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RESEARCH PAPER

Genesis, characterization and classification of some soils of semi arid tropical region of Tamil Nadu

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Abstract : The study was carried out in the three new research stations of TNAU with varied soil types with an objective to characterize and classify the some red, red laterite and black soils in semi arid tropical region of Tamil Nadu in relation to pedogenesis. The red soils were developed on weathered granite-gneiss parent material at gently sloping lands. The red laterite soils were developed on weathered granite-gneiss over laterite parent material at gently sloping lands to moderately steep sloping lands whereas the black soils were formed at nearly level or plain topography on granitic gneiss parent material mixed with calcareous murram. The red soils and red laterite soils are relatively more weathered than black soils. The red and red laterite soil colour varying from dark red to light reddish brown and dark reddish brown to light reddish brown, the black soils colour varying from very dark gray to dark grayish brown under dry and moist conditions, respectively. The soils are shallow (27 cm) to very deep (>170 cm). The surface horizons exhibited mostly medium fine granular to weak sub angular blocky structures whereas in subsurface horizons shown medium fine granular to medium strong sub angular blocky structures in red and red laterite soil pedons. The black soil pedons had coarse strong angular blocky structure. The textural class of fine earth fraction was clayey (52.9 to 64.3%) in black soils, whereas in red and red laterite soil pedons it was coarse textured gravelly sandy loam and sandy clay loam in the surface horizons and sandy loam, sandy clay loam and sandy clay in sub-surface horizons (54.5 to 73.7% sand and 16.5 to 40.9% clay). The silt content in most of the pedons showed an irregular trend with soil depth. Bulk density increased with increasing depth. The moisture retention at field capacity (33 kpa), permanent wilting point (1500 kpa) and available water capacity were high in black soils. Based on the morphology, physical, physico-chemical and chemical properties, the soils were classified as per USDA soil taxonomy into four orders *viz.*, vertisols, alfisols, entisols and inceptisols.

Key Words : Genesis, Characterization, Classification, Red soil, Red laterite, Black soils, Semi arid tropical region

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INTRODUCTION

Tamil Nadu being under a semi-arid tropical monsoon climate has a number of soil types which are found in all types of climates, occupying for 4.0 per cent

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(12.99 m.ha) of the country's geographical area. Hence, their management varies from place to place besides the crop variation effect. Maintaining soil in the state of high productivity on sustainable basis is important for meeting basic needs of the people. Systematic study of soils is important for scientific utilization of these soil and land resources for sustainable agriculture production. Soil characterization determines the soils individual inherent potentials and constraints for crop production besides giving detailed information about the different soil properties. Characterization and systematic classification of dominant soil groups, is an essential tool and a pre requisite for soil fertility evaluation and efficient soil-fertilizer-water management practices and thus, crop management.

Soil characterization and classification studies provide information on the choice of crops to be grown on best suited soil unit for maximizing crop production per unit of land. Soil resource information plays a key role in the management of natural resources and more specifically in the agriculture sector. Management of soil resources on scientific principle is essential to maintain the present level of soil productivity and to prevent soil degradation.Therefore, in recent years increasing emphasis is laid on characterization of soils and developing rational and scientific criteria for land evaluation and interpretation of soils for multifarious land uses. This calls for comprehensive knowledge on soil resources in terms of types of soil, their spatial extent, physical and chemical properties and limitations or capabilities. Remote sensing technology emerged as a powerful tool for studying soil resources because it enables to study the soils in spatial domain in time and cost effective manner (Sharma, 2004).

Keeping this in view, due to diversified nature, the three research stations of Tamil Nadu Agriculrutal University (TNAU) with varied soil types *viz.*, Maize Research Station (MRS), Vagarai of Dindigul district, Cotton Research Station (CRS), Veppanthatai of Perambalur district and Dryland Agricultural Research Station (DARS), Chettinad of Sivagangai district of Tamil Nadu were selected for developing the strong soil resource database for proper appraisal of their productivity, potential and their rational use. This study is an embodiment with the objective to characterize and classify the soils of TNAU New Research Station farms of Vagarai, Vepanthattai and Chettinad.

Material and Methods

Location and brief description of the study area:

The Maize Research Station is extending over an area of 22.94 acres and boundary is surrounded between 10.570' N latitude and 77.56' E longitudes and is situated at an altitude of 254.45 m above mean sea level (Table 1). The physiography of study area was nearly level to gently sloppy in nature. The Cotton Research Station is extending over an area of 55.4 acres bounded in between 11°.32656' N latitude and 78°.832397'E longitudes and situated at an altitude of 147 m above mean sea level. Physiographically the land is characterized by flat terrain level to nearly level.

The Dryland Agricultural Research Station is extending over an area of 317 acre and boundary is surrounded between 10.166 to 10.179 N latitude and 78.785 to 78.805 E longitudes and is situated at an altitude of 108 m above mean sea level. Nearly three fourth of the land is under Pedi plains and characterized by flat terrain nearly level to gently slope in nature. The soil moisture control section is dry for more than 90 cumulative days or 45 consecutive days in the months of summer solstice. The soil moisture and soil temperature regimes of the study area are Ustic and Iso-hyperthermic, respectively. The natural vegetation existing in the study area are grasses, shrubs, thorny bushes such as *Cynodon dactylon, Cyprus rotundus*, *Butea frondosa*, *Dalbergia latifolia, Azadirachta indica, Tectona grandis, Terminalia tomertose* and *Acacia* spp. *Prosopis juliflora, Cacia* sp, broad leaf weeds such as *Selotia, Parthenium, Eucalyptus, Euforbia* sps., etc. The principal crops cultivated and research focused in this station are cotton, redgram and onion.

Collection and processing of soil samples:

Based on the morphological characteristics and physiography, geo-referenced three pedons at Maize Research Station, two pedons at Cotton Research Station and eight pedons at Dryland Agricultural Research Station were selected. Horizon wise soil samples were collected from the representative thirteen pedons for laboratory analysis.

A composite sample of about 1kg was taken through mixing of representative soil samples. The soil samples were air-dried in shade, processed and screened through a 2 mm sieve. Particles greater than 2 mm were considered as gravel. After sieving, all the samples were packed in the polythene bags for determination of physical, and physico-chemical and chemical properties. The standard procedures used for soils analyses are presented in Table 1.

Results and Discussion

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Morphological properties:

The details of the morphological properties of the soils are presented in Table 2. The study area of the three research stations was under cultivation except E block of DARS, Chettinad. The surface horizon was designated as 'Ap' horizon at all the location because of the ploughed and / or disturbed condition due to cultivation except pedons 10, 11, 12 and 13 where the soil was not under cultivation. Similar observation was made by Rajeshwar *et al.* (2009) to represent ploughed condition of the soils. The surface horizon was characterized as 'ochric' epipedon because of less organic matter content and light colour as per the requirements specified by Soil Survey Staff (1999). Similar observation was made by Balapande *et al.* (2007).The 'B' horizon of black soils (pedons 4 and 5) of CRS, Veppanthattai exhibited prominent, well-formed distinct slickensides. Hence the symbol 'ss' (sub-ordinate distinction) was suffixed to the master horizon symbol 'B'. Similar type of designation was represented by Hazare and Mandal (2003).

Argillic horizon was developed in red soils (pedons 1 and 3) and red laterite soils (pedon 6, 7, 8, 9, 11, 12 and 13) in the subsurface layers which might be due to illuviation of clay from the surface horizon. Clay orientation had taken place in the 'B' horizon. That resulted in the formation of clay cutans or clay skins. The broken to common and moderately thick argillans were noticed in between 11 and 40 cm depth in the red soils profiles 1 and 3, whereas in the red laterite soils (pedons 6, 7, 8, 9, 11, 12 and 13) patchy, thin argillans were recorded between 25 and 97 cm depth. Similar results were reported by Nagassa and Gebrekidan, (2003) and by Singh and Agarwal (2005).

The boundary between the sub-horizons of 'Bss' horizon in black soil pedons 4 and 5 was described as diffuse because of the presence slickensides and the clay content was high enough for clay textural class. In the

Table 1: Standard procedures used for soil analysis

Sr. No.	Analytical parameter	Method	Author (s)
	Morphological properties of soil		
	Soil colour	Munsell soil-colour charts with genuine Munsell colour chips of hue, value and chroma (Revised 2009-10)	(Soil Survey Staff, 1951)
	Physical properties of soil		
1.	Mechanical analysis	International pipette method	Piper (1966)
2.	Moisture retention at 33 and 1500 kPa	Pressure plate method	Richards (1954)
3.	Gravel	Gravimetry	Govindarajan and Koppar (1975)
4.	COLE (Co-efficient of linear extensibility)	Soil survey laboratory methods manual	Soil Survey Staff (2010)
5.	Water holding capacity and volume expansion	Keen Raczkowski's box method	Sankaram (1966).
6.	Physical constants	Core sampler method	Gupta and Dakshinamurthi (1980)
	Physico-chemical properties		
7.	Soil reaction (pH)	Potentiometry (1:2.5 Soil : water)	Jackson (1973)
8.	Electrical conductivity (EC)	Conductometry (1 : 2.5 soil : water)	Jackson (1973)
9.	Organic carbon	Chromic acid wet digestion	Walkley and Black (1934)
10.	Free calcium carbonate	Rapid titration method	Piper (1966)
11.	Cation exchange capacity (CEC)	Neutral Normal Ammonium acetate method	Schollenberger and Dreibelbis (1930)
12.	Exchangeable calcium and magnesium	Versenate titration method	Jackson (1973)
13.	Exchangeable sodium	Flame photometry	Stanford and English (1949)
14.	Exchangeable potassium	Flame photometry	Stanford and English (1949)

