MORPHOLOGY AND TAXONOMY OF RED AND BLACK SOILS OF EDLAPADU MANDAL OF GUNTUR DISTRICT, ANDHRA PRADESH

By

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Mr. J. RADHA KRISHNA has satisfactorily prosecuted the course of research and that the thesis entitled **"MORPHOLOGY AND TAXONOMY OF RED AND BLACK SOILS OF EDLAPADU MANDAL OF GUNTUR DISTRICT, ANDHRA PRADESH"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any university.

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No part of the thesis has been submitted by the student for any degree or diploma. The published part has been fully acknowledged. All the assistance and help recieved during the course of the investigation have been duly acknowledged by the author of the thesis.

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D E C L A R A T I O N

I, **Mr. J. RADHA KRISHNA,** hereby declare that the the thesis entitled "**MORPHOLOGY AND TAXONOMY OF RED AND BLACK SOILS OF EDLAPADU MANDAL OF GUNTUR DISTRICT, ANDHRA PRADESH"** submitted to Acharya N. G. Ranga Agricultural University for the degree of **MASTER OF SCIENCE IN AGRICULTURE** in the major filed of **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** is the result of original research work done by me. I also declare that any material contained in the thesis has not been published earlier.

Date: **(J. RADHA KRISHNA)**

LIST OF SYMBOLS AND ABBREVIATIONS

A^0	:	Angstrom
BS	:	Base saturation
^0C	:	degree Celsius
cmol (p^+) kg^{-1}	:	Centimole positive charge per kilogram
CEC	:	Cation exchange capacity
COLE	:	Coefficient of linear extensibility
dS m^{-1}	:	desi Siemens per meter
EC	:	Electrical conductdivity
et al	:	and others
kg ha^{-1}	:	kilograms per hectare
LCC	:	Land capability class
Mg m^{-3}	:	Megagrams per cubic meter
NBSS & LUP	:	National Bureau of Soil Survey and Land Use Planning
%	:	per cent
PBS	:	Per cent base saturation
ppm	:	parts per million
sp	:	species
USDA	:	United States Deaprtment of Agriculture

ABSTRACT

Name of the author	:	**J. RADHA KRISHNA**
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Eight profiles from Turlapadu, Jaggapuram, Edlapadu, Solasa, Kondaveedu, Changeej Khan Peta, Boyapalem and Timmapuram villages of Edlapadu mandal of Guntur district, Andhra Pradesh were studied. Four were red soil profiles and other four were from black soil areas. Soil samples from each horizon were described in the field and characterized in the laboratory. Surface soil samples were also collected from sixty locations throughout the madnal for fertility evaluation. Based on the morphology, physical, physico-chemical, electro-chemical and chemical properties of the soils, the soil profiles were classified as per USDA soil taxonomy.

The study area was confined to semi-arid cliamte with well-defined dry and wet periods. The red soils were formed and developed on weathered

granite-gneiss at higher elements of topography whereas, the black soils were occurring on granitic gneiss parent material mixed with calcareous murram relatively at lower elements of topography. The red soil profiles were relatively more weathered than black soil profiles.

The colour varied from gray to very dark gray in black soil profiles and reddish brown to dark reddish brown in red soil profiles. The texture was loam to clay loam and clay loam to clay in red and black soil profiles, respectively. The structure of black soil profiles was mostly granular in surface, sub-angular or angular blocky in lower layers in red and black soil profiles.

Granulometric data indicated that the black soils had lower and higher percent of sand and clay content, respectively than red soils. The ratios of different fine earth fractions revealed, absence of lithological discontinuity among the adjacent horizons in red and black soil profiles. The black soils had recorded higher water holding capacity, volume expansion and sticky point than the red soils.

The CEC, base saturation, saturation of bases (calcium, magnesium, sodium and potassium) and CEC/clay ratios were higher in black soil profiles compared to red soil profiles.

The results of physico-chemical properties revealed that the red soils were neutral to slightly alkaline in reaction. The soils were non-saline and non-calcareous. The black soils were slightly alkaline to strongly alkaline, non-saline and slightly to moderately calcareous in nature.

The chemical composition of soil samples exhibited the siliceous nature of the soils by the broad and large silica/sesquioxides and silica/alumina ratios. These molar ratios were relatively narrower in black soils than in red soils. While the alumina/iron oxides ratios were higher in black soil profiles than in red soil profiles.

The soils of the mandal were low in organic carbon, low in available nitrogen, medium in available phosphorus, high in available potassium, sufficient in available sulphur and micronutrients except zinc, which was deficient in both red and black soils.

From X-RDA, it was clear that black soil clays were dominated by montmorillonite, with small quanities of illite and kaolinite, while red soil clays had illite, kaolinite and montmorillonite type of clay minerals. Small amount of quartz was also recorded in clays of certain soil profiles.

Black soil profiles were having the moderate limitations of soil (restricted drainage, fine texture and vertic features) besides the influence of semi-arid climate. Red soil profiles were formed on higer elements of topography having slight to moderate limitation of erosion and semiarid climate. Hene, the black soil profiles were grouped under IIIsc land capability sub-class and red soil profiles were grouped under land capability sub-class IIIec.

The taxonomic units of the eight soil profiles were as following.

Black soils:

Profile 1: Very - fine, montmorillonitic, isohyperthermic, Chromic Haplustert

Profile 2: Fine, montmorillonitic, isohyperthermic, Typic Haplustept

Profile 4: Very - fine, montmorillonitic, isohyperthermic, Typic Haplustert

Profile 8: Fine, montmorillonitic, isohyperthermic, Leptic Haplustert

Red soils:

Profile 3: Loamy, mixed, isohyperthermic, Typic Haplustalf

Profile 5: Loamy, mixed, isohyperthermic, Typic Haplustept

Profile 6: Loamy, mixed, isohyperthermic, Typic Haplustept

Profile 7: Loamy, illitic, isohyperthermic, Typic Haplustalf

CHAPTER I

INTRODUCTION

Soil is the most vital and precious natural resource for the existence of mankind. Of late, the pressure on this vital resource has increased to such an extent that the relationship between the living beings and the soil has become critical. This has resulted in various kinds of land degradation, environmental pollution, and decline in crop productivity and sustainability. As per the estimates of NBSS & LUP, 187.7 m.ha land area (57 per cent of total geographical area) in the country is degraded. Moreover, the one billion plus population is expected to reach 1.4 billions by 2025 requiring about 315 mt of food grains (compared to 210 mt at present) with a projected decrease in per capita land availability to 0.08 ha from 0.15 ha at present (Tripathi *et al.,* 2006). Declining land to man ratio happening in the wake of increasing population necessitates optimal utilization of finite resources like soil.

This can be achieved by adopting the advancements of science and technology to inventorise and characterize the soil to suggest optimum land use planning and input management techniques.

India has a geographical area over 328 m.ha with different types of soils. Red and lateritic soils occupied an area of 172.2 mha and balck soils covering an area of 73.5 m.ha (Sarkar, 2005). Andhra Prtadesh had wide variety of soils ranging from low fertile coastal sands to highly productive deltaic alluviums (Rao *et al.,* 1995), occupying 18 percent of of the total geographical area, out of which, 66 per cent are red and laterite soils and 25 per cent black soils (Raman *et al.,* 1985).

Edlapadu mandal of Guntur district in Andhra Pradesh is comprised of red and black soils. Edlapadu madnal has an extent of 18233 ha with 11008 farm holdings. More than 70 per cent were marginal farmers. The soils of the mandal have got agricultural importance as these soils are under food, vegatable and commercial crops cultivation. The major crops grown are cotton, chillies, redgram, and maize. No serious attempt has been made to give impetus on soil – site characteristics and classification. Information available on this aspect to give recommendations for optimum and sustainable utilization of soil resource is scanty. Keeping in mind the agricultural potential of these soils, the present investigation has been taken up to characterize and classify the soils in a scientific way with the following **objectives**:

1. **To study the morphological, physical and chemical characteristics of red and black soils**

2. **To classify red and black soils based on soil taxonomy of USDA, and**

3. **To study the fertility status of the soils.**

CHAPTER II

REVIEW OF LITERATURE

The study area consists of both red soils and black soils. The information available on red soils and black soils is reviewed and presented under the following heads.

1. Soil formation
2. Soil characterization
3. Soil classification
4. Available nutrient status of soils

2.1 SOIL FORMATION

2.1.1 Factors of Soil Formation

2.1.1.1 Climate

Development of red and black soils under dry sub-humid climate and semiarid climate in Karnataka was reported by Rudramurthy *et al.* (1997). The laterites, red loams and black soils of Karnataka were formed under the influence of semi-arid, sub-tropical and sub-humid climate (Reddy and Shivaprasad, 1999). Basavaraju *et al.* (2005) studied the Alfisols and associated soils of Chandragiri mandal which were formed under semi-arid monsoon climate with annual rainfall of 1221 mm, mean annual, maximum and minimum temperatures of 31.9, 32.1 and 27.8^{0}C, respectively. Thangasamy *et al.* (2005) studied the soils which included red and associated soils of Sivagiri micro-watershed of Chittoor district in Andhra Pradesh which were developed under semi-arid monsoon climate with mean annual precipitation of 1215 mm and mean annual temperature of 31.5^{0}C.

Black soils of India were occurring under a wide climatic conditions ranging from arid to moist sub-humid conditions (Murthy *et al.,* 1982). Occurrence of black soils under varied conditions of temperate to tropical climate was noticed by Daijingyu *et al.* (1999) in Jilin province of China. Singh *et al.* (2001) indicated that Vertisols of Rajasthan were developed under semi-arid climate with 787 to 1089 mm annual rainfall. Deep black soils of Wardha district, Maharashtra were formed in tropical dry sub-humid monsoon type climate with annual rainfall of 934 mm (Kadao *et al*., 2003). The mean annual, maximum and minimum temperatures were 26.0, 32.6 and 19.4 ^{0}C, respectively. The soil moisture and temperature regimes were ustic and hyperthermic*,* respectively. Vertisols, vertic sub-group Inceptisols and their associated soils of central India were developed under sub-humid tropical climate (Maji *et al.,* 2005).

Dutta *et al.* (2001) considered the Alfisols of Anantapur district as paleosols, which might have been formed in the earlier sub-humid to humid climate of quaternary period and persisted in the present day aridic / semi-aridic climate. Sarkar *et al*. (2001) found the occurrence of sequence of Alfisols formed under hot dry tropical sub-humid climate influenced by ustic soil moisture regime and hyperthermic soil temperature regime in lower outlier of Chotanagapur plateau. The pedoclimatic environment indicated well-expressed alternate brief wet cycle followed by longer dry cycle with strong desiccation. Alfisols and Inceptisols of Ethiopia were formed in a typical sub-humid climate

(Nagassa and Gebrekidan, 2003). According to Sharma *et al.* (2004) Haplustalfs of Neogal watershed in northwest Himalayas were developed under warm sub-humid to humid eco-region. Udic soil moisture regime and hyperthermic soil temperature regime were characteristics of semi-arid to sub-humid sub-tropical monsoonic climate of the Alfisols developed in eastern region of Uttar Pradesh (Singh and Agarwal, 2005).

2.1.1.2 Parent material and lithosequence

It was stated by Ramaiah and Raghavendrachar (1936) that the origin of black and red soils in close proximity was due to the variation in mineralogical composition of the parent rock. According to them black soils were originated from rocks rich in soda lime feldspars and the red soils on rocks rich in potash feldspars (Rudramurthy and Dasog, 2001). Red and black soils were developed on dharwar rock system in Karnataka (Rudramurthy *et al.,* 1997). Reddy and Shivaprasad (1999) reported development of red loams and black soils on gneiss / schist and basalt, respectively in Western Ghats of Karnataka.

Vertisols of Andhra Pradesh were formed on different parent materials and the soils were having more or less uniform chemical composition (Subbaiah and Manickam, 1989). Hirekurubar *et al.* (1991) reported the development of Vertisols in some parts of India having granite gneiss as parent material. Formation of Vertisols on different parent materials like shale, limestone, charnockite, granite, and granite-gneiss was reported by Surekha *et al.* (1997) in India. Bharambe *et al.* (1999) found the occurrence of Vertisols due to weathering of trap rock rich in iron, lime and magnetite along with augite in Majalgao canal command area of Maharashtra. The black soils in Jabalpur district were originated from a variety of parent materials including granite/gneiss (Gupta *et al*., 2003). Singh *et al.* (2001) reported that Vertisols of Rajasthan were derived from the alluvia of gneissic complex and basalt. According to Kadao *et al*. (2003), the swell – shrink soils of Wardha district were developed on basaltic alluvium. Bandyopadhyay *et al.* (2004) noticed the development of Vertisols on basalt and calcic – gneiss parent material. Singh *et al.* (2004) reported the formation of Vertisols on calcic-gneiss complex and basaltic complex in Rajasthan. The black soils of Nasik district of Maharashtra were developed on basaltic parent material, as per the reports of Balapande *et al.* (2007).

Alfisols of Anantapur district were developed on granite-gneiss parent material (Dutta *et al.,* 1999). The geology of Anantapur district of Andhra Pradesh was mainly granites and gneiss of Archean period over which the red soils were developed (Dutta *et al.,* 2001). The formation of red and associated black soils on basalt, granite-gneiss and chlorite schist from Bidar, B'Gudi and Mantagani in north Karnataka were reported by Rudramurthy and Dasog (2001). Toposequence of Alfisols was developed in old alluviums underlained by granite - gneiss in lower outlier of Chotanagpur plateau (Sarkar *et al.,* 2001). In Bako region of Ethoipioa, tertiary and quaternary rhyolite and basalt were the major rock types (Nagassa and Gebrekidan, 2003) over which red soils were developed. Sharma and Kumar (2003) reported that Alfisols and Inceptisols of Himachal Pradesh had developed on gneiss, granite, phyllite, slate, sandstone etc. According to Patil and Prasad (2004), red soils of Dindori district, Madhaya Pradesh were developed on laterite-capped basalt. The Alfisols of Chandragiri mandal, Andhra Pradesh were formed on calcareous murram and granite-gneiss parent material (Basavaraju *et al., 2*005). Thangasamy *et al.* (2005) reported the development of Alfisols and Inceptisols over granite-gneiss and quartzite parent materials in Sivagiri micro-watershed of Andhra Pradesh.

The less siliceous nature of the substratum of Alfisols of eastern region of Uttar Pradesh was reported by Singh and Agarwal (2005) based on high silica content and its ratio with alumina and sesquioxides in surface layer than in sub-surface layers.

2.1.1.3 Topography and toposequence

Topographical situations associated with different moisture and drainage conditions were instrumental in bringing the changes in properties of Entisols, Inceptisols, Alfisols and Vertisols of Rajamahal trap of Bihar (Tiwary *et al.,* 1989). Red and yellow soils were developing on uplands while black soils on mid and lowlands. Red soils and their associated soils were studied by Rudramurthy and Dasog (2001) in north Karnataka and concluded that it was mostly drainage as conditioned by relief, which had played a role in their genesis.

Coulombe *et al.,* (1996) indicated the Vertisols developed on higher elevation were shallower than the ones developed on lower elevations which were deep. The Vertisols of Wardha district were formed at a slope of 1 to 3 per cent with slight erosion and moderate well-drainage (Kadao *et al*., 2003). Reddy *et al.* (2004) observed the Vertisols and soils of vertic properties formed on 1 to 3 per cent slopes in eastern Maharashtra plateau. According to Gabhane *et al.* (2006), the Vertisol and Inceptisol pedons were developed on 1 to 3 per cent slope while Entisol pedons on 3-5 per cent slope in Vidarbha region of Maharashtra. The Vertisol pedons of Nasik district were developed on gently sloping (1-3 per cent slope) lands (Balapande *et al.,* 2007)

From the studies of soils of Hyderabad, India, Nagelschmidt *et al.* (1940) concluded that red soils were generally formed in the upper elements of undulating topography. Dutta *et al.* (1999) observed occurrence of Alfisols in gently sloping and undulating uplands of Anantapur district. Sarkar *et al.* *(*2001) identified the occurrence of sequence of Alfisols in lower outlier of Chotanagpur formed over very gently sloping lands to gently undulating interfluves with slope of 0 to 5 per cent. The Alfisols and Inceptisols of Bako, Ethiopia were occurring in topographic positions from gently undulating to dissected hills with slopes varying from 5 to 7 per cent (Nagassa and Gebrekidan, 2003). These soils were influenced by slight to moderate erosion and were well-drained. Soils on high land and medium land, both under irrigated and un-irrigated conditions were Alfisols, whereas soils in low land situation were transitional soils, belonging to Inceptisoils in Hirakud command of Orissa (Taha and Nanda, 2003). The red soils of sub-mountane zone of Maharashtra were developing on undulating topography (Chunale, 2004). Singh and Agarwal (2005) studied the Alfisols occurring in eastern region of Uttar Pradesh and found that they are formed on a slope of 0-3 per cent. The red soils and their associated soils of Sivagiri micro-watershed were formed over nearly level to gently sloping topography (Thangasamy *et al.,* 2005). Nikam *et al.* (2006) reported the existence of Haplustalfs at a slope of 1-3 and 3-5 per cent in Nagpur district of central India.

2.1.1.4 Vegetation

Natural vegetation for the development of black soils (Vertisols) was not an important factor (Coulombe *et al.*, 1996). Naitam and Bhattacharyya (2004) identified the natural vegetation occurring in shrink-swell soil areas of sub-humid tropics of India as *Acacia, Zizyhpus jujuba, Madhuca indica, Cynodon dactylon, tectonia sp., Butca sp.,* various bushes and shrubs. In the black soil zone of southern agro-eco sub-region of Andhra Pradesh, Rao *et al.* (2004) found the natural vegetation like *Prosaphis,* babul, palmyra etc.

According to Baral *et al.* (2000), the natural vegetation existing in red clay soils of Nepali middle hills comprised of *Shorea robusta, Scima wallichii* and *Phoenix sylvestris.* Prasad *et al.* (2001) found the existence of natural vegetation like babul, palas, charolio etc., in red soil areas of Nagpur district of Maharashtra. Kurihara *et al.* (2002) observed the occurrence of red soils under deciduous broad-leaved forest vegetation. Swarnam *et al.* (2004) reported that natural vegetation of Sahibi basin of Haryana and Delhi was *Acacia arabica, Azadirachta indica, Dalbergia sisoo, Prosopis julifera, Calotropis procera and Saccharum munja*. High precipitation and coniferous type of vegetation were favourable for the formation of argillic horizon (Pradeepkumar and Verma, 2005). The natural vegetation of red and associated soils of Sivagiri micro-watershed of Andhra Pradesh comprised of grasses, *Prosopis julifera, Parthenium* sp.*, Tridax* sp., mango, neem etc., (Thangasamy *et al.,* 2005).

2.1.1.5 Pedological time

Digar and Barde (1982) reported that it was during the Archean period, the red soils were formed, whereas the black soils were developed during

Cenozoic era, which included tertiary and quatenary periods (Coulombe *et al.*, 1996). The red soils of Zaheerabad region of Andhra Pradesh were found to be moderately weathered and were medium aged due to presence of weatherable minerals (Srivastava *et al.*, 2000).

The ancient plateau was exposed for long ages to denudation and had approached pediplanation over which the paleosols of south India were formed (Dutta *et al.,* 2001). Pal (2005) made a case study of highly weathered ferruginous soils of tropical India and suggested that formation of Alfisols and Ultisols and their pedogenic threshold supported that steady state might existed in soils developed over long periods of time not only spanning a few hundreds to thousands of years but also millions of years. Singh and Agarwal (2005) recognized advanced stage of development of Alfisols of eastern region of Uttar Pradesh based on the silica content and silica alumina ratio in the surface than in the sub-surface.

2.1.2 Soil Forming Processes

Generally soil forming processes lead to additions, losses, translocations and transformations of various constituents in the soil profile (Singh and Agarwal, 2003). Pal *et al.* (2006) indicated that clay illuviation was more important than pedoturbation in the development of shrink-swell soils of central India. A time of a century was not adequate for the formation of slickensides that were hitherto considered to be rapid pedogenic process for structure formation of Vertisols.

2.1.2.1 Red soils

Sheet wash and retreat of hill slopes were the major geomorphic processes responsible for sculpturing of the present day landforms (Bhan and Bhatnagar, 1974) in paleoslols of south India under semi-arid to arid conditions. It was well established that the soils in tropical areas were formed due to desilication, leaching, illuviation, dessication and lateral movement of soil solute along the slopes (Peterschmitt *et al.,* 1996). Dutta *et al.* (1999) stated that clay illuviation as one of the major soil forming processes in the red soils of Anantapur, which was identified by the presence of clay films in the Bt horizon. Based on the micro-morphology of endopedons, Walia *et al.* (2000) pointed out that the dominant processes of soil formation in red soils were decomposition, synthesis, bruanification, eluviation and illuviation, and loosening as evident from mineral alteration, weathering and iron accumulation, argillans, porosity and structure. Gleization seemed to be active on level flood plains, while argillopedoturbation in undulating flood plains. According to Kurihara *et al.* (2002), the dark red soils of Kunimidake series derived from andesite parent material were formed due to hydrothermal action of volcanism, while chloritization was the main pedogenic process occurring in the paleo-red soils of Nyu mountains (Kurihara *et al.*, 2003). Patil and Prasad (2004) while studying the red soils of Dindori district of Madhya Pradesh, observed that laterization as the main process of soil formation. According to Singh and Agarwal (2005), illuviation, lessivage and calcification were the dominant processes responsible for the development of Alfisols of eastern region of Uttar Pradesh.

2.1.2.2 Black soils

According to Ellis *et al.* (1994), podzolization was the pedogenic process operating in some black soils of north east Pakistan. Pedoturbation or churning was a fundamental process in the formation of soils with vertic character (Mermut *et al.*, 1996). Argillopedoturbation was operating in development of black soils on dharwar rock system in Karnataka (Rudramurthy *et al.,* 1997). In Intramountane basins, southwest Nepal, Bronger *et al.* (2000) found rubification as process leading to the formation of black soils. Lakshmi *et al.* (2001) recorded wider molar ratios of silica - sesquioxides and silica – alumina in the black soils of Bapatla-Karlapalem mandals of Andhra Pradesh and concluded that silication might be the dominant process operating in the soils. Development of varied particle size in soils formed on basaltic terrain in central India might be attributed to the transportation of finer particles and partly because of active churning process resulting from swelling and shrinking nature of clay minerals (Maji *et al.,* 2005).

2.2.1 Soil Morphometrics

2.2.1.1 Horizons and horizonation

Hajare and Madal (2003) recognized Ap, A2, Cr; Ap, Bw1, Bw2, Bw3, Cr; and Ap, Bw, Bss1, Bss2, BCk sequence of horizons in different shrink – swell soils of central India. Kadao *et al*. (2003) demarcated the black soil pedons of Wardha district into Ap, AB, Bw, Bss1, Bss2, Bss3; Ap, Bw, BC1, BC2, BC3; Ap, Bw1, Bw2, Bw3, Bw4, BC; Ap, Bw, BC, 2C1 based on the morphological features. Chinchmalatpure *et al.* (2005) reported Ap, Bw1, Bw2, C; Ap, A12, Bss1, Bss2 and BC horizon sequence in certain black soils of

Gujarat. In the black soil pedons of Nasik district of Maharashtra, Balapande *et al. (*2007) demarcated the horizons Ap, Bw, Bss, Cr; Ap, Bw, Bss1, Bss2, And Bss3 in sequence.

Nagassa and Gebrekidan (2003) identified Ap, Bt1, Bt2, Bt3, C horizons in Alfisols and Ap, Bw1, 2Bw2 horizons in Inceptisols of Bako area. The horizon sequence observed by Singh and Agarwal (2005) in Alfisols of eastern region of Uttar Pradesh was Ap, Bt1, Bt2, and 2Bt3. Nikam *et al.* (2006) reported A, Bt and Cr horizon demarcation in Haplustalf pedons of non-vertic shallow soils of Nagpur district of central India.

2.2.1.2 Boundary between adjacent horizons

Ermia *et al.* (2002) described the boundary between horizons of Vertisol of Italy as diffuse smooth and gradual wavy.

Nagassa and Gebrekidan (2003) described the boundary between different horizons of Bako soils as abrupt smooth, gradual smooth, clear wavy and clear smooth. The boundary between the adjacent horizons was clear smooth or gradual smooth in Alfisols of eastern region of Uttar Pradesh (Singh and Agarwal, 2005).

2.2.1.4 Soil colour

Walia and Rao (1997) stated that the variation in colour in soils occurring in toposequence appeared to be the function of chemical and mineralogical as well as textural make up of soils and conditioned by topographical position and moisture. Gupta *et al.* (2003) reported that soils of granitic terrain formed on lower topography exhibited very dark grayish brown to very dark gray colour (Typic Haplusterts) whereas, those occurring on middle were very dark grayish brown (hue 10YR) but subsurface horizons were dark gray to dark grayish brown (Vertic Ustochrepts). The colour of Typic Haplustalfs was dark grayish brown up to 24 cm depth and in Bt horizon it varried from pale brown to brownish yellow colour. The colour of soils of Chandragiri mandal was varying from 10YR 3/1 to 2.5YR 3/6 in different horizons of Alfisols and their associated soils (Basavaraju *et al.,* 2005). The morphological features of red and black soils of Vidarbha region were shallow to deep with colour hue 10YR, value ranging from 3 to 6 and chroma 1 to 3 except in few pockets of red soils (Gabhane *et al.,* 2006). The soils were very dark grayish brown to dark brown in colour.

All the pedons of black soils exhibited hue of 10YR throughout the profile whereas redder hues (5YR and 2.5YR) in red soil pedons in north Karnataka (Rudramurthy and Dasog, 2001). Chroma in red soils was often 3 and 4, whereas, in black soils it was 2 or less in upper part of the solum, which was suggestive of poor internal drainage. The colour of the black soil pedons was in hue 10YR, with value varying from 3 to 5 and chroma 2 to 3 (Kadao *et al*., 2003). The pedons having higher clay content and restricted drainage were relatively darker than other pedons. The dark brown to very dark brown (10YR hues) of black soils was due to the moist condition prevailing for longer period favouring reduction of iron, under the influence of impeded drainage conditions (Maji *et al.,* 2005). 10YR 3/3, 10YR 3/2 and 10YR 3/1 were Munsell colour notations recorded by Balapande *et al.* (2007) in the Vertisol profiles of Nasik district.

The release of iron from weathering in the form of iron oxides imparted the soils a redder hue (Evans and Frazmeir, 1986; Schwertmann, 1993; Peterschmitt *et al.,* 1996) in the paleosols of south India. Bhaskar and Subbaiah (1995) observed large variation in pattern of laterites and associated soils of east coast of Andhra Pradesh, which could be due to the differences in relief and consequent transportation of weathered products. Higher redness rating index showed greater soil development and soils in the gently sloping uplands showed greater pedogenic development (Dutta *et al.,* 1999). The colour became redder with increasing age as indicated by the index, which showed the highest in soils of Archean age, intermediate in Pleistocene age and the lowest in Holocene age (Nayak *et al.,* 1999). The CEC/clay ratio decreased in subsurface horizons with increasing age. Dutta *et al.* (2001) reported that the colour of paleosols of south India were varying from hue of 5YR to 2.5YR due to formation of iron oxides from the iron released by weathering influenced by climate (high rainfall and temperature). The soil colour variation (10YR 6/2 to 2.5YR 4/6 to 2.5Y 6/1) indicated release of iron oxides and their occurrence in various hydrated forms due to difference in internal drainage as influenced by the topography (Sarkar *et al.,* 2001). The dark reddish colour was due to better drainage in higher slopes. The surface horizons of Bako soils were somewhat darker in colour than the sub-surface horizons (Nagassa and Gebrekidan, 2003). According to these scientists the colour notation of these soils was varying from 2.5YR 2.5/4 to 10YR 3/2 under moist condition and 2.5YR 3/6 to 5YR 4/6 under dry condition. The Haplustalfs of Neogal watershed in northwest Himalayas were having colour notation of 10YR 4/3, 4/4 and 5/4 (Sharma *et al.,* 2004). In the Haplustalfs of eatern region of Uttar Pradesh the colour was varying from 10YR 5/2 to 2.5Y 4/2 in different horizons (Singh and Agarwal, 2005).

2.2.1.5 Nodules, calcretes and concretions

Lime nodules in Vertisols developed from calcic gneiss complex were formed due to the precipitation of calcium, magnesium and bicarbonate liberated as result of *in situ* weathering of carbonate rock, using fragments of calcic gneiss nuclei. In contrast, nodules, fragments of basalt as nuclei were formed from precipitation of calcium, magnesium and bicarbonate obtained from weathering of limestone band associated with Vindhyan system (Singh *et al.,* 2003). Basavaraju *et al. (*2005) observed strong effervescences from soils of Chadragiri mandal with dilute HCl test due to presence of calcretes. Calcretes of few, medium to fine size were recorded by Singh and Agarwal (2005) in different horizons of Alfisols of eastern region of Uttar Pradesh which released slight to violent effervescences with dilute HCl test.

2.2.1.6 Soil texture

Gupta *et al*. (2003) reported that the soils of granitic terrain of Jabalpur developed on lower and middle topographic positions had clayey texture whereas, the soils on upper topographic positions exhibited sandy clay loam texture. The higher clay content might be due to its topographic position (lower), which favoured the accumulation and retention of bases thus promoting the formation of smectite.

Kadao *et al*. (2003) stated that although all the pedons were developed on same parent material, the texture of Vertisols of Wardha varied from loamy sand to clay in different horizons owing to physiographic position and paleochannels. Certain black soil pedons had coarse fragments more than 15 per cent. The texture of soils of basaltic terrain of central India was finer because of fine-grained basaltic parent material (Maji *et al.,* 2005).

The texture of the Bako soils was varying from loam to clay through sandy clay loam and sandy clay in different horizons of Alfisols (Nagassa and Gebrekidan, 2003). According to Singh and Agarwal (2005), the texture of Alfisols of eastern region of Uttar Pradesh was sandy clay loam, clay loam or loamy sand in different horizons.

2.2.1.7 Soil structure

According to Harikrishnan and Koshy (1983), the development of soil structure to a greater extent was governed by the particular cation dominating the soil complex, and the better structural development in the red soils of Kerala was attributed to the presence of calcium. Different types of structure (granular, crumb, sub-angular blocky and angular blocky) was observed by Basavaraju *et al.* (2005) in red and associated soils developed on granite-gneiss and calcareous murram.

The strong to medium, moderate sub-angular to angular blocky structure in black soils might be due to swell-shrink phenomenon of smectite clay present in these soils resulting in the development of slickensides (Coulombe *et al.,* 1996). As per the reports of Kadao *et al*. (2003), the Vertisols of Wardha district exhibited typical angular blocky structure particularly in the sub-soils and others had dominantly sub-angular blocky structure. The strength of the peds was varying from moderate to strong and the size from medium to coarse. Gabhane *et* al*.* (2006) described the structure of Vidharbha region as sub-angular blocky type in shallow soils, while the surface soils of remaining soils had sub-angular type with well-developed angular blocky structure in sub-surface horizons. The surface structure of Vertisols of Nasik was moderate medium sub-angular blocky which gradually changed to moderate strong angular blocky in the zone of pressure faces or coarse strong angular blocky in slickensides zone (Balapande *et al.,* 2007).

The structure of Alfisols of Bako, Ethiopia was described by Nagassa and Gebrekidan (2003) as moderate coarse sub-angular blocky, moderate medium sub-angular blocky, weak medium sub-angular blocky, strong coarse sub-angular blocky, and moderate coarse angular blocky in different horizons of Alfisols and Inceptisols. Singh and Agarwal (2005) found weak fine granular, medium moderate sub-angular blocky or strong coarse angular blocky structure in Alfisols of eastern region of Uttar Pradesh. Soil structures were dominantly moderate medium to coarse sub-angular blocky, most likely as a result of low clay content and dominance of bivalent calcium and magnesium on soil complex resulting in well flocculation.

2.2.1.8 Soil consistence

Sureshkumar *et al* (2001) described the consistence as friable in Typic Ustorthents and very friable in Typic Haplustepts of Puralia district, West Bengal. According to Nagassa and Gebrekidan (2003) the consistence of Alfisols and Inceptisols of Bako soils was varying from slightly hard to hard, very friable to friable and slightly sticky to slightly plastic under dry, moist and wet conditions, respectively. Due to low or medium content of clay, the Alfisols of eastern region of Uttar Pradesh were friable in consistence favouring good aggregation (Singh and Agarwal, 2005).

2.2.1.9 Vertic properties

Vertic features under differing moisture regimes were recorded particularly in soils of the foothill and low-lying areas of Amensis sub-catchment of Hirna watershed in Ethiopia by Gebrekidan and Mishra (2005).

The absence of slickensides even with high COLE values of deep black soils of basaltic terrain of Maharashtra indicated that formation of slickensides was a function of lateral and confining pressures (Wilding and Tessier, 1998). Lack of slickensides in the deep black soils of basaltic landform of Mahrashtra was attributed by Paranjape *et al.* (1999) to the young nature of soils as evidenced by the poor plasma separations. Swelling and shrinking smectite needed to continue at least for 550 years after stabilization in the valley.

Coefficient of linear extensibility was a direct measurement of swell-shrink potential (Thomas *et al.,* 2000) of Vertisols dominated by smectitic type of clay minerals. Naitam and Bhattacharyya (2004) reported the COLE values of sub-humid tropics of India varying between 0.13 and 0.27. Singh *et al.* (2004) noted that COLE values and F_2O_3 / clay ratios of Vertisols were ranging from 0.13 to 0.19 cm/cm and 1.2 to 9.1 and concluded that these two parameters were the mirror image of the modifications of vertic properties. The COLE values were varying between 0.105 and 0.172 cm/cm for the surface samples of Vertisols of different locations in India and all the soils fall in the category of very high (greater than 0.09) swell-shrink class (Nayak *et al.,* 2006). The COLE values had a significant positive relationship with 2:1 expanding clay content and pH values.

Ratnam *et al.* (2001) stated that rice growing Vertisols were darker in colour and developed wider cracks than non-rice growing soils. More than 5 mm wide cracks, pressure faces and slickensides close enough to intersect were associated with the morphology of deep black soils of Wardha district, according to Kadao *et al*. (2003). Vertic properties like 3 to 5 mm wide cracks and indistinct slickensides were described by Basavaraju *et al*. (2005) in the Inceptisols formed on plains in Chandragiri mandal of Andhra Pradesh. Mohanty *et al.* (2006) observed significant effect of puddling on crack parameters of Vertisols. The magnitude of cracks increased with increase in puddling intensity. For reduction of cracking after rice harvest in Vertisols, the wheat residue of the previous crop could be retained.

In addition to angular blocky structure, the Vertisols showed well-developed intersecting slickensides in Vidarbha region (Gabhane *et al.,* 2006). These slickensides zone had wedge shaped aggregates and angular blocky structure resulting due to shrink – swell phenomenon of smectitic clay.

2.2.1.10 Cutans

Process of illuviation and formation of clay cutans were observed by Patil and Dasog (1999) in the ferruginous soils of Western Ghats and coastal region of north Karnataka.

