

PEDOTRANSFER FUNCTION MODELLING OF SOIL WATER CHARACTERISTICS FOR PIGEON PEA PRODUCTIVITY IN LATERITIC, RED, AND BLACK SOILS

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ABSTRACT

Field capacity, permanent wilting point and Available water contents are the three vital hydrological properties which determine the retention and availability of water for crop growth. These properties are difficult to measure and time-consuming, but can be easily predicted from the available basic soil information like texture, organic carbon and pH.

Materials and methods: In selected geographical area of Agro climatic zones I, II & III of Karnataka, three types of soils namely Red, Lateritic and Black soils were selected for study. Pedotransfer functions were developed for field capacity, permanent wilting point and available water content for these three types of soils. Cross-Validation of model using coefficient of determination (R^2), root mean square error (RMSE) and mean error (ME) was carried out and the results were found to be satisfactory with low RMSE and higher R^2 . The developed PTFs are useful in predicting soil hydrological properties of respective soil types.

Result and discussion: The linear regressions for crop yield in lateritic, red and black soil series indicated that the basic soil properties viz. clay and organic carbon together contributed to the crop yield to the tune of 89.9 and 99.7 per cent in red and black soils, respectively whereas in lateritic soils sand and organic carbon together caused the 97.6 per cent variation in crop yield.

KEYWORDS: Agro climatic zones, Pedotransfer functions, Root mean square error, Mean error, Hydrological properties.

INTRODUCTION

Soil is a three phase system and it consists of solid, liquid and gaseous phases. Solid phase of mineral soil consists of both mineral and organic matter. The mineral matter of solid phase consists of both primary and secondary minerals. The primary minerals in sand and silt fractions constitute skeleton of soil while the secondary minerals in clay fraction constitute flesh of the soil. Clay and organic matter are the two active and vital components of soil. In addition to both soil texture and organic matter, soil reaction is the most important property of the soil as most of the physical, chemical, biochemical and biological processes are pH dependent. The physical, chemical and biological properties as well as processes are due to both qualitative and quantitative interactions of solid, liquid and gaseous phases of soil under the influence of soil pH as the later is the master determinant property of the soil.

Water is one of the important constituent of the terrestrial ecosystem especially in rainfed regions as the absorption and translocation of nutrients in plant is controlled by soil water. The crop yield in rainfed regions mainly depends on the amount of rainwater entered and stored in a soil profile, and the extent of soil water released during crop growth periods. In recent years, several attempts have been made to estimate soil hydraulic properties indirectly from more easily measurable and more readily available soil properties such as particle size (sand, silt and clay content) classes in fine earth (<2 mm;), and organic matter. Such relationships are referred to as pedotransfer functions (PTFs). The term pedotransfer function was coined by "Johan Bouma" and is a process of translating basic raw soil data into more meaningful and useful soil data and thus it is a predictive function of certain significant soil properties from other soil properties. Huge soil data (Morphological, geomorphological, physical, chemical and biological properties of soil) which can be measured easily, cheaply and routinely (Odeh and McBratney, 2005) are obtained by soil survey is translated into estimates of soil properties or qualities which are laborious, expensive and time consuming for analysis. The estimation of soil water content in laboratory is laborious, expensive and time consuming and thus the present investigation was carried out with an objective of developing and validating PTFs for hydrological properties namely Field Capacity (FC), Permanent wilting point

(PWP) and Available water content (AWC) of red, lateritic and black soils of Agro climatic zones I, II & III of Karnataka.

MATERIAL AND METHODS

The extent of area under three types of soils namely Red, Lateritic and Black soils selected for study from selected geographical area of Agro climatic zones I, II & III of Karnataka (Fig 1 & 2) was delineated using Cartosat-1 merged with LISS-IV satellite imagery and SOI toposheet (Natarajan. and Sarkar., 2010). The samples are drawn under permission of agricultural officers and farmers under the SUJALA watershed Project. From each soil type six soil series were selected and one representative soil profile from each soil series was excavated and horizon wise soil samples were collected and analysed for particle size classes, pH, OC and Water content at FC and PWP by standard procedures. Soil type wise Descriptive statistics, Pearson correlation and PTFs were developed using multiple linear regression method in SPSS for water retention parameters. The soil parameters, viz. sand, silt, clay, organic carbon (OC) and pH were used as predictor variables. The 80 percent of data was used for Training/developing of the model and the 20 percent of data was used for validation. Cross-Validation of model using coefficient of determination (R^2), root mean square error (RMSE) and mean error (ME) were carried out using formulas.

$$RMSE = \sqrt{1/n \sum_{i=1}^n (O_i - P_i)^2}$$

$$ME = \sqrt{1/n \sum_{i=1}^n |O_i - P_i|}$$

$$R^2 = 1 - \frac{\sum_{i=1}^n (O_i - P_i)}{\sum_{i=1}^n (O_i - \bar{O}_i)^2}$$

Where

O_i Observed values

P_i Predicted values

\bar{O}_i Mean of observed values

n number of observations

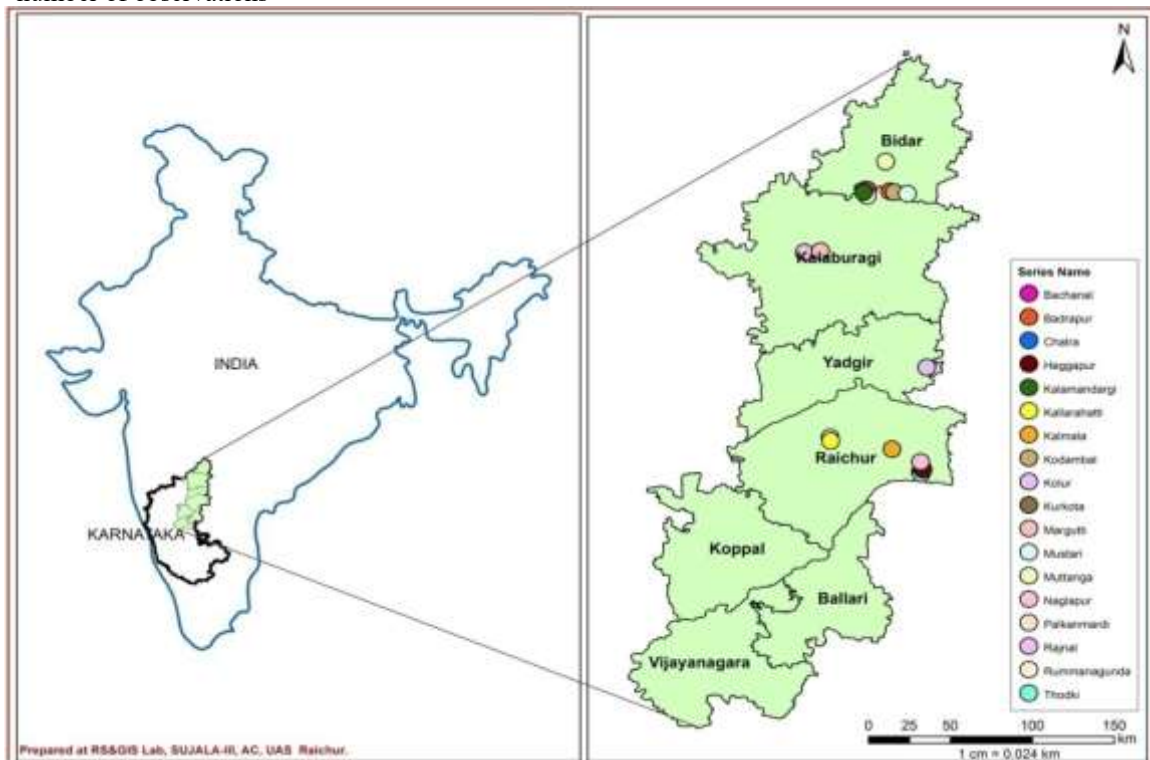


Fig. 1: Location map of soil profile sampling sites of the soils series

Silt	12.17	24.57	17.55	3.31	0.484	-0.492
Clay	20.98	40.33	31.45	6.35	-0.304	-1.340
OC	0.20	1.22	0.62	0.26	0.552	0.193
pH	5.27	8.02	6.30	0.95	0.775	-0.822
FC	17.10	25.98	22.80	2.82	-1.070	0.151
PWP	8.21	13.98	11.42	1.76	-0.496	-0.904
AW	7.51	12.43	11.38	1.36	-1.892	3.220
Red soil						
Sand	49.97	63.15	54.68	4.17	0.567	-0.808
Silt	9.65	17.15	14.57	2.43	-0.913	-0.252
Clay	26.20	35.23	30.78	2.68	-0.152	-1.124
OC	0.12	0.89	0.46	0.23	0.158	-0.827
pH	6.08	7.65	6.92	0.51	-0.154	-1.517
FC	19.68	32.12	25.60	3.27	-0.072	0.066
PWP	9.62	14.53	11.76	1.46	0.391	-0.566
AW	10.06	17.59	13.84	2.12	-0.052	-0.488
Black soil						
Sand	16.20	42.88	30.05	8.59	-0.151	-1.273
Silt	12.11	22.40	16.05	2.08	1.104	3.066
Clay	43.25	67.80	53.89	7.22	0.329	-1.075
OC	0.11	1.30	0.54	0.30	0.917	0.769
pH	6.42	9.38	8.36	0.56	-1.406	2.957
FC	39.10	49.57	43.76	3.17	0.466	-0.937
PWP	20.80	27.46	23.58	2.12	0.652	-0.754
AW	18.12	22.11	20.18	1.15	-0.123	-0.834

Table 1: Descriptive statistics of data set for validation of developed pedotransfer functions of lateritic, red and black soils

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Lateritic soil						
Sand	49.17	60.93	53.71	4.44	1.290	2.175
Silt	12.62	23.36	16.11	4.29	1.693	2.952
Clay	22.37	38.21	30.32	7.32	-0.363	-2.869
OC	0.23	1.14	0.73	0.41	-0.507	-2.729
pH	5.23	7.68	6.32	0.89	0.728	1.790
FC	17.86	25.79	22.61	3.30	-0.752	-0.971
PWP	8.66	12.93	10.98	1.89	-0.482	-2.685
AW	8.60	13.05	11.63	1.80	-1.662	2.926
Red soil						
Sand	48.39	63.15	54.28	4.13	0.58	-0.72
Silt	9.65	17.15	14.66	2.30	-0.98	-0.11
Clay	26.20	36.37	31.08	2.79	0.06	-0.87
OC	0.09	0.89	0.45	0.23	0.17	-0.80
pH	6.08	7.68	6.92	0.53	-0.06	-1.54
FC	21.64	30.27	26.42	3.34	-0.579	-0.333
PWP	9.49	14.28	12.13	2.06	-0.454	-2.259
AW	12.15	17.47	14.29	2.01	1.065	1.604
Black soil						
Sand	23.95	29.59	27.37	2.33	-0.496	-1.636
Silt	14.70	18.25	16.46	1.42	-0.201	-1.533
Clay	52.69	58.45	56.17	2.03	-0.962	1.158

OC	0.08	1.02	0.39	0.36	1.346	1.141
pH	7.45	9.65	8.53	0.78	0.171	-0.408
FC	43.16	47.10	44.17	1.46	1.244	2.242
PWP	21.90	25.64	23.72	1.23	0.202	1.271
AW	19.31	21.46	20.46	0.84	-0.146	-1.479

Table 1: Descriptive statistics for Hydrological characteristics of lateritic, red and black soils