Table 2 : Morphological characteristics of pedons of the research stations

Pedon	Horizon	Depth (cm)	Colour		Texture	Structure	Consistency			Effervescence	Pores	Roots	Boundary	Cutans	Other features
			Dry	Moist			Dry	Moist	Wet						
MRS, Vagarai															
Pedon 1: Loamy-Skeletal, Mixed, Isohyperthermic, Non-calcareous, Lithic Haplustalfs															
	Ap	0-11	5YR5/4	5YR5/3	scl	m1gr	sh	fr	ss	-	f f	c f	cs	-	
	Bt1	11- 23	5YR5/6	5YR5/4	scl	m1sbk	sh	fi	ss and sp	m	f f	f f	cs	T tn p	Argillic horizon
	Bt2	23-40	2.5YR4/4	2.5YR3/4	scl	m1sbk	sh	fi	ss and sp	m	f f	f f	cs	T tn p	
	C	40-47	2.5YR4/4	2.5YR3/4	gsl	m1sbk	l	fr	so	m	f f	f f	cs	-	
Pedon 2: Loamy-Skeletal, Mixed, Isohyperthermic, Calcareous, Calcic Haplustepts															
	AP	0-20	10YR3/3	10YR3/2	c	m3sbk	vh	fi	s and p	m	f f	f f	cs	-	Abundant $CaCO_3$
	A1	20-31	5YR5/4	5YR4/4	scl	m2sbk	h	fr	ss	m	f f	f f	cs	-	concretions at
	Bwk	31-50	2.5YR3/4	2.5YR3/3	scl	m3abk	h	fi	ss and sp	ms	f f	f f	cs	T tn p	lower depth
	Ck	50-60	5YR5/4	5YR4/4	gscl	m2sbk	l	fr	so	s	f f	f f	cw	-	(50cm+)
Pedon 3: Loamy-Skeletal, Mixed, Isohyperthermic, Non-calcareous, Lithic Haplustalfs															
	AP	0-10	2.5YR5/8	2.5YR4/8	scl	m1gr	sh	fr	ss	-	f f	c f	cs	-	
	Bt	10 -28	2.5YR3/4	2.5YR2.5/4	gscl	m1sbk	sh	fi	ss and sp	m	f f	f f	cs	-	Argillic horizon
	C	28-40	2.5YR4/4	2.5YR3/4	gsl	m1sbk	l	fr	so	m	f f	f f	cw	T tn p	
CRS,Veppanthattai															
Pedon 4: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert															
	Ap	0-31	10 YR4/1	10YR3/1	c	c3abk	h	fi	vs andvp	s	f f	ff	cs	-	Gilgai relief
	Bss1	31-73	10 YR3/1	10YR3/1	c	c3abk	vh	fi	vs and vp	ms	f f	ff	cd	-	surface cracks (5-8
	Bss2	73-101	10 YR3/1	10YR3/1	c	c3abk	vh	fi	vs and vp	ms	f f	ff	cd	-	cm wide) and
	Bss3	101-134	10 YR3/1	10YR3/1	c	c3abk	vh	fi	vs and vp	s	f f	ff	cd	-	subsurface
	Ck	134-170	10 YR4/2	10YR4/1	c	c3abk	vh	fi	vs and vp	vs	f f	ff	cs	-	cracks(4-6cm)
															slickensides conca
Pedon 5: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert															
	Ap	0-25	10 YR4/1	10YR3/1	c	c3abk	vh	fi	vs and vp	s	f f	ff	cs	-	Gilgai relief
	Bss1	25-71	10 YR3/1	10YR3/1	c	c3abk	vh	fi	vs and vp	ms	f f	ff	cs	-	surface cracks
	Bss1	71-100	10 YR3/1	10YR3/1	c	c3abk	vh	fi	vs and vp	ms	f f	ff	cs	-	(5-8 cm wide) and
	Bss2	100-125	10 YR3/1	10YR3/1	c	c3abk	vh	fi	vs and vp	s	f f	ff	cd	-	subsurface cracks
	Ck	125-155	10 YR4/2	10YR4/1	c	c3abk	vh	fi	vs and vp	vs	f f	ff	cs	-	(4-6cm)
															slickensides conca
DARS, Chettinad															
Pedon 6: Loamy-Skeletal,Kaolinitic, Isohyperthermic, Non-calcareous, Ultic Haplustalfs															
	Ap	0-14	5YR6/6	5YR4/6	sl	f1gr	sh	fi	ss	-	f f	c f	cs	-	
	A	14-25	2.5YR4/6	2.5YR3/6	scl	m1 sbk	h	fi	ss and sp	-	f f	f f	cs	-	
	Bt1	25-39	2.5YR4/6	2.5YR3/6	scl	m2sbk	h	fi	ss and sp	-	f f	f f	cs	T tn p	
	Bt2	39-63	2.5YR4/6	2.5YR4/6	scl	m2sbk	h	fi	ss and sp	-	f f	f f	cs	T tn p	
	Bt3	63-97	2.5YR4/8	2.5YR4/6	gscl	m2sbk	h	fi	ss and sp	-	f f	f f	cs	T tn p	Argillic horizon
	Bt4	97-143	2.5YR5/6	2.5YR4/6	gscl	m2sbk	h	fi	ss and sp	-	f f	f f	cs	-	
	C	143-150	5YR5/4	5YR4/4	gscl	m2sbk	h	fi	ss	-	f f	f f	cs	-	

Table 2: Contd…………

Table 2: Contd…….

Pedon 7: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Noncalcareous, Ultic Haplustalfs														
Ap	0-20	5YR5/6	5YR4/6	sl	f1gr	l	fr	ss	-	f f	f f	cs	-	
Bt	20-51	2.5YR5/6	2.5YR4/6	gscl	f2gr	sh	fr	ss	-	f f	c f	cs	-	Argillic horizon
C	51-93	2.5YR5/6	2.5YR4/6	gscl	m2gr	sh	fr	so	m	f f	f f	cs	T tn p	
Pedon 8: Fine Loamy, Kaolinitic, Isohyperthermic, Non-calcareous Typic Rhodustalfs														
Ap	0-25	2.5YR4/6	2.5YR3/6	scl	m 3gr	sh	fi	ss and sp	-	f f	cf	cs	-	
Bt1	25-32	2.5YR4/6	2.5YR3/6	scl	m1 sbk	h	fi	ss and sp	-	f f	ff	cs	-	
Bt2	32-56	2.5YR3/6	2.5YR3/4	sc	m2sbk	h	fi	ss and sp	-	f f	fc	cs	T tn p	Argillic horizon
Bt3	56-82	2.5YR4/6	2.5YR3/6	sc	m2sbk	h	fi	ss and sp	-	f f	fc	cs	T tn p	
C	82-105	2.5YR4/6	2.5YR3/6	gscl	m2sbk	h	fi	ss	-	f f	ff	cs	-	
Pedon 9: Fine Loamy, Kaolinitic, Isohyperthermic, Non-calcareous, Typic Rhodustalfs														
Ap	0-10	2.5YR4/8	2.5YR4/6	sl	m 1gr	sh	fr	ss and sp	-	f f	ff	cs	-	
Bt1	10-31	2.5YR4/6	2.5YR3/6	scl	m2sbk	h	fi	ss and sp	m	f f	cf	cs	-	
Bt2	31-64	2.5YR4/6	2.5YR3/6	scl	m2sbk	h	fi	ss and sp	m	f f	f m	cs	T tn p	
Bt3	64-98	2.5YR4/6	2.5YR3/6	gsc	m2sbk	h	fi	ss and sp	m	f f	f f	cs	T tn p	Argillic horizon
C	98-123	2.5YR5/6	2.5YR4/6	gscl	m2sbk	sh	fi	ss and sp	m	f f	f f	cs	--	
Pedon 10: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Ustorthents														
A	0-15	5YR5/6	5YR4/6	gsl	m 1gr	sh	fr	ss	-	f f	f f	cs	-	
C	15-27	5YR5/6	5YR4/6	gsl	m1sbk	sh	fr	ss	-	f f	f f	cd	-	-
Pedon 11: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs														
A	0-18	5YR6/4	5YR6/3	sl	f1gr	Sh	fr	ss	-	f f	f m	cs	-	
Bt1	18-44	5YR5/8	5YR4/8	gscl	m1 sbk	h	fr	ss and sp	-	f f	f m	cs	T tn p	
Bt2	44-80	2.5YR5/6	2.5YR4/6	gscl	m2 sbk	h	fr	ss and sp	-	f f	f f	cs	T tn p	Argillic horizon
C	80-110	2.5YR6/8	2.5YR5/8	gscl	m1 sbk	h	fr	ss	-	f f	f f	cs	-	
Pedon 12: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs														
A	0-10	5YR6/4	5YR6/3	sl	m1 gr	sh	fr	ss and sp	m	f f	mf	cs	-	
Bt1	10-41	5YR5/8	5YR4/8	gscl	m2 sbk	h	fi	ss and sp	m	f f	c f	cs	T tn p	Argillic horizon
BC	41-67	2.5YR5/8	2.5YR4/8	gscl	m2 sbk	h	fr	ss	m	f f	f f	cs	-	
C	67+	Weathered granite-gneiss over lateritic parent material												
Pedon 13: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs														
A	0-10	5YR 6/8	5YR6/6	sl	m2gr	sh	fr	ss	-	f f	mf	cs	-	
Bt1	10-32	2.5YR 6/8	2.5YR6/6	scl	m2 sbk	h	fi	ss and sp	m	f f	c f	cs	-	
Bt2	32-80	2.5YR4/6	2.5YR3/6	gscl	m2 sbk	h	fi	ss and sp	m	f f	f f	cs	T tn p	Argillic horizon
C	80-110	2.5YR4/6	2.5YR3/6	gscl	m2 sbk	sh	fi	ss	m	f f	f f	cs	-	
										-	-			

