**}$), Mn ($r = -0.611^{*}$), Fe ($r = -0.703^{**}$) and Cu ($r = -0.698^{**}$). Electrical conductivity did not exhibit significant correlations with nutrients or organic carbon. Organic carbon was strongly and positively correlated with available N ($r = 0.871^{**}$), while its association with P₂O₅ was moderate and non-significant.

The correlation analysis across irrigated and rainfed black soils of Nagarkurnool district clearly demonstrates the dominant influence of soil texture, particularly clay content, soil reaction, and organic carbon on nutrient and micronutrient availability. The consistently strong positive correlations between clay and micronutrients such as Zn, Cu, and Fe across surface and sub-surface layers indicate that finer-textured black soils enhance micronutrient retention through greater specific surface area, higher cation exchange capacity, and stronger adsorption sites. These findings are in agreement with earlier reports that emphasize the role of clay minerals in regulating micronutrient dynamics in Vertisols and associated black soils (Alloway, 2008; Satyavathi and Reddy, 2004; Meena *et al.*, 2006)^[1, 17, 12].

Soil pH emerged as a key controlling factor for micronutrient availability in black soils. The negative correlations observed between pH and Zn, Mn, and Cu in both irrigated and rainfed conditions suggest reduced solubility of these micronutrients under alkaline soil reaction. Such relationships are well documented in black soils, where increasing pH promotes precipitation and adsorption of micronutrients as hydroxides or carbonates, thereby limiting their availability to crops. The significant negative association of Zn with pH in particular indicates a strong risk of pH-induced Zn deficiency in these soils, as also reported (Thakur *et al.*, 2011, Jatav *et al.*, 2020, and Shukla and Behera, 2017^[22, 9, 19]). Organic carbon showed a consistently strong positive relationship with available nitrogen across all black soil groups, highlighting the central role of soil organic matter in nitrogen mineralization and nutrient cycling. The positive correlations between OC and available P₂O₅ in several soil conditions further suggest that organic matter may contribute to phosphorus availability by reducing fixation and enhancing P solubilization through organic ligand formation (Negash and Mohammed, 2014, Singh *et al.*, 2015, and Braos *et al.*, 2023)^[12, 20, 2]. However, the generally weak relationships between OC and micronutrients indicate that in black soils, clay content and soil pH exert a stronger control over micronutrient

availability than organic matter alone.

The observed positive inter-correlations among micronutrients, particularly between Zn, Cu, and Fe, indicate that these elements tend to co-vary under similar pedogenic and management conditions. This co-variation reflects their common association with clay minerals and their similar sensitivity to soil reaction. Such strong interrelationships imply that micronutrient deficiencies in black soils are likely to occur simultaneously rather than in isolation, especially under high pH conditions and intensive cultivation (Kumar *et al.*, 2016), and Alloway, 2008) [10, 1].

The generally weak or non-significant relationships of available potassium with other soil properties across black soils suggest that K availability is governed more by mineralogical composition and exchangeable K pools rather than by organic matter or soil reaction. Similarly, the occasional negative association between available P_2O_5 and Zn observed in some soil groups supports the occurrence of phosphate-induced Zn antagonism, a common phenomenon in fertilized black soils receiving high P inputs (Prasad *et al.*, 2016; Hafeez *et al.*, 2013) [16, 7].

Overall, the results underscore that in black soils of Nagarkurnool district, clay content and soil pH are the principal regulators of micronutrient availability, while organic carbon primarily governs nitrogen and, to a lesser extent, phosphorus availability. These interactions highlight the need for integrated soil management strategies that consider texture, organic matter status, and soil reaction to sustain nutrient availability and cotton productivity in black soil regions.

