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CORRELATION ANALYSIS OF TEXTURE, PHYSICO-CHEMICAL PROPERTIES AND NUTRIENT AVAILABILITY IN BLACK COTTON-GROWING SOILS OF NAGARKURNOOL DISTRICT TELANGANA INDIA

K. Navya[1*], A. Madhavi[2], T. Prabhakar Reddy[3], P. Leela Rani[4] and D. Srinivasa Chary[1]

[1] Department of Soil Science and Agricultural Chemistry, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad – 500030, India

[2] Soil Health Unit, Agricultural Research Station, PJTSAU, Rajendranagar, Hyderabad – 500030, India

[3] Agroclimate Research Centre, Agricultural Research Station, PJTSAU, Rajendranagar, Hyderabad – 500030, India

[4] Department of Applied Agriculture and Basic Statistics, College of Agricultural Engineering, PJTSAU, Kandi – 502285, India

*Corresponding author E-mail: navyakaringula49@gmail.com

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ABSTRACT

Black cotton-growing soils of semi-arid regions are inherently fertile but often exhibit micronutrient constraints due to high clay content, alkaline reaction, and intensive cultivation. The present study examined the interrelationships among soil texture, physico-chemical properties, and nutrient availability in irrigated and rainfed black cotton growing soils of Nagarkurnool district, Telangana. A total of 120 cotton growing soil samples representing shallow and deep profiles under rainfed and irrigated were collected from surface and sub-surface layers during the 2023 *kharif* season and analyzed for texture, pH, electrical conductivity, organic carbon, available N, P_2O_5, K_2O, and DTPA-extractable Zn, Fe, Mn, and Cu. Correlation analysis revealed that clay content exerted a strong positive influence on micronutrient availability, particularly Zn, Cu, and Fe, across most soil groups. Soil pH showed consistent negative relationships with micronutrients, highlighting reduced availability under alkaline conditions. Organic carbon was strongly associated with available nitrogen and moderately related to phosphorus. Micronutrients exhibited strong positive inter-correlations. Overall, the study demonstrates that texture, soil reaction, and organic carbon are key regulators of nutrient dynamics in black soils and underscores the need for integrated, soil-specific nutrient management strategies to sustain cotton productivity.

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

Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most important commercial crops grown in semi-arid regions of India, where its productivity is strongly influenced by soil fertility and moisture availability (Hebbar *et al.*, 2016, Ping *et al.*, 2004). The crop is predominantly cultivated on black soils, which form extensive tracts across central and southern India associated with shallow soils (<25 cm) soils which generally occupy the eroded upland and deep soils and support both rainfed and irrigated cotton-based production systems (Mandal *et al.*, 2005, Koudahe *et al.*, 2021). These soils are characterized by high smectitic clay content, deep cracking, and pronounced shrink–swell behavior, which significantly affect water retention, aeration, and nutrient dynamics relevant to cotton growth (Teshave, 2023, Bandyopadhyay *et al.*, 2003). The expansive clay mineralogy imparts high cation exchange capacity and strong nutrient-retention capacity, making Vertisols chemically reactive and capable of storing substantial amounts of macro- and micronutrients (Charishma *et al.*, 2023). However, the alkaline reaction and frequent calcareousness of black soils often limit the solubility and plant availability of micronutrients such as Zn, Fe, Cu, and Mn, which are essential for cotton growth and fiber development (Riaz *et al.*, 2020, Samal and Kumar, 2020). Widespread deficiencies of Zn and Fe have been reported in cotton-growing Vertisol regions, contributing to reduced boll formation, impaired enzyme activity, and lower yields (Mamatha 3.2007, Ahmed *et al*., 2020).