Thin and patchy cutans were recorded by Kumar *et al.* (2001) in some lateritic soils classified under Alfisols. Presence of clay skins and cutans as thin to thick, patchy argillans were recognized by Sarkar *et al.* (2001) in lower layers of Alfisols of Chotanagpur plateau. Basavaraju *et al. (*2005) noticed thick patchy cutans developing into argillans in Alfisols of Chandragiri mandal, Andhra Pradesh.

2.2.2 Physical Characterization of Soils

2.2.2.1 Particle size distribution

Comparatively low silt content of red, yellow and black soils of Rajamahal trap of Bihar was suggesting that the chemical composition of the rocks and minerals were active (Tiwary *et al.,* 1989). Gradual increase of clay content with depth was reported in saline alkali soils of Akola district by Puranik *et al.* (1972). Sand content decreased while silt and clay contents increased down the depth of black soils developed on old mica rich landscape of Bihar (Mishra and Ghosh, 1995). Coarse fragments content was more in red soils than that in associated black soils (Rudramurthy and Dasog, 2001). Percent increase in content with depth was more in red soils compared to their black counterparts possibly due to less shrink-swell activity in the former. It was observed by Gabhane *et al.* (2006) that most of the soils (red and black) of Vidarbha region were clay in texture, with clay content ranging from 34.4 to 73.4 per cent and it increased with depth in all the pedons except in AC horizons.

Dominance of secondary over primary minerals in fine earth fraction of paleosols of south India was indicated by lower silt /clay ratios (Dutta *et al.,* 2001). The lithological discontinuity between adjacent horizons as result of several erosion and deposition cycles was indicated by sand / silt and fine sand / total sand ratios. The coarser fractions (42.8 to 87.2 per cent sand) dominated in paleosols, which could be largely of siliceous nature because of granite-gneiss parent material (Wadia, 1985; Simonson, 1994). The dominance of coarser fractions in BC and C horizons of forest soils of north Karnataka might be due to siliceous nature of the granite-gneissic parent material (Dutta *et al.*, 2001).

Gradual migration of clay was reported by Sarkar *et al. (*2001) in Alfisols of Chotanagpur resulted in increase in clay content down the depth. The increase in clay content in argillic horizons could be attributed to vertical migration or translocation of clay (Sarkar *et al.,* 2002). Satyavathi and Reddy (2003) attributed the increase in clay content with depth of red soils of northern Telangana region to vertical migration of clay and translocation of clay to lower horizons. The surface enrichment of sand fraction was due to eluviation and surface run-off. The sand, silt and clay contents were varying from 16 to 60, 6 to 34 and 26 to 64 per cent, respectively in different horizons of Alfisols and Inceptisols of Bako soils, according to Nagassa and Gebrekidan (2003). Wide textural variations in texture, sand and clay content in soils of Chanrdragiri mandal could be due to difference in parent material, physiography, *in situ* weathering and translocation of clay (Basavaraju *et al.,* 2005). The high clay content in the red soils of Chandragiri mandal was attributed to deposition of finer fractions in the plains from the uplands. The enrichment of clay in Bw horizon was primarily due to *in situ* weathering of parent material. Sand constituted the bulk of mechanical fraction, which could be attributed to physical weathering. The clay content in Alfisols of eastern region of Uttar Pradesh was widely varying from 7.5 to 32.6 in different horizons and it increased with depth (Singh and Agarwal, 2005). The sand / silt ratios of some Alfisols of Indo-Gangetic alluvial plains were in between 1.01 and 3.80 and clay content was increased in the solum (Verma *et al.*, 2007).

Hajare and Mandal (2003) analyzed 9.0 to 52.5, 12.5 to 31.9, and 35.5 to 61.5 per cent of sand, silt and clay content, respectively in some black soils of central India. Kadao *et al*. (2003) observed coarse fragments mainly consisting of calcretes that increased with depth in deep black soils of Wardha district. The coarse fragment content ranged from 0.7 to 44.4 per cent on v/v basis. In these soils the sand and clay content was varying from 2.00 to 83.6 and 9.2 to 75.4 per cent, respectively. The Vertisol pedons had clay content more than 67 per cent throughout the profile with a tendency to increase with depth. A maximum of 75.4 per cent clay was recorded in one of the Vertisol pedon in Bss3 horizon at a depth of 0.92 to 1.26 meters. The particle size class was very fine, fine, coarse loamy, fine loamy, or clayey over sandy in different pedons of this district. The Vertisols derived from calcic-gneiss complex contributed to relatively high clay content than those derived from basaltic complex of Rajasthan (Singh *et al*., 2004). Chinchmalatpure *et al. (*2005) analyzed 13.4 to 65.0, 6.9 to 38.6 and 26.6 to 58.2 per cent of sand, silt and clay, respectively in certain black soils of Bharuchi district of Gujarat. In Vertisol pedons of Nasik, Balapande *et al.* (2007) recorded clay content of 58.5 to 67.0, silt content of 25.3 to 28.3 and sand content of 7.7 to 19.6 per cent in black soils of Nasik district. The silt and sand content were decreased while clay content increased with depth. These soils also contained coarse fraction varying between 1.4 and 11.7 per cent. As reported by Nayak *et al.* (2006), the sand, silt and clay contents in surface soils of Vertisols of different locations in

India were varying from 14.9 to 34.5, 19.2 to 29.3 and 43.5 to 61.0 per cent, respectively.

2.2.2.2 Water holding capacity

The water holding capacity of Vertisols of Majalgao canal command area of Maharashtra was varying from 54 to 69 per cent (Bharambe *et al.,* 1999). Kadao *et al*. (2003) reported that the water retention in black soils of Wardha was more dependent on clay content in different horizons.

Basavaraju *et al. (*2005) recorded 15.43 to 52.34 per cent of water holding capacity in red and associated soils formed on granite-gneiss and calcareous murram. Thangasamy *et al.* (2005) reported that the water holding capacity of Alfisols of Sivagiri micro-watershed was varying between 25.50 and 46.64 per cent in different horizons.

The soils having more clay and organic matter retained more moisture in Bako soils (Nagassa and Gebrekidan, 2003). Durgude *et al* (2004) found that water retentivity was significantly and positively correlated with clay, silt+clay, CEC and exchangeable Ca + Mg but negatively correlated with sand content in soils of Mohol Agricultural Research station, Solapur.

As per the reports of Nayak *et al.* (2004), the sand content had negative relationship while clay or clay + silt content had positive relationship with water retention characteristics of saline black soils of Gujarat state. Balapande *et al.* (2007) found relationship between water retention and soil properties. As the contribution of clay towards retention was highly significant, the effect of organic carbon decreased with depth but clay was increased in the Vertisols of Nasik district.

2.2.2.3 Volume expansion and sticky point

In black soils of Bapatla – Karlapalem mandals, the volume expansion and moisture at sticky point were increasing with depth (Lakshmi *et al.,* 2002). Prakash and Rao (2002) observed increasing values of volume expansion and moisture at sticky point with depth in both red and black soils of Krishna district, Andhra Pradesh. Ramesh *et al.* (2004) studied the physical properties of red and black soils of Singarayakonda mandal of Andhra Pradesh and reported that volume expansion in red soils was in between 4.25 and 5.80 and in black soils between 25.6 and 34.5 per cent. The moisture at sticky point in red soils and black soils varied from 13.35 to 17.9 and 31.3 to 42.0 per cent, respectively. Both these values were increasing with depth in red and black soils.

2.2.2.4 Bulk density

Increase in bulk density of the soils with depth might be due to over-burden pressure causing compaction in the sub-surface layers (Ahuja *et al.,* 1988), while the surface soils were less compact probably due to high amount of organic matter and plant root concentration (Coughlan *et al.,* 1986).

The bulk density of black soils of Wardha district was varying from 1.49 to 1.86 Mg m^{-3} in different horizons of pedons, which was showing increasing trend in deep black soils. Maji *et al.* (2005) interpreted that variation in bulk density of the swell-shrink soils might be attributed to moisture content and high content of expanding type of clay minerals. The bulk density values were varying between 1.70 and 1.76 Mg m^{-3} in the Inceptisols and Vertisols of catenary soils of central India, which increased with depth (Mandal *et al.,* 2003). The bulk density values of surface samples of Vertisols of different locations in India were in between 1.66 and 1.80 Mg m^{-3} (Nayak *et al.,* 2006). Balapande *et al.* (2007) recorded the bulk density of Vertisol profiles of Nasik district ranging from 1.57 to 1.73 Mg m^{-3} which showed increasing trend with depth.

The bulk density of the some of the soils of Bako was varying from 1.16 to 1.57 Mg m^{-3} and it showed increasing trend in soils of farmer's fields and virgin lands (Nagassa and Gebrekidan, 2003). The red and associated soils of Chandragiri mandal showed increased bulk density with depth varying from 1.34 to 1.64 Mg m^{-3} (Basavaraju *et al.,* 2005), which could be due to finer particles and overhead weight of surface soils. Varying bulk density of 1.35 to 1.61 Mg m^{-3} was reported in the Alfisols of eastern region of Uttar Pradesh by Singh and Agarwal (2005). It increased with depth due to decrease in organic matter content, more compaction and less aggregation.

2.2.3 Electrochemical Properties

2.2.3.1 Soil pH

Rudramurthy and Dasog (2001) recorded strongly acid to neutral pH in red soil pedons and neutral to strongly alkaline reaction in black soils of north Karnataka. The increase in pH down the depth might be due to dominance of exchangeable Mg^{++} and Na^{+} (Singh and Agrawal, 2003).

The pH of the Alfisols of Chotanagpur plateau was in between 4.5 and 7.0 and the higher pH values in lower slopes were due to deposition of illuvial bases and clay from surrounding upper slope (Sarkar *et al.,* 2001). According to Nagassa and Gebrekidan (2003), the soils of Bako were acidic and the pH ranged from 5.2 to 6.8 in different horizons of Alfisols and Inceptisols. They also observed increase in pH with depth. The lower soil pH value recorded in the surface soil was due to continuous removal of basic cations by high yielding crop varieties, use of acidifying fertilizers and intensive cultivation. The pH of the Alfisols profile of eastern region of Uttar Pradesh was varying from 7.3 to 7.8, which showed increasing trend with depth (Singh and Agarwal, 2005). The high pH was due to presence $CaCO_3$ in these soils.

Hajare and Mandal (2003) found that the pH of black soils of central India varying from 7.6 to 8.9 among different horizons and the pH increased witrh depth. The pH of the black soils ranged between 7.9 and 8.4 (moderately to strongly alkaline) owing to the presence of basic rich clay particles (Kadao *et al*., 2003). The soils at lower physiographic position had high pH and the pH of the soils of Vertisols and vertic sub-group was varying from 8.2 to 9.2 (Srivastava *et al.,* 2004). Chinchmalatpure *et al.* (2005) recorded pH of salt affected black soils of Gujarat that ranged between 7.1 and 9.1. The pH of the Vertisol profiles of Nasik district was varying between 8.0 and 8.9 among different horizons, which increased with depth (Balapande *et al.,* 2007). The increase in pH with depth was attributed to nature of parent material, $CaCO_3$ content and alkaline earth materials. In general, the pH of the red and black soils of Vidarbha region increased with depth as reported by Gabhane *et al.* (2006).

2.2.3.2 Soluble salt concentration (EC)

Electrical conductivity was lower in red soils compared to their black counterparts, which suggested that red soils were better leached than black soils (Rudramurthy and Dasog, 2001). There was not much variation in EC values of Vertisols and Inceptisols of catenary soils of central India (Mandal *et al.,* 2003). The EC varied between 0.19 and 0.25 dS m^{-1}, and the values increased with depth.

The EC of different horizons of black soils of central India was varying from 0.10 to 0.27 dS m^{-1} as per the reports of Hajare and Mandal (2003). According to Chinchmalatpure *et al.* (2005), the salt affected black soils of Gujarat were having EC_e of 0.80 to 16.88 dS m^{-1} in different horizons and the salt content increased with depth. The EC values of Vertisol of Nasik district were not high and were varying between 0.17 and 1.22 dS m^{-1} (Balapande *et al.,* 2007) .

As per the reports of Basavaraju *et al.* (2005), the EC values of red and associated soils of Chandragiri mandal were very low varying from 0.1 to 0.21 dS m^{-1}. An EC of as low as 0.09 dS m^{-1} was recorded by Singh and Agarwal (2005) in Alfisols of eastern region of Uttar Pradesh, which increased up to 0.45 meters depth. EC was increased with depth and followed the trend of clay (Rudramurthy and Dasog, 2001) in red and associated black soils of north Karnataka.

2.2.3.3 CEC, base saturation and exchangeable bases

Since the CEC was the charge behaviour of soils where clay was the fundamental block contributing towards its cation exchange, the high CEC of the soils was attributed to its smectitic clay mineralogy (Pal and Deshpande, 1987).

In the Alfisol pedons of Western Ghats of Karnataka, the base saturation was varying from 60 to 97 per cent according to Reddy and Shivaprasad (1999). Dutta *et al.* (2001) analysed the base saturation of Alfisols of Anantapur district, which varied from 24 to 80 per cent. As per the reports of Nagassa and Gebrekidan (2003), the CEC of Bako soils (Alfisols and Inceptisols) was varying from 11.00 to 36.00 cmol (p^+) kg $^{-1}$soil, while base saturation from 34 to 67 per cent. The CEC of the soils varied markedly both among and within pedons. The Alfisols of Bangalore rural district were characterized by Pillai and Natarajan (2004) by remote sensing technique and reported that CEC was varying from 1.24 to 25.54 cmol (p^+) kg^{-1} soil while base saturation from 46 to 100 per cent in different horizons. According to Basavaraju *et al. (*2005), the CEC values of different horizons of Alfisols and their associated soils were related to the clay content and varying between 1.02 and 32.19 cmol (p^+) kg^{-1} and the per cent base saturation from 63.81 to 94.75. Ca followed by Mg, Na and K dominated the exchange complex. The CEC and base saturation of Alfisol profiles of eastern region of Uttar Pradesh was varying between 14.0 and 18.6 cmol (p^+) kg^{-1}; 87.6 and 93.5 per cent, respectively. The dominant exchangeable cation was calcium followed by magnesium, sodium and potassium (Singh and Agarwal, 2005). In the Alfisols of Sivagiri micro-watershed of Andhra Pradesh, Thangasamy *et al. (*2005) reported CEC and base saturation varying from 3.19 to 45.13 cmol (p^+) kg^{-1} and 31.53 to 89.3 per cent, respectively.

The CEC of shrink – swell soils of central India was varying from a minimum of 25.18 to a maximum of 55.46 cmol (p^+) kg^{-1} soil, whereas the content of exchangeable bases like calcium, magnesium, sodium and potassium ranged from 26.3 to 49.5, 6.42 to 11.19, 0.22 to 0.54 and 0.11 to 0.63 cmol (p^+) kg^{-1} soil among different horizons (Hajare and Madnal, 2003). Kadao *et al*. (2003) reported CEC of black soils of Wardha district as very high ranging from 8.70 to 72.20 cmol (p^+) kg^{-1} and the CEC data followed the trend of clay distribution in the profiles. The CEC of shrink-swell soils of central India varied from 19.3 to 68.1 cmol (p^+) kg^{-1}, CEC to clay ratio from 0.45 to 1.40 and ESP from 0.2 to 25.3 (Srivastava *et al.,* 2004). Chinchmalatpure *et al. (*2005) reported CEC of salt affected black soils of Gujarat ranging from 15.7 to 42.2 cmol (p^+) kg^{-1} soil, whereas the ESP of different horizons in these soils was in between 3.2 and 41.7. The CEC and PBS showed increasing trend with depth in the Inceptisols and Vertisols of catena of central India (Mandal *et al.,* 2003). According to the reports of Gabhane *et al.* (2006), the CEC of soils of Vidarbha region ranged between 51.16 and 62.98 cmol (p^+) kg^{-1}. Generally the soils with lower amount of clay content had lowest CEC values. The soils exhibited slight variation in their per cent base saturation and it varied from 90.95 to 99.24 per cent. The soils derived from basaltic landscape of central India were highly base saturated and the CEC was quite high (Pal *et al*., 2006). High CEC and COLE values in shrink -swell soils of central India indicated the dominance of smectite clay minerals. Balapande *et al.* (2007) recorded CEC and BSP varying from 38 to 59 cmol (p^+) kg^{-1} and 87.7 to 98.1, respectively while exchangeable calcium from 13.7 to 44.1, magnesium from 6.83 to 20, sodium from 0.9 to 4.59 and potassium from 0.46 to 2.91 cmol (p^+) kg^{-1}. The exchangeable sodium and magnesium had increasing trend with depth.

Sarkar *et al.* (2001) found significant positive correlation (r = 0.85) between clay and CEC of soils (Alfisols) of Chotanagpur plateau. The exchangeable cations calcium, magnesium, sodium and potassium were exhibiting increasing trend with depth.

The CEC/clay ratios (values) indicated that black soils were less weathered than red soils (Satyavathi and Reddy, 2003). Higher ratios were due to less weathered nature of the soils with weatherable primary minerals.

2.2.3.4 Organic carbon content

The organic carbon content of black soil pedons of central India was ranging between 0.31 and 0.81 per cent in different horizons and the content decreased with depth (Hajare and Mandal, 2003). Kadao *et al*. (2003) had observed more organic carbon (5.5 to 8.7 g kg^{-1}) in surface layers of black soils of Wardha district and it decreased in sub-surface and sub-soils to a minimum of 1.4 g kg^{-1}. As per the reports of Chinchmalatpure *et al. (*2005), the organic carbon content of Fluventic Haplustepts and Typic / Udic Haplusterts was low, decreased with depth and ranged between 0.03 and 0.24 per cent in different horizons. Nayak *et al. (*2006) recorded 3.0 to 5.3 g kg^{-1} of organic carbon content in surface soils of Vertisols collected from different locations in India.

The surface horizons of Bako soils had higher organic carbon and the values decreased with depth in all the pedons (Nagassa and Gebrekidan, 2003). The low organic carbon content was due to the intensive cultivation. The relatively higher organic carbon content in surface soils was due to addition of plant residues and FYM (Basavaraju *et al., 2*005). The low organic matter content of Alfisols of eastern region in Uttar Pradesh was attributed to high rate of decomposition in sub-tropical climate of the region (Singh and Agarwal, 2005).

2.2.3.5 Total nitrogen content

The total N content of Vertisols of Jamalgao canal command area was varying between 0.03 and 0.07 per cent (Bharambe *et al.,* 1999). The distribution of total N followed the trend of organic carbon in Bako soils and it ranged from 0.4 to 0.33 per cent in different horizons (Nagassa and Gebrekidan, 2003).

2.2.3.6 Carbon nitrogen ratio

The C: N ratio of Vertisol pedons of Jamalgao command area was in between 6.0 and 13.5 and showed decreasing trend with depth (Bharambe *et al.,* 1999). Nagassa and Gebrekidan (2003) reported that the C: N ratios of Bako soils were varying between 9.2 and 17.9 in different horizons of Alfisols and Inceptisols. They also noted that this ratio gradually decreased with depth of the soil.

2.2.3.7 Calcium carbonate content

Hazare and Mandal (2003) reported 0.4 to 18.6 per cent of calcium carbonate in black soils of central India and the content increased with depth. The calcium carbonate content of black soils of Wardha district was varying in between 2.00 and 19.8 per cent in different horizons and, in general the content increased with depth (Kadao *et al*., 2003). The amount of calcium carbonate content varied from 0.9 to 19.9 per cent in salt affected black soils of Gujarat (Chinchmalatpure *et al.,* 2005). The soils developed over basaltic terrain in central India had high calcium carbonate content ranging from 50 to 248 g kg^{-1} (Maji *et al.,* 2005). It was also observed that carbonate content increased with depth and this might be due to leaching of bicarbonate from upper layer during the rainy season and their subsequent precipitation as carbonate in the lower layer. The increasing trend of calcium carbonate content was found to be associated with decreasing topographic situations. Calcium carbonate values of 7.5 to 85.5 g kg^{-1} were recorded in the surface soils of Vertisols in different locations of India, according to Nayak *et al. (*2006). Balapande *et al.* (2007) reported 16.2 to 22.7 per cent of calcium carbonate content in the Vertisol profiles of Nasik district, Maharashtra.

Thangasamy *et al. (*2005) recorded 1.25 to 10.8 per cent of calcium carbonate content in different horizons of Alfisols of Sivagiri micro-watershed of Andhra Pradesh.

2.2.4 Chemical Composition of Soils

2.2.4.1 Silica sesquioxides

Accoridng to Tiwary *et al.* (1989), the silica, aluminia, iron oxides and sequioxides content of different horizons of red, yellow and black soils of Rajamahal trap of Bihar were ranging between 49.7 and 73.3; 9.9 and 28.8; 6.8 and 18.9; 20.8 and 45.7 per cent, respectively.

Accordign to Manjulatha *et al.* (2001), the silica-alumina and silica – sesquioxides ratios showed decreasing trend with depth in Alfisols and Vertisols, in general. Molar ratios of silica / alumina, silica / iron oxides, silica / sesquioxides were broad in the red and black soils of Singarayakonda mandal of Andrha Pradesh and these ratios indicated the siliceous nature of the soils (Ramesh *et al.,* 2004).

Singh and Agarwal (2005) reported silica, aluminia, iron oxides and sequioxides content of different horizons of Alfisols of eastern region of Uttar Pradesh which varied from 66.5 to 80.0, 4.5 to 16.8, 1.3 to 5.2 and 5.8 to 22.0 per cent, respectively, while the SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios were in between 5.62 and 25.51; 6.73 and 30.22, respectively. Illuviation of clay, alumina and iron oxides had lead to fairly high silica, silica alumina ratio and silica sequioxides ratio in surface soils than in sub-surface soils. Alumina content was negatively correlated with silica and sand content. Silica content was decreased in Bw and Bt horizons due to illuviation, which reflected in decreased molar ratios of silica alumina, and silica sesquioxides ratios down the depth.

2.2.4.2 Total macronutrient content

Tiwary *et al.* (1989) reported the per cent of oxides of Ca, Mg and K of the red, yellow and black soils of Rajmahal trap of Bihar and values were ranging between 0.9 and 5.6; 0.3 and 3.8 and 0.1 and 1.4 per cent for CaO, MgO and K_2O, respectively.

Madhuvani *et al.* (2001) surveyed the black soils of Vatticherukuru mandal of Andhra Pradesh and reported that the distribution of total N, P, K and S was more or less uniform throughout the depth of the pedons and the values ranged from 220 to 925, 153 to 482, 2125 to 7876 and 98 to 315 mg kg^{-1}, respectively. The surface horizons of all the pedons invariably recorded higher values than the sub-surface layers.

The total CaO, MgO and K_2O content of different horizons in Alfisols of eastern region of Uttar Pradesh was varying from 1.0 to 6.5, 0.4 to 0.5, 1.7 to 2.4 per cent, respectively (Singh and Agarwal, 2005). The Cao, MgO and K_2O contents put together were less than five per cent indicating moderate weathering of these soils.

2.2.4.3 Total micronutrient content

Madhuvani *et al.* (2001) surveyed the black soils of Vatticherukuru mandal of Andhra Pradesh and reported that the variation in the total content of micronutrients among the pedons might be due to variation in parent material, organic carbon and clay content of the soils. The total zinc, manganese and copper contents showed decreasing trend with depth.

The distribution of total content of zinc, copper, manganese and iron was governed by the soil forming processes (Sharma *et al.,* 2005). They were eluviated from the surface horizons and illuviated into the argillic horizon in harmony with the formation of Alfisols.

2.2.5 MINERALOGY OF SOIL CLAY FRACTION

2.2.5.1 Red soils

The relative quantity of different clay minerals of clay fraction of some Alfisols of northern Bihar indicated the dominant amount of illite followed by kaolinite (Mall and Mishra, 2000). The present environment having neutral to alkaline soil reaction and high base saturation was not conducive for the formation of kaolinite. As such, clay sized kaolinite in the present environment seemed to be inherited from the parent materials. The clay mica was found to be most predominant mineral inherited from parent materials. The existing pedo-chemical environment was favourable for transformation of mica to smectite (Mall and Mishra, 2000).

The clay fraction of Alfisols of Sivagiri micro-watershed of Andhra Pradesh, was constituted by smectite (21 to 56 per cent), kaolinite (40 to 64 per cent), mica (4 to 15 per cent) and traces of quartz (identified by 0.42 nm diffraction peak) (Thangasamy *et al.* (2004). They attributed that genesis of smectite due to retention during Pliopleistocene transition period, kaolinite might have been formed from montmorillonte and mica from alteration of minerals. Based on X-ray diffraction pattern, Singh and Agarwal (2005) found illite as the dominant mineral in the clay fraction of Alfisols followed by kaolinite. Direct conversion of mica to kaolinite might be one of the causes.

The CEC / clay ratios of different horizons of Alfisols of Chotanagpur plateau were in between 0.13 and 0.43 and Sarkar *et al.* (2001) had grouped the clay under mineralogical class ‘mixed’. The CEC / clay per cent varied from 44 to 54 indicating mixed mineralogy in Ultic Haplustalfs of Bhubaneswar (Nayak *et al.*, 2002). The CEC / clay ratio (0.39 to 0.59) indicated the mixed mineralogy in some Alfisols and Inceptisols of wet temperate zone of Himachal Pradesh (Sharma and Kumar, 2003).

2.2.5.2 Black soils

The fine clay fraction of non-vertic deep black soils of basaltic terrain was dominated by smetites with very little amounts of kaolin and mica (Paramjape *et al.,* 1999). The clay fraction of Vertisols of Rajasthan comprised of smectite, illite, kaolinite and vermiculite (Singh *et al.,* 2001). Smectite, illite and kaolinite contents in Bss horizon were 274.2, 359.9 and 197.8 g kg^{-1} in Vertisols developed on gneissic alluviums, while Vertisols formed on basaltic alluviums contained 60.5, 59.2 and 56.8 g kg^{-1} in Bss horizon, respectively. Kadao *et al.* (2003) reported smectitic mineralogy in the clay fraction of most of the black soils of Wardha district. They also noticed mixed mineralogy in some pedons in these black soils.

Rudramurthy *et al. (*1997) observed development of black soils on dharwar rock system at the base of the slope. The soil eroded from upper level might had accumulated at the base of slope and due to impeded drainage at the base of the slope leaching of bases was inhibited which might have been favoured the synthesis of montmorillonite. The X - ray diffraction analysis showed that the fine clay fractions of Vertisols of different locations of India were dominantly smectitic (62 to 85 per cent) with small amount of illite and kaolinite except in Salusterts (Nayak *et al.,* 2006). Based on CEC /clay ratio of black soils of Krishna district, Babu *et al.* (2002) identified the presence of smectite, illite and kaolintie.

Ratnam *et al.* (2001) stated that rate of formation of smectitic clay was hastened due to puddling in rice growing Vertisols than in non – rice growing Vertisols.

Raina *et al.* (2006) studied sand and clay mineralogy of salt affected soils of Uttar Pradesh and presence of quartz in the clay faction was evident from 4.26 Å peak in X-RDA. The clay mineral make up of salt affected soils of Uttar Pradesh mainly consisted of illite, kaolinite, chlorite and mixed layers. Illite was the dominant fraction and its occurrence was attributed to alteration and transformation of potash feldspar and mica. Mica (illite) was the dominant clay mineral in the clay fraction of Inceptisols of salt – affected soils of southwest Punjab (Singh and Sawhney, 2006). The relative similarities in the mineralogy of these alluvium derived soils irrespective of the degree of pedogenesis suggested that all clay minerals were inherited from parent material with very little *in situ* transformation.

2.3 SOIL TAXONOMY

2.3.1 Diagnostic Horizons and Features

2.3.1.1 Epipedons

The presence of ochric epipedon in Alfisols of Chotanagpur plateau was reported by Sarkar *et al.* (2001) due to light colour and low organic matter content. Kadao *et al*. (2003) recognized ochric epipedon in shrink – swell soils of Wardha district, Maharashtra based on colour and other diagnostic features. Presence of ochric epipedon was observed by Singh and Agarwal (2005) in Alfisols of eastern region of Uttar Pradesh. Balapande *et al.* (2007) observed ochric horizon as the diagnostic surface horizon in soils of Nasik district.

2.3.1.2 Endopedons

In the lower piedoment plains of sub-humid ecosystem of Kahsmir region the soils were comparatively well-developed and showed presence of structural B (cambic horizon) as well as clay cutans (argillic horizon) (Mahapatra *et al.,* 2000). Occurrence of cambic horizon was reported by Hajare and Mandal (2003) in swell – shrink soils of central India. The black soils of Wardha district were exhibiting cambic horizon below the surface horizon (Kadao *et al*., 2003) due to alteration of parent material.

Nagassa and Gebrekidan (2003) identified argillic horizons Bt1 to Bt3 in sub-surface of Alfisols and cambic horizons Bw1 and Bw2 in Inceptisols of Bako soils. Bhaskar *et al.* (2004) found increased clay content in B horizon showing the formation of argillic / kandic horizon even in the soils of high altitudes. Cambic horizon and argillic horizon were endopedons recognized by Singh and Agarwal (2005) in soils eastern region of Uttar Pradesh.

2.3.1.3 Diagnostic features

Deep wide cracks and slickensides were the diagnostic features observed by Prasad *et al.* (2001) in the shrink swell soils of Nagpur. Soil Survey Staff (2003) reported that the appearance of slickensides or wedge – shaped aggregates as the unifying morphogenitic marker in all Vertisols and their vertic intergrades.

Pillai and Natarajan (2004) described the presence of features relating to Kanhaplic great group in certain Alfisols. Balapande *et al.* (2007) reported ustic moisture regime and isohyperthermic temperature regime of soils of Nasik district, Maharashtra.

2.3.1.4 Classification of black soils

Prasad *et al.* (2001) classified the typical swell-shrink orange supporting soils of Nagpur district into Typic Ustorthents, Typic Haplustepts and Typic Haplusterts. Black soils developed on granite-gneiss were classified under sub-group, Typic Calciusterts by Rudramurthy and Dasog (2001). Vadivelu and Sarkar (2001) suggested to classify the dark clay soils of sub-humid region under Vertic / Lithic Haplustoll instead of grouping under Lithic / Vertic Ustochrepts like soils of dry semi-arid region. Hazare and Mandal (2003) had reported that shrink – swell soils of central India were belonging to great groups Lithic Ustorthents, Vertic Haplustepts, or Typic Haplusterts.

Some of the deep black soils of Wardha district were classified by Kadao *et al*. (2003) which were more than 50 cm deep with cracks, having more than 30 per cent clay and slickensides (greater than 25 cm thick zone) into Vertisols. Up to great group level these soils were classified as Typic Haplusterts, Typic Haplustepts, or Fluventic Haplustepts.

The black soils of Telangana region of Andhra Pradesh were studied by Satyavathi and Reddy (2004) which were belonging to very-fine, smectitic, isohyperthermic, Typic / Chromic / Sodic Haplusterts or clayey-skeletal, smetitic, isohyperthermic, Vertic Calciustepts / Hplustepts. Nayak *et al.* (2004) reported taxonomic groups of typical saline black soils of Gujarat state as fine-loamy, mixed, hyperthermic Typic Ustorthents or fine, mixed, hyperthermic Typic / Vertic Haplustepts. Some of the salt affected black soils of Gujarat

State were classified by Chinchmalatpure *et al. (*2005) under great groups Fluventic Haplustepts, Typic / Udic Haplusterts, and Typic Halaquepts.

As per the reports of Mandal *et al. (*2003), the catenary soils of central India were classified under Typic Rhodustalf, Lithic / Vertic Haplustetps, and Typic Haplusterts great groups. Nayak *et al. (*2006) studied the Vertisols of different locations of India, which were classified as fine, hyperthermic, smectitic families of different subgroups of Vertisols. These subgroups included Sodic / Typic / Halic Haplusters, Typic Natrusterts, and Aquic Salusterts. Balapande *et al.* (2007) classified some soils of Nasik district up to family level under very-fine, smectitic, Leptic / Typic Haplusterts. By virtue of presence of slickensides of more than 25 cm thick within 100 cm depth, wedge shaped aggregates, more than 30 per cent clay, and cracks, the soils were classified under Vertisols.

2.3.1.5 Classification of red soils

A new 'Ultic' sub-group was proposed by Dutta *et al. (*2001) under Rhodustalf great group for classifying the paleosols of south India.

Red soils developed on granite-gneiss were classified under sub-group, Typic Haplustalfs by Rudramurthy and Dasog (2001). The Alfisols of Chotanagpur plateau occurring in toposequence were classified under four different taxa - Ultic / Rhodic Paleustalfs, Aquic Haplustalfs, and Aeric Endoaqualfs down the topography (Sarkar *et al.,* 2001). The pedons of research farm and virgin lands of Bako, Western Ethiopia were classified as Hapludalfs and that of the farmer's fields as Dystruepts at great group level by Nagassa and Gebrekidan (2003).

The soils of Garakahalli watershed were classified by Pillai and Natarajan (2004) up to family category. The units were loamy – skeletal, mixed, isohyperthermic, Ultic Haplustalfs; fine, kaolinitic, isohyperthermic, Kanhaplic Haplustalfs; fine, kaolinitic, isohyperthermic, Kandic Palustalfs; and fine, kaolinitic, isohyperthermic, Rhodic Kandiustalfs.

Balaguravaiah *et al.* (2005) reported that red sandy loam soils of Anantahpur district, Andhra Pradesh under the taxonomic unit Rhodustalfs. Basavaraju *et al.* (2005) Classified the red soils of Chandragiri mandal of Andhra Pradesh into Typic Haplustalfs and Typic Rhodustalfs based on the morphology of the pedons. The Alfisols of eastern region of Uttar Pradesh were classified by Singh and Agarwal (2005) and they were grouped under family fine-loamy, mixed, hyperthermic Typic Haplustalfs. The red soils of Sivagiri watershed in Chittoor district of Andhra Pradesh, were classified up to family category as per USDA soil taxonomy by Thangasamy *et al. (*2005). The taxonomic units were fine-loamy, mixed, isohyperthermic, Typic Rhodustalf, and fine, kaolintic, iso-hyperthermic, Typic Haplustalf. Pal *et al*. (2006) classified the shrink- swell soils of central India as Vertic Haplustalfs. The soils under study had evidence of clay illuviation enriching the B horizon with clay and there were no slickensides or wedge shaped – peds within 100 cm depth so as to qualify for Vertisols.

Nikam *et al.* (2006) reported classification of some of the non-vertic shallow soils of Nagpur district under clayey, mixed, hyperthermic Typic Haplustalfs family. Verma *et al.* (2007) proposed new taxonomic units, Calcic Natrustalf and Sodic Haplustalf for the Alfisols of Indo-Gangetic alluvial plains.

2.4 AVAILABLE NUTRIENT STATUS

2.4.1 Available Macronutrient Status

Bharambe et al. (1999) recorded available P_2O_5 and K_2O content of Vertisol pedons of Jamalgao canal command area, which ranged between 9.6 and 28.8, 635 and 1252 kg ha^{-1}, respectively. Hajare and Mandal (2003) reported decreased available nitrogen content with depth in black soils of central India. The available N, P_2O_5 and K_2O content ranged from 24.21 to 97.33, 13.33 to 27.90, and 70.40 to 369.50 kg ha^{-1}, respectively. The sulphate sulphur content of shrink swell soils of certain locations in India varied between 48.6 and 377.6 ppm, as per the reports of Murthy (2004). Suresh (2005) reported that magnesium deficiency in dry lands induced by excess calcareousness caused interveinal reddening in cotton grown in Vertisols of Tamilnadu. Balapande *et al.* (2007) observed almost decreasing trend of available nutrient content with depth in the Vertisols of Nasik district. The available Cu, Fe, Zn and Mn were ranged in between 1.5 and 11.52; 3.1 and 8.74; 0.06 and 1.66; 7.16 and 25.5 mg kg^{-1} soil, respectively.

