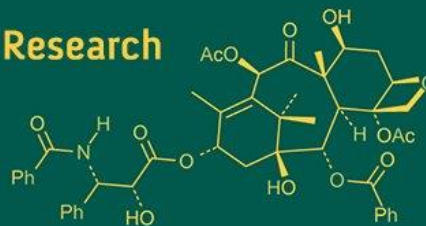
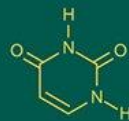
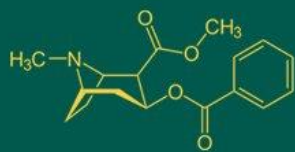


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(8): 1195-1202
www.biochemjournal.com
Received: 09-06-2026
Accepted: 13-07-2026

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Soil fertility status and nutrient availability in predominant soils of Northern Telangana Zone

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i8Sn.9596>

Abstract

A soil fertility assessment was conducted in the Northern Telangana Zone to evaluate the physico-chemical properties, available nutrient status and interrelationships among soil fertility parameters. A total of 120 surface soil samples (0-15 cm) were collected and analysed for pH, electrical conductivity (EC), organic carbon (OC), available N, P, K, S and DTPA-extractable Zn, Fe, Cu and Mn. Most soils were alkaline (70.8%), while 99.16% were non-saline. Organic carbon was low in 55.8% of the samples. Available nitrogen was low in all samples, whereas available P was low, medium and high in 34.2, 40.8 and 25.0% of the samples, respectively. Available K was predominantly medium (66.7%) to high (32.5%), while 89.2% of the soils had high available S. Zinc was the major micronutrient constraint, with 49.2% of the samples deficient, whereas Cu and Mn were sufficient in all samples and Fe was sufficient in 99.2% of the soils. Pearson correlation analysis and the correlation heat map revealed significant interrelationships among soil fertility parameters. The strongest positive correlation was observed between pH and EC ($r = 0.620$), followed by P and K ($r = 0.481$) and OC and N ($r = 0.398$). In contrast, P showed a significant negative correlation with Zn ($r = -0.375$), indicating an inverse association between P and Zn availability. The findings emphasize the interconnected nature of soil nutrient status and support integrated, soil-test-based nutrient management with emphasis on organic matter improvement, efficient N and P management and targeted Zn fertilization for sustaining soil fertility and crop productivity in the Northern Telangana Zone (NTZ).

Keywords: Soil fertility assessment, available nutrients, organic carbon, pearson correlation, heat map, NTZ

1. Introduction

Soil is the basic resource for agricultural production, and its nutrient status has a major influence on crop growth, yield and soil sustainability. Soil survey is a systematic study of soils in a particular area to understand their physico-chemical and chemical properties and their spatial distribution. It includes the assessment of properties such as soil texture, pH, electrical conductivity, organic carbon and the availability of essential nutrients such as nitrogen, phosphorus, potassium and micronutrients. Soil survey help to identify variations in soil fertility from one location to another. The information obtained from soil survey is useful for assessing nutrient deficiencies and determining the fertility status of different areas. It also provides a scientific basis for making suitable fertilizer recommendations and adopting appropriate soil management practices. Thus, soil survey serves as an important link between soil status and agricultural management, helping to improve crop productivity, reduce unnecessary fertilizer use and maintain soil fertility over the long term.

2. Materials and Methods

2.1 Site description

The study was conducted in the Northern Part of Telangana comprising 10 districts. The zone extends geographically between 18°00' N and 19°30' N latitudes and 77°00' E to 80°30' E longitudes. It receives an average annual rainfall of about 1033 mm ranging between 867 mm and 1189 mm and mean maximum temperature ranging from 33.1 to 33.9 °C and mean minimum temperature ranging from 20.1 to 20.9 °C.

2.2 Soil sampling and processes

Total of 120 soil samples (0-15 cm) were selected from the zone. The samples were collected by randomised stratified sampling method from 5-6 places in each site selected for

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sampling. The soils collected were composited and 2 mm sieved and analysed for physico-chemical and chemical parameters.

2.3 Soil analytical methods

Soil pH was determined at 1:2.5 soil water suspension by Glass electrode pH meter (Jackson, 1973) ^[8]. Soil reaction through EC meter (Jackson, 1973) ^[8]. Organic carbon by Wet digestion method (Walkley and Black, 1934) ^[22]. Available N was determined by Permanganate Oxidation distillation method (Subbiah and Asija, 1956) ^[21]. Available P determined by Olsen *et al.* (1954) ^[11] method. Available K was determined by flame photometer (Jackson, 1973) ^[8]. Available sulphur is determined by CaCl_2 extraction (Williams and Steinbergs., 1959) ^[23] and Turbidity development by Chesnin and Yien (1950) ^[3] method. Micronutrients are estimated by DTPA extracting solution (Lindsay and Norvell, 1978) ^[25].

2.4 Statistical analysis

Descriptive statistics was conducted for survey samples and Pearson correlation was done to evaluate the interrelation among soil nutrient status.

