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Soil Fertility Status of Paddy (*Oryza Sativa* L.) Growing Soils of Different Agro-climatic Zones, Telangana, India

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Authors' contributions

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

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ABSTRACT

The main occupation of Telangana State, India, is agriculture. Achieving food security requires intelligent management to increase land use productivity and production per unit area because of the expanding population and decreasing amount of agricultural land per capita. In this sense, assessing the productivity and fertility of the soil is a necessary step toward sustainable agricultural

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development. In the current study, paddy grown different soils in the districts of Telangana State were assessed for soil fertility using random sampling approach. This study was conducted to analyze the fertility characteristics of paddy cultivated soils in different districts of Telangana State. Collected 275 soil samples at 0-15cm depth under paddy crop grown during 2018-19 and 2019-20. The samples were found to be slightly acidic to alkaline in nature and low amount of soil organic matter. Soil nutrients such as available nitrogen (N), phosphorous (P) and potassium (K) ranged from 50-401 kg ha^{-1}, 17-147 kg ha^{-1} and 60-842 kg ha^{-1} in red soil, 63-314 kg ha^{-1}, 33-126 kg ha^{-1} and 95-460 kg ha^{-1} in black soil and 73-312 kg ha^{-1}, 25-158 kg ha^{-1} and 153-458 kg ha^{-1} in alluvial soil, respectively. The paddy cultivated soil survey results conclusively indicate that the soil samples reveals normal soil reaction, electrical conductivity and low organic carbon (0.48% average) and widespread low nitrogen levels (91% of samples). Conversely, phosphorus availability is high (82% of samples) with an average content of 82 kg P_2O_5 ha^{-1}, and potassium levels are notably elevated (57%).

Keywords: Soil fertility; paddy growing soils; physico-chemical properties; macronutrients; agro-climatic zones.

1. INTRODUCTION

About half of the world's population depends on rice (*Oryza sativa* L.), which is produced on 160 million hectares (Mha) of land and yields 493 million tons (Mt) of milled rice annually. The biggest amount of India's 141 Mha net cultivated area roughly 43 Mha is devoted to rice cultivation [1]. Telangana state produces 202.18 lakh tonnes of rice annually on 97 lakh acres of total cultivated land [2]. Due to population growth and dwindling agricultural land per person, achieving food security necessitates intelligent management to boost land use productivity and production per unit area [3]. The escalation of human-driven actions in modern times has led to a decline in the quality of soil fertility [4]. In this regard, determining the soil's fertility and production is an essential first step toward sustainable agricultural development [5,6].

Soil fertility is the condition of a soil's ability to provide the 14 nutrients in adequate amounts that are derived from the soil and necessary for plant growth [7]. Accordingly, sufficient and balanced nutrient supplies are the main components of soil fertility, meeting plant needs [8]. The soil fertility evaluation is the most fundamental tool in order to efficient plan of a specific land use system [9]. There are several techniques for evaluation of soil fertility status. Among them soil testing is a more appropriate one and most popular everywhere. Soil testing provides information about the nutrient availability in soils, which serves as the basis for the fertilizer recommendations for optimizing economic yield of crops. Soil analysis includes physical properties such as texture, structure, colour, bulk density etc. as well as chemical properties (soil pH, organic matter, macro and micronutrients etc.) which represents a requirement for sustainable soil management [10]. Plant nutrition is dependent on a multitude of elements, including the soil's capacity to provide nutrients, the plants' rate of uptake of those nutrients, the distribution of nutrients to their functional locations, and the mobility of those nutrients within the plant [11,12,13].

Evaluation of soil fertility at the regional level is a crucial part of soil management that promotes sustainability and high crop yields. Evaluating the physical quality or fertility condition of field soils that are consistently cultivated for particular crops might be helpful in determining the changes in soil deterioration beneath the crop [14]. Furthermore, it is helpful to periodically evaluate the nutritional status of farmed soils for certain crops wherever in the world in order to overcome nutrient-related stress on the crop and suggest optimal nutrient delivery [15]. Because soils vary so much within a given region or zone, it is challenging to draw any inferences or conclusions from the results of soil-testing parameters at that level of research [16]. This is the reason that several agro-climatic zones of Telangana State, specifically the northern, central, and southern zones, and major soil types, including red, black, and alluvial soils, have been taken into consideration in this study, which have a substantial impact on crop production, especially on staples like rice and maize. Mainly this study aims to analyze the physico-chemical and chemical properties of different soils suitable for rice cultivation across various zonal districts of Telangana. By contributing valuable insights, it seeks to facilitate sustainable agricultural practices in these regions, emphasizing the crucial role of soil fertility analysis in optimizing crop productivity and ensuring food security.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The top 10 most paddy cultivated *mandals* in each district of Telangana state were chosen for the study based on data from the DES, the state government, collected over the course of five years during the *kharif* and *rabi* seasons. Telangana districts comprises of three zones *i.e.,* Northern Telangana Zone (NTZ), Central Telangana Zone (CTZ) and Southern Telangana Zone (STZ) with each zone having 10 districts.

The *mandals* of higher rice acreage were segregated for red, black and alluvial predominant soils in the ratio 56:21:9 reflecting Telangana soil status. With the use of NBSS&LUP soil map, Nagpur, soil types for those *mandals* were collected, segregated and grouped as red soil, black soil and alluvial soil predominated *mandals* according to Northern Telangana Zone (NTZ), Central Telangana Zone (CTZ) and Southern Telangana Zone (STZ) of Telangana state were decided as sampling stations for the investigation.