Soil organic carbon plays a central role in nutrient cycling in these soils by regulating nitrogen mineralization, phosphorus availability, and the chelation of micronutrients through organic ligands (Dhliawal *et al*., 2024, Celi *et al*., 2002, Srinivasarao *et al*., 2014). The interactions among soil texture, pH, and organic matter are therefore critical in determining nutrient mobility, retention, and bioavailability in black soils under cotton-based systems (Bashir *et al*., 2021). Correlation analysis is a widely used diagnostic tool to identify the dominant soil factors influencing nutrient availability and to understand the interrelationships among soil properties in complex soil environments (Fageria *et al*., 2011). Such analyses are particularly relevant in Vertisols, where strong associations between clay content, soil reaction, and micronutrient concentrations have been documented across multiple agro-ecological zones (Ebong *et al*., 2022; Shukla *et al*., 2016). Understanding these relationships is essential for developing site-specific nutrient management strategies aimed at improving soil fertility, correcting micronutrient imbalances, and sustaining cotton productivity in black soil regions (Hosamani *et al*., 2023; Sanjiv kumar *et al*., 2025). In this context, the present study investigates the correlation patterns among texture, physico-chemical properties, and macro- and micronutrient availability in irrigated and rainfed black soils of Nagarkurnool district, with the objective of identifying the key soil factors governing nutrient dynamics across surface and sub-surface horizons.

Material and Methods

The cotton-growing soils of the study area were classified into eight categories soil depth (shallow and deep) and production environment (irrigated and rainfed) and sampling depth (surface and sub surface). A total of 120 representative farmer fields were randomly selected across major cotton-growing regions of Nagarkurnool district following a preliminary survey. From each of the eight soil categories, 15 fields were sampled at two depths, resulting in 120 soil samples (Table 2.1). Soil samples were collected during the *kharif* season of 2023, prior to cotton sowing. In each field, surface (0–15 cm) and sub surface (15-30 cm) samples were obtained using the standard zig-zag sampling method to capture field variability.

Details of soil sampling

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

The collected soil samples were air-dried, gently ground and passed through a 2 mm sieve before laboratory analysis. The sieved samples were stored in labeled plastic bags to prevent contamination and were processed following standard soil laboratory procedures. Physico-chemical analyses included the determination of soil pH and electrical conductivity (EC) using a soil–water suspension (1:2.5), where pH was measured with a calibrated digital pH meter and EC with a conductivity meter as outlined by Jackson (1973). Organic carbon content was estimated using the Walkley and Black wet oxidation method (Walkley and Black, 1935). Available nitrogen was determined by the alkaline permanganate method (Subbiah and Asija, 1956), while available phosphorus was measured using the Olsen extraction method (Olsen *et al.,* 1954). Available potassium was extracted using neutral normal ammonium acetate and quantified accordingly. Micronutrients including Fe, Cu, Zn, and Mn were extracted by DTPA and estimated using an Atomic Absorption Spectrophotometer following the procedure of Lindsay and Norvell (1978).

Results and Discussion

Irrigated deep black soils

The simple correlation analysis among texture, physico-chemical, and chemical properties of irrigated deep black surface soils of Nagarkurnool district (Table 1) revealed significant associations among soil constituents. Clay content exhibited strong and significant positive correlations with zinc (Zn; r = 0.799**) and copper (Cu; r = 0.726**), indicating enhanced micronutrient retention in finer-textured soils. Soil pH showed a significant positive correlation with available phosphorus (P_2O_5; r = 0.523*) but was negatively correlated with Zn (r = –0.679**). Organic carbon (OC) was significantly correlated with available nitrogen (N; r = 0.682**) and P_2O_5 (r = 0.548*), though its associations with texture and pH were weak. Among micronutrients, Zn also showed a significant positive correlation with Cu (r = 0.657**). In irrigated deep black sub-surface soils (Table 2), clay showed positive but non-significant correlations with pH and OC, while exhibiting significant positive correlations with Cu (r = 0.704**) and Zn (r = 0.555*). Soil pH was positively correlated with available P_2O_5 (r = 0.625*). Organic carbon showed a highly significant positive correlation with available N (r = 0.691**) and manganese (Mn; r = 0.685**). Zinc was significantly correlated with clay (r = 0.555*) and Cu (r = 0.526*), while Mn was positively correlated with OC (r = 0.685**) and Zn (r = 0.527*). Available potassium (K_2O) showed only weak, non-significant relationships with other soil properties.