Soil texture	:	ls – Loamy sand ,sl- Sandy loam, scl –Sandy clay loam, sc- Sandy clay, cl- Clay loam and c- Clay
Soil structure	:	c-coarse, m- medium , f- fine , 1- weak, 2- moderate,3 - strong, gr- granular ,abk- angular blocky, sbk- sub-angular blocky
Soil consistence	:	l- loose, sh- slightly hard, h- hard ,vh- very hard ,vfr-very friable ,fr- friable , fi- firm, vf- very firm, so – non-sticky, ss –slightly sticky, s- sticky,vs- very sticky, po- non plastic, ps – slightly plastic, p-plastic, vp- very plastic
Pores	:	Size f-fine, m-medium, c-coarse; Quantity f-few, c-common, m-many
Roots	:	Size f-fine, m-medium, c-coarse; Quantity f-few, c-common, m-many
Effervescence	:	m-mild ,ms-moderately strong s-strong vs-very strong
Boundary	:	c- clear , d- diffuse, s- smooth ,w- wavy, g- gradual, a- abrupt
Cutans	:	T-Argillans;tn-thin; p-patchy

red and red laterite soil pedons, as there was sufficient clay illuviation in argillic horizon (Bt) from the overlying horizons, the texture had become finer. Hence, the boundary between Bt horizon and overlying horizon was clear. Similar observation was made by Thangasamy *et al.* (2005).

The soils at MRS, Vagarai were shallow to moderate (40-60 cm) in depth, very deep (>150 cm) at CRS Veppanthattai while the red laterite soils of DARS, Chettinad were shallow to moderately deep and deep (27 cm to 150 cm). Soil depth was shallow in moderate steep slope whereas deep soils were found in nearly level to very gently sloping plain. The same types of observations were reported by Meena *et al*. (2009). The variation of depth in relation to physiography, mainly because of non-availability of adequate amount of water for prolonged period on upland soils associated with removal of finer particles and their deposition at lower pediplain have resulted in shallow soils in uplands and deeper soils in lowland physiographic units. The results obtained in the present study are in agreement with the findings of Ramprakash and Seshagiri Rao (2002).

The black soils pedons (4 and 5) had colour varying from very dark gray to dark grayish brown under dry and moist condition in different horizons with Munsell colour notation of 10YR 4/2 and 10YR 3/1, respectively due to parent material, topography, high clay content, clay-humus complex, smectite type of clay, moisture etc., were the factors responsible for the dark colour of the soils. The dark brown to very dark brown (10YR hues) colour was due to the moist conditions prevailing for longer period favouring reduction under the influence of impeded internal drainage conditions (Maji *et al.,* 2005). The colour of the red soils (pedons 1, 2 and 3) was varying from dark reddish brown (2.5YR 3/4) to yellowish red (5YR5/6) under dry condition and dark reddish brown (2.5YR2.5/4) to reddish brown (5YR5/4) under moist condition might be due to release of iron, its degree of oxidation, hydration might have given the soil brownish to reddish / red colour. The dark reddish brown colour was due to better drainage conditions in higher slopes. The same types of observations were reported by Thangasamy *et al.* (2005).

The red laterite soils (pedon 6, 7 8, 9, 10, 11, 12 and 13), colour varies from dark red (2.5 YR3/6) to light reddish brown (6YR6/4) under dry condition and dark reddish brown (2.5 YR3/4) to light reddish brown (6YR6/3) under moist condition in different horizons and locations which are indicative of release of oxides of iron during the process of weathering and different stages of hydration. The intensity of the color increased in sub surface horizons. The differences in colour might be due to various pedological process and also variation in organic matter content, quality of iron, diffusion of iron oxides in mineral matters of soil, the degree of oxidation and imperfect hydration as reported by Yadav *et al.* (1977) and Gangopadhyay *et al.* (1990).

Red soils (pedons 1 and 3) and red laterite soils (pedons 6, 7, 8, 9, 10, 11, 12, and 13) were developed weak pedality with granular structure in the surface horizons and sub-angular blocky peds in sub-surface layers. The surface horizons were generally granular type because of organic matter and inter-cultivation operations. The strength of the peds was weak to moderate whereas, the size of the peds was very fine to medium. This type of weak pedality was attributed to less clay content, low CEC and dominance of illite / kaolinite type of clay. These structural descriptions observed in red soil profiles are in agreement with those reported by Nagassa and Gebrekidan (2003) and Patil and Prasad (2004).

The pedality of black soils was more strongly developed because of the high clay content, CEC, PBS, and dominance of montmorillonite type of clay. The surface horizons and subsurface horizons had blocky structure (either sub-angular or angular) and the peds were medium to coarse in size with strong grade (strength). Stronger pedality of soils at lower topographic positions might be due to finer fractions (Shyampura *et al.,* 1994). The pedons 2 showed the medium strong subangular blocky structure, the transported black soils over native subsurface soils have subangular blocky structure might be due to presence of high $CaCO_3$ in transported black soils which may leads the flocculation of soil particles due to leaching. In pedon 2 highly localized $CaCO_3$ was observed at lower depth of the profile.

The texture of red and associated soils and black soils was markedly varying. The texture of the red soils (pedon 1 and 3) and red laterite soils (pedon 6, 7, 8, 9, 10, 11, 12 and 13) was widely ranging from coarse (sandy loam) to medium texture (sandy clay loam) in different horizons. As the red soils were derived from acidic coarse to medium grained granite- gneissic parent material, the red soils were exhibiting these textural classes. Singh and Agarwal (2005) reported similar textural classes in

Table 3 : Physical characteristics of pedons of the research stations

Pedon	Horizon	Depth (cm)	Gravel (%)	Particle size distribution* (%)					B.D (Mg m^{-3})	Pore space (%)	Water retention (kg kg^{-1})		AWC (%)	W.H.C (%)	Volume expansion (%)	COLE
				Coarse sand	Fine sand	Total sand	Silt	Clay			33 kpa	1500 kpa				
MRS, Vagarai																
Pedon 1: Loamy-Skeletal Mixed Isohyperthermic Non-calcareous Lithic Haplustalfs																
	Ap	0-11	25.0	41.3	22.0	63.3	13.8	22.9	1.43	42.1	17.8	7.1	10.7	33.2	3.70	-
	Bt1	11- 23	20.3	38.5	26.1	64.6	12.0	23.4	1.44	43.4	18.0	6.9	11.1	35.2	4.35	-
	Bt2	23-40	38.8	43.3	14.5	59.8	12.5	27.7	1.45	43.7	18.3	7.0	11.3	35.5	4.90	-
	C	40-47	62.2	52.4	13.2	65.6	17	17.4	1.48	40.0	15.6	8.1	7.5	27.5	3.82	-
Pedon 2: Loamy-Skeletal Mixed Isohyperthermic Calcareous Calcic Haplustepts																
	AP	0-20	11.3	19.8	16.9	36.7	17.5	45.8	1.47	37.4	32.4	15.1	17.3	43.8	21.70	-
	A1	20-31	19.3	37.9	18.0	55.9	19.4	24.7	1.45	41.8	23.2	9.9	13.3	34.5	5.10	-
	Bwk	31-50	13.0	38.7	15.8	54.5	18.3	27.2	1.46	43.6	24.6	10.9	13.7	35.9	5.22	-
	Ck	50-60	73.7	42.5	13.1	55.6	15.5	28.9	1.46	40.9	26.8	13.3	13.5	28.3	4.75	-
Pedon 3: Loamy-Skeletal, Mixed, Isohyperthermic, Non-calcareous, Lithic Haplustalfs																
	AP	0-10	26.5	42.3	21.5	63.8	14.0	22.2	1.45	43.6	20.9	9.8	11.1	32.6	3.61	-
	Bt	10 -28	38.4	43.1	16.4	59.5	15.2	25.3	1.46	43.2	20.3	9.2	11.3	36.5	4.55	-
	C	28-40	60.0	53.8	12.3	66.1	17.4	16.5	1.47	42.8	15.4	7.6	7.8	23.8	3.90	-
CRS,Veppanthattai																
Pedon 4: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert																
	Ap	0-31	8.8	21.3	8.8	30.1	17.0	52.9	1.49	35.3	48.4	30.6	17.8	52.2	23.10	0.13
	Bss1	31-73	7.2	19.5	9.8	29.3	15.5	55.2	1.50	35.2	56.5	37.4	19.1	54.7	26.24	0.14
	Bss2	73-101	6.1	15.5	9.1	24.6	16.8	58.6	1.53	31.3	60.9	41.1	19.8	56.0	27.13	0.16
	Bss3	101-134	5.7	14.9	6.9	21.8	19.3	58.9	1.55	30.9	57.6	36.6	21.0	56.8	29.14	0.17
	Ck	134-170	7.1	15.7	6.4	21.1	19.5	59.4	1.56	32.8	60.0	37.9	22.1	58.4	29.93	0.19
Pedon 5: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert																
	Ap	0-25	9.1	20.9	8.3	29.2	16.0	54.8	1.53	36.5	46.9	28.2	18.7	53.2	23.40	0.14
	Bss1	25-71	7.5	17.5	8.9	26.4	18.0	55.6	1.54	34.7	55.7	34.3	21.4	56.2	24.36	0.16
	Bss1	71-100	6.4	15.4	8.4	23.8	19.0	57.2	1.54	33.5	55.6	33.8	21.8	59.2	28.18	0.18
	Bss2	100-125	4.9	13.6	6.1	20.7	15.0	64.3	1.56	30.4	61.5	38.5	23.0	61.5	30.41	0.20
	Ck	125-155	7.3	15.9	6.5	22.4	20.0	57.6	1.57	34.4	58.8	35.9	22.9	57.2	29.22	0.19
DARS, Chettinad																
Pedon 6: Loamy-Skeletal,Kaolinitic, Isohyperthermic, Non -calcareous, Ultic Haplustalfs																
	Ap	0-14	25.6	52.9	17.8	71.7	7.3	20.5	1.30	47.5	11.8	6.0	5.8	21.5	3.07	-
	A	14-25	17.1	51.5	16.9	68.4	9.5	22.1	1.30	44.6	12.4	6.1	6.3	22.7	3.17	-
	Bt1	25-39	19.0	53.3	14.4	67.7	6.9	25.4	1.32	43.8	16.3	7.2	9.1	23.5	3.30	-
	Bt2	39-63	32.0	52.1	15.5	67.0	6.5	26.5	1.34	43.5	16.8	7.7	9.1	23.8	3.53	-
	Bt3	63-97	79.5	48.4	15.7	64.1	8.0	27.9	1.37	42.6	24.6	13.2	11.4	24.4	3.55	-
	Bt4	97-143	74.1	49.3	14.6	63.9	6.1	30.0	1.38	38.8	25.7	14.1	11.6	24.4	3.56	-
	C	143-150	54.4	51.2	11.4	63.6	10.0	26.4	1.38	38.3	25.9	14.8	11.1	22.5	3.20	-
Pedon 7: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Ultic Haplustalfs																
	Ap	0-20	16.5	57.5	13.2	70.7	8.5	20.8	1.30	45.5	9.3	4.7	4.6	20.9	3.06	-
	Bt	20-51	50.6	55.2	6.7	61.9	10.2	27.9	1.38	44.3	10.7	4.5	6.2	22.7	3.10	-
	C	51-93	71.7	59.3	7.7	67.0	10.3	22.7	1.35	46.5	14.4	8.3	6.1	19.6	3.05	
Pedon 8: Fine Loamy, Kaolinitic, Isohyperthermic, Non-calcareous Typic Rhodustalfs																
	Ap	0-25	26.6	50.3	20.1	70.4	4.7	24.9	1.34	43.5	18.0	7.6	10.4	24.4	3.20	-
	Bt1	25-32	23.1	44.3	19.2	63.5	5.3	31.2	1.34	42.8	18.6	7.7	10.9	26.8	3.41	-