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Lateritic soil						
Sand	43.00	60.93	51.62	4.45	0.30	-0.17
Silt	12.17	24.57	17.22	3.50	0.60	-0.64
Clay	20.98	40.33	31.19	6.42	-0.30	-1.44
OC	0.20	1.22	0.65	0.29	0.31	-0.86
pH	5.23	8.02	6.31	0.92	0.72	-0.76
FC	17.10	25.98	22.75	2.85	-0.92	-0.33
PWP	8.21	13.98	11.32	1.76	-0.45	-1.12
AWC	7.51	13.05	11.44	1.43	-1.58	1.88
Red soil						
Sand	48.39	63.15	54.28	4.13	0.58	-0.72
Silt	9.65	17.15	14.66	2.30	-0.98	-0.11
Clay	26.20	36.37	31.08	2.79	0.06	-0.87
OC	0.09	0.89	0.45	0.23	0.17	-0.80
pH	6.08	7.68	6.92	0.53	-0.06	-1.54
FC	19.68	32.12	25.78	3.22	-0.15	-0.27
PWP	9.49	14.53	11.85	1.56	0.19	-1.07
AWC	10.06	17.59	13.94	2.06	0.05	-0.38
Black soil						
Sand	16.20	42.88	29.51	7.78	0.036	-0.935
Silt	12.11	22.40	16.13	1.95	0.963	2.884
Clay	43.25	67.80	54.34	6.55	0.144	-0.785
OC	.08	1.30	0.51	0.31	0.821	0.287
pH	6.42	9.65	8.39	0.59	-0.761	3.491
FC	39.10	49.57	43.84	2.89	0.442	-0.618
PWP	20.80	27.46	23.61	1.95	0.624	-0.527
AWC	18.12	22.11	20.23	1.08	-0.198	-0.724

