CHARACTERIZATION, CLASSIFICATION AND EVALUATION OF SOILS IN CHILLAKUR MANDAL OF SPSR NELLORE DISTRICT, ANDHRA PRADESH

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B.Sc. (Ag.)

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(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)

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BY

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B.Sc. (Ag.)

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2015

DECLARATION

I **U. VEDADRI,** hereby declare that the thesis entitled **"CHARACTERIZATION, CLASSIFICATION AND EVALUATION OF SOILS IN CHILLAKUR MANDAL OF SPSR NELLORE DISTRICT, ANDHRA PRADESH"** submitted to the **Acharya N.G. Ranga Agricultural University**, for the degree of **Master of Science in Agriculture** is the result of original research work done by me. I also declare that no material contained in this thesis has been published earlier in any manner.

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(U. VEDADRI)
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CERTIFICATE

Mr. U. VEDADRI has satisfactorily prosecuted the course of research and that the thesis entitled **"CHARACTERIZATION, CLASSIFICATION AND EVALUATION OF SOILS IN CHILLAKUR MANDAL OF SPSR NELLORE 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 neither the thesis nor its part thereof has not been previously submitted by him for a degree of any university.

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CERTIFICATE

This is to certify that the thesis entitled **"CHARACTERIZATION, CLASSIFICATION AND EVALUATION OF SOILS IN CHILLAKUR MANDAL OF SPSR NELLORE DISTRICT, ANDHRA PRADESH"** submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** to the Acharya N.G. Ranga Agricultural University, Hyderabad, is a record of the bonafide original research work carried out by **Mr. U. VEDADRI** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

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U. Vedadri...

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LIST OF SYMBOLS AND ABBREVIATIONS

%	:	Per cent
<	:	Less than
>	:	Greater than
°C	:	Degree Celsius
CEC	:	Cation Exchange Capacity
cm	:	Centimeter
$cmol(p^+)kg^{-1}$	:	Centimole per kilogram
dSm^{-1}	:	Deci Siemens per meter
EC	:	Electrolyte Conductivity
et al.	:	and others
etc.	:	and so on
Fig.	:	Figure
$g\ kg^{-1}$	:	Gram per kilogram
i.e.,	:	That is
m	:	Metre
MAAT	:	Mean Annual Air Temperature
MAST	:	Mean Annual Soil Temperature
$mg\ kg^{-1}$	:	Milligram per kilogram
$Mg\ m^{-3}$	:	Mega gram per cubic meter
Mha	:	Million hectare
mm	:	Millimeter
msl	:	Mean sea level
MSST	:	Mean Summer Soil Temperature
MWST	:	Mean Winter Soil Temperature
NBSS & LUP	:	National Bureau of soil Survey and Land Use Planning
USDA	:	United States Department of Agriculture
r	:	Correlation coefficient
viz.,	:	Namely

ABSTRACT

Name of the Author	:	**U. VEDADRI**
Title of the thesis	:	**CHARACTERIZATION, CLASSIFICATION AND EVALUATION OF SOILS IN CHILLAKUR MANDAL OF SPSR NELLORE DISTRICT, ANDHRA PRADESH**
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The present investigation involves characterization, classification and evaluation of soils in Chillakur mandal of SPSR Nellore district, Andhra Pradesh. For this, seven representative pedons were selected in seven different locations of the study area covering all types of soils. All the seven pedons were described for their morphological features in the field and horizon-wise samples were collected and analyzed in the laboratory for physical, physico-chemical and chemical properties.

The study area was characterized by semi-arid monsoonic climate with distinct summer, winter and rainy seasons. The pedons selected were located on nearly plain (0-1%) to gently sloping (1-3%) topography. All pedons were developed from granite-gneiss parent material except pedon 7, which was originated from alluvium. The morphological features indicated the presence of AC (Pedons 1, 3, 4 and 7) and ABC (Pedons 2, 5 and 6) profiles. The soils were moderately deep to very deep in depth, pale brown to dark reddish brown in colour, sandy to clay loam in texture and had crumb to angular blocky structure.

The clay content decreased with depth in pedons 1and 4 while pedons 5 and 6 showed an increasing trend up to Bw2 and Bw3 horizons,

respectively later on a decreasing trend with depth. Pedon 3 showed an increasing trend with depth. However, no specific trend with depth was observed in pedons 2 and 7. Physical constants like water holding capacity, loss on ignition and volume expansion followed the trend of clay content. All pedons exhibited an irregular trend of bulk density with depth while pedon 1 showed a decreasing trend, corresponding to decreasing organic carbon content with depth.

The pedons were slightly acidic to moderately alkaline in reaction, non-saline and low to medium in organic carbon. All the pedons registered low $CaCO_3$ status. CEC values were low to medium and exchange complex was dominated by Ca^{+2} followed by Mg^{+2}, Na^{+} and K^{+}. Chemical composition of soils revealed that all the pedons had high silica content indicating siliceous nature.

Regarding nutrients status, the soils were low to medium in available nitrogen and available phosphorus, low to high in available potassium and high in available sulphur. However, soils were deficient in available zinc and sufficient in available copper, iron (except pedon 7) and manganese.

Based on morphological, physical, physico-chemical, mineralogical and meteorological data, the soils of Chillakur mandal were classified as:

Pedon 1 : Fine-loamy, mixed, isohyperthermic, Typic Ustorthent

Pedon 2 : Fine-loamy, smectitic, isohyperthermic, Typic Haplustept

Pedon 3 : Fine-loamy, smectitic, isohyperthermic, Typic Ustorthent

Pedon 4 : Fine-loamy, kaolinitic, isohyperthermic, Typic Ustorthent

Pedon 5 : Fine-loamy, smectitic, isohyperthermic, Typic Haplustept

Pedon 6 : Fine-loamy, mixed, isohyperthermic, Typic Haplustept

Pedon 7 : Sandy, siliceous, isohyperthermic, Typic Ustipsamment

Based on the soil properties, the soils of the Chillakur mandal have been classified into land capability classes and sub-classes viz., IIIs (Pedons 5 and 6), IIIws (Pedon 2), IVs (Pedon 7), IVse (Pedons 1, 3 and 4).

The soil-site suitability evaluation of study area revealed that all pedons were marginally suitable (S3) for rice, groundnut, sesame and sunflower crops except pedon 7 which is temporarily not suitable (N1) for rice crop.

Chapter ~ I

Introduction

Chapter – I

INTRODUCTION

Soil is a finite natural resource, which decides the feasibility in implementation of agricultural developmental programmes in an any nation on the planet of earth. Sustainable yields can be achieved through efficient utilization of agricultural inputs and technology along with the proper soil management. Soil is a base for agriculture and plays a key role in sustainable development and poverty alleviation by providing livelihood opportunities to burgeoning population. Soil act as a substrate in development of mankind either directly or indirectly by providing food, fodder fuel, fiber *etc.* It is neither an exhaustible store of plant nutrients nor a renewable natural resource, capable of withstanding onslaught of exploitative agriculture and soil degrading processes.

Several problems facing humanity in the 21st century includes increasing world population (that is at present more than 6 billion) by 1.3 per cent per year, deteriorating quality of land resources and their declining availability, food insecurity and malnutrition, pollution of soils and fresh waters, eutrophication and acidification of terrestrial and coastal ecosystems, decreasing biodiversity and climate change. Of these, deterioting quality of land resources and its declining availability for agricultural production are major concerns that endanger the very survival of human beings (Prasad, 2013).

India being the seventh largest country in the world having a total area of 328.8 Mha and a land area of 316.6 Mha, with an arable land area of 158 Mha. The per-capita arable land area has declined from 0.34 ha in 1961 to 0.14 ha in 2010 and is projected to decline to 0.09 ha by 2050. The arable land area has been declining because of urbanization, infrastructure development, industrial growth, land degradation losses by accelerated erosion and secondary salinization (Lal, 2013). A degraded soil can be improved and made suitable for profitable production using proper management technology and inputs. Thus, man has the ability and capacity to reclaim and improve the degraded soils and make them productive using a proper management system. However, the time and cost involved in reclaiming a degraded soil are the serious limitations.

Characterization helps in determining the soil potentials and identification of constraints in crop production, besides giving detailed information about different soil properties. This knowledge helps to harvest the nutrients from the soil with sustainable replenishment of nutrients. Further, soil classification helps in grouping of soils with similar properties and suggesting suitable management practices for increasing the productivity of the soils.

No system of farming will be sustainable unless the soil which forms its pivot and is the most important natural resource to be managed scientifically to meet the present and future needs, its productivity and quality are maintained continuously and there is no reduction of output with inputs. For efficient management of soils , knowledge about their morphology, physical and chemical properties, behavior, kind and degree of problems and their extent and distribution on land scape is highly essential, which can be achieved through systematic soil survey (Soil Survey Division Staff, 2000).

Even though information is available regarding characterization and classification of soils in Andhra Pradesh (Satyavathi and Reddy, 2004a) but that is intermittent. Characterization, classification and evaluation of the soils for suitability to different crops (Rice, groundnut, sunflower and sesame) particularly in Chillakur mandal and SPSR Nellore district in general is not attempted in the past. Moreover, a detailed study is necessary for assessing the suitability of land for specific use and further land use planning on mandal wise, to take up various developmental programmes in agriculture on sustainable basis in Andhra Pradesh.

Keeping the above facts in view, the present investigation was taken up with the following objectives:

1. To study the morphological features, physical, physico-chemical and chemical properties of each horizon of the soil profiles in Chillakur mandal of SPSR Nellore district.

2. To study the genesis responsible for the development of different soils in the mandal.

3. To classify the soils as per the Soil Taxonomy up to family level and also into different land capability classes (USDA) for optimum land use planning.

4. To evaluate the suitability of soils for major crops (Rice, groundnut, sunflower and sesame) grown in the area to achieve sustainable yields.

Chapter ~ II

Review of Literature

Chapter II

REVIEW OF LITERATURE

Soil is a major component of the Earth's ecosystem. The world's ecosystems are impacted in far-reaching ways by the processes carried out in the soil. No developmental plan can be successful unless it is based on reliable knowledge on the extent of different kinds of soils in relation to climate, vegetation and potential crop production. The soils in most of the semi-arid tropics are superficially similar in appearance, careful study revealed a great diversity. Soil acts as an engineering medium, a habitat for soil organisms, a recycling system for nutrients and organic wastes, a regulator of water quality, a modifier of atmospheric composition and a medium for plant growth. Since soil has a tremendous range of available niches and habitats, it contains most of the earth's genetic diversity. Information available about spatial distribution of soils in Andhra Pradesh under different categories is not adequate and it is remain a major obstacle in overall implementation of agricultural developmental programmes in the state and it creates immediate attention. Because of the above reasons the present investigation was planned and carried out. Further, the available literature pertaining to the present investigation was reviewed and presented under appropriate sub-heads here under.

2.1 NOMENCLATURE

The name is essential for each class in any category. The names of the classification units are combinations of symbols, most of which are derived from Latin or Greek and have root words in several modern languages. Since, each part of soil name conveys a concept of soil character or genesis, the name automatically describes the general kind of soil being classified. This was the opinion of Brady (1990) about the nomenclature of soils.

The red and associated soils occupy one-fifth of the total geographical area in our country and designated by different names in different parts of the country. In Andhra Pradesh, red sandy loam soils on a permeable murrum base developed on the sides and the foot hills were locally called *chalka* soils while the coarse textured loamy sand and sandy soils were known as *dubba* soils. Red and dark red soils found in Karnataka were commonly called as *kisumattaru*. In Jhansi district of Uttar Pradesh two types of red soils are known as *Parwa* and *Rakar* are observed. The *Parwa* soils are brownish grey in colour and vary in texture from loam to sandy clay loam while the *Rakar* soils are reddish in colour but not suitable for cultivation (Rayachaudhuri and Rajan, 1971). Saline soils occurring in coastal area of peninsular region are called *khar* in Maharashtra. The deltaic alluvial soils in Gujarat are called *Goradu* soils whose texture varied from silty loam to clay loam (Sehgal, 1996).

2.2 PEDOGENESIS

Dokuchaiev (1886) was the first person to show that soils usually form a pattern in the landscape and established that they develop as a result of interplay of soil-forming factors *viz.*, parent material, climate, organisms, topography and time. Among the soil forming factors, he considered vegetation as the most important one. Jenny (1941) reported that soil forming factors were independent variables each of them can change and vary from place to place without the influence of other.

Reddy *et al.* (1993) revealed that plinthite layer was present in hills and hill range pedons indicating that soils were undergoing process of laterization. Accumulation of higher Al_2O_3 / Fe_2O_3 at the surface than in the sub-surface provided confirmatory evidence of clay translocation in the soils (Singh *et al.*, 1998).

Changes in the land use system including deforestation could have brought significant pedogenic modification (Soloman *et al.*, 2002). Kumar (2002) reported that major coffee growing soils of Karanataka have well developed soil profiles which are an expository of all the major pedogenic processes like clay illuviation, acidification and residual enrichment of Fe and Al oxides. Illuviation process occurred during soil development was responsible for higher clay content in the sub-surface horizons as compared to surface horizons (Sharma *et al.*, 2004a).

Physiography influences soil formation through water, temperature, soil erosion and micro climate relations which inturn affects the pedogenic processes resulting varied soils (Verma *et al.*, 2005). Rudramurthy *et al.* (2007) stated that irrespective of land use systems, soil texture was finer in the sub-surface horizon than in the surface horizon and this might be due to pedogenic process *viz.,* clay illuviation. Irregular distribution of organic carbon indicated that pedogenesis was not strong enough to obliterate the mark of stratification (Kumar *et al.*, 2009).

Dolui *et al.* (2010) stated that weathering of minerals, leaching, lateral surface and sub surface processes dominated soil formation in some acid soils of Nagaland. Somasundaram *et al.* (2010) reported that high silt content in pedons of lower basin of Pudukottai district in Tamilnadu was attributed to weathering and advanced pedogenesis. Micro-relief and Salinization plays a vital role in the development of salt-affected soils of Bhind district in Madhya Pradesh (Raghuwanshi *et al.*, 2011).

Accumulation of organic matter , translocation of materials *i.e.,* eluviation and illuviation and transformation of minerals and organic substances were important soil forming processes while studying the pedogenesis in semi-arid region of Banaganapalle mandal of Kurnool district in Andhra Pradesh (Sireesha and Naidu, 2013a). Sekhar *et al.* (2014) stated that soil forming processes like transformation of minerals and organic substances lead to changes in colour and structure in the sub – soil leading to devolmpent of cambic horizon (Bw) in soils of central and eastern parts of Prakasam district in Andhra Pradesh.

2.3 FACTORS OF SOIL FORMATION

The influence of different soil forming factors on soil development was presented below.

2.3.1 Parent material

Parent material is that mass (consolidated rocks, such as igneous, metamorphic or sedimentary to unconsolidated sediments such as alluvium, colluvium, aeolian / loess, glacial-till *etc.*) from which the soil has formed. It is the important initial soil material that determines the soil profile development as well as physical properties of soils. Parent material also influences the quantity and type of clay minerals present in the soil profile.

Chinchmalatpure *et al.* (2000) reported that sub-soil sodicity in alluvial plain is due to alkaline nature of basalt parent material. Prakash and Rao (2002) reported that red soils in Krishna district of Andhra Pradesh were developed from granite-gneiss parent material mixed with sandstone and quartzite. Soils of Amensis sub-catchment of Hirna watershed, Haryana has the evidence of zeolite in the form of white material in the cavities of some basalt (Mishra *et al.*, 2004; Heluf and Mishra, 2004). Some Sal (*Shorea robusta*) growing areas in Dindori district of Madhya Pradesh showed site characteristics of flat-topped hills has developed from basalt (Patil and Prasad, 2004).

Satyavathi and Reddy (2004a) reported that Inceptisols and Vertisols in Telangana region of Andhra Pradesh were originated form igneous rocks such as pink and grey granites, basalt and metamorphic rocks *viz.,* granite-gneiss and hornblende schists. According to Thangasamy *et al.* (2005), Entisols, Inceptisols and Alfisols were developed from granite-gneiss and quartzite parent materials in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh. Singh and Agarwal (2005) assessed that parent materials range from recent alluvium to well weathered residual materials in upland sites and strong effervescence of soils was due to the presence of calcium carbonate in parent material of that soils.

Chaudhary *et al.* (2006) reported that soils of Amethi in Uttar Pradesh developed on alluvium and form part of the Indo-Gangetic plains. According to Tripathi *et al.* (2006) soils of Kair-Nagali micro watershed in north-west Himalayas developed from dolomite. Grape growing soils in Nasik district of Maharashtra were developed over basalt and basaltic alluvium (Balpande *et al.*, 2007). The acidic pH of soils under different land use system might be due to the fact that these soils are derived from acidic granite and / or metamorphic gneiss (Rudramurthy *et al.*, 2007). Soils were formed on alluvium of different sedimental deposits as shown by discontinuity in sand, silt and clay distribution along with depth (Sarade and Prasad, 2008).

Likhar and Prasad (2011) stated that soils developed from phyllite parent material are rich in macronutrients than soils developed from basalt. Niranjana *et al.* (2013) stated that soils in Pulivendula region of Andhra Pradesh have wide textural variation. The soils on strongly sloping lands (10-15%) were developed from quartzite and soils on gently to very gently sloping plains (1-5%) were developed from weathered shale. Distribution and amount of light and heavy minerals and their shape and size indicated that the sand minerals in the north bank plain zone of Assam are derived from sedimentary and partially metamorphed rocks (Karmakar, 2014a).

2.3.2 Climate

Climate is the most significant factor controlling the type and rate of soil formation. Precipitation and temperature are the two main aspects of climate that have more profound influence on soil genesis and development.

Dutta *et al*. (2001) reported that deep weathering required a tropical climate with a rainfall of more than 1600 mm / month. Prakash and Rao (2002) reported that red and black soils in Krishna district of Andhra Pradesh were developed from semi-arid monsoonic climate with a mean annual rainfall of 1090 mm. The red and black soils in Dindori district of Madhya Pradesh were developed under moist sub-humid climate with an annual rainfall of 1460 mm (Patil and Prasad, 2004).

Satyavathi and Reddy (2004b) stated that northern Telengana zone falls under semi-arid (moist) tropics with an annual rainfall of around 1000 mm whereas southern Telengana zone falls under semi-arid (dry) tropics with an annual rainfall of around 740 mm. Further, the moisture and temperature regimes in southern and northern zones were ustic and isohyperthermic. Soils in Chandragiri mandal of Chittoor district comes under semi-arid monsoonic climate with a mean annual soil temperature of 31.9°C and a mean annual summer and winter soil temperatures of 32.1°C and 27.8°C respectively, which qualifies for isohyperthermic temperature regime with ustic soil moisture regime (Basavaraju *et al.*, 2005).

According to Sitanggang *et al.* (2006) soils in watershed area of Shikohpur, Haryana falls under semi-arid climate. Grape growing soils in Nasik district of Maharastra were located within the rainfall range of 477.3 to 753.1 mm with minimum and maximum temperatures of 10.2^0C and 32.4^0C (Balpande *et al.,* 2007). The soils in Ramachandrapuram mandal of Chittoor district were developed from semi-arid monsoonic climate and qualifies for isohyperthermic temperature regime (Rao *et al.,* 2008).

Ram *et al.* (2010) stated that soils in flood-prone area of Rajasthan were characterized by erratic rainfall and was prone to flooding by rain water coming from surroundings during and after monsoon which resulted in degraded soil with low fertility and harsh temperature regime. Niranjana *et al.* (2011) noticed that banana growing soils in Pulivendula region of Andhra Pradesh receives an average rainfall of 564 mm in which 55 per cent of annual rainfall was received during south-west monsoon (Jun-Sept) and 31 per cent was received during north-east monsoon (Oct-Dec).

Orange growing soils in Nagpur district of Maharashtra had tropical dry sub-humid climate with ustic soil moisture regime and hyperthermic soil temperature regime (Likhar and Prasad, 2011). Selvaraj and Naidu (2012) stated that soils in Renigunta mandal of Chittoor district were developed under semi-arid climate with a mean annual precipitation of 1286 mm and qualifies for isohyperthermic soil temperature and ustic soil moisture regime.

Salt-affected soils with selenite deposits developed under arid climate with mean annual rainfall of 255 mm and a mean annual temperature of 5-42^{0}C qualifies for torric soil moisture regime and hyperthermic soil temperature regime (Mandal and Sharma, 2013). Soils developed under semi-arid climatic conditions with dolomite and granite-gneiss as parent material qualified for ustic soil moisture and isohyperthermic soil temperature regime (Sireesha and Naidu, 2013a). Devi and Naidu (2014) reported that soils developed under semi-arid monsoonic climate with distnict summer, winter and rainy seasons having granite-gneiss as parent material qualified for ustic soil moisture and isohyperthermic soil temperature regime in sugarcane growing areas of Chittoor district in Andhra Pradesh.

2.3.3 Time

The period taken by a given soil from the stage of weathered rock (*i.e.* regolith) up to the stage of maturity is considered as time. Time is an important factor in the course of soil development which governs indirectly the activities and interactions of different factors of soil formation.

Studies on sand mineralogy of alluvium derived soils in Southern bank of Bramhaputra river of Assam revealed that the lowest weathering was observed in soils developed on the recent alluvium (Chakravarthy *et al.,* 1979). Soil development increased with the logarithm or power of soil age (Natasa *et al.,* 1997). Lekha *et al.* (1998) stated that soils developed over granite-gneiss were comparatively younger with higher nutrient reserves followed by soils developed over granite, charnockites and laterites.

The colour became redder with increasing age and its quantitative index (Hurst index) showed the highest value in soils of Archaean age, intermediate in pleistocene age and the lowest in soils of Holocene age (Nayak *et al.,* 1999). Tamgadge *et al.* (1999) stated that clay content was less than 35 per cent in young / immature soils while it was medium (35-55%) in mature soil and high (> 55%) in old soils. Verma *et al.* (2001) reported that soils of active flood plain in Etawah district of Uttar Pradesh were formed on repeated fresh sediments and hence could not get sufficient time for development.

The soils of Siwalik lack in structural peds due to their young nature, poor organic carbon, low silt and clay contents (Sawhney *et al.,* 2005). Time along with topography and nature of parent material were the important soil forming factors responsible for the pedogenic differences in the soils developed on different landforms within comparable climate conditions (Kumar *et al.,* 2005).

2.3.4 Topography

Topography relates to the configuration of the land surface and is described in terms of differences in elevation, slope and landscape position. Topography influences the microclimate of a region and influences soil properties by altering soil forming processes.

Powar and Mehta (1999) revealed that in low lands there was an increasing distribution of organic carbon indicating its deposition and fluvial characteristics. Entisols, Inceptisols and Alfisols in Chandragiri mandal of Chittoor district, Andhra Pradesh had the soil colour with a hue varied from 2.5 YR to 10 YR in plains, 2.5 YR to 7.5 YR in uplands and 5 YR to 10 YR on hill slopes, which is due to variation in chemical and mineralogical composition as well as textural make up of soils as conditioned by topographic position (Basavaraju *et al.*, 2005). Soils of Amensis sub-catchment of Hirna watershed in Ethiopia were formed on back slope with a slope gradient of 60, 70 and 88 per cent whereas soils on foot hill with a slope gradient of 10 per cent (Heluf and Mishra, 2005).

Some Entisols and Inceptisols were developed on nearly level (0-1%) and some of the Entisols and Alfisols were developed on gently sloping (3-5%) uplands (Thangasamy *et al.*, 2005). Physiography was marked by undulating landscape dotted by frequent elevations and depressions in the area of outer Himalayas (Sanjeev *et al.*, 2005 and Tripathi *et al.*, 2006). Sitanggang *et al.* (2006) indicated that depth of soil in the watershed area of Shikohpur, Haryana varied from 35 to more than 150 cm due to variations in topography and slope gradient. Hills and hill ranges had (5 YR) redness increased with depth (2.5 YR) due to decrease in organic matter content and increase of free iron oxides in soils of coastal agro-eco system of north Karnataka (Mini *et al.*, 2007).

According to Sharma and Sanjeev (2008), soils of upper piedments belonging to Entisols, associated with Alfisols and Inceptisols were very shallow to deep, low in CEC and moderate to high in base saturation. Meena *et al.* (2009) reported that shallow soils were formed on steep slopes or upper piedments whereas deep soils were found on nearly level to gently sloping in all the geomorphic surfaces. Najar *et al.* (2009) stated that soils on southern aspect possessed moderately fine to fine texture which could be attributed to more exposure of soils to sun on the southern aspect. Somasundaram *et al.* (2010) noticed that typical pedons in lower Vellar basin of Pudukkottai district, Tamilnadu represents different physiographies *viz.*, nearly level, very gentle to gently sloping and undulating land.

The depth of soil on gently sloping uplands varied from moderately shallow (75-100 cm) to deep (100-150 cm) (Niranjana *et al.*, 2011). Mustaq (2011) stated that low altitude soils were loam to silt loam in texture with alkaline pH range whereas high altitude soils were clay loam in texture with slightly acidic pH. Nasre *et al.* (2013) noticed that soils developed on plateau top, escarpments, isolated hillocks and foot slopes are shallow and soils developed on undulating lands, alluvial plains and valleys are deep indicating that soil depth is related to slope and degree of soil erosion. Soils on very gently sloping plains are very deep, well-drained with loamy to clay-loamy texture whereas soils on nearly plains are moderately to imperfectly drained with sandy loamy to loamy texture in tea-growing soils of Jorhat district, Assam (Bandyopadhyay *et al.* 2014).

2.3.5 Vegetation

Natural vegetation influences the type of soil eventually formed from a given parent material. Vegetation cover by higher plants influences the soil in a number of ways, principally through the addition of organic matter, action of roots in binding soil particles and amelioration of climatic conditions at the soil surface. Further, the diversification in vegetation serves as a good sign of indication for the identification of soil properties.

The higher exchangeable Ca in the surface soil may be due to redistribution of calcium by tree species (Patil and Prasad, 2004). The dominant natural vegetation in the sand dunes and beach sands was short and tall grasses whereas *Prosopis juliflora*, babul, palmyra *etc.*, were dominant in transitional alluvium and inland plains of southern coastal agro-eco sub-region soils of Andhra Pradesh (Rao *et al.*, 2004).

Thangasamy *et al.* (2005) reported that natural vegetation of Sivagiri micro watershed area of Andhra Pradesh includes grasses, *Prosopis julifera*, Parthenium species, Tridax species and *N*eem (*Azadiracta indica*) *etc*. Soils on the northern aspects were moderately deep to very deep whereas on the southern aspects these were moderately deep which could be ascribed to differences in parent material and vegetative cover (Najar *et al.*, 2009).

High organic carbon content in soil occurring on hill or hill slopes owing to better vegetative cover (Meena *et al.*, 2009). The natural vegetation in Yerpedu mandal of Chittoor district, Andhra Pradesh comprises of *Tridax procumbens, Parthenium hysterophorus, Prosopis julifera, Calotropis gigantea, Acacia auriculiformis, Commelina bengalensis, Cyanodon dactylon, Cyperus rotundus, Pongamia pinnata and Azardirachta indica* (Leelavathi *et al*., 2009). Tamarind, neem, palmyrah, prosopis, jamun and acacia were the predominant natural vegetation of Cauvery delta region in Tiruvarur district, Tamil Nadu (Kannan *et al.*, 2011).

Gangopadhyay *et al.* (2012) reported that dominant vegetation in rainfed region of West Bengal with sub-humid climate are Mahua (*Madhuca indica*), Palas (*Butea frondosa*), Arjun (*Terminalia arjuna*), Date palm (*Phoniex dactylifera) etc*. Soils belonging to the sahyadri group of Ajanta and Chikhli formations are dominated by teak (*Tectona grandis*), babul

(*Acacia* spp.), neem (*Azadirachta indica*), subabul (*Leucaena leucocephala*), palas (*Butea frondosa*) *etc.* Sidhu and Surya (2014) noticed that Deodar (*Cendrus libani*), Safedi (*poplar* spp.) and willows (*Salix* spp.) are dominant trees in vallys of north-western Himalayan eco-system.

2.4 MORPHOLOGICAL FEATURES

The morphological characteristics are the most imperative key features for classifying soil into defined categories. The morphology of red and associated soils was studied and the pertaining information was well documented. Some of the important contributions are reviewed here under.

2.4.1 Horizon and horizon sequence

Sharma *et al.*(1997) reported that soils on flood plain areas of Inceptisols in north-west India showed Ap, Bw1, Bw2, Bw3, BC and C horizon sequence. Dutta *et al.* (1999) stated that some Alfisols of Andhra Pradesh showed A, Bw, Bt and Cr horizon sequence in Typic Haplustalfs while Typic Rhodustalfs exhibited A, Bw, Bt1, Bt2 and Cr horizon sequence.

Verma *et al.* (2001) studied the soil variability across different landscapes in Etawah district of Uttar Pradesh and the study revealed that Entisols (Ustorthents) showed a horizon sequence of A11, A12, A13, A14, A15, C1 and C2 while the Inceptisols (Haplustepts) exhibited Ap, Bw1, Bw2, Bw3, Bw4 and Bw5. Red soils of Krishna district in Andhra Pradesh showed Ap, B1, BC and C whereas black soils showed Ap, A12, A13, Ass1, Ass2 and AC in Lithic Haplustepts (Prakash and Rao, 2002). Nagpur mandarin (*Citrus reticulata*) growing soils showed Ap, Bw1, Bw2, Bw3, 2Bw4 and 2Bw5 in Typic Haplustepts (Marathe *et al.*, 2003).

Sharma and Kumar (2003) reported that Alfisols and Inceptisols of upper Maul Khad catchment in Himachal Pradesh were characterized by the presence of eluvial (Ap and AB) and illuvial (BA, Bw, Bt and BC) horizons of varying thickness. Salt affected soils of southern Rajasthan showed Ap, A2, A3, Ck1, Ck2 and Ck3 in Aridic Ustorthent (Sharma *et al.,* 2004a). Basavaraju *et al.* (2005) reported that Entisol on plains showed Ap, C1, C2, C3, C4 and C5 horizon sequence.

Balpande *et al.* (2007) reported that grape growing of Shivdi area exhibited Ap, AC, 2C1 and 2C2 and some of the horizons showed lithological discontinuity. The Dhanjnagar and Kakrabon soils showed homogeneity in the profile development (Ap-Bw/Ap-Bw) in contrast to that of khilpara (Ap-Bw1-2Bw) and Chhataria soils (Ap-Bw-2C) which exhibited lithological discontinuity indicating the influence of fluvial activity (Gangopadyay *et al*., 2008).

The morphological characteristics indicated that soils on hills, piedment and old alluvial plain exhibited A-Bt-C horizon sequence and those on plateau, escarpments and valley showed A-Bw-C sequence whereas A-C horizon sequence was noticed for coastal alluvial plains. Soils of high hill and medium hill slopes have altered sub-surface horizons with horizon sequence A-Bw-Cr whereas some soils of low hill and foot hill slopes exhibited argillic horizons at sub-soils with horizon sequence of A-Bt and A-Bt-Cr (Sahoo *et al.,* 2010). Mandal and Sharma (2013) reported that Entisols on plains, dunes and alluvial plains showed Ap, C1, C2, C3 and C4 horizon sequence. Karmakar *et al.* (2014b) noticed that soils on relatively unstable land forms are young and immature with Ap-C-C1-C2 and 2C3 horizon sequence whereas those on alluvial plain have Ap-Bw-2Cg1 and 3Cg2 horizon sequence.

2.4.2 Boundary between the horizons

According to NBSS & LUP, (1994) the boundary of the soils in Chabalpur series (Entisols) of West Bengal was diffuse smooth, abrupt smooth and clear smooth. Dhaliwal *et al.* (1996) reported that abrupt / clear boundaries indicative of marked stratification due to the deposition of different sediments and lack of post depositional inter horizon translocation of chemically mobile constituents and fine particles within a profile.

According to Elahi *et al.* (1996), the boundary of Inceptisols developed on Madhupur clay in Bangladesh was gradual wavy, diffuse wavy, clear wavy, abrupt wavy and abrupt smooth. The Inceptisols of north-west India exhibited clear smooth, gradual smooth, diffuse smooth, abrupt smooth and clear / gradual smooth boundary (Sharma *et al.*, 1997). Lekha *et al.* (1998) noticed that boundary of the Chunda soils of Kerala developed from hard lateritic pan produced clear smooth and gradual smooth boundary while the soils developed on weathered laterite exhibited gradual smooth, clear smooth and abrupt smooth boundary.

The soils of Etawah district of Uttar Pradesh exhibited clear smooth and gradual smooth boundary between the horizons (Verma *et al.*, 2001). Sharma *et al.* (2004b) observed that horizon boundaries in Entisols, Inceptisols and Alfisols of Neogal watershed in north-west Himalayas was clear to diffuse in distinctness and smooth in topography. Rao *et al.* (2008) reported that boundary of the pedons on plains varied from clear to diffuse in distinctness and smooth to wavy in topography whereas pedons situated on hill slopes showed clear and smooth boundary.

The horizon boundaries in pedons of south Tripura district in north-eastern India were clear to gradual in distinctness and smooth in topography (Gangopadhyay *et al.*, 2008). Sireesha and Naidu (2013) stated that the boundaries in the pedons of Banaganapalle mandal in Kurnool district of Andhra Pradesh varied from clear to diffuse in distinctness and smooth to wavy in topography. The lower boundaries of surface horizons of the soils were clear and smooth while lower boundaries of sub-surface horizons were gradual and smooth in distinctness and topography, respectively in soil of Bhagalpur districts of south Bihar (Pandey and Kumar, 2014).

2.4.3 Soil colour

Soil colour is one of the most useful and important characteristics for identification and classification of soils. Soil colour helps to distinguish the different horizons of a soil profile and in identifying diagnostic horizons used in soil classification. The soil colour of an area, often relates to specific chemical, physical and biological properties of the soils in that area. Soil colour was indices of the soil forming process and reflects the mineralogy of the soil.

According to Prakash and Rao (2002), the colour of the red soils developed on granite - gneiss parent material in Krishna district of Andhra Pradesh varied form dark reddish brown (5YR 3/4) to dark brown (7.5 YR 3/4) on upper pediplain whereas very dark grayish brown to dark grayish brown on lower pediplains. Sarkar *et al.* (2002) stated that dark grayish colour in the lower layers of pedon indicates poor drainage condition. Colour of the surface horizon was very dark grayish brown, dark yellowish brown and dark brown. The dark colour of pedons was mainly due to the complexation of humus with mineral matter (Patil and Prasad, 2004).

Soils located on gently sloping topography showed yellowish brown (10 YR 5/6) to dark red (2.5 YR 3/6) colour whereas light yellowish brown (10YR 6/4) to very dark grayish brown (10 YR 3/2) on nearly level lands (Thangasamy *et al.*, 2005). The soils of back slope indicated soil colour (10 YR) with some yellowish shade and changed to redder ones (5 YR) in soils along the topographic lows (Heluf and Mishra, 2005). According to Shashi *et al.* (2005), the soils of western plains of Rajasthan were very deep and yellowish in hue and darker in chroma. Yellowish colour pattern was attributed to dominance of sand fraction and low organic matter content.

Mandal *et al.* (2006) reported that soils of micro-watershed in Nagpur, Maharashtra were grayish brown to dark brown in colour (10 YR). The colour of the surface horizons varied from dark brown (10YR 3/3) to yellowish brown (10YR 5/4) while the sub-surface horizons were brown (10YR 4/3) to dark yellowish brown (10YR 4/4). The dark matrix colour might be due to presence of high organic matter content (Tripathi *et al.*, 2006). Further, more particles of the soils were rich in iron oxides that impart redness to soils, soil colour appears to be the function of chemical and mineralogical composition as well as textural make up of soils and conditioned by topographic position and moisture regime (Sarkar *et al.*, 2002).

Najar *et al.* (2009) noticed that apple growing soils of Kashmir showed various shades of grey colour on southern aspect. This could be due to coagulation of iron and calcium with humus components rather than poor drainage conditions because of absence of iron and manganese concretions. The colour of the surface soils varied from grayish brown to yellowish red. The colour in surface layer of coffee-growing soils in Karnataka varied from reddish brown to very dark grayish brown. The dark colour of the surface layer may be due to high amount of organic matter found in the coffee growing soils (Devi and Kumar, 2010).

The orange growing soils of Nagpur had their Munsell colour notation with a hue ranged from 10YR to 2.5YR, with a value of 3 to 4 and a chroma of 2 to 4 (Likhar and Prasad, 2011). Soils situated on plateau top exhibited dark reddish brown (5YR 3/2) to very dark grayish brown (10YR 3/2) while soils occurring on escarpments showed dark yellowish brown (10YR 3/4) to grayish brown (10YR 5/2) and soils found on isolated hillocks showed dark brown (10YR 3/3) in Karanji watershed of Yavatmal district in Maharashtra (Nasre *et al.*, 2013). Soils developed from different land forms of north bank plain zone of Assam having dominant hue of

10YR , the value of the soil colour ranged from 3 to 7 and chroma ranged from 1 to 8 (Karmakar *et al*., 2014a).

2.4.4 Texture

Soil texture refers to the relative proportion of various soil separates namely sand, silt and clay in a soil. Texture is the basic property of soil and it cannot be altered or changed.

Jagannadham *et al.* (1995) reported that texture of red soils of Kandukur division in Prakasam district of Andhra Pradesh varied from sandy loam, sandy clay loam to clay loam. Clay content varied from 21.5 to 32.3 per cent in surface horizons and 4.3 to 17.1 per cent in B and C horizons. Higher percentage of clay in surface horizons indicates more advanced weathering in surface horizons than in sub-surface horizons. According to Sharma *et al.* (1997), soils of udic zone were comparatively coarser in texture (sandy loam to loam) whereas soils of ustic zone were finer in texture (loam to clay). Fluvial deposits during each year result in the development of strata with varying quantities of soil seperates (Manorama and Jose, 2000).

Prakash and Rao (2002) confirmed that, translocation of finer particles to lower horizons in coarse textured soils derived from resistant parent material could have resulted, relatively finer texture in lower horizons. Kumar *et al.* (2002) noticed that soils occurring on plains had loam to sandy loam texture and recorded higher clay content than upland soils because of deposition of finer fractions from the uplands. Clay content ranged from 24.50 to 84.20 per cent in Nagpur mandarin growing soils of Maharashtra and represents clayey texture (Marathe *et al.,* 2003).

The clay, silt and sand contents in cultivated soils varied from 6.20 to 37.50, 5.50 to 42.80 and 21.50 to 88.30 per cent, respectively. Generally sub-surface horizons exhibited higher clay content than surface horizons due to illuvial process during soil development (Sharma *et al.,* 2004b). Krishnan *et al.* (2004) reported that Entisols of Lakshadweep islands were light textured and predominantly sandy or loamy sand and occasionally sandy loam in texture. These sandy soils were derived by physical weathering of coral limestone.

Basavaraju *et al.* (2005) stated that clay content in soils varied from 1.00 to 42.51 per cent (plain), 12.5 to 28.52 per cent (upland) and 20.35 to 27.27 per cent (hill slope). High clay content in soils of plains as compared to upland and hill slope soils was due to deposition of finer fractions in plains. Balpande *et al.* (2007) observed that clay, silt and sand varied from 28.50 to 68.70, 18.70 to 28.60 and 20.00 to 48.40 per cent, respectively in different horizons of pedons. The soils of Ramachandrapuram mandal showed textural variation *i.e.* from sandy loam to clay loam (Plain), sandy loam to clay loam (upland) and sandy clay loam (hill slope) (Rao *et al.,* 2008).