Rainfed deep black soils

The correlation analysis of rainfed deep black surface soils (Table 3) revealed that clay was significantly and positively correlated with Zn (r = 0.767), iron (Fe; r = 0.724), and Cu (r = 0.723). Organic carbon showed a positive correlation with Cu (r = 0.522), while available N was strongly correlated with OC (r = 0.699*). Zinc was positively correlated with clay but negatively associated with available P_2O_5 (r = –0.517). Manganese exhibited a significant negative correlation with soil pH (r = –0.550). In rainfed deep black sub-surface soils (Table 4), soil pH showed weak and non-significant associations with most properties. Organic carbon was significantly correlated with available N (r = 0.637*) and P_2O_5 (r = 0.578*), while available N was also positively correlated with P_2O_5 (r = 0.527*). Among micronutrients, Zn exhibited strong positive correlations with clay (r = 0.681**), Fe (r = 0.744**), and Cu (r = 0.883**). Iron and Cu were also positively and significantly associated with clay content.

Irrigated shallow black soils

In irrigated shallow black surface soils (Table 5), soil pH was positively but non-significantly correlated with clay (r = 0.438) and negatively correlated with Mn (r = –0.550*). Organic carbon showed a significant positive correlation with available N (r = 0.595*). Zinc was significantly correlated with clay (r = 0.767**), Fe (r = 0.804**), and Cu (r = 0.706**), but negatively correlated with P_2O_5 (r = –0.517*). Iron and Cu also exhibited strong positive correlations with clay.

Table 1 : Simple correlation amongst texture, physico-chemical and chemical properties of irrigated deep black surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P_2O_5	K_2O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.297^{NS}	1.000											
Clay	-0.849**	-0.249^{NS}	1.000										
pH	0.533*	-0.264^{NS}	-0.393^{NS}	1.000									
EC	-0.445^{NS}	-0.199^{NS}	0.572*	-0.134^{NS}	1.000								
OC	-0.078^{NS}	0.412^{NS}	-0.126^{NS}	-0.064^{NS}	0.247^{NS}	1.000							
N	0.087^{NS}	-0.006^{NS}	-0.064^{NS}	0.110^{NS}	0.359^{NS}	0.682**	1.000						
P	0.099^{NS}	0.040^{NS}	-0.099^{NS}	0.523*	0.142^{NS}	0.548*	0.340^{NS}	1.000					
K	0.247^{NS}	-0.131^{NS}	-0.183^{NS}	0.075^{NS}	0.392^{NS}	0.294^{NS}	0.495^{NS}	-0.113^{NS}	1.000				
Zn	-0.855**	0.139^{NS}	0.799**	-0.679**	0.421^{NS}	-0.055^{NS}	-0.126^{NS}	-0.258^{NS}	-0.225^{NS}	1.000			
Mn	-0.386^{NS}	-0.146^{NS}	0.481^{NS}	-0.309^{NS}	0.348^{NS}	0.198^{NS}	0.465^{NS}	-0.030^{NS}	0.322^{NS}	0.366^{NS}	1.000		
Fe	-0.330^{NS}	-0.205^{NS}	0.458^{NS}	-0.392^{NS}	0.076^{NS}	0.039^{NS}	0.051^{NS}	-0.095^{NS}	0.238^{NS}	0.426^{NS}	0.701**	1.000	
Cu	-0.615*	-0.158^{NS}	0.726**	-0.229^{NS}	0.691**	0.132^{NS}	0.359^{NS}	-0.042^{NS}	0.084^{NS}	0.657**	0.269^{NS}	0.137^{NS}	1.000

