Journal of the Indian Society of Soil Science, Vol. 69, No. 2, pp 113-118 (2021)
DOI: 10.5958/0974-0228.2021.00033.5

Shrink-Swell Soils of Palakkad District, Kerala: Their Characteristics and Classification

Jagdish Prasad[1]*, K.S. Anil Kumar, K.M. Nair, B.A. Dhanorkar, K.V. Niranjan, D.S. Mohekar[1] and Arti Koyal

ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Bangalore, 560024, Karnataka

Representative pedons of Karuvapara series (P1) and Vannamada series (P2) from Palakkad district of Kerala were characterized and classified. The soils were very dark grayish brown to dark brown (P1) and very dark grayish brown to black (P2). The texture of the P1 varied from clay loam (Ap horizon) to clay and gravelly clay in sub-soils, while it was sandy clay (Ap horizon) to clay but sandy clay loam in last two horizons of P2. The pH of the soils in different horizon ranged from 7.1 to 8.2. Vannamada soils retained higher organic carbon (1.38% in Ap horizon) than Karuvapara soils. These soils had medium content of available N barring Ap horizon of P2 but high in available P (surface layer) and K. Available S, DTPA-Cu, DTPA-Fe, DTPA-Mn and hot water-soluble B in the soils were above the critical limit but DTPA-Zn was deficient except in Ap horizon of P2. These soils were classified as Typic Haplusterts (P1) and Vertic Epiaquepts (P2) at subgroup level.

Key words: Palakkad eastern plains, shrink-swell soils, characterization, classification, nutrient availability

Shrink-swell soils (Vertisols and their intergrades) of India mainly occurs in southern states (Andhra Pradesh, Tamil Nadu, Karnataka and Telangana), Central India (Maharashtra, Madhya Pradesh and Chhattisgarh) and Western India (Gujarat and Rajasthan). Majority of these soils are developed from alluvium derived from weathering of Deccan basalt and from the exhumed metamorphic rocks during the multi-cycle erosion since Pliocene-Pleistocene (Pal and Deshpande 1987). Their existence has also been reported from Bihar (Diwakar and Singh 1982) and eastern Uttar Pradesh (Singh *et al.* 2017) in Tal lands and as Karail soils (Ram *et al*. 1985) occurring in depression bordering to Varanasi and Mirzapur districts. Occurrence of these soils have also been reported in other parts of Uttar Pradesh (Bundelkhand), Bihar (Ray *et al*. 2014) and Odisha (Sarkar *et al.* 2005). In West Bengal, occurrence of Vertisols in Chinsurah area of Hoogly district have also been reported (Ray *et al*. 2006). Although, these soils occur in states of Punjab, Haryana and Jammu and Kashmir (Ray *et al.* 2014) but their spatial extent is limited and thus, the area under shrink-swell soils are underestimated at national level. The present paper reports the occurrence and characteristics of one Vertisols (Karuvapara series) and one Vertic Inceptisols (Vannamada Series) developed on mixed alluvium in Chittur *taluka* of Palakkad district, Kerala.

Materials and Methods

Site characteristics

Two pedons, one representing Karuvapara series (Vertisols) and other representing Vannamada series (Vertic Inceptisols), were selected for present study in Chittur *taluka* of Pallakkad district of Kerala, wherein the shrink-swell soils occur in association with Alfisols. The pedon 1 (P1) is located (17°43′59.99″N; 76°50′59.99″ E) on nearly level (0.1% slope) low lands in Venkatapalam village (Kozhijampara *panchayat*), Chittur *taluka*, while P2 (17°46′33.6″ N; 76°51′3.6″ E) is situated on nearly level (0-1% slope) lowlands in Attayampathy village of Vadakarapatly *panchayat* in Chittor *taluka* of Palakkad district, Kerala state representing the rain shadow region of Palakkad eastern plains (AUE 23). The Vertisols and Vertic intergrades are spatially

*Corresponding author (Email: jprasad57@gmail.com)
[1]ICAR- National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur, 440033, Maharashtra

distributed in relatively lower landscape positions while upper landscape is covered by Alfisols.