Results and Discussion

Physical and physico-chemical parameters

Most of the soils in the study area were alkaline (>7.5) in nature contributing to about 70.8%, whereas neutral (6.5-7.5) soils contributed to about 29.2%. Acidic soils (<6.5) were not found over the collected area. The pH of soils were ranged from 6.92 to 8.46. The predominance of alkaline soils were similar with findings of Dandu *et al.* (2025) ^[4]. The predominance of alkaline conditions over the vast area lead to fixation of phosphorus and other nutrients. The electrical conductivity (EC) (dS m^{-1}) of the soils ranged from 0.26 to 2.36 dS m^{-1} with the mean value of 1.17 dS m^{-1} . 99.16% of soils were non saline (<2.00) in nature and whereas 0.84% were slightly saline (2.00-4.00). The current research findings were comparable with Yilmaz and Algoz (2010) ^[24]. OC (g kg^{-1}) of soils ranged from 1.00-9.28. The soils were mostly less in organic content. 55.8% of soils were low (<5.00) in Organic Carbon whereas 30.8% of samples collected were found in medium (5.0-7.5) OC content 30.8% and 13.3% soils fell under high (>7.5) category. The dominance of low to medium category were in similar to the findings of Diwakar *et al.* (2021) ^[5]

Available N, P, K (kg ha^{-1}) and S (mg kg^{-1})

Available Nitrogen in soils ranged from 101 to 277 kg ha^{-1} with a mean value of $174.68 \text{ kg ha}^{-1}$. All the samples fell into low category level according to rating of Subbiah and Asija (1956) ^[21]. The uniformly low category level corroborates with the findings of Katkar *et al.* (2017) ^[9] and Dandu *et al.* (2025) ^[4]. The available phosphorus content of the soils

ranged from 6.5 to 38.3 kg ha^{-1} with a mean value of 18.35 kg ha^{-1} . Based on the standard rating, 34.2% of the samples were low ($<11 \text{ kg ha}^{-1}$), 40.8% were medium ($11-26 \text{ kg ha}^{-1}$) and 25.0% were high ($>26 \text{ kg ha}^{-1}$) in available phosphorus status. The predominance of medium and high available phosphorus status making together of about 65.8% observed in this study is consistent with the findings of Harit and Dhalwani (2025) ^[7] in Neemuch district and Hadole *et al.* (2024) ^[6] in Satara district. Available potassium content ranged from 114 to 428 kg ha^{-1} with a mean value of $245.63 \text{ kg ha}^{-1}$. The unjudicious use of P fertilisers may lead to P build up in soil. Only 0.8% (one sample) of the soils were low, 66.7% were medium ($120-280 \text{ kg ha}^{-1}$) and 32.5% were high ($>280 \text{ kg ha}^{-1}$) in available potassium status. The predominance of K-rich and feldspar minerals in parent material lead to higher K content in soils (Srikant *et al.*, 2008) ^[20]. The dominance of medium to high potassium status were similar in findings with Prasad *et al.* (2022) ^[13] and Singh *et al.* (2019) ^[19]. Available sulphur content of the soils ranged from 5.36 to 61.66 mg kg^{-1} with a mean value of 31.95 mg kg^{-1} . The majority of the samples, 89.2%, were high in available sulphur status ($>15 \text{ mg kg}^{-1}$), while 5.8% were medium ($10-15 \text{ mg kg}^{-1}$) and 5.0% were low ($<10 \text{ mg kg}^{-1}$). The results were similar to the findings of Satish *et al.* (2018) ^[17].

Micronutrients (Zn, Cu, Fe and Mn)

Available zinc content ranged from 0.16 to 2.36 mg kg^{-1} with a mean value of 0.80 mg kg^{-1} . Nearly half of the soils, 49.2%, were deficient in zinc ($<0.6 \text{ mg kg}^{-1}$), while 50.8% were sufficient. Available copper content ranged from 0.29 to 5.36 mg kg^{-1} with a mean value of 1.50 mg kg^{-1} . All the samples (100%) were found to be sufficient ($>0.2 \text{ mg kg}^{-1}$) in available copper. Available iron ranged from 2.18 to 21.63 mg kg^{-1} with a mean value of 11.06 mg kg^{-1} . 99.2% of the samples were sufficient ($>2.5 \text{ mg kg}^{-1}$) in iron, with only one sample (0.8%) recording a deficient status. Available manganese ranged from 3.12 to 25.36 mg kg^{-1} with a mean value of 11.25 mg kg^{-1} . All the samples (100%) were sufficient ($>2.0 \text{ mg kg}^{-1}$) in manganese status. The near-universal sufficiency of Cu, Fe and Mn together with widespread zinc deficiency recorded in this study closely parallels to the the observations of Reddy *et al.* (2014) ^[16], Prasad *et al.* (2020) ^[13] and Shukla *et al.* (2021) ^[18].

Correlation among soil properties

Pearson correlation analysis was performed on the 120 surface-soil observations (0-15 cm) to evaluate the interrelation among soil nutrient status. The correlation matrix was developed using the soil parameters viz., pH, EC, organic carbon (OC), available N, P, K, S, Zn, Fe, Cu and Mn.