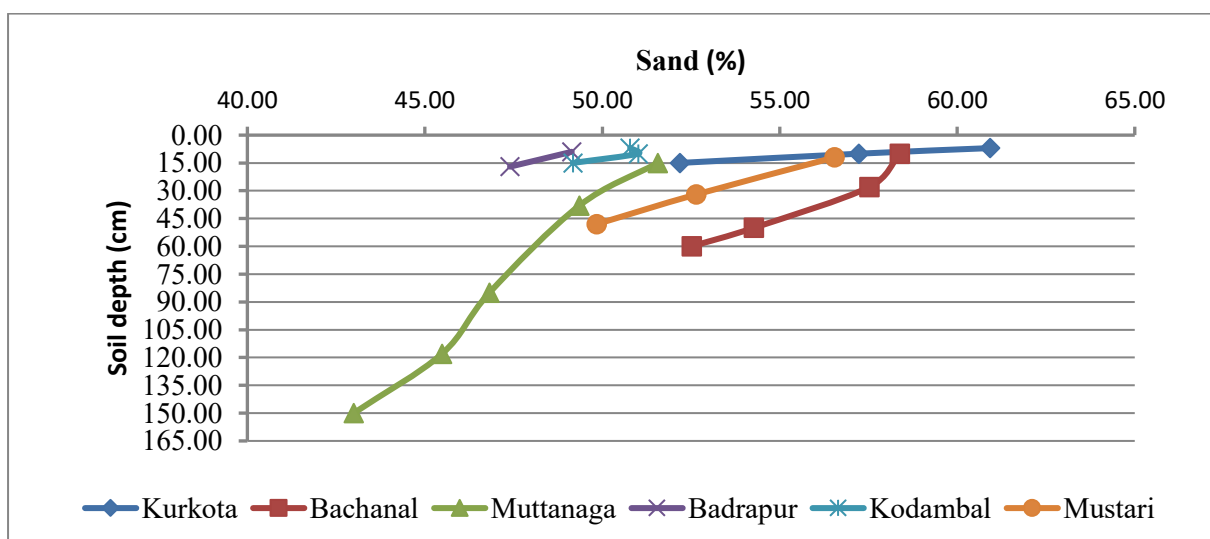


Fig. 3 : Vertical distribution of sand content in lateritic soils series

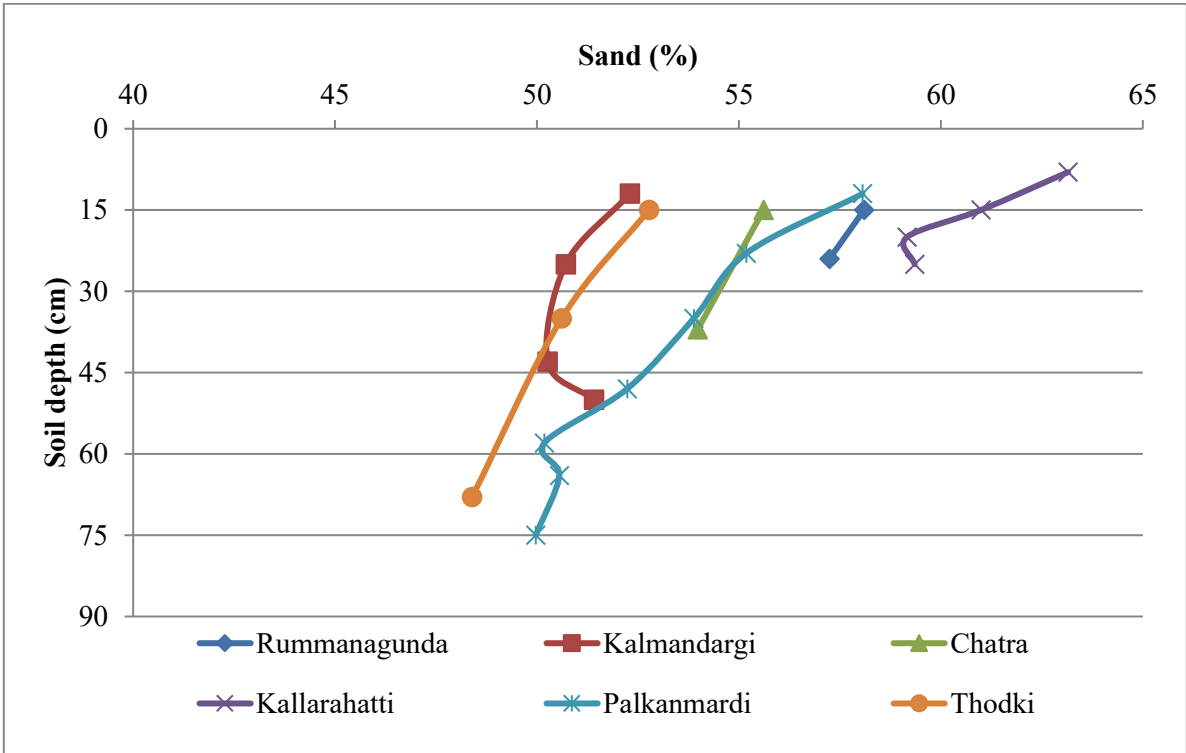


Fig. 4 : Vertical distribution of sand content in red soils series

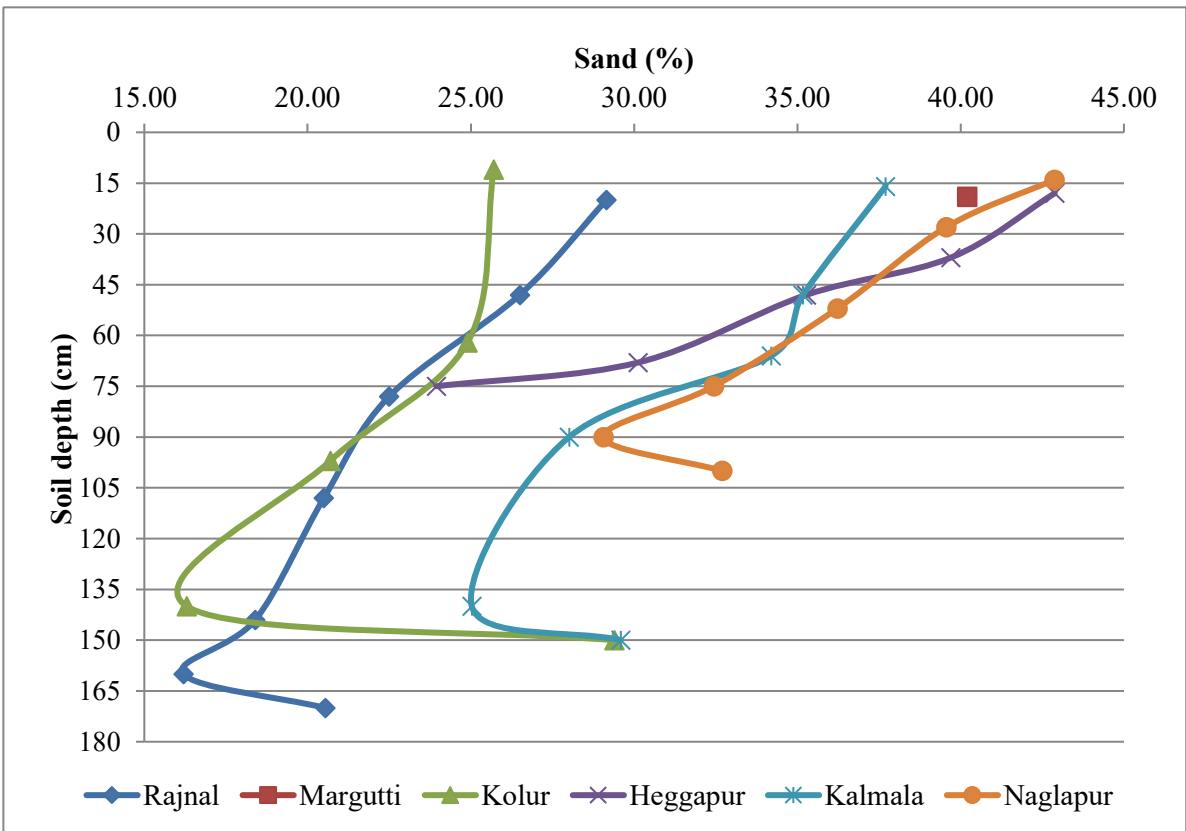


Fig. 5 : Vertical distribution of sand content in black soils series

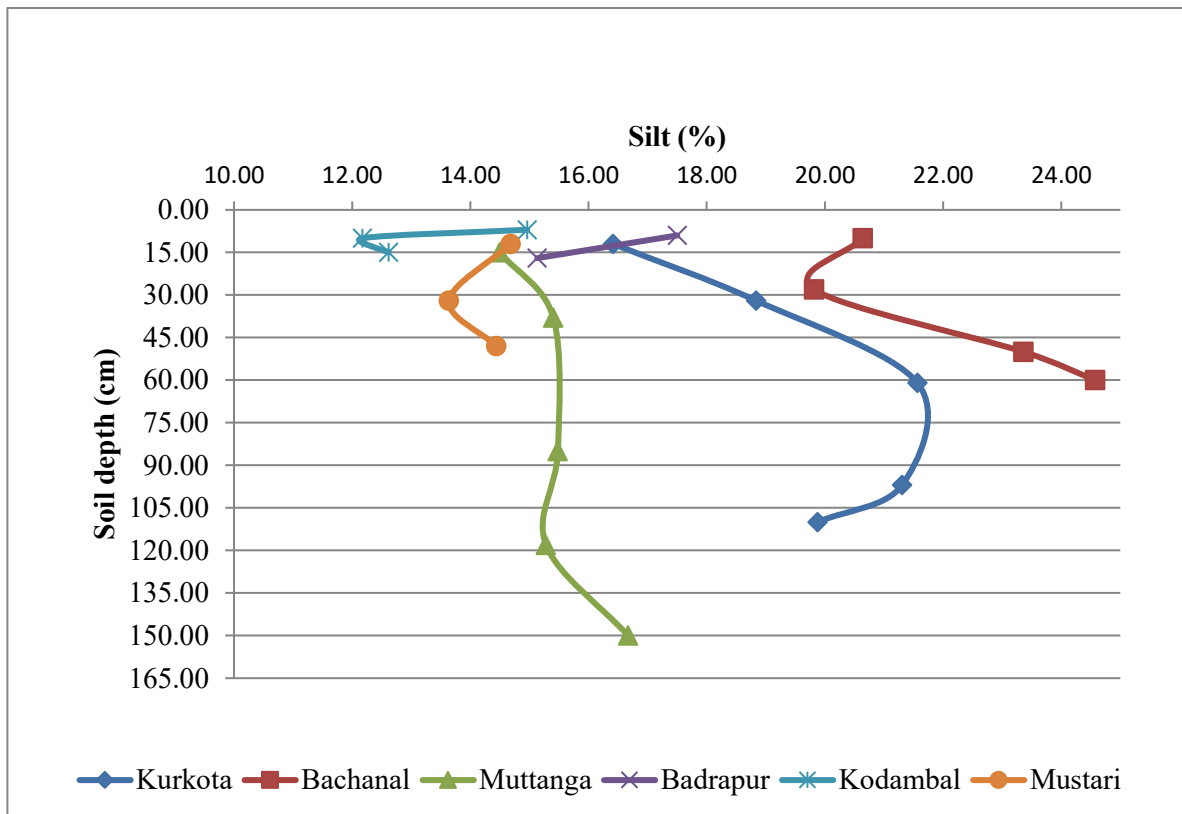


Fig. 6 : Vertical distribution of silt content in lateritic soils series

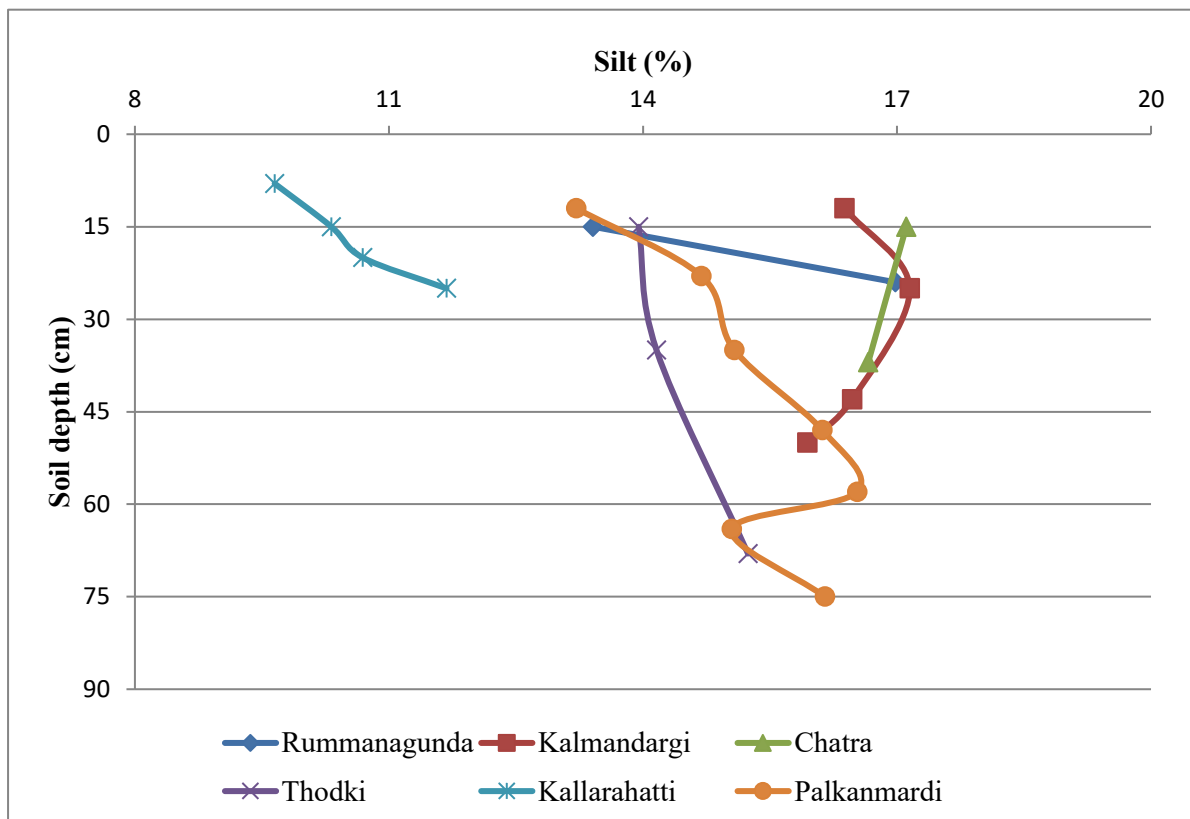


Fig. 7 : Vertical distribution of silt content in red soils series

