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Fertility status of different soil associations of central India

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ABSTRACT

In the study area, GPS based 303 top-surface soil (0–15 cm) samples were collected from different soil associations viz., Typic Ustropepts-Vertic Ustropepts (S-1), Vertic Ustropepts-Typic Haplusterts (S-2), Typic Haplusterts-Lithic Ustorthents (S-3), Typic Ustochrepts-Vertic Ustochrepts (S-4), Chromic Haplusterts-Vertic Haplusterts (S-5), Typic Hapluesterts-Fluventic Ustochrepts (S-6), Lithic Ustorthents-Typic Ustorthents (S-7), and Typic Haplusterts-Vertic Ustochrepts (S-8) and analyzed using standard protocols in laboratory. The results showed that the soil pH was neutral to alkaline in reactions, safe in terms of electrical conductivity, low to medium of soil organic carbon content, and non-calcareous to calcareous in nature. The coefficient of variability (CV) $CaCO_3$ had the furthermost variability, followed by EC, SOC, and pH had the minimum variability in research soils, which varied widely with values of 6.70–83.40%. SOC content was low in the order of S2>S4>S1 and medium in the order of S8>S6>S3=S7>S5 soil associations. Similarly, the available N content in the order of S7>S8>S5>S6>S3>S4>S2>S1. In addition, the Olsen-P was in the order of S8>S5>S6>S3 and medium in the order of S4>=S2>S1>=S7.The available K was in the order of S5>S8>S6>S4>S7>S4 and medium in S2 and S1 in soil associations. The available zinc content was low, in various soil associations in the order of S1>S8>S2>S4=S5>S6>S7. Only S3, S5, S8, S6, and S4 soil associations study areas.

Keywords: Soil physico-chemical properties, soil variability, Soil associations

INTRODUCTION

Soils are an inherently heterogeneous and dynamic natural property, and they can change under the influence of natural and human induced factors (Qu *et al.,* 2014; Liu *et al.,* 2014). As human populations continue to increase, human disturbance of the earth's ecosystem to produce food and fiber will place greater demand on soils to supply essential nutrients. In India, continuous cropping for enhanced yield removes substantial amounts of nutrients from soil (Takkar, 1996). Soil fertility fluctuates throughout the growing season each year due to alterations in the quantity and availability of mineral nutrients. Soil heterogeneities may arise from management activities (Sivarajan *et al.,* 2013) and can occur from land use and management strategies (Yasrebi *et al.,* 2008). Among the all-essential nutrients are macronutrients, as they are required in large quantities for growth, increase crop productivity (Yasrebi *et al.,* 2008), and also help in the occurrence, diversity, distribution, and relative abundance of species (Nonzom and Sumbali, 2014). However, the availability of nutrients in soils differs widely and depends upon the geophysical constraints like the nature of the rock, climate, and topography. The soil pH and the susceptibility of the soil to compaction are dependent on the constituents of the original parent rock (Brady, 1984). The chemistry of P in soils is very peculiar in both calcareous (high Ca^+) and acidic soils (high Al^+ and/or Fe^+), and only about 20% of the total amount of P fertilizer is utilized by the first crop and the remaining 80% is fixed in the soil in an unavailable form, requiring regular annual applications of this element to maintain optimum crop yield (Malakouti *et al.,* 2008). reported that excessive phosphorus accumulation in soils resulted in low productivity because of interactions with other nutrients, especially micronutrients. In addition, application and importance of K are ignored by Indian farmers due to its adequate soil supply.
Today, 49% of Indian soils are Zn deficient, and over 61.70% of soil samples are reported as Zn deficient, with the highest percent in Vertisol soils in Madhya Pradesh (Shukla *et al.,* 2014). Fageria *et al.* (2002) and Amritanshu *et al.* (2023), in their review of micronutrients in crop production, maintained that micronutrient

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deficiencies in crop plants are widespread worldwide. Similar, low levels of sulphur have been reported to limit the growth of oilseed and pulse crops grown on black cotton soils where the incidence of sulphur deficiency is continuously increasing. The reasons are the fertilizer use pattern dominated by sulphur-free fertilizer and the large area of soybean and chickpea growing in Madhya Pradesh.

Physical and chemical properties of soils exhibit large variation across landscapes, regions, and even within a field (Brady and Weil, 2008). Some earlier studies that the effect of variability in soil properties on crop performance could be detrimental, especially when the fields are patchy (Haefele and Wopereis, 2005). Soil variability may result from edaphic factors such as the parent material and position of soil on the catena, climate, topography, vegetation, and land management, among others (Obi and Udoh, 2011). Scientific information concerning spatial variability and distribution of soil properties is critical for farmers attempting to increase efficiency of fertilizers and crop productivity (Tesfahunegn *et al.,* 2011). It is revealed from the literature that most of the research work was done abroad and considered only a single parameter across large-scale regions or, at most, several parameters measured in small-scale areas (Ruth and Lennartz, 2008). Since crop production and soil management differ with the kind of soil and its physico-chemical behavior, soils need to be handled carefully for stabilized and sustainable crop production. Reliable information on the spatial variability of key soil properties is essential for planning sound environmental management decisions and precisely determining sustainable land use practices (Gajda *et al.,* 2016). Information on within field variability is useful for the adoption of site-specific fertilization and other soil management decisions. Whereas regional spatial information can be useful for regional landscape management approaches.