Table 3: Contd…….

Table 3 : Contd…………

Bt2	32-56	28.6	35.7	18.8	54.5	7.1	38.4	1.36	41.9	22.5	11.9	10.6	29.7	3.46	-
Bt3	56-82	29.5	36.6	15.3	51.9	7.2	40.9	1.41	40.6	24.5	13.1	11.4	31.2	3.91	-
C	82-105	78.7	42.8	17.8	60.6	9.0	30.4	1.43	40.1	21.7	15.0	6.7	25.7	3.42	-
Pedon 9: Fine Loamy, Kaolinitic, Isohyperthermic, Non-calcareous, Typic Rhodustalfs															
Ap	0-10	10	50.9	22.1	73.0	8.5	18.5	1.35	43.2	20.1	13.5	6.6	17.3	3.14	-
Bt1	10-31	12.2	45.2	21.3	66.5	9.1	24.4	1.35	42.7	23.5	14.5	9.0	18.9	3.17	-
Bt2	31-64	19.3	42.0	16.4	58.4	7.2	34.4	1.36	42.1	24.7	14.4	10.3	25.7	3.24	-
Bt3	64-98	80.5	40.6	16.1	56.7	7.1	36.2	1.37	41.1	22.2	11.1	11.1	27.2	3.43	-
C	98-123	87.2	48.8	15.5	64.3	8.8	26.9	1.38	42.8	24.4	15.1	9.3	24.8	3.04	-
Pedon 10: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Ustorthents															
A	0-15	86.6	59.8	10.6	70.4	10.2	19.4	1.43	47.3	8.5	4.7	4.8	12.9	2.97	-
C	15-27	93.0	65.9	7.8	73.7	9.5	16.8	1.45	48.3	10.8	6.5	4.3	12.6	2.80	-
Pedon 11: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs															
A	0-18	28.2	54.1	14.9	70.3	7.2	22.5	1.36	44.6	10.4	4.5	5.9	14.9	3.05	-
Bt1	18-44	79.9	54.5	13.5	67.9	7.4	24.7	1.36	42.8	19.2	13.1	6.1	19.6	3.18	-
Bt2	44-80	83.7	49.8	11.9	65.7	7.5	26.8	1.37	42.1	21.3	14.3	7.0	23.8	3.50	-
C	80-110	94.2	51.7	11.9	65.6	8.5	25.9	1.42	42.6	21.9	15.3	6.9	22.7	3.10	-
Pedon 12: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs															
A	0-10	26.4	51.7	19.5	71.2	6.6	22.2	1.34	46.6	11.8	5.2	6.6	17.6	3.11	-
Bt1	10-41	72.4	49.2	16.9	66.1	7.5	26.4	1.36	43.2	23.5	13.5	10.0	21.8	3.30	-
BC	41-67	94.5	55.3	12.8	68.1	8.5	22.4	1.40	44.3	22.8	13.0	9.8	19.4	3.22	-
C	67+	Weathered granite-gneiss over lateritic parent material													
Pedon 13: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs															
A	0-10	12.0	53.8	14.3	68.1	7.5	24.4	1.33	45.1	20.4	14.9	5.5	17.8	3.04	-
Bt1	10-32	14.4	50.7	12.1	62.8	6.8	30.4	1.35	43.9	12.4	5.8	7.6	20.3	3.48	-
Bt2	32-80	82.8	51.0	9.8	60.8	5.9	33.3	1.39	42.6	11.6	4.7	7.9	24.4	3.67	-
C	80-110	93.1	59.6	13.7	73.3	5.3	21.4	1.40	43.3	11.4	4.5	6.9	21.3	3.17	-

*Coarse sand (0.2- 2mm); Fine sand (0.02- 0.2mm); Total sand (<2.0mm); Silt (0.002- 0.02mm) and Clay (<0.002mm)

Alfisols. This wide variation in soil texture was caused by topographic position, nature of parent material, *in-situ* weathering and translocation of clay and age of the soils as explained by Vara Prasada Rao *et al*. (2008). The distinguishing feature of the black soil pedons (4 and 5) have the finer textural class throughout the depth. The texture was clayey. The uniformity in texture was due to the argillo-pedoturbation operating in the black soil profiles (Buol *et al.*, 1998).

The consistence of red soils (pedon1 and 3) and red laterite soils (pedon 6, 7, 8, 9, 10, 11,12 and 13) varied from loose, slightly hard to hard, friable to firm and non-sticky and non-plastic to slightly sticky and slightly plastic in dry, moist and wet conditions, respectively. This physical behaviour of soils influenced by dry, moist and wet conditions was not only due to the textural make up but also due to type of clay minerals present in these soils. The C horizon of all the pedons had shown non-sticky and non-plastic or slightly sticky and slightly plastic consistence, which might be due to less amount of clay. Similar findings were also reported by Thangasamy *et al.* (2005). The horizons of black soils (pedons 4 and 5) and surface horizon of pedon 2 exhibited very sticky to very plastic, firm and hard to very hard in wet, moist and dry conditions, respectively, which might be due to high clay content. Similar observations were made by Sarkar *et al.* (2001).

The black soil pedons (4 and 5) had shown a prominent gilgai formation due to wide deep surface cracks, the surface soil could have been sloughed off during rainy season and swelling pressures developed in the lower layers pushed the peds upward which leads the development of slickensides in the deeper horizons and mounds and depressions on the surface. Similar observations were made by Subbaiah and Manickam (1992).

Moderately strong to violent effervescences were observed with dilute HCl test in black soil pedons of 4 and 5 while the effervescences were slight to strong in different horizons of red soil pedons of 1, 2 and 3 of MRS, Vagarai. Many calcium carbonate nodules (calcrets) were formed in lower horizons of the pedons of 2, 4 and 5. No effervescences were found in surface horizons and mild effervescence observed in subsurface layers of red laterite soils. Few lime concretions and nodules of different sizes were observed in the upper layers of pedons 1 and 3 of red soils while more $CaCO_3$ concretions found in black soils (pedon 4 and 5). The $CaCO_3$ concretions were formed in lower horizons of pedon 2. The colour of $CaCO_3$ concretions vary from pale brown to light grayish white, small to bigger size (0.2mm to 12 cm diameter), hard irregular outlined found in surface layers. The soft and easily separable lime nodules developed a zone of accumulation below 40-50cm (pedon 2) and 155 to 170 cm. Similar observations were also made by Singh *et al.* (2003). The uniform distribution of lime concretions (and pebbles) in surface and subsurface horizon of black soils are observed. It may be probably due to the localized movement of the sub-soil as described by Murthy *et al.* (1982).

Red, reddish brown, brownish yellow to straw yellow and brownish black mottles were observed in the red laterite soil pedons due to periodic wetting and drying favoured concretion formation and more permanent wetting leads to mottling. Brownish yellow to straw yellow mottles were observed might be due to oxidation of FeS_2. The reddish mottles were composed predominantly of Fe whereas black mottles were assumed due to manganese. Similar result was reported by Veneman *et al.* (1976) and Diwakar and Singh (1994). The presence of concretions of Fe and Mn and of clay skins was a common feature of all the red and red laterite soil pedons.