Considering the critical limit of available sulphur as 10 ppm, all the surface soils of Aflisols and Vertisols of rice growing soils of Tamilnadu were sufficient in available sulphur (Appavu *et al.,* 2002). The available S content had a positive association with pH, EC, lime, clay, silt, CEC and ESP.

Available N, P and K content in red and associated soils of Chandragiri mandal varied from 35.73 to 212.37, 7.0 to 37.34, and 100.00 to 315.00 kg ha^{-1}, respectively (Basavaraju *et al., 2*005). The low available nitrogen, deficiency of sulphur and medium level of phosphorus were attributed by them to low organic mater content, whereas high available potassium content to intensive weathering and application of K fertilizers. The surface soils of Alfisols of Sivagiri micro-watershed, Andhra Pradesh contained higher contents of organic carbon, available N, P, K and S than in the lower layers. The available S content varied from 31.1 to 31.8 mg kg^{-1}. The reason for higher content in the surface soils might possibly be the confinement of crop cultivation to the rhizosphere, mineralization, intense weathering and supplementing of the depleted nutrients through external sources (Thangasamy *et al.,* 2005).

Organic carbon and total N showed significant and positive correlation with sulphur (Sharma *et al.,* 2000). Meena *et al.* (2006) found existence of significant positive correlation between organic carbon and available nitrogen. Available N was negatively correlated with pH. Available P was positively correlated with organic carbon and clay and negatively correlated with pH. The retention of added P increased with an increase in clay content (Tisdale *et al.,* 1997). A significant positive correlation also existed between available K and organic carbon, which might be due to creation of favourable environment with the presence of organic matter.

2.4.2 Available micronutrient status

According to Bharambe *et al.* (1999), the available Zn, Fe, Cu and Mn contents in the Vertisols of Majaogao canal command area were ranging from 0.2 to 5.8, 5.8 to 15.8, 0.8 to 5.8 and 8.1 to 28.5 ppm, respectively. According to Satyavathi and Reddy (2004), the available Zn, Cu, Fe, and Mn were ranging from 0.22 to 1.88, 0.26 to 2.00, 2.00 to 62.00 and 6.00 to 57.00 ppm in black soils of Telangana region of Andrha Pradesh. Soil pH, $CaCO_3$, organic carbon content and particle size distribution had strong influence on the distribution of micronutrients in soils. Calcium carbonate decreased the availability of micronutrients owing to their insoluble hydroxides at high pH, contrasting to it organic carbon had positive influence due to complexation. Micronutients especially zinc deficiency was wide spread in the Vertisols of drylands (Suresh, 2005).

Dhage *et al.* (2000) surveyed the soils of Shevgaon tashil of Maharashtra to find the relation between micronutrient availability and soil properties and the statistical analytical data indicated that the availability of manganese was controlled by soil pH while copper content was positively correlated with organic carbon.

Gupta *et al.* (2003) reported that deficiency of micronutrients could either be primary, due to low total content of elements or secondary, caused by soil factors reducing their availability to plants. The availability of micronutrients to plants was influenced by their distribution within the soil profile. These micronutrients showed positive relation with organic carbon but were inversely related with soil pH and $CaCO_3$ content.

The analytical data on available micronutrient status of red and associated soils of Chandragiri mandal of Andhra Pradesh were reported by Basavaraju *et al. (2*005). All the samples were deficient in zinc, while copper and manganese were in between 0.19 and 0.94, 3.88 and 16.37 ppm, respectively. Mehra *et al.* (2005) had detailed studies on zinc and iron content of Haplustalfs of sub-humid southern plain and Aravalli hills of Rajasthan and concluded that iron and zinc deficiency was a major yield limiting factor in these Haplustalfs. Thangasamy *et al. (*2005) found decreasing trend of available iron and manganese with depth in the Alfisols of Sivagiri micro-watershed of Andhra Pradesh, which might be due to higher biological activity and organic carbon in the surface horizons.

Malewar (2005) studied the stresses of micronutrients in soils and crops and concluded that soil zinc would be most limiting micronutrient followed by copper. Deficiency of zinc was of higher order in Maharashstra followed by iron. Cereal-cereal based system appeared to be most exhaustive.

The DTPA extractable form of zinc arose from organic matter pool giving credence to the processes that involve solubilisation from mineral constituents, followed by appearance in solution form, and followed by complexation with the organic constituents (Sharma *et al.,* 2005a). Verma *et al.* (2005) observed significant positive correlation between DTPA extractable micronutrient cations and organic carbon whereas negative relation existed between micronutrient content and sand content in soils developed on different physiography. The complexing agents generated by organic matter promoted their availability, particularly Zn.

Meena *et al.* (2006) observed significant negative correlation between soil pH and available Cu. Positive correlation of Fe and Cu with organic carbon was attributed to the supply of chealting agents, while positive correlation of Fe and Cu with clay content due to increase in surface area for ion exchange and contributed to the extraction with DTPA. Balapande *et al.* (2007) found negative correlation between DTPA extractable micronutrients and pH in soils of Nasik district, Maharashtra.

Sharma and Chaudhary (2007) recorded higher available Zn, Cu, Fe, and Mn contents in surface horizons and the contents were decreased with depth in most of the soil series of lower Shiwaliks of Solan district. Organic matter content, EC and silt content were the properties playing major role in controlling the availability of Zn, Cu and Fe, however, Mn joined by two more factors, clay content and per cent base saturation.

As per the zinc deficiency map of India on the cover page of Journal Indian Society of Soil Science – volume 55 (1) 2007, 51 to 55 per cent soils of Andhra Pradesh were deficient in zinc.

CHAPTER – III

MATERIALS AND METHODS

3.1 COLLECTION OF PROFILE SOIL SAMPLES

The study area *i.e.,* Edlapadu mandal of Guntur district of Andhra Pradesh is having about 60 per cent black soils and 40 per cent red soils.

Eight representative profiles were selected for the present investigation, out of which four are red soil profiles and remaining four are black soil profiles. All the profiles were dug up to parent material / hard substratum after harvest of the crop when the fields were dry and fallow during May 2004.

All eight profiles were described for morphological characters as per the guidelines laid down in USDA Soil Survey Manual by Soil Survey Staff (1998). For laboratory characterization horizon – wise soil samples were collected from each profile. Control section samples were collected for clay mineral analysis (X – RDA). The meteorological data for the last eleven years *i.e.*, 1995 to 2005 were collected from RARS, Lam Farm, Guntur, which is about 20 km away from Edlapadu.

3.2 COLLECTION OF SURFACE SOIL SAMPLES

Sixty surface soil samples (0 to15 cm depth) were collected from the farmers' fields covering the whole mandal. Out of sixty surface soil samples, thirty are red and remaining thirty are black soil samples. The procedure given by Jackson (1973) was followed for the collection of surface soil samples.

3.3 PROCESSING OF SOIL SAMPLES

The profile and surface soil samples were air dried under shade, ground with wooden hammer, passed through 2 mm sieve and the sieved soil was used for laboratory analysis.

The surface soil samples were anlaysed for pH, EC, $CaCO_3$, organic carbon, available nutrients (N, P, K and S) and DTPA extractable micronutrients (Zn, Mn, Fe and Cu).

3.4 LABORATORY ANALYSIS

3.4.1 Physical Properties of Soils

3.4.1.1 Particle size analysis

The particle size analysis was carried out by international pipette method as described by Piper (1966).

3.4.1.2 Bulk density

Bulk density was determined by clod method as per the procedure given by Black and Hartge (1986).

3.4.1.3 Soil colour

Munsell colour notation of hue, value and chroma were observed and noted for both dry and moist soil samples (Soil Survey Staff, 1951).

3.4.1.4 Water holding capacity and volume expansion

These two physical parameters were determined by following Keen Raczkowski's method as described by Sankaram (1966).

3.4.1.5 Sticky point

Sticky point was determined by Sower's method as described by Singh (1980).

3.4.1.6 COLE (Coefficient of linear extensibility)

COLE values were calculated as per the formula given by Soil Survey Staff (1998).

3.4.2 Physico-Chemical Properties of Soils

3.4.2.1 Soil reaction (pH)

pH of the soil samples was determined by glass electrode pH meter (Jackson, 1973)in soil water suspension (ratio of 1 : 2.5).

3.4.2.2 Electrical conductivity (EC)

Electrical conductivity of the soil samples was determined in soil water suspension (ratio of 1 : 2.5) by using conductivity bridge (Jackson, 1973).

3.4.2.3 Organic carbon

Organic carbon content in the soil samples was determined by the chromic acid wet digestion method of Walkley and Black as described by Jackson (1973).

3.4.2.4 Total calcium carbonate ($CaCO_3$)

The calcium carbonate content of the soils was determined by treating the soil with known quantity of standard HCl and back titrating the unused acid with standard alkali (Hesse, 1971).

3.4.2.5 Cation exchange capacity (CEC)

Cation exchange capacity of the soils was determined as per the procedure given by Bower *et al.* (1952) and CEC was expressed as cmol (p^+) kg^{-1} soil.

3.4.2.6 Exchangeable bases (Na^+, K^+, Ca^{++} and Mg^{++})

Neutral normal ammonium acetate was used as an extractant for exchangeable bases from soil samples, by centrifugation as described by Bower *et al.* (1952). The Na^+ and K^+ contents were determined by flamephotometry. The exchangeable Ca^{++} and Mg^{++} were determined by volumetric method using versenate (Kanwar and Chopra, 1976).

3.4.2.7 Preparation of acid extract for total nutrients

Acid extract for total nutrients was prepared as per the procedure given by Hesse (1971).

3.4.2.7.1 Silica

The residue on the filter paper obtained during the preparation of acid extract was washed with warm double distilled water free of acid. Then the residue along with filter paper was ignited in a muffle furnace and weighed to a constant weight. From the weight of the residue the percentage of silica was calculated (Hesse, 1971).

3.4.2.7.2 Sesquioxides

Sesquioxides content was determined by using silica free acid extract as per the procedure given by Hesse (1971) and the results were expressed as per cent sesquioxides.

3.4.2.7.3 Iron oxides

The concentration of iron was estimated by aspirating the silica free acid extract to atomic absorption spectrophotometer and the results were expressed as per cent Fe_2O_3 (Hesse, 1971).

3.4.2.7.4 Alumina

Al_2O_3 content was calculated by deducting the Fe_2O_3 content from the total sesquioxides content (Hesse, 1971).

3.4.2.7.5 Calcium

Calcium was estimated by versenate titration method by taking a suitable quantity of sesquioxides free acid extract using Patton and Reeder's indicator in the presence of 16 per cent sodium hydroxide (Kanwar and Chopra, 1976) to maintain the pH.

3.4.2.7.6 Magnesium

Both calcium and magnesium were combinedly estimated in the same sesquioxides free acid extract by versanate titration using NH_4OH + NH_4Cl

buffer and EBT (Eriochrome Black – T) indicator. Magnesium titre value was obtained by substracting the calcium titre value from the comined titre value of calcium and magnesium (Kanwar and Chopra, 1976).

3.4.2.8 Total macronutrients

3.4.2.8.1 Nitrogen

Total nitrogen in the soil samples was estimated by modified Kjeldahl's method using sulphuric acid – salicylic acid mixture (Hesse, 1971).

3.4.2.8.2 Phosphorus

Total phosphorus content in the acid extract was determined as per the procedure given by Jackson (1973).

3.4.2.8.3 Potassium

Total potassium was estimated by aspirating the acid extract into flame photometer (Jackson, 1973).

3.4.2.9 Total micronutrients

Total micronutrients *viz.,* iron, copper, manganese and zinc were estimated by aspirating the silica free acid extract to atomic absorption spectrophotometer (Hesse, 1971).

3.4.2.10 Available macronutrients

Surface and profile soil samples were analysed for available macronutrients nitrogen, phosphorus, potassium and sulphur.

3.4.2.10.1 Nitrogen

Available nitrogen from soil samples was estimated by the alkaline permanganate method as described by Subbiah and Asija (1956).

3.4.2.10.2 Phosphorus

Available phosphorus content in the soils was extracted by employing Olsen's extractant as described by Olsen's *et al.* (1954) and phosphorus in the extract was determined by Murphy and Riley method using ascorbic acid as reducing agent as described by Watanabe and Olsen (1965) using spectrophotometer with red filter at 660 nm wave length.

3.4.2.10.3 Potassium

Available potassium in the soils was extracted by using neutral normal ammonium acetate and available potassium was determined by aspirating the extract into flame photometer (Jackson, 1973).

3.4.2.10.4 Sulphur (SO_4 – S)

Available sulphur in the soil samples was extracted with 0.15 per cent $CaCl_2$. $2H_2O$ solution as described by Williams and Steinbergs (1959) and available sulphur was estimated by turbidimetric method (Cottenie *et al.,* 1979).

3.4.2.11 Available micronutrients from surface and profile soil samples

20 grams of soil was shaken with 40 mL of DTPA extractant of pH 7.3 for 2 hours. The contents were filtered and in the filtrate available zinc, copper, iron and manganese were determined by using atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.5 CLAY MINERALOGY

3.5.1 Clay Separation

The clay fraction was separated from the soil samples as per the procedure given by Jackson (1979).

3.5.2 Preparation of Ca Saturated Clay

Suitable quantity of sodium clay suspension was transferred to a centrifuge tube and 30 mL of 1 N $CaCl_2$ solution was added. These contents were centrifuged for 5 minutes at 1500 rpm. This treatment was repeated twice and the Ca saturated clay was washed with methanol to remove excess calcium. Then the clay was transferred into a bottle using required quantity of distilled water to make two per cent clay suspension.

3.5.3 Preparation of K Saturated Clay

K saturated clay was prepared in the same way as Ca saturated clay by using 1 N KCl solution.

3.5.4 Preparation of Ca and K Saturated Clay Slides

The Ca and K saturated clay slides were prepared separately by spreading 1 mL of 2 per cent clay suspension on clear microscopic slides and allowed to dry at room temperature.

Thus the clay oriented parallel slides were prepared of the following treatments.

1. Ca - saturated at room temperature.

2. C a - saturated and glycerol solvated at room temperature.

3. K - saturated at room temperature.

4. K - saturated and heated to 550^0C.

3.5.5 X- Ray diffraction analysis (X-RDA)

The X-ray diffraction analysis was carried out on a Philips X – ray diffractometer (PW 1390 with C_0 K_α radiation obtained at a scanning speed of 2^0 2θ / minute).

3.6 PREPARATION OF SOIL TEST SUMMARIES

The analytical data of the soil samples were summarized for evaluating the general fertility status of the entire mandal.

3.6.1 Rating For Available Nutrient Status

The available nutrient contents of surface soil samples were categorized as per the rating given by Ramamoorthy and Bajaj (1969).

3.6.2 Computation and Classification of Nutrient Index

The nutrient indices were worked out as per the formula given by Parker *et al.* (1951).

$$NI = \frac{\begin{pmatrix}\text{No. of samples}\\ \text{falling under}\\ \text{low category x 1}\end{pmatrix} + \begin{pmatrix}\text{No. of samples}\\ \text{falling under}\\ \text{medium category x 2}\end{pmatrix} + \begin{pmatrix}\text{No. of samples}\\ \text{falling under}\\ \text{high category x 3}\end{pmatrix}}{\text{Total number of samples analysed for nutrients in the given area}}$$

The nutrient indices were classified as low, medium and high as per the ratings proposed by Ramamoorthy and Bajaj (1969).

3.7 STATISTICAL ANALYSIS

Various soil properties were tested for their correlation with one another as per the procedure given by Snedecor and Cochran (1980).

C H A P T E R – IV

RESULTS

The information and details of the study area about the site characteristics, morphometrics of the soil profiles, climatic data and soil analytical data are presented in this results chapter (chapter IV).

4.1 LOCATION OF THE STUDY AREA

The study area selected for the present study is Edlapadu madndal of Guntur district in Andhra Pradesh. Edlapadu mandal is situated between 16^0 10” N latitude and 80^0 13” E longitude. It is located at +55.15 meters above mean sea level. It comes under agroecological sub-region 7.3 (South Eastern Ghats) with code H6DmC(cd)5.

4.2 SITE CHARACTERSITICS

The information collected about the site characteristics is presented in table 1. Most of the area in this mandal was under cultivation. Hence, the study area was confined to cultivated lands. The geology was granitic – gneiss complex. The physiography / landform was varying from gently sloping to plain lands via sloping lands. The parent material of the study area was granitic-gneiss and in some places granitic gneiss was mixed with calcareous murram particularly in plain lands and low-lying areas.

4.3 METEOROLOGICAL DATA OF THE STUDY AREA

The meteorological data for the past 11 years from 1995 to 2005 are presented in table 2 and depicted in ombrothermic diagram (Fig. 2). The study area experienced semi-arid type of climate with clear-cut summer, winter and rainy seasons. Most of the rain was received during the months of June to October. The highest rain was recorded for the month of August with 192.91 mm. The winter season was confined to December and January particularly December with average minimum temperature of 17.06^{0}C during December. The average minimum temperature was found to be 22.91^{0}C, whereas maximum temperature was 34.07^{0}C. The main summer months were April, May and June with a highest temperature of 38^{0}C for the month of April. From the ombrothermic diagram, it was considered that June to November as wet period and November to May as dry period.

4.4 NATURAL VEGETATION AND LAND USE

Natural vegetation like neem, *Acacia, prosaphis, Borasus,* tamarind, palmyra, teak, soapnuts etc was dominated in the study area. The important crops cultivated in the area included cotton, chillies, maize, sorghum, orchards under rainfed conditions. Vegetable crops and flowering plants were also cultivated in some places (Table 3).

4.5 MORPHOLOGICAL DESCRIPTION OF SOIL PROFILES

Eight sites were selected in the study area covering the whole mandal. The locations were Turlapadu, Jaggapuram, Edlapadu, Solasa, Kondaveedu, Chageej Khan Peta, Boyapalem and Timmapuram. The morphology of profiles was described (appendix) and summarized in table 4 and 5, and depicted in figure 3 and 5. Profiles 1, 2, 4, and 8 were black soils, while profiles 3, 5, 6, and 7 were red soils (Fig 1).

4.5.1 Soil Colour

The colour of the red soils was reddish brown (5YR 4/4) under dry condition and dark reddish brown (5YR 3/4) under moist condition, while the black soils had colour varying from gray (10YR 5/1) to very dark gray (10YR 3/1) through dark gray (10YR 4/1) in different horizons and locations.

4.5.2 Soil Depth

The depth of the black profiles was ranging from 0.56 to more than 1.5 meters. In red soil areas (profiles 3, 5,6, & 7), the depth was in between 0.60 and 1.46 meters.

4.5.3 Number of Horizons

In black soil areas, six horizons were demarcated in profiles 1 and 4, five in profile 8 and four in profile 2. Five to six horizons were recognized in red soil profiles. All the profiles were characterized as A – B – C profiles.

4.5.4 Boundary Between Horizons

The boundary between the horizons varied from gradual to diffuse in black soil profiles whereas it was gradual, clear or abrupt in red soil profiles.

4.5.5 Soil Structure

The surface horizons exhibited mostly granular type of structure in most of the locations. The sub-surface horizons developed blocky peds either sub-angular or angular except in profile 3. In this profile the columnar structure was noticed (Plate 3).

4.5.6 Soil Texture

The textural class of fine earth fraction was mostly clay in black soil profiles, whereas in red soil profiles, it was sandy loam or loam in the surface horizons and loam or clay loam in sub-surface horizons. As far as coarse fraction (more than 2mm) was concerned, about 10-20 per cent gravel was recorded in red soil profiles while this fraction was less than 5 per cent in the black soil profiles.

4.5.7 Vertic Features

Vertic properties like surface cracks (Plate 8), slickensides (Plate 1 and 5), microknolls and microridges were developed in most of the black soil profiles (1, 4 and 8). Clay cutans were identified in some of the red soil profiles (Profile 3 and 7).

4.5.8 Reaction With Dilute HCl

Strong to violent effervescences were observed with dilute HCl test in black soil profiles while the effervescences were slight to strong in different horizons of red soil profiles. Many calcium carbonate nodules (calcrets) were formed in lower horizons of the profiles.

4.6 LABORATORY CHARACTERIZATION OF SOILS

4.6.1 Physical Characterization

4.6.1.1 Mechanical composition of soils

The data on fine earth fractions of the soil profiles are presented in table 6 and 7 and depicted in figures 5 and 6.

Among different profiles, red soil profiles recorded higher sand content (54.96 to 76.28 per cent), while black soil profiles had higher clay content (33.17 to 68.42 per cent). The silt content varied between 10.19 and 23.19 per cent in different horizons of all the profiles. Maximum coarse sand of 49.48 per cent was present in Ap horizon of profile 6 (red soil), while minimum content of 8.41 per cent was recorded in lower most horizon profile 4 (black soil). The fine sand content varied from 12.98 to 25.37 and 19.68 to 29.16 in black soil profiles and red soil profiles, respectively.

To confirm the presence or absence of lithological discontinuity among adjacent horizons in different soil profiles, the ratios of fine earth fractions were computed. Coarse sand to fine sand ratio was recorded in between 0.63 and 2.00 among different horizons. The red soil profiles (profiles 3, 5, 6, and 7) contained relatively higher sand / silt (3.33 to 7.19), silt / clay (0.50 to 1.30) and sand / (silt + clay) (1.22 to 3.22) ratios than black soil profiles (profiles 1, 2, 4, and 8). The sand / silt, silt / clay and sand / (silt + clay) ratios of black soil profiles were ranging from 1.51 to 2.25, 0.15 to 0.70 and 0.27 to 0.77, respectively.

4.6.1.2 Physical properties of soils

The data on physical properties like bulk density, COLE, water holding capacity, volume expansion and sticky point of soils are presented in table 8.

4.6.1.2.1 COLE

The shrinkage and swelling phenomenon was exhibited only by black soils. Hence coefficient of linear extensibility was determined for black soils. It ranged from 0.11 to 0.22. Among the black soils, profiles 1 and 4 recorded higher COLE values than profiles 2 and 8. All the black soils fall in the category of very high (greater than 0.09) swell-shrink class (Nayak *et al.,* 2006).

4.6.1.2.2 Bulk density

The bulk density values were ranging from 1.21 to 1.49 Mg m^{-3} in black soil profiles and the values ranged from 1.41 to 1.69 Mg m^{-3} in red soil profiles.

4.6.1.2.3 Water-holding capacity

Highest water holding capacity of 64.26 per cent was determined in Bss4 horizon of Solasa profile (deep black soil) while lowest of 20.87 per cent in Ap horizon of red soil profile (Profile 6). The black soil profiles recorded water-holding capacity of 40.56 to 64.26 per cent while red soils recorded 20.87 to 30.77 per cent water holding capacity in different horizons.

4.6.1.2.4 Volume expansion and sticky point

Volume expansion and sticky point values were ranging from 20.23 to 31.71per cent and 19.14 to 30.46 per cent, respectively in different black soil profiles. In red soil profiles, the percent volume expansion ranged from 3.08 to 6.90 and moisture percent at sticky point from 15.47 to 21.52.

4.6.2 Physico-Chemical Properties

The data pertaining to physico-chemical properties like pH, EC, organic carbon content, total N content, C/N ratio and calcium carbonate are presented in table 9.

4.6.2.1 Soil reaction

The pH of the soil profiles in different horizons was found to be varying from 7.0 to 8.7. Maximum pH was recorded in lower horizons of black soil profile 1, while minimum pH was registered in surface horizon of red soil profiles 3 and 7.

4.6.2.2 Soluble salt concentration

The electrical conductivity of the black soil profiles was ranging between 0.235 and 3.883 dS m^{-1}, while that of the red soil profiles from 0.098 to 0.480 dS m^{-1}.

4.6.2.3 Organic carbon content

Highest organic carbon content was recorded in the surface horizon and lowest in the deeper horizon in all the profiles of the study area. The organic carbon content of black soils was in between 0.150 and 0.465 per cent, while in red soils, it varied from 0.075 to 0.450 per cent in different locations.

4.6.2.4 Total nitrogen content

The total nitrogen content was maximum (0.077 per cent) in the surface horizon of black soil profile 2 and minimum N content in the black soils was 0.017 per cent in Bss4 horizon of profile 4. In the red soils, the total N content was ranging between 0.016 and 0.076 per cent in different horizons.

4.6.2.5 Carbon – nitrogen ratio

To understand the stabilization of organic matter, C/N ratios for different horizons were calculated between organic carbon and total nitrogen percent.

The Bss2 horizon of profile 1 (black soil) recorded highest ratio while Bw3 horizon of red soil profile (profile 5) had minimum ratio.

4.6.2.6 Calcium carbonate content

Profile 7 (red soil) had lowest calcium carbonate content varying from 0.00 to 0.50 per cent while, Timmapuram profile (black soil profile 8) contained highest content varying between 13.87 and 15.00 per cent.

4.6.3 Electro-Chemical Properties

The data pertaining to CEC, exchangeable calcium, magnesium, sodium and potassium along with percent saturation of these basic cations are presented in table 10 and 11 and depicted in figure 7 to 10.

4.6.3.1 CEC of soils

The amount and type of clay fraction in soils influenced the exchange properties of the soils. Maximum cation exchange capacity values were recorded in profile 4, black soil profile located at Solasa. The CEC in this profile varied from 47.80 to 58.67 cmol (p^+) kg^{-1} soil. The lowest CEC of 31.50 cmol (p^+) kg^{-1} soil was recorded in Ap hrozion of profile 2 among black soil profiles. In red soil profiles the CEC was varying from 6.51 to 19.55 cmol (p+) kg^{-1} soil.

4.6.3.2 Exchangeable cations

Exchangeable cations calcium, magnesium, sodium and potassium constituted the exchangeable bases. The exchangeable Ca^{++}, Mg^{++}, Na^+ and K^+ on soil complex of different horizons in black soil profiles were varying from 22.68 to 46.71, 4.31 to 9.33, 0.79 to 1.61 and 0.14 to 0.47 cmol (p^+) kg^{-1} soil, respectively. In red soil profiles these exchangeable bases in sequence were 3.64 to 14.08, 0.69 to 2.99, 0.12 to 0.49 and 0.02 to 0.13 cmol (p+) kg^{-1} soil.

4.6.3.3 Per cent base saturation

Highest percent base saturation was recorded in Bss3 horizon at a depth of 1.20 to 1.50 meters in black soil profile of Turlapadu (profile 1). In black soil profiles the base saturation was varying from 89.11 to 98.83 per cent in different horizons. In red soil profiles, these four basic cations constituted to saturation of 69.28 to 89.92 per cent. The Ap horizon of profile 6 (red soil) contained the lowest base saturation (69.28 per cent).

4.6.3.4 Per cent saturation of individual basic cations

As far as saturation of individual bases were considered, exchangeable calcium contributed from 72.00 to 79.53 per cent in black soil profiles and in red soil profiles its contribution ranged from 55.91 to 72.02 per cent. Among the different soil profiles, the saturation of exchangeable Mg^{++}, Na^{+}, and K^{+} was ranging from 10.60 to 15.91, 1.84 to 2.78 and 0.09 to 1.00 per cent, respectively.

4.6.4 Chemical Composition

4.6.4.1 Silica and sesquioxides content

The data about the silica and sesquioxides content, their molar concentrations and mole ratios are presented in table 12 and 13 and depicted in figure 11 and 12.

Red soil profiles (profiles 3, 5, 6 and 7) contained higher silica content varying from 63.26 to 76.83 per cent. The minimum and maximum values were recorded in Bw4 horizon of profile 5 and Ap horizon of profile 6 among red soil profiles, respectively. Among black soil profiles, maximum silica content of 70.98 per cent and minimum of 57.02 per cent were recorded in surface horizon of profile 2 and lower horizon below 1.35 meters depth in profile 4, respectively.

The Fe_2O_3, Al_2O_3 and R_2O_3 (iron oxides and aluminum oxides) content among different horizons in both red soil profiles and black soil profiles ranged from 3.04 to 6.63, 14.42 to 28.69 and from 18.57 to 34.60, respectively.

The concentration of silica in different horizons of red soil profiles ranged from 1.053 to 1.279 moles while in black soil profiles, it ranged from 0.949 to 1.181 moles. The alumina content was varying from 0.141 to 0.281 moles, while iron oxides content from 0.019 to 0.042 moles among all the soil profiles. Maximum R_2O_3 content of 0.318 moles was recorded in Bss4 horizon of Solasa profile, a black soil, while minimum content of 0.167 moles was registered in Ap horizon of Changeej Khan Peta profile (profile 6).

4.6.4.2 Silica – sesquioxides molar ratios

The molar ratios of silica – sequioxides, silica – alumina, silica – iron oxides and alumina- iron oxides are computed. These molar ratios were varying from 3.0 to 5.3, 3.4 to 5.8, and 25.5 to 62.2 and from 6.1 to 10.8 among black soil profiles, and from 3.8 to 7.6, 4.4 to 9.0, 25.1 to 49.2 and 4.0 to 6.1 among red soil profiles, respectively.

4.6.4.3 Nutrient status

4.6.4.3.1 Total nutrient content

4.6.4.3.1.1 Macronutrients

The total contents of phosphorus, potassium, calcium and magnesium are presented in table 14.

4.6.4.3.1.1.1 Total P content

Total phosphorus content of surface horizon (0.0 – 0.10 m) was highest (410 ppm) among all the horizons. Minimum content of 135 ppm was recorded in Bw1 horizon (0.30 – 0.47 m) in red soil profile (profile 6). Among the red soil profiles, maximum content of P (380 ppm) was occurring in subsurface horizon (AB) near Kondaveedu.

4.6.4.3.1.1.2 Total K content

The total K concentration was in between 1375 and 4000 ppm among black soil profiles, while it varied from 625 to 3625 ppm among red soil profiles in different horizons.

4.6.4.3.1.1.3 Total calcium and magnesium content

Maximum total calcium (3.75 per cent) and total magnesium (1.20 per cent) content were recorded in Bss4 horizon of black profile at Solasa (profile 4), while minimum content of total calcium (0.25 per cent) and total magnesium (0.07 per cent) were registered in surface horizon of profile 7 (red soil profile).

4.6.4.3.1.2 Micronutrients

The total contents of copper manganese zinc are presented as oxides in table 14.

The total CuO, MnO_2 and ZnO contents varied from 34 to 56, 752 to 1701 and from 56 to 84 among black soil profiles, and from 22 to 44, 807 to 2037 and 34 to 75 among red soil profiles, respectively.

4.6.4.3.2 Available nutrient status

The available nutrient status (nitrogen, phosphorus, potassium, sulphur, iron, copper, manganese and zinc of different horizons of red and black soil profiles are presented in table 15.

4.6.4.3.2.1 Available N content

The range of available N content was from 44.8 to 224.00 kg ha^{-1} in black soil profiles and 67.2 to 201.60 kg ha^{-1} in red soil profiles. Highest N content was recorded in surface horizon of profile 2 (black soil profile) and lowest in Bss4 horizon at a depth of 150 cm in profile 1, a black soil profile.

4.6.4.3.2.2 Available P_2O_5 content

The available P_2O_5 content was varying from 19.40 to 55.3 kg ha^{-1} among different red and black soil profiles. In black soil profiles maximum P_2O_5 content was recorded in Ap horizon of profile 2, whereas, minimum content of 22.5 kg ha^{-1} was occurring in lower most horizon at a depth of 135 cm in profile 4. Among red soil profiles, Ap horizon of profile 5 had maximum P_2O_5 content of 53.3 kgha^{-1} while BC horizon of profile 3 was containing 19.4 kg ha^{-1}.

4.6.4.3.2.3 Available K_2O content

Among the black soil profiles, profile 1 had recorded highest (483) kg ha^{-1} of K_2O content in Ap horizon while, the lowest was 241 kg ha^{-1} in Bss_2 horizon of profile 8. The K_2O content among the red soil profiles was varying between 201(Bt_2 horizon of profile 7) and 389 (AB horizon of profile 6) kg ha^{-1}.

4.6.4.3.2.4 Available S content

The range of available S content was from 6.87 to 14.37 ppm in black soil profiles and 5.00 to 12.50 ppm in red soil profiles. Highest S content was recorded in surface horizon of profile 4 (black soil profile) and lowest in BC horizon at a depth of 66 to 79 cm in profile 3, a red soil profile.

4.6.4.3.2.5 Available micronutrient content

Among different soil profiles, the available iron, copper, manganese and zinc were ranging from 2.54 to 15.60, 0.78 to 2.48, 2.08 to 24.50 and 0.06 to 1.14 ppm, respectively. Surface horizons had higher micronutrient content than the sub-surface horizons in all the profiles of black and red soils.

4.6.5. Nutrient status of surface (0-15 cms.) soil samples

To know the overall fertility status of soils of the mandal, surface soil samples in 60 (30 in red soil areas and 30 in black soil areas) locations covering whole mandal were collected and analyzed. The data obtained are presented in table 16, 17 and 18 and overall fertility status is depicted in figure 13.

4.6.5.1 Red soils

The pH of the red soils was varying from 6.3 to 8.1, while EC was varying from 0.084 to 0.761 dS m^{-1}. The average organic carbon content of the red soils was 0.307 per cent. The available N, P_2O_5, and K_2O contents of the red soils were varying from 112.00 to 201.60, 23.5 to 53.3, and 255 to 389 kg ha^{-1}, respectively. The mean values of available S, Zn, Fe, Mn, and Cu for the red soils were 11.92, 0.45, 10.39, 25.68, and 1.64 ppm, respectively. The maximum calcium carbonate content recorded in one of the locations of red soil areas was 7.87 per cent.

4.6.5.2 Black soils

The mean pH value for the black soils was 8.00, while mean EC value was 0.538 dS m^{-1}. The organic carbon content of black soils was varying between 0.240 to 0.495 per cent. The mean values of available N, P_2O_5, and K_2O content of the black soils were 184.43, 40.47, and 387 kg ha^{-1}, respectively. The available S content was varying from 11.25 to 15 ppm. The available zinc, iron, manganese and copper were varying from 0.12 to 1.04, 2.72 to 37.14, 3.34 to 21.40 and 0.91 to 4.60 ppm, respectively.

The overall average values of all the surface soil samples of the mandal were 7.62, 0.390 dS m^{-1}, 0.352 per cent, 4.68 per cent, 180.32 kg ha^{-1}, 39.40 kg ha^{-1}, 356 kg ha^{-1}, 12.85 ppm, 0.43 ppm, 8.53 ppm, 17.61 ppm, and 1.79 ppm for pH, EC, organic carbon, $CaCO_3$, available N, P_2O_5, K_2O, S, Zn, Fe, Mn and Cu, respectively.

4.6.6 X-Ray Diffraction of Soil Clay Fraction

X-ray diffraction pattern of soil clay fraction is depicted in figures 14 to 21. Diffraction peaks (d-spacings) recorded in different treatments of soil clay fraction is presented in table 21. Based on the lower and higher order peaks and their nature in the diffractograms, the following clay minerals were identified. The clay minerals identified were secondary minerals present in clay fraction. These minerals identified were all belonging to phyllosilicates (Si_2O_5 group).