The geology of the P1 site is migmatite complex (dominant), charnockite, khondlite groups of rocks and pegmatite/aplite/quartz vein while it is migmatite complex at P2 site. The Western Ghat mountains which dominate in this district have an average altitude of 1538 m. The continuity of majestic Western Ghats stretching over 100 km is broken known as Palakkad gap with a width of 32 km. The mountainous highlands are mostly seen concentrated on the north and southern parts which extend from either side up to the Palakkad gap on the east otherwise major part of the remaining area is midland of mixed crops gardens. Most of the west flowing rivers having their source in the Western Ghat and thus these soils also have the influence of the sediments originating from Western Ghat. The Palakkad district lies on 92 m above sea level and characterized by hot humid tropical climate. According to Köppen and Geiger, this climate is classified as Aw. The average annual temperature in Palakkad is 27.8 °C with an annual mean rainfall of 2135 mm. The average monthly maximum temperature is 30.7 °C (highest in March) and mean monthly minimum temperature is 25.5 °C (lowest in July). However, in the eastern most part of Palakkad, where the Chittur *taluka* is located, the climate is sub-humid tropical with mean annual rainfall of 1340 mm. Rice (autumn, winter and summer) is cultivated on large scale in Chittur *taluka*. At both *panchayats*, some farmers have converted rice land to banana, coconut, mixed trees/crops. Virippu + Mundakan are a common cropping system in both the *panchayats*.

Soil sampling and analysis

The pedons representing Karuvapara series and Vannamada series were exposed at the respective sites and morphological properties were studied as per Soil Survey Manual (Soil Survey Staff 1995) and classified (Soil Survey Staff 2014). Horizon-wise soil samples were collected and processed for laboratory analysis. The soil samples (<2 mm) were analyzed for mechanical composition (Jackson 1979) after removing the cementing agents and for pH, electrical conductivity (EC) and cation exchange capacity (CEC) (Jackson 1973), organic carbon (OC) (Walkley and Black 1934), $CaCO_3$ (Piper 1950), available nitrogen (N) (Subbiah and Asija 1956), available phosphorus (P) (Olsen *et al.* 1954) and available potassium (K) (Hanway and Heidel 1952), available sulphur (S) (Chesnin and Yein 1951), available micronutrient cations *viz*., zinc (Zn), manganese (Mn), copper (Cu) and iron (Fe) by extracting with 0.005 *M* DTPA, 0.01 *M* $CaCl_2$ and 0.1 *M* triethanol amine (Lindsay and Norwell 1978) and available B content was extracted by hot water method and B content in the extract was determined by the improved Azomethine-H method (Wolf 1974; Parker and Gardner 1981).

Results and Discussion

Morphological properties

The representative pedon (P1) of Karuvapara series was characterized by very dark grayish brown colour barring Bss2 horizon (dark brown) in 10 YR hue. Pedon 2 had Munsel colour notation of 10 YR 3/2, 10 YR 2/2, 10 YR 2/1, 10 YR 2/2 and 7.5 YR 4/2 through depth. The colour of different horizons seems to be dependent on OC, texture, gravel content of respective horizons and moisture regime of site. The Bw1 and Bss1 horizons of P1 had clay texture while gravelly clay texture was noticed in Bw2 and Bss2 horizons and it was clay loam in Ap horizon. The surface soil of Vannamada soil had sandy clay texture and underlying Bw1 and Bw2 horizons had clay texture while last two horizons were sandy clay loam. The structure in different horizons of P1 was sub-angular blocky but strong medium angular blocky in slickenside zone. Pedon 2 had moderate medium to strong sub-angular blocky structure throughout the profile barring Bw2 horizon where it was strong medium angular blocky with wedge shaped aggregates and pressure faces. The soils of different horizons of P2 and last horizon of P1 showed slight effervescence barring Ap horizon of P2 which slowed strong effervescence.

Physical properties

The data on particle-size indicate that sand content in Karuvapara soils decreased from 43.0% (Ap horizon) to 17.7% (Bss2 horizon). Contrary to it, sand content in Vannamada soils increased from 44.4 to 60.8% through depth barring Ap horizon. Fine sand constitutes higher proportion in both the soils followed by medium sand, very fine, coarse and very coarse sand in Karuvapara soils while it was medium, coarse, very fine and very coarse fractions in Vannamada soils (Table 1). It was noticed that quantity of all fractions of sand in Vannamada soils had narrow range of variation than that of Karuvapara soils. In general, silt content in both the soils decreased with depth with an exception of Ap horizon