The acreage of these red, black and alluvial soils computed based on extent per cent of soil type in the NTZ, CTZ and STZ zonal districts of Telangana and is as follows:

(i) NTZ has 50 % of red soils, 43% of black soils and 7% of alluvial soils.
(ii) CTZ has 74% of red soils, 16% of black soils and 10% of alluvial soils.
(iii) STZ has 85 % of red soils, 8% of black soils and 7 % of alluvial soils.

As per the NBSS&LUP, Nagpur, Maharashtra the red, black and alluvial soils in state are distributed in the percentage ratio of 56:21:9, respectively. The number of soils to be collected for each type of soil duly reflecting acreage and zone area in entire state is given in Table 1.

Altogether 275 composite soil samples representing of 275 rice cultivating fields (belonging to 47 distinct soil series) were collected during 2018-19 and 2019-2020. Coordinates of each sampling field were noted during sample collection using GPS (Garmin eTrex90). Out of the total 275 fields investigated, 97 were from NTZ, 89 from CTZ, and 89 from STZ. The locations from which these samples were collected are presented in Fig. 1.

2.2 Soil Sampling

Soil sampling was carried out during 2018-19 and 2019-2020, before the crop was going to sow in the field. In each field, the soil sample was collected at a depth of 0-15 cm by following quadrating sampling procedure, three different samples were collected from a sampling field randomly, and the three samples were mixed together to make a composite sample of the field. About 1 kg of each one hundred and seventy (170) composite red surface soil samples, Seventy five composite black samples and thirty composite (30) alluvial soil samples were collected from one hundred and forty seven (147) red soil representative *mandal*, fifty seven (57) black soil representative *mandal* and sixteen (16) alluvial soil representative *mandal* locations of Telangana State, where paddy crops were growing and these samples were carried to the laboratory for physico-chemical analysis. Before being analyzed, the soil samples were allowed to naturally dry in the shade. A wooden mortar and pestle was then used to grind 250 g of soil from the bulk samples, passed through a 2 mm sieve, and then stored in labelled bags for laboratory analysis

Table 1. Soil samples collected from NTZ, CTZ and STZ zones of Telangana State

Crop	Zone	No. of *mandals*	No. of soils collected in *mandals* with predominant soil types			Total
			Red	Black	Alluvial	
Paddy	NTZ	76	41	48	8	97
	CTZ	66	59	19	11	89
	STZ	78	70	8	11	89
Total		220	170	75	30	275

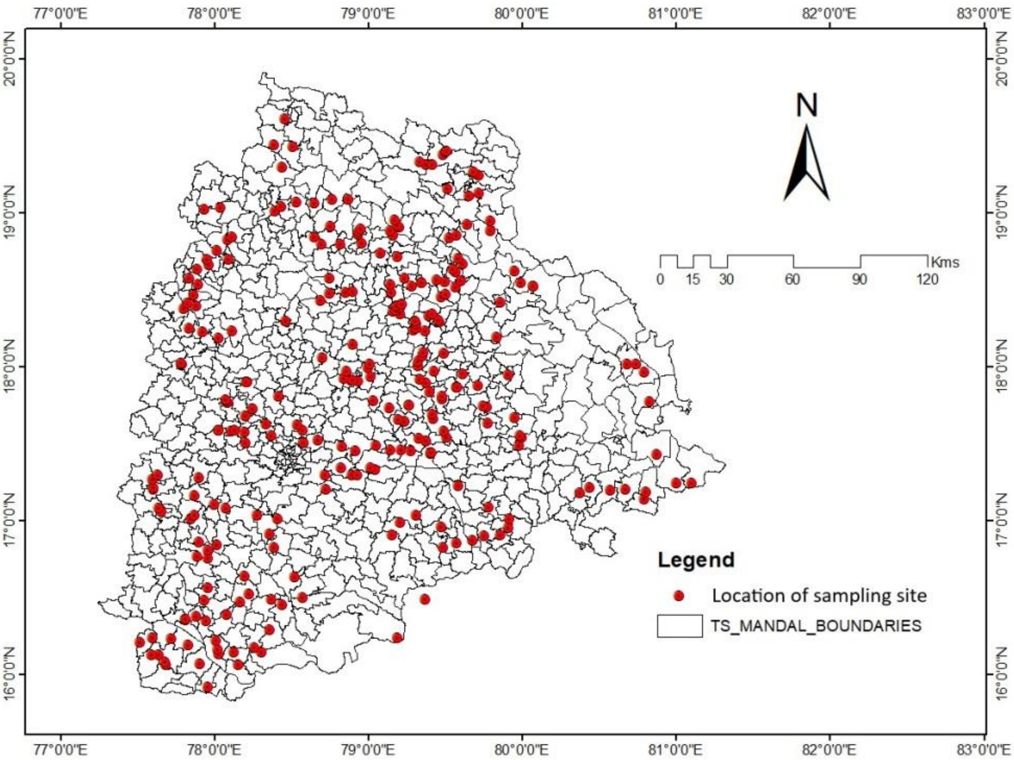

Fig. 1. Study area and sample collection sites mapped in Telangana State, India

2.3 Soil Characterization

In this study, the soil fertility properties studied were pH, EC, organic carbon and available macronutrients. The soil pH was assessed in a soil-water suspension at a ratio of 1:2.5 using a pH meter equipped with a glass electrode (Model Elico LI 127) following the method outlined by Jackson [17]. A digital conductivity meter (Model Elico CM 180) was used to measure the electrical conductivity in a 1:2.5 soil water solution [17]. The Walkley–Black method was used to evaluate the organic carbon content of dry soil samples [18]. Subbaiah and Asija's alkaline potassium permanganate technique was used to estimate the amount of available nitrogen [19]. According to Olsen *et al*. [20], the Olsen's extractant method was used to extract the available phosphorus from the soils. Watanabe and Olsen [21] described the process of using ascorbic acid as a reducing agent to measure the amount of phosphorus in the extract using a colorimeter (Model ECIL GS 5701 SS) at 660 nm wavelength. The neutral normal ammonium acetate method [11] was used to extract the available potassium from the soil, and the extract's concentration was measured by aspirating it into a flame photometer (Model Elico CL 361).