4.6.6.1 Identification of clay minerals

4.6.6.1.1 Montmorillonite type of clay minerals

The diffraction pattern of clay fraction of black soil profiles 1, 2, 4 and 8 had shown typical broad large lower order peak of montmorillonite in calcium saturated – glycerol solvated samples at 18.19, 16.92, 16.83, and 17.14 A^0, respectively. In calcium saturated treatment, the first order peaks were noticed at 15.51, 15.93, 14.43 and 14.32 A^0, d-spacing in samples of profile 1, 2, 4, and 8, respectively. These peaks were expanded to higher d-spacing as mentioned above due to glycerol solvation. Hence these peaks indicated the presence of large quantities of expanding 2:1 type of clay mineral, montmorillonite.Their presence was further confirmed with the diffraction pattern on K treatment and heating. These peaks were shifted to 14 A^0 peaks in K treatment at room temperature. On heating K saturated samples to 550^0C, they were converted to illite peaks having about 10 A^0, d- spacing. The corresponding peaks observed in the diffractograms of all the four treatments were mentioned in the table 21 and depicted in figures14, 15, 17 and 21. Due to the presence of these peaks, it was identified that clay fraction of black soils (profile 1, 2, 4, and 8) were dominated by montmorillonite type of clay minerals.

The clay fraction of red soil profiles 3, 5, 6, and 7 had exhibited first order peaks of montmorillonite at 14.21, 15.84, 15.51 and 16.78 A^0, d-spacing, respectively in Ca treated samples at room temperature. On ethylene glycol solvation, these peaks were expanded to 18.53, 16.54, 18.19 and 18.53 A^0, d-spacings. These peaks were further changed to 10 A^0, peaks on K saturation and heating to 550^0C. However, these peaks were small and narrow. By the presence of characteristic peaks, the presence of montmorillonite was identified in the clay fraction of red soils.

4.6.6.1.2 Illite type of clay minerals

Illite is a non-expanding 2:1 type of mineral. It is a mica type mineral but secondary in origin. The typical diffraction nature of illite is, it is unaffected by the treatments and exhibits same peak in all the treatments particularly in the lower order.

Sharp narrow peaks were noticed in calcium treated samples at room temperature at 10.18, 10.17, 10.02, 10.02, 10.09, 10.05, and 10.03 A^0, d-spacings in the samples of profiles 1 to 7, respectively. However, these peaks were small in diffractograms relating to black soil profiles. The corresponding second and third order peaks were recorded at d-spacing of 4.98 & 3.35, 5.00 & 3.35, 5.00 & 3.35, 5.00 & 3.34, 4.99 & 3.35, 5.00 & 3.37, 4.99 & 3.34, and 4.98 & 3.35 A^0, in samples of profiles 1, 2, 3, 4, 5, 6, 7, and 8, respectively. The peaks were persisted and recognized at all most same d-spacing on glycerol solvation, K saturation and heating to 550^0C temperature. But the peaks had become large on K saturation and heating due to conversion of 2:1 expanding mineral (montmorillonite) to non-expanding 2:1 mineral, illite. These peaks were sharp in higher order diffraction. Due to diffraction peaks of this pattern (persistence of 10 A^0, peak in all the treatments), occurrence of illite was recognized in the clay fraction of all the soil profiles.

4.6.6.1.3 Kaolinite type of clay minerals

Kaolinite is a 1:1 non-expanding mineral having characteristic d-spacing of 7 A^0, of the lower order in all the treatments except at the temperature of 550^0C. Kaolinite mineral gets collapsed at this temperature on heating. The presence of kaolinite was identified due to the presence following peaks.

Small, well-defined first order peaks were recorded in calcium saturation treatment at 7.12, 7.09, 7.18, 7.11, 7.18, 7.13, 7.15 and 7.11A^0, d-spacing in profiles 1, 2, 3, 4, 5, 6, 7 and 8, respectively. The corresponding second order peaks were noticed at 3.59, 3.56, 3.58, 3.54, 3.58, 3.58, 3.57 and 3.58 A^0, d-spacing in profiles 1, 2, 3, 4, 5, 6, 7 and 8, respectively. In the other treatments with glycerol solvation and K– saturation, the peaks were observed almost at the same d- spacing in all the diffractograms. But either the first order 7 A^0, peak or second order 3.5 A^0 peak were not recorded in the treatment heated to 550^0C because of the destruction or collapse of kaolinite at that temperature. These peaks were vanished. Due to the exhibition of this type of pattern in the diffractograms, the presence of kaolinite was confirmed in all the samples. However, the peaks relating to black soils were very small compared to peaks recorded in red soil samples.

4.6.6.1.4 Quartz

Quartz is not a secondary mineral. It is primary in origin. Due to physical weathering, the size of the mineral might have been reduced and occurring in clay fraction of size less than 2 mm. The presence of quartz in the clay fraction of profiles 2, 3, 4, 5 and 6 was revealed due to occurrence of small but sharp peaks at 4.20 / 4.25 / 4.26 A^0 d-spacing in different treatments. Quartz was present only in traces in soil clay fraction of profiles 2, 3, 4, 5 and 6.

4.6.6.2 Semi- quantification

Based on the area of the peaks, relative proportion of clay minerals in clay fraction of soils was calculated and presented in table 22.

Clay fraction of black soils (profile 1, 2, 4, and 8) was dominated by montmorillonite type mineral varying from 92 to 96 per cent. Illite and kaolintie content was less than 4 per cent.

Clay fraction of red sois (profiles 3, 5, 6, and 7) was constituted by all these three types of clay minerals. In profile 3, the soil clay had ‘mixed‘ mineralogy with 39, 40 and 21 per cent of montmorillonite, illite and kaolinite, respectively. The clay of profile 6 also had ‘mixed’ mineralogy with 44, 27 and 29 per cent of montmorillonite, illite and kaolinite, respectively. Soil clay of Boyapalem profile had 50 per cent of illite followed by 31 per cent of kaolinite and 19 per cent montmorillonite.

Plate 1: SLICKENSIDES IN PROFILE-1 (TURLAPADU)

Plate 2: GRANITIC GNEISSIC HILLS NEAR EDLAPADU

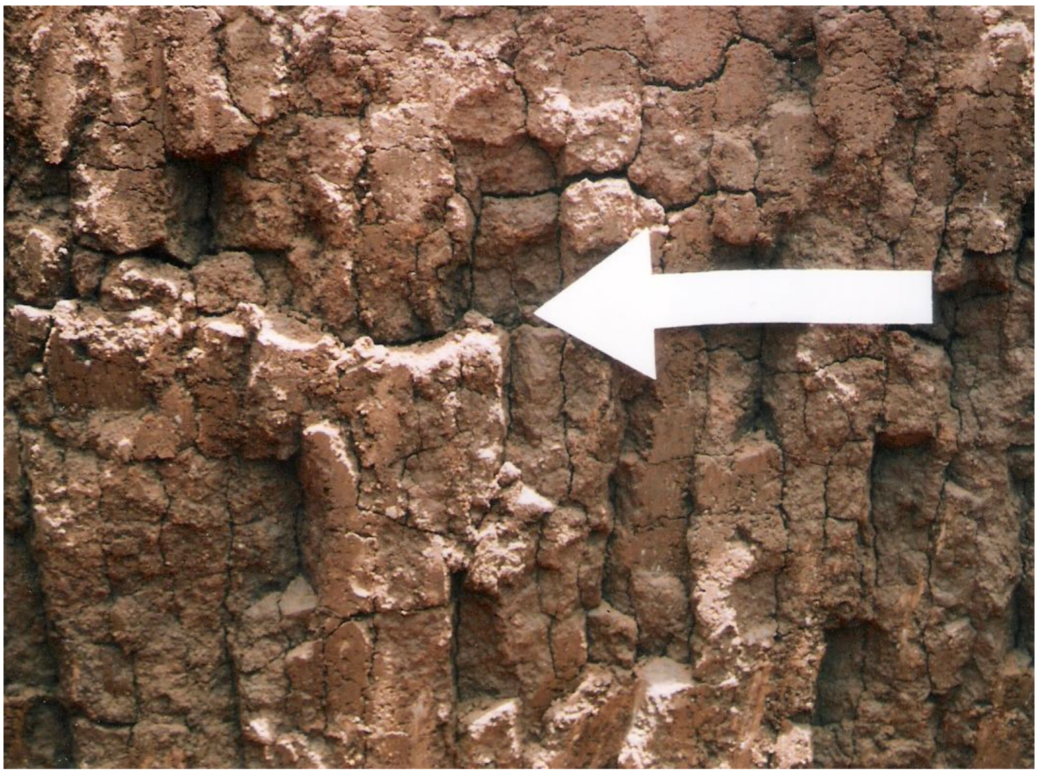


Plate 3: COLUMNAR STRUCTURE IN SUB-SURFACE OF PROFILE-3

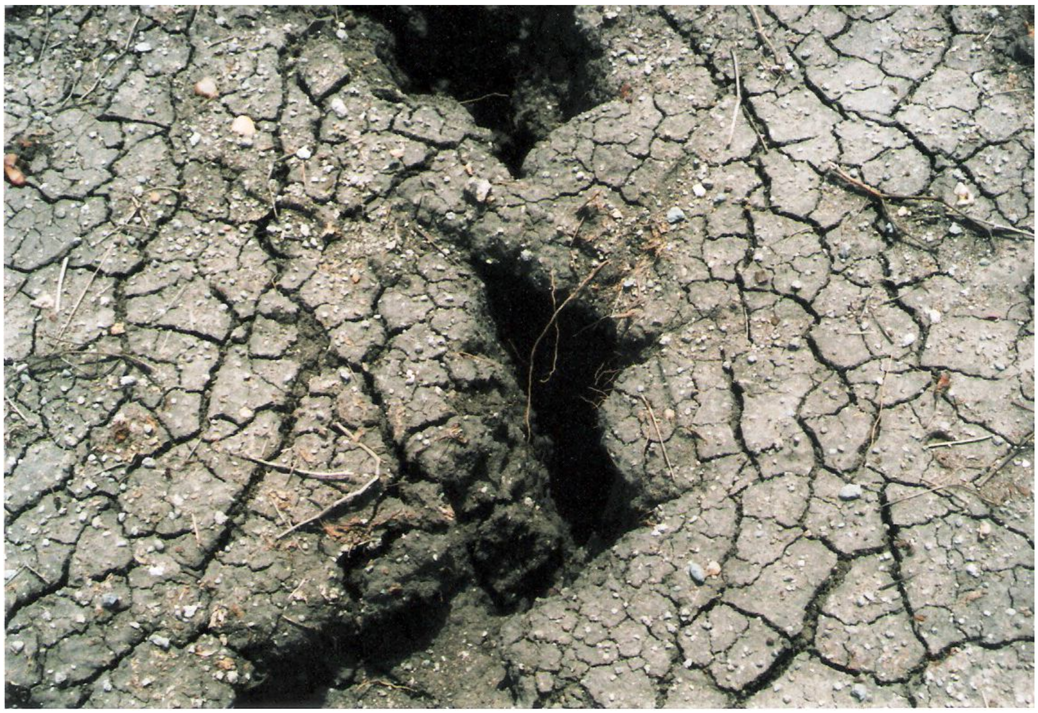
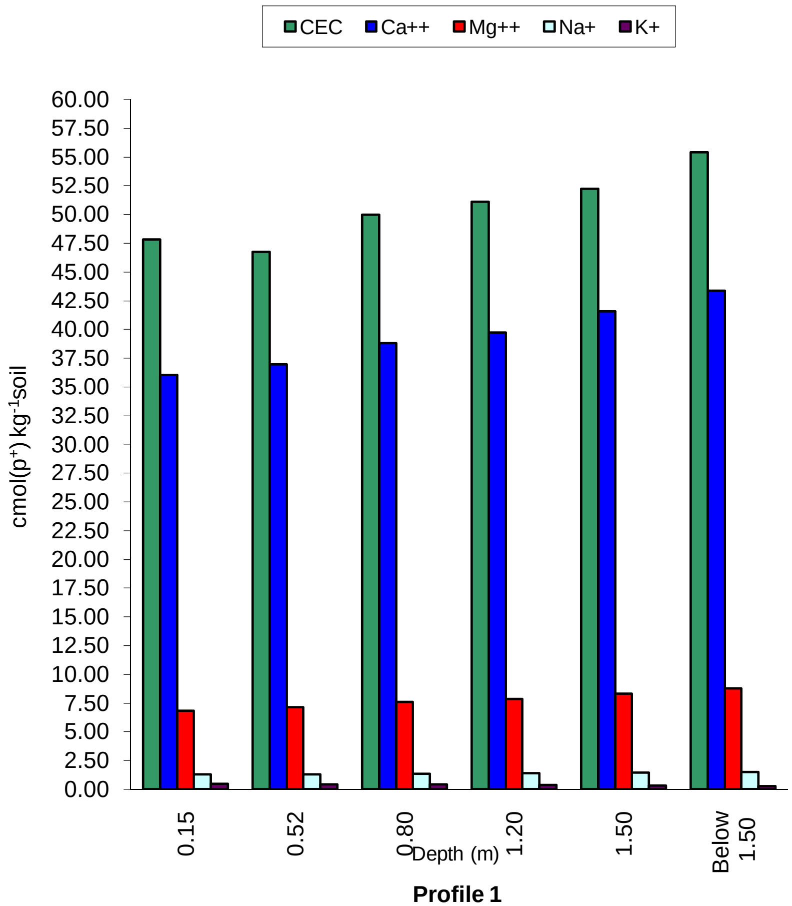


Plate 4: SINK HOLES IN PROFILE-4 (SOLASA)

Plate 5: SLICKENSIDES IN PROFILE-4 (SOLASA)

Plate 6: GRANITIC GNEISSIC HILLS NEAR KONDAVEEDU

Plate 8: CRACKS TAPPERING INTO LOWER HORIZONS (PROFILE-8)



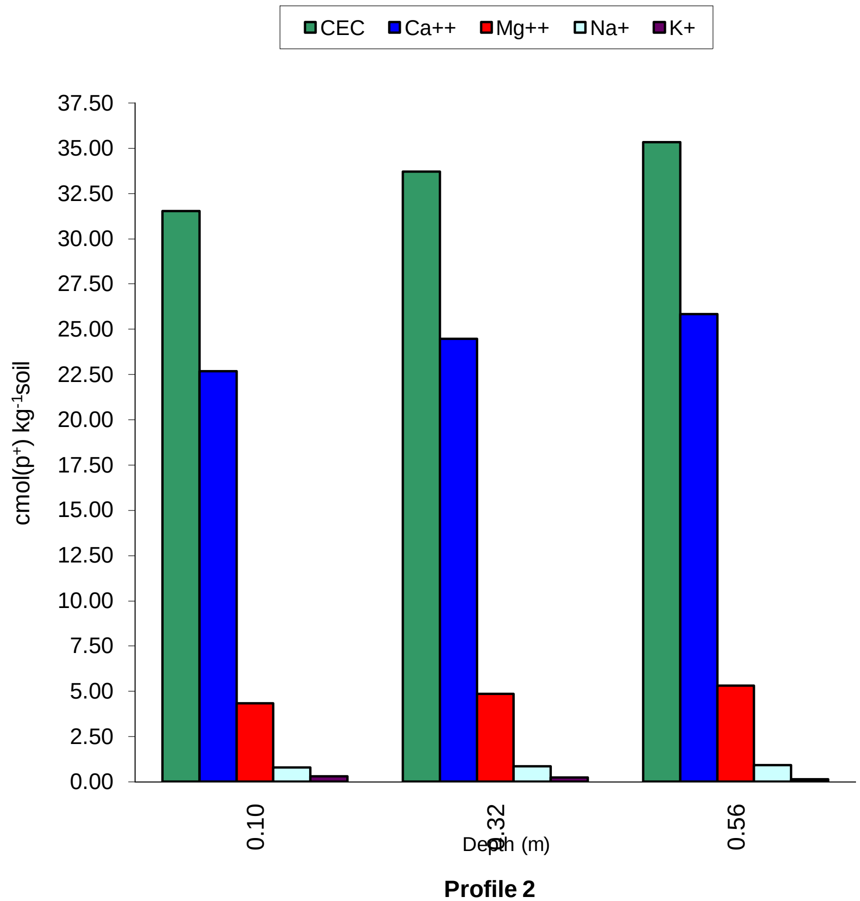
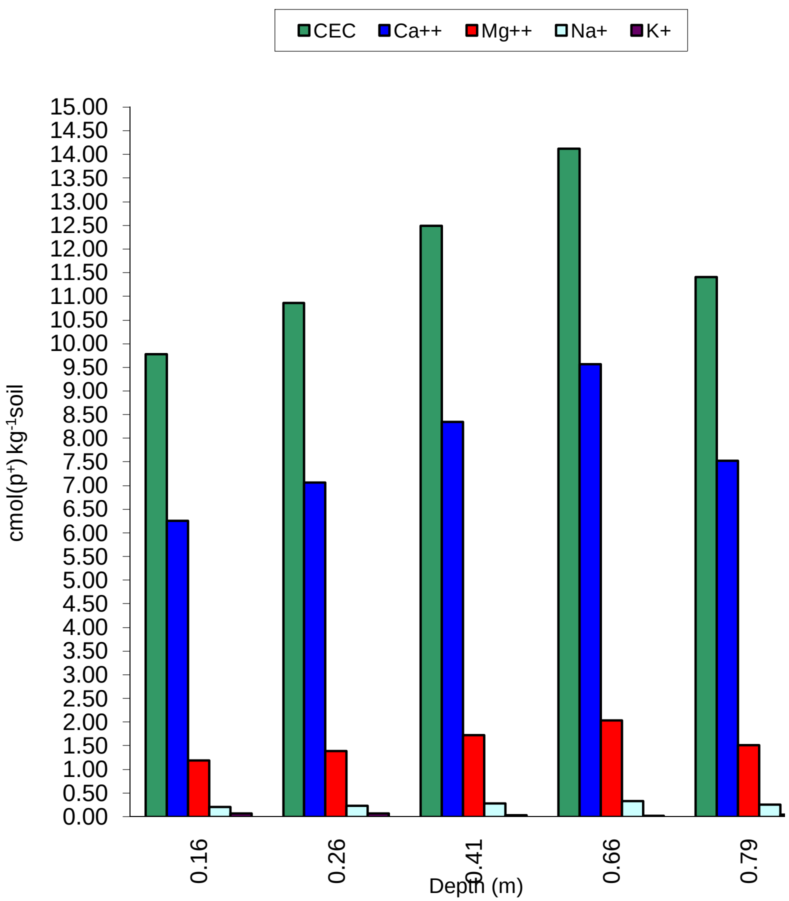
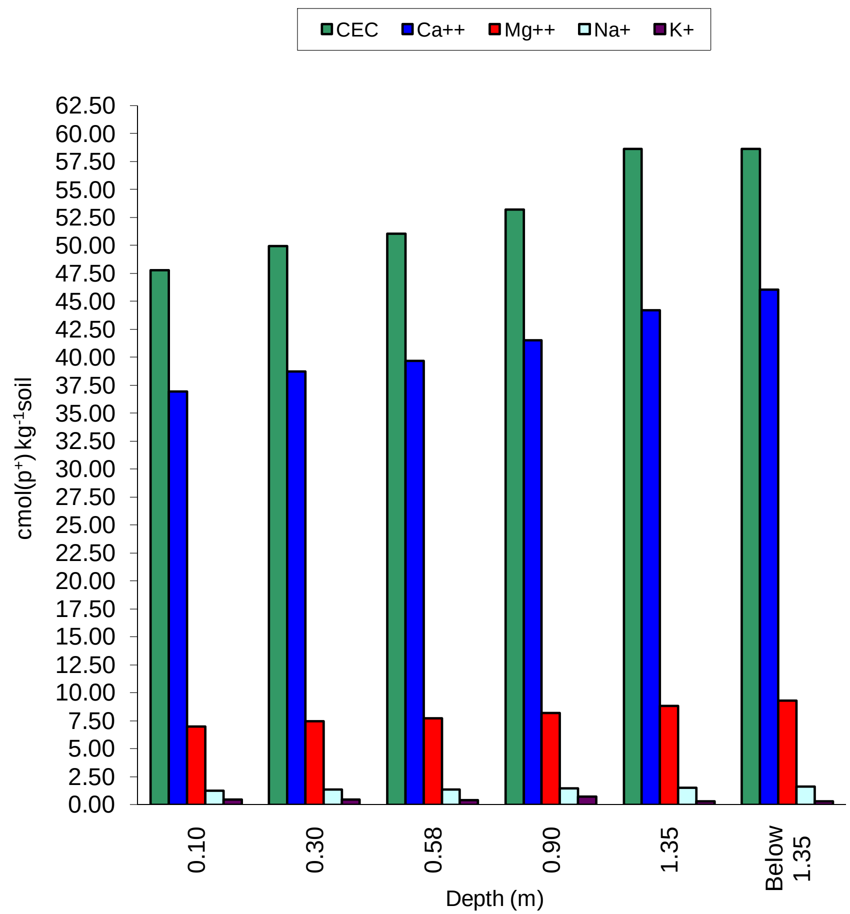


Fig. 7 : DEPTH FUNCTIONS OF CEC AND EXCHANGEABLE BASES

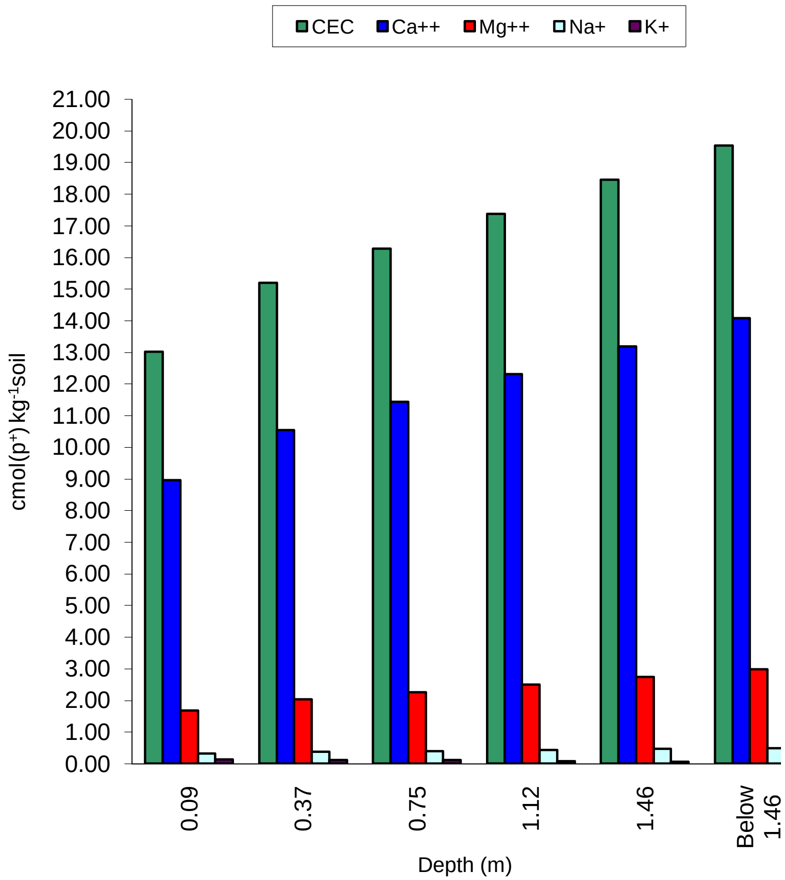


Profile 3

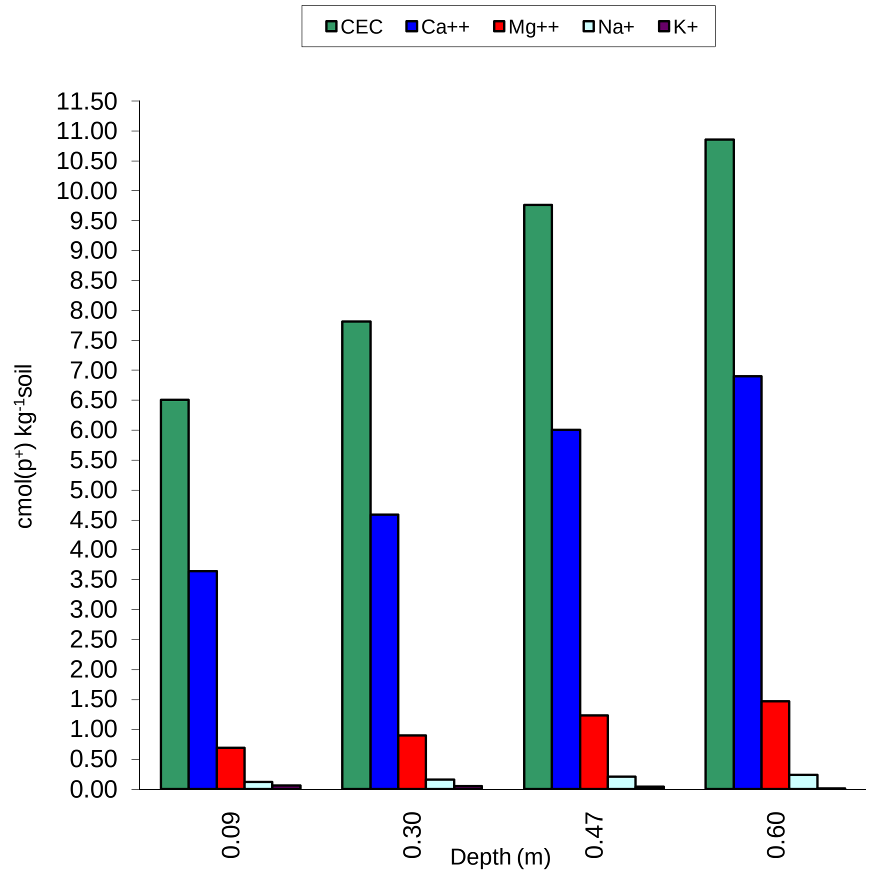


Profile 4

Fig. 8 : DEPTH FUNCTIONS OF CEC AND EXCHANGEABLE BASES

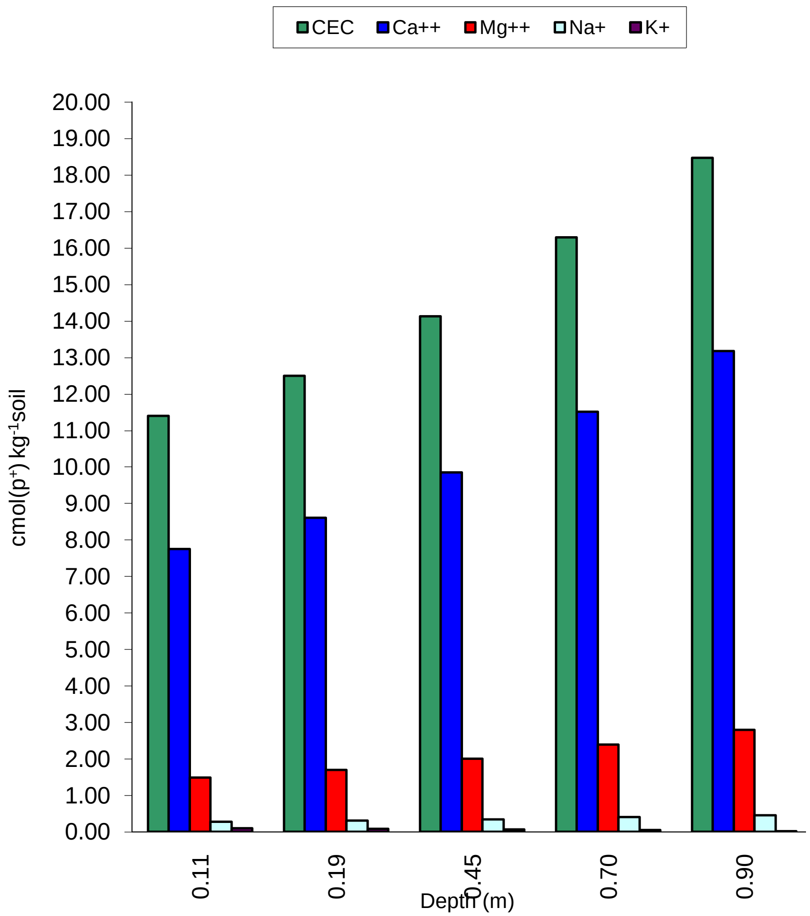


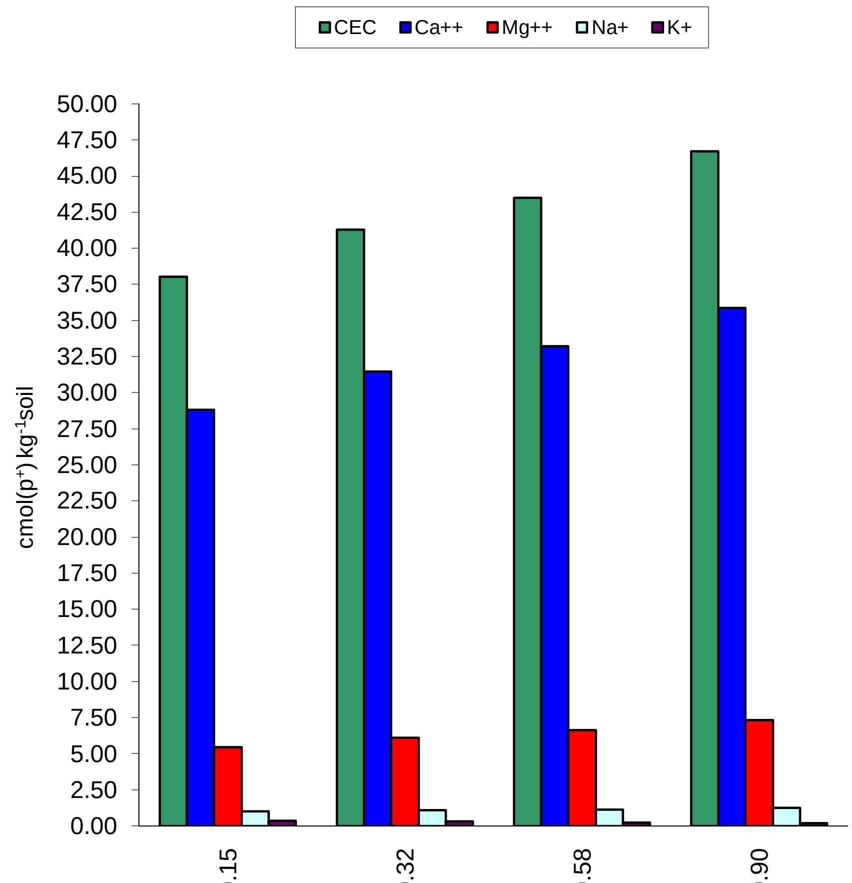
Profile 5



Profile 6

Fig. 9 : DEPTH FUNCTIONS OF CEC AND EXCHANGEABLE BASES





Depth (m)

Profile 7

Profile 8

Fig. 10 : DEPTH FUNCTIONS OF CEC AND EXCHANGEABLE BASES

Table 23: Soil classification

Profile No.	Order	Sub-order	Great group	Sub-group	Family
1	Vertisol	Ustert	Haplustert	Chromic Haplustert	Very-fine, montmorillonitic, isohyperthermic, Chromic Haplustert
2	Inceptisol	Ustept	Haplustept	Typic Haplustept	Fine, montmorillonitic, isohyperthermic, Typic Haplustept
3	Alfisol	Ustalf	Haplustalf	Typic Haplustalf	Loamy, mixed, isohyperthermic, Typic Haplustalf
4	Vertisol	Ustert	Haplustert	Typic Haplustert	Very-fine, montmorillonitic, isohyperthermic, Typic Haplustert
5	Inceptisol	Ustept	Haplustept	Typic Haplustept	Loamy, mixed, isohyperthermic, Typic Haplustept
6	Inceptisol	Ustept	Haplustept	Typic Haplustept	Loamy, mixed, isohyperthermic, Typic Haplustept
7	Alfisol	Ustalf	Haplustalf	Typic Haplustalf	Loamy, illitic, isohyperthermic, Typic Haplustalf
8	Vertisol	Ustert	Haplustert	Leptic Haplustert	Fine, Montmorillonitic, isohyperthermic, Leptic Haplustert.

