

Original Research Article

Soil Fertility Status and Correlation of Available Macro and Micronutrients in Warangal District of Telangana state

ABSTRACT

Fertility status of red and medium black soils and their correlation studies were carried out in soils of Warangal District (R) of Telangana state. All samples in red and medium black soils were neutral to alkaline in reaction and pH values ranged from 7.25 to 8.56 by medium black soil followed (6.50 to 7.52) by red soil with mean values of 7.64 in medium black soil followed 7.53 in red soil. The EC varies from 0.08 to 1.90 dS m⁻¹ in red soil and 0.08 to 2.17 dS m⁻¹ in medium black soil. The calcium carbonate (CaCO₃) content varies from 0.59 to 1.95% in red soil and 1.69 to 2.92% in medium black soil and maximum mean value was recorded in medium black soil (1.69%) followed by red soil (0.69%). Red soils were Loam to Clay loam whereas medium black soils were clay in texture. Organic carbon content ranges from 0.14 to 0.75% in red soil and from 0.50 to 0.79% in medium black soil with an average value of 0.38% in red soil and 0.53% in medium black soil. 81 and 45% of soils were low, 15 and 55% in medium and none of the soil samples were found higher category in OC content in red soil and medium black soils, respectively. Available N, P, K and S content varied from 59 to 201 kg ha⁻¹, 14 to 133 kg ha⁻¹, 211 to 341 kg ha⁻¹ and 6.9 to 24.59 mg kg⁻¹ with mean values of 144 kg ha⁻¹, 56 kg ha⁻¹, 247 kg ha⁻¹ and 19.26 mg kg⁻¹ in red soils, respectively. In medium black soils available N, P, K and S content varied from 100 to 276 kg ha⁻¹, 21 to 103 kg ha⁻¹, 332 to 450 kg ha⁻¹ and 10.50 to 41.40 mg kg⁻¹ with mean values of 177 kg ha⁻¹, 54 kg ha⁻¹, 398 kg ha⁻¹ and 27.40 mg kg⁻¹, respectively. In red soils 100% samples were low in available N, 25% low, 32% medium and 43% higher in available P₂O₅, 1% medium and 99% higher in available K₂O and 62% low and 38% medium in available S. In medium black soils 100% samples were low in available N, 22% low, 38% medium and 40% higher in available P₂O₅, 38% medium and 62% samples were higher in available K₂O and 51% low and 49% medium in available S. The DTPA-Zn in 23% samples were deficient in medium black soil. In case of DTPA-Fe in 47 and 90% samples were found deficient in red and medium black soil, respectively. None of the samples in both soil groups were found deficient in Cu and Mn. In case of available-B in 29 and 34% samples were deficient in red and medium black soils, respectively. The data indicated that only 9.2% samples in medium black soil were deficient in case of available Mo. The nutrient index indicated that the red and medium black soils were low, medium and high in available N, P and K, respectively. Deficiency of micronutrients was in the order: Fe > B in red soils, Fe > B > Zn in medium black soils. Available N, P, K, S, Fe, Cu, Zn, Mn, B decreased, whereas Mo increased with increasing pH. Available N and P decreased, whereas K and S increased with increasing EC. Available N, P, K, S, Fe, Cu, Zn, Mn and B increased with increasing level of organic carbon.

Key words: Red soil, medium black soil, available nutrients, nutrient index, correlation.

INTRODUCTION:

Role of balanced plant nutrition is well-established for sustainable agricultural production. Present agricultural systems are exploitive of nutrients through intensive tillage, monocropping year after year, use of high yielding varieties, imbalanced use of nutrients coupled with limited use of organic manures, less recycling and burning of crop residues, soil erosion, undulated topography and indiscriminate use of irrigation water. Balanced use of organics, fertilizers and bio-fertilizers plays an important role to maintain soil fertility in long run. The availability of macro and micronutrients to plants is influenced by several soil characteristics. Similarly, different cropping systems are suitable for different soil groups as regards to production and productivity. For understanding the reasons of deficiency of available nutrients in soils, correlation of physico-chemical properties with available macro and micronutrients was needed (Singh *et al.* 2014). Also, detailed study on status of macro and micronutrients in major soil groups of Warangal

district in Telangana state had not been undertaken so far. The district has majorly red(41%) and medium black soils(6%) (Surendrababu *et al.* 2019). Hence, present investigation was undertaken to study the status of macro, micronutrients and their relationship with important soil properties in red and medium black soils in Warangal district of telangana state.