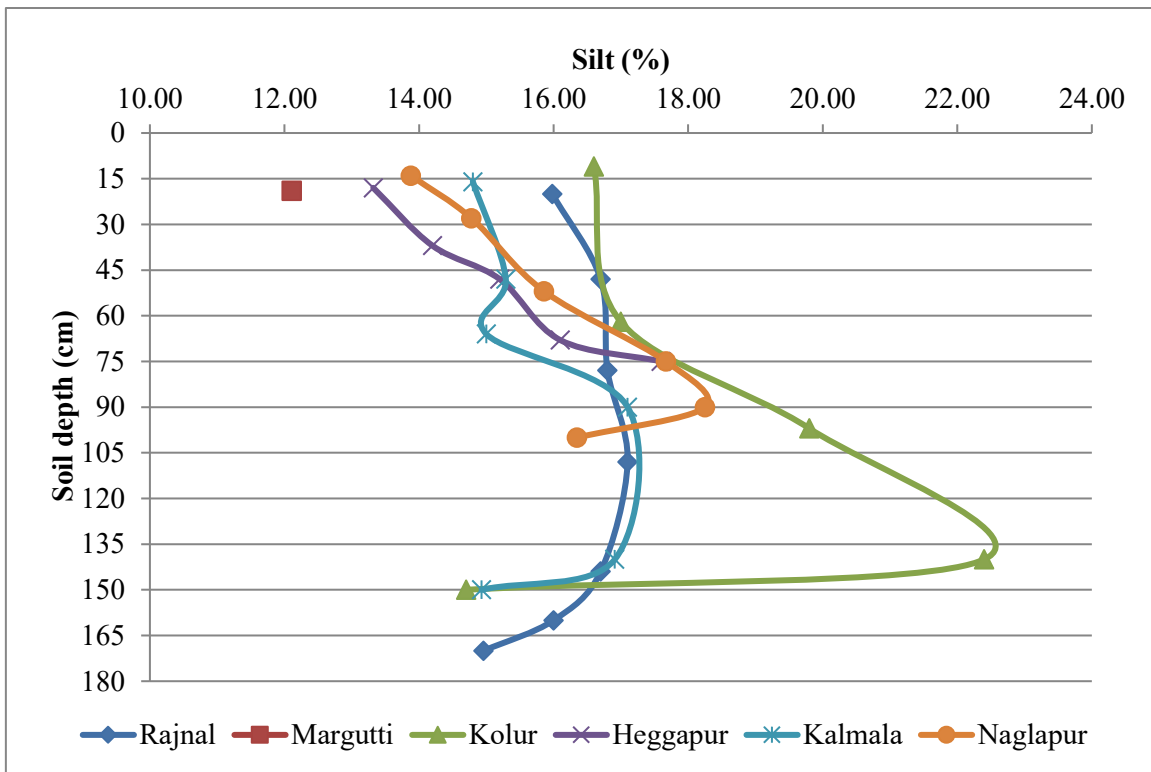


Fig. 8 : Vertical distribution of silt content in black soils series

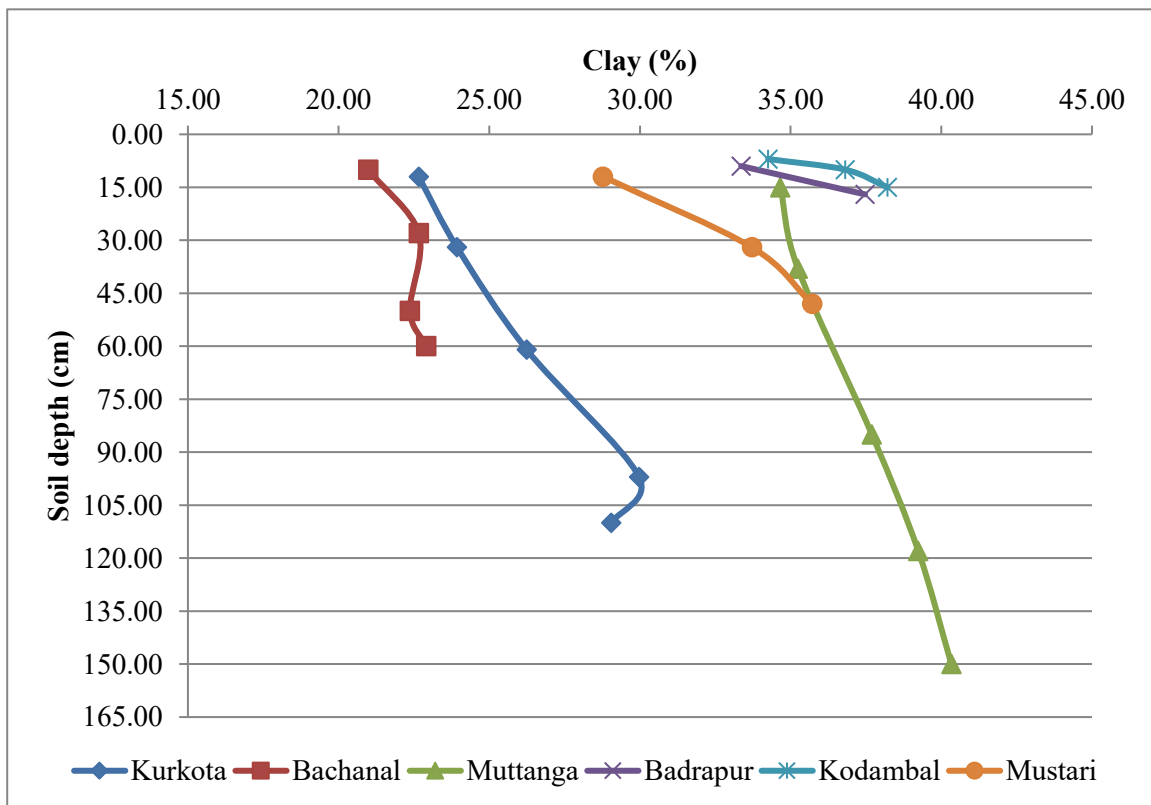


Fig. 9 : Vertical distribution of clay content in lateritic soils series

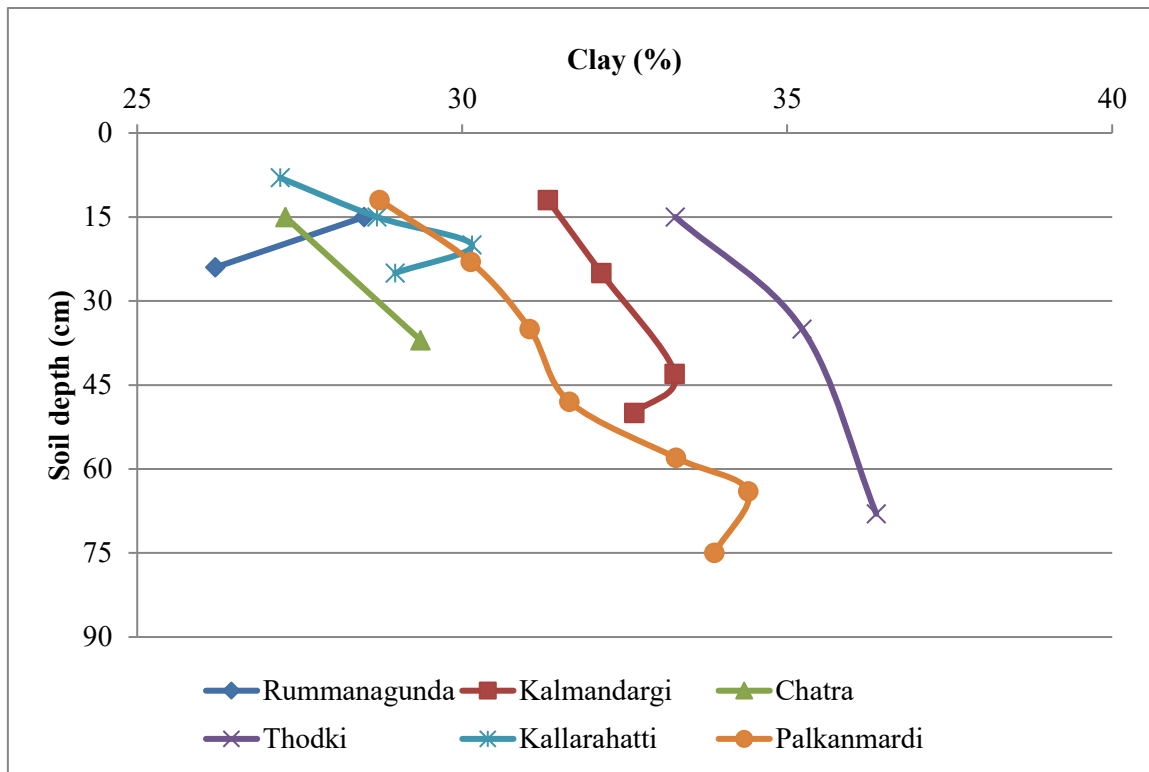


Fig. 10 : Vertical distribution of clay content in red soils series

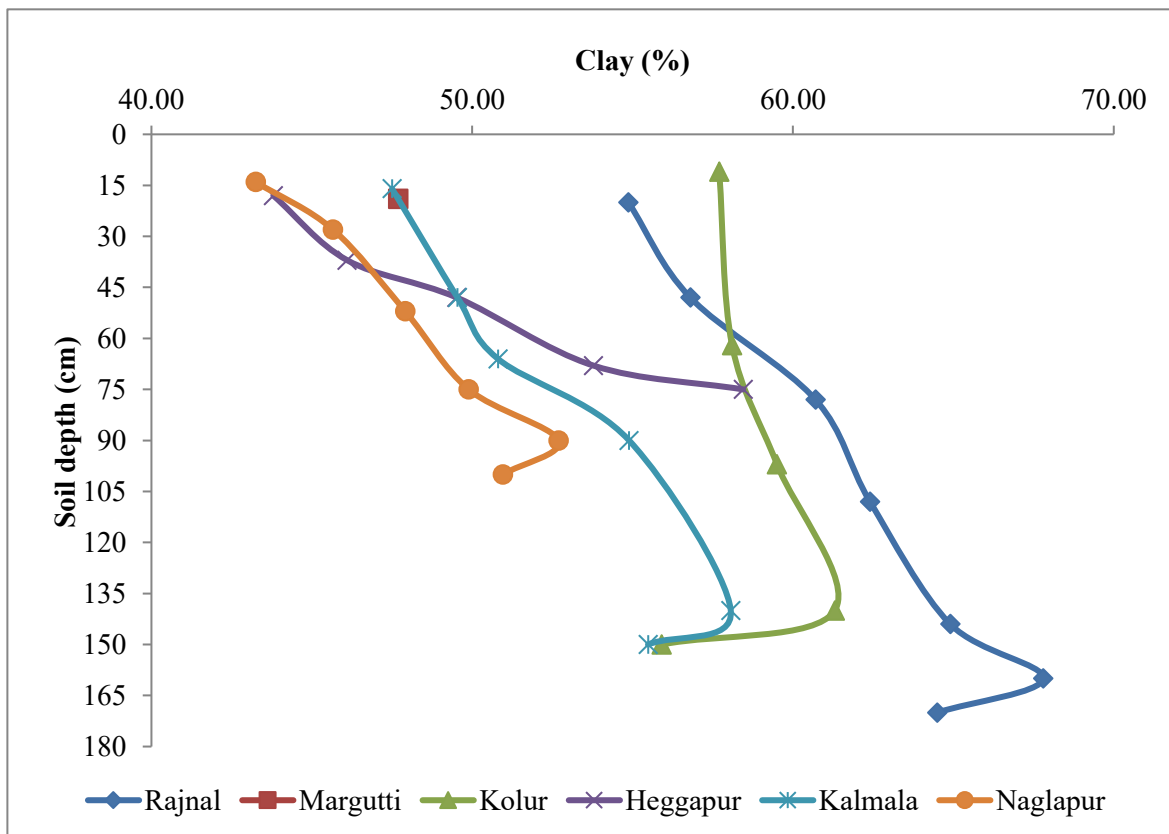


Fig. 11 : Vertical distribution of clay content in black soils series

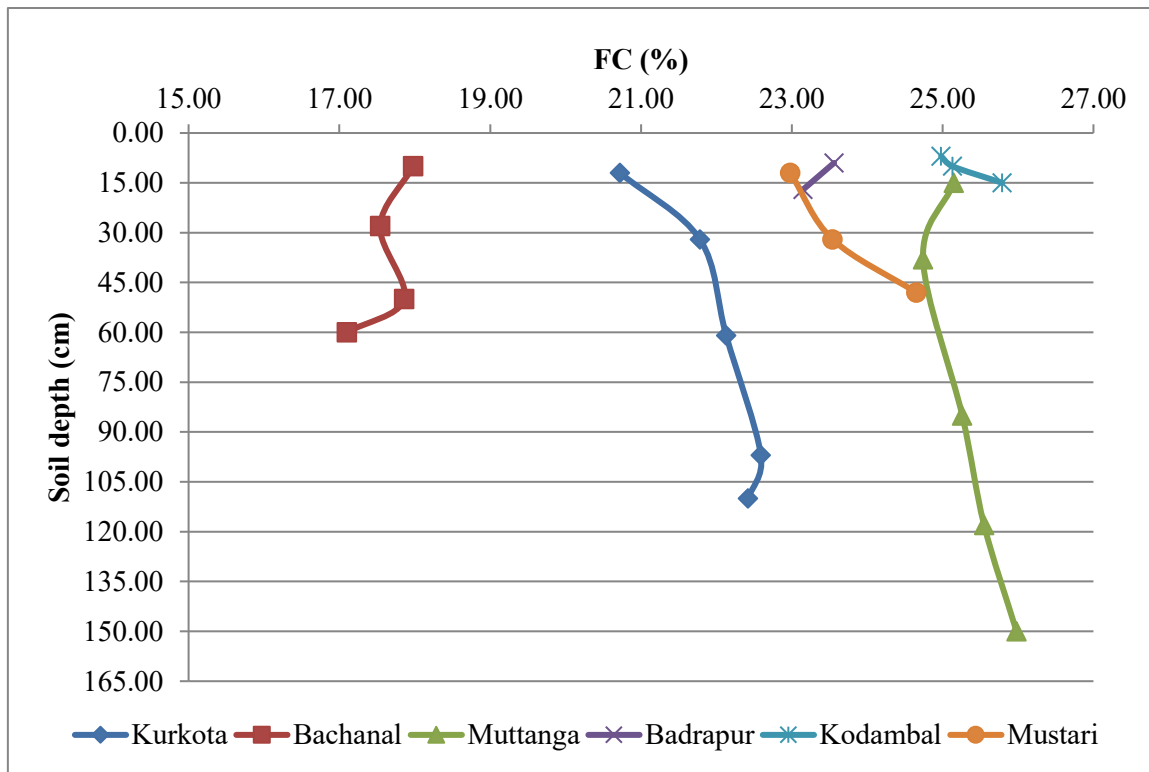


Fig. 12 : Vertical distribution of field capacity content in lateritic soils series