Physical properties :

The data on fine earth fractions of the soil Pedons are presented in Table 3. Among different profiles, red and red laterite soil pedons recorded higher sand content, whereas black soil pedons had higher clay content.

The clay content of the soils ranged from 16.5 to 28.9 per cent in red soil pedons (1, 2 and 3) whereas in red laterite soil pedons (6, 7, 8, 9,10,11,12 and 13), the clay content varied from 16.8 to 40.9 per cent. The clay content of black soil pedons (4 and 5) varied from 52.9 to 64.3 per cent. Increase of clay upto certain depth and a decrease was observed in pedon 1, 3, 5, 6, 7, 8, 9, 11, 12 and 13 due to the illuviation process occurring during soil development. Similar observations were also made by Tripathi *et al.* (2006). The clay content was found gradually increased in pedons 4. The increased clay content with depth was an evidence of pedogenic development as their formation and distribution is time dependent (Bhaskar *et al.*, 2009). These variations could be attributed to the parent material, topography, *in situ* weathering and /or pedogenesis. These results were in concurrence with those of Rudramurthy and Dasog (2001) and Gabhane *et al.* (2006). The silt content in most of the pedons showed an irregular trend with soil depth. It might be due to coarse nature of silt than clay, which restricts its movement with percolating water and irregular trend could be the fluventic nature of the soils in the study area. This corroborates the findings of Sharma *et al.* (2001).

The sand content was high in red soils and red laterite soils compared to black soils. The sand content of red and red laterite soils pedons varied from 54.5 to 73.7 and in black soils varied from 19.7 to 30.1 per cent. This could be due to the translocation / migration of finer particles into the lower layers and surface erosion. These observations are in agreement with those of Monday *et al.* (2003). The high sand content in pedons 1, 3, 6, 7, 8, 9, 10, 11, 12 and 13 were indicative of high degree of transportation of fine fraction of the soil from higher topography to lower topography.

The gravel content was observed in all the horizons and their distribution varied widely with depth and among the pedons. The gravel content varied from 8.8 per cent to 86.6 per cent in surface horizons whereas in subsurface horizons ranged from 4.9 per cent in pedon 5.0 to 94.5 per cent. The gravels of the red and red laterite soils were found to be very hard probably due to periodic wetting and drying favored concretion formation and more permanent wetting leads to mottling (Manickam *et al.*, 1973).

The ratios of different fine earth fractions, there were not many variations among the adjacent horizons in red, red laterite and black soil pedons (Table 4). As such, there was no lithological discontinuity among the different horizons in any profile (Soil Survey Staff, 1999 and Dutta *et al.*, 2001). The silt clay ratio was found to be less than 0.5 in black soils (0.24 to 0.34) indicating the moderate weathering, whereas in red laterite soils (0.20 to 0.56) and red soils ranging from 0.45 to 1.05 indicating the moderate to high weathering. The ratios

Table 4: Ratios of the fine earth fractions of pedons (Particle size-analysis)

Pedon	Horizon	Depth (cm)	Sand+ Silt	Silt + Clay	Coarse sand/ Fine sand	Sand / Silt	Silt / Clay	Sand / (Sand + Silt)	Sand / (Silt + Clay)
MRS, Vagarai									
Pedon 1: Loamy-Skeletal, Mixed, Isohyperthermic, Non-calcareous, Lithic Haplustalfs									
	Ap	0-11	77.1	36.7	1.87	4.58	0.60	4.86	1.72
	Bt1	11- 23	76.6	35.4	1.47	5.38	0.51	4.96	1.82
	Bt2	23-40	72.3	40.2	2.98	4.78	0.45	4.60	1.48
	C	40-47	82.6	34.4	3.96	3.85	0.97	5.04	1.90
Pedon 2: Loamy-Skeletal, Mixed, Isohyperthermic, Calcareous, Calcic Haplustepts									
	AP	0-20	54.2	63.3	1.17	2.09	0.38	2.82	0.57
	A1	20-31	75.3	44.1	2.10	2.88	0.78	4.30	1.26
	Bwk	31-50	72.8	45.5	2.44	2.97	0.67	4.19	1.19
	Ck	50-60	71.1	44.4	3.24	3.58	0.53	4.27	1.25
Pedon 3: Loamy-Skeletal, Mixed, Isohyperthermic, Non-calcareous, Lithic Haplustalfs									
	AP	0-10	77.8	36.2	1.96	4.55	0.63	4.90	1.76
	Bt	10 -28	74.7	40.5	2.62	3.94	0.60	4.57	1.46
	C	28-40	83.5	33.9	4.37	3.79	1.05	5.08	1.94
CRS,Veppanthattai									
Pedon 4: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert									
	Ap	0-31	47.1	69.9	2.40	1.77	0.32	2.31	0.43
	Bss1	31-73	44.8	70.7	1.98	1.89	0.28	2.25	0.41
	Bss2	73-101	41.4	75.4	1.70	1.46	0.28	1.89	0.32
	Bss3	101-134	41.1	78.2	2.15	1.12	0.32	1.67	0.27
	Ck	134-170	40.6	78.9	2.45	1.08	0.32	1.62	0.26
Pedon 5: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert									
	Ap	0-25	45.2	70.8	2.51	1.82	0.29	2.24	0.41
	Bss1	25-71	44.4	73.6	1.96	1.46	0.32	2.03	0.35
	Bss1	71-100	42.8	76.2	1.83	1.25	0.33	1.83	0.31
	Bss2	100-125	35.7	80.3	2.22	1.23	0.24	1.51	0.24
	Ck	125-155	42.4	77.6	2.44	1.12	0.34	1.72	0.28
DARS, Chettinad									
Pedon 6: Loamy-Skeletal,Kaolinitic, Isohyperthermic, Non-calcareous, Ultic Haplustalfs									
	Ap	0-14	79.5	29.3	2.97	8.03	0.42	5.43	2.41
	A	14-25	77.9	31.6	3.04	7.20	0.42	5.26	2.16
	Bt1	25-39	74.6	32.3	3.70	9.81	0.27	5.20	2.09
	Bt2	39-63	73.5	33	3.36	10.30	0.24	5.15	2.03
	Bt3	63-97	72.1	35.9	3.08	8.01	0.28	4.93	1.78
	Bt4	97-143	70	36.1	3.37	10.47	0.20	4.91	1.77
	C	143-150	73.6	36.4	4.49	6.36	0.37	4.89	1.74
Pedon 7: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Ultic Haplustalfs									
	Ap	0-20	79.2	29.3	4.35	8.31	0.40	5.43	2.41
	Bt	20-51	72.1	38.1	8.23	6.06	0.36	4.76	1.62
	C	51-93	77.3	33	7.70	6.50	0.45	5.15	2.03
Pedon 8: Fine Loamy, Kaolinitic, Isohyperthermic, Non-calcareous Typic Rhodustalfs									
8.	Ap	0-25	75.1	29.6	2.50	14.97	0.18	5.41	2.37

Table 4: Conted……….

Table 4: Contd………..

Bt1	25-32	68.8	36.5	2.30	11.98	0.16	4.88	1.73
Bt2	32-56	61.6	45.5	1.89	7.67	0.18	4.19	1.19
Bt3	56-82	59.1	48.1	2.39	7.20	0.17	3.99	1.07
C	82-105	69.6	39.4	2.40	6.73	0.29	4.66	1.53
Pedon 9: Fine Loamy, Kaolinitic, Isohyperthermic, Non-calcareous, Typic Rhodustalfs								
Ap	0-10	81.5	27	2.30	8.58	0.45	5.61	2.70
Bt1	10-31	75.6	33.5	2.12	7.30	0.37	5.11	1.98
Bt2	31-64	65.6	41.6	2.56	8.11	0.20	4.49	1.40
Bt3	64-98	63.8	43.3	2.52	7.98	0.19	4.36	1.30
C	98-123	73.1	35.7	3.14	7.30	0.32	4.94	1.80
Pedon 10: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Ustorthents								
A	0-15	80.6	29.6	5.64	6.90	0.52	5.41	2.37
C	15-27	83.2	26.3	8.44	7.75	0.56	5.66	2.80
Pedon 11: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs								
A	0-18	77.5	29.7	3.63	9.76	0.32	5.40	2.36
Bt1	18-44	75.3	32.1	4.03	9.17	0.29	5.22	2.11
Bt2	44-80	73.2	34.3	4.18	8.76	0.27	5.05	1.91
C	80-110	74.1	34.4	4.34	7.71	0.32	5.04	1.90
Pedon 12: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs								
A	0-10	77.8	28.8	2.65	10.78	0.29	5.47	2.47
Bt1	10-41	73.6	33.9	2.91	8.81	0.28	5.08	1.94
BC	41-67	76.6	30.9	4.32	8.01	0.37	5.23	2.20
C	67+	Weathered granite-gneiss over lateritic parent material						
Pedon 13: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs								
A	0-10	75.6	31.9	3.76	9.08	0.30	5.23	2.13
Bt1	10-32	69.6	37.2	4.19	9.23	0.22	4.83	1.68
Bt2	32-80	66.7	39.2	5.20	10.30	0.17	4.67	1.55
C	80-110	78.6	26.7	4.35	13.83	0.24	5.63	2.74

of coarse sand / fine sand, sand / silt, silt / clay, sand / (silt + clay) were comparatively higher in red laterite soil and red soils pedons indicating the translocation and / or migration of finer particles down the depth (Satyavathi and Reddy, 2003).