METHODS AND MATERIALS

Description of study area

Geographically, Harda district lies in between 21^0 53' - 22^0 36' North latitude and 76^0 47'- 77^0 30' East longitude with an area of 3330 sq. km. It is located in the Narmada River valley and the Narmada forms the district northern boundary. Administratively, the district is divided into six blocks: Rahatgaon, Harda, Khirkiya, Hundia, Sirrali, and Timarani. The district feels maximum temperatures up to 47 °C and minimum temperatures up to 12 °C, with an average rainfall of 916 mm. The districts sub-tropical climatic range, varied physiography, diverse geology, and diverse land use have resulted in diversity in soil development.

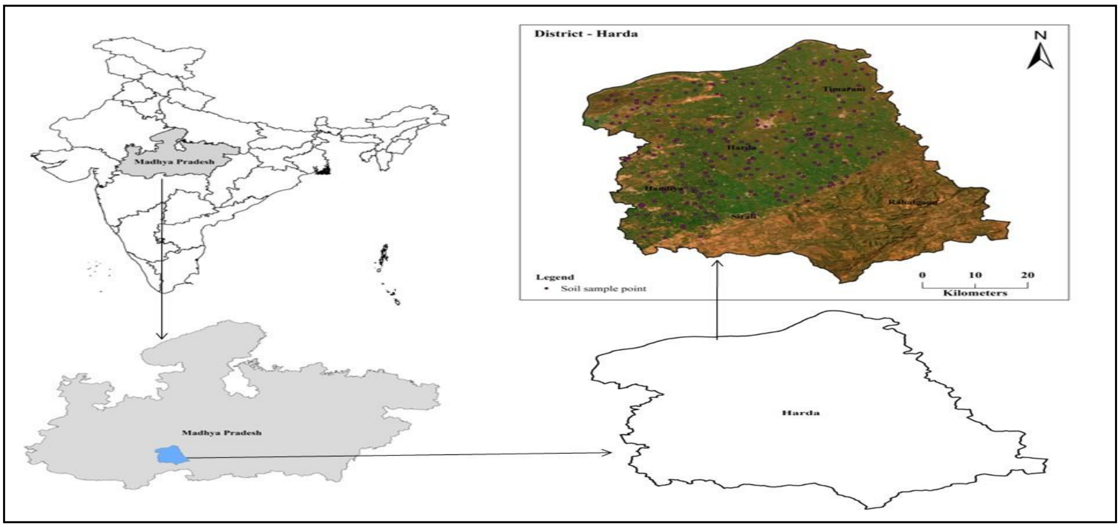

Figure 1: Location map of study and sampling sites

Soil associations in Harda district:

Soil association map (Figure 2) of the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) in Nagpur. the largest area is occupied by Vertisols, followed by Inceptisols and Entisols. It is evident from table 1. that the largestarea (693.22 sq km) falls under the fine, montmorillonitic, (Cal.) hyperthermic, Typic Haplusterts-fine, montmorillonitic, (Cal.) hyperthermic, andVertic Ustochrepts soil associationsand occupies 20.79 percent of the total geographical area.