Table 22 : Relative proportion of clay minerals (from X-ray diffractograms of clay fraction)

Profile No.	Location	Per cent			
		Montmorillonite	Illite	Kaolinite	Quartz
1	Turlapadu (Black Soil)	92	4	4	---
2	Jaggapuram (Black Soil)	96	2	2	Traces
3	Edlapadu (Red Soil)	39	40	21	Traces
4	Solasa (Black Soil)	94	3	3	Traces
5	Kondaveedu (Red Soil)	35	32	33	Traces
6	Changeej Khan Peta (Red Soil)	44	27	29	Traces
7	Boyapalem (Red Soil)	19	50	31	Traces
8	Timmapuram (Black Soil)	96	Traces	4	---

Table 21: d-spacings (A^0) of X-ray diffractograms of soil clay fraction

Profile No.	Calcium saturated		Potassium saturated (temperature ^0C)		Clay mineral
	Room temperature	Glycerol solvated	25	550	
1	15.51	18.19	14.41	---	Montomorillonite
	10.18	10.12	10.05	9.96	Illite
	4.98*	5.00	5.00	5.00	
	3.35	3.34	3.35	3.34	
	7.12	7.10	7.16	---	Kaolinite
	3.59	3.55	3.57	---	
2	15.93	16.92	14.11	---	Montomorillonite
	10.17	10.06	10.11	9.98	Illite
	5.00	---	4.95	5.01	
	3.35	3.35	3.35	3.34	
	7.09	7.10	7.09	---	Kaolinite
	3.56	3.57	3.56	---	
	4.26	---	4.25	4.25	Quartz
3	14.21	18.53	12.50	---	Montomorillonite
	10.02	10.01	10.02	9.93	Illite
	5.00	5.01	4.99	4.97	
	3.35	3.35	3.34	3.35	
	7.18	7.20	7.16	---	Kaolinite
	3.58	3.58	3.59	---	
	4.26	4.26	4.26	4.26	Quartz
4	14.43	16.83	14.33	---	Montomorillonite
	10.02	10.09	10.16	10.09	Illite
	5.00	4.98	4.97	5.01	
	3.34	3.34	3.34	3.34	

Profile No.	Calcium saturated		Potassium saturated (temperature ^{0}C)		Clay mineral
	Room temperature	Glycerol solvated	25	550	
5	15.84	16.54	12.39	---	Montomorillonite
	10.09	10.04	10.01	9.72	Illite
	4.99	5.01	5.00	---	
	3.35	3.34	3.34	3.31	
	7.18	7.19	7.16	---	Kaolinite
	3.58	3.58	3.57	---	
	---	4.25	---	---	Quartz
6	15.51	18.19	13.54	---	Montomorillonite
	10.05	10.01	10.09	10.04	Illite
	5.00	4.99	5.02	5.01	
	3.37	3.34	3.33	3.34	
	7.13	7.19	7.14	---	Kaolinite
	3.58	3.57	3.57	---	
	4.20	---	---	---	Quartz
7	16.78	18.53	---	---	Montomorillonite
	10.03	10.01	9.99	9.98	Illite
	4.99	5.02	4.99	5.02	
	3.34	3.33	3.34	3.34	
	7.15	7.16	7.13	---	Kaolinite
	3.57	3.57	3.58	---	
8	14.32	17.14	14.34	---	Montomorillonite
	---	---	10.14	10.01	Illite
	4.98	---	4.98	---	
	3.35	3.35	3.34	3.34	
	7.11	7.14	7.11	---	Kaolinite
	3.58	3.58	3.58	---	

Table 20 : Correlation coefficient (r) values between soil properties
(surfaces soil samples)

Soil properties			r value
pH	Vs	$CaCO_3$	+0.71
pH	Vs	Available iron	-0.46
pH	Vs	Available manganese	-0.57
$CaCO_3$	Vs	Available Iron	-0.36
$CaCO_3$	Vs	Available manganese	-0.42
Organic carbon	Vs	Available nitrogen	+0.50
Organic carbon	Vs	Available phosphorus	+0.65
Organic carbon	Vs	Available potassium	+0.59
Organic carbon	Vs	Available sulphur	+0.38
Organic carbon	Vs	Available zinc	+0.41
Organic carbon	Vs	Available copper	+0.45

Significant at 5% level (r = 0.210)

Table 19 : Correlation coefficent (r) values between soil properties (profile soil samples)

Soil properties			r value
Sand	Vs	SiO_2	+0.849
Sand	Vs	R_2O_3	-0.791
Sand	Vs	Water holding capacity	-0.984
Clay	Vs	pH	+0.830
Clay	Vs	Base saturation per cent	+0.886
Clay	Vs	EC	+0.652
Clay	Vs	R_2O_3	+0.781
Clay	Vs	SiO_2	-0.844
Clay	Vs	Water holding capacity	+0.979
Clay	Vs	Volume expansion	+0.955
Clay	Vs	Sticky point	+0.927
Clay	Vs	COLE	+0.880
pH	Vs	$CaCO_3$	+0.727
Organic carbon	Vs	Total nitrogen	+0.900
$CaCO_3$	Vs	Available phosphorus	+0.396
Organic carbon	Vs	Available zinc	+0.584
Organic carbon	Vs	Available manganese	+0.207
Organic carbon	Vs	Available copper	+0.349
Organic carbon	Vs	Available iron	+0.342
Organic carbon	Vs	Available sulphur	+0.481

Significant at 5% level (r = 0.260)

Table 18 : Analytical data of the surface soil samples

Property	Red soils		Black soils		Overall	
	Range	Mean	Range	Mean	Range	Mean
pH	6.3-8.1	7.23	7.0-8.5	8.00	6.3-8.5	7.62
EC (dS m^{-1})	0.084-0.761	0.242	0.195-1.501	0.538	0.084-1.501	0.390
OC (%)	0.105-0.480	0.307	0.240-0.495	0.397	0.105-0.495	0.352
$CaCO_3$ (%)	0.00-7.87	1.9	3.00-15.25	7.45	0.00-15.25	4.68
N (kg ha^{-1})	112.0-201.6	176.2	134.4-224.0	184.43	112.0-224.00	180.32
P_2O_5 (kg ha^{-1})	23.5-53.3	38.42	25.6-55.3	40.47	23.50-55.30	39.4
K_2O (kg ha^{-1})	255-389	324	309-483	387	255-483	356
S (ppm)	10.00-13.75	11.92	11.25-15.00	13.17	10.00-15.00	12.85
Zn (ppm)	0.14-1.20	0.45	0.12-1.04	0.4	0.12-1.20	0.43
Fe (ppm)	3.70-40.04	10.39	2.72-37.14	6.67	2.72-40.04	8.53
Mn (ppm)	6.48-106.8	25.68	3.34-21.40	9.54	3.34-106.8	17.61
Cu (ppm)	0.96-6.76	1.64	0.91-4.60	1.94	0.91-6.76	1.79

Table 18 : Analytical data of the surface soil samples

Property	Red soils		Black soils		Overall	
	Range	Mean	Range	Mean	Range	Mean
pH	6.3-8.1	7.23	7.0-8.5	8.00	6.3-8.5	7.62
EC (dS m^{-1})	0.084-0.761	0.242	0.195-1.501	0.538	0.084-1.501	0.390
OC (%)	0.105-0.480	0.307	0.240-0.495	0.397	0.105-0.495	0.352
$CaCO_3$ (%)	0.00-7.87	1.9	3.00-15.25	7.45	0.00-15.25	4.68
N (kg ha^{-1})	112.0-201.6	176.2	134.4-224.0	184.43	112.0-224.00	180.32
P_2O_5 (kg ha^{-1})	23.5-53.3	38.42	25.6-55.3	40.47	23.50-55.30	39.4
K_2O (kg ha^{-1})	255-389	324	309-483	387	255-483	356
S (ppm)	10.00-13.75	11.92	11.25-15.00	13.17	10.00-15.00	12.85
Zn (ppm)	0.14-1.20	0.45	0.12-1.04	0.4	0.12-1.20	0.43
Fe (ppm)	3.70-40.04	10.39	2.72-37.14	6.67	2.72-40.04	8.53
Mn (ppm)	6.48-106.8	25.68	3.34-21.40	9.54	3.34-106.8	17.61
Cu (ppm)	0.96-6.76	1.64	0.91-4.60	1.94	0.91-6.76	1.79

Table 17 : Analytical data of the surface soil samples of the study area (Black soils)

S.No.	pH	EC ($dS\ m^{-1}$)	Organic carbon (%)	$CaCO_3$ (%)	Available nutrients							
					N	P_2O_5	K_2O	S	Zn	Cu	Fe	Mn
					$kg\ ha^{-1}$			ppm				
1	8.5	0.561	0.360	7.87	134.4	38.9	403	12.50	0.20	1.18	3.64	7.64
2	7.9	1.102	0.435	8.50	201.6	52.3	430	13.75	0.22	1.45	5.06	11.68
3	8.5	0.361	0.420	10.37	201.6	50.2	389	11.25	0.20	1.78	7.70	3.54
4	8.2	0.373	0.405	7.75	201.6	47.1	430	15.00	0.58	2.30	2.72	11.78
5	8.2	0.441	0.375	7.50	201.6	37.9	430	13.75	0.24	1.32	3.16	10.54
6	8.1	0.784	0.480	7.25	201.6	55.3	483	11.25	0.26	1.70	3.90	10.96
7	8.4	0.283	0.360	7.62	156.8	33.8	362	12.50	0.12	1.12	3.12	5.82
8	8.1	0.501	0.285	7.37	201.6	29.7	416	15.00	0.22	1.76	3.50	7.02
9	8.4	0.335	0.375	6.25	179.2	28.7	416	13.75	0.30	1.24	4.60	10.04
10	8.1	0.321	0.360	5.50	179.2	32.8	349	15.00	0.34	1.50	5.06	6.75
11	8.0	0.339	0.465	8.37	201.6	51.2	430	12.50	1.04	2.42	6.34	14.40
12	7.8	0.574	0.450	4.12	224.0	49.2	430	11.25	0.70	3.34	14.10	14.34
13	7.6	0.673	0.495	10.00	201.6	54.3	362	15.00	0.30	1.38	3.26	10.56
14	8.4	0.851	0.270	6.37	224.0	36.9	309	11.25	0.24	2.20	8.56	6.38
15	7.7	0.245	0.435	3.00	201.6	46.1	376	13.75	0.60	3.30	7.08	4.46
16	7.9	0.351	0.480	6.62	224.0	48.2	443	12.50	0.88	4.60	4.00	11.08
17	7.7	0.442	0.435	5.62	201.6	45.1	456	11.25	0.62	2.20	12.78	12.90
18	7.7	0.540	0.495	7.75	201.6	53.3	336	15.00	0.50	4.20	37.14	18.86
19	7.9	0.301	0.420	7.25	156.8	44.1	349	13.75	0.40	1.98	14.78	11.94
20	8.0	0.352	0.375	7.12	179.2	27.6	349	12.50	0.24	1.38	6.88	9.58
21	7.9	0.235	0.420	10.75	179.2	43.0	322	13.75	0.40	1.60	3.64	7.16
22	8.2	0.261	0.375	8.25	179.2	35.9	349	11.25	0.24	1.70	7.06	11.98
23	7.6	0.243	0.390	3.50	179.2	31.8	389	12.50	0.62	1.72	2.80	3.34
24	7.8	0.195	0.240	5.62	134.4	42.0	349	15.00	0.32	1.34	3.70	7.60
25	7.0	1.332	0.375	3.37	201.6	25.6	349	15.00	0.36	1.28	5.14	21.40
26	7.6	0.903	0.435	11.50	201.6	41.0	470	11.25	0.46	2.31	3.24	11.44
27	8.2	0.346	0.360	8.50	134.4	26.6	376	13.75	0.22	2.13	4.72	4.50
28	7.8	0.251	0.360	3.75	156.8	34.8	322	12.50	0.40	1.49	5.38	7.66
29	7.7	0.203	0.360	13.75	134.4	30.7	376	15.00	0.36	0.91	2.82	3.56
30	8.4	0.451	0.420	15.25	156.8	40.0	349	12.50	0.32	1.30	4.30	7.36

Table 16 : Analytical data of the surface soil samples of the study area (Red soils)

S.No.	pH	EC (dS m^{-1})	Organic carbon (%)	$CaCO_3$ (%)	Available nutrients							
					N	P_2O_5	K_2O	S	Zn	Cu	Fe	Mn
					kg ha^{-1}			ppm				
1	6.6	0.124	0.165	0.62	112.0	29.7	309	10.00	0.32	1.14	7.54	13.74
2	7.8	0.278	0.375	4.75	156.8	41.0	376	12.50	0.28	1.54	4.80	11.06
3	6.8	0.124	0.375	0.25	201.6	36.9	309	11.25	0.38	1.60	19.92	16.78
4	7.2	0.153	0.480	0.37	179.2	49.2	322	13.75	0.42	1.68	14.64	14.46
5	6.3	0.084	0.135	0.12	134.4	27.6	282	11.25	0.26	1.08	10.14	19.98
6	7.5	0.143	0.165	2.12	134.4	30.7	295	10.00	0.34	1.04	4.54	11.22
7	7.8	0.165	0.465	4.62	179.2	45.1	349	12.50	0.68	1.32	4.48	15.20
8	8.0	0.182	0.255	7.87	179.2	42.0	349	13.75	0.40	1.18	4.22	10.82
9	8.0	0.300	0.480	1.00	201.6	50.2	389	13.75	0.70	3.98	5.42	14.58
10	8.1	0.193	0.105	2.00	112.0	32.8	376	10.00	0.56	1.14	4.40	6.48
11	8.0	0.323	0.300	5.87	179.2	34.8	376	12.50	0.30	1.36	4.22	11.40
12	7.5	0.141	0.210	0.37	156.8	37.9	268	11.25	0.64	0.96	3.84	9.56
13	7.1	0.513	0.405	0.75	201.6	43.0	336	13.75	0.66	1.02	3.70	19.96
14	7.3	0.195	0.480	1.00	179.2	51.2	362	11.25	1.20	1.06	6.62	21.96
15	7.2	0.761	0.405	2.50	201.6	44.1	362	10.00	0.92	1.32	4.70	21.42
16	6.8	0.122	0.225	2.25	156.8	33.8	255	12.50	0.34	1.40	15.60	34.10
17	6.9	0.189	0.480	1.75	201.6	52.3	362	13.75	0.46	1.58	8.34	29.10
18	6.8	0.163	0.165	2.00	201.6	46.1	268	10.00	0.22	1.16	17.40	25.30
19	6.7	0.176	0.285	0.87	179.2	31.8	336	12.50	0.16	1.81	37.60	61.30
20	6.9	0.125	0.225	1.12	179.2	28.7	295	11.25	0.30	1.12	8.88	89.00
21	6.8	0.114	0.480	1.00	201.6	53.3	349	13.75	0.50	1.98	40.04	106.80
22	6.7	0.204	0.165	1.00	201.6	47.1	268	11.25	0.34	3.02	8.46	18.33
23	6.8	0.677	0.300	1.25	201.6	24.6	295	10.00	0.30	1.64	19.92	69.60
24	7.3	0.331	0.300	1.25	201.6	25.6	282	12.50	0.40	1.18	5.12	11.72
25	7.0	0.484	0.465	2.37	179.2	48.2	376	13.75	0.62	6.76	4.62	16.60
26	7.2	0.327	0.345	0.37	201.6	38.9	322	10.00	0.54	1.19	5.56	15.50
27	7.5	0.219	0.270	2.87	179.2	23.5	322	11.25	0.36	1.20	5.80	14.80
28	7.9	0.153	0.150	1.50	156.8	26.6	282	12.50	0.14	1.10	6.28	12.12
29	7.8	0.140	0.375	3.12	156.8	40.0	309	11.25	0.38	1.57	5.50	14.94
30	6.7	0.146	0.195	0.00	179.2	35.9	336	13.75	0.40	1.18	19.26	32.50

Table 15: Available nutrient status of the soils

Profile No. & Horizon	Depth (m)	N	P_2O_5	K_2O	S	Fe	Cu	Mn	Zn
		kg ha^{-1}			ppm				
1. Turlapadu (Black Soil)									
Ap	0.00 - 0.15	156.8	50.2	483	13.12	6.06	1.49	8.42	0.42
AB	0.15 - 0.52	112.0	40.1	403	12.50	5.42	1.47	8.22	0.40
Bss_1	0.52 - 0.80	89.6	44.1	376	10.62	4.76	1.35	8.00	0.34
Bss_2	0.80 - 1.20	67.2	36.9	362	9.37	4.68	1.26	5.96	0.26
Bss_3	1.20 - 1.50	67.2	33.8	322	8.12	4.42	1.23	6.54	0.28
Bss_4	Below 1.50	44.8	31.8	295	7.50	4.34	1.11	4.94	0.16
2. Jaggapuram (Black Soil)									
Ap	0.00 - 0.10	224.0	55.3	376	11.87	12.18	1.67	12.20	0.58
Bw_1	0.10 - 0.32	135.4	45.1	336	10.00	8.04	1.97	10.60	0.18
Bw_2	0.32 - 0.56	134.4	37.9	255	6.87	6.46	1.65	8.22	0.16
3. Edlapadu (Red Soil)									
Ap	0.00 - 0.16	156.8	36.9	336	10.00	15.60	2.48	24.50	0.44
B	0.16 - 0.26	156.8	31.8	282	8.75	5.78	1.82	17.30	0.28
Bt_1	0.26 - 0.41	134.4	27.6	268	6.25	5.72	1.78	15.50	0.18
Bt_2	0.41 - 0.66	134.4	23.5	241	5.62	5.04	1.51	15.20	0.14
BC	0.66 - 0.79	112.0	19.4	215	5.00	4.94	1.35	8.52	0.12
4. Solasa (Black Soil)									
Ap	0.00 - 0.10	156.8	42.0	456	14.37	5.82	1.43	10.62	0.68
AB	0.10 - 0.30	112.0	37.9	389	13.75	5.46	1.38	6.38	0.30
Bss_1	0.30 - 0.58	67.2	33.8	362	11.25	5.40	1.39	5.66	0.28
Bss_2	0.58 - 0.90	67.2	29.7	349	10.62	5.24	1.19	4.90	0.26
Bss_3	0.90 - 1.35	44.8	25.6	309	9.37	3.66	1.03	2.84	0.22
Bss_4	Below 1.35	44.8	22.5	282	8.75	2.54	1.02	2.08	0.20

Profile No. & Horizon	Depth (m)	N	P_2O_5	K_2O	S	Fe	Cu	Mn	Zn
		kg ha^{-1}			ppm				
5. Kondaveedu (Red Soil)									
Ap	0.00 - 0.09	201.6	53.3	349	11.25	4.62	1.49	20.60	1.14
AB	0.09 - 0.37	112.0	49.2	309	12.50	4.16	1.40	17.80	0.24
Bw_1	0.37 - 0.75	89.6	45.1	295	10.00	4.04	1.36	14.78	0.20
Bw_2	0.75 - 1.12	89.6	41.0	282	8.75	4.04	1.28	14.10	0.22
Bw_3	1.12 - 1.46	67.2	36.9	255	8.12	3.62	1.16	12.38	0.16
Bw_4	Below 1.46	67.2	34.8	228	7.50	3.43	1.01	11.86	0.12
6. Changeej Khan Peta (Red Soil)									
Ap	0.00 - 0.09	179.2	40.0	349	11.25	4.54	1.51	18.92	0.24
AB	0.09 - 0.30	179.2	32.8	389	9.37	4.32	1.44	17.32	0.20
Bw_1	0.30 - 0.47	179.2	26.6	295	7.50	3.84	1.37	16.12	0.16
Bw_2	0.47 - 0.60	156.8	20.5	268	6.25	3.84	1.40	13.08	0.10
7. Boyapalem (Red Soil)									
Ap	0.00 - 0.11	201.6	48.2	322	10.62	6.10	1.58	14.64	0.38
AB	0.11 - 0.19	179.2	42.0	268	10.00	5.22	1.38	16.62	0.24
Bw_1	0.19 - 0.45	156.8	37.9	255	8.12	4.74	1.37	12.90	0.18
Bt_1	0.45 - 0.70	156.8	28.7	228	6.87	4.28	1.33	10.72	0.12
Bt_2	0.70 - 0.90	156.8	32.8	201	5.62	4.26	1.30	7.26	0.08
8. Timmapuram (Black Soil)									
Ap	0.00 - 0.15	179.2	45.1	362	13.75	4.72	1.52	6.20	0.26
AB	0.15 - 0.32	134.4	37.9	322	12.50	4.66	1.29	5.58	0.14
Bss_1	0.32 - 0.58	134.4	31.8	268	8.12	4.22	1.25	4.56	0.20
Bss_2	0.58 - 0.90	89.6	25.6	241	9.37	3.78	0.78	4.10	0.06

Table 14: Chemical compositiion of the soils

Profile No. & Horizon	Depth (m)	P	K	Ca	Mg	CuO	MnO_2	ZnO
		ppm		%		ppm		
1. Turlapadu (Black Soil)								
Ap	0.00 - 0.15	395	2750	2.50	0.82	56	1701	84
AB	0.15 - 0.52	360	2375	2.62	0.90	53	1504	81
Bss_1	0.52 - 0.80	325	3000	2.75	0.90	50	1562	75
Bss_2	0.80 - 1.20	300	3375	2.87	0.97	44	1206	78
Bss_3	1.20 - 1.50	275	3625	3.12	1.05	47	1029	72
Bss_4	Below 1.50	245	4000	3.37	1.12	41	910	68
2. Jaggapuram (Black Soil)								
Ap	0.00 - 0.10	410	1375	2.25	0.67	50	1285	68
Bw_1	0.10 - 0.32	340	2375	2.50	0.97	41	1206	65
Bw_2	0.32 - 0.56	260	3500	2.75	1.12	38	1008	56
3. Edlapadu (Red Soil)								
Ap	0.00 - 0.16	315	1625	0.87	0.30	44	2037	62
B	0.16 - 0.26	275	2250	0.75	0.22	38	1820	59
Bt_1	0.26 - 0.41	200	2625	1.62	0.45	41	1701	49
Bt_2	0.41 - 0.66	235	3250	1.87	0.52	34	1464	47
BC	0.66 - 0.79	160	3625	1.00	0.37	31	1285	37
4. Solasa (Black Soil)								
Ap	0.00 - 0.10	370	2125	2.62	0.90	47	1404	75
AB	0.10 - 0.30	345	2500	2.75	0.97	44	1206	78
Bss_1	0.30 - 0.58	320	2875	2.87	1.05	41	1087	68
Bss_2	0.58 - 0.90	285	3125	3.12	1.12	38	968	65
Bss_3	0.90 - 1.35	250	3500	3.00	1.05	38	831	62
Bss_4	Below 1.35	225	3875	3.75	1.20	34	752	59

Profile No. & Horizon	Depth (m)	P	K	Ca	Mg	CuO	MnO_2	ZnO
		ppm		%		ppm		
5. Kondaveedu (Red Soil)								
Ap	0.00 - 0.09	350	625	0.37	0.15	41	1839	75
AB	0.09 - 0.37	380	1000	0.62	0.22	38	1641	56
Bw_1	0.37 - 0.75	330	1625	0.75	0.30	34	1464	53
Bw_2	0.75 - 1.12	295	2125	0.87	0.37	31	1356	49
Bw_3	1.12 - 1.46	260	2500	1.12	0.45	25	1124	47
Bw_4	Below 1.46	235	3125	1.50	0.52	28	1008	44
6. Changeej Khan Peta (Red Soil)								
Ap	0.00 - 0.09	290	875	1.00	0.30	38	1504	59
AB	0.09 - 0.30	245	1500	1.37	0.37	34	1641	47
Bw_1	0.30 - 0.47	135	2375	1.62	0.45	31	1288	44
Bw_2	0.47 - 0.60	150	3250	2.00	0.60	28	1171	41
7. Boyapalem (Red Soil)								
Ap	0.00 - 0.11	340	1125	0.25	0.07	34	1506	53
AB	0.11 - 0.19	295	1625	0.50	0.15	31	1306	49
Bw_1	0.19 - 0.45	260	2250	0.62	0.22	28	1135	41
Bt_1	0.45 - 0.70	215	2875	1.00	0.37	25	1005	37
Bt_2	0.70 - 0.90	175	3375	0.87	0.30	22	807	34
8. Timmapuram (Black Soil)								
Ap	0.00 - 0.15	365	1875	2.25	0.67	53	1522	81
AB	0.15 - 0.32	250	3125	2.25	0.75	50	1321	68
Bss_1	0.32 - 0.58	305	2625	2.37	0.75	47	1245	72
Bss_2	0.58 - 0.90	215	3750	2.37	0.82	44	1147	65

Table 13 : Molar concentrations and molar ratios of the soils

Profile No. & Horizon	Depth (m)	Molar concentrations				Molar ratios			
		SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3 / Fe_2O_3
1. Turlapadu (Black Soil)									
Ap	0.00 - 0.15	1.144	0.229	0.197	0.031	5.0	5.8	36.9	6.4
AB	0.15 - 0.52	1.108	0.238	0.205	0.033	4.7	5.4	33.6	6.2
Bss_1	0.52 - 0.80	1.037	0.272	0.238	0.033	3.8	4.3	31.4	7.2
Bss_2	0.80 - 1.20	1.073	0.260	0.224	0.037	4.1	4.8	29.0	6.1
Bss_3	1.20 - 1.50	1.002	0.294	0.256	0.038	3.4	3.9	26.4	6.7
Bss_4	Below 1.50	0.968	0.313	0.274	0.038	3.1	3.5	25.5	7.2
2. Jaggapuram (Black Soil)									
Ap	0.00 - 0.10	1.181	0.224	0.205	0.019	5.3	5.8	62.2	10.8
Bw_1	0.10 - 0.32	1.103	0.253	0.226	0.027	4.4	4.9	40.9	8.4
Bw_2	0.32 - 0.56	1.032	0.289	0.260	0.029	3.6	4.0	35.6	9.0
3. Edlapadu (Red Soil)									
Ap	0.00 - 0.16	1.224	0.190	0.156	0.034	6.4	7.8	36.0	4.6
B	0.16 - 0.26	1.255	0.176	0.141	0.035	7.1	8.9	35.9	4.0
Bt_1	0.26 - 0.41	1.175	0.210	0.174	0.036	5.6	6.8	32.6	4.8
Bt_2	0.41 - 0.66	1.144	0.224	0.186	0.038	5.1	6.2	30.1	4.9
BC	0.66 - 0.79	1.201	0.203	0.167	0.035	5.9	7.2	34.3	4.8
4. Solasa (Black Soil)									
Ap	0.00 - 0.10	1.121	0.236	0.207	0.029	4.7	5.4	38.7	7.1
AB	0.10 - 0.30	1.095	0.249	0.219	0.030	4.4	5.0	36.5	7.3
Bss_1	0.30 - 0.58	1.060	0.268	0.237	0.031	4.0	4.5	34.2	7.6
Bss_2	0.58 - 0.90	1.024	0.287	0.254	0.033	3.6	4.0	31.0	7.7
Bss_3	0.90 - 1.35	0.986	0.308	0.273	0.035	3.2	3.6	28.2	7.8
Bss_4	Below 1.35	0.949	0.318	0.281	0.037	3.0	3.4	25.6	7.6

Profile No. & Horizon	Depth (m)	Molar concentrations				Molar ratios			
		SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3/ Fe_2O_3
5. Kondaveedu (Red Soil)									
Ap	0.00 - 0.09	1.222	0.199	0.163	0.036	6.1	7.5	33.9	4.5
AB	0.09 - 0.37	1.188	0.216	0.180	0.037	5.5	6.6	32.1	4.9
Bw_1	0.37 - 0.75	1.156	0.234	0.196	0.038	4.9	5.9	30.4	5.2
Bw_2	0.75 - 1.12	1.115	0.255	0.216	0.038	4.4	5.2	29.3	5.7
Bw_3	1.12 - 1.46	1.085	0.269	0.229	0.040	4.0	4.7	27.1	5.7
Bw_4	Below 1.46	1.053	0.281	0.239	0.042	3.8	4.4	25.1	5.7
6. Changeej Khan Peta (Red Soil)									
Ap	0.00 - 0.09	1.279	0.167	0.142	0.026	7.6	9.0	49.2	5.5
AB	0.09 - 0.30	1.245	0.183	0.156	0.028	6.8	8.0	44.5	5.6
Bw_1	0.30 - 0.47	1.201	0.203	0.173	0.030	5.9	6.9	40.0	5.8
Bw_2	0.47 - 0.60	1.162	0.218	0.184	0.033	5.3	6.3	35.2	5.6
7. Boyapalem (Red Soil)									
Ap	0.00 - 0.11	1.235	0.194	0.164	0.029	6.4	7.5	42.6	5.7
AB	0.11 - 0.19	1.200	0.212	0.182	0.030	5.7	6.6	40.0	6.1
Bw_1	0.19 - 0.45	1.169	0.228	0.195	0.033	5.1	6.0	35.4	5.9
Bt_1	0.45 - 0.70	1.134	0.247	0.212	0.035	4.6	5.4	32.4	6.1
Bt_2	0.70 - 0.90	1.101	0.263	0.226	0.038	4.2	4.9	29.0	5.9
8. Timmapuram (Black Soil)									
Ap	0.00 - 0.15	1.163	0.227	0.202	0.024	5.1	5.7	48.5	8.4
AB	0.15 - 0.32	1.112	0.252	0.225	0.028	4.4	4.9	39.7	8.0
Bss_1	0.32 - 0.58	1.060	0.281	0.250	0.031	3.8	4.2	34.2	8.1
Bss_2	0.58 - 0.90	1.012	0.306	0.273	0.033	3.3	3.7	30.7	8.3

Table 10: Electro-chemical properties of the soils

Profile No. & Horizon	Depth (m)	CEC cmol (p^+) kg^{-1}	Exchangeable bases (cmol (p^+) kg^{-1})				BS %	CEC / clay ratio
			Ca^{++}	Mg^{++}	Na^+	K^+		
1. Turlapadu (Black Soil)								
Ap	0.00 - 0.15	47.80	36.00	6.84	1.26	0.46	93.22	0.92
AB	0.15 - 0.52	46.71	36.96	7.11	1.29	0.42	98.01	0.87
Bss_1	0.52 - 0.80	49.97	38.77	7.56	1.35	0.40	96.22	0.87
Bss_2	0.80 - 1.20	51.06	39.72	7.85	1.39	0.35	96.57	0.85
Bss_3	1.20 - 1.50	52.23	41.54	8.31	1.45	0.32	98.83	0.83
Bss_4	Below 1.50	55.41	43.36	8.78	1.51	0.28	97.33	0.84
2. Jaggapuram (Black Soil)								
Ap	0.00 - 0.10	31.50	22.68	4.31	0.79	0.29	89.11	0.95
Bw_1	0.10 - 0.32	33.68	24.46	4.83	0.85	0.22	90.14	0.93
Bw_2	0.32 - 0.56	35.31	25.81	5.29	0.90	0.14	91.02	0.91
3. Edlapadu (Red Soil)								
Ap	0.00 - 0.16	9.77	6.26	1.20	0.21	0.08	79.32	0.67
B	0.16 - 0.26	10.86	7.06	1.39	0.24	0.07	80.66	0.70
Bt_1	0.26 - 0.41	12.49	8.35	1.73	0.29	0.04	83.35	0.71
Bt_2	0.41 - 0.66	14.12	9.57	2.04	0.33	0.02	84.70	0.72
BC	0.66 - 0.79	11.40	7.52	1.52	0.26	0.05	82.02	0.73
4. Solasa (Black Soil)								
Ap	0.00 - 0.10	47.80	36.96	7.02	1.29	0.47	95.69	0.91
AB	0.10 - 0.30	49.97	38.77	7.46	1.35	0.45	96.12	0.90
Bss_1	0.30 - 0.58	51.06	39.68	7.73	1.38	0.40	96.34	0.88
Bss_2	0.58 - 0.90	53.23	41.54	8.20	1.45	0.37	96.86	0.86
Bss_3	0.90 - 1.35	58.67	44.23	8.84	1.54	0.32	93.63	0.88
Bss_4	Below 1.35	58.67	46.05	9.33	1.61	0.29	97.63	0.86

Profile No. & Horizon	Depth (m)	CEC cmol (p^+) kg^{-1}	Exchangeable bases $(cmol (p^+) kg^{-1})$				BS %	CEC / clay ratio
			Ca^{++}	Mg^{++}	Na^+	K^+		
5. Kondaveedu (Red Soil)								
Ap	0.00 - 0.09	13.03	8.96	1.68	0.31	0.13	85.03	0.74
AB	0.09 - 0.37	15.21	10.54	2.04	0.37	0.12	85.93	0.69
Bw_1	0.37 - 0.75	16.29	11.44	2.26	0.40	0.11	87.23	0.67
Bw_2	0.75 - 1.12	17.38	12.32	2.50	0.43	0.08	88.20	0.64
Bw_3	1.12 - 1.46	18.47	13.20	2.74	0.46	0.06	89.12	0.66
Bw_4	Below 1.46	19.55	14.08	2.99	0.49	0.02	89.92	0.67
6. Changeej Khan Peta (Red Soil)								
Ap	0.00 - 0.09	6.51	3.64	0.69	0.12	0.06	69.28	0.64
AB	0.09 - 0.30	7.82	4.59	0.90	0.16	0.05	72.89	0.66
Bw_1	0.30 - 0.47	9.77	6.01	1.23	0.21	0.04	76.61	0.67
Bw_2	0.47 - 0.60	10.86	6.90	1.47	0.24	0.01	79.37	0.69
7. Boyapalem (Red Soil)								
Ap	0.00 - 0.11	11.40	7.75	1.49	0.27	0.09	84.21	0.72
AB	0.11 - 0.19	12.49	8.61	1.70	0.30	0.08	85.59	0.75
Bw_1	0.19 - 0.45	14.12	9.85	2.00	0.34	0.07	86.83	0.69
Bt_1	0.45 - 0.70	16.29	11.51	2.39	0.40	0.05	88.09	0.67
Bt_2	0.70 - 0.90	18.47	13.17	2.80	0.46	0.02	89.06	0.63
8. Timmapuram (Black Soil)								
Ap	0.00 - 0.15	38.02	28.81	5.47	1.00	0.37	93.77	0.91
AB	0.15 - 0.32	41.28	31.45	6.13	1.10	0.32	94.48	0.91
Bss_1	0.32 - 0.58	43.46	33.22	6.64	1.16	0.26	94.98	0.91
Bss_2	0.58 - 0.90	46.71	35.84	7.35	1.25	0.19	95.55	0.93

CEC : Cation exchange capacity
BS : Base saturation

Table 9 : Physico - chemical properties of the soils

Profile No. & Horizon	Depth (m)	pH	EC dS m^{-1}	Organic carbon (%)	Total nitrogen (%)	C/N ratio	$CaCO_3$ (%)
1. Turlapadu (Black Soil)							
Ap	0.00 - 0.15	7.9	0.235	0.390	0.062	6.29	6.25
AB	0.15 - 0.52	8.2	0.241	0.285	0.031	9.19	6.87
Bss_1	0.52 - 0.80	8.5	0.472	0.285	0.024	11.88	7.12
Bss_2	0.80 - 1.20	8.6	0.741	0.270	0.021	12.86	7.00
Bss_3	1.20 - 1.50	8.7	0.913	0.195	0.022	8.86	7.25
Bss_4	Below 1.50	8.7	1.132	0.150	0.021	7.14	7.50
2. Jaggapuram (Black Soil)							
Ap	0.00 - 0.10	7.9	0.293	0.465	0.077	6.03	9.12
Bw_1	0.10 - 0.32	8.0	0.384	0.285	0.041	6.95	9.62
Bw_2	0.32 - 0.56	8.0	0.531	0.225	0.038	5.92	12.50
3. Edlapadu (Red Soil)							
Ap	0.00 - 0.16	7.0	0.098	0.255	0.035	7.29	0.00
B	0.16 - 0.26	7.1	0.122	0.225	0.034	6.62	0.87
Bt_1	0.26 - 0.41	7.4	0.166	0.195	0.031	6.29	0.57
Bt_2	0.41 - 0.66	7.4	0.303	0.210	0.029	7.24	1.00
BC	0.66 - 0.79	8.0	0.480	0.165	0.030	5.69	9.25
4. Solasa (Black Soil)							
Ap	0.00 - 0.10	7.6	0.972	0.360	0.054	6.67	5.75
AB	0.10 - 0.30	7.8	0.815	0.210	0.031	6.77	5.00
Bss_1	0.30 - 0.58	8.4	1.215	0.195	0.023	8.48	6.25
Bss_2	0.58 - 0.90	8.4	1.956	0.180	0.023	7.83	6.37
Bss_3	0.90 - 1.35	8.4	3.783	0.180	0.021	8.57	7.87
Bss_4	Below 1.35	8.4	3.883	0.150	0.017	7.88	8.00

Profile No. & Horizon	Depth (m)	pH	EC dS m^{-1}	Organic carbon (%)	Total nitrogen (%)	C/N ratio	$CaCO_3$ (%)
5. Kondaveedu (Red Soil)							
Ap	0.00 - 0.09	7.5	0.124	0.450	0.076	6.92	0.25
AB	0.09 - 0.37	7.6	0.127	0.120	0.021	5.71	0.62
Bw_1	0.37 - 0.75	7.7	0.152	0.090	0.018	5.00	0.37
Bw_2	0.75 - 1.12	7.7	0.139	0.090	0.018	5.00	0.75
Bw_3	1.12 - 1.46	7.8	0.261	0.075	0.017	4.41	0.87
Bw_4	Below 1.46	7.8	0.307	0.075	0.016	4.69	1.25
6. Changeej Khan Peta (Red Soil)							
Ap	0.00 - 0.09	7.4	0.114	0.435	0.062	7.02	0.00
AB	0.09 - 0.30	7.6	0.311	0.420	0.054	7.77	0.37
Bw_1	0.30 - 0.47	7.5	0.389	0.345	0.059	5.85	0.12
Bw_2	0.47 - 0.60	7.9	0.405	0.210	0.033	6.37	6.50
7. Boyapalem (Red Soil)							
Ap	0.00 - 0.11	7.0	0.160	0.240	0.031	7.74	0.00
AB	0.11 - 0.19	7.1	0.181	0.165	0.030	5.50	0.00
Bw_1	0.19 - 0.45	7.1	0.176	0.165	0.030	5.50	0.25
Bt_1	0.45 - 0.70	7.2	0.186	0.165	0.029	5.69	0.12
Bt_2	0.70 - 0.90	7.2	0.243	0.125	0.028	4.46	0.50
8. Timmapuram (Black Soil)							
Ap	0.00 - 0.15	7.9	0.413	0.345	0.052	6.63	13.87
AB	0.15 - 0.32	8.3	0.521	0.270	0.034	7.94	14.62
Bss_1	0.32 - 0.58	8.1	0.531	0.225	0.022	10.22	14.37
Bss_2	0.58 - 0.90	8.5	0.612	0.240	0.025	9.60	15.00