2.4 Statistics

In order to assess the fertility of different soil types, descriptive statistics were created for the lowest, maximum, and mean of six soil properties [22].

3. RESULTS

3.1 Paddy Cultivated Red Soils

From one hundred and forty seven (147) *mandals* mainly characterized by red soil across three agricultural climate zones in the state, collected One hundred and seventy (170) soil samples from paddy fields. Special attention was given to selecting samples from areas identified as red soil on the NBSSLUP map, confirmed by ground-level field assessments. The analysis of physico-chemical and available macronutrients are presented in Table 2.

pH: The red soils supporting paddy in the state recorded pH in the range of 6.11 to 8.20. Within the agro climatic zones of these red soils pH was registered in the range of 6.11 to 7.95 in NTZ (among 41 samples) 6.65 to 7.78 in CTZ (within 59 samples) and 6.54 to 8.20 in STZ (out of 70

Table 2. Physico-chemical and available macronutrients of paddy grown red soils in different agro-climatic zones of Telangana, India

Zone		pH (1:2.5)	EC (dSm^{-1})	OC (%)	Available Nutrients		
					N (kg ha^{-1})	P_2O_5	K_2O
	Range	6.11 - 7.95	0.008 - 0.753	0.10 - 1.09	63 - 276	24 - 135	118-732
	Mean		0.31	0.39	162.44	77.23	374.09
NTZ (41 no's)	**Low**			33	41	1	1
	% samples			80.49	100.00	2.44	2.44
	Medium			7	0	12	11
	% samples			17.07	0.00	29.27	26.83
	High			1	0	28	29
	% samples			2.44	0.00	68.29	70.73
	Range	6.65 - 7.78	0.02 - 0.719	0.19 - 0.51	50 - 314	17 - 147	72 - 627
	Mean		0.262	0.40	153.23	89.686	314.595
CTZ (59 no's)	**Low**			50	57	1	5
	% samples			84.75	96.61	1.69	8.47
	Medium			8	2	5	26
	% samples			13.56	3.39	8.47	44.07
	High			1	0	53	28
	% samples			1.69	0.00	89.83	47.46
STZ (70 no's)	**Range**	6.54 - 8.20	0.018 - 0.74	0.13 - 1.34	75 - 401	33 - 111	60 - 842
	Mean		0.26	0.52	237.99	77.52	351.50
	Low			38	52	0	6
	% samples			54.29	74.29	0.00	8.57
	Medium			21	18	10	27
	% samples			30.00	25.71	14.29	38.57
	High			11	0	60	37
	% samples			15.71	0.00	85.71	52.86

samples) (Table 2). The lowest pH of paddy field among red soils in the state was recorded at 6.11 in the Dasturabad *mandal* sample of Nirmal district of NTZ. The highest 8.20 pH of paddy soil was recorded in Veligonda *mandal* sample of STZ.

EC: Red soils supporting paddy crops had electrical conductivity values ranging from 0.018 to 0.741 dSm^{-1} in STZ, 0.02 to 0.719 in CTZ, and 0.008 to 0.753 in NTZ (Table 2). It was discovered that the state's red soils supporting this crop had an overall mean EC of 0.272 dSm^{-1}.

OC: In NTZ, CTZ, and STZ, the mean organic carbon content of red soils that sustain paddy was determined to be 0.39, 0.40, and 0.52 percent, respectively. It had a mean of 0.45 percent and varied from 0.10 to 1.34 percent in all the red soils examined throughout the state (Table 2). In paddy-grown red soils, the range of organic carbon was 0.10 to 1.09 percent in NTZ, 0.19 to 0.51 percent in CTZ, and 0.13 to 1.34 percent in STZ.

Available N: It was discovered that the state's red soils, where paddy is produced, had an available nitrogen status ranging from 50 to 401, with an average of 190 kg ha^{-1} (Table 2). The majority of these soils in the state had low amounts of available nitrogen, the mean values in NTZ, CTZ, and STZ were 162, 153, and 238 kg ha^{-1}, respectively. The levels varied from 63 to 276, 50 to 314, and 75 to 401. Thirty per cent of these samples (51 samples), showed extremely low amounts of available nitrogen, measuring less than 140 kg ha^{-1}.

Available P_2O_5: The state's red soils that supporting paddy crops have an average available P_2O_5 of 82 kg ha^{-1}, with a range of 17 to 147 kg ha^{-1}, according to data shown in Table 2. The phosphorus availability varied between 24 and 135 in NTZ, 17 to 147 in CTZ, and 33 to 111 kg P_2O_5 ha^{-1} in STZ. Eighty-three percent of these soils had high available phosphorus status in the state.

Available K_2O: In the state's paddy-grown red soils, the available potassium was found to be high in 55% of samples and medium in 38% of samples. It was discovered that just over 7% of the state's red soils, which are used for rice, had poor potassium status (Table 2). In terms of percentage samples, the trends of high, medium, and low potassium fertility were nearly comparable across the zones. As a result, the state's red soils supporting paddy crop had available potassium ranging from 60 to 842 kg ha^{-1}, with a mean of 344 kg K_2O ha^{-1}.