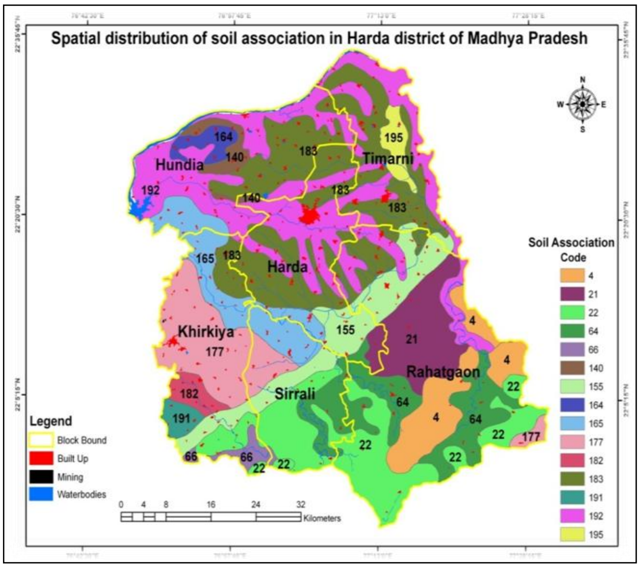

Figure 2: Soil associations in study region

The second most dominant soil association was fine, montmorrilonitic hyperthermic,Typic Haplusterts-fine, montmorrilonitic, hyperthermic, Fluventic Ustochrepts with an area of 622.49 sq km (18.95%) followed by clayey, mixed, isohyperthermic,Typic Ustropepts-fine, mixed, isohyperthermic, Vertic Ustropepts with an area of 397.55 sq km (12.09%), clayey, montmorillonitic, hyperthremic, Typic Ustochrepts-fine, montmorillonitic, hyperthermic, Vertic Ustochrepts with an area of 285.04 sq km (8.66%), loamy, mixed, isohyperthermic, Lithic Ustorthents-loamy, mixed, isohyperthermic, Typic Ustropepts with an 264.7 sq km (8.05%), fine, mixed, hyperthermic, Typic Haplusterts-clayey, mixed, hyperthermic, Lithic Ustorthents with an area of 241 sq km (7.34%) and others.The lowest area of 31.36 sq km was recorded under the fine, montmorillonitic, hyperthermic, Typic Haplusterts-Fine, montmorillonitic, hyperthermic, Vertic Ustochrepts soil associations. Fifteen soil associations were reported (Figure 2).

Table 1: Soil associations in study area

Code	Soil associations-1	Soil associations-2	Area (sq km)	%TSA
4	Loamy, mixed hyperthermic, Lithic, Ustorthents, (Entisols)	Loamy, mixed hyperthermic,Typic Ustrochrepts,(Inceptisols)	185.14	5.71
21	Loamy -Skeletal, mixed, hyperthermic, Lithic Ustorthents, (Entisols)	Fine, mixed hyperthermic, Typic Ustropepts,(Entisols)	205.60	6.26
22	Clayey, mixed, isohyperthermic,Typic Ustropepts, (Entisols)	Fine, mixed, isohyperthermic, Vertic Ustropepts,(Entisols)	397.55	12.09
64	Loamy, mixed, isohyperthermic, Lithic Ustorthents, (Entisols)	Loamy, mixed, isohyperthermic, Typic Ustropepts, (Entisols)	264.70	8.05
66	Fine, montmorillonitic, isohyperthermic, Vertic Ustropepts, (Entisols)	Fine, montmorillonitic, isohyper-thermic,TypicHaplusterts, (Vertisols)	33.19	1.01
140	Clayey, mixed, hyperthermic, Lithic Ustochrepts(Inceptisols)	Clayey, Mixed, hyperthermic, Lithic Ustorthents,(Entisols)	45.39	1.38
155	Fine, mixed, hyperthermic, Typic Haplusterts, (Vertisols)	Clayey, Mixed, hyperthermic, Lithic Ustorthents, (Entisols)	241.10	7.34
164	Loamy skeletal, mixed hyperthermic, Lithic Ustorthents, (Entisols)	Clayey, mixed, hyperthermic,Typic Ustorthents, (Entisols)	39.87	1.21
165	Fine, montmorillonitic, hyperthermic, Chromic Haplusterts, (Vertisols)	Fine montmorillonitic. hyperthermic, Vertic Haplusterts, (Vertisols)	213.70	6.50
177	Clayey,montmorillonitic,hyperthremic,Typic Ustochrepts, (Inceptisols)	Fine, montmorillonitic, hyperthermic,Vertic Ustochrepts, (Inceptisols)	285.04	8.66
182	Fine, montmorillonitic, isohyperthermic, Typic, Ustropepts	Fine, montmorillonitic, isohyperthermic, Vertic Ustropepts, (Entisols)	38.89	1.18
183	Fine, montmorillonitic, hyperthermic, Typic Haplusterts, (Vertisols)	Fine, montmorillonitic, hyperthermic, Fluventic Ustochrepts, (Inceptisols)	622.49	18.95
191	Fine, montmorillonitic, hyperthermic, Typic Haplusterts, (Vertisols)	Fine, montmorillonitic, hyperthermic,Vertic Ustochrepts, (Inceptisols)	31.36	0.95
192&195	Fine, montmorillonitic, (Cal.) hyperthermic, Typic Haplusterts, (Vertisols)	Fine, montmorillonitic, (Cal.) hyperthermic, Vertic Ustochrepts, (Inceptisols)	693.22	20.79
			3286.87	