Table 8 : Physical properties of the soils

Profile No. & Horizon	Depth (m)	Bulk density Mg m-3	Water holding capacity	Volume expansion	Sticky point	COLE
			Per cent			
1. Turlapadu (Black Soil)						
Ap	0.00 - 0.15	1.22	54.30	23.22	21.14	0.13
AB	0.15 - 0.52	1.26	55.61	22.17	22.19	0.14
Bss_1	0.52 - 0.80	1.33	59.01	25.54	24.20	0.16
Bss_2	0.80 - 1.20	1.30	60.51	26.53	25.24	0.18
Bss_3	1.20 - 1.50	1.36	61.23	28.04	29.10	0.19
Bss_4	Below 1.50	1.39	63.50	30.13	27.01	0.21
2. Jaggapuram (Black Soil)						
Ap	0.00 - 0.10	1.34	40.56	20.23	19.14	0.11
Bw_1	0.10 - 0.32	1.41	42.68	21.06	20.01	0.13
Bw_2	0.32 - 0.56	1.49	43.45	22.67	21.51	0.16
3. Edlapadu (Red Soil)						
Ap	0.00 - 0.16	1.52	21.53	3.50	15.81	---
B	0.16 - 0.26	1.56	22.31	4.15	16.44	---
Bt_1	0.26 - 0.41	1.62	24.10	5.10	18.57	---
Bt_2	0.41 - 0.66	1.66	25.55	5.82	19.50	---
BC	0.66 - 0.79	1.59	22.42	4.76	17.61	---
4. Solasa (Black Soil)						
Ap	0.00 - 0.10	1.21	55.67	23.48	23.35	0.14
AB	0.10 - 0.30	1.25	57.63	24.46	22.27	0.15
Bss_1	0.30 - 0.58	1.32	59.83	28.48	25.55	0.17
Bss_2	0.58 - 0.90	1.29	63.16	26.63	27.25	0.19
Bss_3	0.90 - 1.35	1.35	60.07	30.22	29.16	0.20
Bss_4	Below 1.35	1.38	64.26	31.71	30.46	0.22

Profile No. & Horizon	Depth (m)	Bulk density Mg m-3	Water holding capacity	Volume expansion	Sticky point	COLE
			Per cent			
5. Kondaveedu (Red Soil)						
Ap	0.00 - 0.09	1.41	23.34	4.57	16.78	---
AB	0.09 - 0.37	1.44	25.90	5.12	18.65	---
Bw_1	0.37 - 0.75	1.48	28.97	5.87	17.52	---
Bw_2	0.75 - 1.12	1.53	27.57	6.23	19.61	---
Bw_3	1.12 - 1.46	1.57	29.76	6.90	20.53	---
Bw_4	Below 1.46	1.61	30.77	6.70	21.52	---
6. Changeej Khan Peta (Red Soil)						
Ap	0.00 - 0.09	1.58	20.87	3.55	15.47	---
AB	0.09 - 0.30	1.62	21.88	3.08	16.54	---
Bw_1	0.30 - 0.47	1.69	23.75	4.17	17.35	---
Bw_2	0.47 - 0.60	1.65	24.29	4.58	18.55	---
7. Boyapalem (Red Soil)						
Ap	0.00 - 0.11	1.43	22.60	4.21	17.24	---
AB	0.11 - 0.19	1.47	23.59	5.42	16.35	---
Bw_1	0.19 - 0.45	1.52	25.80	4.66	18.32	---
Bt_1	0.45 - 0.70	1.57	30.32	5.81	19.38	---
Bt_2	0.70 - 0.90	1.63	29.32	6.42	20.68	---
8. Timmapuram (Black Soil)						
Ap	0.00 - 0.15	1.36	46.69	21.74	20.54	0.12
AB	0.15 - 0.32	1.30	49.52	23.33	22.26	0.14
Bss_1	0.32 - 0.58	1.40	50.80	24.41	23.27	0.16
Bss_2	0.58 - 0.90	1.45	52.40	26.15	25.09	0.18

Table 7 : Ratios of the fine earth fractions (particle size-analysis)

Profile No. & Horizon	Depth (m)	Sand + silt	Silt + clay	Sand / silt	Silt / clay	Coarse sand/ fine sand	Sand / (sand + silt)	Sand / (silt + clay)
1. Turlapadu (Black Soil)								
Ap	0.00 - 0.15	47.92	67.76	2.06	0.30	0.78	0.67	0.48
AB	0.15 - 0.52	46.12	68.86	2.08	0.28	0.76	0.68	0.45
Bss_1	0.52 - 0.80	42.71	70.93	2.13	0.24	0.74	0.68	0.41
Bss_2	0.80 - 1.20	40.21	72.18	2.25	0.21	0.74	0.69	0.39
Bss_3	1.20 - 1.50	37.18	74.34	2.23	0.18	0.73	0.69	0.35
Bss_4	Below 1.50	34.38	76.49	2.16	0.17	0.70	0.68	0.31
2. Jaggapuram (Black Soil)								
Ap	0.00 - 0.10	66.83	56.36	1.88	0.70	0.72	0.65	0.77
Bw_1	0.10 - 0.32	63.91	58.50	1.85	0.62	0.72	0.65	0.71
Bw_2	0.32 - 0.56	61.03	60.32	1.86	0.55	0.71	0.65	0.66
3. Edlapadu (Red Soil)								
Ap	0.00 - 0.16	85.42	25.01	7.19	0.72	1.57	0.88	3.00
B	0.16 - 0.26	84.53	26.81	6.45	0.73	1.58	0.87	2.73
Bt_1	0.26 - 0.41	82.39	32.11	4.68	0.82	1.73	0.82	2.11
Bt_2	0.41 - 0.66	80.40	38.15	3.33	0.95	1.79	0.77	1.62
BC	0.66 - 0.79	84.37	28.13	5.75	0.80	1.65	0.85	2.56
4. Solasa (Black Soil)								
Ap	0.00 - 0.10	47.41	67.83	2.11	0.29	0.70	0.68	0.47
AB	0.10 - 0.30	44.78	69.54	2.13	0.26	0.70	0.68	0.44
Bss_1	0.30 - 0.58	41.96	71.58	2.10	0.23	0.70	0.68	0.40
Bss_2	0.58 - 0.90	38.28	74.19	2.07	0.20	0.67	0.67	0.35
Bss_3	0.90 - 1.35	33.34	77.94	1.96	0.17	0.63	0.66	0.28
Bss_4	Below 1.35	31.58	78.61	2.10	0.15	0.65	0.68	0.27

Profile No. & Horizon	Depth (m)	Sand + silt	Silt + clay	Sand / silt	Silt / clay	Coarse sand/ fine sand	Sand / (sand + silt)	Sand / (silt + clay)
5. Kondaveedu (Red Soil)								
Ap	0.00 - 0.09	82.39	27.97	6.95	0.59	1.48	0.87	2.58
AB	0.09 - 0.37	78.11	33.34	5.82	0.52	1.46	0.85	2.00
Bw_1	0.37 - 0.75	75.78	36.85	5.00	0.52	1.50	0.83	1.71
Bw_2	0.75 - 1.12	72.77	40.84	4.35	0.50	1.51	0.81	1.45
Bw_3	1.12 - 1.46	71.86	42.72	3.93	0.52	1.50	0.80	1.34
Bw_4	Below 1.46	70.66	45.04	3.50	0.54	1.56	0.78	1.22
6. Changeej Khan Peta (Red Soil)								
Ap	0.00 - 0.09	89.68	23.72	5.69	1.30	1.85	0.85	3.22
AB	0.09 - 0.30	88.59	25.91	5.11	1.27	1.98	0.84	2.86
Bw_1	0.30 - 0.47	86.59	29.90	4.25	1.23	1.96	0.81	2.34
Bw_2	0.47 - 0.60	85.56	31.96	3.88	1.21	2.00	0.80	2.13
7. Boyapalem (Red Soil)								
Ap	0.00 - 0.11	83.49	27.85	6.36	0.69	1.64	0.86	2.59
AB	0.11 - 0.19	81.35	31.08	5.54	0.67	1.66	0.85	2.22
Bw_1	0.19 - 0.45	77.07	35.87	4.69	0.61	1.77	0.82	1.77
Bt_1	0.45 - 0.70	72.15	42.38	4.00	0.52	1.73	0.80	1.37
Bt_2	0.70 - 0.90	70.97	44.27	3.57	0.54	1.82	0.78	1.24
8. Timmapuram (Black Soil)								
Ap	0.00 - 0.15	58.55	63.77	1.61	0.54	0.71	0.62	0.57
AB	0.15 - 0.32	54.62	66.94	1.53	0.48	0.72	0.61	0.49
Bss_1	0.32 - 0.58	52.34	68.04	1.57	0.43	0.73	0.61	0.47
Bss_2	0.58 - 0.90	49.99	69.95	1.51	0.40	0.70	0.60	0.43

Table 6 : Particle - size analysis data of the fine earth fraction of the soils (< 2mm size)

Profile No. & Horizon	Depth (m)	Sand %			Silt %	Clay %	Textural class
		Coarse	Fine	Total			
1. Turlapadu (Black Soil)							
Ap	0.00 - 0.15	14.11	18.13	32.24	15.68	52.08	Clay
AB	0.15 - 0.52	13.48	17.66	31.14	14.98	53.88	Clay
Bss_1	0.52 - 0.80	12.36	16.71	29.07	13.64	57.29	Clay
Bss_2	0.80 - 1.20	11.84	15.98	27.82	12.39	59.79	Clay
Bss_3	1.20 - 1.50	10.79	14.87	25.66	11.52	62.82	Clay
Bss_4	Below 1.50	9.67	13.84	23.51	10.87	65.62	Clay
2. Jaggapuram (Black Soil)							
Ap	0.00 - 0.10	18.27	25.37	43.64	23.19	33.17	Clay loam
Bw_1	0.10 - 0.32	17.32	24.18	41.50	22.41	36.09	Clay loam
Bw_2	0.32 - 0.56	16.43	23.25	39.68	21.35	38.97	Clay
3. Edlapadu (Red Soil)							
Ap	0.00 - 0.16	45.83	29.16	74.99	10.43	14.58	Sandy loam
B	0.16 - 0.26	44.84	28.35	73.19	11.34	15.47	Sandy loam
Bt_1	0.26 - 0.41	43.02	24.87	67.89	14.50	17.61	Loam
Bt_2	0.41 - 0.66	39.69	22.16	61.85	18.55	19.60	Loam
BC	0.66 - 0.79	44.79	27.08	71.87	12.50	15.63	Sandy loam
4. Solasa (Black Soil)							
Ap	0.00 - 0.10	13.30	18.87	32.17	15.24	52.59	Clay
AB	0.10 - 0.30	12.54	17.92	30.46	14.32	55.22	Clay
Bss_1	0.30 - 0.58	11.68	16.74	28.42	13.54	58.04	Clay
Bss_2	0.58 - 0.90	10.37	15.44	25.81	12.47	61.72	Clay
Bss_3	0.90 - 1.35	8.49	13.57	22.06	11.28	66.66	Clay
Bss_4	Below 1.35	8.41	12.98	21.39	10.19	68.42	Clay

Profile No. & Horizon	Depth (m)	Sand %			Silt %	Clay %	Textural class
		Coarse	Fine	Total			
5. Kondaveedu (Red Soil)							
Ap	0.00 - 0.09	43.02	29.01	72.03	10.36	17.61	Sandy loam
AB	0.09 - 0.37	39.58	27.08	66.66	11.45	21.89	Clay loam
Bw_1	0.37 - 0.75	37.89	25.26	63.15	12.63	24.22	Clay loam
Bw_2	0.75 - 1.12	35.60	23.56	59.16	13.61	27.23	Clay loam
Bw_3	1.12 - 1.46	34.37	22.91	57.28	14.58	28.14	Clay loam
Bw_4	Below 1.46	33.50	21.46	54.96	15.70	29.34	Clay loam
6. Changeej Khan Peta (Red Soil)							
Ap	0.00 - 0.09	49.48	26.80	76.28	13.40	10.32	Sandy loam
AB	0.09 - 0.30	49.22	24.87	74.09	14.50	11.42	Sandy loam
Bw_1	0.30 - 0.47	46.39	23.71	70.10	16.49	13.41	Loam
Bw_2	0.47 - 0.60	45.36	22.68	68.04	17.52	14.44	Loam
7. Boyapalem (Red Soil)							
Ap	0.00 - 0.11	44.84	27.31	72.15	11.34	16.51	Loam
AB	0.11 - 0.19	43.02	25.90	68.92	12.43	18.65	Loam
Bw_1	0.19 - 0.45	40.62	22.91	63.53	13.54	22.33	Clay loam
Bt_1	0.45 - 0.70	36.59	21.13	57.72	14.43	27.85	Clay loam
Bt_2	0.70 - 0.90	35.75	19.68	55.43	15.54	29.03	Clay loam
8. Timmapuram (Black Soil)							
Ap	0.00 - 0.15	15.03	21.10	36.13	22.42	41.45	Clay
AB	0.15 - 0.32	13.87	19.19	33.06	21.56	45.38	Clay
Bss_1	0.32 - 0.58	13.51	18.45	31.96	20.38	47.66	Clay
Bss_2	0.58 - 0.90	12.39	17.66	30.05	19.94	50.01	Clay

Table 5 : Morphological features

Profile No. & Horizon	Depth (m)	Boundary	Colour		Texture	Structure			Consistence			Porosity		Roots		Efferve-scences	Other features
			Dry	Moist		S	G	T	D	M	W	S	Q	S	Q		
1. Turlapadu (Black Soil)																	
Ap	0.00 - 0.15	gw	10YR 5/1	10YR 4/1	c	f	2	gr	s	fr	s & p	m	m	m	m	es	
AB	0.15 - 0.52	gw	10YR 5/1	10YR 4/1	c	m	2	sbk	h	fi	vs & vp	f	c	f	c	es	Gilgai relief
Bss$_1$	0.52 - 0.80	ds	10YR 5/1	10YR 4/1	c	c	3	sbk	h	vfi	vs & vp	vf	f	f	c	es	surface cracks
Bss$_2$	0.80 - 1.20	ds	10YR 5/1	10YR 4/1	c	c	3	abk	vh	vfi	vs & vp	vf	f	f	f	es	slickensides
Bss$_3$	1.20 - 1.50	ds	10YR 4/1	10YR 3/1	c	c	3	abk	vh	vfi	vs & vp	vf	f	vf	f	ev	conca
Bss$_4$	Below 1.50	-	10YR 4/1	10YR 3/1	c	c	3	abk	vh	vfi	vs & vp	vf	f	-	-	ev	
2. Jaggapuram (Black Soil)																	
Ap	0.00 - 0.10	gw	10YR 4/1	10YR 4/1	cl	f	1	gr	s	fr	s & p	m	m	m	m	es	
Bw$_1$	0.10 - 0.32	gi	10YR 4/1	10YR 4/1	cl	m	2	sbk	h	fi	s & p	f	c	f	c	es	Cambic horizon
Bw$_2$	0.32 - 0.56	cw	10YR 4/1	10YR 4/1	c	m	2	sbk-abk	h	fi	s & p	f	c	f	c	es	
C	Below 0.56	Weathered granitic gneiss mixed with calcareous murram															
3. Edlapadu (Red Soil)																	
Ap	0.00 - 0.16	cw	5YR 4/4	5YR 3/4	sl	vf	1	gr	l	l	so & po	m	m	m	m	-	
B	0.16 - 0.26	cs	5YR 4/4	5YR 3/4	sl	f	1	sbk	s	vfr	ss & ps	m	m	vf	c	-	
Bt$_1$	0.26 - 0.41	gi	5YR 4/4	5YR 3/4	l	m	2	cpr-sbk	sh	fi	ss & ps	f	c	vf	c	e	Clay cutans
Bt$_2$	0.41 - 0.66	cw	5YR 4/4	5YR 3/4	l	m	2	cpr-sbk	h	fi	ss & ps	f	f	vf	c	e	argillic horizon
BC	0.66 - 0.79	ab	5YR 4/4	5YR 3/4	sl	m	2	sbk	s	fr	ss & ps	f	f	vf	f	e	
C	Below 0.79	Weathered granitic gneiss															
4. Solasa (Black Soil)																	
Ap	0.00 - 0.10	gs	10YR 3/1	10YR 3/1	c	f	2	cr	s	fi	s & p	m	m	m	m	e	
AB	0.10 - 0.30	gw	10YR 3/1	10YR 3/1	c	m	2	sbk	h	fi	vs & vp	f	c	f	c	e	Gilgai relief
Bss$_1$	0.30 - 0.58	dw	10YR 3/1	10YR 3/1	c	c	3	abk	h	vfi	vs & vp	vf	f	f	c	es	surface cracks
Bss$_2$	0.58 - 0.90	ds	10YR 3/1	10YR 3/1	c	c	3	sbk	vh	vfi	vs & vp	vf	f	f	f	es	slickensides
Bss$_3$	0.90 - 1.35	ds	10YR 3/1	10YR 3/1	c	c	3	sbk	vh	vfi	vs & vp	vf	f	vf	f	es	conca
Bss$_4$	Below 1.35	-	10YR 3/1	10YR 3/1	c	c	3	sbk	vh	efi	vs & vp	vf	f	-	-	ev	
5. Kondaveedu (Red Soil)																	
Ap	0.00 - 0.09	cs	5YR 4/4	5YR 3/4	sl	f	1	gr	s	vfr	so & po	f	c	m	m	-	
AB	0.09 - 0.37	gw	5YR 4/4	5YR 3/4	cl	f	1	gr	s	vfr	so & po	m	c	m	m	-	
Bw$_1$	0.37 - 0.75	gi	5YR 4/4	5YR 3/4	cl	m	2	sbk	sh	fi	so & po	f	f	f	f	-	
Bw$_2$	0.75 - 1.12	gw	5YR 4/4	5YR 3/4	cl	m	2	sbk	h	fi	so & ps	vf	f	-	-	-	Cambic horizon
Bw$_3$	1.12 - 1.46	gs	5YR 4/4	5YR 3/4	cl	m	2	sbk	h	fi	ss & po	vf	f	-	-	-	
Bw$_4$	Below 1.46	-	5YR 4/4	5YR 3/4	cl	m	2	sbk	vh	vfi	so & po	m	m	-	-	-	

Profile No. & Horizon	Depth (m)	Boundary	Colour		Texture	Structure			Consistence			Porosity		Roots		Effervescences	Other features
			Dry	Moist		S	G	T	D	M	W	S	Q	S	Q		
6. Changeej Khan Peta (Red Soil)																	
Ap	0.00 - 0.09	gs	5YR 4/4	5YR 3/4	sl	f	1	gr	l	l	so & po	f	c	m	m	-	
AB	0.09 - 0.30	cs	5YR 4/4	5YR 3/4	sl	f	1	sbk	s	vfr	so & po	f	c	m	m	-	Cambic horizon
Bw$_1$	0.30 - 0.47	cs	5YR 4/4	5YR 3/4	l	m	2	sbk	sh	fi	so & po	vf	f	m	c	-	
Bw$_2$	0.47 - 0.60	ci	5YR 4/4	5YR 3/4	l	m	2	sbk	h	fi	so & ps	f	f	vf	f	es	
C	Below 0.60	Weathered granitic gneiss															
7. Boyapalem (Red Soil)																	
Ap	0.00 - 0.11	gw	5YR 4/4	5YR 3/4	l	f	1	gr	l	l	so & po	m	m	m	c	-	
AB	0.11 - 0.19	cw	5YR 4/4	5YR 3/4	l	f	1	sbk	l	l	so & po	f	m	vf	f	-	
Bw$_1$	0.19 - 0.45	cs	5YR 4/4	5YR 3/4	cl	m	2	sbk	s	fi	ss & ps	f	f	vf	f	-	Cambic horizon argillic horizons
Bt$_1$	0.45 - 0.70	gw	5YR 4/4	5YR 3/4	cl	m	2	sbk	h	fi	ss & ps	f	f	vf	f	-	
Bt$_2$	0.70 - 0.90	ci	5YR 4/4	5YR 3/4	cl	m	2	sbk	h	fi	ss & ps	vf	f	vf	f	-	
C	Below 0.90	Weathered granitic gneiss															
8. Timmapuram (Black Soil)																	
Ap	0.00 - 0.15	gw	10YR 4/1	10YR 4/1	c	f	1	sbk	s	vfr	s & p	m	m	m	m	e	
AB	0.15 - 0.32	gw	10YR 4/1	10YR 4/1	c	m	2	abk	h	fi	vs & vp	f	c	f	c	ev	Gilgai relief surface cracks slickensides conca
Bss$_1$	0.32 - 0.58	ds	10YR 4/1	10YR 4/1	c	c	3	abk	h	vfi	vs & vp	vf	f	f	c	ev	
Bss$_2$	0.58 - 0.90	gw	10YR 4/1	10YR 4/1	c	c	3	abk	vh	vfi	vs & vp	vf	f	-	-	ev	
C	Below 0.90	Weathered granitic gneiss mixed with calcareous murrum															

Bourdary : gw=gradual wavy, ds = diffused smooth, dw-diffused wavy, cw = clear wavy, gi = gradual irregular, cs = clear smooth, ab = abrupt broken

Texture : c = clay, cl = clay loam, l = loam, sl = sandy loam

Structure : T = type; gr = granular, sbk - subangular blocky, abk - angular blocky, cr = crumb, cpr - columnar
G = grade; 1 - weak, 2 - moderate, 3 - strong
S = size; vf - very fine, f = fine, m - medium, c= coarse

Consistence : D = Dry ; l = loose, s = soft, sh = slightly hard, h = hard, vh = very hard, eh = extremely hard
M = moist; l = loose, vfr - very friable, fr - friable, fir - firm, vfir - very firm, efir = extremely firm
W = wet; s_0 = non sticky, ss = slightly sticky, s= sticky, vs - very sticky; po = non plastic, ps - slightly plastic, p = plastic, vp - very plastic

Pores & roots: S = size; vf = very fine, f = fine, m = medium, c = coarse; q = quantity; f = few, c = common, m = many.

Effervescences : e= none to slight, es = strong, ev = violent (reaction with dil. HCl)

Table 4 : Profile details

Profile No.	Location	Horizon	Depth (m)	Diagnostic horizon / feature
1	Turlapadu	Ap	0.00 - 0.15	Vertic features
		AB	0.15 - 0.52	
		Bss_1	0.52 - 0.80	
		Bss_2	0.80 - 1.20	
		Bss_3	1.20 - 1.50	
		Bss_4	Below 1.50	
2	Jaggapuram	Ap	0.00 - 0.10	Cambic horizon in subsurface
		Bw_1	0.10 - 0.32	
		Bw_2	0.32 - 0.56	
		C	Below 0.56	
3	Edlapadu	Ap	0.00 - 0.16	Argillans & argillic horizon in subsurface
		B	0.16 - 0.26	
		Bt_1	0.26 - 0.41	
		Bt_2	0.41 - 0.66	
		BC	0.66 - 0.79	
		C	Below 0.79	
4	Solasa	Ap	0.00 - 0.10	Vertic features
		AB	0.10 - 0.30	
		Bss_1	0.30 - 0.58	
		Bss_2	0.58 - 0.90	
		Bss_3	0.90 - 1.35	
		Bss_4	Below 1.35	
5	Kondaveedu	Ap	0.00 - 0.09	Cambic horizon in subsurface
		AB	0.09 - 0.37	
		Bw_1	0.37 - 0.75	
		Bw_2	0.75 - 1.12	
		Bw_3	1.12 - 1.46	
		Bw_4	Below 1.46	
6	Changeej Khan Peta	Ap	0.00 - 0.09	Cambic horizon in subsurface
		AB	0.09 - 0.30	
		Bw_1	0.30 - 0.47	
		Bw_2	0.47 - 0.60	
		C	Below 0.60	
7	Boyapalem	Ap	0.00 - 0.11	Cambic and argillic horizons in subsurface
		AB	0.11 - 0.19	
		Bw_1	0.19 - 0.45	
		Bt_1	0.45 - 0.70	
		Bt_2	0.70 - 0.90	
		C	Below 0.90	
8	Timmapuram	Ap	0.00 - 0.15	Vertic features
		AB	0.15 - 0.32	
		Bss_1	0.32 - 0.58	
		Bss_2	0.58 - 0.90	
		C	Below 0.90	

e

Table 3 : Natural vegetation and land use of the study area

Profile No.	Location	Natural vegetation	Land use
1	Turlapadu	Neem, *Acacia* sp., *Prosphis*	Cotton (55%), maize (10%), redgram (15%), chillies (20%)
2	Jaggapuram	Neem, tamarind	Cotton (90%)
3	Edlapadu	*Acacia* sp., *Prosphis*	Cotton (65%), chillies (30%)
4	Solasa	Neem, *Acacia, Borasus*	Cotton (70%), chillies (30%)
5	Kondaveedu	Palmyra, neem, teak	Bhendi (40%), brinjal (40%), marrygold (20%)
6	Changeej Khan Peta	Palmyra, neem, soapnuts	Mango orchards (98%)
7	Boyapalem	Neem	Cotton (85%), sorghum (15%)
8	Timmapuram	Neem, palmyra	Cotton (96%)

Table 1 :   Site characteristics of the study area

Profile No.	Location	Slope per cent	Physiography	Drainage	Parent material
1	Turlapadu (Black Soil)	0 - 1	Plain lands nearly level	Moderately well drained	Granitic gneiss mixed with calcareous murram
2	Jaggapuram (Black Soil)	1 - 3	Very gently sloping	Moderately well drained	Granitic gneiss mixed with calcareous murram
3	Edlapadu (Red Soil)	3 - 5	Gently sloping	Well drained	Granitic gneiss
4	Solasa (Black Soil)	< 1	Plain lands nearly level	Moderately well drained	Granitic gneiss mixed with calcareous murram
5	Kondaveedu (Red Soil)	3 - 5	Gently sloping	Well drained	Granitic gneiss
6	Changeej Khan Peta (Red Soil)	3 - 5	Gently sloping	Well drained	Granitic gneiss
7	Boyapalem (Red Soil)	3 - 5	Gently sloping	Well drained	Granitic gneiss
8	Timmapuram (Black Soil)	0 - 1	Plain lands nearly level	Moderately well drained	Granitic gneiss mixed with calcareous murram

Profile No. & Horizon	Depth (m)	Bulk density Mg m^{-3}	COLE	Water holding capacity (%)	Volume expansion (%)
1. Turlapadu (Black Soil)					
Ap	0.00 - 0.15	1.22	0.13	54.30	23.22
AB	0.15 - 0.52	1.26	0.14	55.61	22.17
Bss_1	0.52 - 0.80	1.33	0.16	59.01	25.54
Bss_2	0.80 - 1.20	1.30	0.18	60.51	26.53
Bss_3	1.20 - 1.50	1.36	0.19	61.23	28.04
Bss_4	Below 1.50	1.39	0.21	63.50	30.13
2. Jaggapuram (Black Soil)					
Ap	0.00 - 0.10	1.34	0.11	40.56	20.23
Bw_1	0.10 - 0.32	1.41	0.13	42.68	21.06
Bw_2	0.32 - 0.56	1.49	0.16	43.45	22.67
C	Below 0.56				
3. Edlapadu (Red Soil)					
Ap	0.00 - 0.16	1.52		21.53	3.50
B	0.16 - 0.26	1.56		22.31	4.15
Bt_1	0.26 - 0.41	1.62		24.10	5.10
Bt_2	0.41 - 0.66	1.66		25.55	5.82
BC	0.66 - 0.79	1.59		22.42	4.76
C	Below 0.79				
4. Solasa (Black Soil)					
Ap	0.00 - 0.10	1.21	0.14	55.67	23.48
AB	0.10 - 0.30	1.25	0.15	57.63	24.46
Bss_1	0.30 - 0.58	1.32	0.17	59.83	28.48
Bss_2	0.58 - 0.90	1.29	0.19	63.16	26.63
Bss_3	0.90 - 1.35	1.35	0.20	60.07	30.22
Bss_4	Below 1.35	1.38	0.22	64.26	31.71

Profile No. & Horizon	Depth (m)	Bulk density Mg m^{-3}	COLE	Water holding capacity (%)	Volume expansion (%)
<u>5. Kondaveedu (Red Soil)</u>					
Ap	0.00 - 0.09	1.41		23.34	4.57
AB	0.09 - 0.37	1.44		25.90	5.12
Bw_1	0.37 - 0.75	1.48		28.97	5.87
Bw_2	0.75 - 1.12	1.53		27.57	6.23
Bw_3	1.12 - 1.46	1.57		29.76	6.90
Bw_4	Below 1.46	1.61		30.77	6.70
<u>6. Changeej Khan Peta (Red Soil)</u>					
Ap	0.00 - 0.09	1.58		20.87	3.55
AB	0.09 - 0.30	1.62		21.88	3.08
Bw_1	0.30 - 0.47	1.69		23.75	4.17
Bw_2	0.47 - 0.60	1.65		24.29	4.58
Bw_3	Below 0.60				
<u>7. Boyapalem (Red Soil)</u>					
Ap	0.00 - 0.11	1.43		22.60	4.21
AB	0.11 - 0.19	1.47		23.59	5.42
Bw_1	0.19 - 0.45	1.52		25.80	4.66
Bt_1	0.45 - 0.70	1.57		30.32	5.81
Bt_2	0.70 - 0.90	1.63		29.32	6.42
C	Below 0.90				
<u>8. Timmapuram (Black Soil)</u>					
Ap	0.00 - 0.15	1.36	0.12	46.69	21.74
AB	0.15 - 0.32	1.30	0.14	49.52	23.33
Bss_1	0.32 - 0.58	1.40	0.16	50.80	24.41
Bss_2	0.58 - 0.90	1.45	0.18	52.40	26.15
C	Below 0.90				

Table 10 : Electrochemical properties of soils

Sticky point (%)	pH	EC dS m^{-1}	Organic carbon (%)	Total N (%)	C/N ratio	$CaCO_3$ (%)
21.14	7.9	0.235	0.390	0.062	6.29	6.25
22.19	8.2	0.241	0.285	0.031	9.19	6.87
24.20	8.5	0.472	0.285	0.024	11.88	7.12
25.24	8.6	0.741	0.270	0.021	12.86	7.00
29.10	8.7	0.913	0.195	0.022	8.86	7.25
27.01	8.7	1.132	0.150	0.021	7.14	7.50
19.14	7.9	0.293	0.465	0.077	6.03	9.12
20.01	8.0	0.384	0.285	0.041	6.95	9.62
21.51	8.0	0.531	0.225	0.038	5.92	12.50
15.81	7.0	0.098	0.255	0.035	7.29	0.00
16.44	7.1	0.122	0.225	0.034	6.62	0.87
18.57	7.4	0.166	0.195	0.031	6.29	0.57
19.50	7.4	0.303	0.210	0.029	7.24	1.00
17.61	8.0	0.480	0.165	0.030	5.69	9.25
23.35	7.6	0.972	0.360	0.054	6.67	5.75
22.27	7.8	0.815	0.210	0.031	6.77	5.00
25.55	8.4	1.215	0.195	0.023	8.48	6.25
27.25	8.4	1.956	0.180	0.023	7.83	6.37
29.16	8.4	3.783	0.180	0.021	8.57	7.87
30.46	8.4	3.883	0.150	0.017	7.88	8.00

Sticky point (%)	pH	EC dS m^{-1}	Organic carbon (%)	Total N (%)	C/N ratio	$CaCO_3$ (%)
16.78	7.5	0.124	0.450	0.076	6.92	0.25
18.65	7.6	0.127	0.120	0.021	5.71	0.62
17.52	7.7	0.152	0.090	0.018	5.00	0.37
19.61	7.7	0.139	0.090	0.018	5.00	0.75
20.53	7.8	0.261	0.075	0.017	4.41	0.87
21.52	7.8	0.307	0.075	0.016	4.69	1.25
15.47	7.4	0.114	0.435	0.062	7.02	0.00
16.54	7.6	0.311	0.420	0.054	7.77	0.37
17.35	7.5	0.389	0.345	0.059	5.85	0.12
18.55	7.9	0.405	0.210	0.033	6.37	6.50
17.24	7.0	0.160	0.240	0.031	7.74	0.00
16.35	7.1	0.181	0.165	0.030	5.50	0.00
18.32	7.1	0.176	0.165	0.030	5.50	0.25
19.38	7.2	0.186	0.165	0.029	5.69	0.12
20.68	7.2	0.243	0.125	0.028	4.46	0.50
20.54	7.9	0.413	0.345	0.052	6.63	13.87
22.26	8.3	0.521	0.270	0.034	7.94	14.62
23.27	8.1	0.531	0.225	0.022	10.22	14.37
25.09	8.5	0.612	0.240	0.025	9.60	15.00

CEC (c mol (p^+) kg^{-1}	Exchangeable bases (c mol (p^+) kg^{-1})				BS %	Exchan
	Ca^{++}	Mg^{++}	Na^+	K^+		Ca^{++}
47.80	36.00	6.84	1.26	0.46	93.22	75.31
46.71	36.96	7.11	1.29	0.42	98.01	79.13
49.97	38.77	7.56	1.35	0.40	96.22	77.59
51.06	39.72	7.85	1.39	0.35	96.57	77.79
52.23	41.54	8.31	1.45	0.32	98.83	79.53
55.41	43.36	8.78	1.51	0.28	97.33	78.25
31.50	22.68	4.31	0.79	0.29	89.11	72.00
33.68	24.46	4.83	0.85	0.22	90.14	72.62
35.31	25.81	5.29	0.90	0.14	91.02	73.10
9.77	6.26	1.20	0.21	0.08	79.32	64.07
10.86	7.06	1.39	0.24	0.07	80.66	65.01
12.49	8.35	1.73	0.29	0.04	83.35	66.85
14.12	9.57	2.04	0.33	0.02	84.70	67.78
11.40	7.52	1.52	0.26	0.05	82.02	65.96
47.80	36.96	7.02	1.29	0.47	95.69	77.32
49.97	38.77	7.46	1.35	0.45	96.12	77.59
51.06	39.68	7.73	1.38	0.40	96.34	77.71
23.23	41.54	8.20	1.45	0.74	97.56	78.04
58.67	44.23	8.84	1.54	0.32	93.63	75.39
58.67	46.05	9.33	1.61	0.29	97.63	78.49