Table 1. Physical properties of soils

Soils	Horizon	Depth (cm)	Size class and particle diameter (mm)										Coarse fragment
			Total (%)			Sand (%)					Silt (%)		
			Sand (2.0-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Very coarse (2.0-1.0)	Coarse (1.0-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	(0.05-0.02)	(0.02-0.002)	(volume% of <75 mm)
Karuvapara (P1)			Fine, smectitic, isohyperthermic Typic Haplusterts										
	Ap	0-17	43.0	17.2	39.8	0.7	3.1	9.6	18.5	6.8	6.8	10.4	10
	Bw1	17-50	25.2	9.1	53.4	0.4	2.3	5.1	10.2	4.4	4.4	17.0	2
	Bw2	50-71	23.0	10.0	56.0	0.1	4.1	3.8	8.7	5.4	5.4	15.6	15
	Bss1	71-113	18.5	7.0	59.8	0.1	1.5	4.5	7.0	5.3	5.3	16.4	5
	Bss2	113-150	17.7	6.7	61.2	0.3	1.7	1.6	4.0	6.0	6.0	15.1	25
Vannamda (P2)			Fine, smectitic, isohyperthermic Vertic Epiaquepts										
	Ap	0-21	45.8	13.7	40.5	3.2	10.1	11.5	13.9	7.1	1.2	12.5	10
	Bw1	21-48	44.4	14.0	41.6	4.3	9.2	10.1	13.9	6.9	5.1	8.9	-
	Bw2	48-79	44.4	14.0	41.6	4.3	9.2	10.1	13.9	6.9	5.1	8.9	-
	Bw3	79-112	58.7	9.7	31.6	3.1	12.7	16.7	19.3	6.9	2.6	7.1	-
	Bw4	112-150	60.8	8.0	31.2	4.2	16.3	14.5	18.4	7.3	3.3	4.7	-

(P2) and Bw2 horizon of P1. Vannamada soils had higher content of silt throughout the profile than Karuvapara soils barring Ap horizon of later soils. In general, both the fraction of silt increased with depth barring few exceptions in Karuvapara soils but content of silt (0.02-002 mm) decreased with depth (12.5 to 4.7%), while coarser fraction increased and thereafter decreased with depth in Vannamada soils. The clay content in Karuvapara soils showed increasing trend ranging from 39.8 to 61.2% through depth while Vannamada soils showed decreasing trend of clay distribution (41.6-31.2%) through depth barring Ap horizon. The particle size and distribution of different fraction of sand and silt clearly illustrated that these soils have their formation over alluvium of different origin (mixed one), dominated by basaltic one, deposited through different fluvial flows.

Chemical properties

The pH of Karuvapara soils (1:2.5 soil-water) ranged from 7.8 to 8.2 and increased with depth barring Ap horizon while it varied from 7.1 to 7.8 in Vannamada soils with a tendency to decrease with depth (Table 2). The pH of soils in 0.01 *M* $CaCl_2$ (1:5 ratio) remained same as that of water or there was slight change of 0.1 to 0.2 unit but there was decrease in pH to the tune of 0.04 to 1.1 in 1.0 *M* KCL *i.e.* negative delta pH ($\Delta pH = pH_{KCl} - pH_{H_2O}$) indicating that these soils are not near to point of zero charge and contains appreciable amount of clay with relatively constant surface charge and in turn potential acidity. Karuvapara soils had higher EC of saturated extract (0.43-0.88 dS m^{-1}) than that of Vannamada soils (0.16-0.57 dS m^{-1}) and decreased with depth in both the soils.

The Karuvapara soils had OC ranging from 0.50% (Bw1 horizon) to 0.85% in surface horizon, while it ranged from 0.76% in last horizon to 1.38% in Ap horizon of Vannamada soils and decreased with depth except in Bw1 horizon. Kerala State Planning Board (2013) proposed less than 0.75% OC as low and 0.76 to 1.5% as medium. The exchange complex of Karuvapara soils had exchangeable sodium (Na) in the range of 1.13 to 2.70 cmol(p^+) kg^{-1} soil indicating the initiation of sodicity in these soils. The exchangeable K in these soils was higher than that of Vannamada soil. The CEC ranged from 31.4 to 55.6 cmol(p^+)kg^{-1} in Karuvapara soils and in general, increased with depth. The soils of Vannamada soils had relatively lower CEC with 17.5 to 28.5 cmol(p^+) kg^{-1} in different horizons than Karuvapara soils. The CEC of these soils seems to be dependent on clay