The texture of coffee growing soils of Karnataka varied from sandy clay loam to clay (Devi and Kumar, 2010). Sharma *et al*. (2011) stated that clay content in soils of CSSRI experimental farm, Lucknow ranged from 15 to 18 per cent at the surface and increased to 19 to 35 per cent in the B horizon. The increase in clay content in B horizon is due to the presence of dispersed clay on ped surface. Mandal and Sharma (2013) stated that soil texture in salt affected soils of Loonkaransar area varied from loamy sand to sand. The soils in Banaganapalle mandal of Kurnool district showed wide textural variations *i.e.,* from sandy clay loam to clay. The wide textural variation in Banaganapalle mandal soils of Andhra Pradesh was due to variation in parent material, topography, *in-situ* weathering and translocation of clay by eluviations (Sireesha and Naidu, 2013a). Textural class varied from sandy loam to sandy clay cloam in upper pedons whereas in lower pedons the textural class is clay, higher sand content on top soils than lower layers might be due to sudden decrease in threshold velocity for sand particles (Pandey and Kumar, 2014) .

2.4.5 Structure

Sand, silt and clay particles were the building blocks from which soil is constructed. The manner in which these building blocks are arranged together is called soil structure. Soil structure is just as important as soil texture in governing, how water and air move in soils. Structure fundamentally influences the suitability of soils for the growth of plant roots.

The soils developed on the alluvial parent material had weak to moderate, fine to coarse and sub-angular blocky structure (Sharma *et al.*, 1997). Red soils distributed in upper pediplain had shown granular to sub-angular blocky structure while black soils distributed in lower pediplain showed angular blocky structure (Prakash and Rao, 2002).

The structure of the soils were single grain, crumb and sub-angular to angular blocky in plains, uplands and hill slopes respectively in Chandragiri mandal of Andhra Pradesh (Basavaraju *et al.*, 2005). Sub-surface horizons of Shikohpur watershed area of Haryana showed fine to medium, weak, sub angular blocky structure. Weak structural development might be due to low clay and organic carbon content and presence of lime concentration (Sitanggang *et al.*, 2006).

According to Tripathi *et al.* (2006), surface soils had weak to moderate structure whereas sub-surface had sub angular blocky to angular blocky structure.

Leelavathi *et al.* (2009) reported that blocky structure was attributed to the presence of higher quantities of clay fractions whereas single grain structure of the soils was due to inert nature of the parent material in soils of Yerpedu mandal of Chittoor district. In Apple growing soils of Kashmir, surface horizons developed granular structure at higher altitudes on both northern and southern aspects (Najar *et al.*, 2009).

Studies on some typical pedons of lower Vellar basin of Tamilnadu revealed that laterites occur below the soil cover which are brittle and shatter and crumble; the succeeding layers had vesicular or honey comb structure (Somasundaram *et al.*, 2010). Mandal *et al.* (2010) stated that structure of surface horizon in shrink-swell soils of Indian semi-arid tropics showed weak, medium and sub-angular blocky whereas sub-surface soils showed weak to moderate, medium and sub angular to angular blocky.

The surface and sub-surface horizons in pedons of sweet orange growing soils in Nagpur were associated with sub-angular blocky of varying grades and sizes but angular blocky structure associated with slickensides was a common features of sub-soils (Likhar and Prasad, 2011). Salt affected soils in Loonkaransar area showed single grained to weak, coarse and sub-angular blocky structure (Mandal and Sharma, 2013). The structure of soils in Banaganapalle mandal of Kurnool district was crumb, sub-angular blocky and angular blocky. The blocky structure is due to the presence of higher quantities of clay fraction. The crumb structure is due to continuous addition of organic matter through vegetation (Sireesha and Naidu, 2013a). The dominant soil structure was fine to medium, weak to moderate and crumb in surface and sub-angular blocky in sub-surface horizons in sugarcane growing soils of Chittoor district in Andhra Pradesh (Devi and Naidu, 2014).

2.4.6 Consistence

Soil consistency is an important physical and dynamic property which varies with the variation of soil moisture and applied stress, and is defined as the manifestation of physical forces of cohesion and adhesion acting within the soil at various moisture stresses.

According to Sidhu *et al.* (1998), the soils (Ustipsamments) developed on sandstones exhibited hard, friable and non-sticky and non-plastic consistence while the soils (Ustochrepts) in old flood plains of Yamuna river transect showed hard, friable and slightly sticky and slightly plastic consistence. Patil *et al.* (1999) observed that consistence was hard (dry), firm (moist) and slighty sticky and slightly plastic (wet) in case of Entisols (Ustorthents) and hard to very hard (dry), firm to very firm (moist) and very sticky and very plastic consistence (wet) in case of Vertisols (Haplusterts).

The soils in Chhotanagpur plateau had slightly hard to hard (dry), friable to firm (moist) and slightly sticky to very sticky and non-plastic to very plastic (wet) in consistence (Sarkar *et al.*, 2001). According to Sharma and Kumar (2003), the dry consistence in sandy loam to loamy soils varied from soft to hard whereas loamy sand to silty clay loam soils was loose to extremely hard in Maul Khad catchment of Himachal Pradesh. The dry consistence varied from loose to hard in surface horizon and loose to very hard in sub-surface horizon in the Entisols, Inceptisols and Alfisols of Neogal watershed in north-west Himalayas (Sharma *et al.*, 2004b).

Thangasamy *et al.* (2005) observed that consistence of soils in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh was loose to very hard (dry), loose to very firm (moist) and non-sticky and non-plastic to very sticky and very plastic (wet). Leelavathi *et al.* (2009) reported that consistence of the soils was soft to very hard (dry), loose to very firm (moist) and non-sticky to very sticky and non-plastic to very plastic (wet). Presence of loose friable and non-sticky and non-plastic or slightly sticky and slightly plastic consistence in soils of Yerpedu mandal of Chittoor district, Andhra Pradesh might be due negligible or very small amount of expanding clay minerals.

According to Sireesha and Naidu (2013a), the consistence of soils in Banaganapalle mandal of Kurnool district varied from slightly hard to very hard (dry), friable to very firm (moist) and non-sticky and non-plastic to very sticky and very plastic (wet). The consistence of the soils ranged from soft to very hard (dry), loose to firm (moist) and non-sticky and non-plastic to very sticky and very plastic (wet) in soils of central and eastern parts of Prakasam district in Andhra Pradesh (Sekhar *et al*., 2014).

2.5 DIAGNOSTIC HORIZONS

2.5.1 Ochric epipedon

A surface horizon of mineral soil that is too light in colour, too high in chroma, too low in organic carbon or too thin to be a plaggen, mollic, umbric, anthropic or histic epipedon. Most weakly expressed epipedon is ochric.

Saxena (1992) observed that soils of Bhadurgarh, Patiala and Jabalpur had ochric epipedon and these soils were classified as Ochrepts at sub-order level. Sharma *et al.* (1993) reported that soils of Pandgha series showed the presence of an ochric epipedon underlined by the sub-surface horizon showing the absence of rock structure for atleast half the volume. Sen *et al.* (1997) studied the soils (Inceptisols) developed on sedimentary and metamorphic rocks of north eastern region and reported the presence of ochric epipedon with a base saturation less than 60 per cent and included under Dystrochrept.

Sharma *et al.* (1997) stated that soils of north-west India had ochric epipedon, hence these soils were classified under Ochrepts at sub-order level. The Gondal soils of Kathiawar region of Gujarat had ochric epipedon developed over weathered basalt (Sharma *et al.,* 2001a). Due to the presence of ochric epipedon, some salt affected soils in southern Rajasthan were classified under Entisols (Sharma, *et al.,* 2004a). Sam loti soils exhibited ochric horizon at the surface and lacked any evidence of soil development. Therefore, these soils were classified as Entisols at order level (Kumar and

Verma, 2005). There was a little or no evidence of the development of pedogenic horizons other than an ochric eepipedon of low land with shallow water table in soils of coastal argo-eco-regions in north Karnataka (Mini *et al.,* 2007). The Apple growing soils of Kashmir were placed under the sub-order Ochrepts due to presence of ochric epipedon and at great group level under Eutrochrepts (Najar *et al.,* 2009).

Some of the pedons in sugarcane growing soils of Maharastra had ochric epipedon and cambic diagnostic sub-surface horizon and were classified under Inceptisols (Ashokkumar and Prasad, 2010). Niranjana *et al*. (2011) reported that banana growing soils of Pulivendula region in Andhra Pradesh possess ochric epipedon followed by cambic sub-surface diagnostic horizon. Nasre *et al.* (2013) stated that soils belonging to Dharna and Kongara series showed the presence of ochric epipedon with clay >30%, cracks and intersecting slickensides (> 25 cm thickness within 100 cm of solum).

2.5.2 Cambic horizon

A non-sandy, mineral soil horizon that has soil structure rather than rock structure, contains some weatherable minerals and is characterized by the alteration or removal of mineral material as indicated by mottling or grey colours, stronger chromas or redder hues than in underlying horizons, or removal of carbonates. Cambic horizon lack cementation or induration and have too few evidences of illuviation to meet the requirements of argillic or spodic horizons.

Walia and Rao (1996) reported the presence of altered cambic (Bw) horizon in sub-surface of red soils in Bundelkhand region where there was no clay illuviation and clay skin formation. Sharma *et al.* (1997) noticed the development of an altered structural B (cambic) horizon in Inceptisols of north-west India. Khan *et al.* (1998) studied the morphological features and other relevant properties of flood plain soils of Bangladesh, which showed little profile development with a structural B horizon (cambic).

Shivaramu *et al.* (1998) observed the cambic horizon at 0.30 to 1.60 m, 0.11 to 1.59 m and 0.07 to 0.86 m depths in Ustropepts of Hessarghatta farm near Bangalore. According to Pannu *et al.* (1999), the soils of Uchani series in Haryana had an ochric epipedon underlined by an altered B-horizon (cambic) which qualified them for the order Inceptisol. Sharma *et al.* (2001a) stated that Gondal soils of Kathiawar region of Gujarat had ochric epipedon and cambic sub-surface horizon (21 cm thick) developed over basalt. Soils of coastal argo-eco-regions in north Karnataka, pedons on hills, hill ranges and low lands with deep water table and garden lands were classified into Inceptisols owing to the presence of cambic horizon and absence of other diagnostic horizons (Mini *et al.*, 2007). Absence of clay skins and consequent illuvial clay indicated the presence of cambic diagnostic horizon in coffee growing soils of Karnataka (Devi and Kumar, 2010). The soil forming processes like transformation of minerals and organic substances lead to changes in colour and structure in the sub-soil leading to the development of cambic horizon (Bw) in the soils of central and eastern parts of Prakasam district in Andhra Pradesh (Sekhar *et al.*, 2014).

2.6 PHYSICAL PROPERTIES

2.6.1 Particle size distribution

The Granulometric data revealed that clay content of soils in Trans-Yamuna plains varied from 15.40 to 39.40 per cent and such variation could be due to change in depositional pattern as indicated by abrupt change in sand / silt ratio (Walia and Rao, 1997). Clay percentage in rice growing soils ranged from 26.10 to 31.30 per cent and sand content from 45.26 to 48.78 per cent whereas clay percentage in non-rice growing soils varied from 22.42 to 27.12 per cent and sand contributed to 48 to 58 per cent (Pannu *et al.*, 1999).

Particle size distribution of rice growing soils of Chandauli district of Uttar Pradesh indicated that sand was the dominant fraction in all the pedons (Singh and Agarwal, 2003).

The clay content ranged from 44.5 to 50.7 per cent and increased with depth in sal growing soils of Dindori district in Madhya Pradesh. Further, these soils were developed over basalt or partly laterised basalt and hence produced higher amount of clay (Patil and Prasad, 2004). Sub-surface horizons of Neogal watershed in north-west Himalayas exhibited higher clay content as compared to surface horizons due to the illuviation process occurred during soil development. Similarly, the illuviation process also affected the vertical distribution of silt and sand contents (Sharma *et al.,* 2004a).

Maji *et al.* (2005) assessed that soils of sub-humid tropics in central India, the particle size distribution in majority of the soils have fairly high amount of clay as compared to sand and silt fractions. The detailed particle size distribution data revealed that the clay, silt and sand content in soils varied from 13.20 to 33.60, 10.80 to 34.00 and 38.40 to 73.10 per cent, respectively. In general, sub-surface horizon exhibited higher clay content as compared to surface and may be due to illuviation process occurring during soil development (Tripathi *et al.,* 2006).

The clay content of Ramachandrapuram mandal soils varied from 4.3 to 35.6 per cent (plains), 15.0 to 32.1 per cent (uplands) and 20.0 to 24.2 per cent (hill slope). The high clay content in soils was due to deposition of finer fractions in the plains from uplands and hill slopes (Rao *et al.,* 2008). The particle size distribution and sand / silt ratio of orange growing soils of Nagpur showed inflection in sand, silt and clay content in depth-wise distribution and vary significantly in soils having different parent materials. The clay content ranged from 24.10 to 68.20 per cent in different pedons The higher clay in Bt horizon of P_4 and P_5 pedons was probably due to translocation of clay from surface horizon (Likhar and Prasad, 2011).

Selvaraj and Naidu (2012) stated that clay content in Renigunta mandal soils varied from 22.7 to 26.2 per cent in uplands and 13.1 to 37.8 per cent in plains. The high clay content in plains is due to deposition of fine fractions in plains than in uplands. The clay content of the sugarcane growing soils of Chittoor district in Andhra Pradesh is ranged from 1.99 to 35.86 per cent (Devi and Naidu, 2014).

2.6.2 Water holding capacity

Rao (1993) noticed that water holding capacity of sandy soils in Chakicharla village of Prakasam district, Andhra Pradesh ranged from 16.45 to 21.42 per cent and it was gradually decreased with depth. Water holding capacity in coastal soils of Sundarbans, West Bengal ranged from 21.40 to 37.60 per cent (Maji and Bandyopadhyay, 1995). According to Gupta and Chara (1996), the water holding capacity was usually higher in soils on the northern aspect than in the soils on southern aspect.

Singh and Nayak (1999) studied the water retention characteristics of Mahi right bank canal command area of Gujarat and concluded that water retention capacity was in the order of Vertic Haplaquepts > Typic Haplaquepts > Fluventic Ustochrepts > Typic Ustrothents. The available water storage capacity was low (5.30 to 5.90 cm) in poorly maintained terraces as compared to well-maintained terraces (11.00 to 26.30 cm) in some cultivated soils of Ramganga catchment in Uttar Pradesh (Singh *et al.*, 1999).

The water holding capacity in soils of Haldi Ghati region of Rajasthan was low to medium (17.10 to 37.30 %) (Sharma *et al.*, 2001b). The moisture retention in Inceptisols and Entisols of Shahibi basin in Haryana and Delhi at 33 kPa was 8.20 to 19.00 per cent and at 1500 kPa was 3.20 to 8.89 per cent in surface horizons. The low moisture retention was due to lighter texture, low organic matter content and dominance of illite in the clay fraction (Swarnam *et al.*, 2004).

Available water content in sal growing soils in Dindori district of Madhya Pradesh was found to be positively and significantly correlated with clay and organic matter content (Patil and Prasad, 2004). The water holding capacity in soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh was ranged from 13.05 to 58.99 per cent. These differences were due to the variation in the depth, clay, silt and organic carbon content in the soils (Thangasamy *et al.*, 2005).

According to Leelavathi *et al.* (2009), water holding capacity in soils of Yerpedu mandal soils in Andhra Pradesh varied from 19.36 to 55.40%. The irregular trend with depth was due to illuviation and eluviation of finer fractions in different horizons. Water holding capacity in Banaganapalle mandal soils varied from 27 to 70 percent, these variations were due to the difference in depth, clay, silt and organic carbon content. The irregular trend of water holding capacity with depth is due to illuviation and elluviation of fine fractions in different horizons (Sireesha and Naidu, 2013a). The available water capacity of soils in Karanji watershed of Maharashtra ranged from 1.1 cm m^{-1} to 33.1 cm m^{-1} and it increased with increase in amount of clay and depth of soil (Nasre *et al.*, 2013).

2.6.3 Bulk density and particle density

Bulk density values of the sandy soils of Chakicharla village (Prakasam district) of Andhra Pradesh ranged from 1.46 to 1.61 Mg m^{-3} (Rao, 1993). The bulk density values of laterite and associated soils varied from 1.20 to 1.70 Mg m^{-3} (Bhaskar and Subbaiah, 1995).

Gurumurthy *et al.* (1996) stated that particle density in red, black and associated soils of Giddalur mandal in Andhra Pradesh was more or less uniform and the bulk density was higher in the sub-surface horizons due to compaction of soil particles. Walia and Rao (1997) noticed that bulk density in soils of Trans-Yamuna plains ranged from 1.46 to 1.96 Mg m^{-3} and increase of bulk density with depth might be due to enhanced compaction with depth and low organic matter. Bulk density values of Inceptisols varied from 1.3 to 1.9 Mg m^{-3} and in Vertisols varied between 1.5 and 1.7 Mg m^{-3} in some salt affected soils occurring in the Chitravathi river basin of Andhra Pradesh (Bhaskar and Nagaraju, 1998).

Jawahar *et al.* (1999) studied the coastal sand dune soils and reported that the bulk density was varying from 1.30 to 1.95 Mg m^{-3}. Rani *et al.* (1991) noticed that bulk density of Alfisols in Kavali canal area of Andhra Pradesh was increased with depth (1.40 to 1.79 Mg m^{-3}). Prakash and Rao (2002) stated that bulk density values of red soils were higher (1.45-1.63 Mg m^{-3}) than black soils (1.30-1.57 Mg m^{-3}). Marathe *et al.* (2003) reported that bulk density values ranged from 1.46 to 1.74 Mg m^{-3} and were increased with increasing depth in mandarin orchards of Nagpur.

The bulk density in the soils of Maul Khad catchment in Himachal Pradesh varied from 1.38 to 1.62 Mg m^{-3} in surface and 1.35 to 1.72 Mg m^{-3} in sub-surface horizons. The bulk density tended to increase with depth. The variation in bulk density was attributed to variation in organic matter, texture *etc.* (Sharma and Kumar, 2003). The bulk density in the Entisols and Inceptisols of Shahibi basin in Haryana and Delhi varied from 1.48 to 1.87 Mg m^{-3} and 1.50 to 1.69 Mg m^{-3}, respectively. The higher bulk density values could be due to their coarse texture and low organic matter content (Swarnam *et al.*, 2004).

The increase in bulk density with depth was attributed to lower organic matter, more compaction and less aggregation in rice soils of eastern region of Varanasi (Singh and Agarwal, 2005). Maji *et al.* (2005) assessed that soils of sub humid tropics in central India, the bulk density of the soils varied from 1.33 to 1.79 Mg m^{-3}, variation in bulk density of these soils was attributed to the moisture content and high content of expanding type of clay minerals.

The bulk density of the soils in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh varied from 1.32 Mg m^{-3} in Typic Rhodustalfs to 1.90 Mg m^{-3} in Aquic Ustorthents and the values increased with depth. The increase in bulk density with depth was due to compaction of finer particles in deeper layers caused by overhead weight of the surface soils. Further, the low bulk density values in surface soils were due to high organic matter content (Thangasamy *et al.,* 2005). The higher bulk density in soils of Shikohpur watershed of Gurgaon district, Haryana was due to their coarse texture and in some cases the presence of calcium carbonate and low organic carbon content (Sitanggang *et al.,* 2006).

The soil having higher percentage of sand (or) gravel had more bulk density than those having high clay content. Correlation studies have revealed positive correlation with sand, negative with clay and bulk density of soils ranged from 1.23 to 1.73 Mg m^{-3} (Balpande *et al.,* 2007). Ram *et al*., (2010) stated that the bulk density and particle density in flood prone soils of eastern plains in Rajasthan varied from 1.32 to 1.61 and 2.36 to 2.64 Mg m^{-3}. Selvaraj and Naidu (2012) reported that the bulk density of soils in Renigunta mandal varied from1.13 to 1.96 Mg m^{-3} and the increase in bulk density with depth is due to the coarse texture and low organic matter content of soils. Bulk density of west coast of southern Karnataka soils ranged from 1.04 to 1.52 Mg m^{-3} (Patil and Kumar, 2014).

2.7 PHYSICO-CHEMICAL PROPERTIES

2.7.1 Soil reaction

The pH of the soils (Inceptisols) on basaltic terrain in north Deccan plateau of Madhya Pradesh ranged from 5.8 to 7.7 (Tamgadge *et al.,* 1999). Soil pH measured in KCl was low in all the pedons as compared to that measured in water indicated that soils contain appreciable quantities of silicate clay minerals with relatively constant surface charges (Manorama and Jose, 2000). Marathe *et al.* (2003) reported that Typic Haplustepts, Vertic Haplustepts and Typic Ustorthents of Nagpur district had the pH values ranging from 7.70 to 8.05, 7.78 to 7.85 and 8.06 to 8.08, respectively. The salt affected soils of southern Rajasthan were alkaline in pH ranging from 7.66 to 8.98. The pH value showed an increasing trend with an increase in the salinity except in strongly saline soils which could be due to dominance of neutral salts (Sharma *et al.*, 2004a).

The pH of the soils ranged from 6.6 to 7.9 in plateau summits, 8.2 to 9.2 in piedmonts and narrow valleys of Degma and Mohgan villages of Nagpur district Maharashtra (Reddy *et al.*, 2004). The pH varied from slightly acidic (5.83) to moderately alkaline (8.47) in the soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh. The variation in soil pH was related to parent material, rainfall and topography. Further, the KCl-pH values were lower than the water pH values, indicating the existence of net negative charge on colloidal particles (Thangasamy *et al*., 2005).

Sanjeev *et al.* (2005) reported that increase in pH with depth was due to decrease in organic carbon. Lower pH was due to the soils recently brought under cultivation by clear felling the forests once exist there. The pH varied from slightly acidic to alkaline with a range of 6.11 to 8.57 in the soils of Shikohpur watershed of Gurgaon district, Haryana. The increase in soil reaction (both H_2O and KCl) down the slope could be due to leaching of bases from higher topography and getting deposited in lower elevations and also high concentration of $CaCO_3$ in the lower areas. Further, the KCl-pH values were lower than the water pH values and the difference between KCl-pH and H_2O-pH values with large negative value (more than -0.5) indicated a high negative surface charge density in these soils (Sitanggang *et al.*, 2006).

Soil pH varied from 7.1 to 8.6 with an average of 7.8 and the relatively high pH of the soils might be due to the presence of high degree of base saturation in soils of Tonk district of Rajasthan (Meena *et al.*, 2006).

The soils of Ramachandrapuram mandal were slightly acidic to moderately alkaline in soil reaction (Rao *et al.*, 2008). The variations in pH with depth may be due to weathering and leaching of bases from sloping landforms (Devi and Kumar, 2010). The pH of soils in eastern plains of Rajasthan were more than 8.5 and this alkalinity may be due to high temperature during most of the years resulting in accumulation of soluble salts leading to high pH (Ram *et al.*, 2010).

According to Mustaq (2011) soils in low altitude were slightly alkaline in pH range whereas soils in high altitudes were slightly acidic in pH. The pH of Renigunta soils varied from 6.2 to 7.9 (uplands) and 6.2 to 9.0 (plains). The higher pH in soils of plains may be due to more accumulation of bases from uplands. The KCl - pH values of the soils were lower than the water pH values, indicating the existence of net negative charge on colloidal particles (Selvaraj and Naidu, 2012). Nasre *et al.* (2013) reported that soils in Karanji watershed area of Maharashtra are neutral to slightly alkaline in reaction with pH varied from 6.7 to 8.3 (surface) and 8.0 to 9.1 (sub surface). Higher pH in sub-soils of very gently sloping alluvial plain is due to presence of soil sodicity. Sarkar *et al*. (2014) noticed that soils in Chotanagpur plateau of West Bengal are slightly acidic to neutral (5.6-6.7) in reaction.

2.7.2 Electrical conductivity

The EC of Vertisols and Inceptisols developed from different parent materials were normal with very low (< 1 dSm^{-1}) salt content (Chinchmalatpure *et al.*, 1998). Singh and Nayak (1999) stated that EC values of Typic Ustorthents ranged from 0.10 to 0.48 dSm^{-1}. Singh *et al.* (1999) noticed that electrical conductivity was low (0.01 to 0.27 dSm^{-1}) in soils of Ramganga catchment in Uttar Pradesh. Gupta and Tembhare (1999) reported that the EC values ranged from 0.12 to 0.24 $dS\ m^{-1}$ in some typical alluvial soils of Madhya Pradesh.

Rudramurthy and Dasog (2001) observed that electrical conductivity was less in red soils (0.10 to 0.31 dSm^{-1}) as compared to their black counterparts (0.24 to 1.10 dSm^{-1}). According to Pillai and Natarajan (2004), the electrical conductivity of the soils of Garakahalli watershed ranged from 0.02 to 0.20 dSm^{-1} indicating non-saline nature of the soil. However, these soils did not show any relation with depth. This may be due to the undulating nature of the terrain coupled with free drainage conditions, which favoured the removal of released bases by the percolating and drainage water. The Inceptisols and Entisols of Shahibi basin in Haryana and Delhi were non-saline with electrolyte concentration ranging from 0.18 to 0.95 dSm^{-1} (Swarnam *et al.*, 2004).

Maji *et al.* (2005) stated that electrical conductivity in soils of sub-humid tropics in central India, showed very low soluble salt concentration with EC values ranging from 0.07 to 0.20 dSm^{-1} and has no salinity hazards. The soils in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh showed very low electrical conductivity values ranging from 0.02 to 0.36 dSm^{-1}, suggesting presence of very low amount of soluble salts (Thangasamy *et al.*, 2005). The forest soils of north Karnataka were non-saline with EC values ranging from 0.01 to 0.07 dSm^{-1} (Shamsudheen *et al.*, 2005).

The electrical conductivity of grape growing soils in Nasik district of Maharashtra ranged from 0.08 to 1.22 dSm^{-1} and increased down the slope owing to the leaching of salts (Balpande *et al*., 2007). The soils of Yerpedu mandal in Chittoor district of Andhra Pradesh showed low to medium electrical conductivity with values ranging from 0.03 to 1.25 dSm^{-1}, this low EC may be due to free drainage conditions which favoured the removal of released bases by percolating and drainage water (Leelavathi *et al.*, 2009). The EC of saturation extract in sugarcane growing soils of Ahmadnagar district in Maharashtra indicated that Vadala, Mahadev, Umbare and Sonai series was less than 1.0 dSm^{-1} but it ranged from 1.02 to 1.24 dSm^{-1} in

Nandgaon indicating that these soils were not saline (Ashokkumar and Prasad, 2010).

Waterlogged and salt-affected soils in Gandak command area of Bihar had shown higher ECe value of 19.7 dSm^{-1} at the surface and decreased gradually to 0.4 dSm^{-1} at a depth of 1m (Sharma *et al.,* 2010). According to Sireesha and Naidu (2013), all the pedons in Banaganapalle mandal had shown low to medium EC values ranging from 0.12 to 0.93 dSm^{-1}, indicating non-saline nature. The low EC may be due to good drainage conditions which favored the removal of released bases by percolating and drainage water. Karmakar (2014a) reported low EC values (0.04 to 0.32 dSm^{-1}) in soils of north bank plain zone of Assam.

2.7.3 Calcium carbonate

According to Singh and Mishra (1996), the $CaCO_3$ content in soils of Gandak command area of Bihar ranged between 10.40 and 15.20 per cent. The calcium carbonate content in Inceptisols of north-west India varied from 0 to 126 g kg^{-1} (Sharma *et al.,* 1997). The soils of semi-arid region had the lowest available Fe than the soils of sub-humid region which might be due to higher $CaCO_3$ content (Prasad and Gajbhiye, 1999).

Verma *et al.* (2001) stated that $CaCO_3$ content in Etawah district of Uttar Pradesh varied between 5.60 and 252.00 g kg^{-1}. The $CaCO_3$ content was as low as 20 mg kg^{-1} in the Vertisols of Wardha district in Maharastra and as high as 198 mg kg^{-1} in the Inceptisols and $CaCO_3$ content increased with depth in both Inceptisols and Vertisols (Kadao *et al.,* 2003). Presence of higher free calcium carbonate in nodular form (5.0 to 43.7 %) within 150 cm soil depth has been reported to be favourable for regular flowering behaviour of mandarin orchards (Marathe *et al.,* 2003).

The upland soils of Garakahalli watershed have no free $CaCO_3$ while lowland soils have free $CaCO_3$ (Pillai and Natarajan, 2004). The $CaCO_3$

content in Inceptisols and Entisols of Rajasthan varied from 30.10 to 249.10 g kg^{-1}. The calcium carbonate content of these soils increased with depth due to downward movement of calcium and its subsequent precipitation as carbonate and / or decomposition of calcium carbonate (Sharma *et al.*, 2004b). Irregular distribution of $CaCO_3$ with depth may be attributed to differential dissolution of CO_2 rich water which is moderated by physiography, rising and receeding water table and drainage conditions in soils of eastern region of Varanasi (Singh and Agrawal, 2005).

The calcium carbonate content in soils of Sivagiri micro-watershed soils of Chittoor district in Andhra Pradesh was ranged from 4.1 to 108.1 g kg^{-1} (Thangasamy *et al*., 2005). Due to precipitation of soluble Ca^{+2} ions as $CaCO_3$, concentration of Mg^{+2} and Na^{+} ions increased and this caused the dispersion of clays and their sub-sequent movement as Mg and Na-clays downward. Thus $CaCO_3$ showed an increase with depth in soils of central India (Pal *et al.,* 2006).

The free $CaCO_3$ was observed in all the soils of Shikohpur watershed area in Haryana was due to ustic soil moisture regime of the area, which was quite congenial for carbonate formation, besides deposition of $CaCO_3$ bearing alluvium (Sitanggang *et al.,* 2006). The high $CaCO_3$ in Sugarcane growing soils in Ahmadnagar district of Maharastra was may be due to semi-arid climate which was responsible for the pedogenic processes resulting in the depletion of Ca^{+2} ions from the soil solution in the form of calcretes (Ashokkumar and Prasad, 2010). Kharche and Pharande (2010) reported that $CaCO_3$ content varied from 88 to 205 g kg^{-1} in soils of Mula command of irrigated agro eco-system in Maharashtra.

Sharma *et al.* (1996) reported that waterlogged and salt-affected soils in Gandak command area of Bihar had shown both amorphous (1.4 to 2.1 %) and concretion (2-6%) forms of $CaCO_3$. According to Sireesha and Naidu (2013a), $CaCO_3$ content in soils of Banaganapalle mandal ranged from 2.5 to 37.5 percent and the highest $CaCO_3$ content was noticed in Palukuru and Kapulapalle series of soils which is due to semi-arid climate. Nasre *et al.* (2013) noticed that the $CaCO_3$ content was high in soils of foot slopes, undulating lands, alluvial plains and valleys in Karanji watershed area of Maharashtra and it occurred in powdery form in surface soils and a mixture of nodules and powder form in sub-surface soils. According to Devi and Naidu (2014), $CaCO_3$ content varied from 0.5 to 5.5 per cent in sugarcane growing soils of Chittoor district in Andhra Pradesh.

2.7.4 Organic carbon

Prasad *et al.* (1998) stated that the organic carbon content in black and alluvial soils of Andhra Pradesh varied between 0.20 and 8.6 g $kg^{-1.}$ Organic carbon content of Erode district soils was generally low (< 0.55) and in general, decreased with depth which might be due to retention of plant residue on the surface horizons (Saha *et al.*, 2000). Low organic matter content in soils is due to prevalence of tropical conditions, where the degradation of organic matter occurs at a faster rate coupled with low vegetation cover, there by leaving less organic carbon in the soils (Nayak *et al.*, 2002).

According to Singh and Agrawal (2003), the organic carbon content was low (1.0 to 5.6 g kg^{-1}) in Entisols and Inceptisols of Chandauli district, Uttar Pradesh due to the existing rice-wheat cropping system and prevailing semi-arid environment. Organic carbon content ranged from 0.08 to 1.08 per cent in different horizon. Soils of subdued plateau had higher organic carbon content because these soils were under fallow grass-lands (Reddy *et al.*, 2004). The organic carbon in soils of uplands showed a regular decrease with depth while the soils in inter-hill valleys exhibited an irregular trend with depth (Bhaskar *et al.*, 2004a).

The organic carbon was high in the grassland soils on summits and convex plateau tops when compared to the soils on side-slopes and narrow valleys of Meghalaya (Bhaskar *et al.,* 2004b). Organic carbon content of soils varied from 0.6 to 6.3 g kg^{-1} (plains), 0.8 to 4.1 g kg^{-1} (uplands) and 3.7 to 6.6 g kg^{-1} (hill slope). This could be attributed to the addition of plant residues and farmyard manure to surface horizons (Basavaraju *et al.,* 2005). Dark colour of soils under Kair-Nagali micro watershed area was due to high organic matter of these soils (Tripathi *et al.,* 2006). Rao *et al.* (2008) stated that higher organic carbon content was due to leaf litter addition through leaf fall and less intensive cultivation whereas decrease in organic carbon content was due to prevalence of tropical conditions.

Organic carbon content in the flood prone soils of eastern plains of Rajasthan district ranged from 0.08 to 0.32 per cent (Ram *et al.,* 2010). Somasundaram *et al.* (2010) observed that organic carbon content varied from 0.3 to 7.6 g kg^{-1} in lower basin of Pudukkottai district in Tamil Nadu. Organic carbon content in coffee growing soils of Karnataka varied from 1.47 to 5.29 percent (surface soils) whereas in sub-surface soils it decreased with depth. The high organic carbon content may be due to the slow decomposition of organic matter at higher altitude where temperature was low and rainfall was high (Devi and Kumar, 2010).

Nasre et *al.* (2013) reported that the lowest organic carbon content was observed in surface soils occurring on foot slopes and alluvial plains (4.2 g kg^{-1}) and the highest organic carbon content was found on escarpments (28.7 g kg^{-1}). The decreasing trend of organic carbon content with increasing depth is due to addition of plant residues and farmyard manure on surface soils. Organic carbon content was found to be low to medium and varied from 0.12 to 0.68 per cent in soils of central and eastern parts of Prakasam district in Andhra Pradesh (Sekhar *et al.*, 2014).

2.8 ELECTRO-CHEMICAL PROPERTIES

2.8.1 Cation exchange capacity

Mishra and Ghosh (1995) reported that CEC values of soils derived from mica-rich parent material varied between 6.00 and 15.90 cmol(p+)kg^{-1}soil, apparently due to variation in clay and organic matter contents. Cation exchange capacity of Inceptisols in north-west India varied from 2.80 to 32.80 cmol(p+)kg^{-1}soil (Sharma *et al.*, 1997). According to Walia and Rao (1997), the CEC of soils varied from 10.90 to 28.40 cmol(p+)kg^{-1}soil and the surface soil had low CEC in comparison with underlying horizons obviously due to increase in clay content.

Gangopadhyay *et al.* (1998) observed that CEC of rice growing soils on upper Brahmaputra valley of Assam, was low to medium in range (2.20 to 22.80 cmol(p+)kg^{-1}soil) and it was positively correlated with clay and organic carbon content of the soils. Gupta *et al.* (1999) observed that cation exchange capacity in soils of granitic terrain in Jabalpur district of Madhya Pradesh varied from 14.70 to 55.40 cmol(p+)kg^{-1}soil which was mostly related to the clay content of soils.

The cation exchange capacity was due to nature and amount of clay minerals. The higher values and small variation in CEC with depth were indicative of the process of haploidization as observed by Singh *et al.* (2000). Kumar *et al.* (2001) found that CEC of soils in residual hills, denudational hills and pediments was low (11.70 to 16.37 cmol (p+) kg^{-1} soil) whereas the soils of shallow and moderately buried pediments and valley fills had moderately high CEC [15.10 to 28.20 cmol (p+) kg^{-1} soil]. The CEC of Entisols in Etawah district of Uttar Pradesh was low varying from 3.20 to 10.50 cmol(p+) kg^{-1} soil which might be due to the presence of low CEC bearing minerals while the CEC of Inceptisols was medium [10.00

to 19.00 cmol (p+) kg^{-1} soil] because of comparatively higher clay content (Verma *et al.,* 2001).

CEC of the soils ranged from 7.7 to 26.2 cmol (p+) kg^{-1} and decreased with depth. Relatively low CEC may be due to dominance of clay minerals with low CEC and presence of hydrous oxides of iron and aluminium (Sarkar *et al.,* 2002). Swarnam *et al.* (2004) stated that CEC of the soils of Shahibi basin in Haryana and Delhi varied from 3.20 to 10.20 cmol(p+)kg^{-1} soil and decreased with depth. Low CEC of these soils could be attributed to low content of clay and organic carbon.

The CEC of the Garkahalli watershed soils was found to be low to medium. Maximum CEC was observed in the horizons where illuviation of clay from surface to sub-surface horizon had taken place (Pillai and Natarajan, 2004). The CEC of the soils in Dindori district of Madhya Pradesh with smectitic mineralogy was higher 72.0 cmol(p+)kg^{-1} as compared to the soils with mixed mineralogy 28.9 cmol(p+)kg^{-1} (Patil and Prasad, 2004). The CEC of the soils in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh ranged from 1.50 to 45.14 cmol (p+) kg^{-1} soil which corresponds to their clay content in the respective horizons (Thangasamy *et al.,* 2005).

The CEC varied from 23.00 to 59.00 cmol(p^{+})kg^{-1}soil with a tendency to decrease with depth but it was found closely associated with clay ($r = +0.720$) and clay plus organic carbon ($r = +0.730$) in grape growing soils of Nasik district in Maharashtra (Balpande *et al.,* 2007). The CEC values ranged from 16.60 to 38.10 cmol(p^{+})kg^{-1}soil and decreased with depth in coffee growing soils of Karnataka (Devi and Kumar, 2010).

Sharma *et al.* (2011) reported that CEC in sodic and associated soils at CSSRI experimental farm, Lucknow varied from 7 to 14 cmol(p^{+})kg^{-1} soil which is closely related to the clay content. Mandal and Sharma (2013) stated that CEC values in waterlogged and salt affected soils of Loonkaransar area in Haryana varied from 3.33 to 8.90 cmol(p^+)kg^{-1}soil. The low CEC values were due to coarse texture and presence of non-expanding minerals or mixed mineralogy. The CEC of soils in Banaganapalle mandal of Kurnool district in Andhra Pradesh varied from 21.8 to 51.2 cmol(p^+)kg^{-1}soil (Sireesha and Naidu, 2013a). According to Devi and Naidu (2014) CEC of sugarcane soils of Chittoor district in Andhra Pradesh varied from 3.04 to 31.71 cmol(p^+)kg^{-1}soil.

2.8.2 Base saturation

Sridhar and Ananthanarayana (1996) studied the base saturation in two different soil orders under rice fallow profiles in Karnataka and concluded that Inceptisols had 17.00 to 67.00 per cent and Entisols had 24.00 to 71.00 per cent base saturation. Base saturation in Epiaquepts of Banda plain region was varying from 75.00 to 89.00 per cent (Walia and Rao, 1997). Sarkar *et al.* (2001) studied the soils of lower outlier of Chotanagpur plateau and noticed that Ca^{2+} was the dominant cation followed by Mg^{2+}, Na^+ and K^+ and base saturation of these soils ranged from 49.00 to 77.00 per cent.