According to the available N, P, and K status (Fig. 2), 90% of soil samples in the red soils supporting paddy throughout the zones had low available nitrogen status, 81% had high phosphorus status, and 57% had high available K status.

3.2 Paddy Cultivated Black Soils

From paddy cultivated black soils, seventy five soil samples were collected from fifty seven black soil predominant *mandal*s in three agro climatic zones of the state. NBSSLUP soil map was used to identify black soil predominant *mandals* after substituting paddy area statistics. The analysis of physico-chemical and available macronutrients of black soil are presented in Table 3.

pH: The pH in black soils supporting paddy crop was found to range from 7.02 to 8.43. Its range was from 7.02 to 8.05, 7.22 to 8.43 and 7.11 to 8.09 in NTZ, CTZ and STZ, respectively (Table 3). The lowest pH of paddy field among black soils in the state was recorded at 7.02 in the Varni *mandal* of Nizamabad district of NTZ. The highest 8.43 pH of paddy soil was recorded in Patancheruvu *mandal* of Sangareddy district of CTZ.

EC: The EC in these paddy soils of the state was found to be range from 0.04 to1.85 with mean of 0.19 dSm^{-1}. The mean EC status in paddy supporting black soils was 0.208, 0.151 and 0.123 dSm^{-1} in NTZ, CTZ and STZ, respectively (Table 3).

OC: The data indicated that **t**he organic carbon in paddy grown black soils of the state ranged from 0.12 to 1.38 with mean of 0.54%. The OC was found to be low in 49 per cent of samples followed by medium in 28 per cent and high in 23 per cent samples. In different zones, the OC ranged from 0.14 to 1.09, 0.12 to 0.79 and 0.35 to 1.38 with mean of 0.57, 0.41 and 0.67% in NTZ, CTZ and STZ, respectively (Table 3). The high occurrence of low status of OC in paddy grown black soils was observed in CTZ (73.68%) followed by NTZ (43.75%) and STZ (25.00%).

Available N: Data presented in Table 3 indicated that the mean available N of black soils supporting paddy crop in the state was 160 kg ha^{-1} with a range of 63 to 314 kg ha^{-1}. The nitrogen availability ranged from 63 to 269 in NTZ, 63 to 251 in CTZ and 151 to 314 kg ha^{-1} in STZ (Table 3). Most of the soils, to an extent of 99 per cent was found to be low in available nitrogen among these soils. Data presented also indicated that 45 per cent samples have available N status of < 140 kg ha^{-1} (very low status).

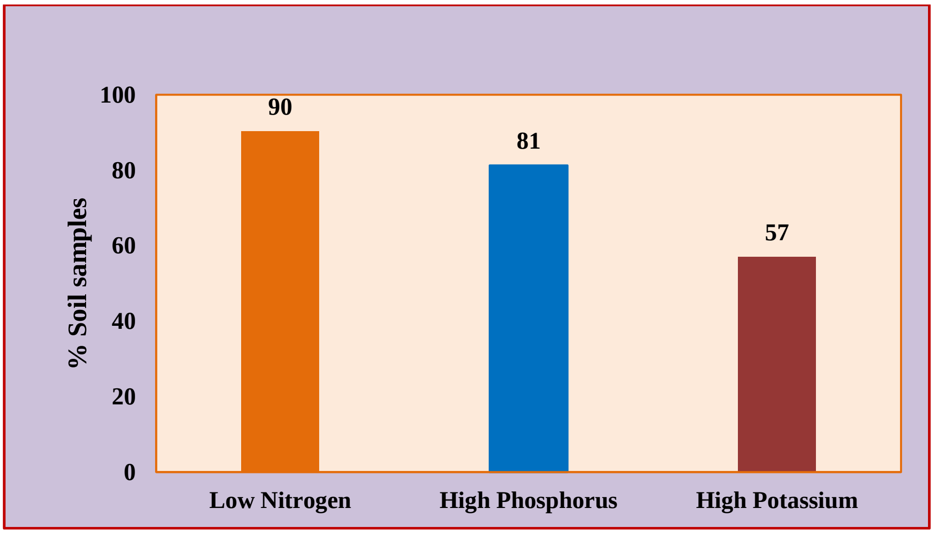

Fig. 2. Soil fertility status of predominantly paddy grown red soils of Telangana State (N, P & K)

Available P_2O_5: The available phosphorus status of black soils on which paddy is grown in state was found to be ranged from 33 to 126 with a mean of 82 kg P_2O_5 ha^{-1}. Most of these soils were high in available phosphorus across the state and it ranged from 33 to 126, 37 to 117 and 57 to 111 with a mean of 80, 84 and 87 kg P_2O_5 ha^{-1} in NTZ, CTZ and STZ, respectively (Table 3). In paddy growing black soils of the state an extent of 83 per cent soil samples were found to be high in available phosphorus status.

Available K_2O: The available potassium status of black soils on which paddy was grown in state was found to be ranged from 95 to 460 with a mean of 332 kg K_2O ha^{-1}. Most of these soils were medium to high in available potassium status across the state and it ranged from 167 to 460, 95 to 423 and 174 to 424 with a mean of 365, 247 and 337 kg K_2O ha^{-1} in NTZ, CTZ and STZ, respectively (Table 3). In paddy grown black soils of the state, the available potassium was high in 64 per cent soil samples, medium in 31 soil samples and low in 5 per cent soil samples only.