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

	Sand	Silt	Clay	pH	EC	OC	N	P_2O_5	K_2O	Zn	Mn	Fe	Cu
Sand	1.000	1											
Silt	-0.691**	1.000											
Clay	-0.636*	-0.118^{NS}	1.000										
pH	-0.131^{NS}	-0.079^{NS}	0.264^{NS}	1.000									
EC	-0.363^{NS}	0.243^{NS}	0.240^{NS}	0.544*	1.000								
OC	-0.314^{NS}	0.002^{NS}	0.429^{NS}	-0.233^{NS}	-0.087^{NS}	1.000							
N	-0.395^{NS}	0.048^{NS}	0.491^{NS}	-0.176^{NS}	0.099^{NS}	0.691**	1.000						

P	-0.183^{NS}	-0.149^{NS}	0.411^{NS}	0.625*	0.359^{NS}	0.125^{NS}	0.174^{NS}	1.000					
K	-0.220^{NS}	0.333^{NS}	-0.054^{NS}	0.128^{NS}	0.403^{NS}	0.389^{NS}	0.390^{NS}	0.086^{NS}	1.000				
Zn	-0.587*	0.235^{NS}	0.555*	-0.332^{NS}	-0.061^{NS}	0.442^{NS}	0.249^{NS}	-0.112^{NS}	-0.350^{NS}	1.000			
Mn	-0.312^{NS}	-0.053^{NS}	0.485^{NS}	-0.122^{NS}	0.106^{NS}	0.685**	0.469^{NS}	0.065^{NS}	0.261^{NS}	0.527*	1.000		
Fe	-0.130^{NS}	0.087^{NS}	0.085^{NS}	-0.245^{NS}	-0.095^{NS}	0.098^{NS}	-0.121^{NS}	-0.229^{NS}	0.079^{NS}	0.321^{NS}	0.616*	1.000	
Cu	-0.541*	0.036^{NS}	0.704**	-0.037^{NS}	0.278^{NS}	0.355^{NS}	0.546*	0.077^{NS}	0.010^{NS}	0.526*	0.321^{NS}	0.098^{NS}	1.000

In sub surface soils (table 6), Sand content showed a highly significant negative correlation with soil pH (r = –0.781), whereas clay content exhibited a significant positive correlation with pH (r = 0.587). Sand and clay were negatively correlated (r = –0.615), confirming their inverse textural relationship. Electrical conductivity was positively and significantly correlated with silt (r = 0.554). Organic carbon did not show significant correlations with texture fractions or pH; however, it was positively and significantly correlated with available nitrogen (r = 0.628). Clay content showed strong positive correlations with Zn (r = 0.690), Mn (r = 0.587), Fe (r = 0.541), and Cu (r = 0.577).

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

	Sand	Silt	Clay	pH	EC	OC	N	P_2O_5	K_2O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.319^{NS}	1.000											
Clay	-0.373^{NS}	-0.761**	1.000										
pH	-0.420^{NS}	-0.153^{NS}	0.438^{NS}	1.000									
EC	0.327^{NS}	0.471^{NS}	-0.685**	-0.213^{NS}	1.000								
OC	-0.135^{NS}	-0.101^{NS}	0.192^{NS}	0.214^{NS}	-0.134^{NS}	1.000							
N	0.168^{NS}	-0.385^{NS}	0.262^{NS}	0.278^{NS}	-0.285^{NS}	0.699**	1.000						
P	-0.020^{NS}	0.452^{NS}	-0.429^{NS}	0.142^{NS}	0.407^{NS}	0.468^{NS}	0.384^{NS}	1.000					
K	0.476^{NS}	-0.024^{NS}	-0.302^{NS}	0.033^{NS}	0.335^{NS}	-0.027^{NS}	0.274^{NS}	0.411^{NS}	1.000				
Zn	-0.243^{NS}	-0.613*	0.767**	-0.075^{NS}	-0.477^{NS}	0.112^{NS}	0.160^{NS}	-0.517*	-0.521*	1.000			
Mn	-0.061^{NS}	-0.154^{NS}	0.193^{NS}	-0.550*	-0.376^{NS}	-0.045^{NS}	-0.001^{NS}	-0.399^{NS}	-0.160^{NS}	0.508^{NS}	1.000		
Fe	-0.069^{NS}	-0.691**	0.724**	-0.021^{NS}	-0.484^{NS}	0.503^{NS}	0.508^{NS}	-0.190^{NS}	-0.272^{NS}	0.804**	0.334^{NS}	1.000	
Cu	-0.097^{NS}	-0.671**	0.723**	-0.011^{NS}	-0.389^{NS}	0.522*	0.315^{NS}	-0.318^{NS}	-0.222^{NS}	0.706**	0.403^{NS}	0.848**	1.000