Table 2. Chemical properties of soils

Soils	Depth (cm)	OC (%)	pH (1:2.5) Water	pH (1:5) 0.01 M $CaCl_2$	pH (1:2.5) 1.0 M KCl	EC Saturn. Extract ($dS\ m^{-1}$)	Exchangeable bases Na	Exchangeable bases K	CEC NH_4OAc (pH=7.0)	$CaCO_3$ Equivt. (%)	Ratio CEC/ Clay
							[cmol(p^+)kg^{-1} soil]				
Karuvapara (P10	0-17	0.85	7.9	7.8	7.3	0.88	1.13	0.85	31.4	3	0.79
	17-50	0.50	7.8	7.8	7.1	0.57	2.36	0.47	47.9	3	0.90
	50-71	0.56	8.0	7.9	7.1	0.46	2.70	0.55	51.5	3	0.92
	71-113	0.56	8.2	7.9	7.1	0.43	2.70	0.58	55.6	4	0.93
	113-150	0.53	8.2	8.0	7.1	0.43	2.69	0.57	53.7	5	0.88
Vannamada (P2)	0-21	1.38	7.8	7.6	7.1	0.57	0.11	0.58	28.5	4	0.70
	21-48	1.00	7.6	7.6	7.0	0.26	0.11	0.32	27.3	2	0.66
	48-79	1.18	7.2	7.2	6.6	0.19	0.12	0.27	18.4	1	0.44
	79-112	0.83	7.1	7.1	6.4	0.16	0.18	0.26	20.1	0	0.64
	112-150	0.76	7.2	7.1	6.3	0.17	0.24	0.26	17.5	1	0.56

content of the respective horizons. Gaikwad *et al.* (2020) reported that high CEC in shrink-swell is attributed to the high clay content and presence of smectite minerals. These calcareous soils had CEC/ clay ratio more than 0.60 in most horizons indicating smectitic mineralogy of these soils.

Available nutrients in soils

The available N ranged from 178.8 to 277.0 kg ha^{-1} (Ap horizon) in Karuvapara soils while it was in the range of 259.2 to 321.8 kg ha^{-1} (surface layer) in Vannamada soils (Table 3) which indicated close association of available N with OC. Barring Ap horizon of Vannamada soils, all the horizons of soils had medium content of available N (140-280 kg ha^{-1}). Both the soils had high content of available P (surface layer) and K than the proposed limit of (>24 kg P_2O_5 ha^{-1}) and 240 kg K_2O ha^{-1} for available P and K, respectively by Kerala State Planning Board (2013). The P content of surface soils was very high (60.5 kg P_2O_5 ha^{-1}) in Karuvapara soils compared to Ap horizon of Vannamada soils (33.7 kg P_2O_5 ha^{-1}). It was noticed that farmers apply large quantity of N and P to rubber plants grown on uplands which might have reached to lowlands with rainwater resulting in higher content of N in all the horizons of soils (N being mobile) and P in surface horizon due to its non-mobile in nature. Farmers are advised to go for (i) any catch crop in between two seasons of rice crop, (ii) skip P application in one of the rice crop in sequence, (iii) seedling inoculation with *Azotobacter* or *Azospirillium* and growing of rice with *Azolla* (Prasad and Singh 1984) and blue green algae, (iv) seedling inoculation with phosphate solubilizing microorganisms to release fixed P into available form. Higher application of N might have replaced lattice Kin soil system as content of available K was higher in both the soils to the tune of 249.0 kg K_2O ha^{-1} in 48-79 cm layer in Vannamada soils to 886.6 kg K_2O ha^{-1} in Ap horizon of Karuvapara soils. These soils had available S (>12.5 mg ha^{-1}) more than the critical limit of 5 mg kg^{-1} as proposed by Kerala State Planning Board (2013).

The availability of DTPA-extractable Fe, Mn and Cu and hot water-soluble B were higher in surface horizon of Karuvapara soils and decreased with depth. The DTPA-Zn was deficient against the critical limit of 0.6 mg kg^{-1}. Data clearly indicated antagonistic effect of P on Zn availability but its effect was moderated by high content of OC in Ap horizon (DTPA-Zn 2.30 mg kg^{-1}) of Vannamada soils. The DTPA-Cu was sufficient against the critical limit of 0.12 mg kg^{-1}. These soils had higher content of DTPA-

Table 3. Available nutrients in soils

Soils	Depth (cm)	Available nutrients								
		N	P_2O_5	K_2O	S	Fe	Mn	Cu	Zn	B
		(kg ha^{-1})			(mg kg^{-1} soil)					
Karuvapara (P1)	0-17	277.0	60.5	886.6	16.6	6.46	3.28	1.64	0.28	0.73
	17-50	196.6	4.6	396.9	22.5	5.64	2.56	1.26	0.06	0.56
	50-71	178.8	4.6	389.2	21.6	5.22	2.16	1.12	0.04	0.57
Vannamada (P2)	0-21	321.8	33.7	515.0	15.0	7.28	8.82	2.44	2.30	0.73
	21-48	277.1	8.9	289.4	16.6	12.70	8.96	2.52	0.26	0.20
	48-79	259.2	8.9	249.0	12.5	10.96	10.40	1.52	0.18	0.20

Mn and DTPA-Fe than the critical limit of 2.0 and 4.5 mg kg^{-1}, respectively. Available B was above the critical limit of 0.5 mg kg^{-1} (Kerala State Planning Board 2013).