Cal. Calcareous, TSA –total study area

Soil Sampling and Laboratory Analyses

The sampling sites were randomly distributed over the agricultural land by considering soil association maps, topography, and the heterogeneity of the soil types. A total of 303 samples of the top 15 cm of soil (sampling sites are shown in Figure 1) were collected with the help of a hand-held Global Positioning System (GPS) during the off-season crops. The soil samples were air dried (25^0 C), then crushed using a wooden pestle and mortar and sieved through with a 2 mm sieve. The samples were analyzed for physico-chemical properties soil pH was measured in a soil: water ratio of 1:2.5 using the pH meter, and supernatant of same was used for EC determination with the help of a conductivity meter. Soil organic carbon was estimated by the Walkley-Black (1934) method. Calcium carbonate content in soils is determined using rapid back titration, as described by Jackson (1973). Available nitrogen was estimated by alkaline $KMnO_4$ method where the organic matter in soil was oxidized with a hot alkaline $KMnO_4$ solution. The ammonia (NH_3) evolved during oxidation was distilled and trapped in boric acid mixed indicator solution. The amount of NH_3 trapped was estimated by titrating with standard acid (Subbiah and Asija, 1956). The available phosphorus of soil was extracted with 0.5 M $NaHCO_3$ (pH 8.5) (Olsen *et al.,* 1954) and available potassium was first extracted with ammonium acetate, and the content of K was determined by the Atomic Absorption + emission flame photometer. The available sulphur will be extracted by the turbidimetric method using spectrophotometer (Chesnin and Yien, 1951). Available micronutrients (Zn, Cu, Fe, and Mn) were extracted with diethylene triamine penta acetic acid (DTPA) and determined with flame atomic absorption spectrometry as described by Lindsay and Norvell (1978) and HWS-B in soil was analyzed by Azomethine-H method as outlined by Berger and Truog (1939).

Soil fertility evaluation

The nutrient index (NI) values for available nutrients present in the soils were calculated utilizing the formula suggested by Parker *et al.* (1951) and classified as low (<1.67), medium (1.67 to 2.33), and high (>2.33).

Statistics analysis

Statistics, such as means and CV, summaries the data calculated using the Statistical Package for Social Science (SPSS) 21 version software and Microsoft Excel.

RESULTS AND DISCUSSION

Descriptive statistics of soil parameters

The descriptive statistics (table 2) for pH, EC, SOC, and $CaCO_3$ are 7.60, 0.20 dSm^{-1}, 5.32 g kg^{-1}, and 37.4 g kg^{-1}, respectively. In addition, the available N, P, K, and S mean values are 231.3 kg ha^{-1}, 23.85 kg kg^{-1}, 472 kg $kg^{-1}$and 28.25 mg kg^{-1}, respectively. The available micronutrients, which include Zn, Cu, Fe, Mn, and hot water-soluble B, had mean values of 0.49, 2.16, 10.05, 18.19, and 1.33 mg kg^{-1}, respectively, in the district as a whole area. The ratio of standard deviation to mean, represented as a percentage, or the coefficient of variation, is a helpful measure of overall variability. According to the data (table 2), $CaCO_3$ had the most variability (CV=83.40%), followed by EC, SOC, and pH, which had the least variability (CV=6.70). Similarly, the results found by Shukla *et al.* (2016) when considering CV are 10% as low, 10% to 100% as moderate, and > 100% as high variability, respectively (Nielsen and Bouma, 1985). The region's CV range indicated different levels of heterogeneity among the low to moderate variability of soil properties studied. The variability observed in the available nutrient concentrations was largely due to variation in soil parent material, rainfall, and soil management (Li *et al.,* 2008; Kashiwar *et al.,* 2023).

Soil physico-chemical properties of different soil associations

The mean and CV of different soil associations are presented in table 3a and 3b indicatedthemean pH in soil associations ranged from 6.9 (Typic Ustropepts-Vertic Ustropepts) to 7.77 (Typic Haplusterts-Vertic Ustochrepts) and it had variability varied from 2.11% (S-7) to 7.84% (S-8). The mean soil EC content in soil associations varied from 0.12 dsm^{-1} (Typic Ustropepts-Vertic Ustropepts) to 0.25 dsm^{-1} (Lithic Ustorthents-Typic Ustorthents) and it had variability ranged from 16.01%(S-2)-62.77% (S-8). The mean soil organic carbon content in different soil associations varied from 3.9 g kg^{-1} (Typic Ustropepts-Vertic Ustropepts) to 5.83 g kg^{-1} (Typic Haplusterts-Vertic Ustochrepts) and it had variability ranged from 7.94 (S-7) to 40.27%(S-1). The mean $CaCO_3$ content in various soil associations varied from 19.0 g kg^{-1} (Typic Ustropepts-Vertic Ustropepts) to 61.66 g kg^{-1} (Lithic Ustorthents-Typic Ustorthents) and it had the CV varied from 44.66(S-7)-91.86 (S-3) percent.