Sharma *et al.* (2001a) stated that soils of Kathiawar region of Gujarat had high base saturation with dominance of Ca^{2+} followed by Mg^{2+} on the exchange complex. The exchangeable calcium ranged from 0.1 to 8.8 cmol(p^+)kg^{-1} soil while exchangeable magnesium varied between 0.5 and 6.5 cmol(p^+)kg^{-1} soil in Entisols (Typic Ustipsamments) and Inceptisols (Typic Haplustepts) of Nellore district in Andhra Pradesh (Venkatesu *et al.*, 2002). Low base saturation in sub-soils was due to dominance of exchangeable Al^{3+} on exchange complex while comparatively high base saturation in the surface horizons may be due to continuous addition of bases from the leaf litter (Sarkar *et al.*, 2002).

The per cent base saturation of the soils in upper Maul Khad catchment of Himachal Pradesh ranged from 45 to 62 indicating moderate soil fertility status. Among different cations, Ca^{2+} dominated the exchange complex followed by Mg^{2+}, K^+ and Na^+ (Sharma and Kumar, 2003). According to Pillai and Natarajan (2004), the base saturation of soils was medium to high due to the low to medium amount of rainfall in Garakahalli watershed of Bangalore rural district. The Entisols and Inceptisols of Shahibi basin were highly base saturated ranging from 75.90 to 89.30 and from 80.80 to 94.30 per cent, respectively. Further, the exchange complex was dominated by Ca^{2+} followed by Mg^{2+}, Na^+ and K^+ (Swarnam *et al.*, 2004).

Patil and Prasad (2004) stated that exchange complex of Inceptisols and Mollisols in Dindori district of Madhya Pradesh were dominated by Ca^{2+} followed by Mg^{2+}, K^+ and Na^+. Further, high and low exchangeable Ca and Mg in Typic Haplustolls and Typic Haplustepts, respectively was attributed to their parent materials and the higher exchangeable Ca in the surface soil may be due to redistribution of Ca by tree species. Variation in base saturation values (58.47 to 90.67%) of the outer Himalayan soils might be due to the varied nature and/or content of soil colloids and soil pH values (Sanjeev *et al.,* 2005).

The base saturation in the soils varied from 31.53 to 92.77 per cent and exchangeable bases were in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ in soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh (Thangasamy *et al.*, 2005). Soils in watershed area of Sikohpur, Gurgaon district, Haryana were highly base saturated (70.09 to 93.52%) indicating low degree of leaching and also showed tendency to increase with depth and followed the distribution pattern of pH (Sitanggang *et al.,* 2006).

The base saturation under Kair-Nagali watershed area in north-west Himalayas varied from 58.5 to 66.3 and 56.6 to 74.3 per cent in surface and sub-surface soils, respectively. Higher base saturation percentage might be due to higher amount of Ca^{+2} ions occupying the exchange sites on the colloidal complex (Tripathi *et al.,* 2006). Ca^{2+} was the dominant cation on the exchange complex followed by Mg^{2+}, Na^{+} and K^{+} in grape growing soils of Nasik district in Maharashtra (Balpande *et al.,* 2007).

Base saturation ranged from 24 to 98 per cent in coffee growing soils of Karnataka in surface layers. These higher values ascribed to recycling of basic cations through vegetation (Devi and Kumar, 2010). High base saturation in orange growing soils of Nagpur district in Maharashtra suggests the presence of base rich zeolites of amygodoloidal basalt (Likhar and Prasad, 2011). Base saturation varied from 70 to 96 per cent in soils of Renigunta mandal in Chittoor district. Exchangeable bases in all the pedons irrespective of landforms were in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ (Selvaraj and Naidu, 2012). Base saturation varied from 1.9 to 100 per cent in low land soils of Chikkarsinkere, Hobli, Mddur taluk of Mandya district of Karnataka and exchangeable bases had distinct pattern regarding their sequential dominance. In all the pedons the order followed was $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ (Meena *et al.*, 2014).

2.8.3 Silica and sesquioxide

The sedentary soils developed on granite-gneiss were highly siliceous and high SiO_2 content indicated the influence of acidic parent rocks (Singh *et al.,* 1993). Mishra and Ghosh (1995) studied the soils derived from mica-rich parent material and reported that silica content (59 to 69 %) increased with depth and sesquioxide content (3.45 to 30.75 %) decreased with depth. SiO_2 content was much higher than Al_2O_3 and thus indicating that process of silication was operating in these soils.

The SiO_2 content in soils of Bundelkhand region of Uttar Pradesh ranged from 59.00 to 76.00 per cent and such variations were due to the nature of parent material. But, the soils developed from shale were less siliceous (Walia and Rao, 1996). Silica was the most dominant element (upto 83 %) in bench mark soils (Entisols) of flood plains in Bangladesh (Khan *et al.,* 1997). According to Walia and Rao (1997) the soils of Trans-Yamuna plains were siliceous in nature and SiO_2 content varied from 59.70 to 76.80 per cent.

According to Ramalakshmi *et al.* (2001), Psamments had more silica and less sesquioxide content than Haplustepts and Haplusterts and exhibited an increasing trend with depth in Bapatla-Karlapalem region of Guntur district in Andhra Pradesh. Free iron oxide content varies from 0.8 to 5.3 per cent and increased with depth (Sarkar *et al.,* 2002). Prakash and Rao (2002) stated that soils developed from granite-gneiss parent material mixed with sandstone and quartzite, were more siliceous (66.20-74.30%) than the soils originated from granite-gneissic complex mixed with schist and calcareous murrum (54.83-63.96%). The soils of eastern region of Varanasi were fairly high in SiO_2 and SiO_2 / R_2O_3 molar ratios in surface soils. This indicates less siliceous substratum and thereby advanced stage of pedogenic development (Singh and Agarwal, 2005).

The free Fe_2O_3 content ranged from 1.4 to 6.2 per cent. Soils on the upper steep slopes contained relatively higher mean values of iron oxides than those in the lower slopes, which could be due to higher degree of weathering (Sitanggang *et al.,* 2006). Silica content of pedons in lower Vellar basin of Pudukottai district in Tamilnadu showed a decreasing trend with depth. The parent material could be prime factor contributing variations in the silica content and the presence of higher coarse fraction. The SiO_2 / R_2O_3 ratio of the pedons ranged from 3.16 to 14.07 and the ratio was wider in all the pedons. The low molar SiO_2 / R_2O_3 ratio indicated moderate weathering in soil whereas high molar ratio indicated *vice-versa* (Somasundaram *et al.,* 2010). The SiO_2 content was found to be very high in comparison to Al_2O_3 and Fe_2O_3 content and varied from 43.1 to 60.3 per cent. High silica-sesquioxide molar ratios was also observed in the surface horizon which gradually decreased down the depth of the pedons in soils of Chotanagpur plateau of West Bengal, which may be due to loss of silica and subsequent enrichment of sesquioxides in the lower part of the profile (Sarkar *et al.,* 2014).

2.9 FERTILITY STATUS

2.9.1 Total and available macronutrients

According to Gurumurthy *et al.* (1996), the red, black and associated soils in Giddalur mandal of Prakasham district in Andhra Pradesh were low in available nitrogen (42 to 105 mg kg^{-1}) and phosphorus (1.40 to 11.50 mg kg^{-1}) while potassium (73 to 210 mg kg^{-1}) was medium to high and the available sulphur content was sufficient (5.00 to 21.20 mg kg^{-1}) in surface soils.

All the hilly soils starting from high hill to foot hill were low in available phosphorus (Sarkar *et al.,* 2002). According to Basavaraju *et al.* (2005), available nitrogen varied from 35.73 to 121.37 kg ha^{-1}, phosphorus ranged from 17.27 to 37.34 kg ha^{-1} potassium ranged from 100 to 315 kg ha^{-1} and available sulphur content varied from 12.5 to 35.2 mg kg^{-1} in surface soils. Thangasamy *et al.* (2005) stated that available N, P, K and S contents varied from 59 to 502 kg ha^{-1}, 4.50 to 29.30 kg ha^{-1}, 22 to 212 kg ha^{-1} and 12.50 to 35.20 mg kg^{-1}, respectively, in the soils of Sivagiri micro-watershed of Chittoor district in Andhra Pradesh.

The available P was medium to high (4.50 to 47.03 kg ha^{-1}), available K was high (212.8 to 680.0 kg ha^{-1}) and very low amount of available N (32.17 to 138.0 kg ha^{-1}) in surface soil as well as in profile and decreased with depth in Amethi soils of Uttar Pradesh (Chaudhary *et al.,* 2006). Available P was low to very high in status (1.12 to 238 kg ha^{-1}) whereas available K was low to high in status (34 to 1193 Kg ha^{-1}) in soils of Punjab (Bali *et al.,* 2010).

Kannan *et al*. (2011) reported that available N, P and K were ranged from 87 to 197, 7 to 15 and 121 to 326 kg ha^{-1}, respectively. Pati and Mukhopadhayay (2011) stated that available nitrogen and phosphorus content ranged from 21.5 to 240 kg $ha^{-1}$and 0.89 to 59.4 mg kg^{-1}, respectively in some acid soils of West Bengal. The available nitrogen (104 to 274 kg ha^{-1}) in banana growing soils of Pulivendla region in Andhra Pradesh was low, the available phosphorous (23 to 75 kg P_2O_5 ha^{-1}) was medium to high and available potassium content was high in all the pedons (337 to 936 kg K_2O ha^{-1}) (Niranjana *et al.*, 2011).

The available nitrogen, phosphorus, potassium and available sulphur in Vadamalapeta mandal in of Chittoor district varied from 108 to 291 kg ha^{-1}, 5.1 to 8.8 kg ha^{-1}, 34 to 314 kg ha^{-1} and 14.5 to 51.5 kg ha^{-1}, respectively (Kumar and Naidu, 2012). Available N, P and K in soils of Banaganapalle mandal of Kurnool district ranged from 190 to 439, 13 to 78 and 44 to 409 kg ha^{-1}, respectively and their content found to be maximum in surface soils and decreased regularly with depth (Sireesha and Naidu, 2013a). According to Devi and Naidu (2014) available N, P and K ranged from 22.4 to 100.8 kg ha^{-1}, 4 to 22 kg ha^{-1} and 14.91 to 201.64 kg ha^{-1} , respectively in sugarcane growing soils of Chittoor district in Andhra Pradesh.

2.9.2 Total and available micronutrients

Gurumurthy *et al.* (1996) stated that available Zn and Fe were deficient in red, black and associated soils in Giddalur mandal of Andhra Pradesh while Cu and Mn were sufficient. The soils developed from basaltic rocks had the highest amount of total micronutrients whereas one derived on granitic granodiorite was the poorest and also stated that clay content and organic carbon were positively correlated with these micronutrients (Murthy *et al.*, 1997). Sharma *et al.* (1999) reported that DTPA-Zn varied from 0.02 to 0.10 mg kg^{-1} in dunes and 0.06 to 1.52 mg kg^{-1} in soils of alluvial plains.

DTPA extractable Fe, Mn, Cu and Zn in surface horizons varied from 2 to 219 mg kg^{-1}, 13.5 to 49.5 mg kg^{-1}, 1.3 to 4.8 mg kg^{-1} and 0.4 to 1.0 mg kg^{-1} respectively in Loktak catchment (Sarkar *et al.*, 2000). The available micronutrients such as Zn, Fe, Cu and Mn were ranged from 0.32 to 1.84, 6.0 to 35.6, 0.25 to 19.8 and 7.2 to 62.4 mg kg^{-1} soil, respectively in Entisols and Inceptisols of Nellore district in Andhra Pradesh (Venkatesu *et al.*, 2002). Gently solping plain contain relatively higher amount of available Cu in comparison with upland area (Sarkar *et al.*, 2002).

Zinc deficiency was wide spread in soils with high pH, low organic matter content and calcareousness (Rattan and Sharma, 2004). Patil and Prasad (2004) reported that higher DTPA-extractable micronutrient cations in surface layers. According to Satyavathi and Reddy (2004b), DTPA-extractable Zn, Cu, Fe and Mn ranged from 0.22 to 1.88, 0.26 to 2.0, 2 to 62 and 6 to 57 mg kg^{-1} respectively in soils of Telangana. Further these soils were deficient in Zn and sufficient in Fe, Cu and Mn by considering the critical limits of 0.6, 0.2, 4.5 and 1 for Zn, Cu, Fe and Mn respectively (Lindsay and Norvell, 1978).

Verma *et al.* (2005) assessed that soils developed from alluvial plain had higher copper content (mean 0.61 mg kg^{-1}) than soils developed from micro basins (mean 0.50 mg kg^{-1}). According to Thangasamy *et al.* (2005), the available iron (0.48 to 7.74 mg kg^{-1} soil) was deficient whereas available Cu (0.28 to 1.68 mg kg^{-1} soil) and Mn (3.68 to 17.24 mg kg^{-1} soil) were well supplied in both surface and sub-surface horizons and the available Zn was sufficient in surface horizons (0.42 to 0.94 mg kg^{-1} soil) and deficient in sub-surface horizons (0.10 to 0.96 mg kg^{-1} soil) in soils of Sivagiri micro-watershed of Chittoor district in Andhra Pradesh.

The DTPA extractable Cu ranged from 1.16 to 22.0 mg kg^{-1}, Fe 2.52 to 9.22 mg kg^{-1}, Zn 0.06 to 3.06 mg kg^{-1} and Mn 3.44 to 9.22 mg kg^{-1} in different horizons of grape growing soils in Nasik district of Maharashtra

(Balpande *et al.,* 2007). The Zn, Cu, Mn and Fe content in soils of Wardha district, Maharashtra varied from 0.16 to 1.65 mg kg^{-1}, 0.61 to 4.59 mg kg^{-1}, 1.31 to 18.10 mg kg^{-1} and 1.61 to 3.72 mg kg^{-1}, respectively. In general, micronutrient cations concentration decreased with depth (Mandal and Sharma, 2008).

Hamza *et al.* (2009) reported that soil CEC and clay content was negatively correlated with soil Fe, Zn and Cu. In general, alkali soils were low in fertility and deficient in DTPA micronutrients particularly Zn and Fe (Ashokkumar and Prasad, 2010). DTPA-extractable Fe and Mn were varied from 2.38 to 60.5 mg kg^{-1} and 0.40 to 6.14 mg kg^{-1} in some acid soils of West Bengal (Pati and Mukhopadhyay, 2011). Available Fe, Mn, Zn and Cu varied from 2.7 to 32.0, 4.0 to 35.0, 0.18 to 4.6 and 0.14 to 2.8 mg kg^{-1}in arid soils of Churu district in Rajasthan (Kumar *et al.*, 2011). The DTPA-Zn, Cu, Fe and Mn ranged from 6.28 to 26.74 mg kg^{-1}, 0.51 to 2.64 mg kg^{-1}, 0.64 to 10.14 mg kg^{-1} and 0.68 to 14.81 mg kg^{-1}, respectively in soils of Vadamalapeta mandal of Chittoor district of Andhra Pradesh (Kumar and Naidu, 2012). According to Devi and Naidu (2014) the DTPA- Zn, Cu, Fe and Mn ranged from 0.29 to 1.49 mg kg^{-1}, 0.48 to 2.76 mg kg^{-1}, 0.97 to 4.46 mg kg^{-1} and 1.82 to 11.58 mg kg^{-1} in sugarcane growing soils of Chittoor district in Andhra Pradesh.

2.10 CLASSIFICATION

Prakash and Rao (2002) stated that soils of Krishna district in Andhra Pradesh were classified into Vertic Haplustepts, Lithic Haplustepts and Typic Haplusterts. Soils of Loktak catchment area of Manipur were classified into the orders Inceptisols with diagnostic cambic horizon and Ultisols having argillic sub-surface diagnostic horizon with base saturation less than 35 per cent (Sarkar *et al.*, 2002). According to Marathe *et al.* (2003), the soils of mandarin orchards in Nagpur were classified into Vertic Haplustepts, Typic Haplustepts, Typic Ustorthents and Typic Haplusterts.

According to Sharma *et al.* (2004a) Inceptisol meet the requirements of cambic horizon and accumilation of clay and calcium carbonate but not other horizons *i.e.* argillic or calcic and salt affected soils of southern Rajasthan were classified as Typic Haplustepts and Typic Calciustepts. The soils of watershed area of Shikohpur, Gurgaon district, Haryana were classified as Entisols and Inceptisols. Entisols had no diagnostic horizons other than ochric epipedon, due to very slight degree of soil formation either because of limited available time for development or because of unfavourable pedoenvironment (Sitanggang *et al.,* 2006).

Tripathi *et al.* (2006) grouped the soils in Kair-Nagali micro-watershed area of north-west Himalayas as Typic Udorthents, Dystric Eutrudepts and Typic Dystrudepts. Pedons located in plains were grouped under Inceptisols and pedons located in uplands were grouped under Alfisols (Rao *et al.,* 2008). The apple growing soils of Kashmir on southern aspects were classified under Mollisol (Hapludolls) and Inceptisols (Eutrochepts) whereas soils formed on northern aspects were grouped under Mollisol (Argiudolls), Alfisol (Hapludalfs) and Entisol (Udorthents) (Najar *et al.,* 2009). Based on the morphological and physico-chemical properties, the oils of Bharatpur and Dholpur districts of Rajasthan were classified under Alfisols, those of Alwar district were classified as Alfisols and those soils of Sawai Madhopur and Karauli were placed under Entisols (Ram *et al.*, 2010).

Coffee growing soils in granitic terrain of Karnataka were classified into Ustic Haplohumults, Dystric Haplustepts, Ultic Paleustalfs, Ustic Palehumults Kanhaplic Haplustalfs and Ustic Haplustalfs (Devi and Kumar, 2010). Ashokkumar and Prasad (2010) classified some typical sugarcane growing soils of Ahmadnagar in Maharastra as Lthic Ustorthents which had lithic contact within 50 cm of mineral soil surface. Soils having very fine texture and calcareous were grouped under Vertic Haplustepts while soils having fine-loamy texture were grouped under Typic Rhodustalfs and Typic Paleustalfs and soils having clayey-skeletal texture and calcareous were grouped under Typic Haplustalfs (Niranjana *et al.,* 2011).

Kannan *et al.* (2011) classified soils of Cauvery delta region of Tamil Naidu as Typic Ustifluvents due to the absence of intergradation with other taxa or any extra gradation from central concept. The soils of Vadamalapeta mandal in Chittoor district of Andhra Pradesh were classified into Typic Haplustalfs, Typic Ustifluvents, Vertic Haplustepts, Typic Haplustepts and Typic Ustorthents (Kumar and Naidu, 2012). Nasre *et al.* (2013) classified soils of Karanji watershed in Maharashtra into Vertisols, Inceptisols and Entisols based on morphological, physical and chemical characteristics. At sub-group level these soils are classified as Sodic Haplusterts, Vertic Haplustepts, Typic Haplustepts, Lithic Ustorthents and Typic Ustorthents. Based on morphological, physical and physico-chemical properties, soils of central and eastern parts of Prakasam district in Andhra Pradesh are classified into Vertisols, Inceptisols and Entisols. At sub-group level these soils are classified as Typic Haplustepts, Typic Ustipsamments, Typic Haplusterts, Typic Haplustepts, Typic Ustorthents and Lithic Haplustepts (Sekhar *et al.,* 2014).

2.11 LAND CAPABILITY CLASSIFICATION

The land capability classification is the grouping of different soil units into defined classes based on their limitations and it serves as a guide to assess the suitability of different land units for arable crops, grazing and forestry. It is mainly based on the inherent soil properties, external land features and environmental factors that limit the land use.

According to Singh and Mishra (1996), the soils in Gandak command area of Bihar were classified into different land capability sub-classes such as I, IIs and IIw. Chinchmalatpure *et al.* (1998) stated that soils of micro-watershed of Wunna catchment near Nagpur were grouped into different land capability sub-classes *viz.,* IIs, IIIs, IIIw and IVes. Effect of land use system on soil properties provides an opportunity to evaluate sustainability of land use system and thus the basic process of soil degradation in relation to land use and hence soil and crop management must be given high research priority (Woldeamlak *et al.,* 2003).

The agricultural lands belonging to class III, requiring regular attention to soil erosion control, water conservation and proper treatment to overcome soil limitations (soil texture / depth / gravelliness) (Sharma *et al.,* 2004b). The soils of Chandragiri mandal in Chittoor district of Andhra Pradesh have been classified into three land capability sub-classes *i.e.* IIs, IIIw, IIIes, IIIse and IVs (Basavaraju *et al.,* 2005). The soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh have been classified into three land capability sub-classes *i.e.* IIs, IIIes, IIIw and IVs (Thangasamy *et al.,* 2005).

Tripathi *et al.* (2006) reported that soils under Kair-Nagali watershed area were placed under IIe (having moderately deep, gentle sloping and slight erosion), IIIes (moderate water erosion, steepness) and VIII (no significance for agriculture). The soils of Ramachandrapuram mandal are classified into three land capability sub-classes for management of lands. Vertic Haplustepts and Typic Haplustepts (plains) were grouped under capability sub-class of IIs, Typic Ustipsamments under IIIs while Typic Haplustalfs and Typic Ustifluvents on uplands were grouped in the capability sub-class of IIIes and Typic Ustorthents located on hill slopes were placed in IVes (Rao *et al*., 2008).

The soils of Lendi watershed in Chandrapur district of Maharashtra were grouped under IIIs, IVs, VIw, VIsw and VIIsw land capability sub-classes. It indicates that the watershed has moderately good to fairly good cultivable lands with limitations of texture, soil depth, slope, and wetness and erosion problems (Girish *et al.*, 2010). Soils in Mula command of irrigated agro-eco-system of Maharashtra were grouped under land capability sub-classes of IIsw, IIse, IIIes, IIIse and IVes based on the limitations (Kharche and Pharande, 2010). Based on the limitations like moderate wind erosion, severe alkalinity / salinity, the soils of flood-prone eastern plain of Rajasthan were classified under three land capability sub-classes *viz.*, IIs, IIIs and IIIes (Ram *et al.*, 2010).

The soils in Renigunta mandal of Chittoor district have been classified into three land capability sub-classes such as IIIe, IIIes, IVs (Selvaraj and Naidu, 2012). Nasre *et al.* (2013) stated that soils in Karanji watershed area of Maharashtra were classified into different land capability sub-classes such as IIs, IIst, IIIs, IVs and VIst. The soils in Banaganapalle mandal of Kurnool district in Andhra Pradesh have been classified into three land capability sub-classes for better management of lands such as IIs, IIIs, IIIsw, IIIes and IVes (Sireesha and Naidu, 2013). Nagaraju and Gajbhiye (2014) have been classified soils of Kukadi command (Minor-25) in Ahmednagar district of Maharastra into three different land capability sub-classes such as IIws, IIIes and IVes.

2.12 SOIL SITE SUITABILITY FOR DIFFERENT CROP

Rao and Shankar (1998) studied the soils of Nalgonda district for their suitability to groundnut through remote sensing and GIS approach and reported that out of 27,234 ha of land, 19,454 ha of land is highly suitable and 293 ha of land is moderately suitable, 7,008 ha is marginally suitable and 533 ha of land is not at all suitable for cultivation of groundnut. Soils of Mandya (Typic Haplustepts), Bhadravathi (Typic Topaquepts) and Chikodi (Vertic Haplustepts) were moderately suitable for growing sugarcane with moderate limitations of nutrient status and relative humidity. However, the Jamkhandi soils (Typic Haplustults) were marginally suitable for growing sugarcane in Karnataka (Naidu and Hunsigi, 2001).

Sarkar *et al.* (2002) stated that soils on very steep high hill slopes, acid tolerant forest species can be grown whereas soils on gently sloping plains rice in *kharif* and vegetables in *rabi* can be grown. Tamgadge *et al.* (2002) evaluated the soil suitability for paddy cultivation in Chattisgarh and reported that Udic Haplusterts, Entic Haplusterts, Chromic Haplusterts, Typic Haplusterts and Udic Haplustepts were highly suitable (S1) whereas Vertic Haplustepts and Typic Haplustepts were moderately suitable (S2) for growing paddy. Further, Udic Haplustalfs, Typic Haplustalfs and Typic Rhodustalfs were marginally suitable (S3), Lithic Haplustepts and Typic Ustorthents were not suitable temporarily (N1) and Lithic Ustorthents was not suitable permanently (N2) for growing paddy in Chattisgarh.

Baun and Phata soils of Neogal Watershed in north-west Himalayas were moderately suitable (S2) and marginally suitable (S3) for growing paddy crop (Sharma *et al.,* 2004a). According to Satyavathi and Reddy (2004b), the soils of Telangana region in Andhra Pradesh were evaluated for crop suitability and reported that Typic Haplustalfs and Typic Rhodustalfs were moderately suitable (S2), Vertic Haplustepts, Typic Haplusterts and Chromic Haplustalfs were marginally suitable (S3) and Typic Ustipsamments were not suitable (N1) for growing groundnut crop.

The land suitability evaluation revealed that soils of a micro-watershed in Vidarbha region of Maharastra such as Typic Haplusterts and Vertic Haplustepts were found to be moderately suitable (S2) for growing cotton, sorghum and pigeonpea (Gabhane *et al.*, 2006). Leelavathi *et al.* (2010) evaluated soils of Yerpedu mandal in Chittoor district of Andhra Pradesh for soil suitability to six major crops (Groundnut, sorghum, maize, sugarcane, paddy and mango) grown in that area and reported that Ultic Haplustalfs, Typic Haplustepts, Ultic Haplustalfs, Typic Haplustepts and Typic Ustifluvents were moderately suitable (S2) for growing groundnut and sugarcane. Ultic Haplustalfs and Typic Haplustepts were marginally suitable (S3) for growing rice crop while Ultic Haplustalfs, Typic Ustipsamments, Typic Haplustepts and Typic Ustifluvents were permanently not suitable (N2) for growing paddy.

Suitability evaluation of six pedons studied from banana growing tracts of Pulivendla region revealed that Typic Rhodustalfs, Typic Paleustalfs and Typic Haplustalfs were moderately suitable due to moderate limitation imposed by alkalinity whereas Typic Haplustepts, Vertic Haplustepts and Typic Haplustalfs were marginally suitable for banana cultivation due to severe limitations of depth, texture and gravelliness in sub-soil and stoniness in surface (Niranjana *et al.*, 2011).

Sireesha and Naidu (2013a) evaluated soil suitability for four major crops (Rice, sorghum, chickpea and sunflower) grown in Banaganapalle mandal of Kurnool District in Andhra Pradesh and reported that Vertic Haplustepts, Typic Haplustepts, Lithic Ustorthents and Typic Ustifluvents were marginally suitable (S3) for growing rice, sorghum, chickpea and sunflower. Typic Ustorthents and Vertic Haplustepts were temporarily not suitable (N1) whereas Fluventic Haplustepts was marginally (S3) suitable for growing chickpea and sunflower crops. Typic Ustorthents was marginally suitable (S3) and Vertic Haplustepts and Typic Haplustepts were temporarily not suitable (N1) for growing rice crop. Sekhar *et al.* (2014) evaluated soil suitability for five major crops (Rice, chickpea, cotton, sorghum and tobacco) grown in central and eastern parts of Prakasam district, Andhra Pradesh and reported that Typic ustipsamments, Typic Haplusterts, Typic Haplustepts and Lithic Haplustepts were marginally (S3) suitable, Typic Haplustepts, Typic Haplustepts, and Typic Ustorthents were permanently not suitable(N2) for rice. Typic Haplusterts and Typic Haplustepts moderately suitable (S2) and Typic ustipsamments, Typic Haplustepts, Lithic Haplustepts and Typic Ustorthents were marginally (S3) suitable for cotton. All pedons (except pedon 4 -Typic Haplustepts) were marginally (S3) suitable for chickpea while pedon 4 was temporarily not suitable (N1) for growing chickpea. Typic Haplustepts and Lithic Haplustepts were marginally (S3) suitable, while Typic Ustorthents, Typic Haplusterts and Typic ustipsamments were temporarily not suitable (N1) for growing tobacco. Typic Haplusterts was highly suitable (S1), Typic Ustorthents, Lithic Haplustepts and Typic Haplustepts were moderately suitable (S2) and Typic ustipsamments was marginally (S3) suitable for growing sorghum crop.

Chapter ~ III

Material & Methods

Chapter III

MATERIAL AND METHODS

The present investigation was taken up to characterize, classify and evaluate the soils in Chillakur mandal of SPSR Nellore district in Andhra Pradesh. Chillakur mandal has a total geographical area of about 14786.00 ha and comprises of twenty-eight revenue villages *viz.*, Addepalle, Ankulapaturu, Annambaka, Ballavolu, Budanam, Chillakur, Chinthavaram, Gummaladibba, Kadivedu Kalavakonda, Lingavaram Momidi, Mutyalapadu (Rural), Nakkalakalva Khandrika, Nelaballi, Oduru, Pallamala, Pentapadu, Ponnavolu, Thamminapatnam, Theepanur, Thikkavaram, Thonukumala, Turpu Kanupur, Udathavaripalem, Udathavariparlapalle, Varagali, Yeruru.

Seven master profiles (pedons) were arranged in Chillakur mandal representing all types of soils by taking into consideration geology, climatic conditions, geomorphic characters and other related pedological information pertaining to the study area. The materials used and methods employed in characterization, classification and evaluation of soils are presented under the following heads.

3.1 COLLECTION OF SOIL SAMPLES

The different morphological characters of each horizon of all the pedons were described in the field (Soil Survey Division Staff, 2000) as per the guidelines laid down in USDA Soil Survey Manual (Soil Survey Staff, 1998). The detailed morphological description for all the seven pedons were studied and climatic particulars of the study area were furnished in Appendix I. Horizon-wise soil samples were collected from each profile for studying the physical, chemical and physico-chemical properties.

3.2 PROCESSING OF SOIL SAMPLES

The soil samples were air dried under shade, ground with wooden mallet, sieved through a 2 mm sieve and preserved in polyethylene bags for laboratory analysis.

3.3 LABORATORY ANALYSIS

3.3.1 Physical properties

3.3.1.1 Particle size analysis

The particle size analysis was carried out in soil samples by the International pipette method. Different USDA textural fractions were estimated and expressed as percentages of sand (2.00 - 0.05 mm), silt (0.05 - 0.002 mm) and clay (< 0.002 mm) on $CaCO_3$ free basis (Piper, 1966).

3.3.1.2 Soil colour

Munsell's colour notation of Hue, Value and Chroma were observed for both air dried and moist soil samples (Soil Survey Staff, 1999).

3.3.1.3 Soil density

Bulk density in soil samples was determined by clod method (Singh, 1980) whereas for sandy soils, core sampler method was followed (Black and Hartge, 1986). True density (P.D.) for soil samples was determined by specific gravity bottle method (Black and Hartge, 1986).

3.3.1.4 Water holding capacity, pore space and volume expansion

The physical constants such as water holding capacity, pore space and volume expansion in the soil samples were determined by following Keen Raczkowski's method as described by Sankaram (1966).

3.3.1.5 Loss on ignition (LOI)

LOI in soil samples was determined by heating a known weight of soil sample taken in silica crucible at 800^0C for 4 hours in muffle furnace. After cooling based on the loss in weight, it was determined as per the procedure given by Piper (1966).

3.3.2 Physico-chemical properties

3.3.2.1 Soil reaction (pH)

pH of the soil samples was determined in 1:2.5 soil water suspension and 1:2.5 soil, 1 *N* KCl suspension by using digital pH meter (Systronics µ pH system 361) (Jackson, 1973).

3.3.2.2 Electrical conductivity (EC)

The electrical conductivity of soil samples was determined in saturation extract by using Elico CM 180 conductivity meter (Jackson, 1973).

3.3.2.3 Organic carbon (OC)

Organic carbon content of the soil samples was estimated by Walkley and Black's wet oxidation method as outlined by Jackson (1973).

3.3.2.4 Free calcium carbonate ($CaCO_3$)

The free calcium carbonate content of soil samples was determined by treating the soil with a known volume of standard HCl and back titrating the unused acid with standard alkali using bromothymol blue as an indicator (Piper, 1966).

3.3.2.5 Cation exchange capacity (CEC)

Cation exchange capacity of the soil samples was determined by saturating a known weight of the soil with 1 *N* sodium acetate (pH 8.2), then the excess sodium acetate was leached with 95 per cent ethanol. The adsorbed sodium was displaced with 1 *N* neutral ammonium acetate (pH 7.0) and the left over sodium concentration in the leachate was determined by aspirating directly into the flame photometer (Systronics flame photometer 128). The CEC was calculated and expressed as cmol (p+)kg^{-1} soil (Bower *et al.,* 1952).

3.3.2.6 Exchangeable cations

Soil samples were pre-treated with 95 per cent ethanol to remove water soluble cations and the exchangeable cations were estimated by extracting the soil with 1 *N* neutral ammonium acetate. The exchangeable sodium and potassium were determined by aspirating the leachate directly into the flame photometer (Systronics flame photometer 128). The exchangeable calcium and magnesium were determined by versenate method. The concentration of exchangeable cations Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were expressed in cmol(p+)kg^{-1} soil (Chopra and Kanwar, 1991).

3.3.3 Chemical properties

3.3.3.1 Preparation of acid extract for total nutrients

One gram of oven dried soil sample was transferred into a 150 ml Erlenmeyer flask to which 20 ml of concentrated nitric acid was added and a small funnel was placed over the Erlenmeyer flask to prevent rapid evaporation of acid. The contents were heated on a hot plate to oxidize the organic matter, then 10 ml of 60 per cent perchloric acid was added and the digestion was continued until dense white fumes appeared. A little quantity of perchloric acid was added to wash down the sides of the flask and the heating was continued for another 15 minutes to dehydrate the silica. The residue was dissolved in 25-30 ml of warm double distilled water and filtered through Whatman number 42 filter paper and the filtrate was collected in 250 ml volumetric flask. The residue was washed with 0.5 *M*

HCl to make it free from chlorides and finally the volume was made upto 250 ml with warm double distilled water (Hesse, 1971).

3.3.3.2 Silica (SiO_2)

Residue which is left over in the filter paper was washed with warm distilled water for free of chlorides. Then the residue along with the filter paper was transferred to a silica crucible and then ignited in a muffle furnace at 800°C for 4 hours. Crucible along with the residue was cooled in a desiccator and then weighed. From the weight of the residue, the percentage of SiO_2 was calculated (Hesse, 1971).

3.3.3.3 Sesquioxides (R_2O_3)

100 ml of acid extract was taken in a 250 ml beaker and it was boiled on a water bath for 5 minutes. A red coloured precipitate of iron and aluminum was obtained by adding ammonium hydroxide in the presence of ammonium chloride, this precipitate was washed with warm distilled water till it becomes free of chlorides, and residue along with the filter paper was dried, ignited at 800°C for 4 hours and cooled in a desiccator and weighed. The results were expressed as per cent sesquioxides (Hesse, 1971).

3.3.3.4 Iron oxide (Fe_2O_3)

Iron concentration was determined by aspirating silica free acid extract into atomic absorption spectrophotometer (VARIAN AA240FS) and the results were expressed as per cent Fe_2O_3 (Hesse, 1971).

3.3.3.5 Alumina (Al_2O_3)

This was determined by deducting the Fe_2O_3 content from the total content of sesquioxides.

3.3.3.6 Total macronutrients

3.3.3.6.1 Nitrogen

Total nitrogen in soil samples was estimated by modified kjeldahl method using sulphuric and salicylic acid mixture (Hesse, 1971).

3.3.3.6.2 Phosphorus

Total phosphorus content in soil samples was determined by perchloric acid digestion method using Barton's reagent as described by Jackson (1973).

3.3.3.6.3 Potassium

Total potassium in the acid extract was estimated by aspirating the extract into the flame photometer (Systronics flame photometer 128) (Jackson, 1973).

3.3.3.6.4 Sulphur

Total sulphur in the soil samples was extracted with diacid (Hesse, 1971) and estimated by turbidimetric method (Cottenie *et al.*, 1979).

3.3.3.6.5 Calcium

Total calcium was estimated by versenate titration by taking a suitable aliquot of sesquioxide free acid extract using murexide as an indicator in the presence of 16 per cent NaOH. The results were expressed as per cent CaO (Chopra and Kanwar, 1991).

3.3.3.6.6 Magnesium

A combined estimation of calcium and magnesium was carried out in the same sesquioxide free acid extract by versenate titration using ammonium hydroxide and ammonium chloride buffer and Eriochrome black-T indicator. Magnesium titre value was obtained by subtracting the calcium titre value from the combined estimation of calcium and magnesium and the results were expressed as per cent MgO (Chopra and Kanwar, 1991).

3.3.3.6.7 Sodium

Sodium was estimated in nitric and perchloric acid extract directly by aspirating into the flame photometer (Systronics flame photometer 128) and the results were expressed as per cent Na_2O (Jackson, 1973).

3.3.3.7 Total micronutrients

The acid extract was directly aspirated into atomic absorption spectrophotometer (VARIAN AA240FS) for the determination of total Zn, Cu, Fe and Mn. The results were expressed in mg kg^{-1} soil (Hesse, 1971).

3.3.4 Fertility properties

3.3.4.1 Available macronutrients

The methods for estimation of available macronutrients (N, P, K and S) are as follows

3.3.4.1.1 Nitrogen

The available nitrogen was estimated by the alkaline potassium permanganate method as described by Subbiah and Asija (1956).

3.3.4.1.2 Phosphorus

Available phosphorus content of soils was extracted by using Olsen's extractant as described by Olsen *et al.* (1954) and phosphorus in the extract was determined by Murphy and Riley method (using ascorbic acid as a reducing agent) as described by Watanabe and Olsen (1965) using spectrophotometer (Jasco V-530 UV/ Visible spectrophotometer) at 660 nm wavelength.

3.3.4.1.3 Potassium

Available potassium in the soils was extracted by employing neutral normal ammonium acetate and determined by aspirating the extract into the flame photometer (Systronics flame photometer 128) (Jackson, 1973).

3.3.4.1.4 Sulphur

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

The soil samples were classified into low, medium and high categories as per the limits suggested by Muhr *et al.,* (1965) for available N, P and K and organic carbon. Available sulphur was classified based on the critical limits proposed by Tandon (1991).

3.3.4.1.5 Rating for organic carbon and available macronutrients

Sl. No.	Nutrient	Low	Medium	High
1.	Organic carbon (%)	< 0.5	0.5-0.75	> 0.75
2.	Available N (kg ha^{-1})	< 280	280-560	> 560
3.	Available P (kg ha^{-1})	< 10	10-24.6	> 24.6
4.	Available K (kg ha^{-1})	< 108	108-280	> 280

3.3.4.1.6 Rating for available sulphur

Sufficient > 10 mg kg^{-1} soil

Deficient < 10 mg kg^{-1} soil

3.3.4.2 Available micronutrients

The available micronutrients in soil samples were extracted by using DTPA extractant solution of pH 7.3 (Lindsay and Norvell, 1978) and the extract was aspirated to atomic absorption spectrophotometer (VARIAN AA240FS) with the following specifications.