The bulk density of the soils ranged 1.30 Mg m^{-3} to 1.58 Mg m^{-3}. Bulk density increased with increasing depth in pedons 1, 3, 4, 5, 6, 8, 9, 10, 11, 12 and 13. The increase in bulk density with depth might be due to decrease in organic matter content, more compaction, and less aggregation (Singh and Agarwal, 2005). The surface soils were less compact due to high organic matter content and more plant root concentration (Coughlan *et al.*, 1986). Whereas in pedons 2 and 7 showed irregular trend with soil depth. In all the pedons the general trend was that the bulk density values were higher in lower layers than in upper layers. The pore space ranged from 35.3 per cent (pedon 4) to 47.5 per cent (pedon 6) in surface horizons, whereas in subsurface horizons ranged from 30.4 per cent in pedon 5 to 46.5 per cent in pedon 7. A reduction in porosity with depth was observed in pedons 3 and 6 whereas reverse trend was noticed in pedon 10.

The variation in moisture retention at two tensions (33 kPa and 1500 kPa) is mostly associated with variations in soil texture. The moisture retention at field capacity (33kPa), permanent wilting point (1500kPa) and available water capacity were high in black soils pedons (4 and 5) followed by the application of transported black soils over the native red soils (Pedon 2) which might be due to the black soils being dominated by smectite clay with large surface area, retained higher amount of water at different soil water suctions (Hirekurubar *et al*., 1991). In the subsurface layer of transported black soils pedon 2 have more moisture retention than the native red soils (pedons 1 and 3). The soils with high sand content retained least amount of moisture at both tensions than soils with high clay content might be due to the red soils and red laterite soils being dominated by kaolinite clay with small surface area, retained lower amount of water at different soil water suctions. The moisture content of soil at different tensions depends on the quantity and quality of clay and the moisture holding capacity of soil. These are in accordance with the findings of Saravanan *et al*. (2000). The application of black soils over native red soils is beneficial for retaining the high soil moisture for sustaining crop growth particularly in rainfed situations under changing climate.

Black soils pedons (4 and 5) having more water holding capacity, volume expansion followed by the red (pedon 2, 1 and 3) and red laterite soils (pedons 6, 7, 8, 9, 10, 11, 12 and 13) and in all the locations these values showed increasing trend with clay content in general. These types of trends were in accordance with those of Rudramurthy and Dasog (2001). Volume expansion was ranging from 23.10 to 30.41 per cent in black soil pedons. In red and red laterite soil pedons, the per cent volume expansion ranged from 2.97 per cent (pedon 10) to 21.70 per cent (pedon 2) in surface horizons whereas in subsurface horizons ranged from 2.80 to 5.22 per cent in pedon 10 and 2, respectively. The shrinkage and swelling phenomenon was exhibited only by black soils. Hence, co-efficient of linear extensibility was determined for black soils. It ranged from 0.13 to 0.20. The black soils fall in the category of very high (greater than 0.09) swell-shrink class (Nayak *et al.,* 2006).

Physico-chemical properties:

The pedon wise physico-chemical properties of respective research stations are described in Table 5. Soil pH of the pedons showed wide variation and the values found to vary from 4.71 to 8.57 in surface horizons whereas in subsurface horizons ranged from 4.40 to 9.13. The results showed that the pedons of red laterite soils had lower pH values (moderately acidic to slightly acidic) followed by red soils (neutral to strongly alkaline) and higher pH values recorded in black soils (moderately alkaline to strongly alkaline). Gabhane *et al.* (2006) reported similar trends of reaction. The pH values were increasing with depth in the pedons 1, 3, 4, 9 and 13 might be due to increase in bases with depth and their complete downward leaching. The pedons 10 and 11 showed decreasing trend which might be due to the chemical weathering which leads to accumulation of exchangeable H^+, Al^{3+}, Fe and Al oxides and clay minerals (Bipul Deka *et al.,* 2009). The distribution was irregular in pedons 2, 5, 6, 7, 8, 11 and 12 which might be due to downward movement of bases and they get adsorbed at different layers irregularly. The lower pH values in surface layers of pedon 1, 3, 4, 5, 7, 8, 9, 11,12 and 13 which might be due to continuous removal of basic cations by crop plants and leaching (Nagassa and Gebrekidan, 2003), movement of basic cations to deeper layers (Singh and Agarwal, 2005) and/or due to precipitation of calcium carbonate (Balapande *et al.*, 2007). The pedons of red laterite soils of DARS, Chettinad had lower pH values varied from 4.71 to 6.59 in surface horizons and 4.40 to 6.37 in subsurface horizons and majority of these soils are moderately acidic in soil reaction and appeared to be related with acidic parent materials and leaching of bases such as calcium, magnesium, potassium and sodium from the soil leading to high hydrogen ion concentration caused by heavy precipitation during rainy season (Nayak *et al.*, 2002).

The EC was very low in red and red laterite soils even in lower horizons because they were formed on relatively higher elevations. The relatively high EC of black soils than red soils could be due to the location and the high clay content resulting in accumulation of soluble salts. The electrical conductivity of pedons ranged from 0.02 to 0.72 dS m^{-1} indicating that these soils were non saline in nature (Masri Sitanggang Rao *et al.*, 2006). The EC gradually increased with depth in majority of the pedons. This may be due to the leaching of electrolytes to the lower depth and also due to foraging of nutrient ions by the vegetation in the surface layer. These observations are in agreement with the findings of Renukadevi (2003). The EC values suggesting low amount of soluble salts which could be attributed to loss of bases (Sidhu *et al.,* 1994) due to heavy rainfall during monsoon.

The organic carbon showed wide variation and the values found to vary from low to medium (2.8 to 6.5 g kg^{-1}) in surface horizons whereas in subsurface horizons it was low and ranged from 0.70 to 5.0 g kg^{-1}. The low to medium content of OC could be attributed to the rapid oxidation and decomposition of added organic matter under tropical condition and lesser addition of organic

Table 5 : Physico-chemical characteristics of pedons of the Research Stations

Pedon	Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	OC ($g\ kg^{-1}$)	Exchangeable cations [c mol (p+) kg^{-1}] Ca	Mg	Na	K	Total exchangeable bases	BSP (%)	CEC [cmol (p+) kg^{-1}]	$CaCO_3$ (%)	ESP (%)	SAR	CEC/ clay ratio
MRS, Vagarai																
Pedon 1: Loamy-Skeletal, Mixed, Isohyperthermic, Non-calcareous, Lithic Haplustalfs																
	Ap	0-11	7.49	0.08	5.2	7.1	3.1	0.69	0.88	12.77	76.0	16.8	0.5	4.1	0.23	0.73
	Bt1	11- 23	7.58	0.09	3.9	7.4	3.3	0.52	0.79	12.01	77.0	15.6	0.7	3.3	0.17	0.66
	Bt2	23-40	7.85	0.11	2.7	7.5	3.4	0.43	0.64	11.97	78.8	15.2	0.9	2.8	0.14	0.55
	C	40-47	7.88	0.18	2.4	8.1	3.7	0.42	0.54	12.76	85.6	15.0	1.5	3.0	0.13	0.66
Pedon 2: Loamy-Skeletal, Mixed, Isohyperthermic, Calcareous, Calcic Haplustepts																
	AP	0-20	8.10	0.25	5.6	14.4	7.8	1.14	0.74	24.08	67.6	35.6	2.6	3.2	0.24	0.77
	A1	20-31	8.00	0.20	4.5	6.9	3.6	0.76	0.78	12.04	73.4	16.4	1.2	4.6	0.25	0.66
	Bwk	31-50	8.50	0.31	3.6	10.2	5.7	0.58	0.69	17.17	89.4	19.2	7.3	2.8	0.16	0.70
	Ck	50-60	8.80	0.46	3.0	14.4	5.6	0.61	0.47	21.08	94.5	22.3	15.3	2.0	0.12	0.77
Pedon 3: Loamy-Skeletal, Mixed, Isohyperthermic, Non-calcareous, Lithic Haplustalfs																
	AP	0-10	7.45	0.15	4.9	7.2	3.2	0.92	0.71	12.03	72.9	16.5	0.7	5.5	0.31	0.74
	Bt	10 -28	7.56	0.18	3.5	7.8	3.4	0.66	0.65	12.51	75.4	16.6	1.2	3.9	0.21	0.65
	C	28-40	7.86	0.27	3.2	8.2	3.5	0.54	0.57	12.81	84.3	15.2	1.4	3.5	0.17	0.72
CRS,Veppanthattai																
Pedon 4: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert																
	Ap	0-31	8.48	0.14	5.5	27.2	8.2	2.32	1.04	38.76	86.9	44.6	9.8	5.2	0.41	0.84
	Bss1	31-73	8.87	0.16	4.6	27.8	9.2	2.81	0.91	39.72	85.4	46.5	8.2	3.8	0.31	0.84
	Bss2	73-101	8.97	0.28	3.5	28.3	9.8	2.84	0.83	41.77	87.9	47.5	7.3	5.9	0.49	0.81
	Bss3	101-134	8.98	0.44	1.5	28.9	9.9	3.34	0.77	42.91	89.0	46.2	9.7	6.9	0.57	0.78
	Ck	134-170	9.13	0.72	0.7	29.2	9.4	3.41	0.56	42.57	92.1	48.2	15.0	7.4	0.58	0.81
Pedon 5: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert																
	Ap	0-25	8.57	0.21	5.4	26.8	8.4	1.71	0.95	37.86	83.2	45.5	9.6	3.7	0.30	0.83
	Bss1	25-71	9.04	0.23	4.2	27.9	9.8	1.86	0.75	40.31	86.9	46.4	8.1	4.0	0.32	0.83
	Bss1	71-100	8.96	0.38	3.6	27.8	9.8	3.13	0.77	41.50	88.8	46.7	8.6	6.7	0.54	0.81
	Bss2	100-125	9.08	0.46	1.8	28.4	10.3	3.41	0.81	42.92	89.8	48.8	11.5	7.1	0.58	0.75
	Ck	125-155	9.10	0.68	1.5	29.8	9.8	3.45	0.68	43.73	91.4	47.9	15.5	7.6	0.58	0.83
DARS, Chettinad																
Pedon 6: Loamy-Skeletal,Kaolinitic, Isohyperthermic, Non-calcareous, Ultic Haplustalfs																
	Ap	0-14	6.59	0.20	6.5	1.85	0.84	0.09	0.28	3.06	40.8	7.5	-	1.0	0.069	0.36
	A	14-25	6.32	0.14	5.0	1.34	0.61	0.08	0.31	2.34	36.0	6.5	-	1.2	0.062	0.29
	Bt1	25-39	6.10	0.05	4.8	1.48	0.65	0.05	0.31	2.49	37.7	6.6	-	0.7	0.037	0.26
	Bt2	39-63	6.06	0.05	3.0	1.32	0.62	0.05	0.32	2.31	35.5	6.5	-	0.7	0.039	0.24
	Bt3	63-97	6.23	0.07	1.7	1.41	0.64	0.04	0.33	2.42	39.6	6.1	-	0.5	0.030	0.23
	Bt4	97-143	6.25	0.05	1.4	1.31	0.57	0.04	0.34	2.26	32.7	6.9	-	0.5	0.031	0.23
	C	143-150	5.94	0.04	1.0	0.99	0.43	0.03	0.38	1.83	32.6	5.6	-	0.4	0.027	0.21
Pedon 7: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Ultic Haplustalfs																
	Ap	0-20	4.85	0.03	4.9	1.41	0.63	0.06	0.22	2.32	38.0	6.1	-	0.9	0.045	0.29
	Bt	20-51	5.12	0.03	3.6	1.72	0.51	0.04	0.25	2.52	41.3	6.1	-	0.6	0.028	0.22
	C	51-93	4.78	0.04	2.9	1.76	0.39	0.03	0.27	2.45	39.5	6.2	0.3	0.5	0.021	0.27
Pedon 8: Fine Loamy, Kaolinitic, Isohyperthermic, Non-calcareous Typic Rhodustalfs																