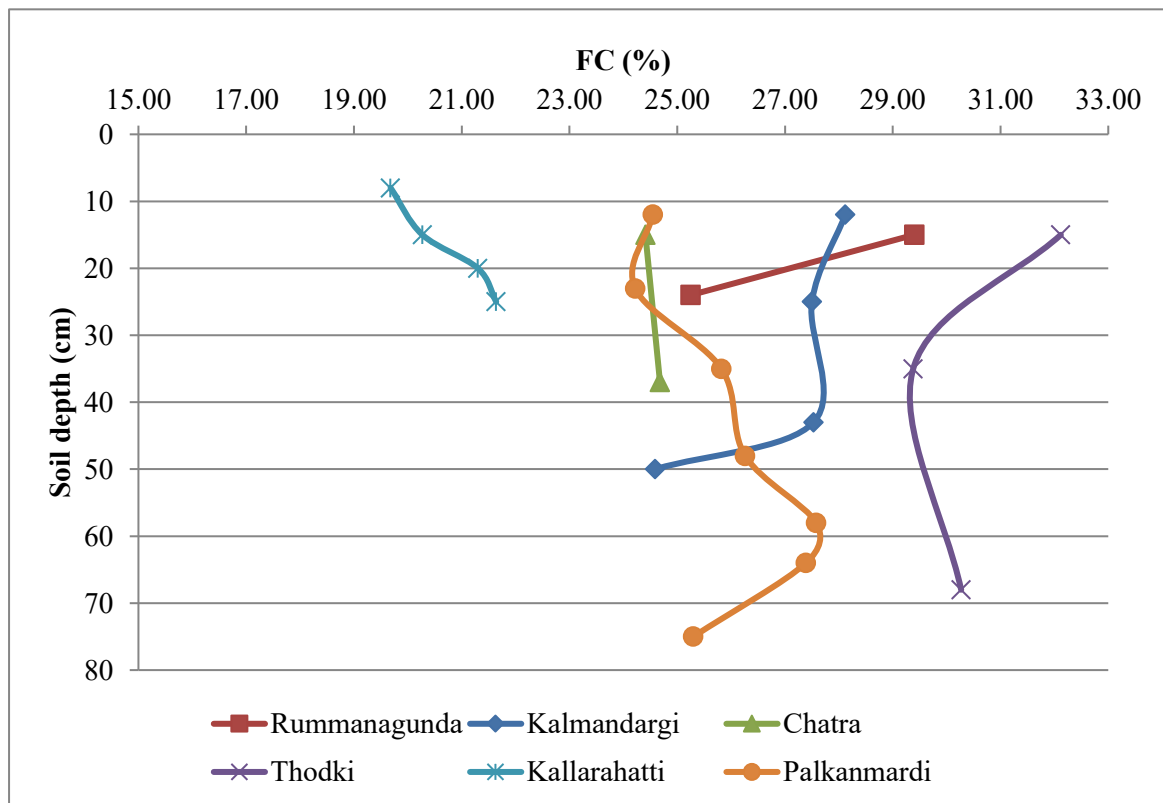


Fig. 13: Vertical distribution of field capacity content in red soils series

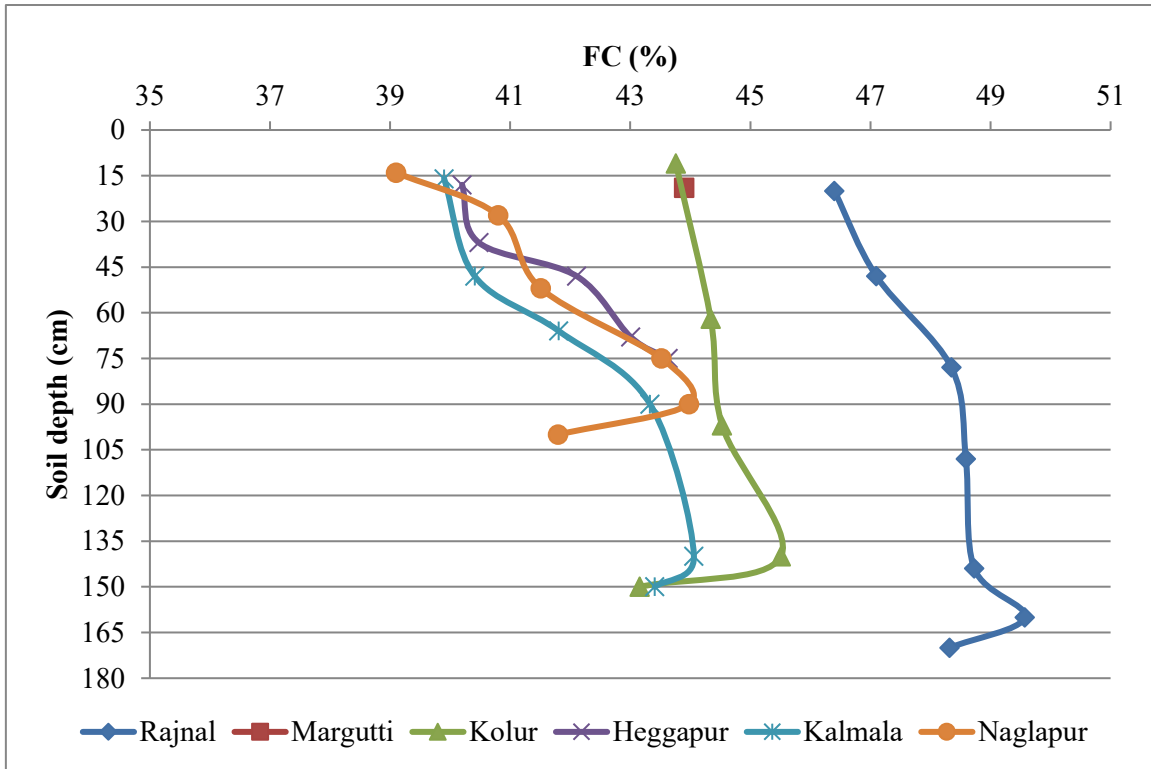


Fig. 14: Vertical distribution of field capacity in black soils series

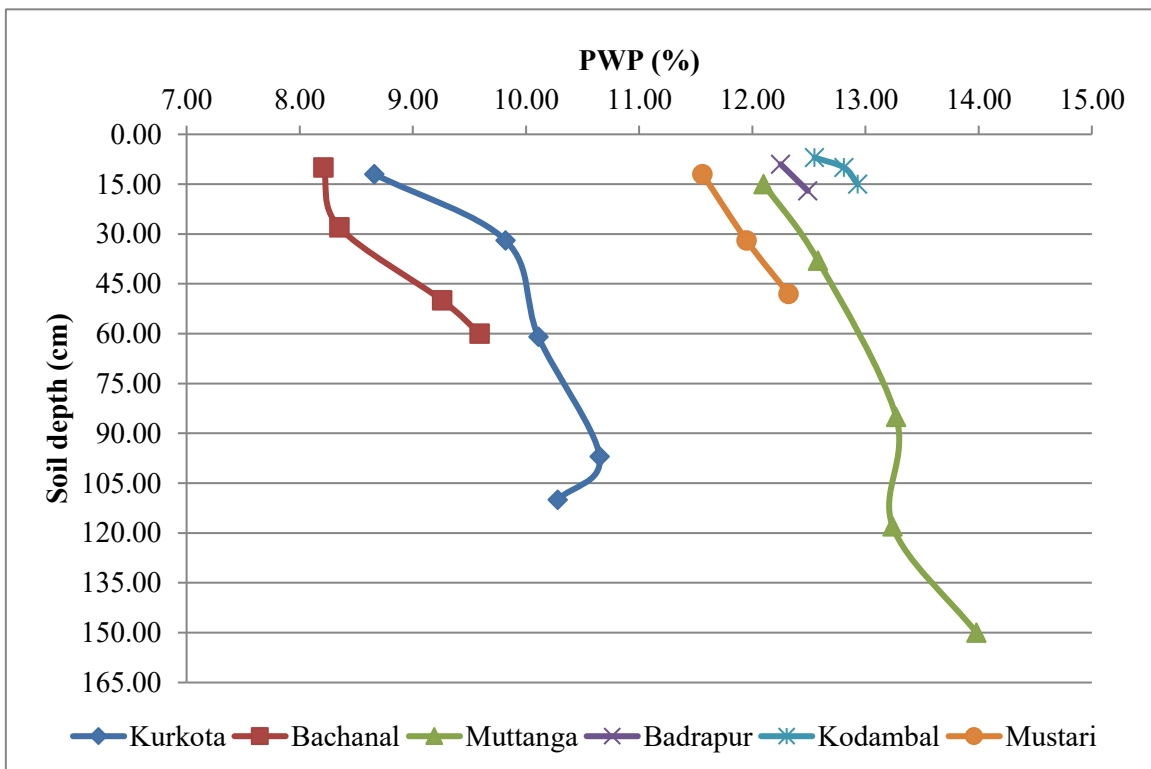


Fig. 15: Vertical distribution of permanent wilting point in lateritic soils series