Nutrient	Wave length (nm)	Lamp current (milli amperes)
Zn	213.9	5
Cu	327.4	4
Fe	372.0	5
Mn	403.1	5

3.3.4.2.1 Rating for available cationic micronutrients

Available cationic micronutrient	Critical limits * (mg kg^{-1} soil)
Zinc	0.6
Copper	0.2
Iron	4.5
Manganese	1.2

* In respect of available micronutrients, the ratings given by Lindsay and Norvell (1978) were followed

3.4 SOIL CLASSIFICATION

A set of soil properties are diagnostic for differentiation of pedons. The differentiating characters are the soil properties that can be observed in the field or measured in the laboratory or can be inferred in the field. Some diagnostic soil horizons, both surface and sub-surface, soil moisture regimes, soil temperature regimes and physical, physico-chemical and chemical properties of soils determined in the present study were used as criteria for classifying the soils. The soils of Chillakur mandal of SPSR Nellore district were classified into different orders, sub-orders, great groups, sub-groups, families and finally into tentative series as per keys to USDA Soil Taxonomy (Soil Survey Staff, 2014).

3.5 LAND CAPABILITY CLASSIFICATION

The land capability classes were fixed to the soils of Chillakur mandal based on their potentialities and limitations for sustained productivity by following USDA land capability classification (Klingebiel and Montgomery, 1966).

Land capability classification is an interpretative grouping of soils mainly based on their inherent soil characteristics, external land features and environmental factors that limits the use of land for agriculture. There are eight land capability classes designated by Roman letters from I to VIII in the increasing order of hazards and limitations in the use of land. Classes I to IV are suitable for agriculture under proper and specific management. Classes V to VII are not suitable for arable agriculture but suitable for pasture or forestry. Class VIII is suited only for wild life sanctuary and recreational purposes.

Land capability sub-classes are soil groups within a land capability class that were designated by small letters like ‘e’ for erosion, ‘s’ for soil limitations, ‘c’ for climatic limitations and ‘w’ for wetness. Land capability units are grouping of one or more soil mapping units having similar potentials, limitations and responses to management.

3.6 CROP SUITABILITY CLASSIFICATION

Seven dominant soils in Chillakur mandal of SPSR Nellore district, Andhra Pradesh were selected for evaluation (Figure 4.1) and their morphometric (Table 4.1) characteristics were studied. Physical and chemical properties were estimated using standards procedures were presented in Table 4.26. Their suitability was assessed using limitation method regarding number and intensity of limitation (Sys *et al.,* 1991). This evaluation procedure consists of three phases.

In phase I, the data has been collected in terms of characteristics (Table 4.26). The following landscape and soil characteristic were used to evaluate soil suitability: topography (% slope), wetness (flooding and drainage), physical soil characteristics (texture, structure, % coarse fragments by volume, soil depth in cm, $CaCO_3$), soil fertility characteristics [apparent CEC (cmol(p+)kg^{-1} clay), % base saturation, sum of basic cation (cmol(p+)kg^{-1} soil), pH (H_2O), % organic carbon, salinity (EC, dsm^{-1}) and alkalinity (ESP)]. The study area was almost flat to gently sloping and never been flooded (F0). Drainage conditions (Table 4.28) were compared with regard to texture: (a) fine and medium textured soils and (b) coarse textured soils as per the guideline given in Sys *et al.* (1991). Soil characteristics were evaluated as suggested in Sys *et al.* (1991).

In phase II, the landscape and soil requirements for these four crops (Appendix II) are taken from tables given by Sys *et al.* (1993).

In phase III, the land suitability under rainfed conditions has been assessed by comparing the landscape and soil characteristics with crop requirements at different limitation levels: no (0), slight (1), moderate (2), severe (3) and very severe (4) (Table 4.27). Limitations are deviations from the optimal conditions of a land characteristics and land quality, which adversely affect a kind of land use. If a land characteristic optimal for plant growth, it has no limitation on the other hand, when the same characteristic is unfavourable for plant growth, it has severe limitation for particular land evaluation type. Thus, the evaluation was done by comparing the land characteristics with the limitation levels of the crop requirements tables (Sys *et al.* (1993). The number and degrees of limitations suggested the suitability class of the soil for a particular crop given by (Sys *et al.* (1991) were as follows:

Criteria for the determination of the land suitability classes

Land Classes	Criteria
S1 : Very suitable	Land units with no, or only 4 slight limitations.
S2 : Moderately suitable	Land units with more than 4 slight limitations, and / or no more than 3 moderate limitations.
S3 : Marginally suitable	Land units with more than 3 moderate limitations, and / or one or more severe limitations (s)
N1 : Actually unsuitable and potentially suitable	Land units with very severe limitations which can be corrected.
N2 : Unsuitable	Land units with very severe limitations which cannot be corrected.

The present suitability classes can be improved if the correctable limitations such as pH, organic carbon and sodicity are altered through soil amelioration measures. The potential land suitability sub-classes were determined after considering the improvement measures to correct the limitations Sys *et al.* (1991).

3.7 STATISTICAL ANALYSIS

Various soil properties were tested for their correlation with one another as per the procedure described by Gomez and Gomez (1984).

Chapter ~ IV

Results & Discussion

Chapter – IV

RESULTS AND DISCUSSION

4.1 LOCATION

The study area is located in Chillakur mandal of SPSR Nellore district in Andhra Pradesh lies in between 14°01′ and 14°12′ North latitude and 79°51′ and 80°04′ East longitude (Figure.4.1).

4.2 SOIL FORMING FACTORS

4.2.1 Climate

The study area is confined to semi-arid monsoonic climate with distinct summer, winter and rainy seasons. The mean annual atmospheric temperature is 28.78°C and the mean annual rainfall is 1113.25 mm (Table 4.1). The meteorological data were also depicted in ombrothermic diagram (Fig. 4.2).

Climate is regarded as the most significant factor controlling the type and rate of soil formation. The importance of climate on soil formation was emphasized by Russian scientists Dokuchaiev (1886), Sibirtsev (1901) and Glinka (1931). Soil genesis and development were influenced by soil temperature and moisture (Buol *et al.*, 1998).

The meteorological data for the past ten years (2005-2014) indicated that study area is confined to semi-arid monsoon type of climate with distinct summer (April to June), rainy (July to November) and winter (December to March) seasons. The overall climate of the study area is hot summer and mild winter. The soils of Chillakur mandal in SPSR Nellore district of Andhra Pradesh were developed from granite-gneiss and alluvium parent material under semi-arid monsoonic climate. Entisols and Inceptisols were developed under semi-arid monsoonic climate with a mean annual

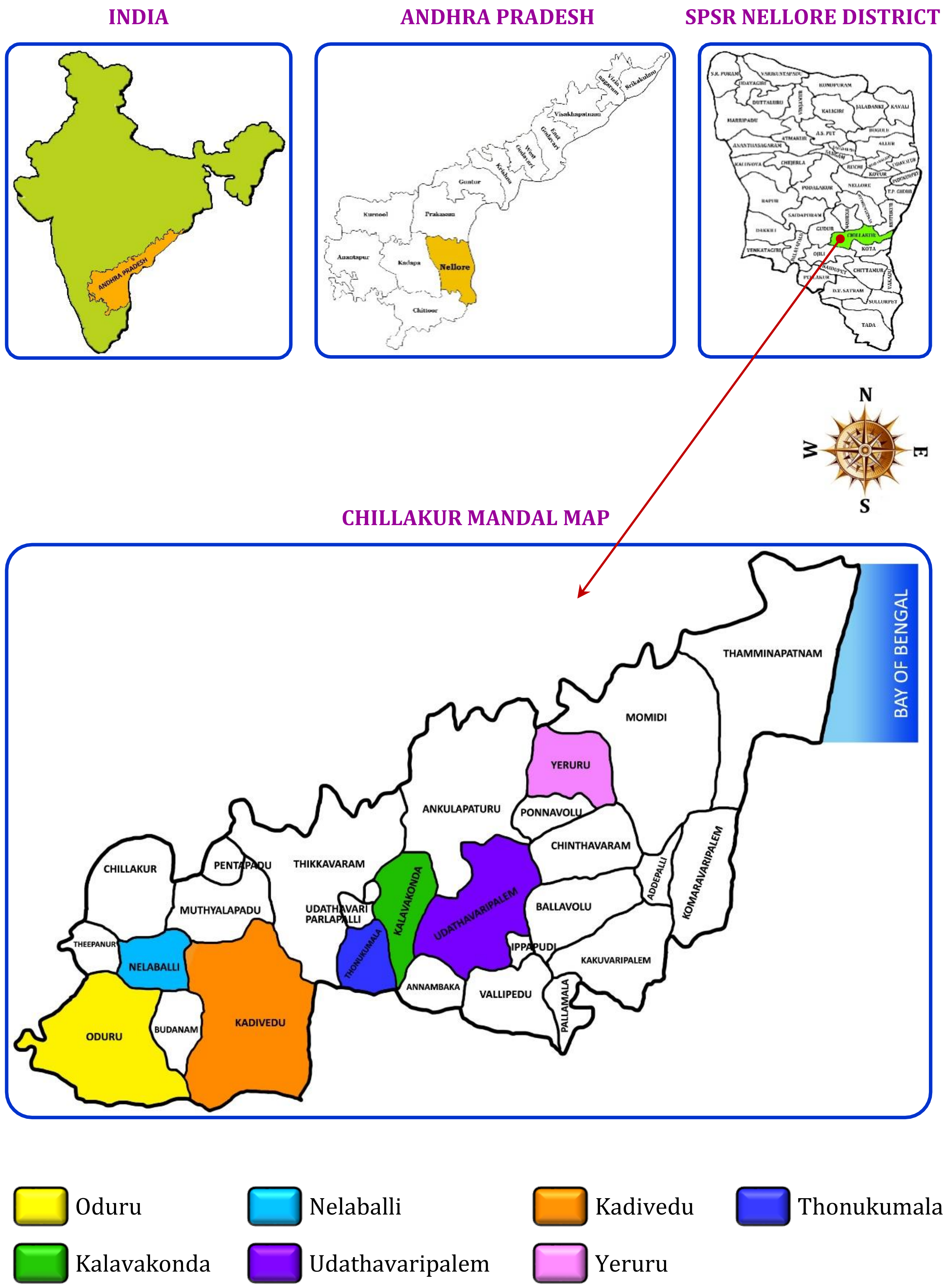


Fig. 4.1. Location map of Chillakur Mandal

Table 4.1. Meteorological data of the study area (2005 – 2014)*

Month	Rainfall (mm)		Temperature (°C)		
			Maximum	Minimum	Mean
January	6.20		31.26	19.62	25.44
February	12.32		32.41	18.17	25.29
March	13.20		32.87	22.64	27.76
April	9.65		37.82	23.24	30.53
May	32.67		40.17	29.17	34.67
June	45.14		39.14	28.21	33.68
July	197.03		35.42	25.26	30.34
August	124.83		34.17	25.14	29.66
September	183.20		34.64	25.52	30.08
October	184.52		32.21	23.17	27.69
November	173.7		29.47	22.62	26.05
December	130.79		28.17	20.13	24.15
Total	**1113.25**	**Mean**	**33.98**	**23.57**	**28.78**

Mean annual rainfall = 1113.25 mm
Mean annual air temperature = 28.78^{o}C
Lang's precipitation factor = 38.68

*Mean values of ten years data from 2005– 2014

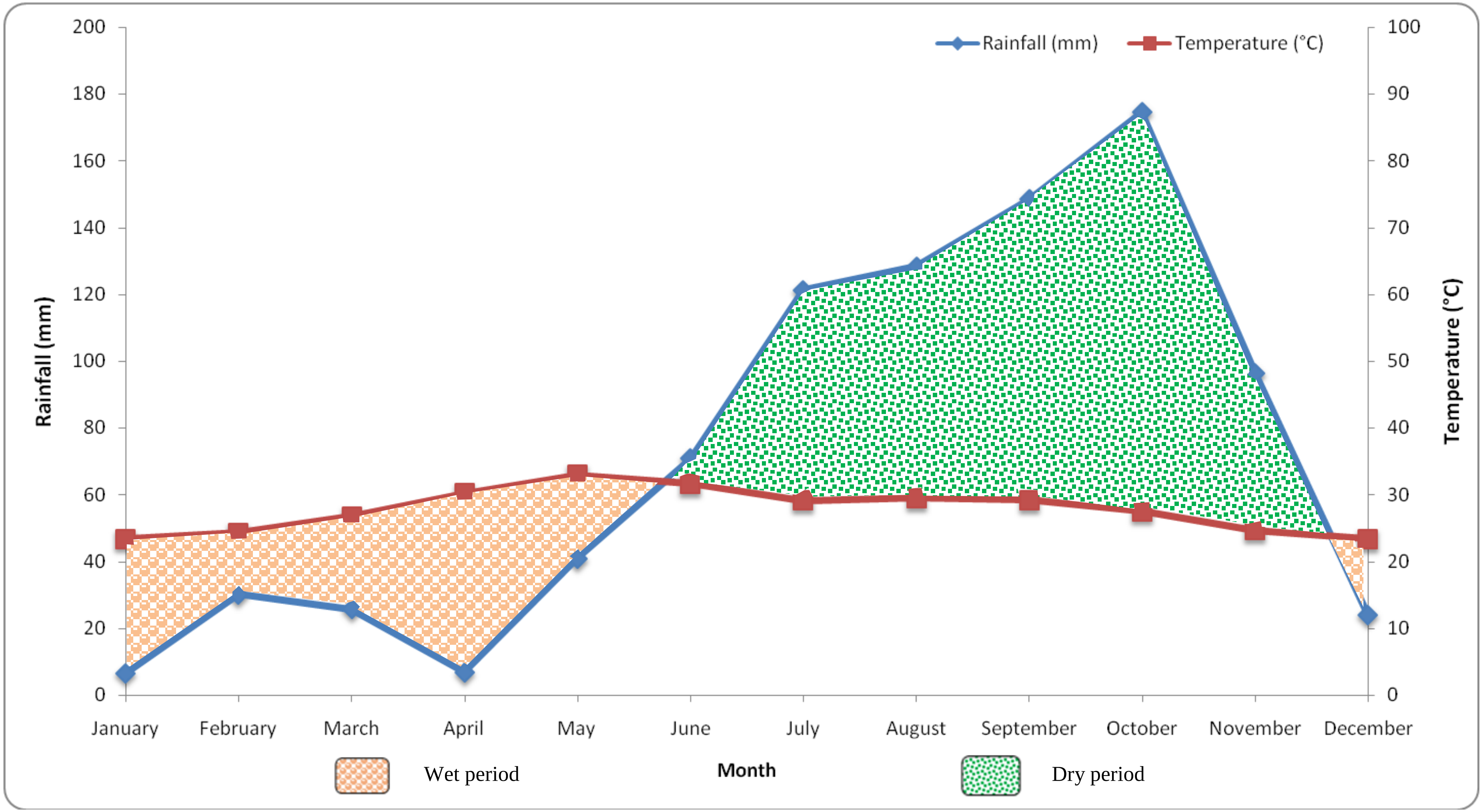


Fig. 4.2. Ombrothermic graph of study area (Chillakur mandal)

rainfall of 893.63 mm of which 94.31 per cent was received during May to December in Chittoor district of Andhra Pradesh (Devi and Naidu, 2014). The Entisols and Inceptisols in Banaganapalle mandal of Kurnool district in Andhra Pradesh were developed under semi-arid monsoonic climate with an annual rainfall of 775 mm of which 90 per cent was received during June to September and mean annual air temperature of 28.7°C (Sireesha and Naidu, 2013a). Prakash and Rao (2002) also stated that red and black soils were confined to semi-arid monsoonic climate in Krishna district of Andhra Pradesh. Similar climatic conditions were also observed by Dutta *et al.* (2001) in parts of South India.

4.2.2 Parent material

Parent material is an important initial soil material that determines the soil profile development. Further, the parent materials were mechanically comminuted or chemically decomposed mass (Soil Survey Division Staff, 2000) interacting with or acted upon by other environmental genetic factors over time and space developing soils.

Pedons 1, 2, 3, 4, 5 and 6 were developed from granite-gneiss parent material whereas pedon 7 was originated from alluvium. Similar results were observed in soils of central and eastern parts of Prakasam district in Andhra Pradesh, where in the soils were developed from granite-gneiss and alluvium parent material (Sekhar *et al*., 2014). According to Thangasamy *et al.* (2005), the red and associated soils in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh were developed from granite-gneiss and quartzite. Satyavathi and Reddy (2004b) also stated that Inceptisols and Vertisols in Telengana region were originated from pink and grey granites, basalt, granite-gneiss and hornblende-schists. Further, the red soils of Krishna district in Andhra Pradesh were developed from granite-gneiss parent material mixed with sandstone and quartz (Prakash and Rao, 2002).

4.2.3 Topography

The topography of Chillakur mandal varied from nearly level plains (0-1 %) to very gently sloping uplands (1-3 %) with very slight to moderate erosion. Pedons 2, 5, 6 and 7 occur on nearly level plains (0-1 %) whereas the pedons 1, 3 and 4 were located on very gentle sloping (1-3 %) uplands.

Topography influences the climate and vegetation of an area and also affects the soil formation through slope and exposure. These results were in agreement with the findings of Tiwary *et al.*, (1989), who reported the occurrence of red soils in the uplands with steep slopes. Rao *et al.* (2004) noticed that Inceptisols were formed on very gently to gently sloping uplands with a slope of 0-1 per cent. Soils on very gently sloping plains are very deep and well-drained with loamy to clay-loamy texture whereas soils on nearly plains are moderately to imperfectly drained with sandy loamy to loamy texture in tea-growing soils of Jorhat district in Assam (Bandyopadhyay *et al.* 2014).

4.2.4 Time

Time was an important factor in the course of soil development, which governs indirectly the activities and interactions of different factors of soil formation. Thus, it has dominant effects in changing the forms and mode of development of different kinds of soils and their properties. All the soils do not age at the same rate. In general, aging was more rapid in warm and humid climate than in cold or hot arid climate. Parent material and relief also influence the age of the soil. Time along with topography and nature of parent material were the important soil forming factors responsible for the pedogenic differences in the soils developed on different landforms within comparable climate conditions (Kumar *et al.*, 2005). The soils developed over granite-gneiss were comparatively younger with higher nutrient reserves followed by soils developed on granite, charnockites and laterites

Table 4.2. Vegetation and land use of the study area

Pedon No.	Village	Natural vegetation	Land use
1.	**Oduru**	*Azadirachta indica,* *Borassuss flaciflora* *Cynodon dactylon,* *Calotropis gigantia* *Cyprus rotundus* *Pongamia pinneta*	Maize, Groundnut and Tomato
2.	**Nelaballi**	*Azadirachta indica,* *Calotropis gigantia,* *Cyprus rotundus* *Parthenium hysterophorus* *Acacia nilotica* *Cynodon dactylon,*	Rice, Sunflower and Sesame
3.	**Kadivedu**	*Cyprus rotundus* *Cynodon dactylon* *Acacia nilotica* *Azadirachta indica* *Calotropis gigantia* *Eucalyptus* spp.	Citrus orchard and Leafy vegetables
4.	**Thonukumala**	*Parthenium hysterophorus* *Cyprus rotundus* *Tephrosia purpurea*	Mango orchard
5.	**Kalavakonda**	*Cyprus rotundus* *Cynodon dactylon* *Parthenium hysterophorus* *Azadiracta indica* *Eucalyptus* spp.	Rice and Mango orchard
6.	**Udathavaripalem**	*Calotropis gigantia,* *Cynodon dactylon* *Cyprus rotundus Parthenium* *hysterophorus Borassuss* *flaciflora*	Rice and Groundnut
7.	**Yeruru**	*Azadiracta indica,* *Borassuss flaciflora* *Acacia nilotica* *Eucalyptus* spp.	Groundnut

(Lekha *et al.,* 1998) and the colour become redder with increasing age (Nayak *et al.,* 1999).

4.2.5 Land use and vegetation

The pedons were selected from the cultivated fields. The major crops grown in the study area were paddy, groundnut, sunflower, tomato, sesame and mango and citrus orchards. The natural vegetation of the study area was *Borassuss flaciflora, Eucalyptus* species, *Parthenium hysterophorus, Cyprus rotundus, Calotropis gigantia, Azadiracta indica, Amaranthus* species, *Tephrosia purpurea, Acacia nilotica* and *Cynodon dactylon* (Table. 4.2).

The nature of soil developed was governed to a great extent by the kind of vegetation as it influences soil evolution by production and addition of organic matter, profile development, translocation and accumulation of mineral substances. The natural vegetation in Yerpedu mandal of Chittoor district, Andhra Pradesh comprises of *Parthenium hysterophorus, Prosopis julifera, Calotropis gigantea, Acacia auriculiformis, Commelina bengalensis, Cyanodon dactylon, Cyprus rotundus, Pongamia pinnata* and *Azardirachta indica* (Leelavathi *et al.,* 2010). Rani *et al.* (1991) and Thangasamy *et al.* (2005) reported similar type of natural vegetation in Somasila project area and Sivagiri micro-watershed in Chittoor district of Andhra Pradesh, respectively.

4.3 SOIL GENESIS

Careful examination of soil profiles revealed distinctive horizontal layers, some of which were highly visible. Significant changes observed as the soils were developed from relatively unconsolidated parent material. Except pedon 7, all pedons were developed from granite-gneiss parent material while pedon 7 was developed from alluvium.

Brady (1995) stated that, study of soil formation or genesis gives some notion as to how these changes occurred and why they can stimulate the development of so many different kinds of soils. Soil genesis was brought about by series of processes, the most significant of which are as follows.

- Weathering and organic matter break down by which some soil constituents were modified or destroyed and others were synthesized.
- Translocation of inorganic and organic materials up and down the soil profile, the material was being moved mostly by water but also by soil organisms.
- Accumulation of soil materials in horizontal layers (horizons) in the soil profile, either as they were formed in place or translocated from the above or below the zone of accumulation.

Simonson (1959) outlined the process of soil formation include

- Additions of organic and mineral materials to the soil as solids, liquids and gases.
- Losses of these from the soil.
- Translocation of materials from one point to another within the soil.
- Transformation of mineral and organic substances within the soil.

Accumulation of organic matter and humus was noticed on the surface soils and to a certain depth of sub-soil in all the pedons. The surface horizon in all these pedons was dark in colour as compared to sub-surface horizons due to accumulation of organic matter.

Next to soil formation was translocation of material from one point to another within the soil. In this category eluviation and illuviation were of importance. The development of B horizons in the pedons 2, 5 and 6 was a result of illuviation and eluviation. Due to these processes the cambic horizons were formed. However, processes such as eluviation and illuviation were not operated in the pedons 1, 3, 4 and 7, hence they don't exhibit the soil development in sub-surface horizons and hence the B horizon was absent.

Next category of soil forming processes was the transformation of minerals and organic substances within the soil. The colour and structure get transformed in the sub-soil leading to the development of cambic horizon (Bw) in pedons 2, 5 and 6. The study area has semi-arid climate with high summer temperatures with high rainfall and monsoonic type of climate. Natural vegetation in the study area comprises of medium to short grasses.

Further, the topography of the study area varied from very gently sloping uplands to nearly level plains. The interplay of climate, topography and vegetation acting on parent material over a period of time resulted in the development of different soils *viz.,* Entisols and Inceptisols in this Chillakur mandal.

4.4 MORPHOLOGY OF TYPIFYING PEDONS

The detailed morphological and pedological features were presented in Appendix I. The summary of morphological features was presented in Table.4.4 and Figures. 4.3, 4.4, 4.5 and 4.6.

4.4.1 Depth of Pedons

The morphological characters of the pedons revealed that these soils were moderately deep to very deep. Marked variation in depth was observed between different pedons. The depth (0.52-0.55 m) of pedons 1, 3 and 4

Table 4.3. Details of the pedons

Pedon No.	Village	Location	Elevation above msl (m)	Horizon	Horizon thickness (m)
1	**Oduru**	14º02′44.6″ N	41	Ap	0.00-0.20
		79º52′36.3″ E		A1	0.20-0.52
				Cr	0.52+
2	**Nelaballi**	14º05′26.3″ N	3	Ap	0.00-0.18
		79º53′02.5″ E		Bw1	0.18-0.33
				Bw2	0.33-0.55
				Bw3	0.55-0.80
				Bw4	0.80-1.15
				Bw5	1.15-1.50+
3	**Kadivedu**	14º04′42.8″ N	25	Ap	0.00-0.20
		79º53′54.8″ E		A1	0.20-0.33
				A2	0.33-0.52
				Cr	0.52+
4	**Thonukumala**	14º06′35.6″ N	23	Ap	0.00-0.25
		79º57′16.5″ E		A1	0.25-0.55
				Cr	0.55+
5	**Kalavakonda**	14º″0748.5″ N	6	Ap	0.00-0.21
		79º58′07.7″ E		A1	0.21-0.35
				Bw1	0.35-0.57
				Bw2	0.57-0.78
				Bw3	0.78-1.00
				Cr	1.00+
6	**Udathavaripalem**	14º08′23.6″ N	3	Ap	0.00-0.27
		80º00′33.5″ E		A1	0.27-0.37
				A2	0.37-0.58
				Bw1	0.58-0.78
				Bw2	0.78-0.91
				Bw3	0.91-1.20
				Bw4	1.20-1.50+
7	**Yeruru**	14º10′16.6″ N	3	Ap	0.00-0.30
		80º02′34.7″ E		A1	0.30-0.58
				A2	0.58-0.80
				A3	0.80-0.98
				A4	0.98-1.27
				A5	1.27-1.48
				A6	1.48-1.90+

occurring on gentle slope was comparatively lesser than the depth (1.00-1.90 m) of pedons 2, 5, 6 and 7 lying on plains. Solum depth was extended to 1.50 m in case of pedons 2 and 6 and beyond 1.90 m incase of pedon 7.

The depth of the pedons was the manifestation of topography (Singh and Mishra, 1996). Agbenin and Tiessen (1995) stated that solum thickness increased from upper to the lower slope in soils of north-east Brazil. Prakash and Rao (2002) noticed the non-availability of adequate amount of water for prolonged period in the gently sloping soils associated with removal of finer particles and their deposition at lower pediplain have resulted in shallow soils in upper pediplain and deeper soils in lower pediplain. Similarly, in the present investigation also the pedons occurring in lower pediplain had deeper solum than the soils located on the upper pediplains.

4.4.2 Number of horizons

Based on the different morphological features, pedons 6 and 7 were distinguished into 7 horizons. Pedons 2 and 5 were differentiated into 6 horizons, pedon 3 was distinguished into 4 horizons and pedons 1 and 4 distinguished into 3 horizons, respectively. Similar number of horizons were noticed in red, black and associated soils of Ramchandrapuram mandal in Chittoor district of Andhra Pradesh (Rao *et al.,* 2008).

4.4.3 Horizons and horizon sequence

The pedons in the study area were characterized by AC and ABC profiles. A horizon was designated as Ap by taking considerable change in colour and structure due to cultivation in all the profiles. Based on the macro morphological features the A horizon in pedons 1, 3, 4, 5, 6 and 7 were vertically sub-divided into different sub-horizons. Pedons 2, 5 and 6 exhibited ABC horizons with ‘B’ horizon differentiated into Bw1, Bw2, Bw3, Bw4 and Bw5 in pedon 2, Bw1, Bw2 and Bw3 in pedon 5 and Bw1, Bw2, Bw3 and Bw4 in pedon 6 (Table. 4.3).

Horizonation was the main pedogenic process in Inceptisols. According to Simonson (1959) the basic processes involved in soil formation were gains such as addition of water, organic and mineral matter to the soil, losses of the above materials from the soil and transformation and / or translocation. Any one of the above processes might have taken place in these pedons, hence profile development occurred with ABC horizon.

Development of cambic horizon (Bw) was observed in pedons 2, 5 and 6, as these pedons did not have rock structure, argillic, kandic, oxic and spodic horizons. Development of cambic (Bw) horizon in Inceptisols of Etawah district of Uttar Pradesh, sugarcane-growing soils of Ahmadnagar district of Maharashtra and banana-growing soils of Pulivendla region, Andhra Pradesh was observed by Verma *et al*. (2001), Ashokkumar and Prasad (2010) and Niranjana *et al*. (2011), respectively.

Further, the findings of the present investigation revealed that pedons 1, 3 and 4 did not exhibit any diagnostic sub-surface horizon, based on which they were characterized as Entisols. In Entisols, weak / no profile development was observed due to inert nature of parent material. The horizons recognized were only A and C. Similar observations were made by Leelavathi *et al*. (2009) and Kharche and Pharande (2010).

4.4.4 Horizon thickness and Horizon boundaries

The thickness of Ap horizon varied from 0.18 to 0.30 m for all the pedons whereas thickness of sub-surface horizons varied from 0.18 to 1.90 m. Surface horizons of all the pedons and Bw1, Bw2 horizons in pedon 2 exhibited clear and smooth boundary. However, pedon 6 exhibited clear and smooth boundary throughout the profile whereas sub-surface horizons of all the profiles (except pedon 6) showed diffuse and wavy boundary. Similar results were reported by Thangasamy *et al.* (2005) and Rao *et al.* (2008).

4.4.5 Soil colour

In pedons 1, 3 and 4 the colour varied from dark reddish brown to yellowish red with a hue of 5 YR, value of 3 to 5 and chroma in the range of 3 to 6. The pedons 5, 6 and 7 exhibited brown to yellow colour with a hue varied from 7.5 YR to 10 YR, value ranged from 3 to 7 and chroma varied from 3 to 6. In case of pedon 2, the colour varied from pale brown to dark yellowish brown with a hue of 10 YR, value ranged from 3 to 6 and chroma in between 1 and 6.

The Munsell colour notation of hue, value and chroma were more or less similar in both moist and dry conditions. Occurance of iron oxides at various hydrated forms might have resulted in dark brown colour to the soils (Prakash and Rao, 2002). The colour appears to be the function of chemical and mineralogical composition of the soil (Swarnam *et al.,* 2004). These colours indicated the release of iron oxides and their occurrence in various hydrated forms due to difference in drainage of the soils (Walia and Rao, 1996). Similar findings were also reported by Thangasamy *et al.* (2005) and Sanjeev *et al*. (2005).

The dark matrix colour in the above pedons might be due to presence of high organic matter content (Tripathi *et al.,* 2006). The various shades of grey colour could be due to coagulation of iron and calcium with humus rather than poor drainage conditions (Najar *et al.,* 2009). Low chroma in surface horizons of some pedons was due to the fact that surface horizons were more moist than sub-surface horizons (Rao *et al.,* 2008).

4.4.6 Soil structure

Structure designates the mode of arrangement of the particles. This determines the spatial distribution of solid material and voids. Pedons 1 and 2 showed medium, moderate and sub-angular blocky to coarse, strong and angular blocky structure in surface and sub-surface horizons. Pedon 3 exhibited fine, weak and crumb in surface horizons whereas sub-surface horizons showed coarse, strong and angular blocky structure. Pedons 4, 5 and 6 exhibited fine, weak and crumb structure in surface horizons. The sub-surface horizons of pedon 5 exhibited fine to medium, moderate to strong and sub-angular blocky to angular blocky structure while sub-surface horizons of pedon 6 showed medium to coarse, moderate to strong and sub-angular blocky to angular blocky structure. Pedon 7 showed fine, structureless and single grain structure throughout the profile.

The structural variations in soils were useful to differentiate the horizon (Landay *et al.,* 1982). Soil structure observed in the field showed considerable variations among the pedons. The study area had single grain, crumb, sub-angular blocky and angular structure. The blocky structures *i.e.* angular and sub-angular blocky were attributed to the presence of higher quantities of clay fractions (Kadao *et al.,* 2003 and Leelavathi *et al.,* 2009). Crumb structure in the surface horizon of pedons 3, 4, 5 and 6 might be due to continuous addition of organic matter through vegetation. Structureless and single grain structure was found in pedon 7, might be due to inert nature of parent material. Similar results were observed in the Entisols of flood plains in Punjab which showed single grain structure in control section (Sidhu *et al.*, 1994).

4.4.7 Soil texture

Texture of surface horizons varied from sand to silty clay loam whereas in sub-surface horizons it varied from sand to clay loam. These variations were caused by topographic position, nature of parent material, *in-situ* weathering, translocation of clay and age of soils. Rayachaudhuri and Rajan (1971) reported that red soils of Andhra Pradesh were light in texture, being loamy to sandy but rarely clayey. The variation in texture of the soils was also mainly due to the differences in composition of parent materials (Nayak *et al.,* 2002). Krishnan *et al.* (2004) stated that Entisols of Lakshadweep islands were light textured, predominantly, sandy or loamy sand and occasionally sandy loam in texture. Similar results were also made by Walia and Rao (1997), Leelavathi *et al.* (2009) and Sireesha and Naidu (2013a).

4.4.8 Soil consistence

Soil consistence refers to manifestation of the physical forces of cohesion and adhesion acting within the soil at various levels of moisture. The consistence varied from soft to very hard, loose to very firm and non-sticky and non-plastic to very sticky and very plastic in dry, moist and wet conditions, respectively in different horizons of all the studied pedons.

This qualitative physical behaviour of soils, as influenced by dry, moist and wet conditions was not only due to the textural make up but also due to the type of clay minerals present in these soils. Presence of loose, friable and non-sticky and non-plastic or slightly sticky and slightly plastic consistence might be due to negligible or very small amount of expanding clay minerals. Similar findings were also reported by Thangasamy *et al.* (2004) in the soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh.

Sticky and plastic to very sticky and very plastic, firm to very firm and slightly hard to very hard consistence in wet, moist and dry conditions, respectively might be due to high clay content of the soils. Similar observations were also made by Lingade *et al.* (2008) and Sarkar *et al.* (2001) in soils of Nagpur of Maharashtra and in soils of lower outlier of Chhotanagpur plateau, respectively.

Sharma and Kumar (2003) noticed dry consistence in sandy loam to loamy soils varied from soft to hard whereas in loamy sand to silty clay loam soils it was loose to extremely hard in Maul Khad catchment of Himachal Pradesh. Similar findings were also made by Sharma *et al.* (2004a) in soils of Neogal watershed in north-west Himalayas.

Table 4.4. Summary of the morphological characters of the pedons

Pedon No.& Horizon	Depth (m)	Colour		Texture	Structure			Consistence			Effervescence	Boundary		Pores		Roots	
		Dry	Moist		S	G	T	Dry	Moist	Wet		D	T	S	Q	S	Q
Pedon 1																	
Ap	0.00.-0.20	5 YR 4/4	5 YR 3/4	scl	m	2	sbk	sh	f	sssp	-	c	s	f	f	f	f
A1	0.20-0.52	5YR 5/4	5 YR 4/4	cl	m	2	sbk	h	f	sp	-	c	s	f	f	f	f
Cr	0.52+	Weathered gneiss															
Pedon 2																	
Ap	0.00-0.18	10 YR 4/6	10 YR 3/4	sicl	m	2	sbk	h	f	sp	es	c	s	f	f	f	f
Bw1	0.18-0.33	10 YR 4/6	10 YR 4/6	cl	m	2	sbk	h	f	sp	es	c	s	f	f	-	-
Bw2	0.33-0.55	10 YR 4/3	10 YR 4/3	cl	c	3	abk	vh	vf	vssp	ev	c	s	-	-	-	-
Bw3	0.55-0.80	10 YR 5/3	10 YR 5/2	cl	c	3	abk	vh	vf	vssp	ev	d	w	-	-	-	-
Bw4	0.80-1.15	10 YR 6/3	10 YR 4/2	cl	c	3	abk	vh	vf	vssp	ev	d	w	-	-	-	-
Bw5	1.15-1.50+	10 YR 4/3	10 YR 4/1	cl	c	3	abk	vh	vf	vssp	ev	d	w	-	-	-	-
Pedon 3																	
Ap	0.00-0.20	5 YR 5/3	5 YR 4/2	sl	f	1	cr	sh	fr	sssp	-	c	s	f	f	f	f
A1	0.20-0.33	5 YR 4/3	5 YR 4/3	scl	m	2	sbk	sh	fi	sp	-	c	s	f	f	-	-
A2	0.33-0.52	5 YR 5/4	5 YR 4/4	cl	c	3	abk	h	vfi	vsvp	-	c	s	-	-	-	-
Cr	0.52+	Weathered gneiss															
Pedon 4																	
Ap	0.00-0.25	5 YR 5/4	5 YR 4/4	scl	f	1	cr	s	fr	sssp	-	c	s	f	f	f	f
A1	0.25-0.55	5 YR 5/6	5 YR 4/6	scl	m	2	sbk	sh	fi	sssp	-	c	s	f	f	f	f
Cr	0.55+	Weathered gneiss															
Pedon 5																	
Ap	0.00-0.21	10 YR 5/4	10 YR 5/4	scl	f	1	cr	sh	fr	sssp	-	c	s	f	f	f	f
A1	0.21-0.35	10 YR 6/4	10 YR 4/4	scl	f	2	sbk	sh	fi	sp	-	c	s	f	f	f	f
Bw1	0.35-0.57	7.5YR 5/4	7.5YR 4/4	cl	m	3	abk	h	vf	vsvp	-	d	w	-	-	-	-
Bw2	0.57-0.78	7.5YR 5/4	7.5YR 4/3	cl	m	3	abk	h	vf	vsvp	-	d	w	-	-	-	-
Bw3	0.78-1.00	7.5YR 5/4	7.5YR 4/3	cl	m	3	abk	h	vf	vsvp	-	d	w	-	-	-	-
Cr	1.00+	Weathered gneiss															

Cont…

Table 4.4 (Cont.).

Pedon No.& Horizon	Depth (m)	Colour		Texture	Structure			Consistence			Effervescence	Boundary		Pores			Roots	
		Dry	Moist		S	G	T	Dry	Moist	Wet		D	T	S	Q		S	Q
Pedon 6																		
Ap	0.00-0.27	10 YR 6/6	10 YR 6/6	scl	f	1	cr	sh	fr	sssp	-	c	s	f	f		f	f
A1	0.27-0.37	7.5 YR 5/2	10 YR 7/4	scl	m	2	sbk	sh	fi	Sp	-	c	s	f	f		f	f
A2	0.37-0.58	10 YR 6/4	10 YR 6/4	scl	c	3	abk	h	vfi	Sp	-	c	s	-	-		f	f
Bw1	0.58-0.78	10 YR 7/4	10 YR 6/4	sicl	c	3	abk	vh	vfi	Sp	-	c	s	-	-		-	-
Bw2	0.78-0.91	10 YR 6/3	10 YR 6/2	sicl	c	3	abk	vh	vfi	Sp	-	c	s	-	-		-	-
Bw3	0.91-1.20	7.5YR 5/4	10 YR 7/2	sicl	c	3	abk	vh	vfi	Sp	-	c	s	-	-		-	-
Bw4	1.20-1.50+	10 YR 6/3	10 YR 6/3	sicl	c	3	abk	vh	vfi	Sp	-	c	s	-	-		-	-
Pedon 7																		
Ap	0.00-0.30	7.5 YR 5/4	10 YR 7/6	s	f	0	sg	l	l	sopo	-	c	s	f	m		f	f
A1	0.30-0.58	7.5 YR 5/4	10 YR 6/4	s	f	0	sg	l	l	sopo	-	c	s	f	f		f	f
A2	0.58-0.80	10 YR 6/4	10 YR 6/4	s	f	0	sg	l	l	sopo	-	d	w	-	-		-	-
A3	0.80-0.98	10 YR 6/4	10 YR 6/2	s	f	0	sg	l	l	sopo	-	d	w	-	-		-	-
A4	0.98-1.27	10 YR 6/4	10 YR 6/1	s	f	0	sg	l	l	sopo	-	d	w	-	-	-	-	-
A5	1.27-1.48	10 YR 7/4	10 YR 7/1	s	f	0	sg	l	l	sopo	-	d	w	-	-	-	-	-
A6	1.48-1.90+	10 YR 7/4	10 YR 7/1	s	f	0	sg	l	l	sopo	-	d	w	-	-	-	-	-

Texture: c – clay, cl – clay loam, l – loam, s – sand, sl – sandy loam, scl – sandy clay loam, sc – sandy clay, ls – loamy sand
Structure: Size (S) – vf – very fine, f – fine, m – medium, c – coarse; Grade (G) – O – structureless, l – weak, 2 – moderate, 3 – strong; Type (T) cr – crumb, sg – single grain, abk – angular blocky, sbk – sub-angular blocky.
Consistence:
Dry: s – soft, l – loose, sh – slightly hard, h – hard, vh – very hard
Moist: l – loose, fr – friable, fi – firm, vfi – very firm
Wet: so – non-sticky, ss – slightly sticky, s – sticky, vs – very sticky; po – non-plastic, ps – slightly plastic, p – plastic, vp – very plastic
Cutans: Ty – type – t – Argillan, Th – Thickness, tn – thin, th – thick, Quantity (Q), p – patchy, c – continuous
Pores: Size (S) f – fine, m- medium, c- coarse; Q – Quantity, f – few, c – common, m - many
Roots: Size (S) f – fine, m- medium, c- coarse; Q – Quantity, f – few, c – common, m - many
Effervescence: es – strong effervescence, ev – violent effervescence
Boundary: D – Distinctness, c – clear, g – gradual, d – diffuse
T – Topography; s – smooth; w – wavy

4.4.9 Porosity

The pores were fine in size and few to many in quantity in different layers of the pedons. High porosity of these soils was due to finer texture of the soils. The porosity in general indicated that the drainage varied from poorly drained to well- drained.