The available N, P, and K status of the black soils supporting paddy across the zones (Fig. 3), indicated that 96 per cent of soil samples had low available nitrogen status, 83 per cent had high phosphorus status, and 54 per cent had high available K status.

3.3 Paddy Cultivated Alluvial Soils

Thirty soil samples were collected in three of the state's agroclimatic zones from paddy-cultivated fields in sixteen alluvial soil-predominant *mandals*. Samples were carefully collected from the NBSS&LUP map's plotted unit area of alluvial soil as well as by on-site field observations. The analysis of physico-chemical and available macronutrients is presented in Table 4.

pH: The pH of the paddy supporting alluvial soils in Telangana state ranged from 6.50 to 8.25. The pH in paddy growing in these soils ranged from 6.65 to 8.25, 6.50 to 7.69 and 6.59 to 7.65 in NTZ, CTZ and STZ, respectively (Table 4). The highest pH (8.25) was recorded in NTZ zone, whereas lowest pH of 6.50 was recorded in CTZ of paddy supporting alluvial soils.

Table 3. Physico-chemical and available macronutrients paddy grown black soils in different agro-climatic zones of Telangana State

Zone		pH (1:2.5)	EC	OC	Available Nutrients		
			(dSm^{-1})	(%)	N (kg ha^{-1})	P_2O_5	K_2O
	Range	7.02 - 8.05	0.036 - 1.853	0.14 - 1.09	63 - 269	33 - 126	. 67 - 460
	Mean		0.208	0.571	154.576	80.025	364.609
	Low			23	48	0	0
NTZ	% samples			47.92	100.00	0.00	0.00
(48 no's)	Medium			12	0	11	10
	% samples			25.00	0.00	22.92	20.83
	High			13	0	37	38
	% samples			27.08	0.00	77.08	79.17
	Range	7.22 - 8.43	0.04 - 0.29	0.12 - 0.79	63 - 251	37 - 117	95 - 423
	Mean		0.15	0.41	139.68	83.58	246.92
	Low			14	19	0	4
CTZ	% samples			73.68	100.00	0.00	21.05
(19 no's)	Medium			4	0	3	11
	% samples			21.05	0.00	15.79	57.89
	High			1	0	16	4
	% samples			5.26	0.00	84.21	21.05
	Range	7.11-8.09	0.041-0.203	0.35-1.38	151-314	57-111	161-424
	Mean		0.123	0.67	233	87	318
STZ	Low			2	7	0	0
(8 no's)	% samples			25.00	87.50	0.00	0.00
	Medium			4	1	1	3
	% samples			50.00	12.50	12.50	37.50
	High			2	0	7	5
	% samples			25.00	0.00	87.50	62.50

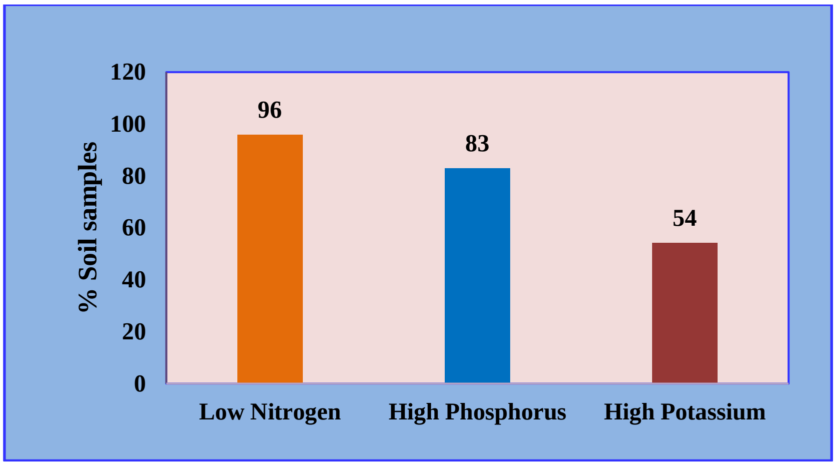

Fig. 3. Soil fertility status of predominantly paddy grown black soils of Telangana State (N, P & K)

EC: The EC ranged from 0.08 to 0.26, 0.14 to 0.30 and 0.14 to 0.30 with mean of 0.17, 0.21 and 0.18 dSm^{-1} in NTZ, CTZ and STZ, respectively in paddy supporting alluvial soils (Table 4). The EC in paddy growing alluvial soils of the state was recorded in the range of 0.08 to 0.31 with a mean of 0.19 dSm^{-1}.

OC: The organic carbon in paddy supporting alluvial soils of the state indicated that 60 per cent, 27 per cent and 13 per cent of soil samples were low, medium and high in status, respectively. In paddy growing alluvial soils of the state, the OC ranged from 0.10 to 1.07 with mean of 0.48 per cent. The OC ranged from 0.23 to 0.65, 0.10 to 0.79 and 0.10 to 1.07 with mean of 0.38, 0.57 and 0.45 per cent in NTZ, CTZ and STZ, respectively. The highest OC (1.07%) was observed in STZ, whereas lowest OC (0.10%) was found in CTZ of paddy supporting alluvial soils in the state (Table 4).

Available N: The available nitrogen status in paddy supporting alluvial soils of the state ranged from 73 to 312 with mean of 171 kg ha^{-1}. The available nitrogen ranged from 73 to 151, 88 to 239 and 129 to 312 with a mean of 114, 147 and 237 kg ha^{-1} in NTZ, CTZ and STZ, respectively (Table 4). In paddy supporting alluvial soils of the state the available nitrogen status indicated that 90 per cent, 10 per cent and nil soil samples were belonging to low, medium and high status, respectively. Forty eight per cent of these alluvial soils supporting paddy crop in the state recorded very low < 140 kg ha^{-1} status of available nitrogen.