MATERIALS AND METHODS

General Characteristics of Study Area

The study area is located between 17.61 to 18.12N – latitude and 79.47 to 80.04E – longitude with an altitude ranging from 210 to 259 m above mean sea level. The agro-climatic region of Telangana state of India is Southern Plateau and Hills Region; the state is further divided into 3 sub agro-climatic zones and Warangal district comes under Central Telangana Zone. Total geographical area of Warangal district is 2.09 lakh ha. Out of this total area 1.0 lakh ha is Red soil and 0.5 lakh ha is black soil. The red soil is found in entire district and black soil is found in some patches surrounded by red soil. The medium black soil is darker with dark grey-brown to dark grayish brown colour with black shades (Tamgadge *et al.* 1999). These soils are non calcareous in nature, no hard pan up to 120 cm depth was found and effective soil depth varies from 30 to 90 cm. Permeability and drainage conditions of these soils are poor. Annual rainfall ranges from 779 to 1213 mm, received mostly from south-west monsoon and maximum temperature varied between 29 and 39°C and minimum varied between 16 and 25°C. Predominant crops exist in this district are cotton, rice, maize, redgram, greengram, mango and chillies.

Soil Sampling and Analysis

Eighty soil samples (0–15 cm) from each soil group of red soil and medium black soil and in all 160 soil samples were collected from different locations randomly. Samples were air-dried, ground in wooden pestle and mortar. These ground soil samples were passed through 2-mm sieve and stored in properly labeled plastic bags for analysis. Processed soil samples were analyzed for particle size distribution as described by Piper (1968). The dry soil colour, infiltration rate, bulk density, organic carbon (OC), electrical conductivity (EC), pH (1:2 soil water ratio), CaCO₃ by rapid titration, available N, P, K and S were determined as per methods described by Soil Survey Staff (1966) and Jackson (1973). The available Zn, Fe, Cu and Mn in soil samples were extracted with DTPA (0.005 M DTPA + 0.01 M CaCl₂ + 0.10 M triethanolamine, pH 7.3) as per method described by Lindsay and Norvell (1978). Concentration of Zn, Fe, Cu and Mn in the DTPA extracts was determined using atomic absorption spectrophotometer. Available Mo was determined by ammonium oxalate method and B was extracted by hot water (boiling) and determined colorimetrically (Gupta 1967). The correlation analysis of data was computed in relation to available major and micronutrients content with different physicochemical properties of the soils as suggested by Panse and Sukhatme (1961). The formula of nutrient index (NI) and classification of available nutrients as low (<1.5), medium (1.5 to 2.5) and high (>2.5) as suggested by Parker *et al.* (1951) was evaluated as follows:

Nutrient index = [(1 × no. of samples in low categories) + (2 × no. of samples in medium categories) + (3 × no. of samples in high categories)] / Total number of samples

RESULTS AND DISCUSSION

Physicochemical Properties

The soil colour varies from red to yellowish brown in red soil and dark grey to dark grayish brown in medium black soil (Table 1). The bulk density of red soil and medium black soil ranged between 1.61 - 1.72 Mg m⁻³, 1.53-1.69 Mg m⁻³ with mean value 1.68 and 1.57 Mg m⁻³, respectively. The higher mean value of bulk density was measured in red soil followed by medium black soil. The infiltration rate ranges from 3.8 to 5.6 cm h⁻¹ in red soil, 3.2 to 5.1 cm h⁻¹ in medium black soil. Among the soils, infiltration rate was higher in red soil (4.2 cm h⁻¹) followed by medium black soil (3.9 cm h⁻¹). All the samples in red and medium black soil were neutral to alkaline in reaction and pH values ranged from 7.25 to 8.56 in medium black soil followed by 6.50 to 7.52 in red soil with mean values of pH were 7.64 in medium black soil and 7.53 in red

soil. The higher pH could be due to increase in accumulation of exchangeable sodium and calcium carbonate. The EC varies from 0.08 to 1.90 dS m⁻¹ in red soil and 0.08-2.17 dS m⁻¹ in medium black soil. The maximum mean values of EC were recorded in medium black soil (0.55dS m⁻¹) followed by red soil (0.47dS m⁻¹). The calcium carbonate (CaCO₃) content varies from 0.59-1.95% in red soil and 1.69-2.92% in medium black soil. The maximum mean value of CaCO₃ was recorded in medium black soil (1.69%) followed by red soil (0.69%). As per rating limit proposed by FAO (1973), none of the soil samples were found in calcareous (CaCO₃ content < 5%). red soils were Loam to Clay loam in texture, whereas texture of medium black soils are clay.