CEC (c mol (p^+) kg^{-1}	Exchangeable bases (c mol (p^+) kg^{-1})				BS %	Exchan
	Ca^{++}	Mg^{++}	Na^+	K^+		Ca^{++}
13.03	8.96	1.68	0.31	0.13	85.03	68.76
15.21	10.54	2.04	0.37	0.12	85.93	69.30
16.29	11.44	2.26	0.40	0.11	87.23	70.23
17.38	12.32	2.50	0.43	0.08	88.20	70.89
18.47	13.20	2.74	0.46	0.06	89.12	71.47
19.55	14.08	2.99	0.49	0.02	89.92	72.02
6.51	3.64	0.69	0.12	0.06	69.28	55.91
7.82	4.59	0.90	0.16	0.05	72.89	58.70
9.77	6.01	1.23	0.21	0.04	76.61	61.51
10.86	6.90	1.47	0.24	0.01	79.37	63.54
11.40	7.75	1.49	0.27	0.09	84.21	67.98
12.49	8.61	1.70	0.30	0.08	85.59	68.94
14.12	9.85	2.00	0.34	0.07	86.83	69.76
16.29	11.51	2.39	0.40	0.05	88.09	70.66
18.47	13.17	2.80	0.46	0.02	89.06	71.30
38.02	28.81	5.47	1.00	0.37	93.77	75.78
41.28	31.45	6.13	1.10	0.32	94.48	76.19
43.46	33.22	6.64	1.16	0.26	94.98	76.44
46.71	35.84	7.35	1.25	0.19	95.55	76.73

geable bases (% saturation)			SiO_2	Fe_2O_3	Al_2O_3	R_2O_3	SiO_2
Mg^{++}	Na^+	K^+	(Per cent)				
14.31	2.64	0.96	68.71	5.00	20.12	25.12	1.144
15.22	2.76	0.90	66.6	5.21	20.89	26.10	1.108
15.13	2.70	0.80	62.31	5.32	24.31	29.63	1.037
15.37	2.72	0.69	64.48	5.89	22.80	28.69	1.073
15.91	2.78	0.61	60.18	6.01	26.14	32.15	1.002
15.85	2.73	0.51	58.14	6.09	27.98	34.07	0.968
13.68	2.51	0.92	70.98	3.04	20.86	23.90	1.181
14.34	2.52	0.65	66.3	4.39	23.01	27.40	1.103
14.98	2.55	0.40	62.02	4.62	26.50	31.12	1.032
12.28	2.15	0.82	73.57	5.38	15.95	21.33	1.224
12.8	2.21	0.64	75.39	5.57	14.42	19.99	1.255
13.85	2.32	0.32	70.58	5.75	17.70	23.45	1.175
14.45	2.34	0.14	68.76	6.10	18.97	25.07	1.144
13.33	2.28	0.44	72.19	5.63	17.07	22.70	1.201
14.69	2.70	0.98	67.33	4.63	21.12	25.75	1.121
14.93	2.70	0.90	65.78	4.83	22.34	27.17	1.095
15.14	2.70	0.78	63.71	5.00	24.17	29.17	1.060
15.4	2.72	1.39	61.55	5.28	25.87	31.15	1.024
15.07	2.62	0.55	59.27	5.60	27.80	33.40	0.986
15.9	2.74	0.49	57.02	5.91	28.69	34.60	0.949

geable bases (% saturation)			SiO_2	Fe_2O_3	Al_2O_3	R_2O_3	SiO_2
Mg^{++}	Na^+	K^+	(Per cent)				
12.89	2.38	1.00	73.4	5.70	16.65	22.35	1.222
13.41	2.43	0.79	71.36	5.83	18.32	24.15	1.188
13.87	2.46	0.68	69.45	6.00	20.02	26.02	1.156
14.38	2.47	0.46	67.02	6.11	22.06	28.17	1.115
14.83	2.49	0.32	65.18	6.37	23.33	29.70	1.085
15.29	2.51	0.10	63.26	6.63	24.39	31.02	1.053
10.6	1.84	0.92	76.83	4.14	14.43	18.57	1.279
11.51	2.05	0.64	74.78	4.40	15.90	20.30	1.245
12.59	2.15	0.36	72.15	4.74	17.68	22.42	1.201
13.54	2.21	0.09	69.79	5.29	18.81	24.10	1.162
13.07	2.37	0.79	74.19	4.70	16.75	21.45	1.235
13.61	2.40	0.64	72.12	4.86	18.54	23.40	1.200
14.16	2.41	0.50	70.27	5.20	19.90	25.10	1.169
14.67	2.46	0.31	68.13	5.57	21.58	27.15	1.134
15.16	2.49	0.11	66.18	6.02	23.00	29.02	1.101
14.39	2.63	0.97	69.87	3.86	20.64	24.50	1.163
14.85	2.66	0.78	66.82	4.44	22.91	27.35	1.112
15.28	2.67	0.60	63.71	4.94	25.46	30.40	1.060
15.74	2.68	0.41	60.81	5.28	27.84	33.12	1.012

R_2O_3	Al_2O_3	Fe_2O_3	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3/ Fe_2O_3	P
(moles)							pp
0.229	0.197	0.031	5.0	5.8	36.9	6.4	395
0.238	0.205	0.033	4.7	5.4	33.6	6.2	360
0.272	0.238	0.033	3.8	4.4	31.4	7.2	325
0.260	0.224	0.037	4.1	4.8	29.0	6.1	300
0.294	0.256	0.038	3.4	3.9	26.4	6.7	275
0.313	0.274	0.038	3.1	3.5	25.5	7.2	245
0.224	0.205	0.019	5.3	5.8	62.2	10.8	410
0.253	0.226	0.027	4.4	4.9	40.9	8.4	340
0.289	0.260	0.029	3.6	4.0	35.6	9.0	260
0.190	0.156	0.034	6.4	7.8	36.0	4.6	315
0.176	0.141	0.035	7.1	8.9	35.9	4.0	275
0.210	0.174	0.036	5.6	6.8	32.6	4.8	200
0.224	0.186	0.038	5.1	6.2	30.1	4.9	235
0.203	0.167	0.035	5.9	7.2	34.3	4.8	160
0.236	0.207	0.029	4.8	5.4	38.7	7.1	370
0.249	0.219	0.030	4.4	5.0	36.5	7.3	345
0.268	0.237	0.031	4.0	4.5	34.2	7.6	320
0.287	0.254	0.033	3.6	4.0	31.0	7.7	285
0.308	0.273	0.035	3.2	3.6	28.2	7.8	250
0.318	0.281	0.037	3.0	3.4	25.6	7.6	225

R_2O_3	Al_2O_3	Fe_2O_3	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3/ Fe_2O_3	P
(moles)							pp
0.199	0.163	0.036	6.1	7.5	33.9	4.5	350
0.216	0.180	0.037	5.5	6.6	32.1	4.9	380
0.234	0.196	0.038	4.9	5.9	30.4	5.2	330
0.255	0.216	0.038	4.4	5.2	29.3	5.7	295
0.269	0.229	0.040	4.0	4.7	27.1	5.7	260
0.281	0.239	0.042	3.7	4.4	25.1	5.7	235
0.167	0.142	0.026	7.7	9.0	49.2	5.5	290
0.183	0.156	0.028	6.8	8.0	44.5	5.6	245
0.203	0.173	0.030	5.9	6.9	40.0	5.8	135
0.218	0.184	0.033	5.3	6.3	35.2	5.6	150
0.194	0.164	0.029	6.4	7.5	42.6	5.7	340
0.212	0.182	0.030	5.7	6.6	40.0	6.1	295
0.228	0.195	0.033	5.1	6.0	35.4	5.9	260
0.247	0.212	0.035	4.6	5.3	32.4	6.1	215
0.263	0.226	0.038	4.2	4.9	29.0	5.9	175
0.227	0.202	0.024	5.1	5.8	48.5	8.4	365
0.252	0.225	0.028	4.4	4.9	39.7	8.0	250
0.281	0.250	0.031	3.8	4.2	34.2	8.1	305
0.306	0.273	0.033	3.3	3.7	30.7	8.3	215

K	Ca	Mg	CuO	MnO_2	ZnO	N	P_2O_5
pm	%		ppm			kg ha^{-1}	
2750	2.50	0.82	56	1701	84	156.8	50.2
2375	2.62	0.9	53	1504	81	112.0	40.1
3000	2.75	0.9	50	1562	75	89.6	44.1
3375	2.87	0.97	44	1206	78	67.2	36.9
3625	3.12	1.05	47	1029	72	67.2	33.8
4000	3.37	1.12	41	910	68	44.8	31.8
1375	2.25	0.67	50	1285	68	224.0	55.3
2375	2.50	0.97	41	1206	65	135.4	45.1
3500	2.75	1.12	38	1008	56	134.4	37.9
1625	0.87	0.3	44	2037	62	156.8	36.9
2250	0.75	0.22	38	1820	59	156.8	31.8
2625	1.62	0.45	41	1701	49	134.4	27.6
3250	1.87	0.52	34	1464	47	134.4	23.5
3625	1.00	0.37	31	1285	37	112.0	19.4
2125	2.62	0.9	47	1404	75	156.8	42.0
2500	2.75	0.97	44	1206	78	112.0	37.9
2875	2.87	1.05	41	1087	68	67.2	33.8
3125	3.12	1.12	38	968	65	67.2	29.7
3500	3.00	1.05	38	831	62	44.8	25.6
3875	3.75	1.2	34	752	59	44.8	22.5

K	Ca	Mg	CuO	MnO_2	ZnO	N	P_2O_5
pm	%		ppm			kg ha^{-1}	
625	0.37	0.15	41	1839	75	201.6	53.3
1000	0.62	0.22	38	1641	56	112.0	49.2
1625	0.75	0.3	34	1464	53	89.6	45.1
2125	0.87	0.37	31	1356	49	89.6	41.0
2500	1.12	0.45	25	1124	47	67.2	36.9
3125	1.50	0.52	28	1008	44	67.2	34.8
875	1.00	0.3	38	1504	59	179.2	40.0
1500	1.37	0.37	34	1641	47	179.2	32.8
2375	1.62	0.45	31	1288	44	179.2	26.6
3250	2.00	0.6	28	1171	41	156.8	20.5
1125	0.25	0.07	34	1506	53	201.6	48.2
1625	0.50	0.15	31	1306	49	179.2	42.0
2250	0.62	0.22	28	1135	41	156.8	37.9
2875	1.00	0.37	25	1005	37	156.8	28.7
3375	0.87	0.3	22	807	34	156.8	32.8
1875	2.25	0.67	53	1522	81	179.2	45.1
3125	2.25	0.75	50	1321	68	134.4	37.9
2625	2.37	0.75	47	1245	72	134.4	31.8
3750	2.37	0.82	44	1147	65	89.6	25.6

K_2O	S	Fe	Cu	Mn	Zn
	ppm				
483	13.12	6.06	1.49	8.42	0.42
403	12.50	5.42	1.47	8.22	0.40
376	10.62	4.76	1.35	8.00	0.34
362	9.37	4.68	1.26	5.96	0.26
322	8.12	4.42	1.23	6.54	0.28
295	7.50	4.34	1.11	4.94	0.16
376	11.87	12.18	1.67	12.20	0.58
336	10.00	8.04	1.97	10.60	0.18
255	6.87	6.46	1.65	8.22	0.16
336	10.00	15.60	2.48	24.50	0.44
282	8.75	5.78	1.82	17.30	0.28
268	6.25	5.72	1.78	15.50	0.18
241	5.62	5.04	1.51	15.20	0.14
215	5.00	4.94	1.35	8.52	0.12
456	14.37	5.82	1.43	10.62	0.68
389	13.75	5.46	1.38	6.38	0.30
362	11.25	5.40	1.39	5.66	0.28
349	10.62	5.24	1.19	4.90	0.26
309	9.37	3.66	1.03	2.84	0.22
282	8.75	2.54	1.02	2.08	0.20

K_2O	S	Fe	Cu	Mn	Zn
	ppm				
349	11.25	4.62	1.49	20.60	1.14
309	12.50	4.16	1.40	17.80	0.24
295	10.00	4.04	1.36	14.78	0.20
282	8.75	4.04	1.28	14.10	0.22
255	8.12	3.62	1.16	12.38	0.16
228	7.50	3.43	1.01	11.86	0.12
349	11.25	4.54	1.51	18.92	0.24
389	9.37	4.32	1.44	17.32	0.20
295	7.50	3.84	1.37	16.12	0.16
268	6.25	3.84	1.40	13.08	0.10
322	10.62	6.10	1.58	14.64	0.38
268	10.00	5.22	1.38	16.62	0.24
255	8.12	4.74	1.37	12.90	0.18
228	6.87	4.28	1.33	10.72	0.12
201	5.62	4.26	1.30	7.26	0.08
362	13.75	4.72	1.52	6.20	0.26
322	12.50	4.66	1.29	5.58	0.14
268	8.12	4.22	1.25	4.56	0.20
241	9.37	3.78	0.78	4.10	0.06

CHAPTER V

DISCUSSION

From the review presented in the chapter II, it was understood that the formation, development and occurrence of red soils and black soils in peninsular India was common having associated with semi-arid monsoon type climate. The study area (Edlapadu mandal of Guntur district in Andhra Pradesh) is situated in agro-ecological sub-region 7.3 (Velayutham *et al.,* 1999), which is to the south of Eastern Ghats with code H6DmC(cd)5. The code representes physiography (H = Eastern Ghats), soils (6 = mixed red and black soils), climate [Dm(cd) = semi-arid to sub-humid], and length of growing period (5 = 150 to 180 days).

In this chapter of discussion, the factors and processes of soil formation along with characteristics (morphological, physical and chemical) and classification (taxonomic and land capability) are presented.

5.1 SOIL FORMATION

5.1.1 Climate

The mean annual air temperature (MAAT) of the study area was 28.49^{0}C. From this, the mean annual soil temperature (MAST), mean summer soil temperature (MSST) and mean winter soil temperature (MWST) were computed as suggested by Sehgal (1996). The average annual rainfall was 970.22 mm. The temperature pattern and rainfall pattern depicted in the ombrothermic diagram indicated the semi-arid monsoon type of climate with distinct and well-defined dry season and wet season. The soil moisture regime was ‘ustic’ and the soil temperature regime was ‘iso-hyperthermic’. Thus the soils of the study area were influenced and formed under semi-arid type of climate. Dutta *et al.* (2001) noticed the occurrence of red soils under semi-arid climate in south India, whereas, the black soils developing under similar type of climate was reported by Bandyopadhyay *et al*. (2004) in Maharashtra. The formation and development of red and black soils were occurring under the semi-arid climate in Karnataka (Rudramurthy *et al.,* 1997; Reddy and Shivaprasad, 1999) and Andhra Pradesh (Basavaraju *et al.,* 2005; Thangasamy *et al.,* 2005).

5.1.2 Parent Material

Eastern Ghats (south) 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. Granite – gneiss complex covered most of the area of Andhra Pradesh (Rao *et al.,* 1995). Red soils (profile 3, 5, 6 and 7) were formed and developed on weathered granite-gneiss whereas; black soils (profile 1, 2, 4 and 8) 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) in Tamilnadu, Vijaykumar *et al.* (1994) in Andhra Pradesh, Reddy and Shivaprasad (1999) in Karnataka.

According to Rudramurthy and Dasog (2001); Singh *et al.* (2003a); Natarajan *et al.* (2003); and Basavaraju *et al.* (2005), the parent material for the genesis of the red soils was calcic-gneiss in Karnataka, Bangalore, Tamilnadu and Andhra Pradesh, respectively.

The pedogenesis of black soils over calcic-gneiss was also noticed by Bandyopadhyay *et al.* (2004) and Singh *et al.* (2004) in Bhopal and Rajasthan, respectively.

5.1.3 Landform and Topography

Red soils located at Edlapau (profile 3), Kondaveedu (profile 5), Changeej Khan Peta (profile 6) and Boyapalem (profile 7) were formed near the foothills of granitic –gneiss or at higher topographic positions with the slope varying from 3 to 5 per cent on gently sloping lands. Black soils located at Turlapadu (profile1), Solasa (profile 4), Timmapuram (profile 8) were observed at almost plain topography on nearly level lands with slope less than one per cent. The black soil located at Jaggapuram (profile 2) was developed on very gently sloping lands with slope percent 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; Gajbhiye and Deshmukh (1992) in Maharashtra; Rudramurthy and Dasog (2001) in north Karnataka; Nagassa and Gebrekidan (2003) in Bako soils of

Ethiopia; Thangasamy *et al.* (2005) in Sivagiri micro-watershed of Andhra Pradesh; and Gabhane *et al.* (2006) in Vidarbha region, observed the occurrence of red soils on higher elements of topography and black soils on lower elements of topography.

Undulating and gently sloping lands had developed deep to very deep, well drained and moderately eroded Haplustalfs in south of Eastern Ghats on granite-gneiss landform (Reddy *et al.,* 1996). Occurrence of red soils in gently sloping and undulating uplands was observed by Dutta *et al.* (1999) in Anantapur district of Andhra Pradesh; Sarkar *et al.* (2001) in Chotanagpur plateau; Chunale, (2004) in sub-mountane zone of Maharashtra; Singh and Agarwal (2005) in eastern region of Uttar Pradesh; Nikam *et al.* (2006) in central India.

Black soils were formed in lower topographic positions due to accumulation of clay and basic cations in Karnataka (Rudramurthy and Dasog, 2001); in Wardha region (Kadao *et al.,* 2003), in eastern Maharashtra plateau (Reddy *et al.,* 2004); in Nasik district of Maharashtra (Balapande *et al.,* 2007).

5.1.4 Vegetation

The natural vegetation in the study area included *prosophis*, tamarind, neem, palmyra, soapnuts, teak, *Acacia*, short grasses and shrubs. Similar type of vegetation was reported by Satish (2003); Bhaskar (2005); and Thangasamy *et al.* (2005) in red and black soil areas of Guntur, Prakasam and Chittoor districts of Andhra Pradesh, respectively. 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 Vertisol formation was not influenced by vegetation.

5.1.5 Pedological Time

The red 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).

5.1.6 Soil Forming Processes

Argillic horizons (textural 'B' horizons) were recognized in the sub-surface of red soils located at Edlapadu (profile 3), and Boyapalem (profile 7) due to presence of clay cutans (argillans). These two profiles were situated at the foothills of granitic-gneiss complex. 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 two profiles. The thickness of the argillic horizon in both the locations was 40 cm or more. Illuviation was the dominant process operating in the red soils (Peterschmidt *et al.,* 1996; Dutta *et al., 1999;* Walia *et al.,* 2000; Kurihara *et al.,* 2003; Patil and Prasad, 2004; Singh and Agarwal, 2005).

In red soil profiles 5 and 6 at Kondaveedu and Changeej Khan Peta, respectively, illuviation was no doubt operating as there was increase in the clay content in the ‘B’ horizon, but the ‘B’ hoirizons were not meeting the criteria for argillic horizon and at the same time, no clay skins were noticed. The ‘B’ horizons in these two profiles were 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 profiles. Similar pedogenic processes were responsible for the formation of red soils, according to Walia *et al.* (2000).

In the black soil areas of Turlapadu (profile 1), Solasa (profile 4) and Timmapuram (profile 8), 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 up to the deeper layers. The pedogeneic process was nothing but argillopedoturbation. Similar reports were earlier given by Mermut *et al.* (1996), Rudramurthy *et al.* (1997) 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 shallow black soil profile 2 located at Jaggapuram was not exhibiting slickensides in the profile and / or cracks on the surface. Argillopedoturbation was not much /

sufficient enough to produce these features. Simple translocation might be operating as described by Sehgal (1996). According to Pal *et al.* (2006), illuviation was more important than argillopedoturbation in balck soils having no slickensides developoment. The time had been not sufficient enough for their development.

5.2 MORPHOMETRICS OF SOIL PROFILES

5.2.1 Horizons and Boundary between Horizons

The study area was under cultivation. Because of the ploughed and / or disturbed condition due to cultivation, the surface horizon was designated as 'Ap' horizon at all the locations. Similar symbol was used by Mandal *et al.* (2003); Chinchmalatpure *et al.* (2005); Thamapatti and Jose, (2006); Sharma and Chaudhary (2007) 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). Singh and Agarwal (2005) and Balapande *et al.* (2007) recognized the presence of ochric epipedon in red soils of eastern region of Uttar Pradesh and black soils of Nasik district of Maharashtra, respectively.

The 'B' horizon of black soil profiles 1,4 and 8 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); Chinchmalatpure *et al.* (2005); Balapande *et al.* (2007) in black soils of central India, Gujarat and Maharashtra, respectively.

In the profiles 2, 5, 6 and 7, the diagnostic subsurface cambic horizon was demarcated based on the following features. Clay content was higher than the overlying horizon, and absence of clay cutans, sulphide materials, fragipan characteristics and rock structure. Basavaraju *et al.* (2005) and Balapande *et al.* (2007) identified the cambic horizon in red soils of Andhra Pradesh and black soils of Maharashtra, respectively.

Argillic horizon was developed in red soil profiles 3 and 7 in the subsurface. 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. Broken to common and moderately thick to thick argillans were noticed between 26 and 66 cm depth in the profile 3, whereas in the profile 7, patchy, thin argillans were recorded between 45 and 90 cm depth. Such occurrence of argillic horizons were identified in Alfisols of Bako soils in Ethiopia by Nagassa and Gebrekidan, (2003) and by Singh and Agarwal (2005) in soils of eastern region of Uttar Pradesh.

The boundary between the sub-horizons of 'Bss' horizon in black soil profiles 1, 4 and 8 was described as diffuse because of the presence slickensides and the clay content was high enough for clay textural class. In the red soil profiles, 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. Thangasamy *et al.* (2005) observed clear boundary in some red soils of Andhra Pradesh while, diffuse boundary was noticed by Balapande *et al.* (2007) in balck soils of Nasik district of Maharashtra.

5.2.2 Soil Colour

The colour of black soils (profiles 1, 2, 4 and 8) was gray, dark gray or very dark gray in different horizons with Munsell colour notation of 10YR 5/1, 10YR 4/1 and 10YR 3/1, respectively. Sarkar and Sahoo (2000) described the colour of vertic sub-group of Inceptisols as 10YR 5/1 or 10YR 4/1. Dark grayish brown to dark brown colour in black soils of northern Karnataka was reported by Prasad *et al.* (2001). The black soils of Nasik district were exhibiting the Munsell colour notations varying from 10YR 3/1 to 10YR 3/3 (Balapande *et al.,* 2007).

Santsingh (1987) stated that 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 colour of black soils might be due to the formation of stable clay humus complex (Subbaiah and Manickam, 1992). 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 (Kadao *et al.,* 2003; Maji *et al.,* 2005).

The colour of the red soils was varying between reddish brown (5YR 4/4) and dark reddish brown (5YR 3/4). These colour observations of red soils were corroborated with those of Dutta *et al.* (2001) and Thangasamy *et al.* (2005). Agarwal and Bali (1984), Dutta *et al.* (2001) and Sarkar *et al.* (2001) indicated that the 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.

5.2.3 Soil Texture and Structure

The texture of red soils and black soils was markedly varying. The texture of the red soils was widely ranging from coarse (sandy loam) to medium texture (loam or 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. Wide textural changes from sandy clay loam to clay loam were exhibited in red soil profiles of western Uttar Pradesh (Sharma *et al.,* 2000). Gupta *et al. (2003*); Nagassa and Gebrekidan (2003); Singh and Agarwal (2005) reported similar textural classes in Alfisols of Jabalpur, Bako area in Ethiopia and eastern part of Uttar Pradesh, respectively.

The distinguishing feature of the black soil profiles was the finer textural class throughout the depth. The texture was either clay loam or clay. The uniformity in texture was due to the argillopedoturbation operating in the black soil profiles (Buol *et al.,* 1998). Similar aggregate development was observed by Marathe *et al*. (2003) and Balapande *et al.* (2007) in black soils.

Red soils (profiles 3, 5, 6 and 7) developed weak pedality with granular structure in the surface horizons and sub-angular blocky peds in sub-surface layers. Even in the argillic horizon of pedon 3, the columnar structure formed due to illuviation of clay was breaking to sub-angular blocky type. 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 were in agreement with those reported by Nagassa and Gebrekidan (2003) in Afisols of Ethiopia; Patil and Prasad (2004) in red soils of Dindori district, Madhya Pradesh; Singh and Agarwal (2005) in Alfisols of eastern Uttar Pradesh.

The pedality of black soils was more strongly developed in black soils because of the high clay content, CEC, PBS, and dominance of montmorillonite type of clay. The surface horizons were generally granular type because of organic matter and inter-cultivation operations. The lower layers 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 more finer fractions (Shyampura *et al.,* 1994). Similar type of aggregation was described by Pacharne *et al.* (1996), Gabhane *et al.* (2006) and Balapande *et al.* (2007) in black soils.

5.3 PHYSICAL PROPERTIES

5.3.1 Granulometric Data

According to Barshad (1964), the relative amount of clay and non-clay fractions in each horizon could give approximate evolution of soil development.

The clay content was widely varying between red soil profiles (10.32 to 29.34) and black soil profiles (33.17 to 66.66 per cent). 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) in red and black soils of northern Karnataka and Vidarbha region of Maharashtra, respectively.

The silt content in both red and black soils was not varying much among different horizons. Tiwary *et al.* (1989) reported similar results of comparatively low silt content in red, black and yellow soils of Bihar suggesting the chemical composition of the rocks and minerals.

The sand content was high in red soils compared to black soils. This could be due to the translocation / migration of finer particles into the lower layers. These observations were in agreement with those of Bhaskar and Subbaiah (1995), Mishra and Ghosh (1995), Sarkar *et al.* (2001) and Monday *et al.* (2003).

As seen from the granulometric data on the ratios of different fine earth fractions, there were not many variations (almost uniform) among the adjacent horizons in red and balck soil profiles. As such, there was no lithological discontinuity among the different horizons in any profile (Soil Survey Staff, 1999 and Dutta *et al.,* 2001). The ratios of coarse sand / fine sand, sand / silt, silt / clay, sand / (silt + clay) were comparatively higher in red soil profiles indicating the translocation and / or migration of finer particles down the depth (Satyavathi and Reddy, 2003).

5.3.2 Bulk Density

The bulk density values were higher in red soil profiles than in black soil profiles. This might be due to the relatively high sand content and low clay content of the red soils. Similar results were reported by Prakash and Rao (2002) and Ramesh *et al.* (2003) in red and black soils of Andhra Pradesh. In all the profiles the general trend was that the bulk density values were higher in lower layers than in upper layers. 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).

5.3.3 Water Holding Capacity, Volume Expansion and Sticky Point

All these three parameters were influenced by the clay content, base saturation, and exchangeable bases like calcium. These physical properties followed trend of the clay content in red and black soils. The significant and positive correlation was obtained between clay and water holding capacity; clay and sticky point; clay and volume expansion. Black soils registered more water holding capacity, volume expansion and sticky point values than the red soils and in all the locations these values showed increasing trend with depth, in general. These types of trends were in accordance with those of Rudramurthy and Dasog (2001) in Karnataka, Lakshmi *et al.* (2002) and Bhaskar (2005) in red and black soils.

5.4 Physico - Chemical Properties

5.4.1 pH and EC

The pH values of these red and black soil profiles were varying between 7.0 and 8.7 among different horizons. The red soils were neutral to slightly alkaline while; the black soils were slightly to strongly alkaline in reaction. Thangasamy *et al.* (2004 and 2005) and Gabhane *et al.* (2006) reported similar trends of reaction in red and black soils of Andhra Pradesh and Vidarbha region of Maharashtra, respectively. The pH values were also increasing with depth, in general, in red soils as well as in black soils. The lower pH values in surface layers might be due to continuous removal of basic cations by crop plants (Nagassa and Gebrekidan, 2003), movement of basic cations to deeper layers (Singh and Agarwal, 2003) and / or due to precipitation of calcium carbonate (Balapande *et al.,* 2007). A significant positive correlation (r = 0.721) existed between pH values and $CaCO_3$ content.

The soluble salts content was not high enough to make these soils saline. The EC values were varying between 0.124 and 3.883 dS m^{-1} in different profiles. The EC was very low in red 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. Significant postive correlation (r = 0.652) was observed between clay and EC values. It was only in the lower layers of black soil profiles, the EC was more than 1.0 dS m^{-1}. Hence these soils were non - saline. Similar EC values were reported by Appavu *et al.* (2002) in red soils of Tanjavur and Nayak *et al.* (2002) in black soils of Maharashtra.

5.4.2 Calcium Carbonate Content

The calcium carbonate content of red soil profiles was very low ranging from 0.00 to 9.25 per cent than the balck soil profiles containing 5.0 to 15.0 per cent of calcium carbonate content. 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.

5.4.3 Organic Matter Content

Both red and black soils contained low organic matter content in different locations, which, was attributed to the sparse vegetaion, rapid decomposition and mineralisation (Singh and Agarwal, 2005). The organic matter content was also decreased with depth. The surface soils contained relatively higher organic carbon content due to addition of plant residues and FYM (Basavaraju *et al.,* 2005).

5.4.4 Total Nitrogen

Total N content was relatively higher in black soil profiles than in red soil profiles, in general. However the content decreased with depth in all the locations, which ranged from 0.077 to 0.21 per cent. The total N content followed the trend of organic carbon. The correlation was very significant between these two properties with ‘r’ value of 0.90. Similar trends and relations were observed by Bharambe *et al.* (1999) in Vertisols; Nagassa and Gebrekidan (2003) in Alfisols.

5.4.5 C: N Ratio

The C: N ratios in the soils of study area were varying from 4.41 to 12.86 in different horizons. These ratios indicated the stabilized nature of organic matter in the soils (Tisdale *et al.,* 1997). Bharambe *et al.* (1999); Nagassa and Gebrekidan (2003) reported C: N ratios of Vertiosls and Alfisols, which, were corroborating with these values.

5.5 ELECTRO-CHEMICAL PROPERTIES

5.5.1 Cation Exchange Capacity of Soils

The exchange capacity of soils was higher in black soils than in red soils. 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). Confirming the above statement it showed the increasing trend of clay content with depth. Similar results were reported by Rudramurthy and Dasog (2001) in red and black soils of north Karnataka; Kadao *et al.* (2003) in black soils of Wardha region; Gabhane *et al.* (2006) in balck soils of Vidarbha region; Balapande *et al.* (2007) in black soils of Nasik.

The CEC / clay ratios for black soils were relatively higher (0.84 to 0.95) than the ratios of red soils (0.67 to 0.74). From these values, it was understood that smetitic clay was dominant in black soils and the clay mineralogy of red soils was mixed or illitic because the ratios were about 0.7 (± 0.3 or 0.4) in red soils as per the specifications of SSLM (1995).

5.5.2 Base Saturation

The percent base saturation was very high in black soils. This could be due to the dominance of smectitic type of clays and moderate to strongly alkaline reation. The high CEC of black soils was attributed to the smectitic clay mineralogy (Pal and Deshpande, 1987). These results on PBS were in accordance with the findings of Singh and Agarwal (2005) and Gabhane *et al.* (2006).

The red soils were having either mixed or illitic mineralogy in clay fraction and neutral to slightly alkaline reaction, hence, the PBS values were lower than those of black soils. Reddy and Shivaprasad (1999); Pillai and Natarajan (2004), reported similar extent of base saturation in different horizons of Alfisols of Karnataka.

In both red and black soils, the PBS increased with depth following the trend of clay and pH, which might be due to translocation of clay and basic cations down the depth. The significant positive correlation of clay with pH (0.83) and with PBS (0.89) had confirmed these relations. Similar type of results were reported by Rudramurthy and Dasog (2001) in red and black soils of Karnataka, Basavaraju *et al.* (2005) in red and associated black soils of Andhra Pradesh.

5.5.3 Exchangeable Bases

Irrespective of the location and horizon, the soil complex was dominantly saturated with calcium followed by magnesium, sodium and potassium. The calcium saturation was about five times (4.69 to 5.33) than the magnesium saturation. The saturation of all these four basic cations was more in black soils compared to those of red soils. Thangasamy *et al*. (2005) reported similar sequence of saturation with bases on soil complex. The exchangeable sodium and potassium saturation values were not varying much among different horizons, but exchangeable calcium and magnesium followed the trend of PBS. These findings were in accordance with those of Singh and Agarwal (2005).

5.6 CHEMICAL COMPOSITION OF SOILS

5.6.1 Silica Sesquioxides Content

The silica content was gradually decreased down the depth in all the locations and the content was less in the black soils, which, were formed on the nearly plain lands than red soils, which were formed at higher elevations. It followed the trend of sand. Highly significant positive correlation (r = 0.849) had confirmed the relation between sand and silica. Ramesh *et al.* (2004) obtained similar trends in red and black soils of Singarayakonda soils of A.P. The mobilization of silica did not take place because it was soluble only under neutral pH and solubility was very low under alkaline medium (Sehgal, 1996). Hence accumulation had taken place in higher elevations and upper horizons.

The trends of alumina, iron oxides and sesquioxides were quite opposite to that of silica. They exhibited the trend of clay which, increased with depth and the content was high in soils of plains (black soils) than the soils at higher levels of topography (red soils) because of translocation and mobilization and / or illuviation. These observations were in conformity with those of Manjulatha *et al.* (2001) and Singh and Agarwal (2005).

5.6.2 Silica – Sesquioixides Ratios

The silica – alumina, silica – sesquioxides, silica – iron oxides ratios were relatively narrower in black soils than those of red soils, while alumina – iron oxides ratios were quite opposite to those of silica – alumina, silica – sesquioxides, silica – iron oxides ratios. Significant positive correlation (r = 0.781) also existed between clay and R_2O_3. These ratios were, in general, broader and wider indicating the siliceous nature of parent material (Ramesh *et al.,* 2004). Because of the translocation of clay to the lower layers, these silica – alumina, silica – sesquioxides, and silica – iron oxides ratios were increasing down the depth (Singh an Agarwal, 2005).

5.7 TOTAL NUTRIENT CONTENT

5.7.1 Nitrogen, Phosphorus, Potassium, Calcium and Magnesium

The total N and P contents decreased down the depth of the profiles while, the total K, Ca and Mg contents increased following the trends of organic matter and clay contents, respectively. Babu *et al.* (2002) reported similar observations in red and black soils of Andhra Pradesh. Among the contents of total N, P, K, Ca and Mg, calcium content was high in all soils followed by magnesium. Because of semi-arid climate influencing the formation of these soils, the basic cations like calcium might have accumulated in these soils (Gurumurthy *et al.,* 1996). The accumulation was better reflected in black soils due to restricted leaching and drainage.

5.7.2 Total Micronutrient Content

The total copper, manganese and zinc contents were expressed as oxides. These contents were not varying much among red and black soils in all locations and these contents were more in surface layers than in sub-surface layers. Such decreasing trends of total micronutrient contents were reported by Madhuvani *et al.* (2001) in black soils of Guntur district, Andhra Pradesh. The distribution of total micronutrients in the soil profiles might have been influenced by parent material, organic carbon and clay contents (Madhuvani *et al.,* 2001) and soil forming processes (Sharma *et al.,* 2005).

5.8 AVAILABLE NUTRIENT CONTENT

The available nitrogen, phosphorus, potassium, iron, manganese, copper and zinc contents were relatively more in surface soils than in lower layers. In general the nutrients availability was decreasing with depth coinciding with the organic carbon content. These results were in agreement with those of Babu *et al.* (2002), Ramesh *et al.* (2003) and Balapande *et al.* (2007) in soils of Krishna district, Prakasam district and Nasik district, respectively. Due to the addition of organic litter and fertilizers, the surface horizons contained relatively higher available nutrient status.