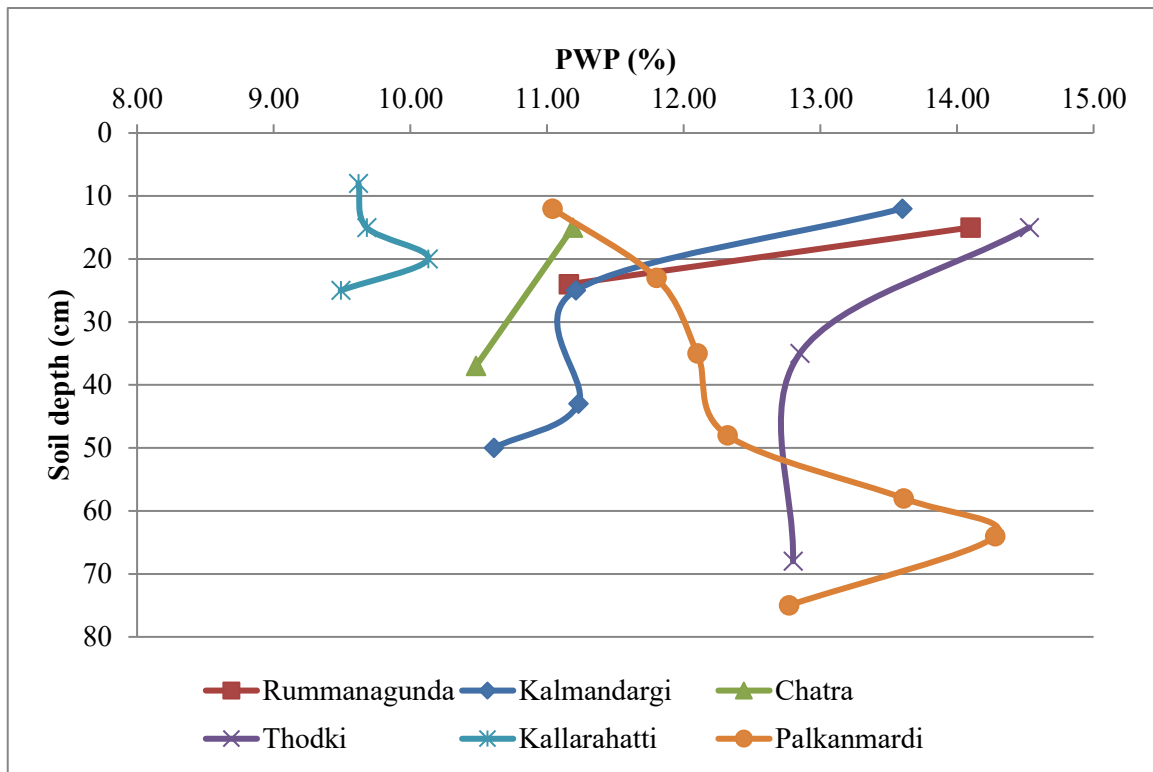


Fig. 16: Vertical distribution of permanent wilting point in red soils series

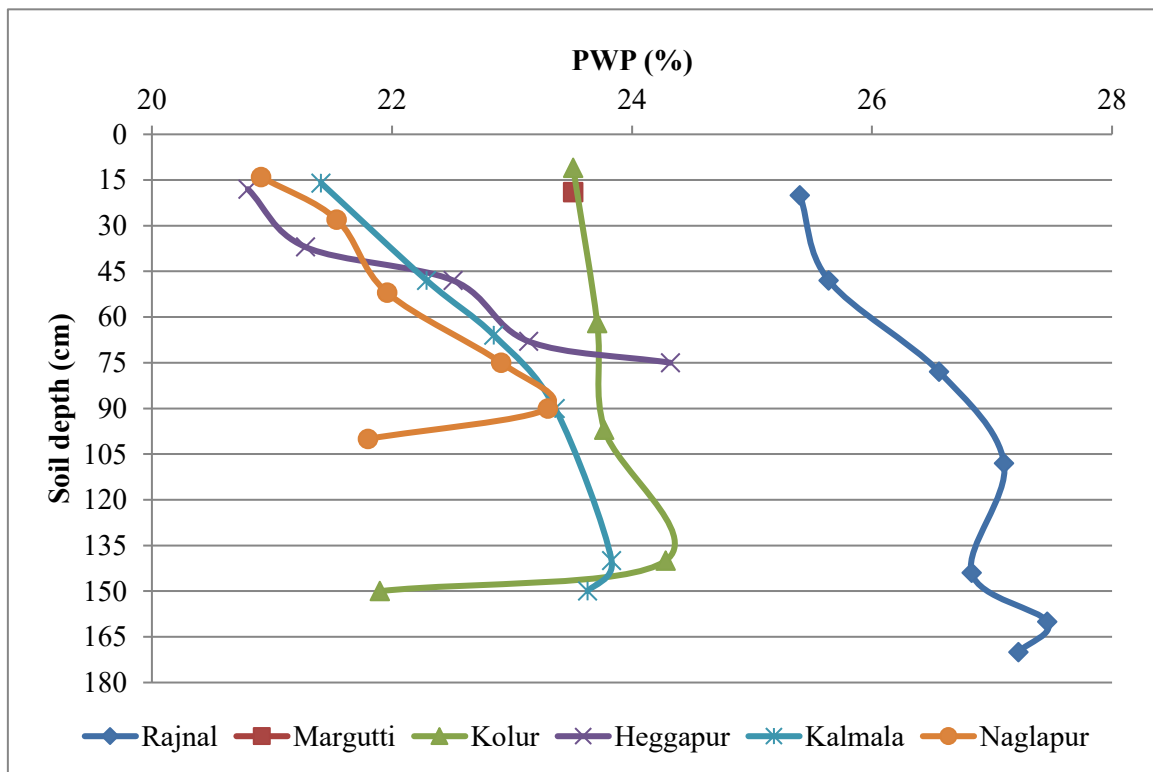


Fig. 17: Vertical distribution of permanent wilting point in black soils series

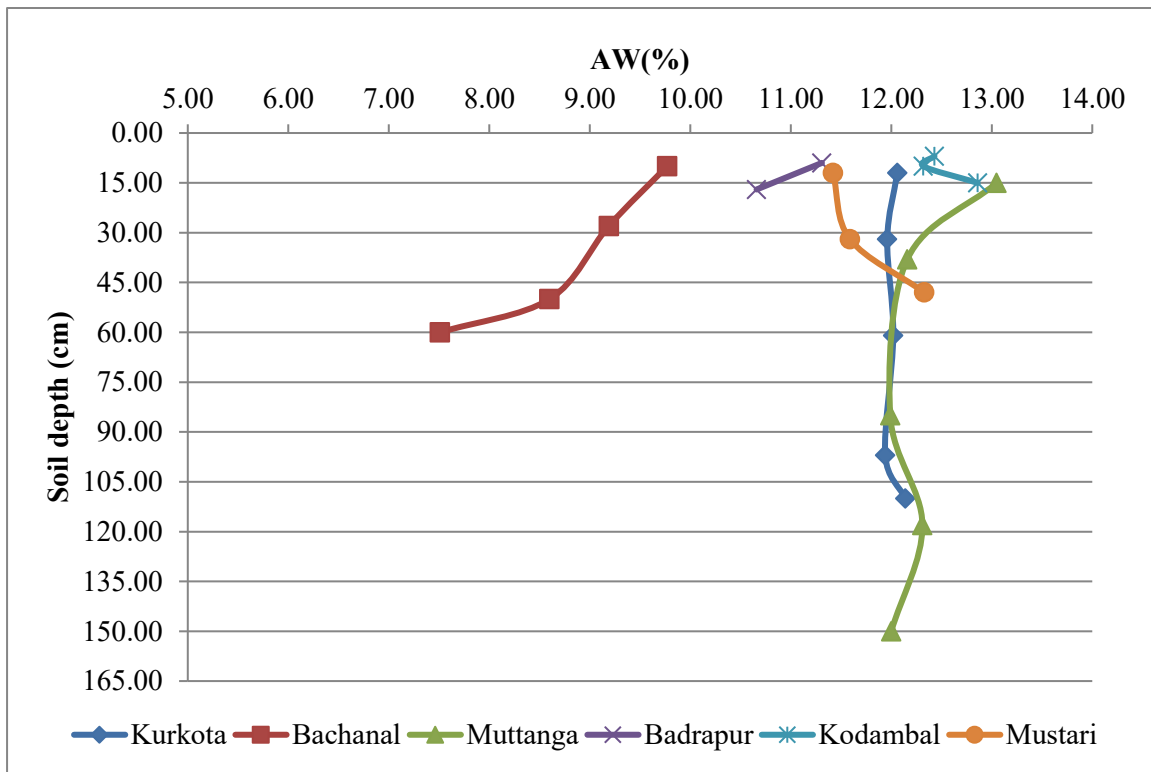


Fig. 18: Vertical distribution of available water in lateritic soils series

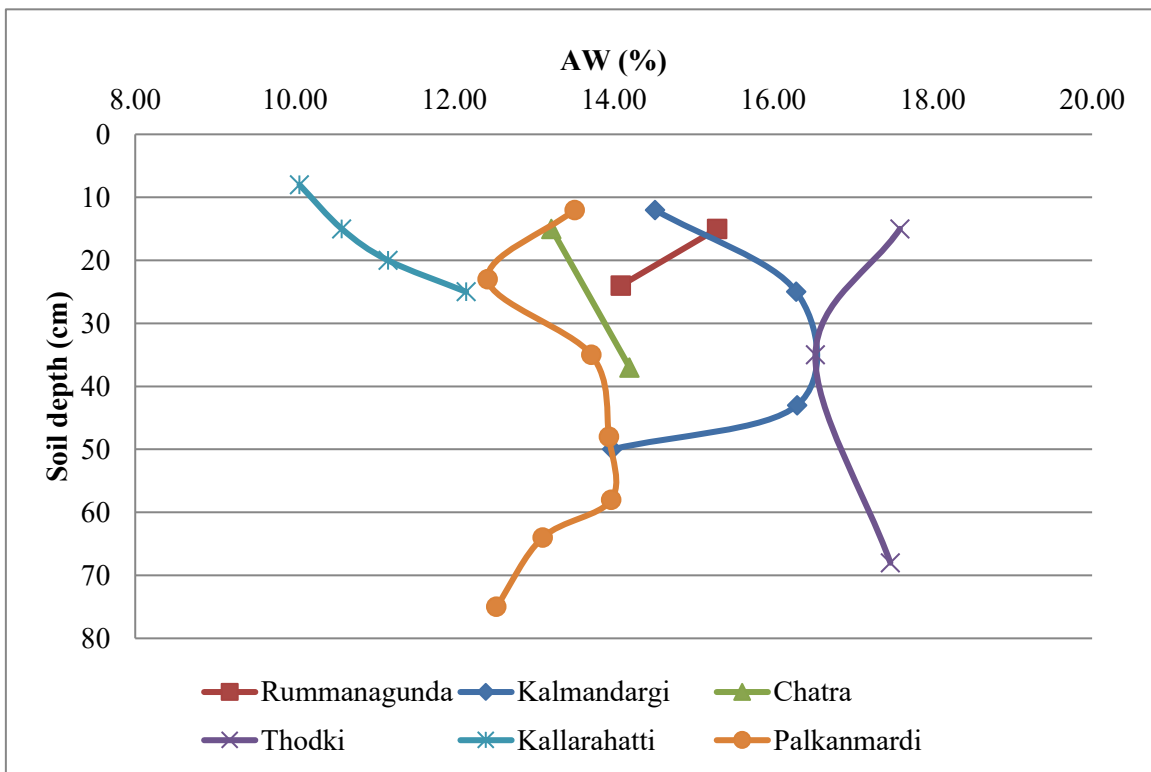


Fig. 19: Vertical distribution of available water in red soils series

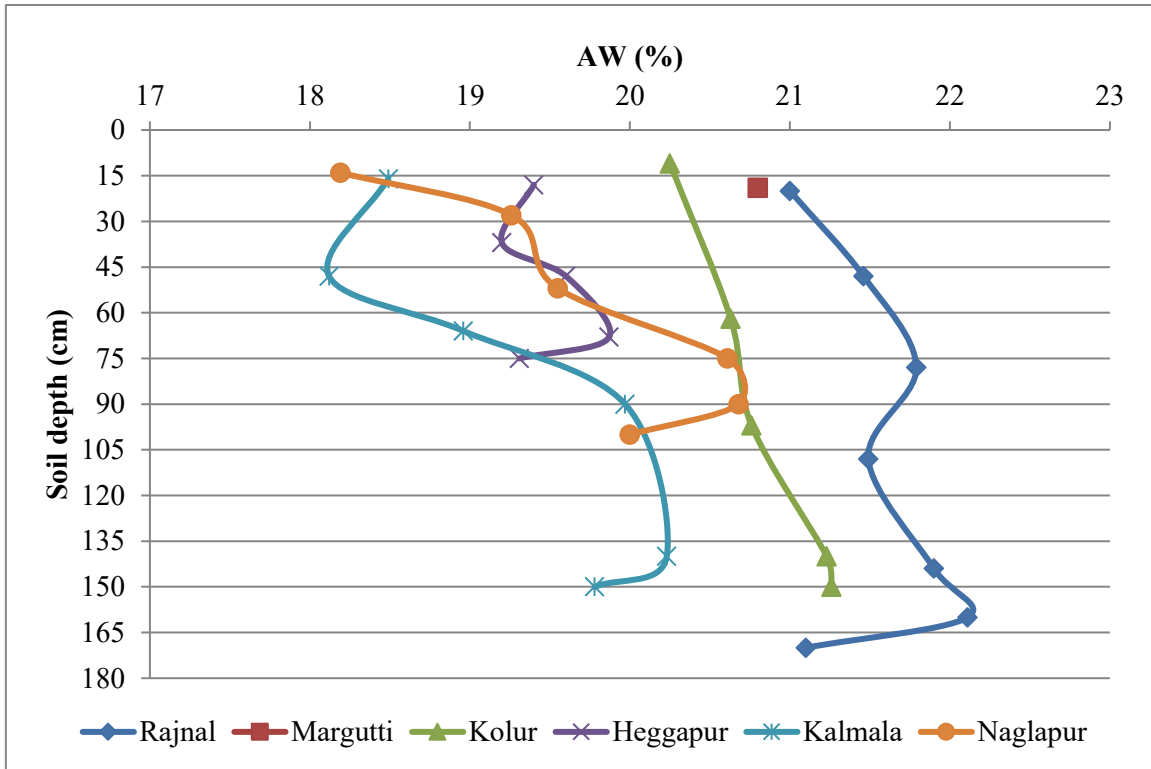


Fig. 20: Vertical distribution of available water in black soils series

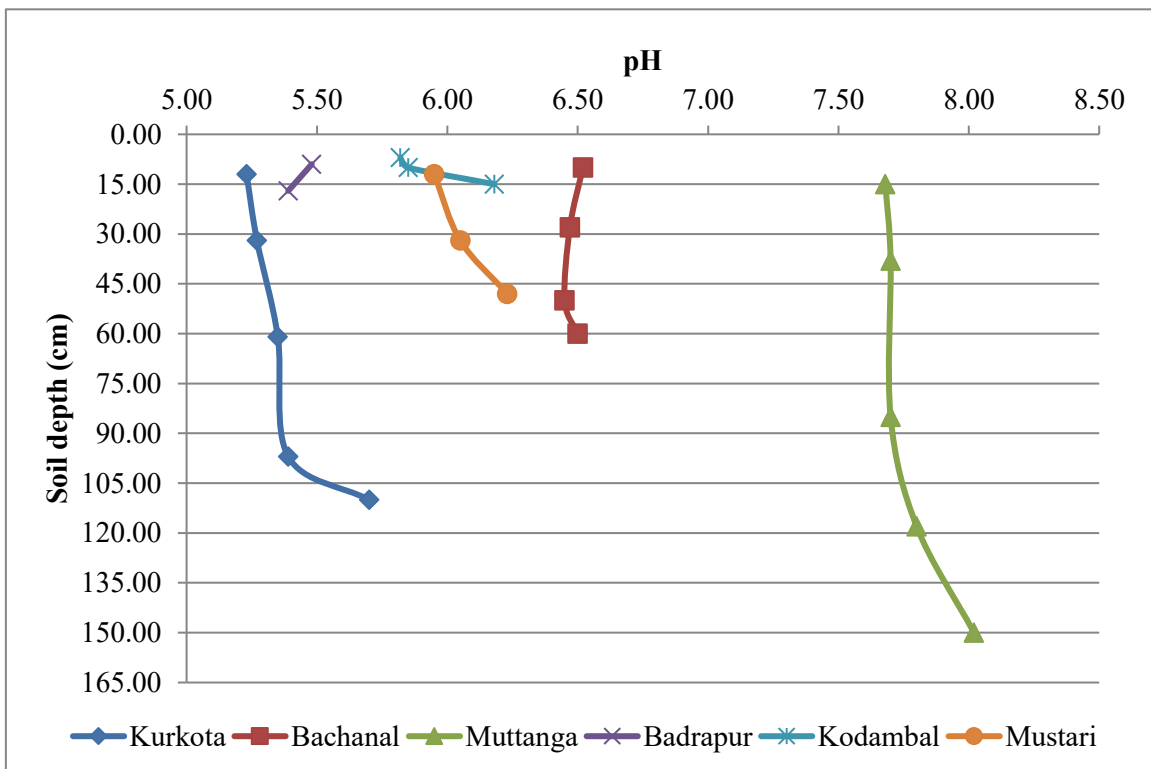


Fig. 21: Vertical distribution of pH in lateritic soils series