Available P_2O_5: The available phosphorus in paddy supporting alluvial soils in the state indicated that about 77 per cent samples were high in available phosphorus and 23 per cent were medium in available P status. None of the samples were found to be low in status of available P in analysed paddy supporting alluvial soils of the state. The available phosphorus in paddy supporting alluvial soils of the state ranged from 25 to 158 with mean of 84 kg P_2O_5 ha^{-1}. The available phosphorus ranged from 25 to 158, 64 to 122 and 30 to 104 with mean of 81, 96 and 70 kg P_2O_5 ha^{-1} in NTZ, CTZ and STZ, respectively. The high available phosphorus status of these alluvial soils was noticed mostly in CTZ (91%) followed by in NTZ (88%) and STZ (55%) (Table 4).

Available K_2O: The available potassium status in paddy supporting alluvial soils (n=30) of the state ranged from 153 to 458 with mean of 335 kg K_2O ha^{-1}. The available potassium ranged from 250 to 431, 206 to 458 and 153 to 458 with mean of 309, 362 and 328 kg ha^{-1} in NTZ, CTZ and STZ, respectively (Table 4). In paddy supporting alluvial soils of the state the available potassium indicated that 43 per cent, 57 per cent and nil soil samples were falling under medium, high and low status, respectively. Thus, the low status potassium availability was almost nil among analysed samples.

Fig. 4 indicates that the available N, P, and K status of the black soils supporting paddy across the zones, 91 per cent of soil samples had low available nitrogen status, 84 per cent had high phosphorus status, and 54 per cent had high available K status.

Table 4. Physico-chemical and available macronutrients paddy grown alluvial soils in different agro-climatic zones of Telangana State

Zone		pH(1:2.5)	EC (dSm^{-1})	OC (%)	Available Nutrients N (kg ha^{-1})	P_2O_5	K_2O
	Range	6.65-8.25	0.077-0.263	0.23-0.65	73-151	25-158	250-431
	Mean		0.17	0.38	114	81	309
NTZ (8 no's)	Low			6	8	0	0
	% samples			75.00	100.00	0.00	0.00
	Medium			2	0	1	6
	% samples			25.00	0.00	12.50	75.00
	High			0	0	7	2
	% samples			0.00	0.00	87.50	25.00
	Range	6.50-7.69	0.142-0.304	0.10-0.79	88-239	64-122	206-458
	Mean		0.207	0.57	147	96	362
CTZ (11 no's)	Low			4	11	0	0
	% samples			36.36	100.00	0.00	0.00
	Medium			5	0	1	3
	% samples			45.45	0.00	9.09	27.27
	High			2	0	10	8
	% samples			18.18	0.00	90.91	72.73
	Range	6.59-7.65	0.144-0.304	0.10-1.07	129-312	30-104	153-458
	Mean		0.177	0.45	237	70	328
STZ (11 no's)	Low			8	8	0	0
	% samples			72.73	72.73	0.00	0.00
	Medium			1	3	4	4
	% samples			9.09	27.27	36.36	36.36
	High			2	0	7	7
	% samples			18.18	0.00	63.64	63.64

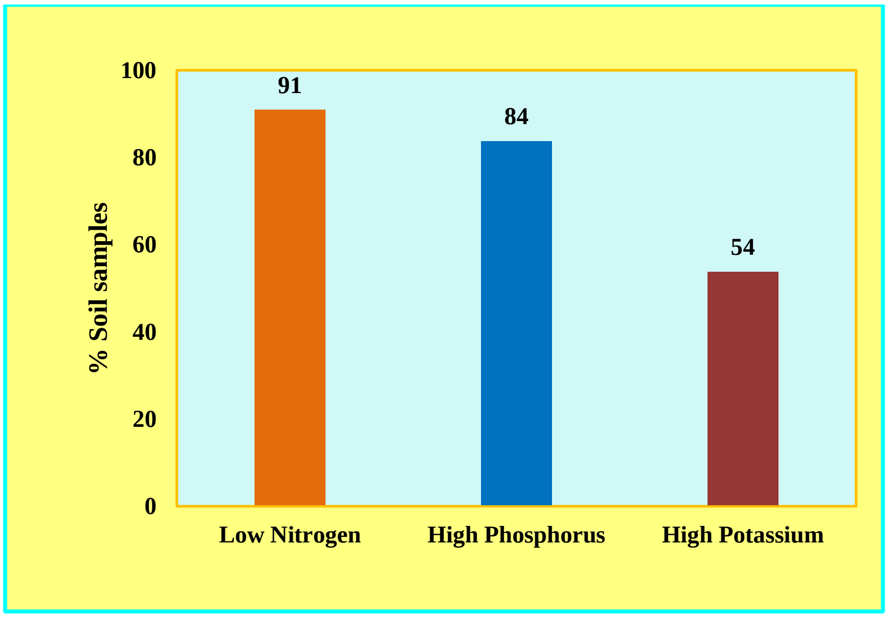

Fig. 4. Soil fertility status of predominantly paddy grown alluvial soils of Telangana State (N, P & K)

3.4 Paddy Supporting All Soils (Red, Black and Alluvial)

In all 275 paddy supporting soils of state, the pH ranged from 6.11 to 8.43, EC from 0.01 to 1.85 with mean of 0.24 dSm^{-1} and organic carbon from 0.10 to 1.38 with mean of 0.48 per cent. The paddy supporting soils in the state were found to record 65, 23 and 12 per cent of low, medium and high category of OC, respectively (Table 5).