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Competing Interests

Authors have declared that no competing interests exist

References

- Alloway BJ. Zinc in soils and crop nutrition. Paris: International Zinc Association and International Fertilizer Industry Association; 2008.
- Braos LB, Carlos RS, Bettiol ACT, Bergamasco MAM, Terçariol MC, Ferreira ME, *et al.* Soil carbon and nitrogen forms and their relationship with nitrogen availability affected by cover crop species and nitrogen fertilizer doses. *Nitrogen*. 2023;4(1):85-101.
- Celi L, Said-Pullicino D, Bol R, Lang F, Luster J. Interconnecting soil organic matter with nitrogen and phosphorus cycling. In: Multi-scale biogeochemical processes in soil ecosystems: critical reactions and resilience to climate changes. 2022. p. 51-77.
- Chen L, Li C, Feng Q, Wei Y, Zhao Y, Zhu M, *et al.* Direct and indirect impacts of ionic components of saline water on irrigated soil chemical and microbial processes. *Catena*. 2019;172:581-589.
- Fageria NK, Baligar VC, Jones CA. Growth and mineral nutrition of field crops: nutrient interactions and crop response. *J Plant Nutr*. 2011;34:1863-1881.
- Gondal AH, Hussain I, Ijaz AB, Zafar A, Ch BI, Zafar H, *et al.* Influence of soil pH and microbes on mineral solubility and plant nutrition: a review. *Int J Agric Biol Sci*. 2021;5(1):71-81.
- Hafeez BMKY, Khanif YM, Saleem M. Role of zinc in plant nutrition: a review. *Am J Exp Agric*. 2013;3(2):374-391.
- Jackson ML. Soil chemical analysis. New Delhi: Prentice Hall of India Pvt Ltd; 1973.
- Jatav HS, Sharma LD, Sadhukhan R, Singh SK, Singh S, Rajput VD, *et al.* An overview of micronutrients: prospects and implication in crop production. In: *Plant micronutrients: deficiency and toxicity management*. Elsevier; 2020. p. 1-30.
- Kumar A, Choudhary AK, Pooniya V, Suri VK, Singh U. Soil factors associated with micronutrient acquisition in crops: biofortification perspective. In: *Biofortification of food crops*. New Delhi: Springer; 2016. p. 159-176.
- Lindsay WL, Norvell WA. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Sci Soc Am J*. 1978;42:421-428.
- Meena HB, Sharma RP, Rawat US. Status of macro and micronutrients in some soils of Tonk district of Rajasthan. *J Indian Soc Soil Sci*. 2006;54(4):508-512.
- Negash H, Mohammed M. Soil fertility in Koka Nagawo area of Lumme district in East Shoa zone of Oromia region, Ethiopia. *East Afr J Sci*. 2014;8(1):1-12.
- Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. Washington DC; 1954.
- Piper CS. Soil and plant analysis. Bombay: Hans Publishers; 1966.
- Prasad R, Shivay YS, Kumar D. Interactions of zinc with other nutrients in soils and plants: a review. *Indian J Fertilisers*. 2016;12(5):16-26.
- Satyavathi PLA, Reddy MS. Distribution of DTPA-extractable micronutrients in soils of Telangana and Andhra Pradesh. *Agropedology*. 2004;14(1):32-37.
- Schapel A, Bell R, Yeap S, Hall D. Sandy soil constraints: organic and clay amendments to improve the productivity of sandy soils. In: *Soil constraints and productivity*. CRC Press; 2023. p. 343-364.
- Shukla AK, Behera SK, Prakash C. Micronutrient research in India: retrospect and prospects. *J Indian Soc Soil Sci*. 2014;62(4):287-306.
- Singh YP, Raghubanshi BPS, Tomar RS, Verma SK, Dubey SK. Soil fertility status and correlation of available macro and micronutrients in Chambal region of Madhya Pradesh. *J Indian Soc Soil Sci*. 2015;62(4):369-375.
- Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. *Curr Sci*. 1956;25:259-260.
- Thakur R, Kaurav DL, Singh M. Profile distribution of micronutrient cations in a Vertisol as influenced by long-term application of manure and fertilizers. *J Indian Soc Soil Sci*. 2011;59(3):239-244.
- Walkley A, Black IA. An examination of the Kjeldahl method for determining soil organic matter. *Soil Sci*. 1934;37:29-38.