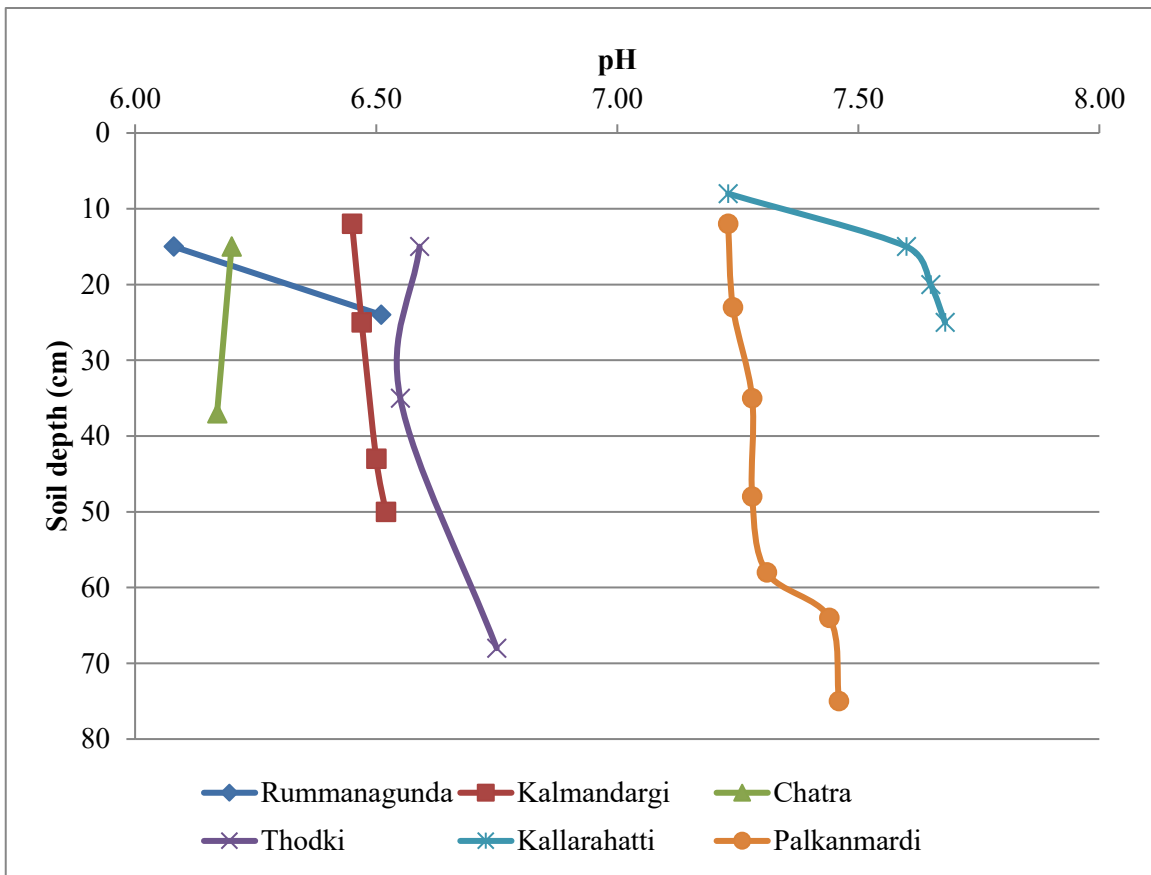


Fig. 22: Vertical distribution of pH in red soils series

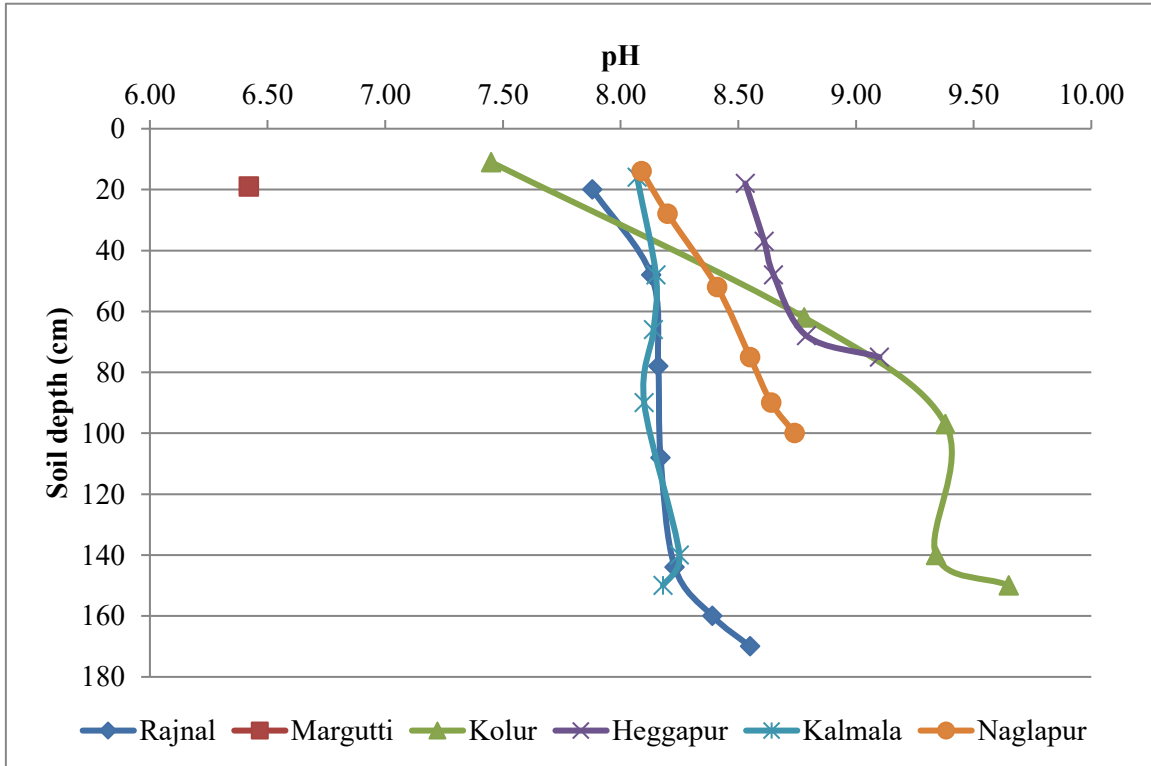


Fig. 23: Vertical distribution of pH in black soils series

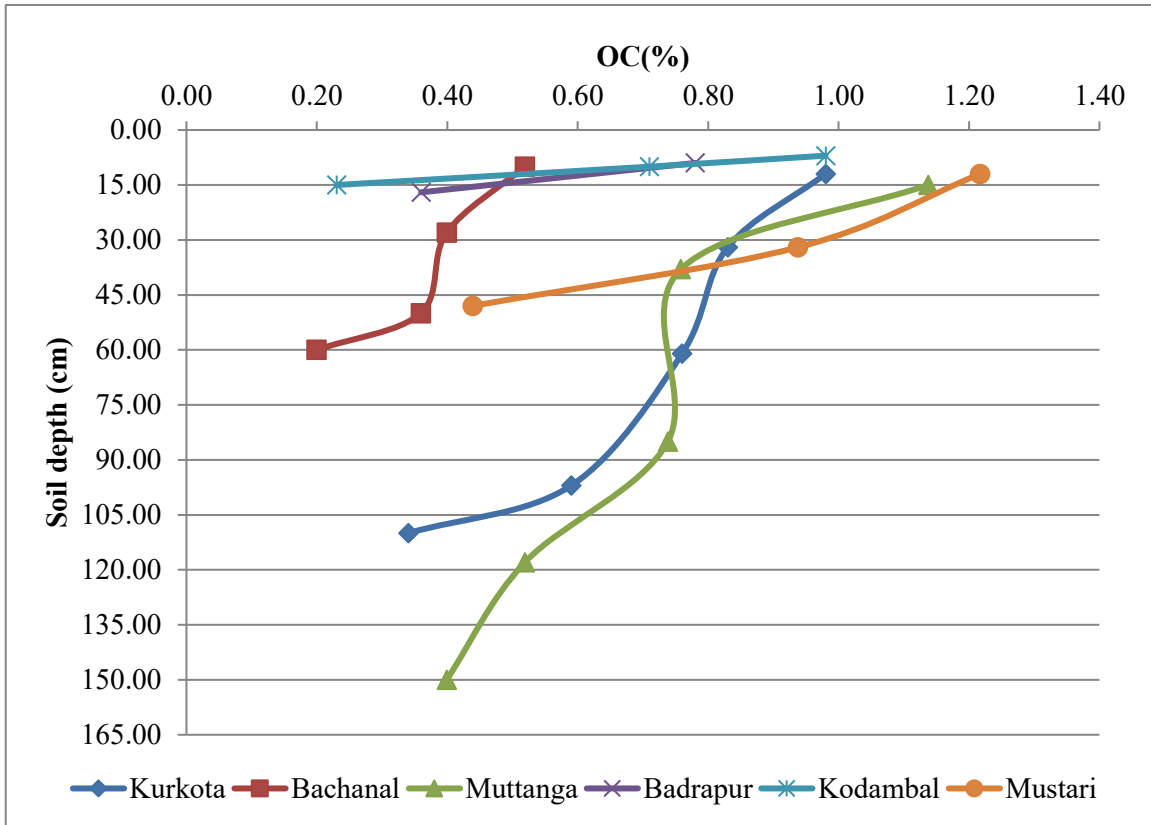


Fig. 24: Vertical distribution of organic carbon in lateritic soils series

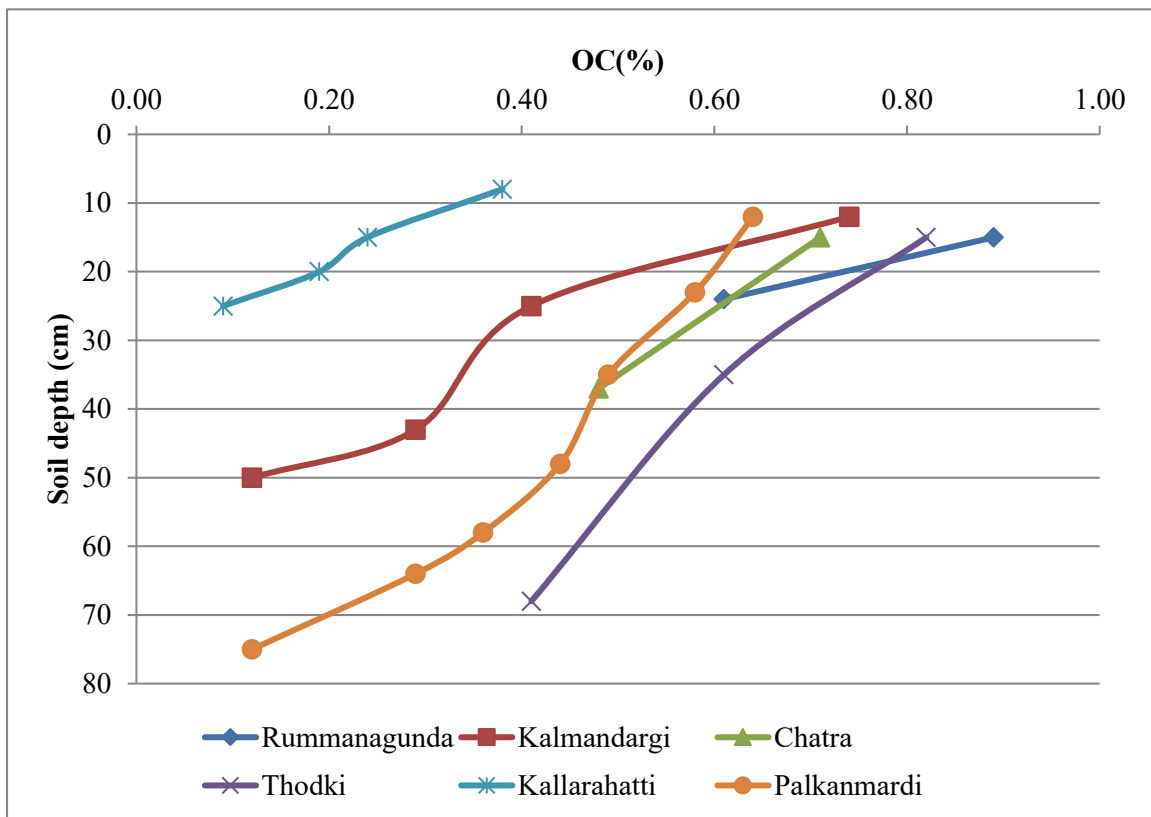


Fig. 25: Vertical distribution of organic carbon in red soils series

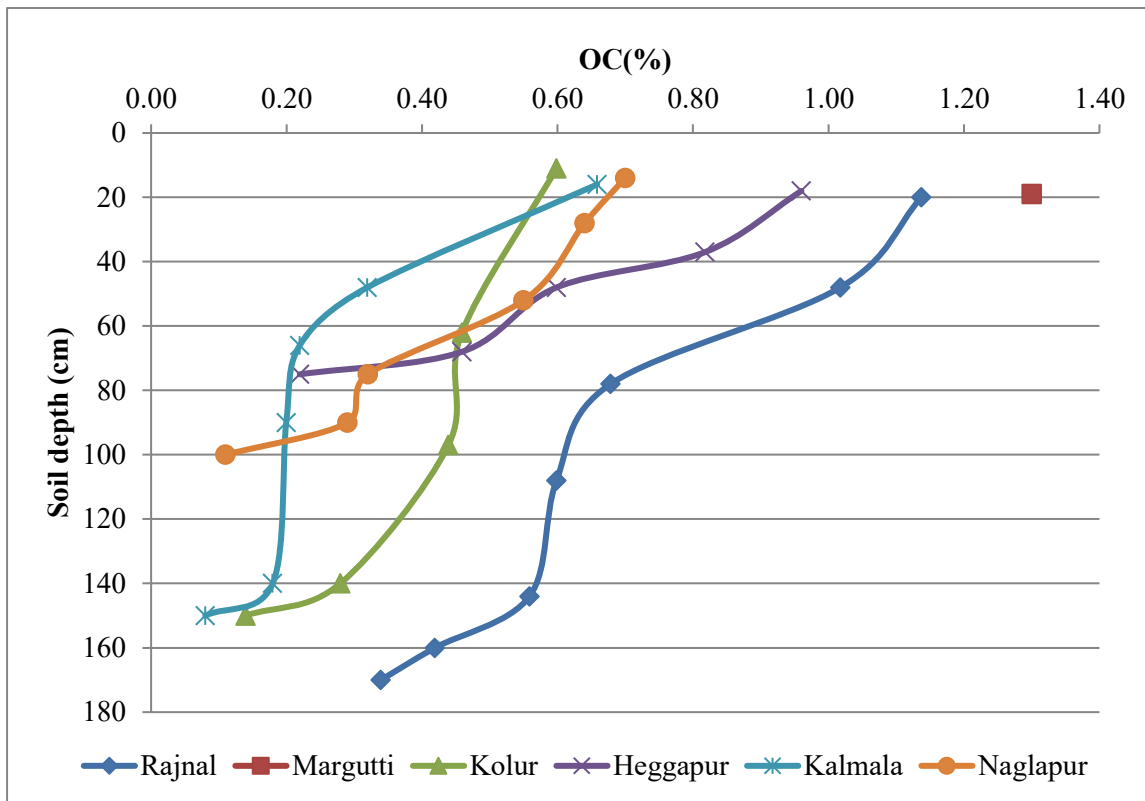


Fig. 26: Vertical distribution of organic carbon in black soils series

Table 2: Association of soil properties for Hydrological characteristics of lateritic, red and black soils