4.4.10 Roots

Roots were abundant in surface layers and decreased with depth. Further, the roots in different horizons of pedons were fine to few in size and quantity. Root distribution indicated that vegetation of the area comprises of annuals and grasses.

4.5 IMPORTANT MORPHOLOGICAL CHARACTERS OF THE TYPIFYING PEDONS

4.5.1 Pedon 1

This pedon was moderately deep in depth extending beyond 0.52 m with three horizons *viz.,* Ap, A1 and Cr. This pedon had reddish brown to dark reddish brown in colour and sandy clay loam to clay loam in texture. Further, surface and sub-surface horizons exhibited medium, moderate and sub-angular blocky structure. Slightly hard to hard, firm and slightly sticky and slightly plastic to sticky and plastic consistence in dry, moist and wet conditions, respectively. Fine and few pores and few and fine roots were noticed. All the horizons showed clear and smooth boundary **(Plate 1)**.

4.5.2 Pedon 2

This pedon was very deep and extending beyond 1.50 m with six horizons *viz.,* Ap, Bw1, Bw2, Bw3, Bw4 and Bw5. This pedon had pale brown to dark yellowish brown in colour and silty clay loam to clay loam in texture. Surface horizon showed medium, moderate and sub-angular blocky

Depth (m) and Horizon		Texture	pH	Colour
Ap	0.00 – 0.20	cl	6.60	5 YR 4/4
A1	0.20 – 0.52	cl	6.73	5 YR 5/4
Cr	0.52			

Pedon 1

Depth (m) and Horizon		Texture	pH	Colour
Ap	0.00 – 0.18	sicl	7.43	10 YR 4/6
Bw1	0.18 – 0.33	cl	7.93	10 YR 4/6
Bw2	0.33 – 0.55	cl	8.40	10 YR 4/3
Bw3	0.55 – 0.80	cl	8.50	10 YR 5/3
Bw4	0.80 – 1.15	cl	8.20	10 YR 6/3
Bw5	1.15 – 1.50+	cl	8.40	10 YR 4/3

Pedon 2

Fig. 4.3: PROFILE DIAGRAMS

Plate 4.1. Pedon 1

Plate 4.2. Pedon 2

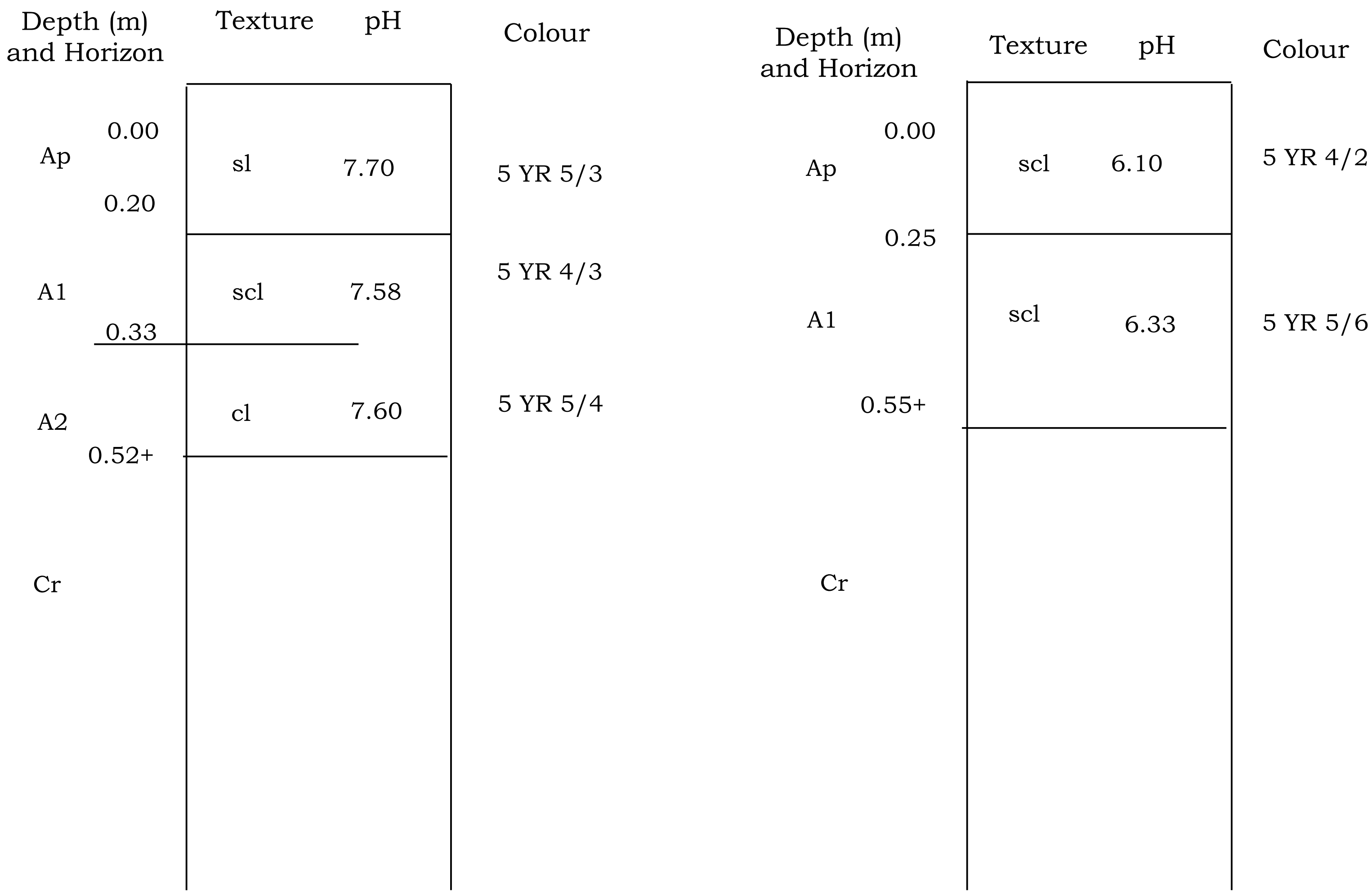
whereas sub-surface horizons exhibited coarse, strong and angular blocky structure. Hard to very hard, firm to very firm and slightly sticky slightly plastic to very sticky slightly plastic consistence in dry, moist and wet conditions, respectively. Strong to violent effervescence. Fine and few pores and few and fine roots were noticed. The surface horizon showed clear and smooth boundary and sub-surface horizons exhibited diffuse and wavy boundary **(Plate 2)**.

4.5.3 Pedon 3

This pedon was moderately deep in depth and extending beyond 0.52 m with four horizons *viz.*, Ap, A1, A2 and Cr. This pedon had reddish brown to dark reddish brown in colour and showed sandy loam, sandy clay loam and clay loam texture. Further, surface horizon showed fine, weak and crumb whereas sub-surface horizons exhibited medium to coarse, moderate to strong and angular blocky structure. Slightly hard to hard, friable to very firm and slightly sticky and slightly plastic to very sticky and very plastic consistence in dry, moist and wet conditions, respectively. Fine and few pores and few and fine roots were noticed. The surface and sub-surface horizons showed clear and smooth boundary **(Plate 3)**.

4.5.4 Pedon 4

This pedon was also moderately deep extending beyond 0.55 m with three horizons *viz.*, Ap, A1 and Cr. This pedon had yellowish red to reddish brown in colour and sandy clay in texture. Further, surface horizons showed fine, weak and crumb structure while sub-surface horizons exhibited medium, moderate and sub-angular blocky structure. Soft to slightly hard, friable to firm and slightly sticky and slightly plastic consistence in dry, moist and wet conditions, respectively. Fine and few pores and few and fine roots were noticed. All the horizons showed clear and smooth boundary **(Plate 4)**.



Pedon 3 **Pedon 4**

Fig. 4.4: PROFILE DIAGRAMS

Plate 4.3. Pedon 3

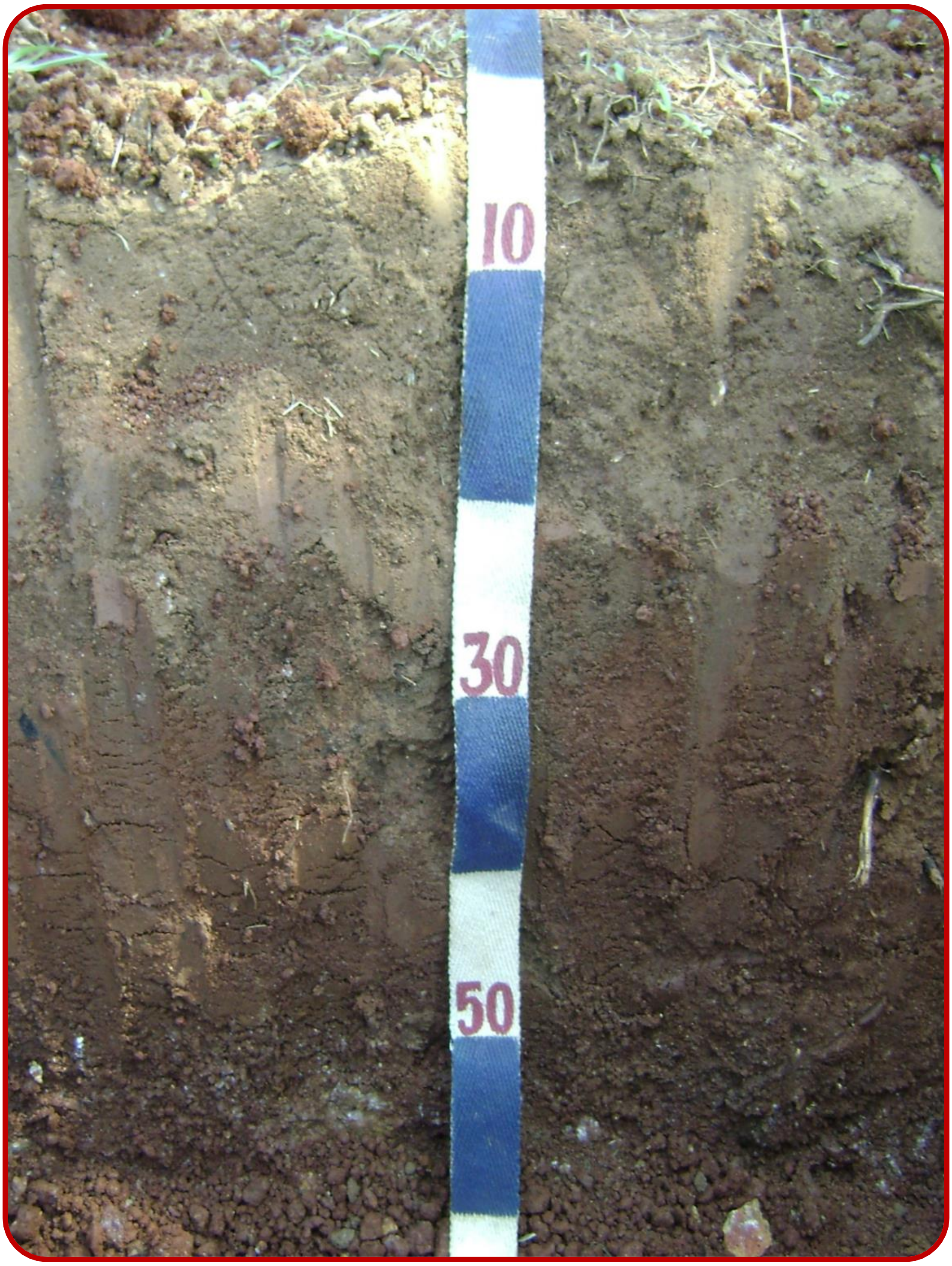


Plate 4.3. Pedon 3

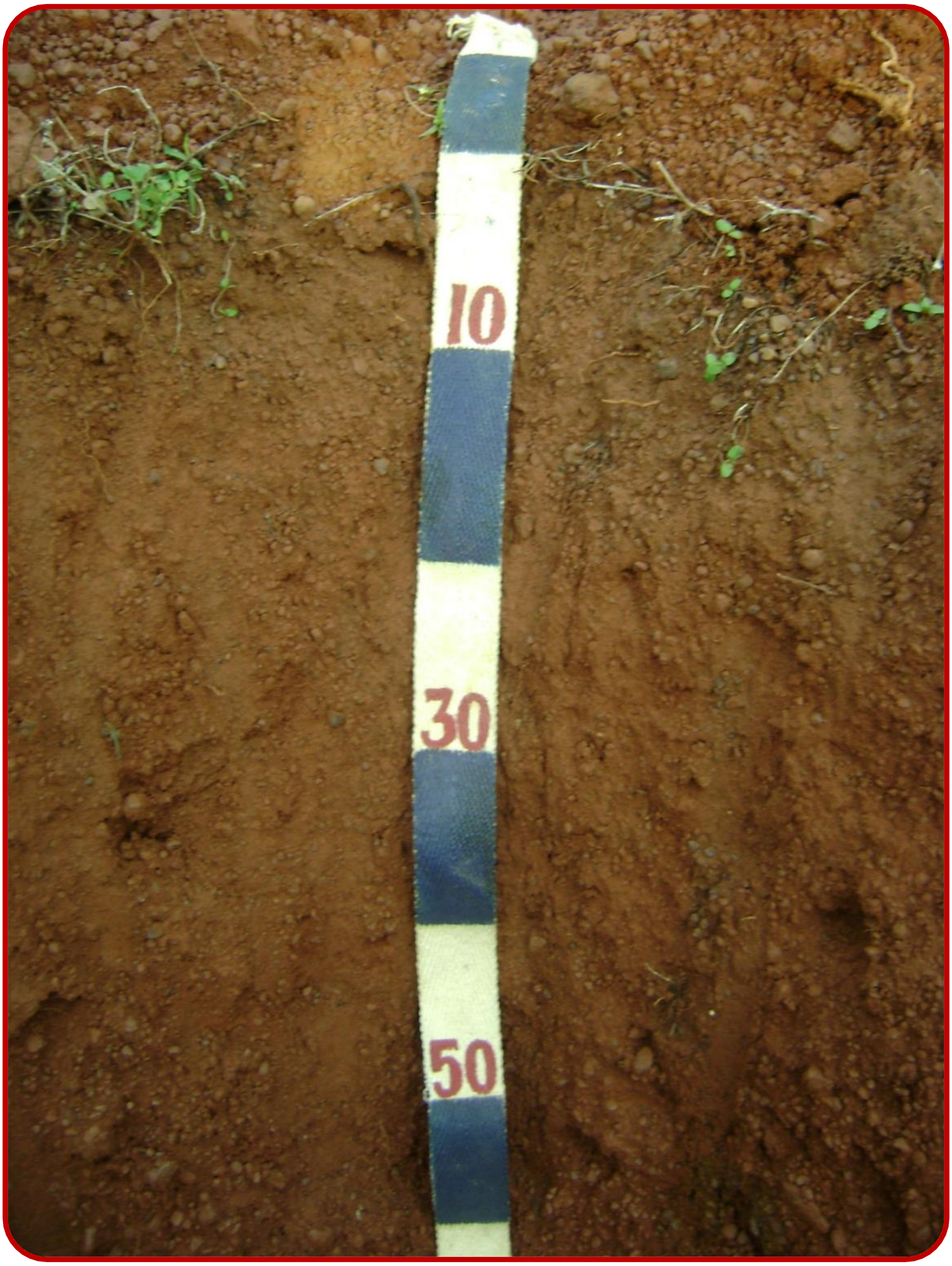


Plate 4.4. Pedon 4

4.5.5 Pedon 5

This pedon was very deep extending beyond 1.00 m with six horizons *viz.*, Ap, A1, Bw1, Bw2, Bw3 and Cr. This pedon had light yellowish brown to brown in colour and sandy clay loam to clay loam in texture. Further, surface horizons showed fine, weak and crumb structure whereas sub-surface horizons showed fine to medium, moderate to strong and sub-angular blocky structure. Slightly hard to hard, friable to firm, slightly sticky and slightly plastic to very sticky and very plastic consistence in dry, moist and wet conditions, respectively. Fine and few pores and few and fine roots were noticed. The surface horizon showed clear and smooth boundary whereas sub-surface horizons exhibited diffuse and wavy boundary **(Plate 5)**.

4.5.6 Pedon 6

This pedon was very deep extending beyond 1.50 m with seven horizons *viz.*, Ap, A1, A2, Bw1, Bw2 Bw3 and Bw4. This pedon had brown to brownish yellow in colour and sandy clay loam to silty clay loam in texture. Further, surface horizons exhibited, fine, weak and crumb structure and sub-surface horizons exhibited medium to coarse, moderate to strong and sub-angular blocky to angular blocky structure. Surface horizons exhibited slightly hard, friable and slightly sticky and slightly plastic whereas sub-surface horizons showed slightly hard to very hard, firm to very firm and sticky and plastic consistence in dry, moist and wet conditions, respectively. Fine and few pores and few and fine roots were noticed. All the horizons showed clear and smooth boundary **(Plate 6)**.

4.5.7 Pedon 7

This pedon was very deep extending beyond 1.90 m with seven horizons *viz.*, Ap, A1, A2, A3, A4, A5 and A6. This pedon had brown to yellow in colour and sandy in texture. The surface and sub-surface horizons exhibited fine, structureless and single grain structure. Loose consistence in

Pedon 5

Depth (m)	Horizon	Texture	pH	Colour
0.00–0.21	Ap	scl	6.20	10 YR 4/2
0.21–0.35	A1	scl	6.21	10 YR 5/2
0.35–0.57	Bw1	cl	6.38	7.5 YR 5/4
0.57–0.78	Bw2	cl	6.17	7.5 YR 5/4
0.78–1.00+	Bw3	cl	6.60	7.5 YR 5/4
1.00+	Cr			

Pedon 6

Depth (m)	Horizon	Texture	pH	Colour
0.00–0.27	Ap	scl	6.30	10 YR 6/6
0.27–0.37	A1	scl	6.80	7.5 YR 5/2
0.37–0.58	A2	scl	7.12	10 YR 6/4
0.58–0.78	Bw1	sicl	7.24	10 YR 7/4
0.78–0.91	Bw2	sicl	7.28	10 YR 6/3
0.91–1.20	Bw3	sicl	7.20	7.5 YR 5/4
1.20–1.50+	Bw4	sicl	6.90	10 YR 6/3

Fig. 4.5: PROFILE DIAGRAMS

Depth (m) and Horizon		Texture	pH	Colour
Ap	0.00–0.30	s	6.23	7.5 YR 5/4
A1	0.30–0.58	s	6.40	7.5 YR 5/4
A2	0.58–0.80	s	6.45	10 YR 6/4
A3	0.80–0.98	s	6.50	10 YR 6/4
A4	0.98–1.27	s	6.20	10 YR 7/4
A5	1.27–1.48	s	6.10	10 YR 7/4
A6	1.48–1.90	s	7.50	10 YR 7/4

Pedon 7

Fig. 4.6: PROFILE DIAGRAMS

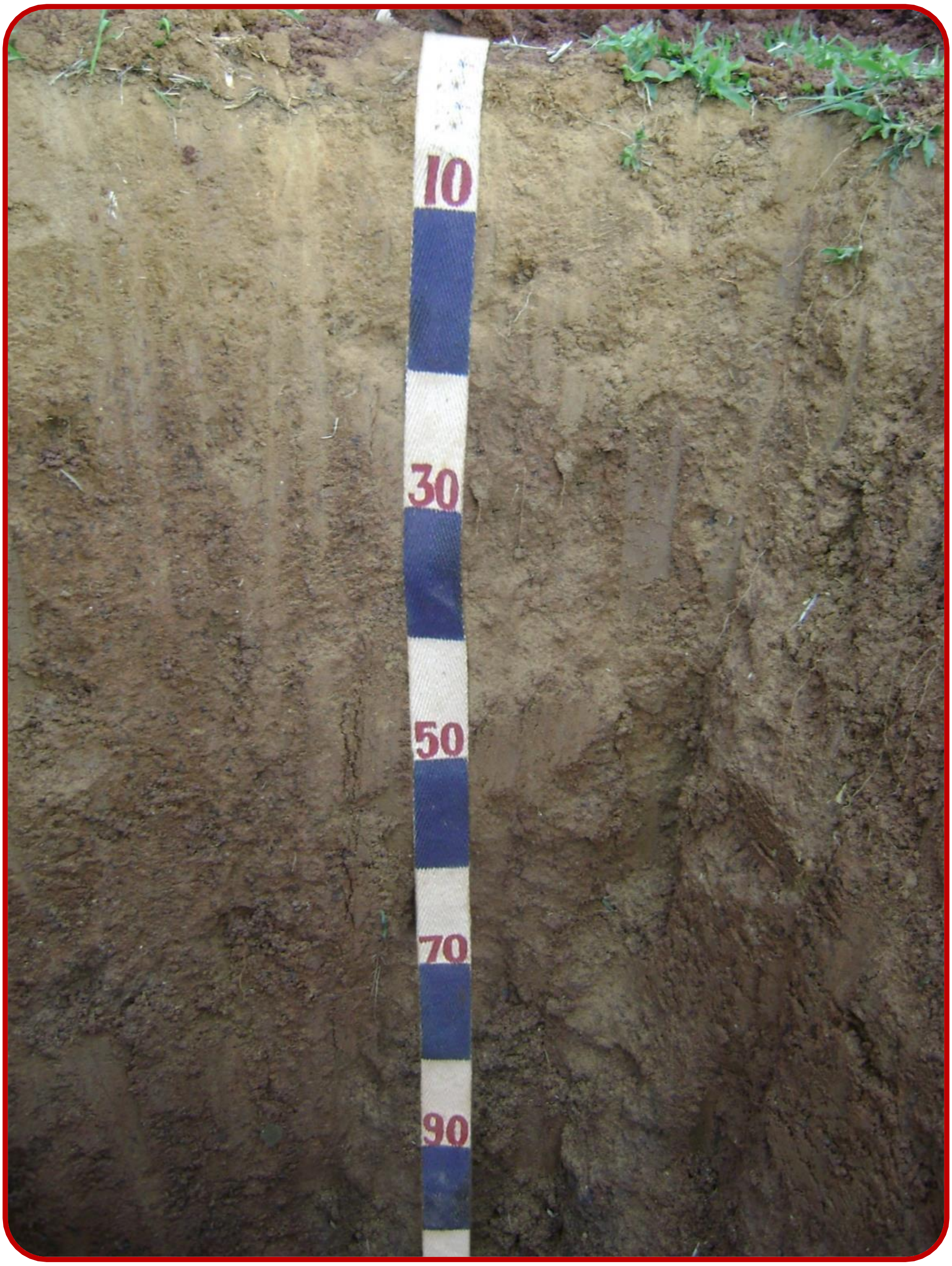


Plate 4.5. Pedon 5

Plate 4.6. Pedon 6

Plate 4.7. Pedon 7

dry and moist conditions whereas non-sticky and non-plastic consistence in wet conditions. Fine and few pores and few and fine roots were noticed. The surface horizon showed clear and smooth boundary whereas sub-surface horizons showed diffuse and wavy boundary **(Plate 7)**.

LABORATORY ANALYSIS DATA

4.6 PHYSICAL PROPERTIES

Physical characteristics of the soils *viz.*, particle size, bulk density, particle density, water holding capacity, pore space, volume expansion and loss on ignition were presented in Tables 4.5, 4.6, 4.7 and 4.8 and depth functions were presented in Figures 4.7 and 4.8.

4.6.1 Particle size analysis

The results of particle size analysis were presented in Tables 4.5 and 4.6 and depth functions were depicted in the Figures 4.7 and 4.8.

4.6.1.1 Clay (< 2 microns) fraction

The clay content was ranged from 5.20 to 38.30 per cent. The highest amount of clay was observed in Bw3 and Bw2 horizons of pedons 2 and 5, respectively while the lowest clay content was recorded in A1 horizon of pedon 7. Pedons 1 and 4 exhibited a decreasing trend with depth. Pedons 5 and 6 showed an increasing trend up to Bw2 and Bw3 horizons, respectively and later on a decreasing trend with depth. Pedon 3 showed an increasing trend with depth. However, no specific trend with depth was observed in pedons 2 and 7. The mean clay content in all these pedons varied from 5.75 (Pedon 7) to 33.45 (Pedon 2) per cent.

The decrease in clay content with depth in pedons 1 and 4 might be due to variability of weathering in different horizons. These results were in accordance with the findings of Prakash (1997) and Leelavathi *et al.* (2009)

Table 4.5. Particle size analysis of soils (< 2 mm size)

Pedon No. & Horizon	Depth (m)	Sand Silt Clay (%)			Textural class	Sand/Silt	Silt/Clay	Sand/Silt+clay
Pedon 1								
Ap	0.00-0.20	49.10	22.30	28.60	scl	2.20	0.78	0.96
A1	0.20-0.52	25.40	40.70	33.90	cl	0.62	1. 20	0.34
Cr	0.52+	Weathered gneiss						
Pedon 2								
Ap	0.00-0.18	15.70	53.80	30.50	sicl	0.29	1.76	0.19
Bw1	0.18-0.33	43.70	27.70	28.60	cl	1.58	0.97	0.78
Bw2	0.33-0.55	41.60	25.80	32.60	cl	1.61	0.79	0.71
Bw3	0.55-0.80	37.70	24.00	38.30	cl	1.57	0.63	0.61
Bw4	0.80-1.15	38.00	29.70	32.30	cl	1.28	0.92	0.61
Bw5	1.15-1.50+	41.00	28.20	30.80	cl	1.45	0.92	0.69
Pedon 3								
Ap	0.00-0.20	54.00	33.60	12.40	sl	1.61	2.71	1.17
A1	0.20-0.33	49.80	23.80	26.40	scl	2.09	0.90	0.99
A2	0.33-0.52	50.30	18.50	34.60	cl	2.72	0.53	0.95
Cr	0.52+	Weathered gneiss						
Pedon 4								
Ap	0.00-0.25	33.30	32.10	31.20	scl	1.04	1.03	0.53
A1	0.25-0.55	62.30	15.60	22.10	scl	3.99	0.71	1.65
Cr	0.55+	Weathered gneiss						
Pedon 5								
Ap	0.00-0.21	55.20	21.10	23.70	scl	2.62	0.89	1.23
A1	0.21-0.35	51.50	19.10	29.40	scl	2.70	0.65	1.06
Bw1	0.35-0.57	33.20	28.50	32.10	cl	1.16	0.89	0.55
Bw2	0.57-0.78	42.30	25.60	38.30	cl	1.65	0.67	0.66
Bw3	0.78-1.00	40.60	28.40	31.00	cl	1.43	0.92	0.68
Cr	1.00+	Weathered gneiss						
Pedon 6								
Ap	0.00-0.27	58.70	18.20	23.10	scl	3.23	0.79	1.42
A1	0.27-0.37	54.80	20.40	24.10	scl	2.69	0.85	1.23
A2	0.37-0.58	52.40	21.70	25.90	scl	2.41	0.84	1.10
Bw1	0.58-0.78	18.70	50.40	30.90	sicl	0.37	1.63	0.23
Bw2	0.78-0.91	17.40	52.60	30.00	sicl	0.33	1.75	0.21
Bw3	0.91-1.20	15.20	53.40	31.40	sicl	0.28	1.70	0.18
Bw4	1.20-1.50+	14.30	55.00	30.70	sicl	0.26	1.79	0.17
Pedon 7								
Ap	0.00-0.30	88.4	5.30	6.30	s	16.68	0.84	7.62
A1	0.30-0.58	90.6	4.20	5.20	s	21.57	0.81	9.64
A2	0.58-0.80	90.5	3.70	5.80	s	24.46	0.64	9.53
A3	0.80-0.98	90.6	3.20	6.20	s	28.31	0.52	9.64
A4	0.98-1.27	89.6	4.30	6.10	s	20.84	0.70	8.62
A5	1.27-1.48	90.6	3.70	5.70	s	24.49	0.65	9.64
A6	1.48-1.90+	91.2	3.30	5.50	s	27.64	0.60	10.36

Table 4.6. Range and mean of particle size analysis of the soils

Pedon No.	Range & Mean	Sand (%)	Silt (%)	Clay (%)	Sand/Silt	Silt/Clay	Sand / Silt + Clay
1	Range	25.40-49.10	22.30-40.70	28.60-33.90	0.62-2.20	0.78-1.20	0.34-0.96
	Mean	37.25	31.50	31.25	1.41	0.99	0.65
2	Range	15.70-43.70	24.00-53.80	28.60-38.30	0.29-1.61	0.63-1.76	0.19-0.78
	Mean	29.70	38.90	33.45	0.95	1.20	0.49
3	Range	49.80-54.00	18.50-33.60	12.40-34.60	1.61-2.72	0.53-2.71	0.95-1.17
	Mean	51.90	26.05	23.50	2.17	1.62	1.06
4	Range	33.30-62.30	15.60-32.10	22.10-31.20	1.04-3.99	0.71-1.03	0.53-1.65
	Mean	56.80	23.85	26.65	2.52	0.87	1.35
5	Range	33.20-55.20	19.10-28.50	23.70-38.30	1.16-2.70	0.65-0.92	0.55-1.23
	Mean	44.35	23.80	31.00	1.93	0.79	1.09
6	Range	14.30-58.70	18.20-55.00	23.10-31.40	0.26-3.23	0.79-1.79	0.17-1.42
	Mean	36.50	36.60	27.25	1.75	1.29	0.80
7	Range	88.40-91.20	3.20-5.30	5.20-6.30	16.68-28.31	0.52-0.84	7.62-10.36
	Mean	89.80	4.25	5.75	22.50	0.68	8.99

who reported an irregular decrease of clay content with depth in soils of Gudiyatham taluk in Tamil Nadu and also soils in Yerpedu mandal in Chittoor district, respectively.

Increase in clay content with depth in pedons 3 and 5 might be due to more intensive weathering at deeper layers and impoverishment of finer particles from surface horizons leaving behind coarse sand particles in surface horizons. Kumar and Naidu (2012a) observed an increase in clay content in sub-surface horizons as compared to surface horizons in soils of Vadamalapeta mandal of Chittoor district in Andhra Pradesh.

4.6.1.2 Silt (0.002 to 0.05 mm) fraction

The silt content was ranged from 3.20 to 55.00 per cent. The highest amount of silt was observed in Bw4 horizon of pedon 6 while the lowest was recorded in A3 horizon of pedon 7. Pedons 1 and 6 exhibited an increasing trend with depth while pedons 3 and 4 showed a decreasing trend with depth. Pedon 7 showed a decreasing trend up to A3 horizon and later on an increasing trend with depth. However, no specific trend with depth was observed in pedons 2 and 5. The mean silt content in all these pedons varied from 4.25 (Pedon7) to 38.90 (Pedon 2) per cent.

Irregular distribution of silt might be due to variation in weathering of parent material or *in-situ* formation. These results were in agreement with the findings of Naidu (2002) who noticed an irregular trend in silt content with depth in some sugarcane growing soils of Karnataka.

4.6.1.3 Sand (0.05 to 2.00 mm) fraction

The sand content was ranged from 14.30 to 91.20 per cent. The highest amount of sand was observed in A6 horizon of pedon 7 while the lowest content was recorded in Bw4 horizon of pedon 6. Pedons 1, 5 and 6 exhibited a decreasing trend with depth whereas pedons 4 and 7 exhibited an increasing trend with depth. However, no specific trend with depth was observed in pedons 2 and 3. The mean sand content in all these pedons varied from 29.70 (Pedon 2) to 89.80 (Pedon 7) per cent.

Pedons 4 and 7 showed an increasing trend with depth. Higher sand content in these soils could be attributed to the dominance of physical weathering of parent material and dominance of alluvial parent material (Pedon 7) in the study area. Similar findings were also made by Basavaraju *et al*. (2005) and Rao *et al*. (2008).

4.6.1.4 Ratios of different soil fractions

4.6.1.4.1 Sand / Silt ratio

The values of sand / silt ratio ranged from 0.26 (Pedon 6) to 28.31 (Pedon 7). The mean values of sand / silt ratio *i.e.*, 1.41 to 22.50 were recorded in pedons 1 and 7, respectively. In pedons 1 and 6 the values showed a decreasing trend with depth whereas pedons 3 and 4 showed an increasing trend with depth. Further, pedons 2, 5 and 7 did not show any specific trend with depth.

4.6.1.4.2 Silt / Clay ratio

The values of silt / clay ratio ranged from 0.52 (Pedon 7) to 2.71(Pedon 3). The mean values of silt / clay ratio *i.e.*, 0.68 to 1.62 were registered in pedons 7 and 3, respectively. Pedon 1 exhibited an increasing trend with depth whereas pedons 3 and 4 showed a decreasing trend with depth. However, pedons 2, 5, 6 and 7 did not show any specific trend with depth.

4.6.1.4.3 Sand / Silt + Clay ratio

The ratio ranged from 0.17 (pedon 6) to 10.36 (pedon 7). The mean values ranged from 0.49 to 8.99, which were registered in pedons 2 and 7,

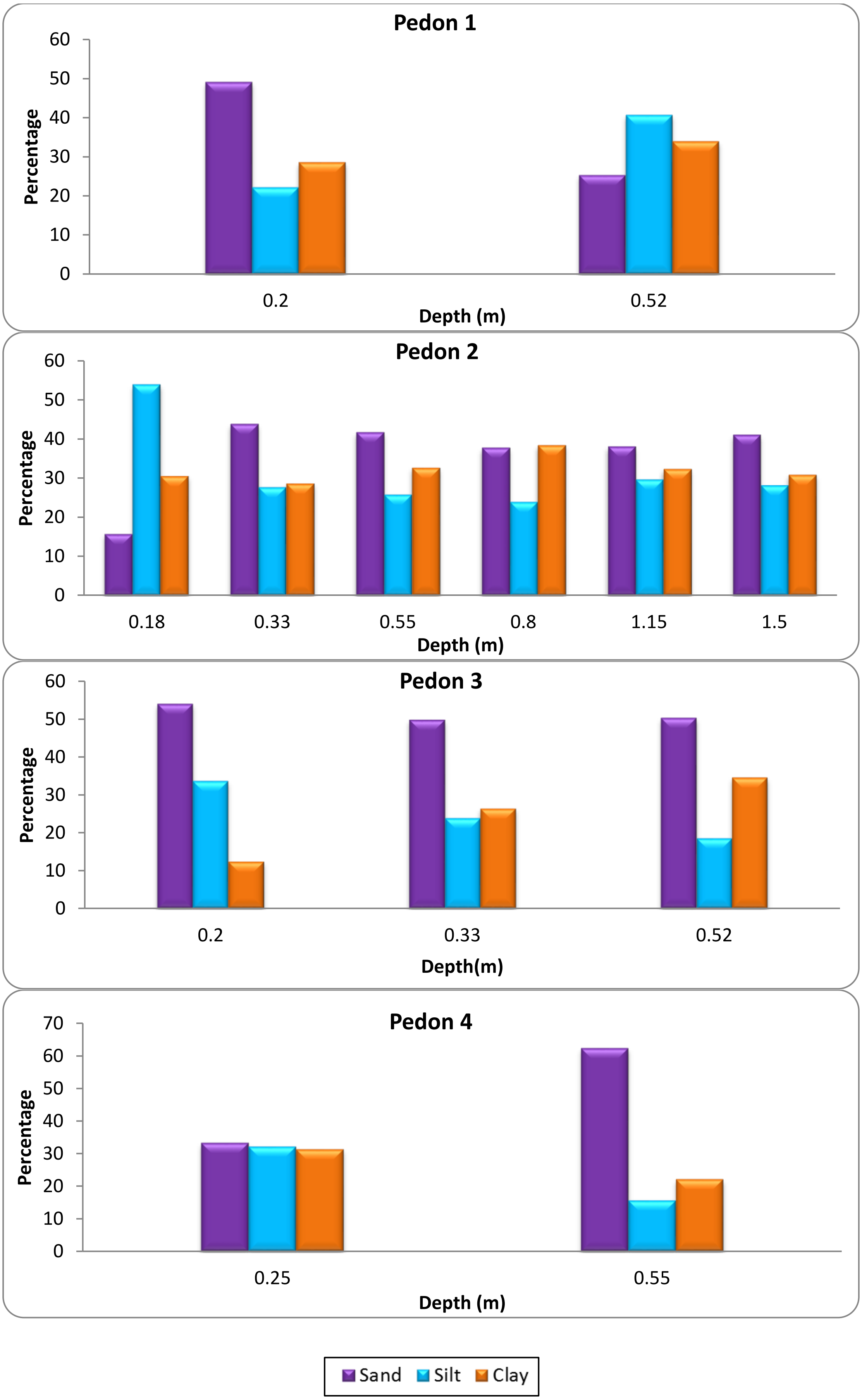


Fig. 4.7. Vertical distribution of soil particles

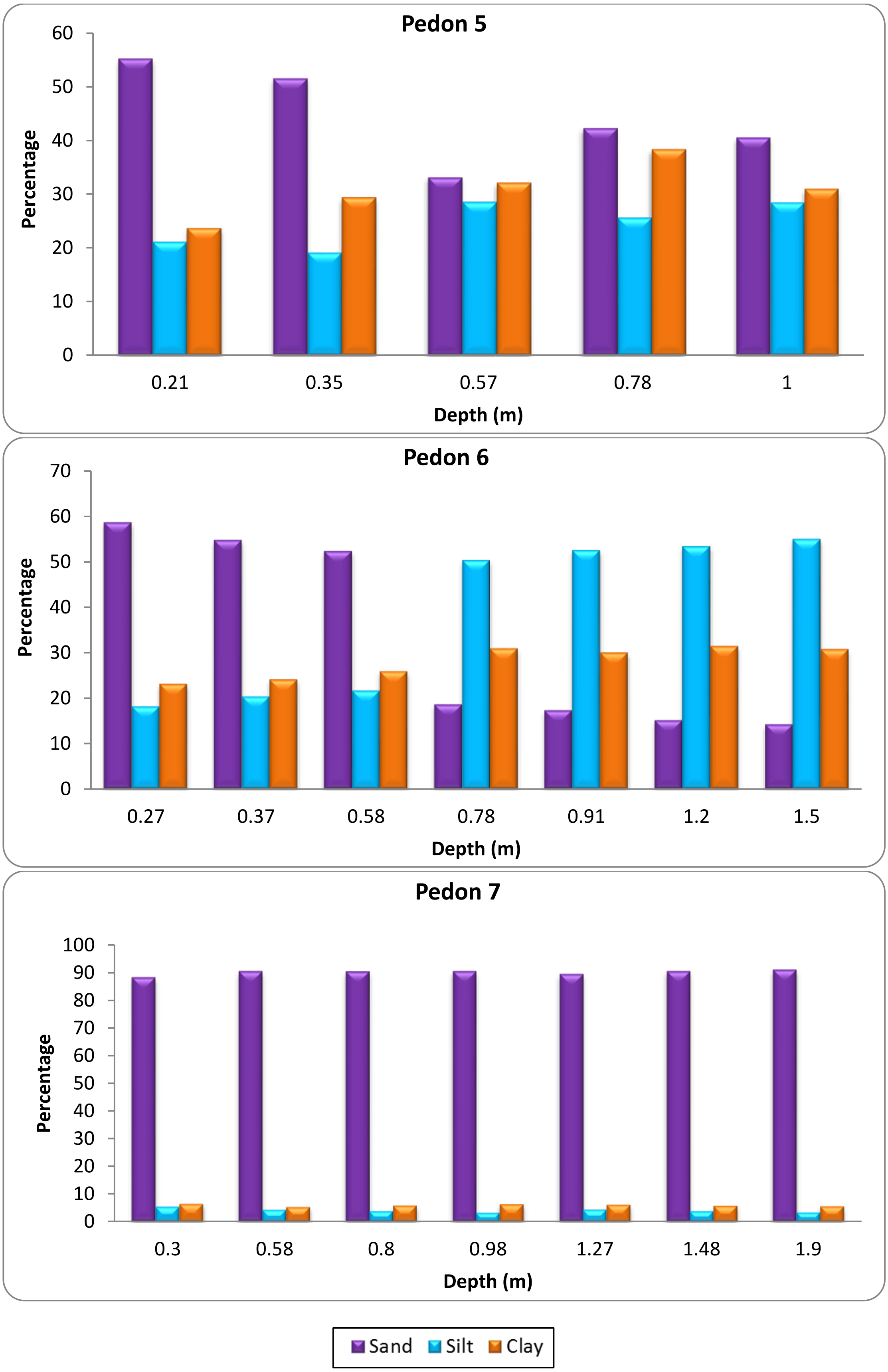


Fig. 4.8. Vertical distribution of soil particles

respectively. Pedons 5 and 6 showed a decreasing trend while pedon 4 exhibited an increasing trend with depth. However, pedons 1, 2, 3 and 7 did not show any specific trend with depth.