Organic carbon contents range from 0.14 to 0.75% with an average value of 0.38% in red soil and 0.50 to 0.79% with an average value of 0.53% in medium black soil (Table 1). According to Muhret *al.* (1965) rating limit, 81 and 45% of soils are in low (< 0.50%), 15 and 55% in medium (0.50 to 0.75%) and non of the soil samples were found in higher category (> 0.75%) in OC content in red soil and medium black soils, respectively (Fig. 1, 2). The majority of the samples come under low OC content in 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. Removal of the surface soil containing high OC due to erosion was responsible for the lower OC. Besides this, due to finer-textured nature these red and black soils contain OC in medium range. The results confirm the finding of Meena *et al.* (2006).

Available Nitrogen and Effect of Soil Characteristics

Available N content varied from 59 to 201 kg ha⁻¹, with an average value of 144 kg ha⁻¹ in red soil and 100 to 276 kg ha⁻¹ with an average value of 177 kg ha⁻¹ in medium black soil (Table 1). On the basis of the rating as suggested by Subbiah and Asija (1956), the red and medium black soils were 100% low (< 280 kg N ha⁻¹) and non of the soil samples comes under medium and low category in available N status (Fig. 1, 2,). A significant and positive correlation of available N was observed with OC (r = 0.4164). Available N was negative and non significantly correlated with pH (r = -0.1079) and EC (r = -0.2041). (Table 2). This might be due to increased rate of denitrification at lower values. Similar results were also reported by Meena *et al.* (2006).

Available Phosphorus and Effect of Soil Characteristics

Available P content varied from 14 to 133 kg ha⁻¹ with an average value of 56 kg ha⁻¹ of red soil and 21 to 103 kg ha⁻¹, with an average value of 54 kg ha⁻¹ in medium black soil (Table 1). On the basis of the limits suggested by Muhret *al.* (1965), the red soil and medium black soil were 25 and 23% low (< 29 kg P₂O₅ ha⁻¹), 32 and 38% medium (29 to 59 kg P₂O₅ ha⁻¹) and 43 and 40% higher (>59 kg P₂O₅ ha⁻¹) in available P₂O₅, respectively (Fig.1, 2). A non significant and positive correlation of available P was observed (Table 2) with OC (r = 0.0318). This relationship might be due to the presence of more than 50% of P in organic forms and after the decomposition of organic matter as humus is formed which forms complex with Al and Fe and that is a protective cover for P-fixation with Al and Fe, thus reduce P adsorption/ fixation (Tisdale *et al.* 1997). Available P was non significant and negatively correlated with EC (r = -0.1888) and pH (r = -0.0713). This is because at higher pH, calcium precipitates with P as Calcium phosphate and reduce P availability (Tisdale *et al.* 1997). Similar results were also reported by Meena *et al.* (2006).

Available Potassium and Effect of Soil Characteristics

Status of available K in the soils ranged from 211 to 341 kg ha⁻¹ with an average of 247 kg ha⁻¹ in red soil and 332 to 450 kg ha⁻¹ with an average value of 398 kg ha⁻¹ in medium black soil (Table 1). According to Muhret *al.* (1965), in red and medium black soils none of the soil samples comes under low category (<145 kg K₂O ha⁻¹), only 1 and 38% medium (< 145 -340 kg K₂O ha⁻¹), 99 and 62% samples were high (>340 kg K₂O ha⁻¹) in available K₂O, content, respectively (Fig. 1, 2). A non significant and positive correlation of available K was observed (Table 2) with OC (r = 0.1564) and EC (r = 0.2158). This might be

due to creation of favourable soil environment with presence of high organic matter. Similar results were also reported by Meena *et al.* (2006). Available K showed negative and non-significant correlation with pH ($r = -0.0690$).