Table 2: Descriptive statistics of soil attributes (n = 303**)**

Soil Variables	Unit	Mean	Coefficient of variation (CV%)
pH		7.61	6.70
EC	dSm^{-1}	0.20	60.00
SOC	%	0.53	24.06
$CaCO_3$	g kg^{-1}	37.35	83.40
Avail. N		231.30	18.62
Avail. P	kg ha^{-1}	23.85	71.19
Avail. K		472.00	32.15
S		28.25	61.03
Zn		0.49	77.55
Cu		2.16	54.17
Fe	mg kg^{-1}	10.05	60.30
Mn		18.19	48.16
B		1.33	39.85

n: total number of soil samples

Result indicatedthat these soils are neutral to alkaline in reaction, whereas EC of soil were categorized as normal. It may also be due to formation of these soils from basaltic parent material rich in basic cations. Similar findings were reported by Jibhakate *et al.* (2009). Data represented in table indicates that majority of these soils were low to moderate in organic carbon content. This might be due to increased rate of decomposition of organic matter as concluded by Rashmi *et al.* (2009). In addition, the soils were categorized as calcareous in nature. Similar results also reported in fine, montmorillonitlc, isohyperthermic Chromic Haplusterts by Prasad *et al.* (1995).

The mean soil organic carbon content of the soils varied from 3.9 g kg^{-1} (Typic Ustropepts-Vertic Ustropepts) to 5.83 g kg^{-1} (Typic Haplusterts-Vertic Ustochrepts). The low SOC content of these soils may be attributed to the poor vegetation and high rate of organic matter decomposition under hyperthermic temperature regime which leads to extremely high oxidizing conditions. The results of the present investigation are in close proximity with the findings of Singh *et al.* (2003) also reported that Haplusterts of Vertisols should have higher organic carbon density than Haplustalfs of Alfisols because of higher rainfall and larger quantity of 2: 1 type of clay minerals.

Macronutrients (N, P &K)

The mean available nitrogen content in various soil associations varied from 184.39 kg ha^{-1} (Typic Ustropepts-Vertic Ustropepts) to 250.88 kg ha^{-1} (Lithic Ustorthents-Typic Ustorthents) and CV ranged from 5.0(S-7)-25.86(S-1) percent. The mean phosphorus content in soil associations varied from 14.52 kg ha^{-1} (Lithic Ustorthents-Typic Ustorthents) to 30.73 kg ha^{-1} (Typic Haplusterts-Vertic Ustochrepts) and it had variability ranged from 25.86 (S-1)-85.58 (S-7) percent. The mean potassium content in soil associations varied from 358.84 kg ha^{-1} (Typic Ustropepts- Vertic Ustropepts) to 503.93 kg ha^{-1} (Chromic Haplusterts-Vertic Haplusterts) and had CV value ranged from 28.56 (S-5)-51.34 (S-7) percent. The available N content was low in major portion of study area, which might be related to soil management, application of FYM and fertilizer to previous crop by Ashok Kumar (2000). The low content of available phosphorous could also be ascribed to the high amount of free oxides of Ca^{2+}, $Mg^{2+}$and Na^{+} which induce the fixation and subsequent precipitation of phosphorus as well as to the low amount of organic matter. Black soils were higher in available potassium status may be due to predominance of K rich micaceous and feldspars minerals in parent material. Similar results were observed by Ravikumar *et al.* (2007).

Sulphur

The mean S content in soil associations varied from 17.49 mg kg^{-1} (Typic Ustropepts- Vertic Ustropepts) to 28.61 mg kg^{-1} (Lithic Ustorthents- Typic Ustorthents) and it had variability from 40.43(S-2)- 84.33(S-3) percent.

Micronutrients

The mean Zn content in soil associations varied from 0.30 mg kg^{-1} (Typic Ustorthents - Vertic Ustorthents) to 0.61 mg kg^{-1} (Typic Haplusterts - Lithic Ustorthents) and it had variability ranged from 10.86(S-2)-89.35(S-8) percent. The mean Cu content in soil associations varied from 1.66 $mgkg^{-1}$ (Lithic - Typic Ustorthents) to 3.53 $mgkg^{-1}$ (Typic Ustropepts- Vertic Ustropepts) and it had variability ranged from 12.27(S-2)-61.84(S-3) percent. The mean Fe content in soil associations varied from 7.74 mg kg^{-1} (Chromic Haplusterts- Vertic Haplusterts) to 17.45 $mgkg^{-1}$ (Typic Ustropepts- Vertic Ustropepts) and it had variability ranged from 19.80 (S2)-74.53 (S3) percent. The mean Mn content in soil associations varied from 12.76 mg kg^{-1} (Chromic Haplusterts- Vertic Haplusterts) to 27.68 $mgkg^{-1}$ (Typic Ustropepts- Vertic Ustropepts) and it had variability ranged from 17.79 (S2)-59.07 (S3) percent. The mean hot water-soluble B content in soil associations varied from 0.95 mg kg^{-1} (Typic Ustropepts-Vertic Ustropepts) to 1.42 mg kg^{-1} (Typic Haplusterts- Vertic Ustochrepts) and it had variability varied from 25.59 (S-4)-44.32 (S-8) percent.