Table 5: Contd……….

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Ap	0-25	5.03	0.04	5.5	1.31	0.93	0.06	0.31	2.61	41.4	6.3	-	0.9	0.045	0.25
Bt1	25-32	5.07	0.03	3.5	1.61	0.81	0.05	0.28	2.75	43.6	6.3	-	0.7	0.035	0.20
Bt2	32-56	5.33	0.04	2.4	1.81	0.89	0.06	0.31	3.07	46.5	6.6	-	0.9	0.039	0.17
Bt3	56-82	5.44	0.04	1.7	1.84	0.96	0.04	0.34	3.18	48.1	6.7	-	0.6	0.026	0.16
C	82-105	5.28	0.05	1.4	1.94	1.01	0.04	0.36	3.35	50.0	6.6	-	0.6	0.025	0.21
Pedon 9: Fine Loamy, Kaolinitic, Isohyperthermic, Non-calcareous, Typic Rhodustalfs															
Ap	0-10	5.02	0.04	5.3	1.8	0.98	0.03	0.21	3.02	48.7	6.2	-	0.4	0.019	0.33
Bt1	10-31	5.48	0.05	3.3	2.1	1.08	0.04	0.28	3.50	53.0	6.6	0.2	0.6	0.024	0.27
Bt2	31-64	5.65	0.13	3.1	2.3	1.14	0.04	0.32	3.80	56.7	6.7	0.2	0.5	0.023	0.19
Bt3	64-98	6.07	0.11	2.6	2.5	1.16	0.06	0.32	4.04	59.4	6.8	0.2	0.8	0.034	0.18
C	98-123	6.37	0.06	1.5	3.0	1.21	0.11	0.38	4.70	66.1	6.7	0.4	1.5	0.057	0.24
Pedon 10: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Ustorthents															
A	0-15	5.08	0.04	2.8	1.65	0.66	0.05	0.22	2.58	46.9	5.5	-	0.9	0.035	0.28
C	15-27	4.41	0.09	1.4	1.48	0.43	0.04	0.22	2.17	40.9	5.3	-	0.7	0.030	0.31
Pedon 11: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs															
A	0-18	4.72	0.03	5.0	1.49	0.75	0.02	0.24	2.50	36.7	6.8	-	0.2	0.014	0.30
Bt1	18-44	4.69	0.03	3.8	1.49	0.73	0.04	0.26	2.52	36.5	6.9	-	0.5	0.029	0.27
Bt2	44-80	4.47	0.04	3.0	1.81	0.87	0.14	0.35	3.17	45.9	6.9	-	1.9	0.093	0.25
C	80-110	4.40	0.04	1.2	2.11	1.01	0.09	0.31	3.52	49.5	5.9	-	1.2	0.055	0.22
Pedon 12: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs															
A	0-10	4.71	0.03	5.1	1.56	0.71	0.06	0.31	2.64	41.2	6.6	0.2	0.9	0.043	0.29
Bt1	10-41	4.82	0.04	3.2	1.75	0.66	0.04	0.36	2.81	42.5	6.9	0.3	0.6	0.027	0.26
BC	41-67	4.77	0.04	1.9	1.81	0.83	0.07	0.36	3.07	44.5	6.4	0.2	1.0	0.046	0.28
C	67+	Weathered granite-gneiss over lateritic parent material													
Pedon 13: Loamy-Skeletal, Kaolinitic, Isohyperthermic, Non-calcareous, Lithic Haplustalfs															
A	0-10	4.76	0.04	5.3	1.61	0.66	0.07	0.37	2.71	38.7	7.0	-	1.0	0.050	0.28
Bt1	10-32	4.98	0.03	2.6	1.69	0.58	0.06	0.41	2.74	38.6	7.1	0.3	0.8	0.042	0.23
Bt2	32-80	5.01	0.02	1.7	1.75	0.56	0.07	0.42	2.80	38.9	7.2	0.2	0.9	0.049	0.21
C	80-110	5.26	0.03	1.4	1.81	0.71	0.05	0.45	3.02	41.4	7.0	0.2	0.7	0.033	0.32

manures in the block (Saha *et al.*, 1996 and Mustapha *et al.*, 2011). The organic carbon content relatively higher in surface horizons was higher than sub-surface horizons in all the pedons and it decreased with depth. This was attributed to the addition of farmyard manure and plant residues to surface horizons which resulted in higher organic carbon content in surface horizons than that of lower horizons. These observations are in accordance with results of Rajeshwar *et al.* (2009). Organic carbon had positive relation with the availability of all nutrients (Table 5) which might be due to chelating action (Meena *et al.*, 2006).

The calcium carbonate content of red laterite soil pedons (6 to 13) was very low ranging from 0.00 to 0.4 per cent. The red soil pedons (1, 2 and 3) having 0.5 to 15.3 per cent whereas, in the black soil pedons (4 and 5) containing 7.3 to 15.5 per cent. The difference in the content among red and black soils was due to the variation in elevation, drainage and parent material. The black soils were developed over granitic gneiss mixed with calcareous murram on plain topography and had higher clay content resulting in the accumulation of calcium carbonate. The content was relatively higher in deeper layers than in surface layers. Pal *et al.* (2000) reported that higher content of calcium carbonate in deeper layers might be due to the downward movement of it along with percolating water (pedogenic and / or lithogenic) in soils of semi-arid regions. Maji *et al.* (2005) stated that increase in the calcium carbonate content down the depth was attributed to the leaching of bicarbonate from upper layer during rainy season and their subsequent precipitation as carbonate in the lower layer. The irregular distribution of $CaCO_3$ in pedons 2, 4 and 5 with depth could be due to the variable nature of the geological material (Rajkumar *et al.*, 2005).

The exchange capacity in black soil pedons ranged from 44.6 to 48.8 c mol (p+) kg^{-1} and CEC/clay ratios were found to vary from 0.75 to 0.84 than in red soils pedons and red laterite soil pedons. Since CEC was the charge behaviour of soils, where clay was the fundamental block contributing towards cation exchange, the high CEC of the black soils was attributed to the high clay content and smectitic clay mineralogy (Pal and Deshpande, 1987). The cation exchange capacity (CEC) values varied from 5.3 to 7.5 c mol (p+) kg^{-1} in red laterite soils pedons of DARS, Chettinad whereas CEC/clay ratio ranged from 0.16 to 0.36. The CEC of the red laterite soils was quite low despite high clay content indicating that the dominance of low activity clay minerals. The CEC values of red soil pedons of MRS, Vagarai ranged from 15.0 to 35.6 c mol (p+) kg^{-1}, whereas CEC/clay ratios were found to vary from 0.55 to 0.77. The CEC values are indicating that the black soils are less weathered than the red soils and red laterite soils. Higher values of CEC/clay ratio indicate the less weathered nature of the soils with weatherable primary minerals (Buol *et al*., 1998).

The exchangeable bases in the red and black soil pedons (1, 2, 3, 4 and 5) were in order of $Ca^{+2} > Mg^{+2} > Na^{+} > K^{+}$ on the exchange complex. From the distribution of Ca^{+2} and Mg^{+2}, it is evident that Ca^{+2} shows the strongest relationship with all the species, comparing these ions (Ca^{+2}, Mg^{+2}, K^{+} and Na^{+}) it was clear that Mg^{+2} was present in low amount than Ca^{+2} because of its higher mobility. These results are in conformity with findings of Thangasamy *et al.* (2005). The exchangeable cations of red laterite soils (pedons 6 to 13), the exchangeable bases were in order $Ca^{+2} > Mg^{+2} > K^{+} > Na^{+}$. Low exchangeable Na and K percentage was noticed in all the pedons as the exchange complex was dominated by divalent cations like Ca and Mg.