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

	Sand	Silt	Clay	pH	EC	OC	N	P_2O_5	K_2O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.319^{NS}	1.000											
Clay	-0.378^{NS}	-0.757**	1.000										
pH	-0.300^{NS}	-0.161^{NS}	0.365^{NS}	1.000									
EC	0.237^{NS}	0.523*	-0.674**	-0.170^{NS}	1.000								
OC	-0.093^{NS}	-0.131^{NS}	0.192^{NS}	0.154^{NS}	-0.160^{NS}	1.000							
N	0.288^{NS}	-0.090^{NS}	-0.111^{NS}	0.139^{NS}	-0.070^{NS}	0.637*	1.000						
P	-0.133^{NS}	0.504^{NS}	-0.401^{NS}	0.203^{NS}	0.237^{NS}	0.578*	0.527*	1.000					
K	0.446^{NS}	0.004^{NS}	-0.312^{NS}	0.051^{NS}	0.422^{NS}	0.066^{NS}	0.331^{NS}	0.291^{NS}	1.000				
Zn	-0.238^{NS}	-0.529*	0.681**	-0.336^{NS}	-0.513^{NS}	0.327^{NS}	-0.002^{NS}	-0.288^{NS}	-0.208^{NS}	1.000			
Mn	-0.018^{NS}	-0.472^{NS}	0.474^{NS}	-0.431^{NS}	-0.460^{NS}	-0.036^{NS}	0.020^{NS}	-0.471^{NS}	-0.121^{NS}	0.765**	1.000		
Fe	0.161^{NS}	-0.704**	0.577*	-0.289^{NS}	-0.404^{NS}	0.265^{NS}	0.072^{NS}	-0.289^{NS}	-0.221^{NS}	0.744**	0.481^{NS}	1.000	
Cu	-0.221^{NS}	-0.419^{NS}	0.562*	-0.341^{NS}	-0.257^{NS}	0.497^{NS}	-0.029^{NS}	-0.163^{NS}	-0.182^{NS}	0.883**	0.490^{NS}	0.750**	1.000

Rainfed shallow black soils

The correlation analysis of rainfed shallow black surface soils of Nagarkurnool district is presented in Table 7. Organic carbon was significantly correlated with available nitrogen (r = 0.557*). Available phosphorus (P_2O_5) was significantly and positively correlated with copper (Cu; r = 0.555*), while other associations remained weak. Among micronutrients, zinc (Zn) displayed a highly significant positive correlation with clay (r = 0.679**). Manganese (Mn) showed a significant negative correlation with pH (r = –0.572*). Iron (Fe) was positively associated with clay (r = 0.513 NS), though not at a significant level. Copper (Cu) was negatively and significantly correlated with pH (r = –0.580*), and positively related to P_2O_5 (r = 0.555*). In rainfed shallow black sub-surface soils (Table 8), clay showed significant positive correlations with OC (r = 0.604) and Cu (r = 0.586). Organic carbon was significantly correlated with available N (r = 0.639*). Zinc and Mn were positively associated with clay, while Cu exhibited a strong positive correlation with OC (r = 0.738).