Available N in these all soils ranged from 50 to 401, P_2O_5 from 17 to 158 and available K from 60 to 842 with a mean of 180, 82 and 340 kg ha^1, respectively. The available N, P and K status in the state that supporting paddy indicated that (Fig. 5) 92 per cent of soil samples were low in available nitrogen status, 83 per cent were high in phosphorus and 55 per cent of soil samples were high in available K (Table 5).

4. DISCUSSION

Sampling during survey is usually carried out in grid basis. However, in this study to represent paddy grown soils and to cover all three major types of soils and all districts of state, the following methodology was adopted.

Table 5. Physico-chemical and available macronutrients of paddy grown soils belonging to different agro-climatic zones of Telangana State (Pooled data)

SOIL		pH (1:2.5)	EC (dSm^{-1})	OC (%)	Available Nutrients		
					N (kg ha^{-1})	P_2O_5	K_2O
All soils (275 no's)	Range	6.11-8.43	0.01- 1.85	0.10-1.38	50- 401	17- 158	60- 842
	Mean	7.36	0.24	0.48	180.04	81.88	339.79
	Low			178	251	2	16
	% samples			61.04	92.35	0.46	4.50
	Medium			64	24	47	101
	% samples			26.25	7.65	16.90	40.48
	High			33	0	226	158
	% samples			12.62	0.00	82.64	55.02

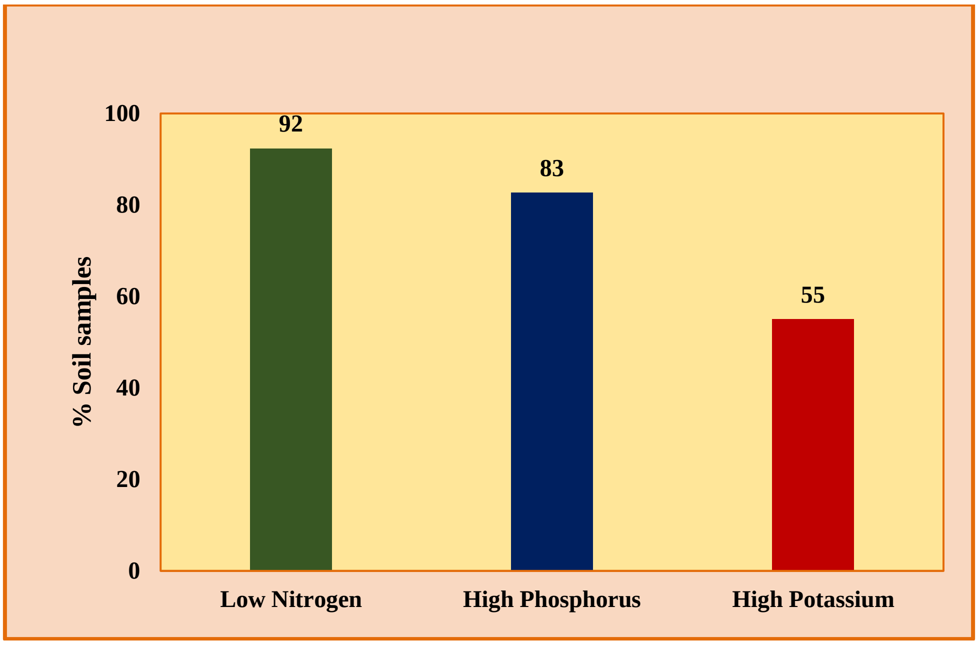

Fig. 5. Soil fertility status of predominantly paddy grown *mandals'* soils of Telangana State (N, P & K)

Based on five years data (prior to survey), the top 10 *mandals* having highest paddy acreage was selected from 32 districts of state. Based on occurrence major soils of state in the ratio of 56:21:9 of red/black/alluvial soils number of *mandals* in state about 105 *mandals* in NTZ, 108 *mandals* in CTZ and 91 *mandals* in STZ totaling to 364 out of 528 *mandals* of state were selected for collection of soil and crop samples. Thus NBSS&LUP soil maps for major soil type identification (at *mandal* level) and Department of Agriculture, Telangana State government data for acreage formed basis to cover entire state and 3 major types of soils for paddy supporting areas which is predominant staple crop in the state.

Thus, two hundred and seventy five (275) soil samples were collected from paddy cultivated soils of red, black and alluvial soil predominated *mandals* across all districts of Telangana state. One hundred and seventy (170) soil samples from red soil, seventy five (75) soil samples from black soil and thirty (30) soil samples from alluvial soil predominated *mandals,* were collected during the survey in 2018-19 and 2019-20 and analyzed as specified. The pH, EC and OC and other important elements like N, P and K were also studied /analyzed to find out the fertility status of paddy cultivated different soils. The results are discussed here with.

4.1 Physico-Chemical Properties

The survey was carried out with emphasis to know about the fertility status of paddy grown soils of Telangana state. The pH of 275 soil samples ranged from 6.11 to 8.43 in paddy supporting soils (Table 5) in case of zonal variation the pH of the soils was in the narrow range of 6.11 to 8.25 in NTZ, 6.50 to 8.43 in CTZ, 6.59 to 8.09 in STZ. Among the soils the pH was 6.11 to 7.95 in case of red soils, 7.02 to 8.05 in black soils and 6.65 to 8.25 in alluvial soils. These pH values observed in the study were similar like that of earlier reports of Surendra Babu et al. [23] who have extensively mapped the soil fertility characteristics of Telangana state.