Classification

The representative pedon of Karuvapara series had more than 30% clay associated with 71 cm thick slickenside zone against required 25 cm and hence classified under the order Vertisols. As there is Ustic moisture regime, it has been grouped as Usterts at Suborder level and Haplusterts at Great Group level. The pedon does not meet the requirement to qualify any other subgroups but as Typic Haplusterts. The soil has <60% clay in fine earth fraction, less than 35% (by weight) coarse fragments (>2 mm diameter), therefore qualify for fine particle-size family class. Owing to CEC/clay ratio more than 0.60 and isohyperthermic soils temperature regime, the pedon can be grouped as Fine, smectitic, isohyperthermic Typic Haplusterts at family level.

Pedon 2 had cambic horizon and hence grouped under order Inceptisols. Due to presence of aquic moisture regime at the site, the pedon is classified as Aquepts at Suborder level. These soils qualify for Epiaquepts at great group due to epi-saturation. It possessed pressure faces with wedge shaped aggregates in a layer of 15 cm or more thick that has upper boundary within 125 cm of the mineral soil surface and hence have been placed in Vertic Epiaquepts at subgroup level. Clay content more than 35% (by weight) but less than 60% qualify for fine particle-size family class. The presence of pressure face with wedge shaped aggregates, and CEC/clay ratio of more than 0.6 in most of the horizons indicated dominance of smectite minerals and thus classified as Fine, smectitic, isohyperthermic Vertic Epiaquept at family level.

Conclusions

Palakkad eastern plains (Agro Ecological unit, AEU 123) of Palakkad district represent the rain shadow region with comparatively low rainfall and presence of mixed alluvium of alkaline nature favoured the formation of these shrink-swell soils in the vicinity of Nilgiris of Western Ghat. Karuvapara soils (Typic Haplusterts) had higher clay content (39-61%) than Vannamada soils (Vertic Epiaquepts) having 31-41% clay in different horizons but there was reverse trend for sand content. These soils had available N, P, K, S, Mn, Fe, Cu and B above the critical limit proposed by Kerala State Planning Board but DTPA-Zn was low barring Ap horizon of Vannamada soils owing to high available P. Although both soils are inherently potential for agriculture but these soils have to be cultivated under suitable agro-managements including irrigation (protective/assured) for sustained production of vegetables, coconut, mango, rice and even pulses. Besides, soil test based fertilizer application is suggested for higher productivity.

References

Chesnin, L. and Yien, C.H. (1951) Turbidimetric determination of available sulfates. *Soil Science Society of America Proceedings* **15**, 149-151.

Diwakar, D.P.S. and Singh, R.N. (1992) Tal land soils of Bihar-I: Characterization and classification. *Journal of the Indian Society of Soil Science* **40**, 496-504.

Gaikwad, S.S., Jagdish Prasad, Ray, S.K. and Rajeev Srivastava (2020) Characteristics, mineralogy and spectral properties of some typical Vertisols of Vidarbha, Maharashtra, India. *Journal of the Indian Society of Soil Science* **68**, 367-384.

Hanway, J.J. and Heidel, H. (1952) Soil analysis methods as used in Iowa State College soil testing laboratory. *Iowa State College of Agriculture Bulletin* **57**, 1-31.

Jackson, M.L. (1979) *Soil Chemical Analysis*. Advanced Course 2nd Edition. Published by the Author, University of Wiscon. Madison, WI, USA.

Jackson, M.L. (1973) *Soil Chemical Analysis*. Prentice Hall of India (Pvt.) Limited, New Delhi.

Kerala State Planning Board (2013) *Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala*. Kerala State Planning Board. Thiruvananthapuram, 514p.

Lindsay, W.L. and Norwell, W.A. (1978) Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal* **42**, 421-428.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954) Estimation of available phosphorus in soil by extracting with sodium bicarbonate. *United States Department of Agricultural Circular No*. 989.