Table 5 : Simple correlation amongst texture, physico-chemical and chemical properties of irrigated shallow black surface cotton growing soils of Nagarkurnool district

	Sand	Silt	Clay	pH	EC	OC	N	P_2O_5	K_2O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.319^{NS}	1.000											
Clay	-0.373^{NS}	-0.761**	1.000										
pH	-0.420^{NS}	-0.153^{NS}	0.438^{NS}	1.000									
EC	0.327^{NS}	0.471^{NS}	-0.685**	-0.213^{NS}	1.000								
OC	-0.048^{NS}	0.019^{NS}	0.014^{NS}	0.067^{NS}	0.029^{NS}	1.000							
N	0.168^{NS}	-0.385^{NS}	0.262^{NS}	0.278^{NS}	-0.285^{NS}	0.595*	1.000						
P_2O_5	-0.020^{NS}	0.452^{NS}	-0.429^{NS}	0.142^{NS}	0.407^{NS}	0.477^{NS}	0.384^{NS}	1.000					
K_2O	0.476^{NS}	-0.024^{NS}	-0.302^{NS}	0.033^{NS}	0.335^{NS}	-0.033^{NS}	0.274^{NS}	0.411^{NS}	1.000				
Zn	-0.243^{NS}	-0.613*	0.767**	-0.075^{NS}	-0.477^{NS}	0.058^{NS}	0.160^{NS}	-0.517*	-0.521*	1.000			
Mn	-0.061^{NS}	-0.154^{NS}	0.193^{NS}	-0.550*	-0.376^{NS}	0.071^{NS}	-0.001^{NS}	-0.399^{NS}	-0.160^{NS}	0.508^{NS}	1.000		
Fe	-0.069^{NS}	-0.691**	0.724**	-0.021^{NS}	-0.484^{NS}	0.383^{NS}	0.508^{NS}	-0.190^{NS}	-0.272^{NS}	0.804**	0.334^{NS}	1.000	
Cu	-0.097^{NS}	-0.671**	0.723**	-0.011^{NS}	-0.389^{NS}	0.448^{NS}	0.315^{NS}	-0.318^{NS}	-0.222^{NS}	0.706**	0.403^{NS}	0.848**	1.000

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

	Sand	Silt	Clay	pH	EC	OC	N	P_2O_5	K_2O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.395	1.000											
Clay	-0.615*	-0.482	1.000										
pH	-0.781***	0.184	0.587*	1.000									
EC	-0.285	0.554*	-0.204	0.436	1.000								
OC	0.088	-0.149	0.044	-0.119	-0.227	1.000							
N	0.22	-0.049	-0.167	0.001	-0.065	0.628*	1.000						
P_2O_5	-0.339	0.555*	-0.153	0.391	0.369	0.475	0.495	1.000					
K_2O	0.294	-0.068	-0.221	0.061	0.331	0.134	0.331	0.315	1.000				
Zn	-0.331	-0.436	0.69**	0.064	-0.288	0.26	-0.03	-0.183	-0.19	1.000			
Mn	-0.307	-0.343	0.587*	0.178	-0.152	-0.107	0.002	-0.279	-0.102	0.78**	1.000		
Fe	-0.014	-0.615*	0.541*	-0.016	-0.243	0.212	0.019	-0.22	-0.227	0.754**	0.513	1.000	
Cu	-0.32	-0.316	0.577*	0.052	-0.074	0.423	-0.067	-0.068	-0.162	0.889**	0.535*	0.752**	1.000