5.9 CHARACTERIZATION OF SURFACE SOIL SAMPLES

To find out the overall fertility status of the Mandal as a whole, sixty surface soil samples were collected covering the whole mandal.

The black soils were slightly to moderately alkaline, slightly to moderately calcareous and non-saline (low EC). The red soils were neutral to slightly alkaline, non-saline, and none to slightly calcareous.

Organic carbon had positive relation with the availability of all nutrients that might be due to chelating action (Meena *et al.,* 2006). pH and $CaCO_3$ were positively correlated, while relation between pH and iron, pH and manganese, $CaCO_3$ and iron, $CaCO_3$ and manganese were negatively correlated. Similar types of correlations were reported by Satyavathi and Reddy (2004), Basavaraju *et al.* (2005) and Thangasamy *et al.* (2005) in red and black soils of Andhra Pradesh.

Both red and black soils were low in organic carbon, low in nitrogen, medium in phosphorus, high in potassium, sufficient in sulphur and micronutrients except zinc, which was deficient in soils of the mandal. Basavaraju *et al.* (2005) reported deficiency of zinc in red and assoiciated soils of Chandragiri mandal of Andhra Pradesh. According to Malewar (2005), zinc was the most limiting nutrient in soils and crops. Mehra *et al.* (2005) had found that zinc deficiency as a major yield limiting factor in Haplustalfs of Rajasthan. Suresh (2005) made a review of dry land areas and finally concluded that zinc deficiency was very wide spread in soils.

5.10 MINERALOGY OF SOIL CLAY FRACTION

Based on the pattern of X-ray diffraction, it was found that clay fraction of all black soil profiles were dominated by montmorillonite type of clay minerals (92 to 96 per cent). Montmorillonite was 2:1 expanding (under moist conditions) type of phyllosilicates. The dominance of montmorillonite type clay was also confirmed by the CEC / clay ratio. The CEC /clay ratios of these black soils were also higher (more than 0.7). Similar type of clay mineralogy in black soils was reported by Rudramurthy *et al.* (1997), Ratnam *et al.* (2001), Kadao *et al.* (2003), Nayak *et al.* (2006) and Balapande *et al.* (2007).

The black soils were formed at lower topographic positions (nearly level plains). The soluble weathering products including finer soil constituents, calcium carbonate and basic cations and eroded products from surrounding slopes had moved laterally and vertically down the slope and accumulated at the plain topography. Because of the slow permeability, low hydraulic conductivity and restricted drainage of the black soils formed at lower topography these constituents were accumulating in the profile and not leached / removed out of the profile. Because of the semi-arid type of climate, the ionic environment was concentrated by basic cations and the base saturation was very high even above 98 per cent. At the same time there was precipitation and deposition of calcium carbonate resulted either pedogenically or lithogenically. The texture of these soils was very heavy (clay textural class). Because of these conditions, the soil reaction was moderately to strongly alkaline. Thus, the soil environment had created a favourable pathway for the synthesis of montmorillonite type of clay minerals. Formation of montmorillonite took place under such congenial conditions in black soils of Karanataka (Rudramurthy *et al.,* 1997). Water-logging (Singh *et al.,* 1998) and puddling (Ratnam *et al.,* 2001) conditions hastened the process of genesis of montmorillonite.

In the clay fraction of red soils, illite (27 to 50 per cent), montmorillonite (19 to 44 per cent) and kaolinite (21 to 31per cent) were present. The CEC /

clay ratios of these red soils also indicated similar mixed or illitic mineralogy. Presence of these three types secondary clay minerals were reported by Hussain *et al.* (1998), Mall and Mishra (2000), Sarkar *et al.* (2001), Thangasamy *et al.* (2004) and Singh and Agarwal (2005) in the clay fraction of red soils / Alfisols.

The illite might have been inherited from the parent material (Mall and Mishra, 2000; Singh and Sawhney, 2006). The geology of the study area was granitic gneiss complex (Rao *et al.,* 1995). Granitic gneiss was an acid rock contianing some mica as essential mineral. Transformation / alteration of mica (primary mineral) of parent rock into illite (secondary mineral) was possible (Sehgal *et al.,* 1974).

Significant amounts of kaolinite existed in the clay fraction of red soils and very negligible amounts in the clay fraction of black soils. Direct conversion of mica to kaolinite might be one of the causes for the synthesis of kaolinite (Singh and Agarwal, 2005). According to Verma *et al.* (1994), acid leaching and tropical climate were favourable for the formation of kaolinite. The kaolinite clays might have been formed in the earlier tropical humid climate and preserved or persisted in the present semi-arid climate (Agarwal and Singh, 1995). Dutta *et al.* (2001) also predicted the existence of paleolsols (red soils) in the present day dry climate in India.

Sehgal (1996) suggested the intensity or the stage of weathering of soils based on the clay minerals present in the soil clay fraction. According the weathering index of clay size minerals (Jackson, 1964), montmorillonite was 9th while kaolinite was 10th stage of weathering. Black soils (dominated by montmorillonite type of minerals) were grouped under intermediate weathering stage, while, red soils because of the significant proportion of kaolinite could be grouped under advanced weathering stage according to the stages in weathering of soil minerals as suggested by Sehgal (1996). This was further confirmed by the CEC/clay ratios. Black soils were having relatively high ratios than red soils and hence, the black soils were comparatively less weathered than red soils. Similar conclusions were drawn by Satyavathi and Reddy (2003) after studying the red and black soils of Telangana region of Andhra Pradesh. Singh and Agarwal (2005) recognized advanced stage of development of Alfisols of eastern region of Uttar Pradesh.

5.11 CLASSIFICATION OF SOILS BASED ON USDA SOIL TAXONOMY

Considering the morphology of soil profiles, characteristics of soils (physical, physico-chemical and chemical properties) and diagnostic features, the soils under study were classified up to family level according to the criteria specified by the Soil Survey Staff (2003).

5.11.1 Classification at Order Category

The black soil profiles 1, 4 and 8 showed the following diagnostic features.

1. More than 100 cm depth
2. More than 30 per cent clay in fine earth fraction throughout the depth
3. Gilgai micro-relief (micro-knolls and micro-ridges) on the surface
4. Distinct intersecting slickensides in lower horizons

5. Cracks of greater than 1 cm width which remained open periodically to the surface from a depth of more than 40 cm and

6. Absence of lithic or paralithic contact, duripan, petrocalcic horizon within 50 cm from the surface.

   Based on these characters, the soils were grouped under order "Vertisols".

The profiles 2 (black soil), 5 and 6 (red soils) developed in sub-surface, structural or altered 'B' horizon (cambic horizon) identified by the presence of the following diagnostic features.

1. Texture was finer than very fine sand or loamy very fine sand

2. No rock structure in atleast 50 per cent volume

3. No argillic, kandic, oxic or spodic horizons

4. Absence of cementation

5. Regular decrease in the amount of organic carbon with depth and

6. Higher clay content than the overlying horizons.

The presence of cambic horizon (colour 'B') in these three profiles was recognized by the above criteria. Hence, these 3 soil profiles were keyed out as "Inceptisols" at order level.

Argillic horizon (textural B) was developed in sub-surface layers in red soil profiles 3 and 7. The criteria for argillic horizon were:

1. Sandy clay loam to sandy clay texture
2. Illuvial accumulation of clay
3. Thickness of horizon was more than 7.5 cm
4. Presence of argillans (clay cutans) and
5. The base saturation was more than 35 per cent throughout the thickness.

Based on the presence of argillic horizon in sub-surface, profiles 3 and 7 were kept under the order “Alfisol”.

5.11.2 Classification at Sub-order Category

It was justified to classify further, the profiles1, 4 and 8 under “Usterts” at sub-order level because these profiles exhibited cracks of 5 mm or more wide extending up to 40 cm or more within 50 cm of the mineral soil surface for a period of more than 90 cumulative days per year and the mean annual soil temperature was greater than 22^0C. The soil moisture regime of the study area was ustic and soils were dry for more than 90 cumulative days. Hence the profiles 2, 5 and 6 were placed under “Ustepts” and the profiles 3 and 7 as “Ustalfs” at sub-order level.

5.11.3 Classification at Great Group Category

The EC of the soil profiles1, 4 and 8 was less than 4.0 dS m^{-1} in all the horizons and salic, gypsic or calcic horizons were not formed in these profiles. Hence, these soil profiles were qualified for ‘Haplusterts’ great group. Similarly, Walia and Rao (1997) and Singh et al. (1998) classified the black soils of trans - Yamuna plain and alluvial soils of Bihar as Haplusterts.

The profiles (2, 5 and 6) did not exhibit duripan or calcic horizon and had a base saturation of greater than 60 per cent. These characters indicated that the profiles represented the central concept of Ustept. Therefore they were placed under "Haplustepts" at great group level. Rudramurthy and Dasog (2001) classified some red soils of northern Karnataka as Haplustepts.

At great group level the profiles (3 and 7) were classified under "Haplustalfs" because of the following reasons.

1. Absence of natric horizon, petrocalcic horizon, duripan and plinthite
2. Presence of argillic horizon that has colour hue of 5YR (no redder than 2.5YR)

5.11.4 Classification at Sub- Group Category

The profile 1 showed a colour value of 4 in all the horizons under moist condition. Hence, classified under "Chromic Haplusterts". Whereas, the profile 4 had not shown colour value moist of 4 or more, colour value dry of 6 or more and chroma 3 or more, hence, classified under " Typic Haplusterts ". The profile 8 keyed out to be "Leptic Haplusterts" due to presence of lithic contact within 100 cm of the mineral soil surface. Surekha *et al*. (1997) taxonomically classified some Vertisols of Andhra Pradesh as Chromic / Typic Haplusterts. Prasad *et al.* (2001) classified the typical swell-shrink orange supporting soils of Nagapur district as Typic Haplusterts.

The profiles 2, 5 and 6 were classified as Typic Haplustepts at subgroup level because of iso-hyperthermic soil temperature regime and dry period of more than 120 cumulative days per year.

The Profile 3 and 7 was classified as “Typic Haplustalf” because of the following features.

1. The profile had argillic horizon with base saturation of more than 75 per cent
2. The profile did not have lithic contact within 50 cm of soil surface
3. Texture was finer than loamy fine sand in some sub-surface horizons within 50 cm
4. The soil temperature regime was iso-hyperthermic
5. The dry period was more than 120 cumulative days

Similar taxonomic units (Typic Haplustalfs) were proposed by Rudramurthy and Dasog (2001) for red soils developed on granite –gneiss.

5.11.5 Classification at Family Category

The profiles 1 and 4 had clay content greater than 60 per cent on weighted average in fine earth fraction. Hence qualified for “very - fine” particle size class. The profiles 2 and 8 had showed clay content in between 30 and 60 per cent on weighted average in fine earth fraction. Hence qualified for ”fine” particle size class. The profiles 3, 5, 6 and 7 had showed clay content less than 35 per cent on weighted average in fine earth fraction. Hence qualified for “loamy” particle size class.

The profiles 1, 2, 4 and 8 showed relative dominance of (more than 90 per cent) montmorillonite mineral. Hence the clay mineralogical class of these profiles was “montmorillonitic”. The profile 7 showed relative dominance of (50 per cent) illite mineral in the clay fraction. Hence, the clay mineralogical class of the profile was “illitic”. The clay faction of soil profiles 3, 5 and 6 showed no mineral of more than 50 per cent. Hence the clay mineralogical class of these profiles was “mixed”.

Sehgal (1996) recognized April, May and June as summer months and October, November and December as winter months for the places between 8^0 and 26^0 N latitude. As per these criteria, the difference between mean summer and winter temperatures was less than 6^0 C and the mean annual soil temperature was more than 22^0 C. Therefore, the study area was classified as “iso- hyperthermic” temperature regime.

Based on all these features, the eight soil profiles were classified up to family level

Black soils:

Profile 1 : Very - fine, montmorillonitic, isohyperthermic, Chromic Haplustert

Profile 2 : Fine, montmorillonitic, isohyperthermic, Typic Haplustept

Profile 4 : Very - fine, montmorillonitic, isohyperthermic, Typic Haplustert

Profile 8 : Fine, montmorillonitic, isohyperthermic, Leptic Haplustert

Some of the black soils of Gujarat state were grouped under taxonomic units fine, mixed, hyperthermic, Typic Haplustepts by Nayak *et al.* (2004). Balapande *et al.* (2007) classified some black soils of Nasik district up to family level under very-fine, smectitic, isohyperthermic Leptic / Typic Haplusterts.

Red soils:

Profile 3: Loamy, mixed, isohyperthermic, Typic Haplustalf

Profile 5: Loamy, mixed, isohyperthermic, Typic Haplustept

Profile 6: Loamy, mixed, isohyperthermic, Typic Haplustept

Profile 7: Loamy, illitic, isohyperthermic, Typic Haplustalf

Prakash and Rao (2002) classified the red soils of Krishna district, Andhra Pradesh under loamy, mixed, isohyperthermic, Lithic Haplustepts. The red soils of Sivagiri watershed of Andhra Pradesh were placed under taxonomic units fine-loamy, mixed / kaolinitic, isohyperthermic, Typic Rhodustalf / Haplustalf (Thangasamy *et al.,* 2005).

5.12 LAND CAPABILITY CLASSIFICATION

Black soils (profiles 1,2, 4, and 8) were having the moderate limitation of soil (restricted drainage, heavy, fine texture and / or vertic properties) besides the influence of semi-arid climate. Hence, these were grouped under land capability class III and sub-class IIIsc. Ramalakshmi (1999) and Rani *et al.* (2005) grouped the black soils of Bapatla – Karlapalem mandals and Madanuru watershed under land capability sub-class IIIcs and IIs, respectively.

Red soils (profiles 3, 5, 6 and 7), were having the slight to moderate limitations of erosion as they were formed on gentle to very gentle sloping lands, and climate (semi-arid). The water hodling capacity was low. Hence, they were grouped under land capability sub-class IIIec. Some of the red soils (Haplustalfs) formed on granite-gneiss were grouped under IIes and IIIes capability sub-class in Patloinala micro-watershed of Wet Bengal (NBSS & LUP, 2001).

The red and black soils (Patancheru and Kasireddypalli series) of Andhra Pradesh were grouped under land capability sub-class IIIs based on the moderate limitations of soil (NBSS & LUP, 1994).

CHAPTER VI

SUMMARY

The present study was on ‘Morphology and taxonomy of red and black soils of Edlapadu mandal of Guntur district in Andhra Pradesh’. Eight representative profiles were selected from the study area and described morphologically. The soil samples collected from each horizon in these eight profiles were analysed for physical properties (mechanical composition, bulk density, water holding capacity, volume expansion, sticky point and COLE), physico-chemical properties (pH, EC and $CaCO_3$), electrochemical properties (CEC, PBS, and exchangeable Ca^{++}, Mg^{++}, Na^{+} and K^{+}), chemical composition (silica, sesquioxides and total N, P, K, Ca, Mg, Zn, Mn, Cu and Fe) and fertility status (organic carbon, available N, P, K and S) and available micronutrients(Zn, Fe, Mn and Cu).

The study area was under the influence of semi-arid monsoon type climate with mean annual rainfall of 970.22 mm and mean annual atmospheric temperature of 28.49^{0}C.

The selected red soil profiles (3, 5, 6 and 7) were developed on weathered granite-gneiss parent material at gently sloping lands whereas the black soils (profiles 1, 2, 4 and 8) were formed at nearly level or plain topography on granitic gneiss parent material mixed with calcareous murram.

Illuviation was the dominant pedogenic process operating in the red soil profiles, while argillo-pedoturbation was responsible for the development of black soil profiles. Vertic properties like COLE, slickensides, gilgai-releif, cracks were obsereved in black soil profiles 1, 4 and 8, while red soil profiles (3 and 7) exhibited argillans in sub-surface. Cambic horizons were recognized in profiles 2, 5, 6 and 7, while the surface horizon was ochric epipdon in all the locations.

Black soils showed gray to very dark gray colour and red soils showed reddish brown to dark reddish brown colour in different horizons under dry and moist conditions.

The structure was granular at surface while it was blocky (sub-angular or angular) or columnar in subsurface in red and black soil profiles, in general. The textural classes were sandy loam, loam or clay loam in red soils while, it was clay loam / clay in black soils.

Due to migration of finer particles as indicated by the ratios of soil particles, the sand content decreased with depth while clay content increased in red and black soil profiles, in general. The coarse fragments content was high in red soil profiles than in black soil profiles.

The bulk density values were higher in red soils than in black soils correlating with sand content and the values increased with depth due to less aggregation in the sub-surface. Black soils recorded higher water holding capacity, volume expansion and sticky point following the trend of clay than the red soil profiles.

The pH, EC and calcium carbonate content of black soil profiles was higher than in red soil profiles. All these values were showing increasing trend with depth (just like clay content in both red and black soil profiles).

The data on exchange properties like CEC, PBS and saturation of exchangeable cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) indicated that black soils were having more exchange capacity and base saturation than red soils and these values increased with depth.

The silica content was more in red soils correlating with sand while; sesquioxides content was more in black soils correlating with clay content. Hence, their ratios were broader in red soils than in black soils. The siliceous nature of the soils was also exhibited by the large and broad silica and sesquioxides ratio confirming the acidic nature of the parent material – granitic gneiss.

Among the total nutrients, calcium content was higher in all the profiles. The total N and P content decreased down the depth while total K, Ca, Mg content was showing opposite trend. The total oxides of Zn, Fe, Mn and Cu values were not much varying among red and black soil profiles but surface layers recorded relatively higher values than lower layers.

The available nitrogen was low, phosphorus was medium, potassium was high, sulphur and micronutrients were sufficient except zinc in red and black soils of the mandal. Zinc was deficient. Organic carbon was positively and significantly correlated with available nutrients.

The clay fraction of red soils had mixed or illitic mineralogy while black soil clay fraction was montmorillonitic. Based on clay mineral dominance and CEC/clay ratio, it was understood that red soils were relatively in advanced stage of soil development while; black soils were in intermediate stage of weathering.

Based on the moderate limitation of soil and climate, the black soils were grouped under IIIsc while red soils under IIIec land capability sub-class because of moderate limitation of erosion and climate.

The soil temperature regime was isohyperthermic while soil moisture regime was ustic. According the criteria of USDA soil taxonomy, the black soil profiles were keyed out to the taxonomic units Chromic / Typic / Leptic Haplustert and Typic Haplustept. The red soil profiles were belonging to sub-groups Typic Haplustalf / Haplustept.

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***Orignal not seen**

Note: The literature cited was according to the "Guidelines for Thesis Presentation" given by Acharya N G Ranga Agricultural University, Rajendra Nagar, Hyderabad - 500 030.

APPENDIX

PROFILE – 1

I. Soil site description

a.	Village	:	Turlapadu
b.	Physiography	:	Plain land – Nearly level
c.	Slope	:	< 1%
d.	Parent material	:	Granitic gneiss mixed with calcareous murram
e.	Natural vegetation	:	Neem, *Acacia sp., Prosphis*
f.	Land use	:	Cotton, maize, redgram, chillies
g.	Erosion	:	None
h.	Drainage	:	Moderately well drained
i.	Ground water depth	:	10-12 meters
j.	Location	:	Near Turlapadu 0.5 km north of waterhead tank on Chilakaluripeta Prattipadu Road.

II. Soil characteristics

Horizon	Depth (m)	Brief description
Ap	0.00-0.15	Gray (10YR 5/1 D), dark gray (10YR 4/1 M); clay; moderate, fine, granular; sticky, plastic, friable, soft; many, medium pores; many, medium roots; strong effervescences; gradual, wavy; gilgai relief; cracks of 20 - 30 cm wide; sink holes.

AB	0.15-0.52	Gray (10YR 5/1 D), dark gray (10YR 4/1 M); clay; moderate, medium, sub-angular blocky; very sticky, very plastic, firm, hard; common, fine pores; common, fine roots; strong effervescences; gradual, wavy; cracks.
Bss_1	0.52-0.80	Gray (10YR 5/1 D), dark gray (10YR 4/1 M); clay; strong, coarse, sub-angular blocky; very sticky, very plastic, very firm, hard; few, very fine pores; common, fine roots; strong effervescences; diffused, smooth; cracks; distinct slickensides.
Bss_2	0.80-1.20	Gray (10YR 5/1 D), dark gray (10YR 4/1 M); clay; strong, coarse, angular blocky; very sticky, very plastic, very firm, very hard; few, very fine pores; few, fine roots; strong effervescences; diffused, smooth; cracks in the upper portion; distinct slickensides.
Bss_3	1.20-1.50	Gray (10YR 4/1 D), dark gray (10YR 3/1 M); clay; strong, coarse, angular blocky; very sticky, very plastic, very firm, very hard; few, very fine pores; common, fine conca; very few, fine roots; violent effervescences; diffused, smooth; distinct slickensides.
Bss_4	Below 1.50	Gray (10YR 4/1 D), dark gray (10YR 3/1 M); clay; strong, coarse, angular blocky; very sticky, very plastic, very firm, extremely hard; few, very fine pores; many, fine conca; violent effervescences; distinct slickensides.

Other features : Gilgai microrelief on the surface, surface cracks of 20-30 cm wide tapering down up to 100 cms, distinct slickensides from 50 cms depth, calcium carbonate nodules below 100 cm depth.

Taxonomic unit : Very-fine, montmorillonitic, isohyperthermic, Chromic Haplustert

PROFILE – 2

I. Soil site description

a.	Village	:	Jaggapuram
b.	Physiography	:	Plain to – very gently sloping
c.	Slope	:	1 - 3%
d.	Parent material	:	Granitic gneiss mixed with calcareous murram
e.	Natural vegetation	:	Neem, Tamarind
f.	Land use	:	Cotton
g.	Erosion	:	Slight erosion
h.	Drainage	:	Moderately well drained to well drained
i.	Ground water depth	:	10-15 meters
j.	Location	:	Near Edlapadu 2.5 km towards south of Edlapadu – Jaggapuram Road.

II. Soil characteristics

Horizon	Depth (m)	Brief description
Ap	0.00-0.10	Dark gray (10YR 4/1 D & M); clay loam, gravel 5-10 per cent; weak, fine, granular; sticky, plastic, friable, soft; many, medium pores; many, medium roots; strong effervescences; gradual, wavy.
Bw1	0.10-0.32	Dark gray (10YR 4/1 D & M); clay loam, gravel 10 per cent; moderate medium, sub-angular blocky; sticky, plastic, firm, hard; common, fine pores; common, fine roots; strong effervescences; gradual, irregular.

Bw_2	0.32-0.56	Dark gray (10YR 4/1 D & M); clay loam, gravel less than 10 per cent; moderate, medium, sub-angular blocky to angular blocky; sticky, plastic, firm, hard; common, fine pores; common, fine roots; strong effervescences; clear, wavy.
C	Below 0.56	Weathered granitic-gneiss mixed with calcareous murram.

Other features : Altered / changed / brown B / structural B horizon below 10 cm depth.

Taxonomic unit : Fine, montmorillonitic, isohyperthermic, Typic Haplustept.

PROFILE – 3

I. Soil site description

a.	Village	:	Edlapadu
b.	Physiography	:	Gently sloping land
c.	Slope	:	3 - 5%
d.	Parent material	:	Granitic gneiss
e.	Natural vegetation	:	*Acacia sp., Prosphis*
f.	Land use	:	Cotton and chillies
g.	Erosion	:	Slight to moderate
h.	Drainage	:	Well drained
i.	Ground water depth	:	15 meters
j.	Location	:	Near granitic gneiss hills 1 km away from Edlapadu 100 mts south on Edlapadu to Karuchola road.

II. Soil characteristics

Horizon	**Depth (m)**	**Brief description**
Ap	0.00-0.16	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); sandy loam; weak, very fine, granular; non-sticky, non-plastic, loose, loose, common, coarse pores; common, fine roots; no effervescences; clear, wavy.
B	0.16-0.26	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); sandy loam; weak, fine, sub-angular blocky; slightly sticky, slightly plastic, very friable soft, many, medium pores, common, very fine roots; no effervescences; clear, smooth.

Bt_1	0.26-0.41	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); loam; moderate, medium, columnar breaking to sub-angular blocky; slightly sticky, slightly plastic, firm, slightly hard; common, fine pores; broken, moderately thick, clay cutans; common, very fine roots; slight effervescences; gradual, irregular.
Bt_2	0.41-0.66	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); loam; moderate, medium, columnar breaking to sub-angular blocky; slightly sticky, slightly plastic, firm, slightly hard; few, fine pores; common, thick, clay cutans; common, very fine roots; slight effervescences; clear, wavy.
BC	0.66-0.79	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); sandy loam; 10-20 per cent gravel; moderate, medium, sub-angular blocky; slightly sticky, slightly plastic, friable, soft, few, fine pores; few, fine roots; slight effervescences; abrupt, broken.
C	Below 0.79	Weathered granitic gneiss

Other features **:** Clay cutans below 26 cm depth.

Taxonomic unit **:** Loamy, mixed, isohyperthermic, Typic Haplustalf

PROFILE – 4

I. Soil site description

a.	Village	:	Solasa
b.	Physiography	:	Plain land – Nearly level
c.	Slope	:	0 - 1%
d.	Parent material	:	Granitic gneiss mixed with calcareous murram
e.	Natural vegetation	:	Neem, *Acacia sp., Prosphis*
f.	Land use	:	Cotton, maize, redgram and chillies
g.	Erosion	:	None
h.	Drainage	:	Moderately well drained
i.	Ground water depth	:	10 meters
j.	Location	:	0.5 km towards west 2 km away from Linga rao palem on Linga rao palem to Solasa road.

II. Soil characteristics

Horizon	Depth (m)	Brief description
Ap	0.00-0.10	Very dark gray (10YR 3/1 D & M); clay; moderate, fine, crumb; sticky, plastic, firm, soft; many, medium, pores; few, very fine conca; many, medium roots; slight effervescences; gradual, smooth; gilgai relief; cracks of about 30 cm wide; sink holes.
AB	0.10-0.30	Very dark gray (10YR 3/1 D & M); clay; moderate, medium, sub-angular blocky; very sticky, very plastic, firm,

		hard; common, fine pores; few, very fine conca; common, fine roots; slight effervescences; gradual, wavy; cracks.
Bss_1	0.30-0.58	Very dark gray (10 YR 3/1 D & M); clay; strong, coarse angular blocky; very sticky, very plastic, very firm, hard; few, very fine pores; few, very fine conca; common, fine roots; strong effervescences; gradual, wavy; cracks in upper part; distinct slickensides in lower part.
Bss_2	0.58-0.90	Very dark gray (10YR 3/1 D & M); clay; strong, coarse angular blocky; very sticky, very plastic, very firm, very hard; few, very fine pores; few, very fine conca; few, fine roots; strong effervescences; diffused, smooth; distinct slickensides.
Bss_3	0.90-1.35	Very dark gray (10 YR 3/1 D & M); clay; strong, coarse angular blocky; very sticky, very plastic, very firm, very hard; few, very fine pores; few, coarse conca; few, very fine roots; strong effervescences; diffused, smooth; distinct slickensides.
Bss_4	Below 1.35	Very dark gray (10YR 3/1 D & M); clay; strong, coarse angular blocky; very sticky, very plastic, extremely firm, extremely hard; few, very fine pores; coarse, many conca; violent effervescences; distinct slickensides.

Other features : Gilgai microrelief on the surface, surface cracks of about 30 cm wide tapering down up to 60 cms, distinct slickensides from 40 cms depth, calcium carbonate nodules throughout depth.

Taxonomic unit : Very-fine, montmorillonitic, isohyperthermic, Typic Haplustert.

PROFILE – 5

I. Soil site description

a.	Village	:	Kondaveedu
b.	Physiography	:	Gently sloping land
c.	Slope	:	3 - 5%
d.	Parent material	:	Granitic gneiss
e.	Natural vegetation	:	Neem, palmyra, teak
f.	Land use	:	Vegetable crops & flowering plants under bore wells
g.	Erosion	:	Moderate
h.	Drainage	:	Well drained
i.	Ground water depth	:	10 - 12 meters
j.	Location	:	Near granitic gneiss hills 100 m away from Kondaveedu to Firangipuram road 2 km away from Kondaveedu.

II. Soil characteristics

Horizon	Depth (m)	Brief description
Ap	0.00-0.09	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); sandy loam, 10-15 per cent gravel; weak, fine, granular; non-sticky, non-plastic, very friable, soft; common, fine pores; moderate, medium roots; no effervescences; clear, smooth.
AB	0.09-0.37	Reddish brown (5YR 4/4 D), dark reddish brown (5 YR 3/4 M); Clay loam, 10-15 per cent gravel; weak, fine, granular; non-sticky, non-plastic, loose, loose; many, coarse pores; many, medium roots, no effervescences; gradual, wavy.

Bw_1	0.37-0.75	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); clay loam, moderate, medium, sub-angular blocky; non-sticky, non -plastic, firm, slightly hard; many, coarse pores; few, fine roots; no effervescences; gradual, irregular.
Bw_2	0.75-1.12	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); clay loam, moderate, medium, sub-angular blocky; non-sticky, slightly plastic, firm, hard; few, common, pores; few, very fine roots; no effervescences; gradual, wavy.
Bw_3	1.12-1.46	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); clay loam, moderate, medium, sub-angular blocky; non-sticky, non plastic, firm, hard; few, very fine pores; no effervescences; gradual, smooth.
Bw_4	Below 1.46	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); clay loam, moderate, medium, sub-angular blocky; non-sticky, non plastic, very firm, very hard; few, very fine pores; no effervescences.

Other features **:** Cambic horizon in sub-surface.

Taxonomic unit **:** Loamy, mixed, isohyperthermic, Typic Haplustept.

PROFILE – 6

I. Soil site description

a.	Village	:	Changeej Khan Peta
b.	Physiography	:	Gently sloping land
c.	Slope	:	3 - 5%
d.	Parent material	:	Granitic gneiss
e.	Natural vegetation	:	Neem, palmyra, soapnuts
f.	Land use	:	Orchards
g.	Erosion	:	Moderate
h.	Drainage	:	Well drained
i.	Ground water depth	:	10 - 15 meters
j.	Location	:	Near Chageej Khan Peta 200 meters towards south of Kondaveedu Kota.

II. Soil characteristics

Horizon	Depth (m)	Brief description
Ap	0.00-0.09	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); sandy loam, weak, fine, granular; non-sticky, non-plastic, loose, loose; common, fine pores; moderate, medium roots; no effervescences; gradual, smooth.
AB	0.09-0.30	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); sandy loam, weak, fine, sub-angular blocky; non-sticky, non-plastic, very friable, soft; common, fine pores; many, medium roots; no effervescences; clear, wavy.

Bw_1	0.30-0.47	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); moderate, medium, sub-angular blocky; non-sticky, non-plastic, friable, slightly hard; few, very fine pores; many, coarse roots; no effervescences; gradual, smooth.
Bw_2	0.47-0.60	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); loam, moderate, medium, sub-angular blocky; non-sticky, slightly plastic, firm, hard; few, fine pores; few, very fine roots; strong effervescences; clear, irregular.
C	Below 0.60	Weathered granitic - gneiss

Other features **:** Cambic horizon in sub-surface.

Taxonomic unit **:** Loamy, mixed, isohyperthermic, Typic Haplustept.

PROFILE – 7

I. Soil site description

a.	Village	:	Boyapalem
b.	Physiography	:	Gently sloping land
c.	Slope	:	3 - 5%
d.	Parent material	:	Granitic gneiss
e.	Natural vegetation	:	Neem
f.	Land use	:	Cotton and sorghum
g.	Erosion	:	Moderate
h.	Drainage	:	Well drained
i.	Ground water depth	:	10 meters
j.	Location	:	Near granitic gneiss hills 2 km away from Boyapalem 100 mts south on Sangam Gopalapuram to Boyapalem road.

II. Soil characteristics

Horizon	Depth (m)	Brief description
Ap	0.00-0.11	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); weak, fine, granular; non-sticky, non-plastic, loose, loose; many, medium pores; common, coarse roots; no effervescences; gradual, wavy.
AB	0.11-0.19	Reddish brown (5YR 4/4 D), dark reddish brown (5 YR 3/4 M); weak, fine, sub-angular blocky; non-sticky, non-plastic, loose, loose; many, fine pores; few, fine roots; no effervescences; clear, smooth.

Bw_1	0.19-0.45	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); clay loam; moderate, medium, sub-angular blocky; slightly sticky, slightly plastic, friable, soft; few, very fine pores; few, fine roots; no effervescences; clear, smooth.
Bt_1	0.45-0.70	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); clay loam; moderate, medium, sub-angular blocky; slightly sticky, slightly plastic, firm, hard; few, fine pores; patchy, thin argillans; few, very fine roots; no effervescences; gradual, wavy.
Bt_2	0.70-0.90	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); clay loam; moderate, medium, sub-angular blocky; slightly sticky, slightly plastic, firm, hard; few, very fine pores; patchy, thin argillans; few, very fine roots; no effervescences; abrupt, irregular.
C	Below 0.90	Weathered granitic gneiss.

Other features : Clay cutans below 45 cm depth.

Cambic and argillic horizons in sub-surface.

Taxonomic unit : Loamy, illitic, isohyperthermic, Typic Haplustalf.

PROFILE – 8

I. Soil site description

a.	Village	:	Timmapuram
b.	Physiography	:	Plain land-Nearly level
c.	Slope	:	<1%
d.	Parent material	:	Granitic gneiss mixed with calcareous murram
e.	Natural vegetation	:	Neem, palmyra
f.	Land use	:	Cotton
g.	Erosion	:	None to slight
h.	Drainage	:	Moderately well drained
i.	Ground water depth	:	About 15 meters
j.	Location	:	200 meters south of Timmapuram on Guntur to Chilakluripeta road.

II. Soil characteristics

Horizon	Depth (m)	Brief description
Ap	0.00-0.15	Dark gray (10YR 4/1 D & M); clay; weak, fine, sub-angular blocky; sticky, plastic, very friable, soft; many, medium pores; many, medium roots; violent effervescences; gradual, wavy; gilgai relief; cracks of 10-20 cm wide.
AB	0.15-0.32	Dark gray (10YR 4/1 D & M); clay; moderate, medium, angular blocky; very sticky, very plastic, firm, hard; common, fine pores; few, coarse roots; violent effervescences; gradual, smooth; cracks.

Bss_1	0.32-0.58	Dark gray (10 YR 4/1 D & M); clay; strong, coarse, angular blocky; very sticky, very plastic, very firm, hard; few, very fine pores; common, fine roots; violent effervescences; diffused, smooth; cracks in upper part; slickensides in lower part.
Bss_2	0.58-0.90	Dark gray (10YR 4/1 D & M); clay; strong, coarse, angular blocky; very sticky, very plastic, very firm, very hard; few, very fine pores; violent effervescences; gradual, wavy; distinct slickensides.
C	Below 0.90	Weathered granitic-gneiss mixed with calcareous murram.

Other features : Gilgai microrelief on the surface, surface cracks of 10-20 cm wide tapering down up to 40 cms, distinct slickensides from 45 cms depth, calcium carbonate nodules throughout the depth.

Taxonomic unit : Fine, montmorillonitic, isohyperthermic, Leptic Haplustert.