The per cent base saturation was very high in black soils pedons (4 and 5). This could be due to the dominance of smectitic type of clays and moderate to strongly alkaline reaction. The high CEC of black soils was attributed to the smectitic clay mineralogy. These results are in accordance with the findings of Singh and Agarwal (2005) and Gabhane *et al.* (2006). The red soils (pedons 1, 2 and 3) of MRS, Vagarai were having either mixed or illitic mineralogy in clay fraction and neutral to slightly alkaline reaction, hence, the base saturation values were lower than those of black soils. Pillai and Natarajan (2004) reported similar extent of base saturation. The red laterite soils pedons (6, 7, 8, 9, 10, 11, 12 and 13), exhibited kaolinite mineralogy in clay fraction and moderately acidic to slightly acidic reaction, hence, the base saturation values were lower than those of black soils and red soils.

Soil classification :

Soils of three different Research Stations were classified based on morphological, physical, physico-chemical, chemical and meteorological data, according to revisions of USDA Soil Taxonomy (2010). The soils of the study area were characterized and classified into four soil orders *viz.*, alfisols, vertisols, inceptisols and entisols.

The pedons 4 and 5 were classified under vertisols because of the presence they exhibited following features. A layer 25 cm or more thick, with an upper boundary with in 100 cm of the mineral soil surface; clayey texture, more than 30 per cent clay in fine earth fraction throughout the depth; Gilgai micro-relief (micro-knolls and micro-ridges) on the surface; distinct intersecting slickensides in lower horizons; cracks of greater than 1 cm width which remained open and close periodically to the surface from a depth of more than 40 cm and absence of lithic or paralithic contact, duripan, petrocalcic horizon within 50 cm from the surface. As the moisture regime is Ustic, the pedons 4 and 5 were classified as Usterts at sub order level. Similar results were reorted by Walia and Rao (1996).

The pedons 1, 3, 6, 7, 8, 9, 11, 12 and 13 were classified under alfisols because of the presence of an argillic horizon. The argillic horizon was identified by the following features. Sandy clay loam to sandy clay texture; Illuvial accumulation of clay; Thickness of horizon was more than 7.5 cm; Presence of argillans (clay cutans) and the base saturation was more than 35 per cent. Based on the presence of argillic horizon in sub-surface, pedons 1, 3, 6, 7, 8, 9, 11, 12 and 13 were kept under the order "Alfisol". As the moisture regime is Ustic, the pedons 1, 3, 6, 7, 8, 9, 11, 12 and 13 were classified as Ustalfs at sub order level.

The pedon 2 was classified under the order Inceptisols based on the presence of cambic subsurface horizon. In these pedons the subsurface horizons were recognized as cambic horizons because of the following features *viz.*, texture of loamy very fine sand or finer; absence of rock structure in one half or more of its volume. Similar results were noted by Sarkar *et al.* (2002).

The pedon 10 was classified under entisols because of the slight degree of soil formation and presence of less than 30 per cent clay in sub horizons within depth of 50 cm and do not have gilgai micrirelief, wedge shaped natural aggregates and silken sides close enough to intersect (Ahuja *et al.*, 1997).The study area has semiarid climate with high summer temperatures with optimum rainfall and monsoonic type of climate. The topography of the study area varied from very gently sloping to steeply sloping. The interplay of climate, topography and vegetation acting on parent material over a period of time in three different research stations resulted in the development of different soils *viz.*, entisols, inceptisols, alfisols and vertisols as pointed out by Leelavathi *et al.* (2009). Among the soils alfisols occupied a major area of MRS, Vagarai and DARS, Chettinad followed by less area of entisols and inceptisols whereas, vertisols occupied by the total area of CRS, Veppanthattai.

Soil formation :

Climate :

The temperature and rainfall pattern of the study area indicated that the climate is semi-arid monsoon type with distinct and well-defined dry season and wet season. The soil moisture control section is dry for more than 90 cumulative days or 45 consecutive days in the months of summer solstice. The soil moisture and soil temperature regimes of the study area are Ustic and Iso-hyprerthermic, respectively. The soils of the study area were influenced and formed under semi-arid type of climate. Similar type of climate was reported by Dutta *et al.* (2001) and Bandyopadhyay *et al*. (2004).

Parent material:

Eastern Ghats (south) of Deccan trap had been divided into three landforms *viz.*, granite and granite - gneiss, Dharawars and Cuddapahs and Kurnools (Reddy *et al.*, 1996). The first landform was characterized by hills to very gently sloping plains and valleys. The eroded soil constituents and soluble constituents were washed / leached down the slope. In the very gently sloping lands and valleys, the finer factions and calcium carbonate were accumulating with weathered granitic gneiss. Hence, the parent material for the development of these red and black soils was weathered granite - gneiss at higher elevations and it was mixed with calcareous murram in very gently sloping lands, plains and valleys. Red soils (pedons 1, 2 and 3) were formed and developed on weathered granite-gneiss and red laterite soils (pedons 6, 7, 8, 9, 10, 11, 12 and 13) were developed on weathered granite-gneiss over lateritic parent material whereas; black soils (pedons 4 and 5) were derived from weathered granite-gneiss mixed with calcareous murram. Similar occurrence of red and black soils on granite-gneiss was reported earlier by Paramasivam and Gopalaswamy (1993) and Subbaiah and Manickam (1992).

Landform and topography :

Red soils were formed near the foothills of granitic-gneiss at higher topographic positions with the slope varying from 3 to 5 per cent on gently sloping lands. Red laterite soils (pedons 6, 7, 8, 9, 10, 11, 12 and 13) were formed near the foothills of laterite granitic –gneiss with the slope varying from 3 to 5 per cent on gently sloping lands. Black soils were developed on nearly level to very gently sloping lands with slope per cent varying between 1 and 3. Many scientists in different locations also reported formation of red soils on higher elements of topography and black soils on lower elements of topography. Nagelschmidt *et al.* (1940) in Deccan State of India*;* Curi and Franzmeir (1984) in central plateau of Brazil; Tiwary *et al.* (1989) in Rajmahl trap of Bihar; Rudramurthy and Dasog (2001) in north Karnataka; Nagassa and Gebrekidan (2003) in Bako soils of Ethiopia; and Gabhane *et al.* (2006) in Vidarbha region also observed the occurrence of red soils on higher elements of topography and black soils on lower elements of topography.

Vegetation:

The natural vegetation in the study area included *Cynodon dactylon*, *Cyprus rotundus*, *Azadirata indica*, *Prosopis juliflora*, *Cacia* species, *Manjifera indica*, *Tectona grandis*, *Tamarindus indica*, *Palmyra*, *Tadipalm*, broad leaf weeds such as *Selotia*, *Parthenium*, *Euforbia* spp. and shrubs etc. Similar type of vegetation was reported by Bhaskar *et al.* (2005). Though vegetation served as a good sign of indication of soil properties, the influence of natural vegetation on soil formation and development was not observed, as the natural vegetation was sparse in different locations of the study area. Coulombe *et al.* (1996) stated that Vertisols formation was not influenced by vegetation.

Pedological time:

The red, red laterite and black soils of the study area might have been formed during Archean period about 3800 million years back (Rao *et al.*,1995). Digar and Barde (1982) reported that it was during Archean period, the red soils were formed, whereas the black soils were developed during Cenozoic era, which included tertiary and quaternary period (Coulombe *et al.*, 1996).

Soil forming processes:

Argillic horizons (textural clay enriched 'B' horizons) were recognized in the sub-surface of red soils and red laterite soils (pedon 1, 3, 6, 7, 8, 9, 11, 12, and 13) due to presence of clay cutans (argillans). There was translocation of clay and iron oxides from 'Ap' horizon to 'B' horizon in the solum. The clay enrichment due to illuviation was sufficient enough to meet the requirement of argillic horizon (Bt). The texture was finer than the overlying horizon. Thus, illuviation was the main pedogenic process in these pedons. Similar observations were also reported by Singh and Agarwal (2005).

In the black soils (pedons 4 and 5), prominent or distinct slickensides were noticed in the lower layers. Slickensides were originated due to sliding of one soil mass over the other due to swelling and expansion of clay minerals in wet season. They were seen as polished smooth surfaces in dry period when profile was opened upto the deeper layers. The pedogeneic process was nothing but argillo-pedoturbation. Similar reports were earlier given by Mermut *et al.* (1996) and Maji *et al.* (2005). In the black soil locations, wide cracks were noticed revealing the shrinking nature of the clay minerals in dry period. The soil particles particularly clay which were loose on the surface, due to slight disturbance, wind and / or rain migrate to the deeper layers along the sides of the cracks. This type of mechanical migration of inorganic particles in the profile was described as lessivage (Buol *et al.*, 1998).

The transported black soil over native red soil profile 2 located at MRS, Vagarai illuviation was no doubt operating as there was increase in the clay content in the 'B' horizon, but the 'B' horizons were not meeting the criteria for argillic horizon and at the same time, no clay skins were noticed which might be due to application of transported black soil over native soil. The 'B' horizon in these pedons was exhibiting features of altered horizon and thereby resulted in structural / colour 'B' horizon (cambic horizon, a sub-surface diagnostic horizon). The colour of the soil was reddish brown or darker in dry and moist conditions due to release of iron oxides from weathering of rocks and minerals and their accumulation in the solum. Hence, rubification/ braunification must be operating in these red soil pedons. Similar results were also reported by Walia *et al.* (2000).

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