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

	Sand	Silt	Clay	pH	EC	OC	N	P_2O_5	K_2O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.539*	1.000											
Clay	-0.222^{NS}	-0.702**	1.000										
pH	0.199^{NS}	-0.171^{NS}	0.030^{NS}	1.000									
EC	-0.022^{NS}	-0.205^{NS}	0.256^{NS}	0.149^{NS}	1.000								
OC	0.204^{NS}	-0.311^{NS}	0.187^{NS}	0.126^{NS}	-0.168^{NS}	1.000							
N	0.446^{NS}	-0.201^{NS}	-0.144^{NS}	-0.205^{NS}	-0.279^{NS}	0.557*	1.000						
P	-0.231^{NS}	0.324^{NS}	-0.180^{NS}	-0.306^{NS}	-0.111^{NS}	0.026^{NS}	0.195^{NS}	1.000					
K	0.491^{NS}	-0.299^{NS}	-0.070^{NS}	-0.063^{NS}	-0.072^{NS}	0.413^{NS}	0.237^{NS}	-0.209^{NS}	1.000				
Zn	-0.439^{NS}	-0.266^{NS}	0.679**	-0.199^{NS}	-0.114^{NS}	0.371^{NS}	-0.162^{NS}	-0.036^{NS}	-0.158^{NS}	1.000			
Mn	0.204^{NS}	-0.207^{NS}	0.067^{NS}	-0.572*	-0.079^{NS}	-0.304^{NS}	0.324^{NS}	0.050^{NS}	-0.053^{NS}	-0.156^{NS}	1.000		
Fe	-0.280^{NS}	-0.239^{NS}	0.513^{NS}	-0.271^{NS}	0.283^{NS}	-0.114^{NS}	-0.084^{NS}	-0.303^{NS}	-0.003^{NS}	0.383^{NS}	0.192^{NS}	1.000	
Cu	-0.069^{NS}	-0.086^{NS}	0.157^{NS}	-0.580*	0.315^{NS}	-0.084^{NS}	0.201^{NS}	0.555*	-0.076^{NS}	-0.049^{NS}	0.360^{NS}	-0.079^{NS}	1.000

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

	Sand	Silt	Clay	pH	EC	OC	N	P_2O_5	K_2O	Zn	Mn	Fe	Cu
Sand	1.000												
Silt	-0.762**	1.000											
Clay	-0.135^{NS}	-0.448^{NS}	1.000										
pH	-0.344^{NS}	0.454^{NS}	-0.304^{NS}	1.000									
EC	0.144^{NS}	0.117^{NS}	-0.444^{NS}	0.449^{NS}	1.000								
OC	-0.176^{NS}	-0.203^{NS}	0.604*	-0.251^{NS}	-0.140^{NS}	1.000							
N	-0.339^{NS}	0.232^{NS}	0.213^{NS}	-0.047^{NS}	-0.237^{NS}	0.639*	1.000						
P	0.121^{NS}	-0.130^{NS}	-0.111^{NS}	-0.226^{NS}	-0.130^{NS}	0.127^{NS}	0.373^{NS}	1.000					
K	-0.403^{NS}	0.200^{NS}	0.420^{NS}	-0.013^{NS}	-0.191^{NS}	0.393^{NS}	0.017^{NS}	-0.492^{NS}	1.000				
Zn	0.242^{NS}	-0.480^{NS}	0.346^{NS}	-0.527*	-0.105^{NS}	0.313^{NS}	0.076^{NS}	-0.034^{NS}	-0.126^{NS}	1.000			
Mn	0.005^{NS}	-0.279^{NS}	0.539*	-0.667**	-0.421^{NS}	0.348^{NS}	0.104^{NS}	-0.085^{NS}	0.138^{NS}	0.709**	1.000		
Fe	0.252^{NS}	-0.337^{NS}	0.129^{NS}	-0.446^{NS}	-0.330^{NS}	0.015^{NS}	-0.061^{NS}	-0.097^{NS}	-0.277^{NS}	0.560*	0.459^{NS}	1.000	
Cu	0.087^{NS}	-0.375^{NS}	0.586*	-0.410^{NS}	0.015^{NS}	0.738**	0.388^{NS}	0.236^{NS}	0.115^{NS}	0.603*	0.599*	0.187^{NS}	1.000