	TS	Silt	Clay	OC	pH
Lateritic soil					
FC	-.687**	-.800**	.916**	.290	.287
PWP	-.835**	-.723**	.974**	.101	.425*
AWC	-.343	-.709**	.630**	.454*	.050
Red soil					
FC	-.734**	.549**	.635**	.521*	-.528*
PWP	-.600**	.399	.558**	.492*	-.236
AWC	-.693**	.556**	.570**	.442*	-.647**
Black soil					
FC	-.852**	.387*	.896**	.035	-.018
PWP	-.841**	.353	.893**	.010	-.069
AWC	-.751**	.392*	.775**	.076	.076

Table 3: PTF for hydrological characteristics of lateritic, red and black soils

	SI No	Prediction variable	Predictor variables	Intercept	coefficient	F	R2	RMSE	ME
Lateritic	1	FC	Clay	10.154	0.402	69.587	0.823	1.00	0.850
			Clay OC	8.291	0.395 3.369	80.707	0.920	0.986	0.835
	2	PWP	Clay	2.950	0.269	238.987	0.941	0.267	0.243
			Clay OC	2.360	0.267 1.066	198.065	0.966	0.571	0.518
	3	AWC	Clay	5.931	0.128	9.636	0.579	0.993	0.875
			OC		2.302				
Red	1	FC	TS	54.310	-0.602	42.539	0.859	1.54	1.47
			OC		9.04				
	FC	TS	25.042	-0.348	39.36	0.901	1.23	0.98	
		OC		10.00					

			CLAY		0.485				
	2	PWP	TS	21.812	-0.217	13.177	0.653	1.24	0.88
			OC		3.862				
	3	AWC	pH	20.467	-2.915	24.768	0.780	1.01	0.98
					CLAY				
			AWC	pH	10.399	-2.064	28.860	0.869	1.28
			CLAY	0.524					
			OC	3.452					
Black	1	FC	Clay	21.908	0.406	129.127	0.854	1.562	1.47
					Clay				
			FC	OC	17.841	3.139	142.881	0.923	1.165
	2	PWP	Clay	8.936	0.272	134.933	0.860	1.17	0.92
					Clay				
			PWP	OC	6.601	1.802	115.569	0.917	0.88
	3	AWC	Clay	11.245	0.152	43.928	0.807	0.861	0.711
					OC				

The PTF equations developed for FC, PWP and AWC in lateritic soil are as follow.

$$FC=8.291+0.395**clay+3.369**OC$$

$$PWP=2.360+0.267**clay+1.066*OC$$

$$AWC=5.931+0.128**clay+2.302**OC$$

The predictions for FC, PWP and AWC from developed PTFs were satisfactory as both RMSE (0.986, 0.571 and 0.993) and ME (0.835, 0.518 and 0.875) values were low while R2 (0.920, 0.966 and 0.579) values were high respectively.

The PTF equations developed for FC, PWP and AWC in red soil are as follow.

$$FC=25.042-0.348TS+10OC+0.485clay$$

$$PWP=21.812-0.217TS+3.862OC$$

$$AWC=10.399-2.064+0.524**clay+3.452**OC$$

The predictions for FC, PWP and AWC from developed PTFs were satisfactory as both RMSE (1.23, 1.24 and 1.28) and ME (0.98, 0.88 and 1.18) values were low while R2 (0.901, 0.653 and 0.869) values were high respectively. The coefficient of determination for FC revealed that 90% variation in FC was explained by clay, organic carbon and sand together. However the PTF developed for FC indicated that the predicted FC was positively influenced by the predictors both clay and organic carbon while another predictor sand negatively influenced the predicted FC (Dharumarajan et al, 2019).

The PTF equations developed for FC, PWP and AWC in black soil are as follow.

$$FC=17.814+0.540**clay+3.139**OC$$

$$PWP=6.601+0.272**clay+1.802*OC$$

$$AWC=11.245+0.152*clay+1.339*OC$$

The predictions for FC, PWP and AWC from developed PTFs were satisfactory as both RMSE (1.165, 0.880 and 0.861) and ME (0.494, 0.678 and 0.711) values were low while R2 (0.923, 0.917 and 0.807) values were high respectively. The coefficient of determination for FC revealed that 92% variation was explained by the clay and organic carbon (Table 3).

Irrespective the soil types the PTFs developed for water retention parameters suggested the both clay and organic carbon was positively correlated while sand and pH was negatively correlated and the per cent increase in water retention parameters was more with respect to the unit rise organic carbon as compare to the unit rise in clay content and this could be attributed to the surface area of organic matter is four times more than that of clay and these results are line with Adhikary et al. (2008); Gunarathna et al. (2019) and Lipsius (2002)

Among the lateritic soils, the yield attributes like number of pods per plant, seed yield and stover yield witnessed by Bachanal series was the lowest (99, 965 Kg ha-1 and 3100 Kg ha-1) and it was followed by Badrapur series (108, 1048 Kg ha-1 and 3165 Kg ha-1), Kodambal series (111, 1076 Kg ha-1 and 3260 Kg ha-1), Kurkota series (112, 1088 Kg ha-1 and 3310 Kg ha-1), Mustari series (115, 1114 Kg ha-1 and 3364 Kg ha-1) and Muttanaga series (117, 1136 Kg ha-1 and 3431 Kg ha-1), respectively. Among the red soils, the yield attributes like number of pods per plant, seed yield and stover yield recorded by Kallarhatti series was the lowest (111, 1077 Kg ha-1 and 3353 Kg ha-1) and it was followed by Palkanamardi series (115, 1115 Kg ha-1 and 3367 Kg ha-1), Chatra series (116, 1125 Kg ha-1 and 3398 Kg ha-1), Kalamandargi series (118, 1149 Kg ha-1 and 3470 Kg ha-1), Rummanagunda series (112, 1179 Kg ha-1 and 3565 Kg ha-1) and Thodki series (128, 1246 Kg ha-1 and 3763 Kg

ha-1), respectively. Among the black soils, the yield attributes like number of pods per plant, seed yield and stover yield were registered by Naglapur series was the lowest (118,1145 Kg ha-1 and 3780 Kg ha-1) and it was followed by Kalmala series (120, 1168 Kg ha-1 and 3813 Kg ha-1), Heggapur series (124,1198 Kg ha-1 and 3852 Kg ha-1), Kolur series (128,1245 Kg ha-1 and 3869 Kg ha-1), Margutti series (134,1300 Kg ha-1 and 3959 Kg ha-1) and Rajnal series (139,1348 Kg ha-1 and 3996 Kg ha-1), respectively (Fig. 27).

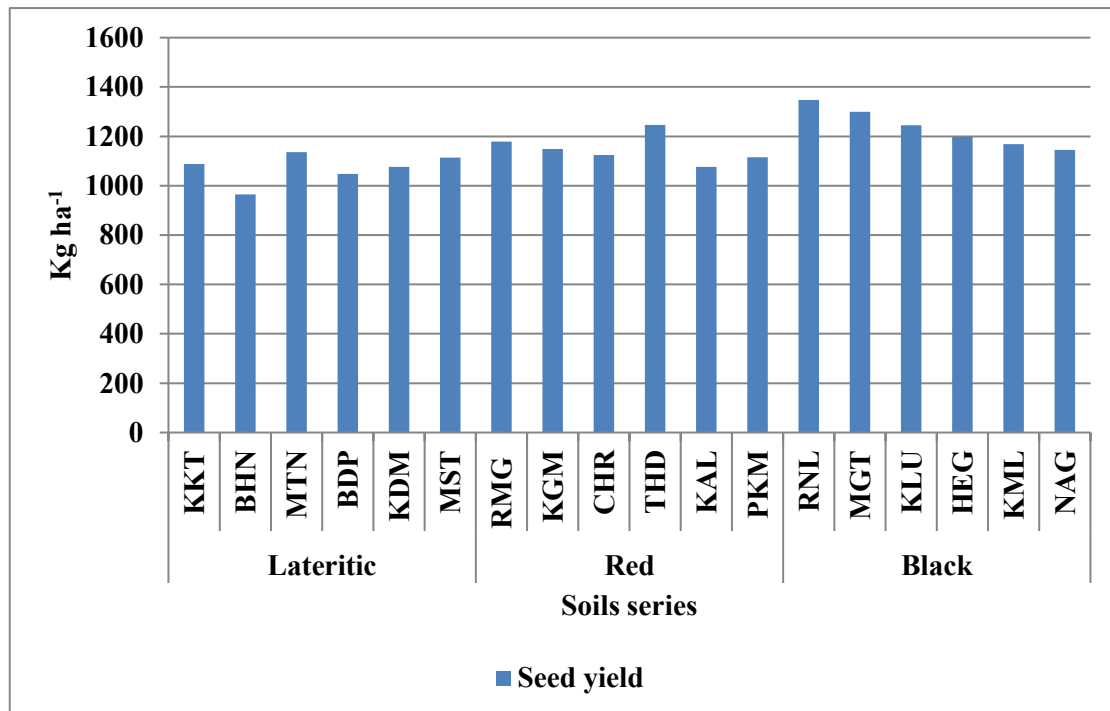


Fig. 27: Pigeon pea seed yield of soils series

Influence of soil properties on crop yield used to predict soil quality indicators from developed pedotransfer functions

The basic soil properties such as sand, silt, clay, organic carbon and pH were used as independent variables to develop PTFs for various soil quality indicators and in most of the PTFs developed for various soil quality indicators only clay and organic carbon were found to be significant independent variables and in addition to that both clay and organic carbon were strongly correlated with crop yield as compared to rest of the independent variables used in PTFs and thus simple regression equations were developed to find out the contribution of these basic soil properties to the crop yield and found that in both red and black soils both clay and organic carbon together contributed positively to the crop yield to the tune of 89.9 and 99.7 per cent respectively whereas in lateritic soils both sand and organic carbon together responsible for 97.6 per cent variation in crop yield and however sand contributed negatively while organic carbon contributed positively. Thus the basic soil properties used as independent variables to develop PTFs for various soil quality indicators in lateritic, red and black soil series were found to be appropriate. Yield (Lateritic) = $1763.117 - 14.414 * \text{sand} + 377.89 * \text{OC}$ DF=5, F = 27.677* R²=0.976 Yield (Red) = $593.756 + 14.310 * \text{clay} + 231.271 * \text{OC}$ DF=5, F = 13.373* R²=0.899 Yield (Black) = $544.117 + 12.192 * \text{clay} + 178.413 * \text{OC}$ DF=5, F = 255.466** R²=0.997 The regression equations developed for crop yield in different soil types showed that every one unit rise in both clay and organic carbon increased the yield by 14.310 and 231.271 units in red soils and 12.192 and 178.413 units, respectively in black soils where as in lateritic soils every one unit rise in both sand and organic carbon decreased and increased the yield by 14.414 and 377.890 units, respectively.

CONCLUSION

The pedotransfer functions provide more useful information in relation to soil attributes and or soil functions. Pedotransfer functions for FC, PWP and AWC showed that clay and organic carbon were the most important parameter for predicting the soil hydrological properties. As Clay and organic matter are the vital components of soil can be used as predictors in developing PTFs for the most relevant dynamic soil quality indicators that respond to land use and management as well as more expensive and laborious to determine. Developed PTFs were validated and found that RMSE was low and R² was more and thus these PTFs can be used to predict FC, PWP and AWC of red, lateritic and black soils from the minimum soil data on clay and organic carbon contents. The linear regressions for crop yield in lateritic, red and black soil series indicated that the basic soil properties viz. clay and organic carbon together contributed to the crop yield to the tune of 89.9 and 99.7 per cent in red and black soils, respectively whereas in lateritic soils sand and organic carbon together caused the 97.6 per cent variation in crop yield.

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