Table 1: Soil physico-chemical and chemical contents of 120 samples collected from NTZ zone

S. No		Mandal	Village	pH	EC dS m ⁻¹	OC g kg ⁻¹	N kg ha ⁻¹	P kg ha ⁻¹	K kg ha ⁻¹	S mg kg ⁻¹	Zn mg kg ⁻¹	Fe mg kg ⁻¹	Cu mg kg ⁻¹	Mn mg kg ⁻¹
1	Adilabad	Neradigonda	Wankidi	8.34	1.82	8.80	213	29.3	428	48.26	0.27	11.35	2.18	24.21
2				7.8	1.41	6.82	186	10.2	360	27.06	1.38	19.56	1.08	12.92
3				7.76	0.95	3.15	124	29.0	343	38.56	0.16	11.32	0.98	17.28
4				7.32	0.96	8.34	218	31.3	360	25.02	0.29	15.35	2.12	25.36
5			Bondemregod	7.62	1.24	7.73	158	33.9	371	24.77	0.81	19.19	1.12	13.36
6				7.69	1.15	6.26	224	18.2	354	31.23	1.32	15.26	0.36	16.28
7				7.08	1.19	9.26	193	15.3	230	36.50	0.92	13.15	0.29	16.52
8			Ispur	7.82	1.68	7.02	176	10.2	361	49.24	1.08	12.17	1.88	20.38
9				7.33	1.12	5.34	120	10.6	210	35.05	2.11	21.32	1.26	25.26
10				7.38	0.55	2.67	154	17.8	290	28.54	1.92	14.26	1.02	9.56
11			Purushothampur	7.01	1.57	4.82	129	14.3	194	32.26	1.85	17.36	0.59	15.42
12				7.01	0.42	2.81	195	19.6	193	23.28	2.36	14.28	1.29	11.25
13				7.53	0.86	2.43	147	23.0	326	16.27	0.50	18.36	0.66	16.32
14		Boath	Pochera	7.83	1.29	9.28	226	25.4	293	26.20	1.29	4.62	3.29	6.36
15				7.65	1.42	8.86	214	10.7	281	48.52	2.16	12.56	3.98	5.28
16				7.83	1.29	8.98	219	10.2	293	47.89	1.28	16.32	2.18	17.36
17				7.88	1.27	7.88	210	8.6	326	55.60	2.24	18.92	0.35	15.42
18		Ichoda	Gerjam	7.10	1.06	5.99	132	20.6	224	26.20	0.96	15.43	0.37	12.82
19				7.78	1.17	7.54	176	18.3	288	23.67	2.18	21.26	0.92	11.18
20			Jamidi	7.62	1.31	8.56	196	28.3	332	36.52	1.09	9.26	1.12	7.36
21	Nizamabad	Yargatla	Gumerial	7.62	1.41	7.93	158	32.0	349	24.77	0.89	6.34	0.56	6.18
22				7.83	1.30	5.64	124	9.8	220	7.16	1.21	5.42	1.26	7.34
23				7.96	0.82	2.29	189	30.4	257	12.75	0.56	3.86	2.18	5.46
24				7.97	1.31	7.94	145	17.5	124	16.56	0.42	6.21	1.12	3.12
25		Mortad	Tadla rampur	7.98	0.79	6.23	172	9.8	214	6.61	0.81	12.82	0.56	4.26
26			Domchanda	7.36	0.82	9.26	242	8.6	140	21.25	0.63	17.36	0.84	8.34
27				7.47	1.31	7.94	145	17.5	284	28.51	0.41	5.12	0.83	3.26
28				7.94	1.50	7.95	158	16.4	248	18.20	0.69	6.23	1.12	4.85
29		Kotgiri	Zainapur	7.92	1.96	3.99	136	9.2	214	12.11	0.21	10.19	1.38	7.62
30				7.85	1.86	6.28	154	17.3	146	33.25	0.43	15.32	2.18	8.24
31				8.31	1.67	4.56	221	12.3	240	21.00	0.28	11.26	2.16	11.12
32		Rudrur	Ramanpalle	7.54	1.16	3.85	176	9.3	183	26.50	1.21	16.23	2.21	12.45
33				8.22	1.31	4.20	134	23.6	270	34.37	0.36	9.35	1.27	7.42
34				8.02	1.12	4.86	194	25.3	285	24.36	0.41	17.26	2.2	7.91
35	Varni	Govoor	Govoor	8.00	1.18	2.56	176	13.6	241	18.23	1.32	6.21	1.68	8.16
36				7.97	0.89	2.36	165	29.3	296	18.84	0.28	6.27	1.34	3.91
37				7.68	1.08	4.39	259	24.4	284	36.20	0.56	9.24	1.19	4.56
38		Nizamabad	Srinagar	7.34	1.45	6.20	135	26.3	324	43.00	0.49	11.21	0.89	8.21
39				7.32	1.08	3.20	150	12.6	232	34.00	0.86	10.21	0.76	7.36
40				8.06	1.16	5.32	172	15.8	236	25.20	0.71	14.28	1.15	6.24
41	Mancherial	Bellampally	Rangapet	8.10	1.2	4.56	199	21.1	179	30.28	0.91	9.26	2.12	22.18
42				8.06	1.14	5.21	220	19.3	186	49.55	0.56	11.18	0.36	10.29
43			Chandravelli	7.99	1.31	7.42	277	29.0	169	56.24	0.38	6.32	1.19	21.29
44				8.21	1.56	3.28	154	19.3	176	38.88	1.09	5.12	1.28	18.36
45		Malagurjal	Malagurjal	8.16	1.2	4.26	176	28.3	240	59.45	0.34	6.15	1.36	24.26
46				8.17	1.54	5.74	154	22.5	236	24.20	1.26	7.54	0.89	22.11
47				7.89	0.84	2.79	157	16.8	180	60.24	1.88	14.29	0.65	10.56
48				7.54	1.26	5.26	165	23.9	168	32.21	1.59	7.63	0.66	7.28
49		Bheemini	Rampur	7.83	1.68	6.20	182	20.4	227	56.70	1.63	10.29	1.04	14.36
50				7.26	0.84	2.28	158	10.5	162	28.00	2.02	11.18	0.89	12.19
51				7.24	0.42	1.66	132	10.2	164	8.20	1.32	9.28	1.09	19.12
52		Chennur	Dugnepally	7.23	0.39	4.98	246	24.3	290	29.80	0.36	7.28	0.39	11.18
53				7.01	0.36	3.26	172	15.2	199	23.52	1.80	6.38	0.76	17.26
54				8.46	1.72	5.32	166	10.9	256	17.56	1.36	9.27	2.02	13.28
55				8.32	1.89	2.24	234	10.6	245	32.54	1.12	2.82	1.38	7.28
56		bhimaram	bhimaram	7.42	1.24	2.34	196	16.2	235	39.65	1.08	3.19	0.84	5.17
57				7.45	1.33	2.84	225	11.0	229	34.20	1.36	6.37	1.28	7.18
58				7.82	1.76	4.12	260	21.6	312	42.14	0.98	4.56	0.63	8.39
59		Mandamarri	Chirrakunta	7.64	1.54	5.57	242	25.0	326	58.20	0.46	7.82	0.52	6.28
60				8.16	1.32	3.28	182	16.3	167	32.16	1.12	3.79	1.09	10.89
61				7.36	1.59	7.26	270	34.2	354	45.26	0.58	6.38	1.63	15.21
62	Jagtial	Sarangapur	Laxmidevpally	7.84	1.35	6.85	252	27.2	336	45.63	0.36	9.24	1.57	17.26
63				7.05	0.64	5.24	232	30.0	390	36.00	0.22	7.63	1.89	11.18
64				7.99	1.63	6.28	222	14.4	324	32.46	0.24	6.82	1.68	13.42
65				7.96	1.68	3.28	160	11.0	225	58.42	1.09	14.24	1.28	5.13
66		Raikal	Mootapally	8.21	1.71	5.24	131	26.0	282	35.00	0.51	10.82	2.19	7.29
67				7.86	1.19	3.82	156	17.7	150	26.86	0.66	11.16	1.26	8.16
68				7.58	1.06	3.01	180	9.3	160	29.72	1.48	13.27	1.79	8.02