Table 3a: Mean and variation of soil chemical properties in different soil associations

Soil associations	n	pH 1:2.5	EC 1:2.5 dSm^{-1}	SOC g kg^{-1}	$CaCO_3$ g kg^{-1}	N (kg/ha)	Avail. nutrients P (kg/ha)	K (kg/ha)
Typic Ustropepts-Vertic Ustropepts (S-1)	10	7.15 (7.84)	0.15 (35.33)	3.91 (40.27)	43.00 (90.10)	184.39 (25.86)	14.79 (25.86)	358.84 (34.49)
Vertic Ustropepts-Typic Haplusterts (S-2)	5	6.90 (5.71)	0.12 (16.01)	4.66 (15.47)	19.00 (68.12)	210.73 (11.45)	16.58 (36.24)	366.01 (29.19)
Typic Haplusterts-Lithic Ustorthents(S-3)	41	7.64 (7.33)	0.17 (26.59)	5.08 (27.50)	25.37 (91.86)	222.73 (22.16)	21.22 (78.31)	453.29 (39.61)
Typic Ustochrepts-Vertic Ustochrepts(S-4)	36	7.34 (5.86)	0.18 (26.31)	4.30 (25.34)	33.05 (86.27)	212.89 (18.82)	16.64 (81.98)	462.15 (29.37)
Chromic Haplusterts-Vertic Haplusterts(S-5)	16	7.59 (5.84)	0.15 (29.54)	5.04 (19.22)	38.75 (58.94)	243.04 (9.59)	25.21 (58.57)	503.93 (28.56)
Typic Hapluesterts-Fluventic Ustochrepts(S-6)	109	7.66 (6.20)	0.20 (58.56)	5.62 (20.45)	37.97 (87.46)	233.91 (16.18)	22.48 (72.76)	474.58 (31.52)
Lithic Ustorthents-Typic Ustorthents(S-7)	3	7.23 (2.11)	0.25 (47.42)	5.08 (7.94)	61.66 (44.66)	250.88 (5.00)	14.52 (85.58)	457.70 (51.34)
Typic Haplusterts-Vertic Ustochrepts(S-8)	83	7.77 (6.34)	0.22 (62.77)	5.83 (18.29)	42.83 (75.81)	245.89 (17.76)	30.73 (58.19)	497.89 (29.10)

Table 3b: Mean and variation of sulphur and micronutrients in different soil associations

Soil associations	n	S	Zn	Cu mg kg^{-1}	Fe	Mn	HWS-B
Typic Ustropepts-Vertic Ustropepts (S-1)	10	17.49 (47.61)	0.54 (34.35)	3.53 (25.72)	17.45 (26.94)	25.59 (30.37)	0.95 (33.01)
Vertic Ustropepts-Typic Haplusterts (S-2)	5	20.46 (40.43)	0.49 (10.86)	2.37 (12.27)	11.64 (19.80)	27.68 (17.79)	0.98 (30.95)
Typic Haplusterts-Lithic Ustorthents(S-3)	41	24.28 (84.33)	0.61 (59.48)	2.83 (61.84)	12.57 (74.53)	17.49 (59.07)	1.29 (25.93)
Typic Ustochrepts-Vertic Ustochrepts(S-4)	36	24.51 (74.69)	0.47 (71.98)	2.28 (40.61)	9.24 (42.04)	19.48 (36.32)	1.04 (25.59)
Chromic Haplusterts-Vertic Haplusterts (S-5)	16	17.49 (62.53)	0.47 (66.57)	1.80 (27.69)	7.74 (38.87)	12.76 (52.0)	1.16 (27.18)
Typic Hapluesterts-Fluventic Ustochrepts(S-6)	109	25.73 (83.57)	0.40 (84.37)	1.85 (54.83)	9.70 (59.36)	17.81 (49.18)	1.45 (39.83)
Lithic Ustorthents-Typic Ustorthents(S-7)	3	28.61 (65.49)	0.30 (32.83)	1.66 (20.40)	7.95 (20.58)	23.68 (43.71)	1.06 (37.89)
Typic Haplusterts-Vertic Ustochrepts(S-8)	83	21.77 (73.05)	0.50 (89.35)	2.05 (48.98)	9.04 (56.17)	17.62 (46.94)	1.42 (44.320

CV= coefficient variation, n= number of samples

Percent sample deficiency (PSD) Macronutrients in different soil associations

The data showed (table 4 and Fig. 3a) that among the various soil associations, deficiency of N was well observed in the samples drawn from S-2 (100%), followed by S-1 (80%), S-4 (72.22%), S-3 (70.73%), S-6 (56.19%), S-5 (43.75%), S-8 (39.76%), and S-7 (33.33%). Low levels of P were more prevalent in S-7 (66.66%), followed by S-4 (61.11%), S-1 (60%) S-3 (39.02%), S-6 (32.38%), S-2 (20%), S-8 (14.46%), and S-5 (12.5%). The K deficiency was low in S-8 (2.41%), S-4 (5.56%), S-6 (6.67%), S-3 (12.2%), and almost the same (20%) in S-1 and S-2.