The sand-silt ratio increased with depth in pedons 3, 4 and 7 was due to deposition of alluvial materials (Gangopadhyay *et al.*, 1998). Similar observations were also made by Singh and Agrawal (2005) in rice growing soils of Eastern region of Varanasi, Uttar Pradesh.

According to higher silt / clay ratio revealed. Pedons 1, 5 and 6 showed high silt / clay ratio in sub-surface horizons as compared to surface horizons. This higher silt / clay in sub-surface horizons might be due to slightly higher rate of weathering due to the presence of soil water for fairly long time as compared to the surface horizons (Raghuwanshi *et al.*, 2011).

4.6.2 Physical constants

The results of physical constants were presented in Tables 4.7 and 4.8.

4.6.2.1 Bulk density

Bulk density values of different layers in these seven pedons varied from 1.22 to 1.85 Mg m^{-3}. The highest value of 1.85 Mg m^{-3} was recorded in A4 horizon of pedon 7 and the lowest value was noticed in Ap horizon of pedon 4. The mean values ranged from 1.23 to 1.80 Mg m^{-3} and were registered in pedons 4 and 7, respectively. Pedon 4 showed an increasing trend with depth. Pedon 1 exhibited a decreasing trend with depth whereas remaining pedons did not show any specific trend with depth.

The higher bulk density values of soils was due to their coarse texture and in some cases due to the presence of calcium carbonate and low organic carbon content. Similar results were reported by Sharma *et al.* (1994) in lower Siwaliks of Himachal Pradesh. Variation in bulk density of these soils was attributed to the moisture content and high content of expanding type of clay minerals. Similar results were obtained by Prakash and Rao (2002), Sharma and Kumar (2003), Swarnam *et al.* (2004) and Basavaraju *et al.* (2005) in red soils of Krishna district of Andhra Pradesh, Maul Khad catchment of Himachal Pradesh, in the Entisols and Inceptisols of Shahibi basin in Haryana and Delhi and in the soils of Chandragiri mandal in Chittoor district of Andhra Pradesh, respectively.

Sub-surface horizons exhibited higher bulk density values as compared to surface horizons. High bulk density values in the sub-surface could be ascribed to decreased organic matter and secondary accumulation of illuviated clays in pores space. Similar results were reported by Ram *et al.* (2010).

Low bulk density of surface soils could be attributed to higher organic matter content. This was evident from the negative (r = -0.329) correlation of bulk density with organic carbon. But its progressive increase with depth was probably related to increase in coarse fragments of soils or filling of pores by eluvial materials leading to compaction as noticed by negative correlation of bulk density (r = -0.340) with pore space. Similar results were reported by Walia and Rao (1996) in Bundelkhand region of Uttar Pradesh.

4.6.2.2 Particle density

Particle density values of different layers in these seven pedons varied from 2.18 to 2.87 Mg m^{-3}. The highest value of 2.87 Mg m^{-3} was recorded in A6 horizon of pedon 7 whereas A1 horizon of pedon 3 exhibited the lowest value. The mean values ranged from 2.22 to 2.67 Mg m^{-3} were registered in pedons 4 and 7, respectively. In pedon 1 the values showed an increasing trend and in pedon 4, the values exhibited a decreasing trend with depth. Pedons 2, 3, 5, 6 and 7 did not show any specific trend with depth.

Further, particle density did not show any trend with depth and more or less uniform values were recorded in all the pedons. Gurumurthy *et al.* (1996) observed more or less uniform particle density in soils of Giddalur mandal in Prakasam district of Andhra Pradesh.

4.6.2.3 Pore space

Pore space in all the pedons was ranged from 20.14 to 51.42 per cent. The mean values *i.e.*, 22.5 to 46.37 were registered in pedons 7 and 2, respectively. Pedon 1 showed an increasing trend with depth while pedons 3 and 4 exhibited a decreasing trend with depth. However, pedons 5, 6 and 7 did not show any specific trend with depth. This corroborates the study of Gurumurthy *et al.* (1996). Walia and Rao (1996) stated that a decrease in pore space with depth might be due to increase in coarse fraction or coarse fragments in Inceptisols and Entisols.

4.6.2.4 Water holding capacity

The values of water holding capacity varied from 13.82 to 46.24 per cent. The mean values ranged from 16.28 to 41.24 per cent were registered in pedons 7 and 2, respectively. Pedon 1 exhibited an increasing trend with depth. Pedon 4 exhibited a decreasing trend with depth whereas pedons 2 and 5 showed a increasing trend with depth up to Bw4 and Bw2 horizons, respectively later on increased with depth. However, pedons 3, 6 and 7 showed an irregular trend with depth. These differences in water holding capacity were due to variation in the depth, clay, silt and organic carbon content of the pedons. These results were coincided with those of Singh *et al.* (1999) in soils of Ramganga catchment in Uttar Pradesh. Similar results were reported by Thangasamy *et al.* (2005) in soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh. Water holding capacity was very less in sandy soils due to high sand and less clay content as evidenced by significant and negative correlation (r = -0.721**) between water holding capacity and sand content. Rao and Prasadini (1998) also observed similar type of negative correlation between water holding capacity and sand.

Except in pedons 1 and 4, the water holding capacity did not show any specific trend with depth. The irregular trend was due to the illuviation and eluviation of finer fractions in different horizons of the remaining pedons.

4.6.2.5 Volume expansion

The per cent volume expansion varied from 0.68 to 30.17 per cent. pedon 2 recorded the higher mean value of 24.23 per cent and pedon 7 registered a lower mean values of 1.08 per cent. Pedons 1, 3 and 4 exhibited an increasing trend with depth whereas pedon 2 showed an increasing trend with depth up to Bw4 horizon and later on decreased. Further, the remaining pedons 5, 6 and 7 did not show any particular trend with depth.

The volume expansion had significant and positive correlation ($r = +0.828^{**}$) with clay content. The volume expansion indicates the presence of shrinking and swelling type of clay minerals. Sandy soils have very low volume expansion. Increase in volume expansion with increase in clay content was reported by Gurumurthy *et al.* (1996) in soils of Giddalur mandal in Andhra Pradesh.

4.6.2.6 Loss on ignition

These values varied from 1.20 to 8.60 per cent. The highest value of 8.60 per cent was observed in Bw1 horizon of pedon 5 and the lowest value of 1.20 per cent was noticed in A5 horizon of pedon 7. A decreasing trend with depth was observed in pedon 4 whereas pedons 1 and 3 showed an increasing trend with depth. However, pedon 5 showed an increasing trend with depth up to Bw1 horizon and later on decreased. Further, the remaining pedons 2, 4 and 7 did not showed any particular trend with depth.

Table 4.7. Physical characteristics of the soils

Pedon No. & Horizon	Depth (m)	Bulk density (Mg m^3)	Particle density (Mg m^{-3})	Water holding capacity (%)	Pore space (%)	Volume expansion (%)	WHC/ clay	LOI (%)
Pedon 1								
Ap	0.00.-0.20	1.52	2.28	25.52	32.47	6.24	0.89	5.10
A1	0.20-0.52	1.50	2.32	28.42	33.24	7.86	0.84	7.80
Cr	0.52+	Weathered gneiss						
Pedon 2								
Ap	0.00-0.18	1.68	2.23	36.24	51.42	18.28	1.19	6.00
Bw1	0.18-0.33	1.72	2.53	38.15	48.32	20.14	1.33	4.75
Bw2	0.33-0.55	1.64	2.20	42.64	44.64	28.74	1.31	7.50
Bw3	0.55-0.80	1.48	2.24	43.71	43.27	29.32	1.14	8.50
Bw4	0.80-1.15	1.76	2.42	46.24	41.32	30.17	1.43	7.20
Bw5	1.15-1.50+	1.74	2.31	38.72	42.37	28.52	1.26	6.10
Pedon 3								
Ap	0.00-0.20	1.35	2.35	27.24	42.32	13.82	2.20	2.50
A1	0.20-0.33	1.52	2.18	28.36	38.24	15.37	1.07	4.70
A2	0.33-0.52	1.50	2.24	25.52	35.67	17.46	0.74	8.40
Cr	0.52+	Weathered gneiss						
Pedon 4								
Ap	0.00-0.25	1.22	2.23	26.72	24.35	14.32	0.86	6.45
A1	0.25-0.55	1.24	2.21	25.87	23.42	17.27	1.17	3.05
Cr	0.55+	Weathered gneiss						
Pedon 5								
Ap	0.00-0.21	1.26	2.24	28.31	40.62	17.41	1.19	4.20
A1	0.21-0.35	1.34	2.40	29.62	44.47	19.24	1.01	5.65
Bw1	0.35-0.57	1.39	2.20	30.24	48.83	22.37	0.94	8.60
Bw2	0.57-0.78	1.28	2.23	31.67	43.27	18.42	0.83	7.00
Bw3	0.78-1.00	1.46	2.34	30.51	42.34	19.58	0.98	6.25
Cr	1.00+	Weathered gneiss						
Pedon 6								
Ap	0.00-0.27	1.75	2.40	35.27	34.24	14.68	1.53	4.10
A1	0.27-0.37	1.62	2.40	33.52	31.45	15.37	1.39	4.35
A2	0.37-0.58	1.48	2.57	27.68	26.62	14.62	1.07	4.40
Bw1	0.58-0.78	1.78	2.34	25.62	28.74	17.68	0.83	6.10
Bw2	0.78-0.91	1.72	2.47	32.84	29.52	19.47	1.09	5.70
Bw3	0.91-1.20	1.52	2.58	34.27	27.42	16.32	1.09	6.80
Bw4	1.20-1.50+	1.65	2.45	31.62	26.38	14.82	1.03	6.20
Pedon 7								
Ap	0.00-0.30	1.77	2.46	18.34	24.36	0.82	2.91	1.72
A1	0.30-0.58	1.74	2.58	18.74	22.67	1.32	3.60	1.40
A2	0.58-0.80	1.82	2.74	17.62	20.14	1.48	3.04	1.85
A3	0.80-0.98	1.84	2.82	15.26	21.45	0.68	2.46	1.67
A4	0.98-1.27	1.85	2.78	16.31	24.62	1.15	2.67	1.40
A5	1.27-1.48	1.82	2.85	14.63	23.48	0.74	2.57	1.20
A6	1.48-1.90+	1.84	2.87	13.82	21.74	0.92	2.51	1.52

Table 4.8. Range and mean of physical properties of the soils.

Pedon No.	Range & Mean	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Water holding capacity (%)	Pore space (%)	Volume expansion (%)	WHC/Clay	LOI (%)
1	Range	1.50-1.52	2.28-2.32	25.52-28.42	32.47-33.24	6.24-7.86	0.84-0.89	5.10-7.80
	Mean	1.51	2.30	26.97	32.86	7.05	0.87	6.45
2	Range	1.48-1.76	2.20-2.53	36.24-46.24	41.32-51.42	18.28-30.17	1.14-1.43	4.75-8.50
	Mean	1.62	2.37	41.24	46.37	24.23	1.29	6.63
3	Range	1.35-1.52	2.18-2.35	25.52-28.36	35.67-42.32	13.82-17.46	0.74-2.20	2.50-8.40
	Mean	1.44	2.27	26.94	39.00	15.64	1.47	5.45
4	Range	1.22-1.24	2.21-2.23	25.87-26.72	23.42-24.35	14.32-17.27	0.86-1.17	3.05-6.45
	Mean	1.23	2.22	26.30	23.89	15.80	1.02	4.75
5	Range	1.26-1.46	2.20-2.40	28.31-31.67	40.62-48.83	17.41-22.37	0.83-1.19	4.20-8.60
	Mean	1.36	2.30	29.99	44.73	19.89	1.01	6.40
6	Range	1.48-1.78	2.34-2.58	25.62-35.27	26.38-34.24	14.62-19.47	0.83-1.53	4.10-6.80
	Mean	1.63	2.46	30.45	30.31	17.04	1.18	5.45
7	Range	1.74-1.85	2.46-2.87	13.82-18.74	20.14-24.36	0.68-1.48	2.51-3.60	1.20-1.85
	Mean	1.80	2.67	16.28	22.25	1.08	3.06	1.53

This loss in weight on ignition was attributed to loss of organic matter, crystal lattice water and $CaCO_3$ content. More the clay content more was the loss of weight due to loss of crystal lattice water held by the clay. Sand content exhibited significant and negative correlation (r = -0.834**) with LOI. Similarly, Sharma *et al.* (1996) reported the fact that loss on ignition followed the same distribution pattern as that of clay content. Higher values of LOI may be due to the presence of expanding type minerals. Similar results were reported by Thangasamy *et al.* (2004).

4.7 PHYSICO-CHEMICAL PROPERTIES

The results of physico-chemical properties were depicted in Tables 4.9 and 4.10.

4.7.1 Soil reaction

The pH values of 1:2.5 soil water suspensions ranged from 6.10 to 8.50 indicating slightly acidic to moderately alkaline in reaction. Pedons 1 and 4 showed an increasing trend with depth whereas pedon 6 exhibited an increasing trend with depth up to Bw2 horizon and later on decreased. Pedons 2, 3, 5 and 7 did not show any particular trend with depth.

This wide variation in pH was attributed to the nature of the parent material, leaching, presence of calcium carbonate and exchangeable sodium. Similar findings were reported by Devi and Kumar (2010). Pedons 1 and 4 showed an increasing trend with depth due to accumulation of exchangeable bases and $CaCO_3$ lower horizons. Similar results were also made by Walia and Rao (1996) in Bundhelkhand region of Uttar Pradesh.

Comparatively pH values were low in surface soils than in sub-surface soils in most of the pedons. This might be due to release of organic acids during decomposition of organic matter and these acids might have

Table 4.9. Physico-chemical properties of the soils

Pedon No. & Horizon	Depth (m)	Organic carbon (%)	Total nitrogen (%)	C/N ratio	$CaCO_3$ (%)	pH (1:2.5)		EC (dSm^{-1})
						H_2O	1 *N* KCl	
Pedon 1								
Ap	0.00-0.20	0.32	0.030	10.67	4.50	6.60	6.32	0.01
A1	0.20-0.52	0.30	0.028	10.71	4.00	6.73	6.43	0.02
Cr	0.52+	Weathered gneiss						
Pedon 2								
Ap	0.00-0.18	0.61	0.062	9.84	9.50	7.43	7.15	0.08
Bw1	0.18-0.33	0.57	0.059	9.67	11.50	7.93	7.81	0.02
Bw2	0.33-0.55	0.46	0.057	8.07	10.00	8.40	8.10	0.03
Bw3	0.55-0.80	0.43	0.053	8.11	12.00	8.50	8.36	0.05
Bw4	0.80-1.15	0.38	0.045	8.44	15.00	8.20	7.92	0.03
Bw5	1.15-1.50+	0.41	0.038	10.78	16.00	8.40	8.12	0.30
Pedon 3								
Ap	0.00-0.20	0.28	0.032	8.75	6.00	7.70	7.41	0.03
A1	0.20-0.33	0.26	0.031	8.39	6.50	7.58	7.28	0.02
A2	0.33-0.52	0.23	0.029	7.93	5.50	7.60	7.53	0.02
Cr	0.52+	Weathered gneiss						
Pedon 4								
Ap	0.00-0.25	0.24	0.025	9.60	4.50	6.10	6.03	0.02
A1	0.25-0.55	0.22	0.022	10.00	3.50	6.33	6.21	0.03
Cr	0.55+	Weathered gneiss						
Pedon 5								
Ap	0.00-0.21	0.57	0.063	9.05	5.50	6.20	6.06	0.03
A1	0.21-0.35	0.54	0.060	9.00	6.00	6.21	5.91	0.03
Bw1	0.35-0.57	0.49	0.062	7.90	7.50	6.38	6.30	0.03
Bw2	0.57-0.78	0.46	0.055	8.36	6.50	6.17	5.97	0.03
Bw3	0.78-1.00	0.41	0.048	8.54	7.00	6.60	6.32	0.03
Cr	1.00+	Weathered gneiss						
Pedon 6								
Ap	0.00-0.27	0.46	0.057	8.07	8.50	6.30	6.18	0.32
A1	0.27-0.37	0.43	0.053	8.11	7.00	6.80	6.50	0.02
A2	0.37-0.58	0.42	0.053	7.92	5.50	7.12	6.80	0.03
Bw1	0.58-0.78	0.32	0.045	7.11	6.50	7.24	6.90	0.06
Bw2	0.78-0.91	0.35	0.039	8.97	6.00	7.28	6.98	0.02
Bw3	0.91-1.20	0.22	0.038	5.79	8.00	7.20	6.85	0.21
Bw4	1.20-1.50+	0.20	0.057	3.51	8.50	6.90	6.60	0.02
Pedon 7								
Ap	0.00-0.30	0.24	0.017	14.11	1.50	6.23	5.92	0.05
A1	0.30-0.58	0.22	0.020	11.00	2.00	6.40	6.10	0.04
A2	0.58-0.80	0.18	0.013	13.84	2.00	6.45	6.15	0.03
A3	0.80-0.98	0.14	0.013	10.77	2.50	6.50	6.22	0.03
A4	0.98-1.27	0.16	0.011	14.55	2.00	6.20	6.06	0.31
A5	1.27-1.48	0.12	0.010	12.00	2.00	6.10	5.98	0.02
A6	1.48-1.90+	0.12	0.010	12.00	2.50	7.50	7.20	0.02

Table 4.10. Range and mean of physico-chemical properties of the soils

Pedon No.	Range & Mean	Organic carbon (%)	Total nitrogen (%)	C/N ratio	$CaCO_3$ (%)	pH (1:2.5)		ECe (dSm^{-1})
						H_2O	1 *N* KCl	
1	Range	0.30-0.32	0.028-0.030	10.67-10.71	4.00-4.50	6.60-6.73	6.32-6.43	0.01-0.02
	Mean	0.31	0.029	10.69	4.25	6.70	6.38	0.015
2	Range	0.38-0.61	0.038-0.062	8.07-10.78	9.50-16.00	7.43-8.50	7.15-8.36	0.02-0.30
	Mean	0.50	0.05	9.43	12.75	7.97	7.76	0.025
3	Range	0.23-0.28	0.029-0.032	7.93-8.75	5.50-6.50	7.58-7.70	7.28-7.53	0.02-0.03
	Mean	0.26	0.03	8.34	6.00	7.64	7.40	0.025
4	Range	0.22-0.24	0.022-0.025	9.60-10.00	3.50-4.50	6.10-6.33	6.03-6.21	0.02-0.03
	Mean	0.23	0.024	9.80	4.00	6.22	6.12	0.025
5	Range	0.41-0.57	0.048-0.063	7.90-9.05	5.50-7.50	6.17-6.60	5.91-6.32	0.03-0.03
	Mean	0.49	0.056	8.48	6.50	6.39	6.12	0.03
6	Range	0.20-0.46	0.038-0.057	3.51-8.97	5.50-8.50	6.30-7.28	6.18-6.98	0.02-0.32
	Mean	0.33	0.048	6.24	7.00	6.79	6.58	0.165
7	Range	0.12-0.24	0.010-0.020	10.77-14.55	1.50-2.50	6.10-7.50	5.92-7.20	0.02-0.31
	Mean	0.18	0.015	12.66	2.00	6.80	6.56	0.165

brought down the pH in the surface soils. Vadivelu and Bandyopadhyay (1997) observed similar results in soils of Minicoy Island in Lakshadweep.

The pH values of soil in 1:2.5 and 1 *N* KCl suspension ranged from 5.91 to 8.36. The lowest value of 5.91 was observed in A1 horizon of pedon 5 and the highest value of 8.36 was observed in Bw3 horizon of pedon 3. Pedons 1 and 4 exhibited an increasing trend with depth whereas pedon 6 showed an increasing trend with depth up to Bw2 horizon later on decreased. However, remaining pedons did not show any particular trend with depth.

The KCl-pH values were lower than the water pH values. The difference between pH_{kcl} and pH_{H2O} values ($\Delta pH = pH_{kcl} - pH_{H2O}$) with large negative value (more than -0.5) indicated a high negative surface density of these soils. Further, similar results were noticed by Thangasamy *et al*. (2005) and Sitanggang *et al.* (2006) who reported the existence of net negative charge on colloidal particles.

4.7.2 Electrical conductivity

The electrical conductivity in soil water extract of different pedons ranged from 0.01 to 0.32 dSm^{-1}. Pedon 1 showed an increasing trend with depth whereas pedons 3 and 4 exhibited a decreasing trend with depth. However, pedons 2, 5, 6 and 7 did not show any particular trend with depth.

Electrical conductivity values in all pedons indicated non-saline nature of the soil. The low electrical conductivity may be due to free drainage conditions which favoured the removal of released bases by percolating and drainage water. Pillai and Natarajan (2004) reported similar low electrical conductivity values indicating the non-saline character in the soils of Garakahalli watershed. These results were coincided with those of Thangasamy *et al.* (2005) and Sitanggang *et al*. (2006) in soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh and in soils of Shikohpur watershed in Gurgaon district of Haryana, respectively.

4.7.3 Organic carbon

The organic carbon content in different horizons of pedons ranged from 0.12 to 0.61 per cent indicating **low to medium** in organic carbon status. The highest value of 0.61 was registered in Ap horizon of pedon 2 and the lowest value was recorded in A5 and A6 horizons of pedon 7. The pedon 7 showed an irregular trend with depth whereas remaining pedons 1, 3, 4 and 5 exhibited a decreasing trend with depth. However, pedons 2 and 6 noticed a decreasing trend up to Bw4, Bw3 horizons, respectively later on an increasing trend with depth.

The low organic carbon content in the soils might be attributed to the prevalence of tropical condition, where the degradation of organic matter occurs at a faster rate coupled with low vegetation cover, there by leaving less organic carbon in the soils. Similar observations were also made by Nayak *et al.* (2002) in soils of Central Research Station (OUAT), Bhubaneswar.

High organic carbon in the surface horizons was attributed to the addition of plant residues and farm yard manure to surface horizons which resulted in higher organic carbon content in surface horizons than in the lower horizons. This observation was in accordance with results of Basavaraju *et al*. (2005) in soils of Chandragiri mandal of Chittoor district in Andhra Pradesh.

4.7.4 C / N ratio

The C / N ratio varied from 3.51 to 14.55. The lowest ratio of 3.51 was observed in Bw4 horizon of pedon 6 and the highest ratio of 14.55 was noticed in A4 horizon of pedon 7. Pedon 3 exhibited a decreasing trend with depth whereas pedons 1 and 4 showed an increasing trend with depth. Further, pedons 2 and 5 observed a decreasing trend up to Bw2 and Bw1 horizons, respectively later on an increasing trend with depth. The remaining pedons did not show any particular trend with depth. The C: N ratio of these soils was low, this could be attributed to rapid mineralization of litter, as these soils possess good soil moisture condition for microbial activity. Similar views were expressed by Prakash and Rao (2002) in red soils of Krishna district in Andhra Pradesh.

4.7.5 Calcium carbonate

The calcium carbonate content ranged from 1.50 to 16.00 per cent. Higher mean value of 12.75 per cent was registered in pedon 2 while lower mean value of 2.00 per cent was observed in pedon 7. Pedon 5 exhibited an increasing trend up to Bw1 horizon later on a decreasing trend with depth whereas pedons 1 and 4 showed a decreasing trend with depth. The remaining pedons did not show any particular trend with depth.

The highest $CaCO_3$ content was noticed in the lower horizons of pedons 2 and 6. This might be due to high clay content which led to impeded leaching, consequently accumulation of $CaCO_3$ in the lower horizon. Similar results were reported by Prakash and Rao (2002) in soils of Krishna district, Andhra Pradesh.

The $CaCO_3$ content of the pedon 2 was increased with depth which might be due to downward movement of calcium and its subsequent precipitation as carbonate and / or decomposition of calcium carbonate. Similar observations were found in the soils of southern Rajasthan (Sharma *et al.,* 2004b).

The $CaCO_3$ content of the pedons 3 and 7 showed an irregular distribution with depth. This may be either due to variable nature of geological material that contributed to these soils or rapid leaching of carbonates from the porous sandy soils. Similar findings were observed by Singh and Agarwal (2005) who reported an irregular distribution of $CaCO_3$ with depth was attributed to differential dissolution by CO_2 rich water which was moderated by physiography, rising and receding water table and drainage conditions.

4.8 ELECTRO-CHEMICAL PROPERETIES

The results of electro-chemical properties were presented in Tables 4.11 and 4.12 and depicted in Figures 4.9 and 4.10.

4.8.1 Cation exchange capacity

The CEC values varied from 4.70 to 25.52 cmol (p^+) kg^{-1} soil. The highest value of 25.52 cmol (p^+) kg^{-1} soil was noticed in the Bw5 horizon of pedon 2 and the lowest value of 4.70 cmol (p^+) kg^{-1} soil was observed in A1 horizon of pedon 7. Further, the data on mean values revealed that mean CEC values were ranged from 5.05 to 20.15 cmol (p^+) kg^{-1} soil. Pedon 4 exhibited a decreasing trend with depth whereas pedons 1 and 3 exhibited an increasing trend with depth. Pedon 5 showed an increasing trend up to Bw2 horizon and later on a decreasing trend with depth. The remaining pedons did not show any particular trend with depth.

The CEC values were found to be **low to medium**. The highest CEC value 25.52 cmol (p^+) kg^{-1} was recorded in Bw5 horizon of pedon 2 which might be due to comparatively higher clay content in this horizon. The CEC values showed more or less an increasing trend with depth in pedons 1 and 3 where in the CEC corresponds to clay and organic carbon content and also type of clay mineral present in these soils. A significant positive correlation coefficient (r = +0.773*) between clay and CEC in the present study also

Table 4.11. Electro-chemical properties of the soils

Pedon No. & Horizon	Depth (m)	CEC [cmol $(p^+)kg^{-1}$]	Exchangeable bases [cmol $(p^+)kg^{-1}$]				Base saturation (%)	Ca/Mg	CEC/ Clay
			Ca^{2+}	Mg^{2+}	Na^+	K^+			
Pedon 1									
Ap	0.00.-0.20	9.67	4.19	3.19	0.16	0.19	79.94	1.31	0.34
A1	0.20-0.52	14.78	6.25	4.50	0.20	0.21	75.51	1.39	0.44
Cr	0.52+	Weathered gneiss							
Pedon 2									
Ap	0.00-0.18	16.52	6.30	5.20	0.33	0.19	72.76	1.21	0.54
Bw1	0.18-0.33	14.78	6.50	4.80	0.32	0.18	79.84	1.35	0.52
Bw2	0.33-0.55	17.93	7.80	4.30	0.43	0.11	70.50	1.81	0.55
Bw3	0.55-0.80	20.87	8.20	4.70	0.35	0.15	64.21	1.74	0.54
Bw4	0.80-1.15	21.84	9.60	5.30	0.29	0.09	69.96	1.81	0.68
Bw5	1.15-1.50+	25.52	9.80	7.80	0.38	0.02	70.53	1.26	0.83
Pedon 3									
Ap	0.00-0.20	5.15	2.80	1.40	0.12	0.08	85.44	2.00	0.42
A1	0.20-0.33	14.34	6.20	4.30	0.18	0.07	74.97	1.44	0.54
A2	0.33-0.52	18.69	8.70	4.50	0.15	0.05	71.70	1.93	0.54
Cr	0.52+	Weathered gneiss							
Pedon 4									
Ap	0.00-0.25	6.30	3.30	1.90	0.06	0.05	84.29	1.74	0.20
A1	0.25-0.55	5.10	3.20	1.70	0.07	0.04	98.24	1.88	0.23
Cr	0.55+	Weathered gneiss							
Pedon 5									
Ap	0.00-0.21	13.80	4.20	3.80	0.09	0.06	59.06	1.11	0.58
A1	0.21-0.35	14.24	5.90	3.30	0.17	0.12	66.64	1.79	0.48
Bw1	0.35-0.57	14.56	4.90	3.70	0.18	0.10	60.99	1.32	0.45
Bw2	0.57-0.78	22.82	7.60	6.00	0.15	0.09	60.65	1.27	0.60
Bw3	0.78-1.00	15.43	7.20	3.80	0.09	0.07	72.33	1.89	0.50
Cr	1.00+	Weathered gneiss							
Pedon 6									
Ap	0.00-0.27	10.22	3.50	3.20	0.10	0.04	66.93	1.09	0.44
A1	0.27-0.37	6.74	3.40	2.30	0.17	0.09	88.43	1.48	0.28
A2	0.37-0.58	9.46	4.70	1.40	0.18	0.09	67.34	3.36	0.37
Bw1	0.58-0.78	12.06	4.40	3.41	0.13	0.07	66.42	1.29	0.39
Bw2	0.78-0.91	10.00	3.80	2.30	0.15	0.10	63.50	1.65	0.33
Bw3	0.91-1.20	10.90	4.10	2.40	0.11	0.10	61.56	1.71	0.35
Bw4	1.20-1.50+	9.45	3.70	2.70	0.18	0.06	70.26	1.37	0.31
Pedon 7									
Ap	0.00-0.30	5.40	1.70	1.30	0.07	0.04	57.59	1.31	0.86
A1	0.30-0.58	4.70	1.50	1.30	0.07	0.04	61.91	1.15	0.90
A2	0.58-0.80	5.10	1.70	2.10	0.08	0.03	76.67	0.81	0.88
A3	0.80-0.98	5.30	1.80	1.90	0.08	0.01	71.51	0.95	0.85
A4	0.98-1.27	5.10	1.60	1.60	0.06	0.06	65.10	1.00	0.84
A5	1.27-1.48	4.90	1.40	1.19	0.06	0.05	55.10	1.18	0.86
A6	1.48-1.90+	4.80	1.30	1.20	0.05	0.04	53.96	1.08	0.87

Table 4.12. Range and mean of electro-chemical properties of the soils.

Pedon No.	Range & Mean	CEC [cmol (p^+) kg^{-1}]	Exchangeable bases [cmol (p^+) kg^{-1}]				Base saturation (%)	Ca/Mg
			Ca^{2+}	Mg^{2+}	Na^+	K^+		
1	Range	9.67-14.78	4.19-6.25	3.19-4.50	0.16-0.20	0.19-0.21	75.51-79.94	1.31-1.39
	Mean	12.23	5.22	3.85	0.18	0.20	77.73	1.35
2	Range	14.78-25.52	6.30-9.80	4.30-7.80	0.29-0.43	0.02-0.19	64.21-79.84	1.21-1.81
	Mean	20.15	8.05	6.05	0.36	0.11	72.03	1.51
3	Range	5.15-18.69	2.80-8.70	1.40-4.50	0.12-0.18	0.05-0.08	71.70-85.44	1.44-2.00
	Mean	11.92	5.75	2.95	0.15	0.07	78.57	1.72
4	Range	5.10-6.30	3.20-3.30	1.70-1.90	0.06-0.07	0.04-0.05	84.29-98.24	1.74-1.88
	Mean	5.70	3.25	1.80	0.065	0.045	91.27	1.81
5	Range	13.80-22.82	4.20-7.60	3.30-6.00	0.09-0.18	0.06-0.12	59.06-72.33	1.11-1.89
	Mean	18.30	5.90	4.65	0.14	0.09	65.70	1.50
6	Range	6.74-12.06	3.40-4.70	1.40-3.41	0.10-0.18	0.04-0.10	61.56-88.43	1.09-3.36
	Mean	9.40	4.05	2.50	0.15	0.07	74.75	2.23
7	Range	4.80-5.40	1.30-1.80	1.19-2.10	0.05-0.08	0.01-0.06	53.96-76.67	0.81-1.31
	Mean	5.10	1.55	1.25	0.065	0.035	65.32	1.06

suggest that clay contributes to CEC in these soils. Similar results were also reported by Thangasamy *et al.* (2005) and Sitanggang *et al*. (2006). These results were further supported by findings of Kumar *et al.* (2002), who reported a significant positive correlation between CEC and clay content and suggested that clay was the contributor to the CEC in the soils of lower Palar-Manimuthar watershed of Tamil Nadu. Relatively low CEC may be due to dominance of clay minerals with low CEC and presence of hydrous oxides of iron and aluminium (Sarkar *et al.*, 2002).

4.8.2 Base saturation

The per cent base saturation on the exchange complex was in between 53.96 to 98.24. The highest value of 98.24 per cent was observed in A1 horizon of pedon 4 and the lowest value of 53.96 per cent was noticed in A6 horizon of pedon 7. Pedon 3 exhibited an increasing trend with depth whereas pedon 7 showed an increasing trend up to A2 horizon and later on a decreasing with depth. Pedon 3 showed a decreasing trend with depth. However, remaining pedons had shown an irregular trend with depth.

The variation in per cent base saturation indicates the degree of leaching. However, the variation in base saturation of the soils might also be due to variation in nature and / or content of soil colloids and soil pH values. Low base saturation in sub-soils was due to dominance of exchangeable Al^{3+} on exchange complex while comparatively high base saturation in the surface horizons may be due to continuous addition of bases from leaf litter (Sarkar *et al.*, 2002).

The higher base saturation observed in the pedons might be due to higher amount of Ca^{2+} in exchange sites on the colloidal complex. Similar results were reported by Tripathi *et al.* (2006) in the soils of Kiar-Nagali micro-watershed in North-West Himalayas. Relatively higher base saturation in surface soils could be attributed to the recycling of basic cations through vegetation (Devi and Kumar, 2010). Similar findings were reported by Basavaraju *et al.* (2005).

4.8.3 Exchangeable bases

The exchangeable bases in all the pedons were in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ on the exchange complex. Exchangeable Ca^{+2} was found to be dominant cation followed by Mg^{+2} on the exchange complex.

4.8.3.1 Calcium

The exchangeable calcium was found to be the dominant cation on the exchange complex and the values varied from 1.30 to 9.80 cmol (p^{+}) kg^{-1} soil. The lowest value of 1.30 cmol (p^{+}) kg^{-1} soil was noticed in A6 horizon of pedon 7 while the highest value of 9.80 cmol (p^{+}) kg^{-1} soil was observed in Bw5 horizon of pedon 2. The per cent saturation of calcium varied from 17.81 to 62.75 on the exchange complex. Further, the exchangeable calcium had shown an increasing trend with depth in pedons 1, 2 and 3 while pedon 4 showed a decreasing trend with depth. However, remaining pedons did not show any particular trend with depth.

4.8.3.2 Magnesium

Next to calcium, magnesium was the dominant cation on the exchange complex. Magnesium contributed 10.21 to 34.12 per cent on the exchange complex. Magnesium content was ranged from 1.19 to 7.80 cmo (p^{+}) kg^{-1} soil. The lowest value of 1.19 cmol (p^{+}) kg^{-1} soil was recorded in A5 horizon of pedon 7 and the highest value of 7.80 cmol (p^{+}) kg^{-1} soil was recorded in Bw5 horizon of pedon 2. Pedon 4 exhibited a decreasing trend with depth whereas pedons 1 and 3 showed an increasing with depth. However, remaining pedons did not show any particular trend with depth.

4.8.3.3 Sodium

The exchangeable sodium content on the exchange complex varied from 0.05 to 0.43 cmol (p^+) kg^{-1} soil. The highest value of 0.43 cmol (p^+) kg^{-1} soil was noticed in Bw2 horizon of pedon 2 while the lowest value of 0.05 cmol (p^+) kg^{-1} soil was recorded in A6 horizon of pedon 7. Pedons 1 and 4 exhibited an increasing trend with depth whereas pedons 5 and 7 showed an increasing trend with depth up to Bw1 and A3 horizons, respectively later on a decreasing trend. The remaining pedons did not show any particular trend with depth.

4.8.3.4 Potassium

The exchangeable potassium content of different horizons in pedons ranged from 0.01 to 0.21 cmol (p^+) kg^{-1} soil. Pedon 1 recorded an increasing trend with depth while pedon 4 registered a decreasing trend with depth. However, remaining pedons did not show any particular trend with depth. As high as 1.97 per cent saturation of potassium was observed in Ap horizon of pedon 1 while as low as 0.08 per cent saturation was noticed in Bw5 horizon of pedon 2.

The exchangeable bases in all the pedons were in the order of Ca^{2+} > Mg^{2+} > Na^+ > K^+ on the exchange complex. The exchangeable Ca was found to be dominant cation followed by the Mg on the exchangeable complex. From the distribution of Ca^{2+} and Mg^{2+}, it was evident that Ca^{2+} showed the strongest relationship with all the species, comparing these ions (Ca^{2+}, Mg^{2+}, K^+ and Na^+) it was clear that Mg^{2+} was present in low amounts than Ca^{2+} because of its higher mobility, earlier removal than the later.