69		Beerpur	Beerpur	7.12	0.43	4.82	192	10.3	264	29.05	0.68	12.26	1.69	7.29
70				8.32	1.93	5.02	124	22.0	348	40.20	0.34	8.29	2.15	11.12
71				7.94	1.78	4.00	246	27.0	320	28.00	0.46	7.62	1.18	8.34
72				8.12	1.56	4.82	221	27.1	262	21.26	0.51	6.37	1.27	14.28
73				7.36	1.26	3.80	157	23.5	245	17.16	0.39	14.26	3.18	15.29
74				7.91	0.95	2.81	172	28.3	312	28.34	0.68	11.18	2.19	17.26
75				7.24	1.26	3.21	168	38.3	345	42.30	0.21	7.36	3.27	18.14
76				7.05	0.36	1.57	120	10.3	254	18.59	0.72	8.12	3.16	21.29
77				8.15	1.16	1.82	127	21.3	226	29.84	0.42	12.26	2.16	17.53
78				7.16	0.26	1.36	120	13.9	212	17.57	0.51	17.19	3.29	14.28
79				7.02	0.56	2.36	144	10.3	245	39.75	0.89	21.29	1.29	11.12
80				7.65	1.32	5.82	254	30.2	258	42.14	0.21	6.34	2.16	18.26
81				8.26	1.36	3.34	192	10.2	293	39.20	0.52	17.84	1.84	3.62
82				7.62	1.02	3.18	156	14.3	180	35.61	0.48	19.12	0.39	7.18
83				7.66	0.74	6.78	248	15.3	193	49.48	0.32	11.18	1.24	5.46
84				7.66	1.12	3.26	146	10.2	193	18.36	0.29	14.36	0.79	4.80
85				6.92	0.63	1.00	101	8.3	214	14.04	0.84	19.24	1.09	3.24
86				7.20	0.58	2.86	112	8.0	114	10.10	0.82	21.63	1.32	6.34
87				7.48	0.30	3.86	210	6.5	181	45.26	0.72	11.28	2.16	12.25
88				7.66	1.62	1.79	101	9.5	195	39.63	0.56	14.34	1.18	17.36
89				8.20	1.08	4.28	134	16.2	270	42.26	0.21	9.56	2.21	10.27
90				7.64	0.76	3.26	158	10.6	258	14.48	0.58	8.20	2.27	5.26
91				7.48	0.96	1.68	145	8.6	136	6.54	0.82	3.56	0.63	6.87
92				7.81	1.02	5.63	192	17.4	243	10.15	0.43	4.38	0.79	10.26
93				7.26	0.96	2.59	176	20.6	194	8.92	0.65	2.18	0.76	8.30
94				8.21	1.25	4.36	168	11.0	183	35.23	0.96	7.56	2.19	12.56
95				8.18	1.32	6.42	193	16.0	283	36.20	0.72	8.42	1.36	16.82
96				7.56	1.16	3.39	132	8.6	212	14.86	1.27	9.28	0.82	17.26
97				8.15	1.16	4.26	151	10.9	166	29.73	1.32	7.36	0.76	15.24
98				8.16	1.92	7.42	154	32.3	285	61.66	0.21	17.28	3.8	11.28
99				8.45	1.32	4.86	156	10.8	230	24.36	0.48	11.19	2.86	12.21
100				8.32	1.42	5.26	191	27.0	211	5.36	0.28	14.26	3.16	15.21
101				7.62	1.42	7.98	126	9.2	124	57.80	0.26	11.12	2.56	7.42
102				7.15	0.56	4.32	150	31.3	169	41.84	0.48	9.58	5.36	4.29
103				7.07	0.59	2.24	133	23.3	290	35.78	1.36	12.54	2.18	3.29
104				7.02	0.38	5.24	159	29.0	312	35.78	0.36	5.23	3.16	5.28
105				7.71	1.54	4.96	168	30.8	188	59.45	0.21	7.24	0.96	7.28
106				7.67	1.09	5.43	154	19.3	254	37.43	0.45	13.26	1.82	9.56
107				7.52	0.95	6.01	221	24.3	231	44.00	0.31	11.81	2.19	11.29
108				8.17	1.51	3.64	154	10.2	254	26.32	1.26	17.25	1.28	17.36
109				8.12	2.36	4.82	194	16.5	245	31.24	0.86	13.10	2.12	12.34
110				8.11	1.32	5.82	122	18.3	224	38.26	0.91	11.28	1.19	14.36
111				7.90	0.96	4.38	145	11.0	293	42.26	0.49	8.24	0.89	6.28
112				8.18	1.32	3.56	124	10.8	186	36.20	0.46	12.26	1.12	12.15
113				8.03	0.91	2.26	124	8.3	210	23.26	0.41	7.86	0.94	15.26
114				7.62	0.34	6.62	236	27.6	280	32.00	0.21	11.19	0.86	6.37
115				8.26	1.26	4.48	154	10.9	174	39.28	0.48	17.32	1.91	5.28
116				7.50	0.84	3.26	112	9.3	124	35.20	0.84	14.56	1.32	14.32
117				7.63	1.09	5.26	156	29.1	224	28.30	0.26	18.32	0.88	8.24
118				7.34	0.64	6.32	209	25.9	262	21.36	0.30	9.76	0.49	9.20
119				7.56	0.89	5.29	160	23.2	242	41.20	0.28	8.20	0.83	8.26
120				8.12	1.24	2.77	184	10.5	254	25.00	0.36	11.26	1.29	5.64
Mean				7.72	1.17	4.82	175	18.3	245.65	31.95	0.80	11.06	1.50	11.25
S.D				0.39	0.42	2.04	41	7.9	65.20	13.22	0.53	4.67	0.87	5.44
Range				6.92-8.46	0.26-2.36	1.00-9.28	100-277	6.5-38.3	113-428	5.36-61.66	0.16-2.36	2.18-21.63	0.29-5.36	3.12-25.36