Data represented in table 4 described that all soil associations were neutral to slight alkaline and slightly calcareous in nature. The organic carbon content in soils were low in the order of S2>S4>S1 and medium in the order of S8>S6>S3=S7>S5. Low organic carbon in the soil was due to low input of FYM and crop residues as well as rapid rate of decomposition due to high temperature. Similarly, the available N content in soil associations was lower in the order of S7>S8>S5>S6 >S3>S4>S2>S1. In addition, the available P content in soil associations was higher in the order of S8>S5>S6>S3 and medium in the order of S4>=S2>S1>=S7. However, the available K in soil associations was higher in the order of S5>S8>S6>S4>S7>S3 and medium in S2 and S1. The low nitrogen content in the soils is attributed due to high temperature and low SOC, low rainfall and low vegetation facilitate faster degradation and removal of organic matter leading to nitrogen deficiency. The medium nitrogen status in some area may be due to application of N fertilizer recommended for the crops.

Table 4: Percent sample deficiency of nutrients in different soil associations

Parameters	Soil associations							
	S1	S2	S3	S4	S5	S6	S7	S8
N	10	5	41	36	16	109	3	83
N	80.00	100	70.73	72.22	43.75	56.19	33.33	39.76
P	60.00	20.00	39.02	61.11	12.50	32.38	66.67	14.46
K	20.00	20.00	12.20	5.56	0.00	6.67	0.00	2.41
S	80.00	60.00	56.10	47.22	50.00	50.48	33.33	53.01
Zn	70.00	100	58.54	86.11	87.50	87.62	100	77.11
Fe	0.00	0.00	14.63	2.78	12.50	5.71	0.00	10.84

S-1 Typic Ustropepts-Vertic Ustropepts, S-2 Vertic Ustropepts-Typic Haplusterts, S-3 Typic Haplusterts-Lithic Ustorthents, S-4 Typic Ustochrepts-Vertic Ustochrepts, S-5 Chromic Haplusterts-Vertic Haplusterts, S-6 Typic Hapluesterts-Fluventic Ustochrepts, S-7 Lithic Ustorthents-Typic Ustorthents, S-8 Typic Haplusterts-Vertic Ustochrepts

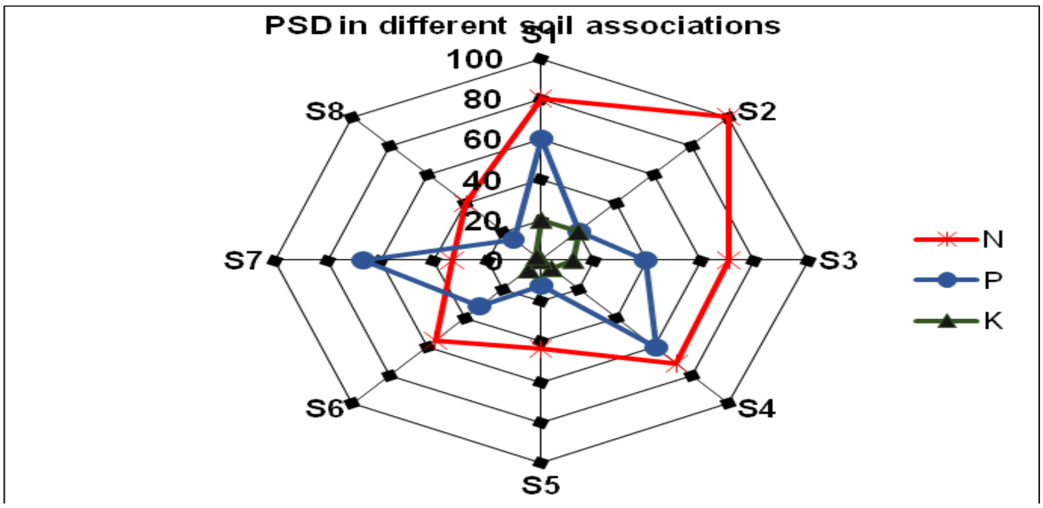

Fig. 3a: PSD of macronutrients in different soil associations

Micronutrients and sulphur

The deficiency levels of S in various soils associations were high in S-1(80%) followed by S-2(60%), S-3 (56.1%), S-8(53.01%), S-6(50.48%), S-5(50%), S-4(47.22%) and S-7(33.33%). The deficiency of Zn in various soils associations was well pronounced in S-2 and S-7 (100%) followed by S-6(87.62%), S-5(87.5%), S-4 (86.11%), S-8 (77.11%), S-1(70%), and S-3(58.54%). Low level of Fe was more in S-3(14.63%), followed by S-5(12.5%), S-8(10.84%), S-6 (5.71%) and S-4 (2.78%). The deficiency level of Cu, Mn and B were negligible in all soil associations as well as study area (Fig.3b).