Available Sulphur and Effect of Soil Characteristics

Available S in the studied soils varied from 6.90 to 24.59 kg ha⁻¹ with an average value of 19.26 kg ha⁻¹ in red soil and 10.50 to 41.40 kg ha⁻¹ with an average value of 27.40 kg ha⁻¹ in medium black soil (Table 1). On the basis of the ratings suggested by Hariram and Dwivedi (1994) as low (<20 kg ha⁻¹), medium (20 to 40 kg ha⁻¹) and high (> 40 kg ha⁻¹) for available S in red and medium black soils were 62 and 51% low, 38 and 49% in medium and none of the soil samples were found in high category, respectively (Fig. 1, 2). A significant positive correlation of available S was observed (Table 2) between EC ($r = 0.4710$) and OC ($r = 0.482$). This may be due to organic S constitutes the major share of total S present in soil. Available S was negatively and significantly correlated with pH ($r = -0.593$). The result resembles to the findings of Hariram and Dwivedi (1994).

Available Micronutrients and Effect of Soil Characteristics

The DTPA-Zn in red and medium black soil varied from 0.51 to 3.53 and 0.28 to 2.65 mg kg⁻¹ and corresponding mean values were 1.33 and 1.21 mg kg⁻¹, respectively (Table 1). As per critical limit (< 0.6 mg kg⁻¹) of Zn as suggested by Bansal and Takkar (1986) the per cent deficiency of DTPA-Zn were 23 in medium black soil (Fig. 3,4). The availability of Zn increased non significantly (Table 2) with increase in OC ($r = 0.1215$). The DTPA-Zn was negative and non significantly correlated with pH ($r = -0.0158$) whereas significantly negatively correlated with EC ($r = -0.4337$). The results confirm the findings of Sharma *et al.* (2006) and Bhanwaria *et al.* (2011).

The content of DTPA-Fe in soils varied from 0.44 to 20.75 mg kg⁻¹ with an average value of 5.35 mg kg⁻¹ in red soil and 0.49 to 10.22 mg kg⁻¹ with an average value of 2.15 mg kg⁻¹ in medium black soil (Table 1). Considering the critical limits (> 4.5 mg kg⁻¹) proposed by Lindsay and Norvell (1978), 47 and 90% soils were found deficient in red and medium black soils, respectively (Fig. 3,4). The DTPA-Fe had non significant and positive correlation (Table 2) with OC ($r = 0.0911$) and EC ($r = 0.2185$) whereas negative and non significant correlation with pH ($r = -0.0158$). Non-significant and positive correlation was seen with DTPA-Fe and EC. Similar results were also reported by Sharma *et al.* (2006) and Bhanwaria *et al.* (2011).

The DTPA-Cu content in soil samples varied from 0.58 to 4.34 mg kg⁻¹ with mean value of 1.66 mg kg⁻¹ in red soil and 0.62 to 29.90 mg kg⁻¹ with mean value of 4.98 mg kg⁻¹ in medium black soil (Table 1). Considering critical limits (< 0.2 mg Cu kg⁻¹) as suggested by Lindsay and Norvell (1978), none of the soil samples in both soil groups were found deficient in Cu (Fig. 3,4). The availability of Cu increased non significantly with increase of OC ($r = 0.1175$) and EC (0.4337) whereas non significantly decreased with increase in pH ($r = -0.0507$). The result resembles to the findings of Sharma *et al.* (2006) and Bhanwaria *et al.* (2011).

Available Mn in the soil samples varied from 6.41 to 27.52 mg kg⁻¹ with mean value of 16.07 mg kg⁻¹ in red soil, 6.56 to 42.11 mg kg⁻¹ with mean value of 19.07 mg kg⁻¹ in medium black soil (Table 1). Considering the critical limits (> 2 mg kg⁻¹) as suggested by Lindsay and Norvell (1978), none of the samples in both soil groups were found deficient in Mn (Fig. 3,4). The DTPA-Mn showed non significant and positive correlation with OC ($r = 0.0452$), whereas non significantly decreased with increasing of pH ($r = -0.0158$). The results are close conformity with the findings of Sharma *et al.* (2006) and Bhanwaria *et al.* (2011). Electrical conductivity had significantly positive relationship with DTPA-Mn ($r = 0.2941$).