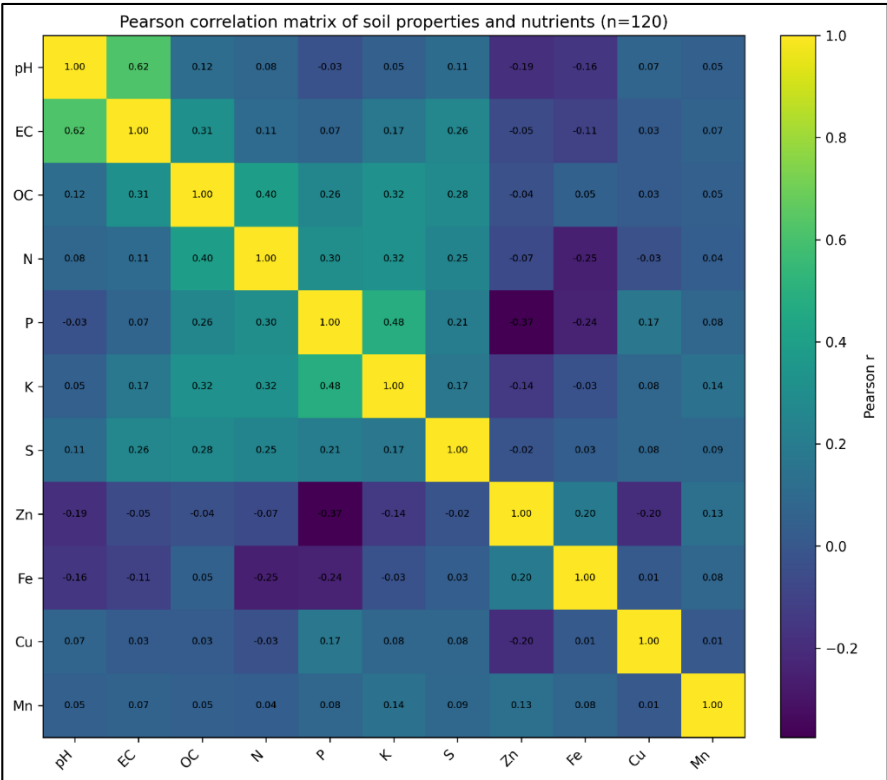


Table 2: Significant levels in relation among the soil properties

Variable	pH	EC	OC	N	P	K	S	Zn	Fe	Cu	Mn
pH	1.000	0.620***	0.118	0.081	-0.026	0.049	0.112	-0.185*	-0.156	0.071	0.049
EC	0.620***	1.000	0.314***	0.107	0.072	0.174	0.261**	-0.053	-0.107	0.026	0.065
OC	0.118	0.314***	1.000	0.398***	0.258**	0.320***	0.276**	-0.036	0.054	0.025	0.049
N	0.081	0.107	0.398***	1.000	0.303***	0.320***	0.248**	-0.067	-0.252**	-0.034	0.036
P	-0.026	0.072	0.258**	0.303***	1.000	0.481***	0.206*	-0.375***	-0.243**	0.171	0.077
K	0.049	0.174	0.320***	0.320***	0.481***	1.000	0.170	-0.141	-0.030	0.079	0.137
S	0.112	0.261**	0.276**	0.248**	0.206*	0.170	1.000	-0.020	0.034	0.081	0.092