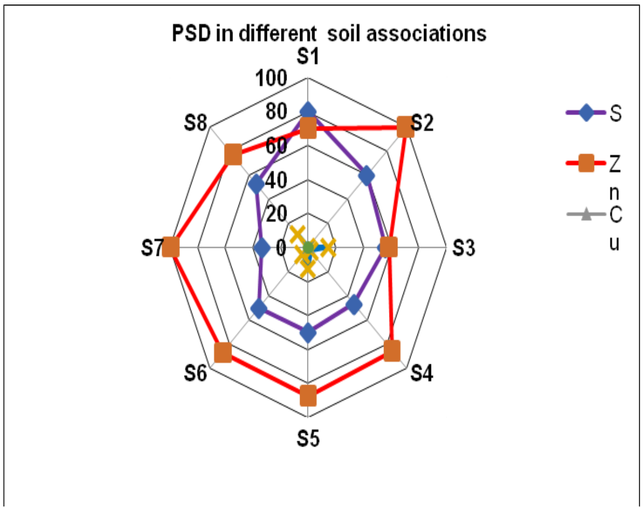

Figure 3b: PSD of S and micronutrients in different soil associations

Only the soil associations i.e., S1 and S2 were found deficient in available S and remaining soil associations were found medium. From the results, it is observed that copper, manganese and boron content in soils was high. However, available Fe content was found to be deficient and zinc content was very low. The deficiency of zinc is due to low SOC values in study areas. Similar results were supported by Rahman and Haq (2007).

Considering the available zinc rating values, that is, low (<0.6 mg kg^{-1}), it was observed that all soil associations were found low in available zinc in the order of S1>S8>S2>S4=S5>S6>S7. The lowest zinc content in S7 and sufficient content of available zinc in (S3). Low content of zinc in the S7 soil associations, which is alkaline and richest in $CaCO_3$, might be due to precipitated as hydroxides and carbonates. Therefore, their solubility and mobility may be decreased resulting in reduced availability. The similar results were also reported by (Ravikumar *et al.,* 2007; Alloway, 2008).

Lower content of zinc in black soils is due to its fixation by clay due to high soil pH values which have resulted in the formation of insoluble compounds of zinc (Tandon, 1995). In conformity with this study, Asgelil *et al.* (2007) also reported deficiency of Zn in 78.4% of the soil samples collected from Vertisols of Ethiopia. The general observation revealed that in many studies conducted elsewhere (Rashid *et al.,* 2006) the soils were not deficient in Cu, Fe and Mn but Zn was low. In addition, observed that 44 % of the soils of Badin district were deficient in Zn. This work is also in agreement with the results of Zia *et al.* (2006) who observed Zn deficiency in soils of with orchards in Balochistan (43%) and Sindh (90%).

Only the soil association i.e., S3, S5, S8, S6 and S4 were found deficient in available Fe and remaining soil associations (S1, S2 and S7) were observed sufficient in available Fe content. In black soils, low Fe content may be due to precipitation of Fe^{2+} by $CaCO_3$ and decrease the availability. This high Fe content in soil may be due to presence of minerals like Feldspar, Magnetite, Hematite and Limonite, which together constitute bulk of trap rock in these soils Vijaya *et al.* (2013). None of soil samples were found deficient in case of Cu, Mn and B in studied soil associations. These results were in confirmatory with results reported by Tagore *et al.* (2023). The higher amount of Cu might be due to higher biological activities and chelating effect (Jibhakate *et al.,* 2009). The high content of Mn in these soils could be due to the soils derived from basaltic parent material, which contained higher ferromagnessiume minerals. Hundal *et al.* (2008) reported similar results. No deficiency was observed in case of B because the availability of B in heavy soils (fine-texture soils) was higher than light soils or sandy (coarse texture) soils. However contradictory results reported by Fleming (1980) and Sarkar *et al.* (2008).

CONCLUSIONS

The study revealed the wide variability of soil physico-chemical properties in soils of the research area with CV values of 6.70–83.40%. soil pH was neutral to alkaline based on soil reactions, safe in terms of electrical conductivity, and the soil organic carbon content in various soil associations was low in the order of S2>S4>S1 and medium in the order of S8>S6>S3=S7>S5. Similarly, the available N content in soil associations was lower in the order of S7>S8>S5>S6>S3>S4>S2>S1. In addition, the available P was higher in the order of S8>S5>S6>S3 and medium in the order of S4>=S2>S1>=S7. The available K was high in various soil associations in the order of S5>S8>S6>S4>S7>S4 and medium in S2 and S1. However, only the S1 and S2 soil associations were deficient in available S, and the rest of that was in medium. It was observed that the available zinc content in various soil associations was low, in the order of S1>S8>S2>S4=S5>S6>S7. Only S3, S5, S8, S6, and S4 soil associations were deficient in available Fe, while S1, S2, and S7 soil associations were sufficient.

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