The available B content in red and medium black soil varied from 0.29 to 2.10 and 0.48 to 2.88 and corresponding mean values were 1.56 and 1.95 mg kg⁻¹, respectively (Table 1). Considering the critical limits (> 0.52 mg kg⁻¹) as suggested by Lindsay and Norvell (1978), 29 and 34 % samples deficient in red and medium black soils, respectively. The DTPA-B showed significant and positive correlation with OC ($r = 0.5140$), whereas non significantly decreased with increasing of pH ($r = -0.4880$).

The results are close conformity with the findings of Sharma *et al.* (2006) and Bhanwaria *et al.* (2011). Electrical conductivity had non significantly negative relationship with DTPA-B ($r = -0.0320$).

The available Mo content in red and medium black soil varied from 0.26 to 1.98 and 0.10 to 1.45 mg kg⁻¹ and corresponding mean values were 0.74 and 0.62 mg kg⁻¹, respectively (Table 1). The data (Fig.3,4) indicated that only 9.2% samples in medium black soil were deficient in available Mo taking critical limit as 0.2 mg kg⁻¹ (Katyal and Rattan 2003). The DTPA-Mo showed significant and positive correlation with pH ($r = 0.8570$), whereas non significantly decreased with increasing of Ec ($r = -0.0040$). The results are close conformity with the findings of Sharma *et al.* (2006) and Bhanwaria *et al.* (2011). Organic carbon content had significantly negative relationship with DTPA-Mo ($r = -0.6120$).

Table-1: Soil physical, physico-chemical and chemical properties of soil

S.No	Soil parameters	Red soil		Medium Black soil	
		Range	Mean	Range	Mean
1	Dry Soil colour (Munsell)	2.5YR3.5/6 Red to Yellow	-	10YR2.5/1 dark grey to dark grayish brown	-
2	Soil texture	Loam to Clay loam	-	Clay	-
4	BD (Mg m ⁻³)	1.61-1.72	1.68	1.53-1.69	1.57
5	pH	6.50-7.52	7.53	7.25-8.56	7.64
6	Infiltration Rate(cm h ⁻¹)	3.8-5.6	4.2	3.2-5.1	3.9
7	Ec (dSm ⁻¹)	0.08-1.90	0.47	0.08-2.17	0.55
8	CaCO ₃ (%)	0.59-1.95	0.69	1.69-2.92	1.69
9	Oc (%)	0.14-0.75	0.38	0.50-0.79	0.53
10	Available Nitrogen(kg ha ⁻¹)	59-201	144	100-276	177
11	Available Phosphorus (kg ha ⁻¹)	14-133	56	21-103	54
12	Available Potassium (kg ha ⁻¹)	211-341	247	332-450	398
13	Available S (kg ha ⁻¹)	6.90-24.59	19.26	10.50-41.40	27.40
14	Available Zinc (mg kg ⁻¹)	0.51-3.53	1.33	0.28-2.65	1.21
15	Available Copper (mg kg ⁻¹)	0.58-4.34	1.66	0.62-29.90	4.98
16	Available Iron (mg kg ⁻¹)	0.44-20.75	5.35	0.49-10.22	2.15
17	Available Manganese (mg kg ⁻¹)	6.41-27.52	16.07	6.56-42.11	19.07
18	Available Molybdenum (mg kg ⁻¹)	0.26-1.98	0.74	0.10-1.45	0.65
19	Available Boron (mg kg ⁻¹)	0.29-2.10	1.56	0.48-2.88	1.95

Table-2: Correlation between soil properties and available nutrients

Nutrient	pH	Ec	Oc
N	-0.1079	-0.2041	0.4164*
P	-0.0713	-0.1888	0.0318
K	-0.0690	0.2158	0.1564
S	-0.5930	0.4710	0.4820
Cu	-0.0507	0.4337	0.1175
Zn	-0.0158	-0.4337*	0.1215
Fe	-0.0158	0.2185	0.0911
Mn	-0.0158	0.2941*	0.0452
B	- 0.4880*	-0.0320	0.5140*
Mo	0.8570*	-0.0040	-0.6120*