Zn	-0.185*	-0.053	-0.036	-0.067	-0.375***	-0.141	-0.020	1.000	0.195*	-0.195*	0.133
Fe	-0.156	-0.107	0.054	-0.252**	-0.243**	-0.030	0.034	0.195*	1.000	0.013	0.081
Cu	0.071	0.026	0.025	-0.034	0.171	0.079	0.081	-0.195*	0.013	1.000	0.009
Mn	0.049	0.065	0.049	0.036	0.077	0.137	0.092	0.133	0.081	0.009	1.000

Significance: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. Positive values indicate positive linear association; negative values indicate inverse association

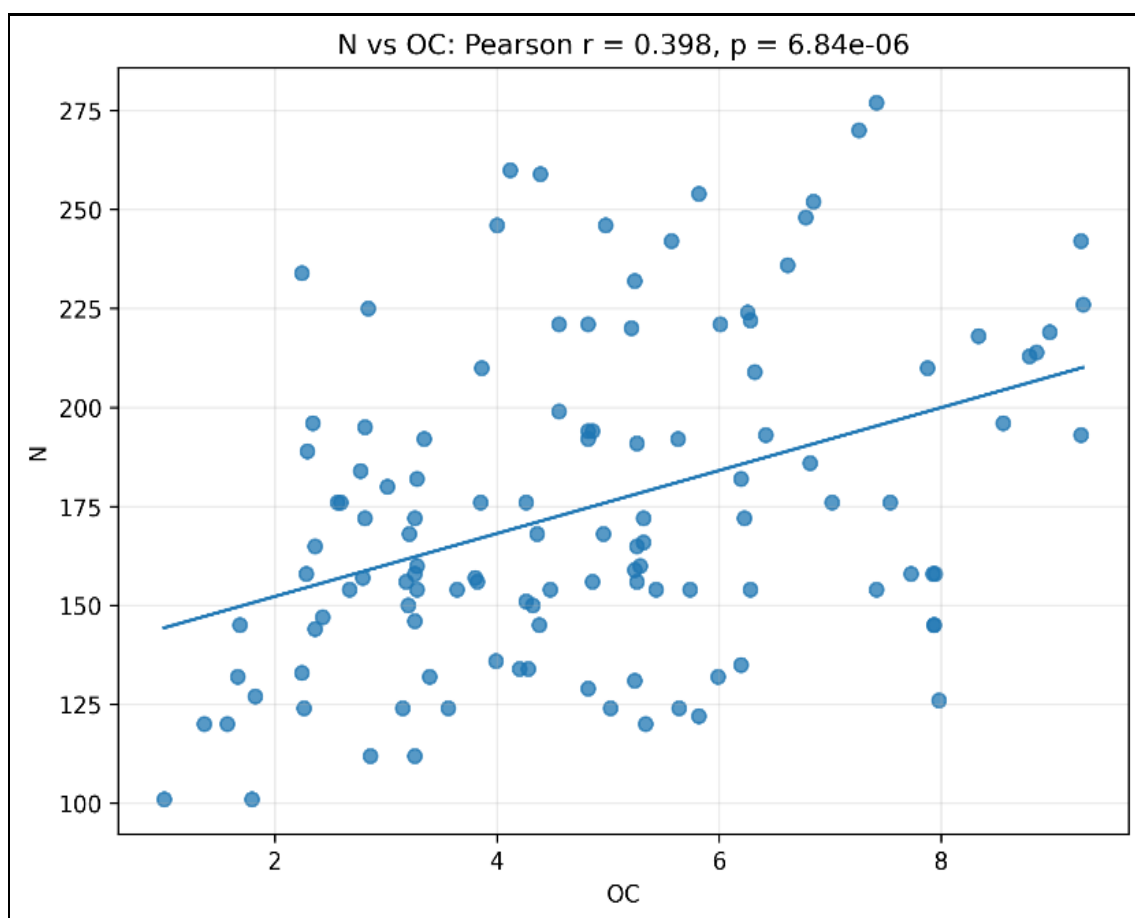
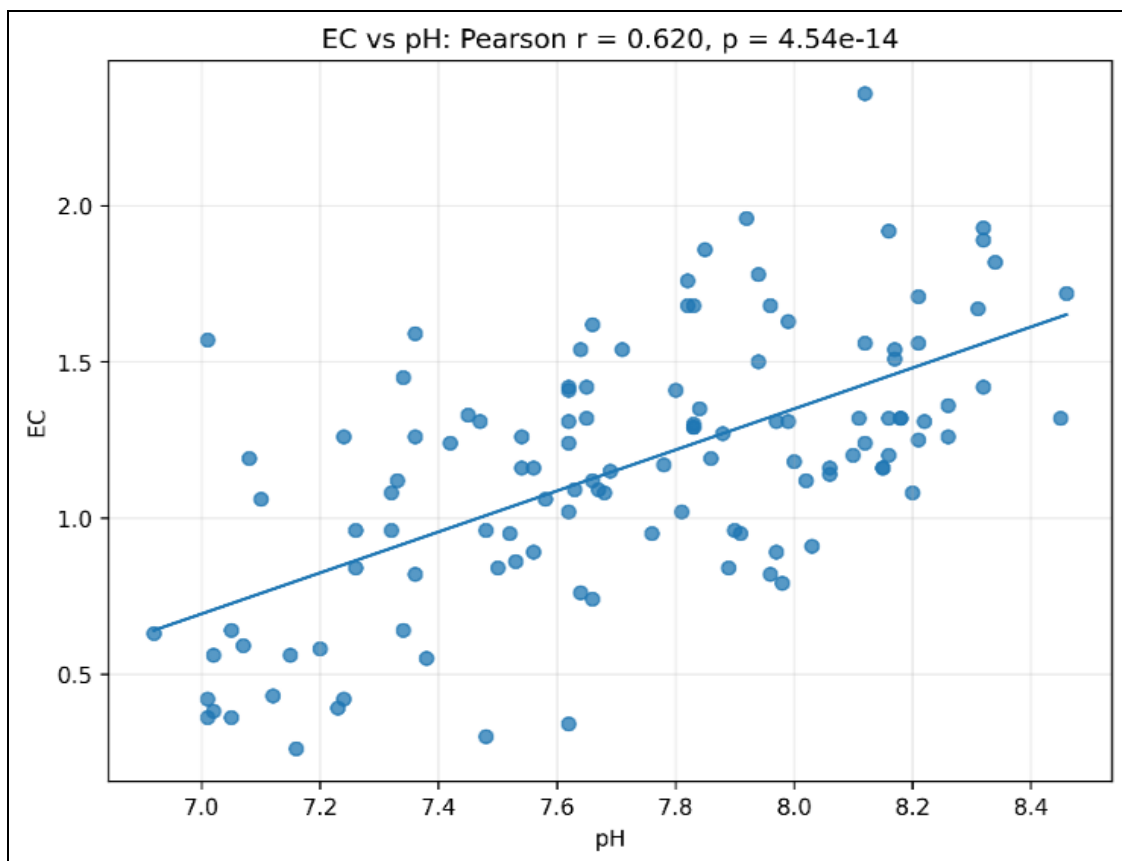
Table 3: Key findings on interrelation among the soil properties established through correlation heat map