Presence of basic cations in decreasing order Ca, Mg, Na and K reflects the decreasing energy of adsorption by the complex and accordingly the increasing mobility of ions against the leaching environment. Calcium dominates in the prevailing semi-arid weathering environment and

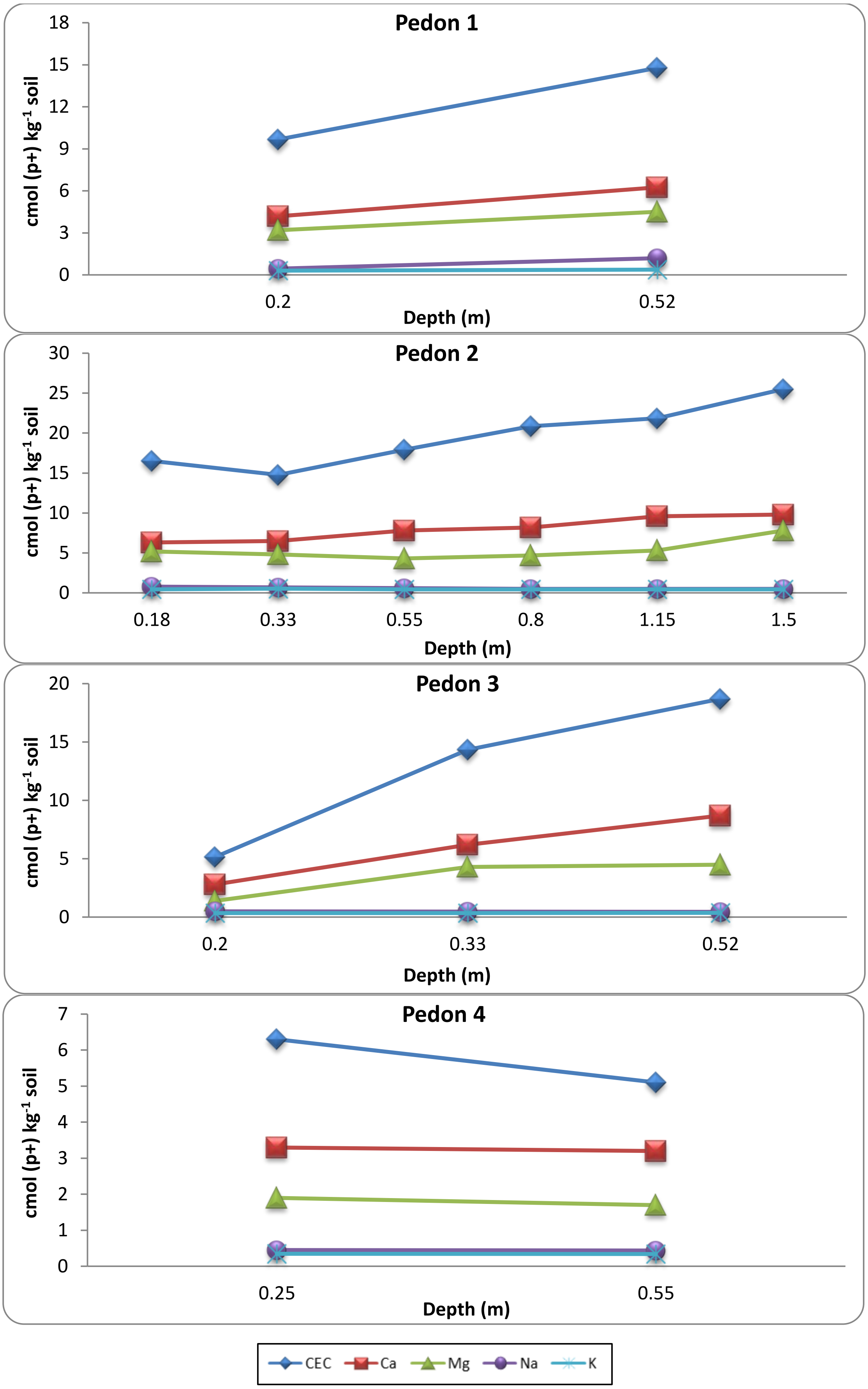


Fig. 4.9. Depth functions of electro-chemical characters

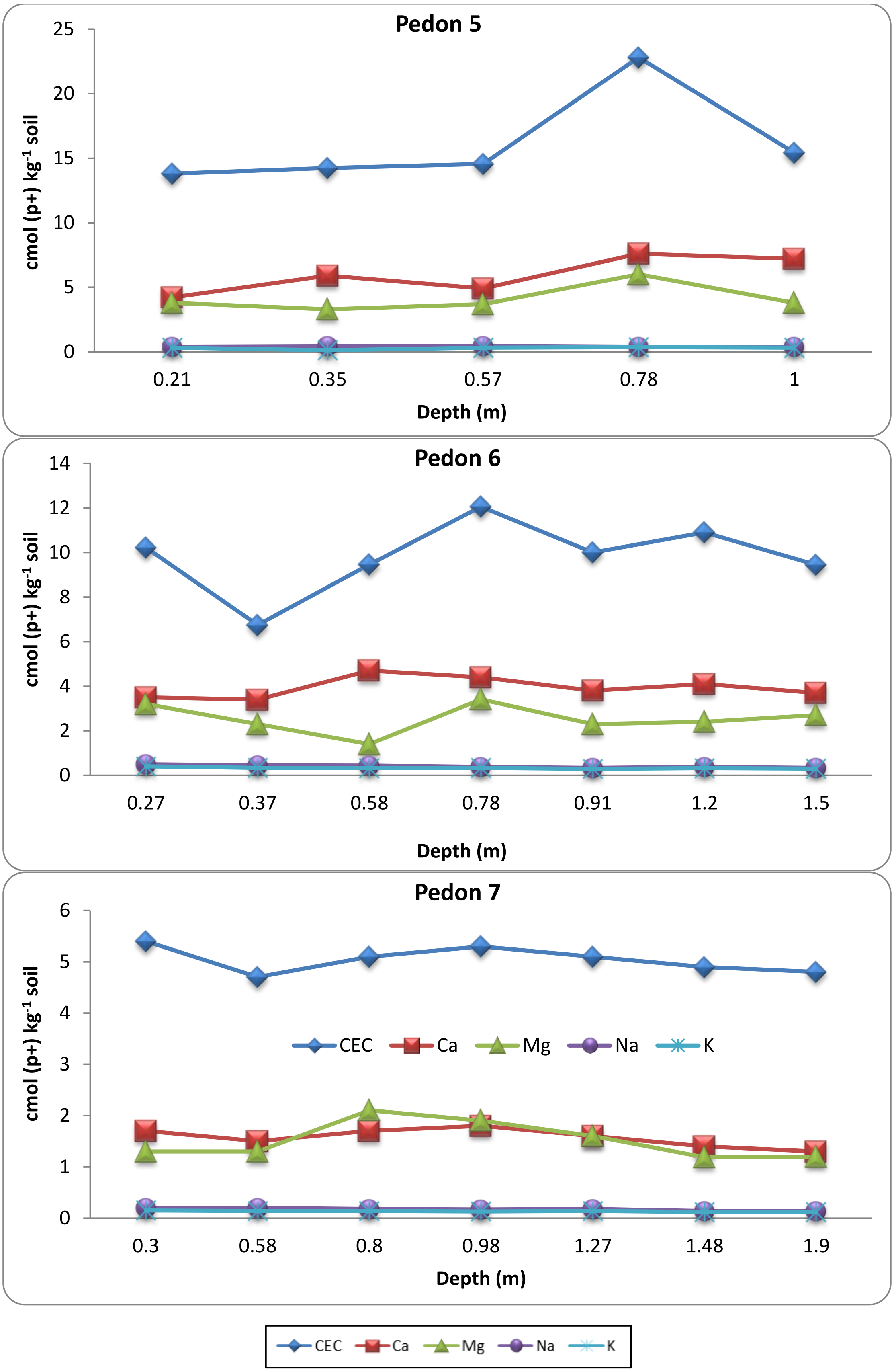


Fig. 4.10. Depth functions of electro-chemical characters

Table 4.13. Per cent saturation of individual bases

Pedon No. & Horizon	Depth (m)	Exchangeable bases (%)			
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Pedon 1					
Ap	0.00.-0.20	43.36	33.01	1.66	1.97
A1	0.20-0.52	42.29	30.45	1.35	1.42
Cr	0.52+	Weathered gneiss			
Pedon 2					
Ap	0.00-0.18	38.14	31.48	2.00	1.15
Bw1	0.18-0.33	43.98	32.48	2.17	1.22
Bw2	0.33-0.55	43.50	23.98	2.40	0.61
Bw3	0.55-0.80	17.81	10.21	0.76	0.33
Bw4	0.80-1.15	54.69	30.20	1.65	0.51
Bw5	1.15-1.50+	38.40	30.56	1.49	0.08
Pedon 3					
Ap	0.00-0.20	54.37	27.18	2.33	1.55
A1	0.20-0.33	43.24	29.99	1.26	0.49
A2	0.33-0.52	46.55	24.08	0.80	0.27
Cr	0.52+	Weathered gneiss			
Pedon 4					
Ap	0.00-0.25	52.38	30.16	0.95	0.79
A1	0.25-0.55	62.75	33.33	1.37	0.78
Cr	0.55+	Weathered gneiss			
Pedon 5					
Ap	0.00-0.21	30.43	27.54	0.65	0.43
A1	0.21-0.35	41.43	23.17	1.19	0.84
Bw1	0.35-0.57	33.65	25.41	1.24	0.69
Bw2	0.57-0.78	33.30	26.29	0.66	0.39
Bw3	0.78-1.00	46.66	24.63	0.58	0.45
Cr	1.00+	Weathered gneiss			
Pedon 6					
Ap	0.00-0.27	34.25	31.31	0.98	0.39
A1	0.27-0.37	50.45	34.12	2.52	1.34
A2	0.37-0.58	57.48	17.12	2.20	1.10
Bw1	0.58-0.78	36.44	28.24	1.08	0.58
Bw2	0.78-0.91	38.00	23.00	1.50	1.00
Bw3	0.91-1.20	37.61	22.02	1.01	0.92
Bw4	1.20-1.50+	39.15	28.57	1.90	0.63
Pedon 7					
Ap	0.00-0.30	31.48	24.07	1.30	0.74
A1	0.30-0.58	31.91	27.66	1.49	0.85
A2	0.58-0.80	26.75	33.04	1.26	0.47
A3	0.80-0.98	27.36	28.88	1.22	0.15
A4	0.98-1.27	29.48	29.48	1.11	1.11
A5	1.27-1.48	28.68	24.38	1.23	1.02
A6	1.48-1.90+	27.19	25.10	1.05	0.84

consequently occupied the major position on the exchange complex (Sharma *et al.,* 1996). The higher exchangeable Ca in the surface soil may be due to redistribution of calcium by plant species (Patil and Prasad, 2004).

4.8.4 Ratio between Ca and Mg

The ratio between Ca and Mg ranged from 0.81 to 3.36 which were registered in pedons 7 and 6, respectively. Pedons 1 and 4 showed an increasing trend with depth whereas remaining pedons did not show any particular trend with depth.

Narrower Ca^{+2} / Mg^{+2} ratio was due to extreme suppression of Ca solubility, substitution of Mg^{+2} or Ca^{+2} by plants and recycling of unusual amount of Mg. Similar results were reported by Raghuwanshi *et al.* (2011).

4.8.5 Ratio between CEC and Clay

The ratio between CEC and clay ranged from 0.20 to 0.90 which were registered in pedons 4 and 7, respectively. Pedons 1, 3 and 4 showed an increasing trend with depth whereas remaining pedons did not showed any particular trend with depth.

The CEC: Clay ratio was used to identify the mineralogy. If ratio was more than 0.45 indicated presence of smectite mineral. Similar results were reported by Ashokkumar and Prasad (2010) and Babu *et al.* (2001) in soils of Ahmadnagar district of Maharastra and A.Konduru mandal in Krishna district of Andhra Pradesh, respectively. Low CEC/Clay ratio indicates low activity clays (Bhattacharya *et al.,* 2010) and mixed mineralogy (Smith, 1986).

4.9 CHEMICAL COMPOSITION OF SOILS

The results of chemical composition in the horizon samples of pedons estimated by acid extract method were presented in Tables. 4.14 and 4.15 and depth functions were depicted in Figures. 4. 11 and 4.12.

4.9.1 Silica (SiO_2)

The value of total silica content varied from 81.13 to 94.16 per cent. The highest value of 94.16 per cent was noticed in A6 horizon of pedon 7 and the lowest value of 81.13 per cent was noticed in Bw1 horizon of pedon 5. Pedons 1 and 3 exhibited a decreasing trend with depth whereas pedon 5 exhibited a decreasing trend up to Bw1 horizon later on an increasing trend. Pedon 4 showed an increasing trend with depth. However, remaining pedons did not show any particular trend with depth.

The variation in silica content was mainly associated with variation in chemical composition of parent material and also relative amount of sand fraction. Pedons 1 and 3 exhibited a decreasing trend with depth due to high clay content and low sand content in deeper layers. Similar results were also reported by Prakash and Rao (2002) in soils of Krishna district in Andhra Pradesh.

A decreasing trend with depth could be due to removal of weatherable products by leaching, leaving SiO_2 in surface under existing climate of the area and intimate association of SiO_2 with coarser fraction of the soil (Singh *et al.,* 1993). Pedon 5 exhibited a decreasing trend with depth up to Bw1 horizon and later on an increasing trend due to more sand content in deeper layers. Similar increase in sand content with depth in soils located on active flood plain was reported in Etawah district of Uttar Pradesh (Verma *et al.,* 2001). The sedentary soils developed on granite-gneiss were highly siliceous and high SiO_2 content indicated the influence of acidic parent rocks (Singh *et al.,* 1993). Siliceous nature of the parent material and decrease in sand content with depth resulted in trends showed by silica in different soils (Prakash and Rao, 2002).

4.9.2 Sesquioxides (R_2O_3)

The values of sesquioxides varied in between 3.65 and 15.75 per cent. The highest value of 15.75 per cent was observed in Bw3 horizon of pedon 2 and the lowest value of 3.65 per cent was noticed in A6 horizon of pedon 7. Pedons 1, 3 and 6 exhibited an increasing trend with depth whereas pedon 5 had shown an increasing trend with depth up to Bw1 horizon later on decreased with depth. Pedon 4 showed a decreasing trend with depth. However, remaining pedons did not show any particular trend with depth.

These variations in R_2O_3 content might be due to the kind of parent material from which the soils were derived. Sesquioxide values showed an increasing trend with increase in clay content and a significant and positive correlation between clay and sesquioxides (r = +0.884**). Similarly the sesquioxides content of the soil varied in accordance with clay (Prakash and Rao, 2002). These results were in good agreement with the findings of Gurumurthy *et al.* (1996) and Subbaiah and Manickam (1992).

4.9.3 Aluminium oxide (Al_2O_3)

The aluminum oxide content was in between 2.73 and 11.27 per cent. The highest value of 11.27 was noticed in Bw4 horizon of pedon 6 while the lowest value of 2.73 was noticed in A5 horizon of pedon 7. Pedons 1 and 3 exhibited an increasing trend with depth whereas pedon 4 showed a decreasing trend with depth. However, remaining pedons did not show any particular trend with depth.

Contribution of the alumina to the sesquioxide content was major hence, the pattern of distribution of sesquioxides was similar to that of alumina. These results were in corroboration with the findings of Ramalakshmi *et al.* (2001). Sandy soils had very less alumina content because they were major contributors of silica.

Table 4.14. Chemical composition of the soils (%)

Pedon No. & Horizon	Depth (m)	SiO_2	R_2O_3	Fe_2O_3	Al_2O_3	P_2O_5	K_2O	Na_2O	CaO	MgO
Pedon 1										
Ap	0.00.-0.20	88.24	7.75	2.18	5.57	0.15	0.19	0.12	2.24	1.31
A1	0.20-0.52	81.15	13.72	3.25	10.47	0.14	0.13	0.09	2.59	2.18
Cr	0.52+	Weathered gneiss								
Pedon 2										
Ap	0.00-0.18	85.38	8.74	2.44	6.30	0.11	0.23	0.20	2.66	2.68
Bw1	0.18-0.33	86.53	8.32	3.52	4.80	0.08	0.19	0.16	2.94	1.78
Bw2	0.33-0.55	82.12	12.67	4.52	8.15	0.07	0.19	0.15	3.07	1.73
Bw3	0.55-0.80	80.56	15.75	6.33	9.42	0.06	0.14	0.12	2.35	1.02
Bw4	0.80-1.15	81.74	11.48	4.07	7.41	0.06	0.12	0.15	4.34	2.11
Bw5	1.15-1.50+	83.43	9.67	3.11	6.56	0.06	0.09	0.12	4.47	2.16
Pedon 3										
Ap	0.00-0.20	87.62	7.02	2.24	4.78	0.09	0.28	0.13	2.75	2.11
A1	0.20-0.33	87.15	7.76	1.84	5.92	0.09	0.27	0.10	2.47	2.16
A2	0.33-0.52	81.62	14.37	3.36	11.01	0.06	0.25	0.09	1.40	2.21
Cr	0.52+	Weathered gneiss								
Pedon 4										
Ap	0.00-0.25	84.14	11.47	3.86	7.61	0.12	0.25	0.10	2.24	1.68
A1	0.25-0.55	89.32	6.74	1.03	5.71	0.10	0.23	0.10	1.93	1.58
Cr	0.55+	Weathered gneiss								
Pedon 5										
Ap	0.00-0.21	87.62	6.72	2.41	4.31	0.14	0.15	0.10	2.59	2.68
A1	0.22-0.35	86.31	7.46	2.32	5.14	0.12	0.14	0.05	2.95	2.97
Bw1	0.35-0.57	81.13	14.43	5.74	8.69	0.11	0.12	0.04	2.06	2.11
Bw2	0.57-0.78	81.71	13.62	1.60	4.94	0.10	0.11	0.06	2.38	2.02
Bw3	0.78-1.00	83.17	11.86	2.04	5.38	0.08	0.10	0.09	2.59	2.11
Cr	1.00+	Weathered gneiss								
Pedon 6										
Ap	0.00-0.27	86.75	7.53	3.37	4.16	0.11	0.25	0.06	3.15	2.16
A1	0.27-0.37	86.93	8.37	2.52	4.85	0.14	0.24	0.04	2.94	1.34
A2	0.37-0.58	86.77	8.62	3.78	4.84	0.10	0.20	0.03	3.08	1.20
Bw1	0.58-0.78	83.31	10.32	3.25	7.07	0.10	0.22	0.05	3.36	2.63
Bw2	0.78-0.91	83.11	10.32	4.43	5.89	0.11	0.19	0.05	3.44	2.78
Bw3	0.91-1.20	82.34	13.62	3.36	10.26	0.12	0.20	0.04	2.24	1.44
Bw4	1.20-1.50+	81.85	14.54	3.27	11.27	0.10	0.20	0.05	1.96	1.30
Pedon 7										
Ap	0.00-0.30	92.40	4.84	1.63	3.21	0.06	0.07	0.04	1.56	1.03
A1	0.30-0.58	92.27	4.21	1.36	2.85	0.06	0.07	0.04	1.76	1.59
A2	0.58-0.80	91.75	4.90	1.28	3.62	0.05	0.06	0.04	1.42	1.78
A3	0.80-0.98	92.96	4.06	1.12	3.28	0.04	0.07	0.03	1.32	1.52
A4	0.98-1.27	93.53	4.06	1.12	2.94	0.04	0.06	0.02	1.42	0.87
A5	1.27-1.48	94.10	3.69	0.96	2.73	0.03	0.06	0.01	1.35	0.76
A6	1.48-1.90+	94.16	3.65	0.80	2.85	0.03	0.04	0.01	1.35	0.76

Table 4.15. Range and mean of chemical composition of the soils (%)

Pedon No.	Range & Mean	SiO_2	R_2O_3	Fe_2O_3	Al_2O_3	P_2O_5	K_2O	Na_2O	CaO	MgO
1	Range	81.15-88.24	7.75-13.72	2.18-3.25	5.57-10.47	0.14-0.15	0.13-0.19	0.09-0.12	2.24-2.59	1.31-2.18
	Mean	84.70	10.74	2.72	8.02	0.15	0.16	0.11	2.42	1.75
2	Range	80.56-86.53	8.32-15.75	2.44-6.33	4.80-9.42	0.06-0.11	0.09-0.23	0.12-0.20	2.35-4.47	1.02-2.68
	Mean	83.55	12.04	4.39	7.11	0.09	0.16	0.16	3.41	1.85
3	Range	81.62-87.62	7.02-14.37	1.84-3.36	4.78-11.01	0.06-0.09	0.25-0.28	0.09-0.13	1.40-2.75	2.11-2.21
	Mean	84.62	10.70	2.60	7.90	0.08	0.27	0.11	2.08	2.16
4	Range	84.14-89.32	6.74-11.47	1.03-3.86	5.71-7.61	0.10-0.12	0.23-0.25	0.10-0.10	1.93-2.24	1.58-1.68
	Mean	86.73	9.12	2.45	6.66	0.11	0.24	0.10	2.09	1.63
5	Range	81.13-87.62	6.72-14.43	1.60-5.74	4.31-8.69	0.08-0.14	0.10-0.15	0.04-0.10	2.06-2.95	2.02-2.97
	Mean	84.38	10.58	3.67	6.50	0.11	0.13	0.07	2.51	2.50
6	Range	81.85-86.93	7.53-14.54	2.52-4.43	4.16-11.27	0.10-0.14	0.19-0.25	0.03-0.06	1.96-3.44	1.20-2.78
	Mean	84.39	11.04	3.48	7.72	0.12	0.22	0.05	2.7	1.99
7	Range	91.75-94.16	3.65-4.90	0.80-1.63	2.73-3.62	0.03-0.06	0.04-0.07	0.01-0.04	1.32-1.76	0.76-1.78
	Mean	92.96	4.28	1.22	3.18	0.05	0.06	0.03	1.54	1.27

4.9.4 Iron oxide (Fe_2O_3)

The iron oxide content was in between 0.80 and 6.33 per cent. The highest value of 6.33 per cent was observed in Bw3 horizon of pedon 2 and the lowest value of 0.80 per cent was noticed in A6 horizon of pedon 7. Pedon 4 exhibited a decreasing trend with depth whereas pedon 1 showed an increasing trend with depth. The remaining pedons showed an irregular distribution of iron oxide with depth.

The variation in Fe_2O_3 was due to the variation in chemical and mineralogical composition of the parent materials. The distribution of Fe_2O_3 within the profile was related to the degree of weathering and nature of parent material (Walia and Rao, 1996). Soils on the upper steep slopes contained relatively higher mean values of iron oxides than those in the lower slopes, which could be due to higher degree of weathering (Sitanggang *et al.*, 2006). Higher amount of Fe_2O_3 in all soils clays indicated the possibility of octahedral substitution of Al by Fe in soils of Jumar watershed in Jharkhand (Deb and Sahu, 2011).

4.9.5 Phosphorus pentoxide (P_2O_5)

The P_2O_5 content of the pedons ranged from 0.03 to 0.15 per cent. The highest value of 0.15 per cent was observed in Ap horizons of pedon 1 while the lowest value of 0.03 per cent was noticed in A5 and A6 horizons of pedon 7. All pedons exhibited a decreasing trend with depth while pedons 3 and 6 showed an irregular trend with depth.

Relatively higher values of P_2O_5 in soil might be due to presence of P-bearing minerals such as calcium apatite, high organic matter in surface horizons and also due to use of higher dose of phosphatic fertilizers. Similar results was also reported by Leelavathi *et al.* (2008).

4.9.6 Potassium oxide (K_2O)

These values ranged from 0.04 to 0.28 per cent. Relatively lower value of 0.04 per cent was noticed in pedon 7 whereas higher value of 0.28 per cent was recorded in pedon 3. Pedons 1, 2, 4 and 5 exhibited a decreasing trend with depth while the remaining pedons did not show any particular trend with depth.

Higher amount of K_2O in all the pedons indicates the presence of K-bearing minerals and it also indicates the presence of micaceous minerals. The findings were in agreement with findings of Raina *et al.* (2004) who reported that higher content of K_2O in different horizons of pedons was due presence of K-bearing minerals.

4.9.7 Sodium oxide (Na_2O)

The Na_2O content ranged from 0.01 to 0.20 per cent. The higher value of 0.20 per cent was noticed in pedon 3 whereas the lower value of 0.01 was recorded in pedon 7. Pedons 1, 3 and 7 showed a decreasing with depth. However, remaining pedons not showed any specific trend with depth.

4.9.8 Calcium oxide (CaO)

These values ranged from 1.32 to 4.47 per cent. Highest value of 4.47 per cent was noticed in pedon 2 whereas the lowest value of 1.32 per cent was recorded in pedon 7. Pedon 1 exhibited an increasing trend with depth while pedon 4 showed a decreasing trend with depth. Further, remaining pedons did not show any specific trend with depth.

4.9.9 Magnesium oxide (MgO)

The magnesium oxide content varied from 0.76 to 2.97 per cent. The highest value of 2.97 per cent was recorded in A1 horizon of pedon 5 whereas the lowest value of 0.76 per cent was registered in A5 and A6

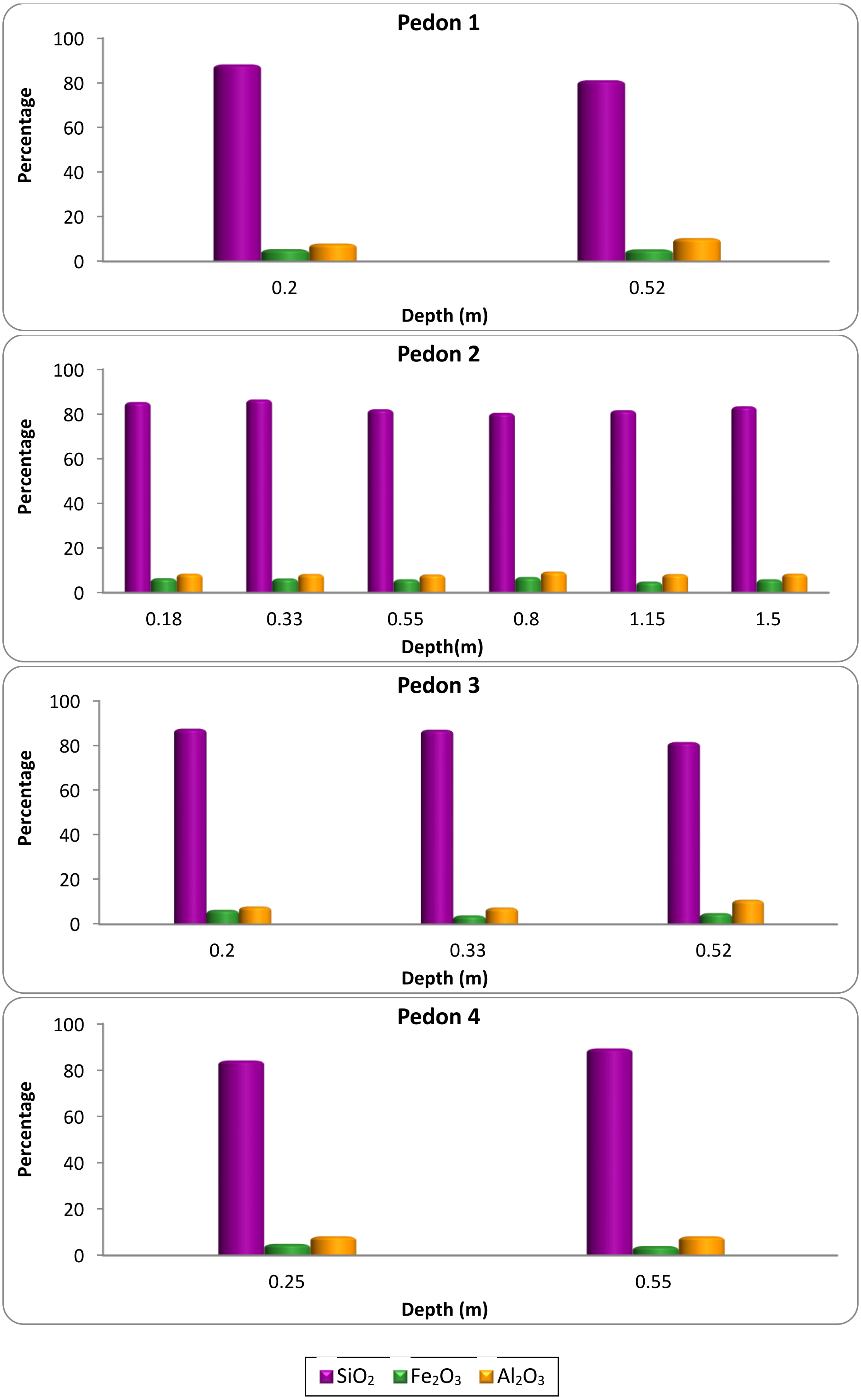


Fig. 4.11. Vertical distribution of silica and sesquioxides

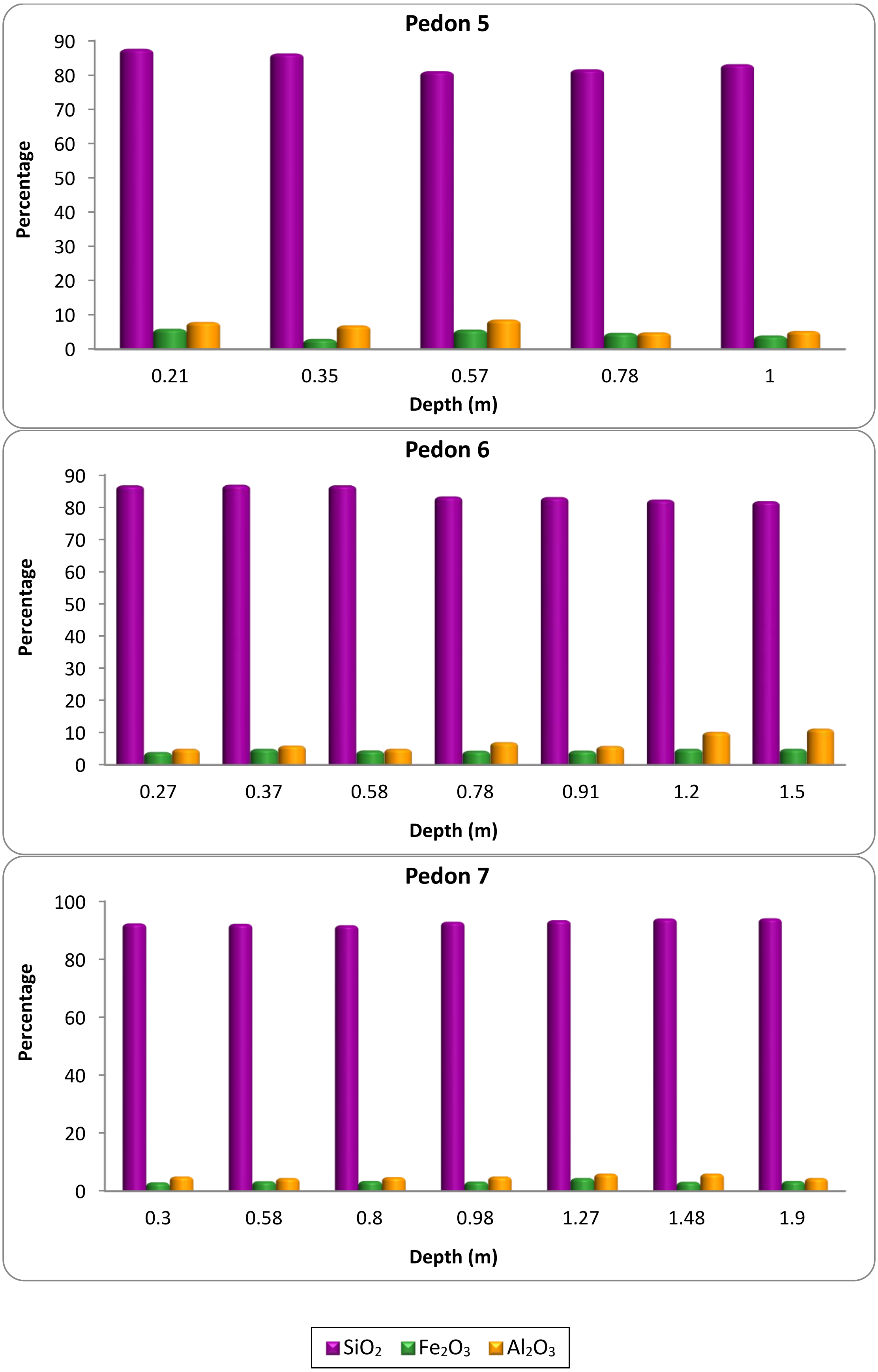


Fig. 4.12. Vertical distribution of silica and sesquioxides

horizons of pedon 7. Pedons 1 and 3 showed an increasing trend with depth whereas pedon 4 exhibited a decreasing trend with depth. However, remaining pedons did not show any particular trend with depth.

Higher value of MgO and CaO indicates the presence of minerals rich in magnesium and calcium. Presence of MgO indicates the possible occurrence of smectite group of minerals (Mall and Mishra, 2000).

4.9.10 Molar ratios of chemical constituents of soils

The values of molar concentrations and molar ratios were presented in Tables. 4.16 and 4.17.

The molar concentrations of SiO_2 ranged from 1.34 to 1.57 in between the horizons of all the pedons while the molar concentration of R_2O_3 (Fe_2O_3 + Al_2O_3) ranged from 0.014 to 0.060. Molar concentration of SiO_2 in pedon 4 exhibited a decreasing trend with depth whereas pedons 1 and 3 showed an increasing trend with depth. Molar concentration of R_2O_3 in pedons 1, 3 and 6 exhibited an increasing trend with depth whereas pedon 4 showed a decreasing trend with depth. However, remaining pedons did not show any specific trend with depth.

The silica / sesquioxide values were varying from 22.33 to 112.14. The highest value of 112.14 was observed in A5 and A6 horizons of pedon 7 whereas the lowest value of 22.33 was noticed in Bw3 horizon of pedon 2. Pedons 1 and 3 exhibited a decreasing trend with depth. Further, pedon 5 showed an increasing trend up to Bw1 horizon later on a decreasing trend. Pedon 4 showed an increasing trend with depth. However, remaining pedons did not show any specific depth function.

The silica / alumina ratios varied from 12.25 to 58.52. The highest value of 58.52 was observed in A5 horizon of pedon 7 whereas the lowest value of 12.25 was noticed in Bw4 horizon of pedon 6. Pedons 1 and 3 showed a decreasing trend with depth whereas pedon 4 exhibited an increasing trend with depth. However, remaining pedons had shown an irregular trend with depth.

The silica / iron oxide ratio ranged from 33.50 to 314.00. The highest value of 314.00 was recorded in A6 horizon of pedon 7 while the lowest value of 33.50 was noticed in Bw3 horizon of pedon 2. Pedons 4 and 7 showed an increasing trend with depth whereas pedon 1 exhibited a decreasing trend with depth. Further, remaining pedons showed an irregular trend with depth.

The ratios (Al_2O_3 / Fe_2O_3) were ranging from 1.95 to 9.33. The lowest value of 1.95 was exhibited by Ap horizon of pedon 6 while the highest value of 9.33 was recorded in A1 horizon of pedon 4. An increasing trend with depth was observed in pedons 1, 3 and 4 whereas the remaining pedons showed an irregular trend with depth.

Wide molar ratios of these soils revealed that silication was the dominant process operating in these soils. Slight variations within the pedons could be due to variation in chemical composition of parent material. These results were in good agreement with those of Tiwary and Mishra (1992). The decreasing trend of SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios with depth might be due to decrease in sand content and increase in clay content. This was in conformity with the studies of Babu (1992) and Anitha (1996). Similar findings were also reported by Ratnam *et al.* (2000) in the soils of Kakumanu mandal of Guntur district in Andhra Pradesh.

The ratios of SiO_2 / R_2O_3, SiO_2 / Al_2O_3, SiO_2 / Fe_2O_3 and Al_2O_3 / Fe_2O_3 were higher in all the soils which might be due to siliceous nature of the parent material and earlier stage of weathering. Similar results were also reported by Prakash and Rao (2002) in red soils of Krishna district, Andhra Pradesh. The soils of eastern region of Varanasi were fairly high in SiO_2 and

Table 4.16. Molar concentrations and molar ratios of the soils

Pedon No. & Horizon	Depth (m)	Molar concentration				Molar ratio			
		SiO_2	Fe_2O_3	Al_2O_3	R_2O_3	SiO_2/R_2O_3	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3
Pedon 1									
Ap	0.00.-0.20	1.47	0.014	0.055	0.030	49.00	26.73	105.00	3.93
A1	0.20-0.52	1.35	0.020	0.103	0.052	25.96	13.11	67.50	5.15
Cr	0.52+	Weathered gneiss							
Pedon 2									
Ap	0.00-0.18	1.42	0.015	0.062	0.033	43.03	22.90	94.67	4.13
Bw1	0.18-0.33	1.44	0.022	0.047	0.032	45.00	30.64	65.45	2.14
Bw2	0.33-0.55	1.37	0.028	0.080	0.048	28.54	17.13	48.93	2.86
Bw3	0.55-0.80	1.34	0.040	0.092	0.060	22.33	14.57	33.50	2.30
Bw4	0.80-1.15	1.36	0.025	0.073	0.044	30.91	18.63	54.40	2.92
Bw5	1.15-1.50+	1.39	0.019	0.064	0.037	37.57	21.72	73.16	3.37
Pedon 3									
Ap	0.00-0.20	1.46	0.014	0.047	0.027	54.07	31.06	104.29	3.36
A1	0.20-0.33	1.45	0.012	0.058	0.030	48.33	25.00	120.83	4.83
A2	0.33-0.52	1.36	0.021	0.108	0.055	24.73	12.59	64.76	5.14
Cr	0.52+	Weathered gneiss							
Pedon 4									
Ap	0.00-0.25	1.40	0.024	0.075	0.044	31.82	18.67	58.33	3.13
A1	0.25-0.55	1.49	0.006	0.056	0.026	57.31	26.61	248.33	9.33
Cr	0.55+	Weathered gneiss							
Pedon 5									
Ap	0.00-0.21	1.46	0.015	0.042	0.026	56.15	34.76	97.33	2.80
A1	0.21-0.35	1.44	0.015	0.050	0.029	49.66	28.80	96.00	3.33
Bw1	0.35-0.57	1.35	0.036	0.085	0.055	24.55	15.88	37.50	2.36
Bw2	0.57-0.78	1.36	0.010	0.048	0.052	26.15	28.33	136.00	4.80
Bw3	0.78-1.00	1.38	0.013	0.053	0.045	30.67	26.04	106.15	4.08
Cr	1.00+	Weathered gneiss							
Pedon 6									
Ap	0.00-0.27	1.44	0.021	0.041	0.029	49.66	35.12	68.57	1.95
A1	0.27-0.37	1.45	0.016	0.048	0.032	45.31	30.21	90.63	3.00
A2	0.37-0.58	1.44	0.024	0.047	0.033	43.64	30.64	60.00	1.96
Bw1	0.58-0.78	1.39	0.020	0.069	0.039	35.64	20.14	69.50	3.45
Bw2	0.78-0.91	1.38	0.028	0.058	0.039	35.38	23.79	49.29	2.07
Bw3	0.91-1.20	1.37	0.021	0.101	0.052	26.35	13.56	65.24	4.81
Bw4	1.20-1.50+	1.36	0.020	0.111	0.056	24.29	12.25	68.00	5.55
Pedon 7									
Ap	0.00-0.30	1.54	0.010	0.031	0.018	85.56	49.68	154.00	3.10
A1	0.30-0.58	1.54	0.009	0.028	0.016	96.25	55.00	171.11	3.11
A2	0.58-0.80	1.53	0.008	0.036	0.019	80.52	42.78	191.25	4.50
A3	0.80-0.98	1.55	0.007	0.032	0.016	96.88	48.44	221.42	4.57
A4	0.98-1.27	1.56	0.007	0.029	0.016	97.50	54.14	222.86	4.14
A5	1.27-1.48	1.57	0.006	0.027	0.014	112.14	58.52	261.67	4.50
A6	1.48-1.90+	1.57	0.005	0.028	0.014	112.14	56.07	314.00	5.60

Table 4.17. Range and mean of molar concentrations and molar ratios of the soils

Pedon No.	Range & Mean	Molar concentrations				Molar ratios			
		SiO_2	Fe_2O_3	Al_2O_3	R_2O_3	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3 / Fe_2O_3
1	Range	1.35-1.47	0.014-0.020	0.055-0.103	0.030-0.052	25.96-49.00	13.11-26.73	67.50-105	3.93-5.15
	Mean	1.41	0.017	0.079	0.041	37.48	19.92	86.25	4.54
2	Range	1.34-1.44	0.015-0.040	0.047-0.092	0.032-0.060	22.33-45.00	14.57-30.64	33.50-94.67	2.14-4.13
	Mean	1.39	0.028	0.07	0.046	33.67	22.61	64.09	3.27
3	Range	1.36-1.46	0.014-0.021	0.047-0.108	0.027-0.055	24.73-54.07	12.59-31.06	64.76-120.83	3.36-5.14
	Mean	1.41	0.018	0.078	0.041	39.40	21.83	92.80	4.25
4	Range	1.40-1.49	0.006-0.024	0.056-0.075	0.026-0.044	31.82-57.31	18.67-26.61	58.33-248.33	3.13-9.33
	Mean	1.45	0.015	0.066	0.035	44.57	22.64	153.33	6.23
5	Range	1.35-1.46	0.010-0.036	0.042-0.085	0.026-0.055	24.55-56.15	15.88-34.76	37.50-136	2.80-4.80
	Mean	1.41	0.023	0.064	0.041	40.35	25.32	86.75	3.80
6	Range	1.36-1.45	0.016-0.028	0.041-0.111	0.029-0.056	24.29-49.66	12.25-35.12	49.29-90.63	1.95-5.55
	Mean	1.41	0.022	0.076	0.043	36.98	23.69	69.96	3.75
7	Range	1.53-1.57	0.005-0.010	0.027-0.036	0.014-0.019	80.52-112.14	42.78-58.52	154.00-314	3.10-5.60
	Mean	1.55	0.009	0.032	0.017	96.33	50.65	234	4.35

SiO_2 / R_2O_3 molar ratios in surface soils. This indicates less siliceous substratum and thereby advanced stage of pedogenic development (Singh and Agarwal, 2005). The low molar SiO_2 / R_2O_3 ratio indicated moderate weathering in soil whereas high molar ratio indicated *vice-versa* (Somasundaram *et al.*, 2010).