Pal, D.K. and Deshpande, S.B. (1987) Characteristics and genesis of minerals in some benchmark Vertisols of Southern India. *Pedologie* **37**, 259-275.

Parker D, R. and Gardner, E.H. (1981) The determination of hot water soluble boron in some acid Oregon soils using a modified azomethine H procedure. *Communications in Soil Science and Plant Analysis* **12***,* 1311-1322.

Piper, C.S. (1950) *Soil and Plant Analysis*. Reprint of original, 1942 Eds. Published by Interscience published INC., NY. The university of Adelaide, Australia, 368p.

Prasad, J. and Singh, R.S. (1984) Effect of *Azolla*, seeding bacterization with *Azotobacter* and *Azospirillum* with and without nitrogen on paddy (*Oryza sativa* L.). *Indian Journal of Agricultural Research* **18**, 63-67.

Ram, H., Singh, B.N. and Prasad, J. (1985) Seasonal variations in enzymatic activity in cultivated, pond and virgin soils. *Journal of the Indian Society of Soil Science* **33**, 805-810.

Ray, S.K., Bhattacharyya, T., Chandran, P., Sahoo, A.K., Sarkar, D., Durge, S.L., Raja, P., Maurya, U.K. and Pal, D.K. (2006) On the formation of cracking clay soils (Vertisols) in West Bengal. *Clay Research* **25**, 141-152.

Ray, S.K., Bhattacharyya, T., Reddy, K.R., Pal, D.K., Chandran, P., Tiwary, P., Prasad, J., Mandal, D.K., Mandal, C., Sarkar, D., Karthikeyan, K., Venugopalan, M.V., Velmourougane, K., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Srivastava, R., Sen, T.K., Chatterji, S., Patil, N.G., Obireddy, G.P.,Mahapatra, S.K., Anil Kumar, K.S., Das, K., Singh, A.K., Reza, S.K., Dutta, D., Srinivas, S., Raychaudhuri Mausumi, Srivastava, A., Dongare, V.T., Balbuddhe, D., Bansod, N.G., Wadhai, K., Lokhande, M., Hukare, A., Kolhe, A., Kuchankar, H., Sheikh, S., Telpande, B.A., Nimje, A.M., Dasgupta, D., Kundu, D.K., Mandal, K.G., Kar, G., Durge, S.L., Kamble, G.K., Gaikwad, M.S., Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S.V.,Sahu, V.T., Gaikwad, K.M., Bhondwe, H., Dohtre, S.S., Gharami, S., Khapekar, S.G., Koyal, A., Sujatha, Reddy, B.M.N, Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N., Halder, A.S., Likhar, C., Thakre, S., Gautam, N., Basu, R., Singh, R., Jat, B.L., Ola, D.L., Ola, N.R., Khuspure, J., Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R.S., Sahu, A., Mahapatra, S., Puspamitra, S. and Kumar, A. (2014) *Baseline Data of Indo-Gangetic Plains (IGP)*,Working Report No.1, Part-I, NAIP Component-4 Project on "Georeferenced Soil Information System for Land Use Planning and Monitoring Soil and Land Quality for Agriculture" (Lead Center), NBSS Publ. No. 1062(a), NBSS & LUP, Nagpur, pp. 1-424.

Sarkar, D., Sah, K.D., Sahoo, A.K. and Gajbhiye, K.S. (2005) *Soil Series of Orissa*. NBSS Publ. No. 119, NBSS&LUP (ICAR), Nagpur, 254p.

Singh, A.K., Shukla, N.K., Singh, A.K., Yadav, M.K., Ranjan, A., Singh, M. and Pal, M. (2017) Study of soil fertility of Suraha Tal in Ballia district, Uttar Pradesh. *Krishika Shodh Patrika* **6**, 18-26.

Soil Survey Staff (1995) *Soil Survey Manual*, USDA Handbook No. 18, Revised Edition. Scientific Publishers, Jodhpur.

Soil Survey Staff (2014) *Keys to Soil Taxonomy*. United States Department of Agriculture, Natural Resource Conservation Service, Washington DC, 9th Edition.

Subbiah, B.V. and Asija, G.L. (1956) A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**, 259-260.

Walkley, A. and Black, I.A. (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29-38.

Wolf, B. (1974) Improvement in the Azomethine-H method for the determination of boron. *Communications in Soil Science and Plant Analysis* **5,** 39-44.

Received 3 April 2021; Accepted 19 June 2021