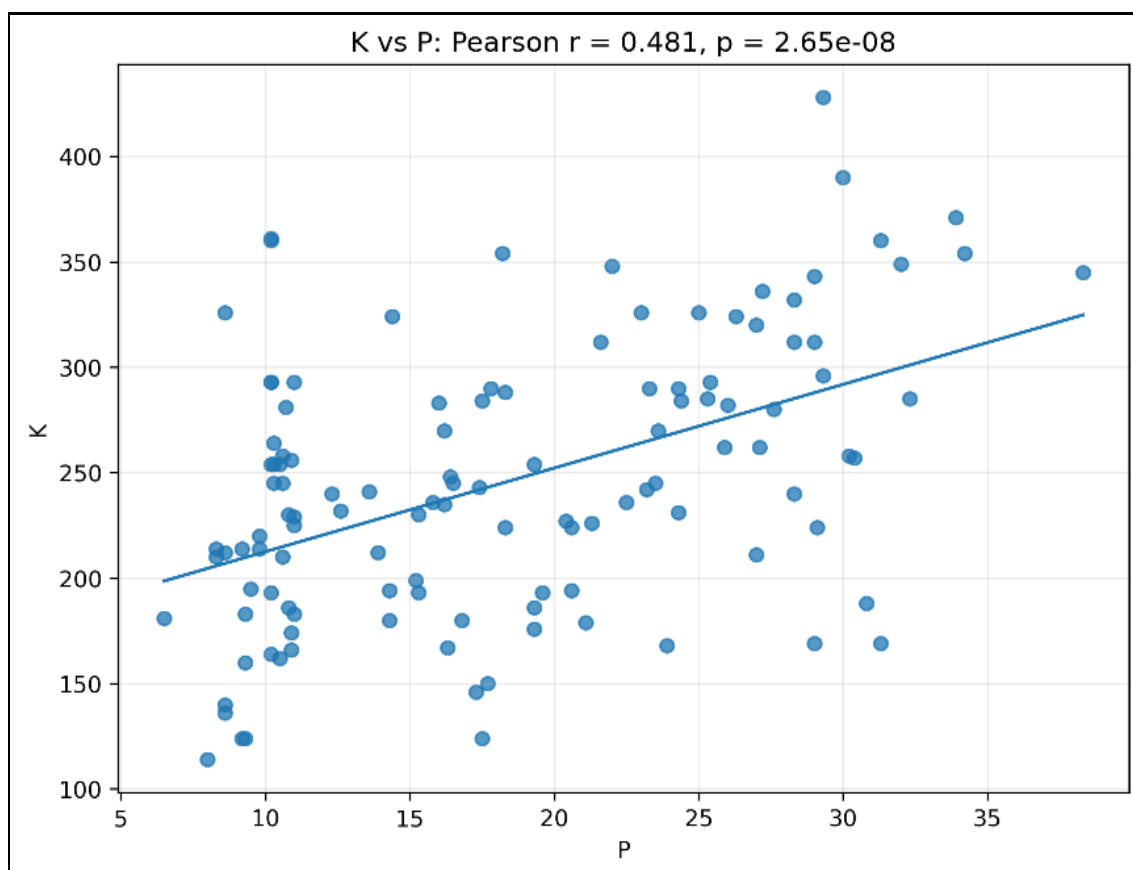
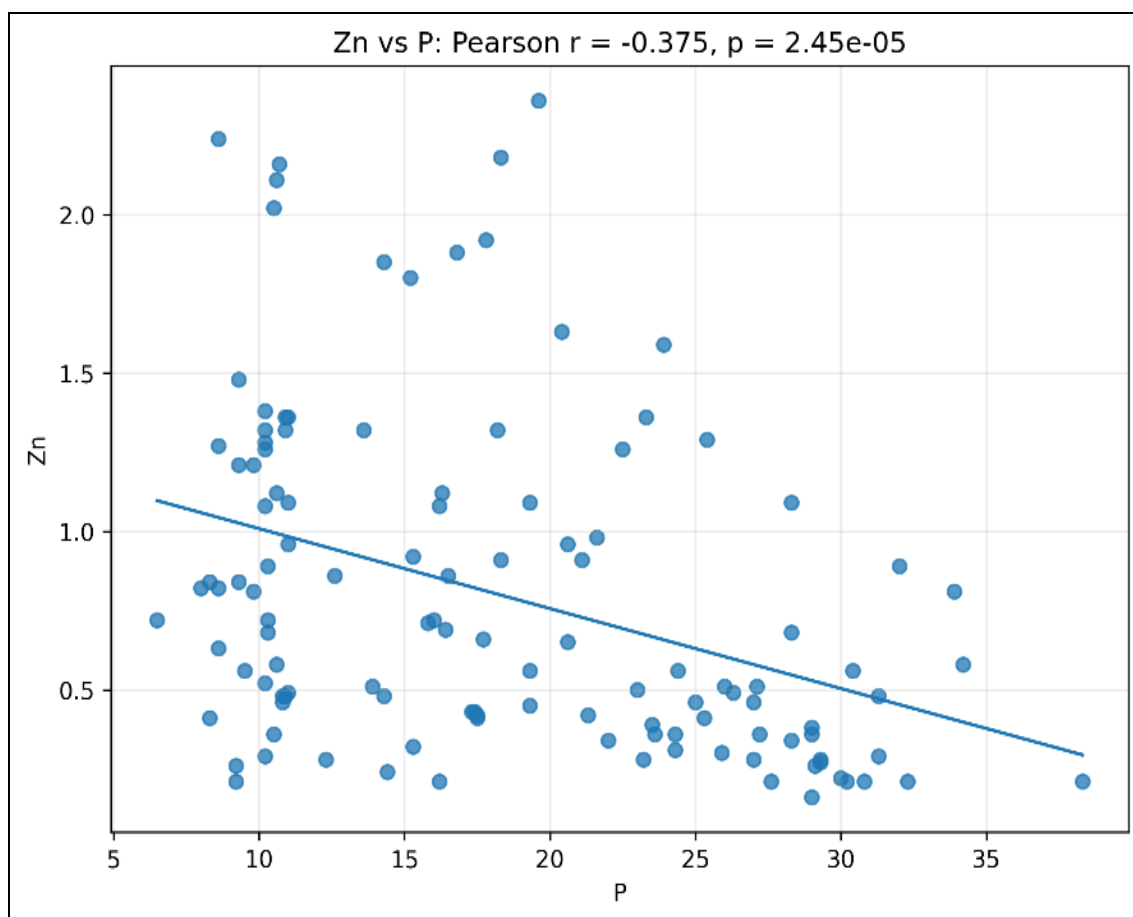
Pair	r	p-value	Interpretation
pH-EC	0.620	4.54e-14	strong positive association
P-K	0.481	2.65e-08	moderate positive association
OC-N	0.398	6.84e-06	moderate positive association
P-Zn	-0.375	2.45e-05	moderate negative association
N-K	0.320	0.000369	moderate positive association
OC-K	0.320	0.000371	moderate positive association
EC-OC	0.314	0.00047	moderate positive association
N-P	0.303	0.000767	moderate positive association