*Significant at 5% level

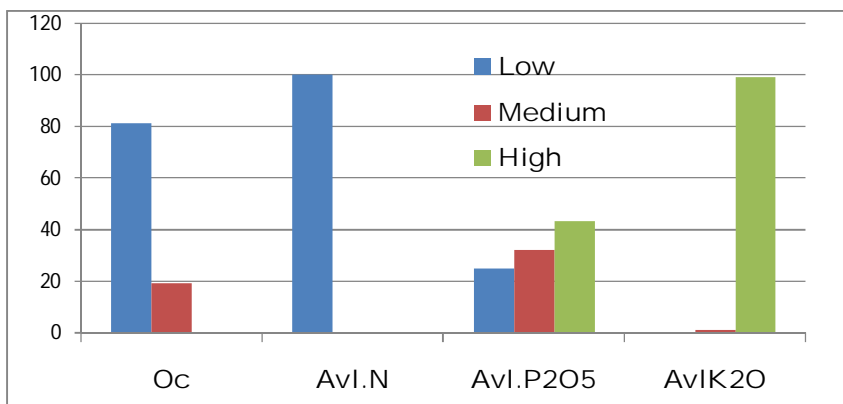


Fig-1: Status of organic carbon and available nutrients in red soil

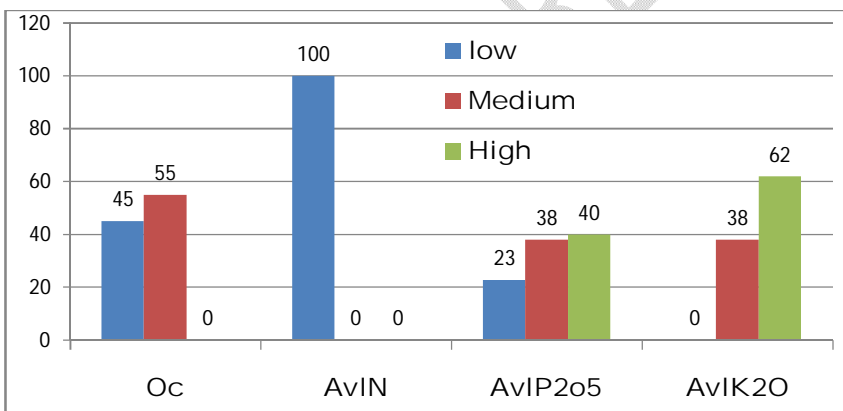


Fig-2: Status of organic carbon and available nutrients in medium black soil

Soil Nutrient Index

Considering concept of soil nutrient index the soils of studied area was found in low category in red soils and medium category in medium black soils of organic carbon content in two soil groups (Table 2). The values of organic carbon content worked out from nutrient index for red and medium black soils were 1.19 and 1.51, respectively. The available nitrogen in red and medium black soil found in lower category, the nutrient index value for available nitrogen in red and medium black soils was 1.0. The available P in red and medium black soil found in medium category, the nutrient index value for available P in red and medium black soils was 2.18. As per nutrient index value, available K was high in red and medium black soils were 2.99 and 2.63, respectively.

Table-3: Nutrient index of available nutrients in two soil groups

Available nutrient	Red soil	Black soil
Organic carbon	1.19	1.51
Nitrogen	1.00	1.00
Phosphorus	2.18	2.18
Potassium	2.99	2.63

Conclusions

All the samples in red and medium black soil were neutral to alkaline in reaction. In general, the soils were low in soluble salts, organic carbon and calcium carbonate content. The nutrient index indicates that the red and medium black soils were low, medium and high in available N, P and K, respectively. Deficiency of micronutrients was in the order: Fe > B in red soils, Fe > B > Zn in medium black soils. Available N, P, K, S, Fe, Cu, Zn, Mn, B decreased, whereas Mo increased with increasing pH. Available N and P decreased, whereas K and S increased with increasing EC. Available N, P, K, S, Fe, Cu, Zn, Mn and B increased with increasing level of organic carbon.

Comment [DDEA1]:

In the conclusion you should highlight the state of soil fertility based on the correlation of macro and micronutrients.