Elsewhere, such pH ranges in red soils supporting paddy [24], wheat soils of central India [25], Red soils of Tamil Nadu [26] Black soils supporting paddy [27] in a similar range was reported.

The electrical conductivity of 275 samples ranged from 0.01 to 1.85 $dSm^{-1}$and within the red soils (Table 2), black soils (Table 3) and Alluvial soils (Table 4) supporting paddy crop, the EC was normal without any salinity. The EC in soils across different zones also did not vary much as both red and black soils are available in these zones such EC ranges of soils not only reported from Telangana but also by several workers like Sharma et al. [28] and Bhatt and Singh [29] in different areas for normal agricultural fields and in paddy soils of different soil texture [30].

The organic carbon content in entire Telangana with in the surveyed 275 samples ranged from 0.10 to 1.38% with a mean of 0.48% (Table 5). In general the mean organic carbon content was low in NTZ and CTZ (0.48 & 0.42%), respectively and was medium (0.53%) in STZ. Within the soils the mean organic carbon was highest in black soils (0.54%) followed by alluvial soils (0.48%) and red soils (0.45%).

In general the organic carbon not only in Telangana, but in several states across the country in different types of soils is low to medium [31,32] and this is mainly because dwindling supply of organic manures into agricultural fields, high temperatures and less residue recycling [32,33]. The variation in the mean organic content between different crop supporting soil groups may be because of input variation, variation in the exhaustiveness of crops and major season in which these crops are grown.

4.2 Available Macronutrients

Major nutrients availability in surveyed soil samples was studied. The available nitrogen, reflecting the organic carbon status was found to be low and ranged from 50 to 401 kg ha^{-1} in 275 samples with a mean of 180 kg ha^{-1}. In order to have more meaningful insight into nitrogen availability in the currently grouped low category available nitrogen (< 280 kg ha^{-1}) was further divided into very low category (< 140 kg ha^{-1}) and low (141 to 280 kg ha^{-1}). Based on this 101 of samples among 275 were found to be very low in available nitrogen and constituted 40%. Within the currently accepted low category of < 280 kg ha^{-1} such a sub classification of very low category of nitrogen is meaningful to prioritize green manuring, organic manure addition etc., and is being reported and advocated in Telangana state and is yet to be completely adopted as of now.

Among soils, the mean available nitrogen content was higher at 238 kg ha^{-1} in STZ zone followed

155 kg ha^{-1} and 150 kg ha^{-1} in NTZ and CTZ zones, respectively. Low available nitrogen status is the common observation in many soils and in many areas of the state as well as country because of the reason that were already enumerated for organic carbon content. The low available nitrogen status of the soil; as common phenomenon across the country is being reported over long time [34,35,36].

Available phosphorus status in surveyed samples mostly remained in high status category. As much as 82 % of 275 samples analyzed were found to have high available phosphorous as per the Muhr et al. [37] classification with mean content of 82 kg P_2O_5 ha^{-1} like in nitrogen, but in different approach to high category of phosphorous was further classified as high and very high sub categories as mapped for soils in Telangana state [23]. Thus, 167 number of soils out of 226 high P Status soil constituting 74% have been grouped as soils with very high phosphorous availability with in high category. Madhavi and Reddy [38] also reported more phosphorous saving is possible in very high phosphorous soils for crops like in sunflower.

Similarly, the very high P Status Soils (75 kg P_2O_5 ha^{-1}) was found to be in the high P category 62 (51), 83 (74) and 70 (58) % NTZ, CTZ and STZ respectively within over all 275 samples. The available phosphorous status also varied with types of soils among surveyed samples. The mean available phosphorous was highest in red soils with 83% in high category. This was followed by samples from alluvial and black soils with 82 and 80% high, respectively. Low phosphorous availability in surveyed 275 samples was found to be less in an extent of < 1% only.

Continuous use of high analysis P fertilizer like DAP, indiscriminate use of the same, slowly resulted in buildup of phosphorous in soils and in a different manner among different soils [39,40]. This phenomenon over years has changed the soil P fertility map of India over time. The reports of excess phosphorous availability occurrence in Telangana soils was reported by Surendra Babu et al. [23] and the present result also collaborate the same.

Potassium availability analyzed in surveyed 275 samples from different districts of the state revealed that 6 % are low, 37% are medium and 57% are high in its availability. Highest potassium availability status of soils was higher in NTZ zone (70%) whereas medium category was highest in CTZ zone (45%) and low category was also highest in CTZ zone (10%). The data was also reorganized to find out the variation in potassium availability among soil types in the state. The high potassium availability category soils was found to be more in black soils (63%) followed by in alluvial soils (57%) and in red soils (55%).

The potassium availability in Indian soils is reported to be medium to high in any instances [41,42,43]. Potassium rich minerals that varies in different types of soils and hence the present variation in potassium availability of surveyed samples expected [44,45].

5. CONCLUSION

The soil survey of paddy fields in Telangana reveals normal soil reaction and electrical conductivity, with no salinity issues detected. However, the soil has low organic carbon (0.48% average) and widespread low nitrogen levels (91% of samples). Conversely, phosphorus availability is high (82% of samples) with an average content of 82 kg P_2O_5 ha^{-1}, and potassium levels are notably elevated (57%). To enhance soil productivity, focus on increasing organic matter with cover cropping and compost, managing nitrogen through balanced fertilization and nitrogen-fixing crops and optimize phosphorus use based on soil tests, regulating potassium application to avoid excess, monitoring pH and electrical conductivity, and implementing effective irrigation and drainage practices to prevent potential salinization issues.

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 writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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