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

The correlation analysis across irrigated and rainfed black soils of Nagarkurnool district clearly demonstrates the dominant role of soil texture, soil reaction, and organic carbon in regulating nutrient and micronutrient availability. A consistent and pronounced trend observed across surface and sub-surface layers was the strong positive association between clay content and micronutrients, particularly Zn, Cu, and Fe. In irrigated deep black surface soils, clay showed highly significant correlations with Zn and Cu, while similar strong associations were evident in rainfed deep and shallow black soils. These findings indicate that the higher clay content of black soils enhances micronutrient retention due to increased specific surface area, greater cation exchange capacity, and stronger adsorption of micronutrient cations, as reported earlier for Vertisols and associated black soils (Alloway, 2008; Satyavathi and Reddy, 2004; Meena *et al*., 2006; Kumar *et al*., 2016). Soil pH emerged as a critical determinant of micronutrient availability in black soils. The significant negative correlations of pH with Zn, Mn, and Cu observed in both irrigated and rainfed conditions, particularly in surface layers, indicate reduced micronutrient solubility under alkaline soil reaction. Black soils are often calcareous in nature, and increasing pH promotes precipitation and adsorption of micronutrients as hydroxides and carbonates, thereby limiting their availability to crops. The strong negative association of Zn with pH highlights the risk of pH-induced Zn deficiency in cotton-growing black soils, a phenomenon widely reported in central and southern India (Thakur *et al*., 2011; Shukla and Behera, 2017; Jatav *et al*., 2020; Negash and Mohammed, 2014). Organic carbon showed a consistently strong and significant positive relationship with available nitrogen across all black soil groups, irrespective of moisture regime or depth. This confirms the central role of soil organic matter in nitrogen mineralization and nutrient cycling. The positive correlations between OC and available P_2O_5 observed in several soil situations suggest that organic matter may indirectly enhance phosphorus availability by reducing fixation through chelation and organic ligand formation. Similar relationships between OC, N, and P availability in black soils have been reported by Meena *et al*., 2006, Singh *et al*., 2015 and Braos *et al*., 2023. However, the generally weak relationships between OC and micronutrients indicate that in black soils, clay content and soil reaction exert a stronger control over micronutrient availability than organic matter alone.

Strong positive inter-correlations among micronutrients, particularly between Zn, Cu, and Fe, were observed across most black soil groups. Such interrelationships suggest that these micronutrients co-vary under similar pedogenic and management conditions and are jointly influenced by clay content and soil pH. This co-occurrence implies that micronutrient deficiencies in black soils are likely to appear simultaneously rather than individually, especially under intensive cultivation and alkaline soil conditions (Fageria *et al*., 1997; Alloway, 2008; Kumar *et al*., 2016).

The relationships between major nutrients and micronutrients were largely weak or non-significant, except for the negative association between available P_2O_5 and Zn observed in some soil groups, such as irrigated shallow black soils. This supports the occurrence of phosphate-induced Zn antagonism, a common problem in fertilized black soils receiving high phosphorus inputs, where excessive phosphate reduces Zn uptake by crops (Hafeez *et al.*, 2013; Prasad *et al.*, 2016).

Overall, the results indicate 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 availability and contributes secondarily to phosphorus dynamics. These findings emphasize the need for integrated nutrient management practices that consider soil texture, organic matter status, and soil reaction to sustain soil fertility and cotton productivity in black soil regions.

Conclusion

The study demonstrates that nutrient and micronutrient availability in black cotton-growing soils of Nagarkurnool district is primarily governed by soil texture, soil reaction, and organic carbon status. Clay-rich soils consistently enhanced the availability of micronutrients such as Zn, Cu, and Fe, while higher soil pH reduced their solubility, indicating a risk of pH-induced deficiencies. Organic carbon played a key role in regulating nitrogen and, to a lesser extent, phosphorus availability across soil depths and moisture regimes. These findings highlight the importance of integrated soil fertility management strategies that consider texture, pH, and organic matter to sustain soil health and cotton productivity in black soil regions.

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