Correlation among the OC, N and K contents were similar to the findings Adhikari *et al.* (2015) ^[1]. The negative correlation of P-Zn content were similar to the findings of Mondal *et al.* (2017) ^[10]. The highest correlated value ($r = 0.620$) was among pH and EC and the positive correlation

among OC, N, P and K contents were in similarity to the findings of Ramulu *et al.* (2026) ^[15].

Scatter plots of strongest relationship among the soil physico-chemical and chemical properties





The scatter plots showed significant linear relationships among the selected soil properties and available nutrients. Soil pH exhibited the strongest positive association with EC ($r = 0.620$), followed by available P with K ($r = 0.481$) and

organic carbon with available N ($r = 0.398$). In contrast, available P showed a significant negative association with Zn ($r = -0.375$), indicating an inverse relationship between P and Zn availability. Overall, the scatter plots confirmed the trends

observed in the Pearson correlation matrix, with the relationships being statistically significant at $P < 0.001$.

Conclusions

- Application of Organic manures and incorporation of crop residues can improve the soil organic carbon, nutrient cycling and sustain long term fertility.
- Integrated nutrient management involving organic manures, crop residue incorporation, legume-based crop rotations and judicious application of nitrogen fertilizers should be adopted to improve nitrogen availability and sustain crop productivity.
- Phosphate solubilising Organisms is to be added to high P soils in order to increase the plant P content and judicious use of P fertilisers based on soil test and recommendations.
- K and S should be applied based on the soil test recommendations as the contents in soil was observed at higher rate due to higher fertilizer imposition to soils.
- Application of zinc fertilizers such as $ZnSO_4$ should be included in nutrient management programmes wherever deficiency is identified to prevent yield losses and improve crop growth.

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