References:

1. Bansal RL, Takkar PN. Micronutrient status of soils in Amritsar district. *Indian Journal of Ecology*. 1986;13: 158-160
2. Bhanwaria, Rajendra, Kameeria, PR, Yadav BL. Available micronutrient status their relationship with soil properties of Mokala soil series of Rajasthan. *Journal of the Indian Society of Soil Science*. 2011;59: 392-396.
3. Chakraborty SK, Sinha H, Prasad R. Distribution of boron and molybdenum and their relationship with certain properties of soil from Assam. *Journal of the Indian Society of Soil Science*. 1982;30: 92-93.
4. FAO Calcareous soils. *FAO Soils Bulletin No. 21*. Gupta, U.C. (1967) A simplified method for determining hot-water soluble boron in Podsol. *Soil Science*. 1973;103:224-229.
5. Hariram, Dwivedi KN. Delineation of sulphur deficient soil group in the central alluvial tract of Uttar Pradesh. *Journal of the Indian Society of Soil Science*. 1994;42:284-286.
6. Jackson ML. *Soil Chemical Analysis*, Prentice Hall India (Pvt.) Ltd., New Delhi. 1973
7. Katyal KC, Rattan RK. Secondary and micronutrients research gap and future needs. *Fertiliser news* 2003;48: 9-14 and 17-20.
8. Lindsay WL, Norvell WA. Development of a DTPA soil test for Zn, Fe, Cu and Mn. *Soil Science Society of American Journal*. 1978;42: 421-428.
9. Meena HB, Sharma RP, Rawat US. Status of macro- and micronutrients in some soils of Tonk district of Rajasthan. *Journal of the Indian Society of Soil Science*. 2006;54: 508-512.
10. Muhr GR, Datta NP, Sankara Subramoney H, Liley VK, Donahue RR. *Soil testing in India*. US Agency for International Development, New Delhi. 1965: 120.
11. Panse VG, Sukhatme PV. *Statistical Methods for Agricultural Workers*, ICAR, New Delhi.
12. Parker FW, Nelson WL, Winter Eric, Miller IE. The broad interpretation of soil test informations. *Agronomy Journal*. 1951;43: 105-102.
13. Piper CS. *Methods of Soil Analysis*. Hans Publishers, Bombay. 1968.

14. Sharma PK, Sood, Anil, Setia RK, Verma VK, Mehara, Deepak, Tur NS, Nayyar VK. Use of information technology for mapping of DTPA extractable micronutrients in soils of Amritsar district, Punjab. *Journal of the Indian Society of Soil Science*. 2006;54: 465–474.
15. Sharma RP, Singh M, Sharma JP. Correlation studies on micronutrients vis-à-vis soil properties in some soils of Nagpur district in semi-arid region of Rajasthan. *Journal of the Indian Society of Soil Science* 2003;51: 522–527.
16. Soil Survey Staff and Soil Survey Manual, *Agriculture* 18 Indian reprint, Oxford @ IBH Pub. Co., New Delhi. 1966.
17. Singh YP, Raghubanshi BPS, Rajbeer S, Tomar SK, Verma, Dubey SK. Soil Fertility Status and Correlation of Available Macro and Micronutrients in Chambal Region of Madhya Pradesh. *Journal of the Indian Society of Soil Science*. 2014 : 62(4): 369-375
18. Surendra Babu P, Chandini Patnaik M, Sri Jaya T, Madhavi A, Shankaraiah M, Soniya P, Shukla AK, Praveen Rao V. Warangal district soil fertility status and fertilizer use Guidelines. 2019. 123/SP/PJTSAU/2019. PJTSAU Rajendranagar HYD.
19. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soil. *Current Science*. 1956;25: 259-260.
20. Tamgadge DB, Gajbhiye KS, Velayutham M, Kaushal GS. Soils Series of Madhya Pradesh, NBSS Publ. No. 78, NBSS&LUP, Nagpur. 1999: 236: 252-256.
21. Tisdale SL, Nelson WL, Beaton JD, Havilin JL. Soil Fertility and Fertilizers, 5th Edition, Macmillan Publishing Co., New Delhi. 1997: 144, 180, 198, 201.
22. Tomar VS, Gupta GP, Kaushal GS. Soil resources and agroclimatic zones of Madhya Pradesh. Published by Professor and Head, Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur, Madhya Pradesh. 1995: 132.