4.10 NUTRIENT STATUS

The results of the available and total macro and micronutrients in horizon samples were presented in Tables 4.18, 4.19, 4.20 and 4.21 and depth functions were depicted in Figures 4.13, 4.14, 4.15 and 4.16.

4.10.1 Macronutrients

Results of macronutrients were presented in the Tables 4.18 and 4.19 and depicted in Figures 4.13 and 4.14.

4.10.1.1 Nitrogen

The total nitrogen content ranged from 98 to 630 mg kg^{-1} soil. All pedons showed a decreasing trend with depth. This might be due to decreasing trend of organic carbon with depth, as evident from significant and positive correlation of total nitrogen ($r = +0.939^{**}$) with organic carbon. The mean values of the total nitrogen varied from 147 to 553 mg kg^{-1} soil.

The available nitrogen ranged in between 26.25 to 196.00 mg kg^{-1} soil and these soils were **low to medium** in available nitrogen. All the pedons exhibited a decreasing trend with depth. The data of mean values of available nitrogen was varying from 47.25 to 158.56 mg kg^{-1} soil. However, available nitrogen found to be maximum in the surface horizons and decreased regularly with depth of the pedons, which might be due to decreasing trend of organic carbon with depth, since available nitrogen was significantly and positively correlated ($r = +0.907^{**}$) with organic carbon.

Moreover, low available nitrogen in these soils was attributed to be semi-arid condition of the area might have favoured rapid oxidation and lesser accumulation of organic matter, releasing more NO_3-N which could have been lost by leaching (Finck and Venkateswarlu, 1982). The reason for the maximum available nitrogen content observed in the surface soils could be attributed to the fact that cultivation of crops were mainly confined to the surface horizon (rhizosphere) only and at regular interval the depleted nitrogen content was supplemented by the external addition of fertilizers during crop cultivation. This observation was in accordance with the results of Sarkar *et al*. (2002) and Thangasamy *et al*. (2005).

4.10.1.2 Phosphorus

The total phosphorus content varied from 150 to 650 mg kg^{-1} soil. Pedons 5, 6 and 7 exhibited an irregular decreasing trend with depth whereas the pedons 1, 2, 3 and 4 showed a decreasing trend with depth. Mean values for total phosphorus in these soils were varied between 207 and 638 mg kg^{-1} soil.

More or less a decrease in total phosphorus content with increase in depth was noticed. High organic matter in the surface and addition of phosphotic fertilizers to soils were the causes for high phosphorus content in the surface soils. Similar results were also observed by Sekhar *et al*. (2014) in soils of central and eastern parts of Prakasam district in Andhra Pradesh.

The available phosphorus varied from 3.76 to 13.42 mg kg^{-1} soil and these soils were **low to medium** in available phosphorus. All pedons exhibited a decreasing trend with depth whereas pedon 7 showed an irregular trend with depth. The mean values of available phosphorus varied from 3.97 to 10.42 mg kg^{-1} soil.

Available phosphorus is high in surface horizons and it decreased regularly with depth. The higher phosphorus in the surface soils was due to the higher organic carbon in surface soils and this was further supported by significant and positive correlation (r = +0.819**) between organic carbon and available phosphorus. The other reason for higher phosphorus in surface horizons might possibly be due to the confinement of crop cultivation to the rhizosphere and supplementing the depleted phosphorus by external sources *i.e.,* fertilizers and presence of smaller amounts of free iron oxide and exchangeable Al^{3+} in surface soils (Thangasamy *et al.,* 2005). The lower phosphorus content in sub-surface horizons might be attributed to the fixation of released phosphorus by clay minerals and oxides of iron and aluminium (Rani *et al.,* 1992).

4.10.1.3 Potassium

The total potassium content varied from 350 to 2300 mg kg^{-1} soil. Pedons 1, 2, 3, 4 and 5 exhibited a decreasing trend with depth and the remaining pedons did not show any definite pattern with change in depth. Mean values for total potassium in these soils were ranging from 478 to 2188 mg kg^{-1} soil. In general high total potassium content in different horizons of pedons was due to the existence of semi-arid climate (Mehta *et al.,* 1996). Wide variation of potassium content might be due to nature of parent material (variation in potassium bearing minerals). Similar observations were earlier made by Rani *et al*. (1992) in red soils of Nellore district in Andhra Pradesh.

The available potassium in different pedons varied from 35 to 146.00 mg kg^{-1} soil and these soils were **low to high** in available potassium. The mean values of available potassium were ranging from 68.67 to 274.00 mg kg^{-1} soil. Slow weathering of mica and fixation of released potassium might have resulted in low exchangeable potassium status (Prakash and Rao, 2002). Pedons 1, 2, 3, 4, 5 and 6 exhibited a decreasing trend with depth. This could be attributed to more intense weathering, release of liable K from organic residues, application of K fertilizers and upward translocation of potassium from lower depths along with capillary raise of ground water. Similar results were reported by Basavaraju *et al*. (2005) in soils of Chandragiri mandal of Chittoor district in Andhra Pradesh.

Amount and type of Clay, organic carbon, soil pH and CEC significantly affected the soil K- availability. This is evidenced by the positive and highly significant correlation of available K with organic cabon (r =+0.791**), in the present study. Similar observations was made by Sharma and Kumar (2003) who noticed a significant and positive correlation between clay content and available K, as K availability was largely controlled by clay minerals.

4.10.1.4 Sulphur

Total sulphur content in the horizons of different pedons ranged from 283 to 1250 mg kg^{-1} soil. . Mean values for total sulphur in these soils were ranging from 329 to 1129 mg kg^{-1} soil. All pedons exhibited a decreasing trend with depth whereas pedon 6 showed an irregular trend with depth.

In general, all the pedons had invariably recorded higher total sulphur content which might be due to regular addition of organic matter and sulphur containing fertilizers and pesticides. More or less all pedons showed a decreasing trend with increasing depth was observed. Similar results were also reported by Bhatnagar *et al*. (2003) in soils of Shivapuri district in Madhya Pradesh.

The available sulphur content varied from 15.25 to 40.00 mg kg^{-1} soil and these soils were **high** in available sulphur. The mean values of available sulphur ranged from 17.00 to 33.75 mg kg^{-1} soil. All pedons exhibited a decreasing trend with depth.

Surface layers contained almost more available sulphur than sub-surface layers which might be due to higher amount of organic matter in

Table 4.18. Available and total macronutrient content (mg kg^{-1}) of the soils

Pedon No. & Horizon	Depth (m)	Available macronutrients				Total macronutrients			
		N	P	K	S	N	P	K	S
Pedon 1									
Ap	0.00.-0.20	128.78	10.62	125.00	35.00	308	650	1550	1000
A1	0.20-0.52	119.73	7.24	110.50	32.50	280	625	1100	916
Cr	0.52+	Weathered gneiss							
Pedon 2									
Ap	0.00-0.18	196.00	11.52	141.50	37.50	616	500	1925	1250
Bw1	0.18-0.33	190.42	8.51	136.00	32.50	588	375	1600	1233
Bw2	0.33-0.55	174.32	8.48	98.50	30.00	574	312	1550	1216
Bw3	0.55-0.80	173.63	8.34	97.00	28.50	532	250	1125	1099
Bw4	0.80-1.15	123.19	8.17	91.00	24.50	448	275	1025	1066
Bw5	1.15-1.50+	121.19	7.54	87.00	23.00	378	250	725	916
Pedon 3									
Ap	0.00-0.20	100.79	10.81	124.50	27.50	322	425	2300	1174
A1	0.20-0.33	84.00	6.24	90.00	21.00	308	387	2225	1116
A2	0.33-0.52	67.19	5.39	87.00	20.25	294	262	2075	1066
Cr	0.52+	Weathered gneiss							
Pedon 4									
Ap	0.00-0.25	134.40	8.24	123.50	24.25	252	562	2100	1141
A1	0.25-0.55	117.58	5.14	88.00	20.50	224	437	1950	1083
Cr	0.55+	Weathered gneiss							
Pedon 5									
Ap	0.00-0.21	190.39	13.42	146.00	40.00	630	625	1225	1224
A1	0.21-0.35	180.24	11.81	142.50	35.00	629	538	1175	1208
Bw1	0.35-0.57	179.19	8.31	107.00	22.75	602	513	975	1166
Bw2	0.57-0.78	128.24	7.86	91.50	22.00	546	475	900	1149
Bw3	0.78-1.00	100.79	7.42	88.00	21.00	476	375	800	1033
Cr	1.00+	Weathered gneiss							
Pedon 6									
Ap	0.00-0.27	134.66	11.24	138.00	34.50	574	513	1300	1033
A1	0.27-0.37	123.19	8.48	132.00	28.00	549	625	2000	1124
A2	0.37-0.58	112.00	7.64	90.00	23.00	532	438	1675	949
Bw1	0.58-0.78	89.58	6.82	70.00	21.75	448	475	1800	1183
Bw2	0.78-0.91	84.00	7.12	62.50	20.25	392	500	1550	1124
Bw3	0.91-1.20	83.54	5.89	56.00	19.50	378	525	1675	891
Bw4	1.20-1.50+	67.19	5.93	41.00	18.50	374	438	1700	849
Pedon 7									
Ap	0.00-0.30	67.19	4.12	37.00	18.75	196	263	600	374
A1	0.30-0.58	65.24	4.10	36.90	17.75	168	250	550	349
A2	0.58-0.80	68.24	3.82	36.25	17.00	126	225	525	341
A3	0.80-0.98	44.78	3.96	36.10	16.50	126	188	550	333
A4	0.98-1.27	50.39	4.17	35.90	16.00	112	200	500	316
A5	1.27-1.48	28.00	3.76	35.70	15.50	98	150	475	299
A6	1.48-1.90+	26.25	3.87	35.00	15.25	98	150	350	283

Table 4.19. Range and mean of available and total macronutrient content (mg kg^{-1}) of the soils

Pedon No.	Range & Mean	Available macronutrients				Total macronutrients			
		N	**P**	**K**	**S**	**N**	**P**	K	**S**
1	Range	119.73-128.78	7.24-10.62	110.50-125.00	32.50-35.00	280-308	625-650	1100-1550	916-1000
	Mean	124.26	8.93	117.75	33.75	294	638	1325	958
2	Range	121.19-196.00	7.54-11.52	87.00-141.50	23.00-37.50	378-616	250-500	725-1925	916-1250
	Mean	158.56	9.53	114.25	30.25	497	375	1325	1083
3	Range	67.19-100.79	5.39-10.81	87.00-124.50	20.25-27.50	294-322	262-425	2075-2300	1066-1174
	Mean	83.99	8.10	105.75	23.88	308	344	2188	1120
4	Range	117.58-134.40	5.14-8.24	88.00-123.50	20.50-24.25	224-252	437-562	1950-2100	1083-1141
	Mean	125.99	6.69	105.75	22.38	238	500	2025	1112
5	Range	100.79-190.39	7.42-13.42	88.00-146.00	21.00-40.00	476-630	375-625	800-1225	1033-1224
	Mean	145.59	10.42	117.00	30.50	553	500	1013	1129
6	Range	67.19-134.66	5.89-11.24	41.00-138.00	18.50-34.50	374-574	438-625	1300-2000	849-1183
	Mean	100.93	8.57	89.50	26.50	474	532	1775	1016
7	Range	26.25-68.24	3.76-4.17	35.00-37.00	15.25-18.75	98-196	150-263	350-600	283-374
	Mean	47.25	3.97	36.00	17.00	147	207	475	329

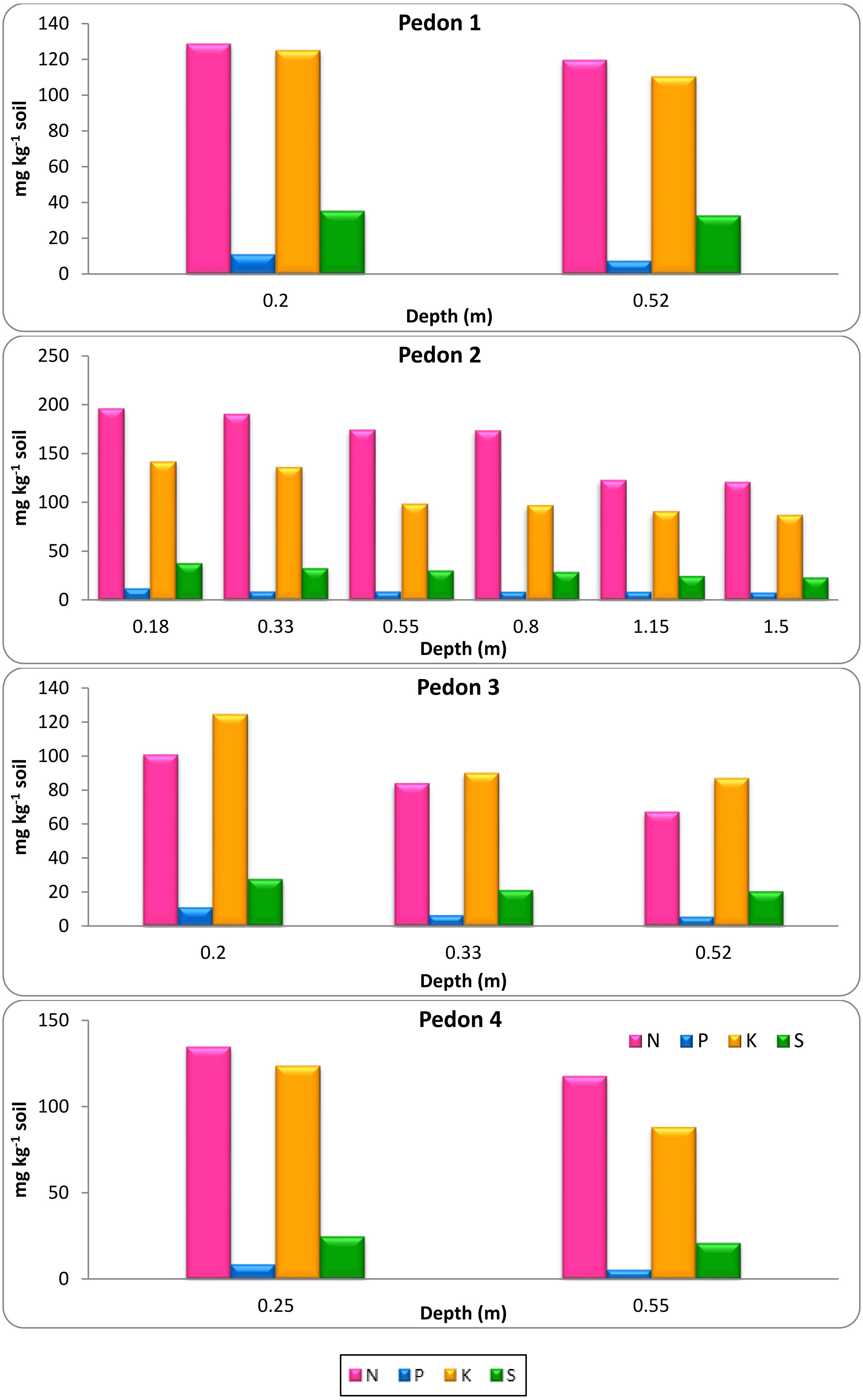


Fig. 4.13. Vertical distribution of available macronutrients

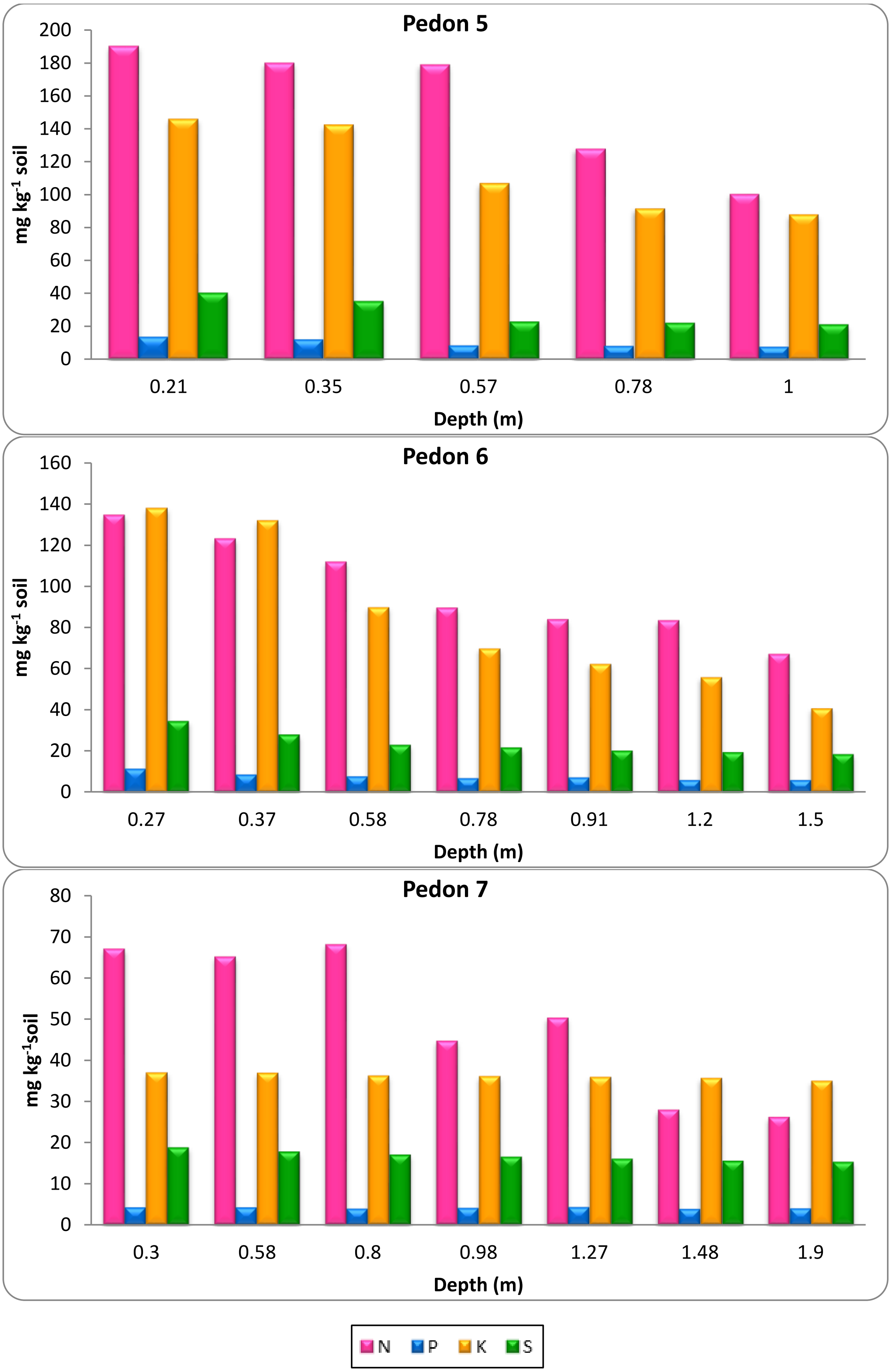


Fig. 4.14. Vertical distribution of available macronutrients

surface layers than in deeper layers. Similar results were reported by Basavaraju *et al*. (2005). These findings were further supported by significant and positive correlation between available sulphur and organic carbon (r=0.789**).

4.10.2 Micronutrients

The results pertaining to available and total micronutrients were presented in Table. 4. 20 and 4.21 and depicted in Figures. 4.15 and 4.16.

4.10.2.1 Zinc

Total zinc was ranging from 1.82 to 15.25 mg kg^{-1} soil. All pedons exhibited a decreasing trend with depth whereas pedon 6 showed an irregular trend with depth. The mean values of total zinc were between 2.67 and 10.20 mg kg^{-1} soil. Parent materials and nature of associated minerals were the predominant determinants of total micronutrients in soils (Murthy *et al.,* 1997). Similar results were also reported by Samanta *et al*. (2002) in soils of West Bengal.

The available zinc varied from 0.28 to 0.57 mg kg^{-1} soil. Pedons 1, 2, 4 and 5 exhibited a regular decreasing trend with depth whereas pedons 3 and 7 exhibited an irregular trend with depth. The mean values of available zinc were between 0.42 to 0.50 mg kg^{-1} soil. Considering 0.6 mg kg^{-1} soil as critical level (Lindsay and Norvell, 1978) for available zinc, these soils were below the critical limit and are found to be **deficient** in available zinc. The low available zinc was possibly due to high soil pH values which might be resulted in the formation of insoluble compounds of zinc or insoluble calcium zincate (Sarkar *et al.,* 2000). Zinc deficiency was wide spread in the high pH, low organic matter and calcareous soils (Rattan and Sharma, 2004).

The relatively low values of available Zn may be attributed to low amount of organic carbon in these soils. These results further supported by significant and positive correlation of available zinc with organic carbon (r = 0.601**) and negative correlation with pH (r = -101). These findings were in accordance with the results of Murthy *et al*. (1997). Similar trend was observed by Sarkar *et al*. (2000) and Satyavathi and Reddy (2004a) in some Inceptisols and Entisols of Madhubani district of Bihar and in soils of Telangana region, respectively. Calcareous soils accompanied by high pH may agravate the deficiency of available Zinc due to deleterious effect of $CaCO_3$ and formation of insoluble $Zn(OH)_2$ or ZnO (Prasad *et al.*, 2009).

4.10.2.1 Copper

The total copper content of the horizons in different pedons varied from 1.52 to 11.32 mg kg^{-1} soil. Pedons 1, 3, 4, 6 and 7 exhibited a regular decrease with depth. Further, pedons 2 and 5 did not show any particular trend with depth. The mean values of the total copper content varied from 2.39 to 8.13 mg kg^{-1} soil. The variation in total copper content among the pedons might be due to variation in copper bearing minerals in these soils.

The available copper content varied from 0.21 to 1.74 mg kg^{-1} soil. Pedons 1, 3, 4, 5 and 7 showed a decreasing trend with depth. However, remaining pedons exhibited an irregular trend with depth. The mean values of the available copper content varied from 0.26 to 1.06 mg kg^{-1} soil.

All the pedons were found to be **sufficient** in available copper, since all the values were well above critical limit of 0.2 mg kg^{-1} soil as suggested by Lindsay and Norvell (1978). Available copper was significantly and positively correlated (r = + 0.440*) with organic carbon. Similar results were expressed by Sarkar *et al*. (2000) and Verma *et al*. (2005) in soils of Madhubani district in Bihar and in soils developed on different physiographic units of Fatehgarh Sahib district of Punjab, respectively.

Table 4.20. Available and total micronutrients status (mg kg^{-1}) of the soils

Pedon No. & Horizon	Depth (m)	Available micronutrients				Total micronutrients			
		Zn	Cu	Fe	Mn	Zn	Cu	*Fe (%)	Mn
Pedon 1									
Ap	0.00.-0.20	0.52	1.12	8.31	2.17	7.50	6.12	1.52	110
A1	0.20-0.52	0.47	0.58	7.42	2.12	6.85	5.47	2.27	104
Cr	0.52+	Weathered gneiss							
Pedon 2									
Ap	0.00-0.18	0.57	1.74	5.31	5.27	15.25	10.34	1.71	450
Bw1	0.18-0.33	0.52	0.61	5.24	4.84	11.35	9.62	2.46	378
Bw2	0.33-0.55	0.48	0.82	4.81	3.17	8.14	6.17	3.16	472
Bw3	0.55-0.80	0.46	0.74	5.12	2.14	6.25	5.12	4.43	351
Bw4	0.80-1.15	0.44	0.52	4.62	1.98	6.50	6.24	2.85	323
Bw5	1.15-1.50+	0.42	0.37	5.14	1.17	5.15	7.17	2.17	344
Pedon 3									
Ap	0.00-0.20	0.45	0.75	14.17	2.54	5.32	6.37	1.57	107
A1	0.20-0.33	0.41	0.64	12.24	1.76	4.71	5.82	1.29	102
A2	0.33-0.52	0.42	0.58	11.18	1.52	3.94	5.16	2.35	97
Cr	0.52+	Weathered gneiss							
Pedon 4									
Ap	0.00-0.25	0.52	0.82	12.76	1.82	5.17	5.72	2.70	101
A1	0.25-0.55	0.48	0.67	11.24	1.72	4.32	4.81	0.72	98
Cr	0.55+	Weathered gneiss							
Pedon 5									
Ap	0.00-0.21	0.54	1.30	11.42	6.24	12.47	11.32	1.69	430
A1	0.21-0.35	0.51	0.71	10.38	5.37	8.14	6.34	1.62	312
Bw1	0.35-0.57	0.48	0.41	10.64	5.24	7.42	8.21	4.01	284
Bw2	0.57-0.78	0.44	0.54	9.74	4.82	6.81	4.94	1.12	222
Bw3	0.78-1.00	0.42	0.52	8.37	2.24	5.18	5.12	1.43	217
Cr	1.00+	Weathered gneiss							
Pedon 6									
Ap	0.00-0.27	0.55	0.73	8.21	5.21	10.32	5.47	2.36	321
A1	0.27-0.37	0.51	0.64	7.64	3.17	8.64	5.31	1.76	284
A2	0.37-0.58	0.47	0.53	5.28	4.52	5.74	5.17	2.64	275
Bw1	0.58-0.78	0.45	0.41	6.47	3.89	6.37	4.84	2.27	119
Bw2	0.78-0.91	0.46	0.52	7.42	4.12	4.81	4.37	3.10	254
Bw3	0.91-1.20	0.48	0.62	6.27	2.17	5.27	4.14	2.35	174
Bw4	1.20-1.50+	0.45	0.41	5.24	2.41	3.94	2.12	2.29	125
Pedon 7									
Ap	0.00-0.30	0.55	0.31	3.25	2.12	3.52	3.27	1.14	110
A1	0.30-0.58	0.48	0.28	3.17	1.97	2.82	2.14	0.95	97
A2	0.58-0.80	0.37	0.27	2.84	1.84	2.27	1.97	0.90	98
A3	0.80-0.98	0.45	0.26	2.86	1.74	1.87	1.94	0.78	101
A4	0.98-1.27	0.42	0.24	2.15	1.21	2.12	1.81	0.78	96
A5	1.27-1.48	0.28	0.23	1.98	1.11	1.94	1.54	0.67	58
A6	1.48-1.90+	0.30	0.21	1.94	1.10	1.82	1.52	0.56	321

*Total iron is presented in percentage (%)

Table 4.21. Range and mean of available and total micronutrient content (mg kg^{-1}) of the soils

Pedon No.	Range & Mean	Available micronutrients				Total micronutrients			
		Zn	Cu	Fe	Mn	Zn	Cu	Fe (%)	Mn
1	Range	0.47-0.52	0.58-1.12	7.42-8.31	2.12-2.17	6.85-7.50	5.47-6.12	1.52-2.27	104-110
	Mean	0.50	0.85	7.87	2.15	7.18	5.80	1.90	107
2	Range	0.42-0.57	0.37-1.74	4.62-5.31	1.17-5.27	5.15-15.25	5.12-10.34	1.71-4.43	323-472
	Mean	0.50	1.06	4.97	3.22	10.20	7.73	3.07	398
3	Range	0.41-0.45	0.58-0.75	11.18-14.17	1.52-2.54	3.94-5.32	5.16-6.37	1.29-2.35	97-107
	Mean	0.43	0.67	12.68	2.03	4.63	5.77	1.82	102
4	Range	0.48-0.52	0.67-0.82	11.24-12.76	1.72-1.82	4.32-5.17	4.81-5.72	0.72-2.70	98-101
	Mean	0.50	0.75	12.00	1.77	4.75	5.27	1.71	100
5	Range	0.42-0.54	0.41-1.30	8.37-11.42	2.24-6.24	5.18-12.47	4.94-11.32	1.12-4.01	217-430
	Mean	0.48	0.86	9.90	4.24	8.83	8.13	2.57	324
6	Range	0.45-0.55	0.41-0.73	5.24-8.21	2.17-5.21	3.94-10.32	2.12-5.47	1.76-3.10	119-321
	Mean	0.50	0.57	6.73	3.90	7.13	3.80	2.43	220
7	Range	0.28-0.55	0.21-0.31	1.94-3.25	1.10-2.12	1.82-3.52	1.52-3.27	0.56-1.14	58-321
	Mean	0.42	0.26	2.60	1.61	2.67	2.39	0.85	190

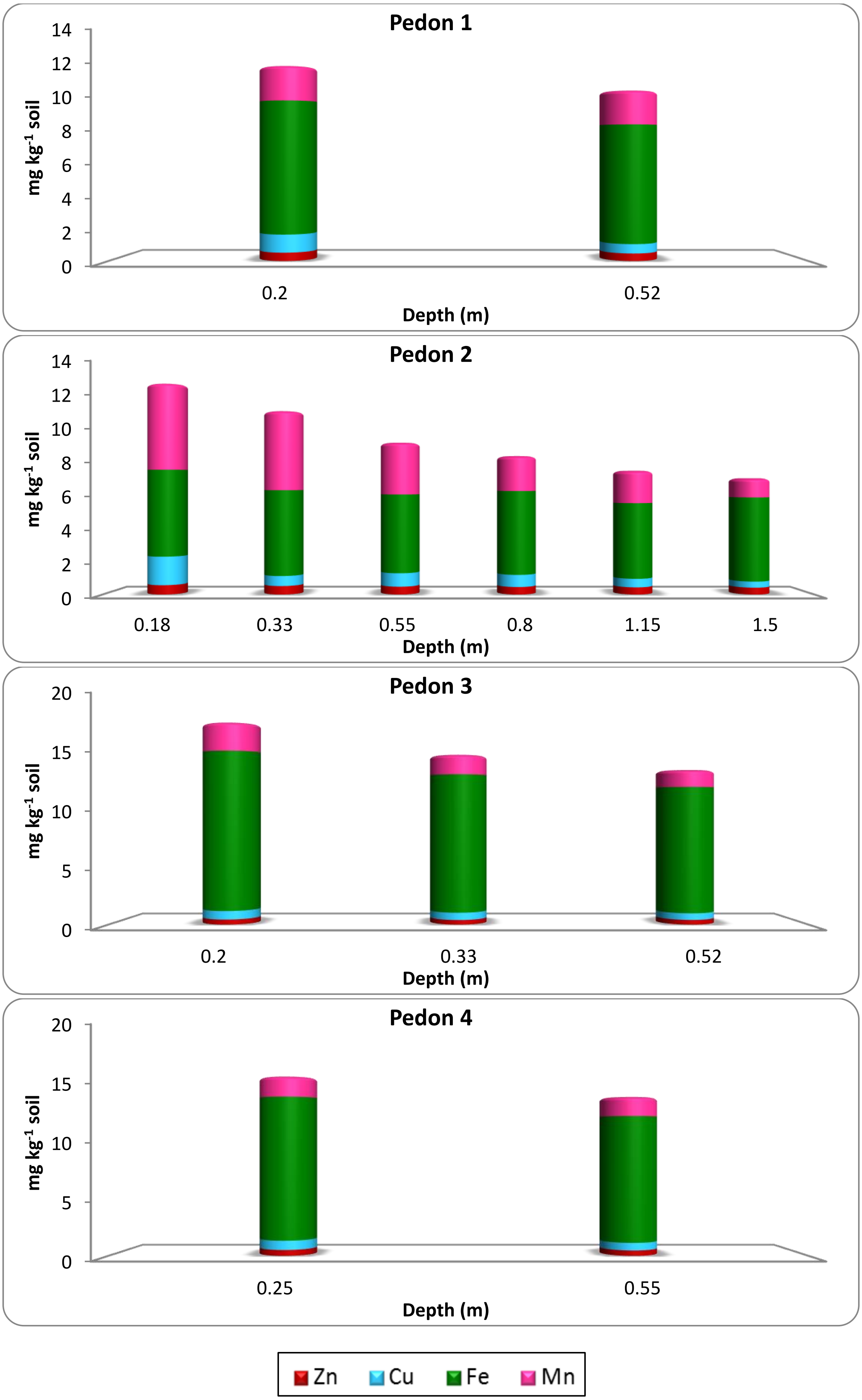


Fig. 4.15. Vertical distribution of available micronutrients

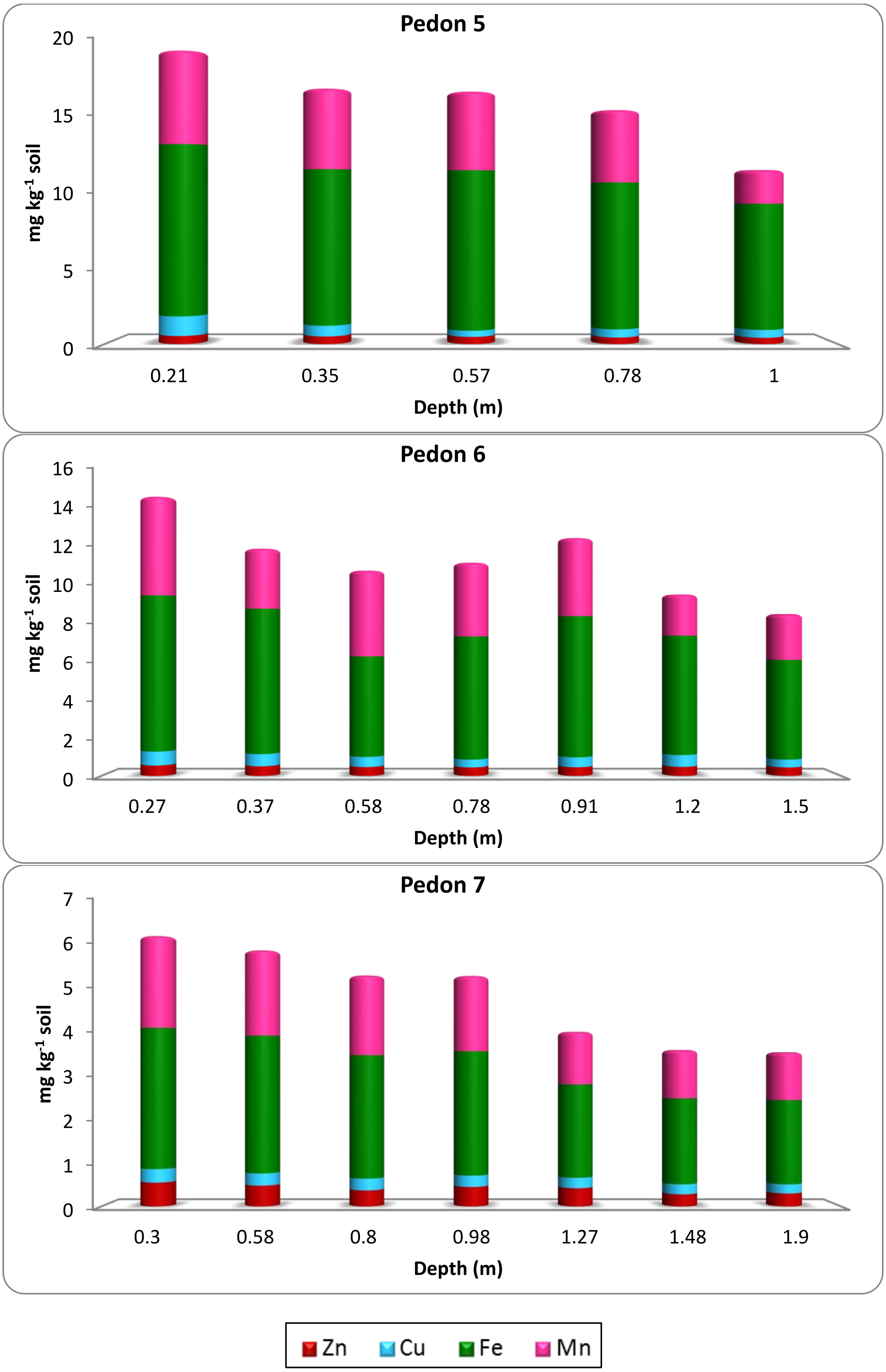


Fig. 4.16. Vertical distribution of available micronutrients

4.10.2.3 Iron

The total iron content ranged from 0.56 to 4.43 per cent. Pedon 1 exhibited an increasing trend with depth whereas pedon 2 showed an increasing trend up to Bw3 horizon and later on decreased. Pedons 4 and 7 showed a decreasing trend with depth. However, remaining pedons exhibited an irregular trend with depth. The mean values of the total iron content varied from 0.85 to 3.07 per cent. Variation in total iron among the pedons could be attributed to variation in ferro-magnesium minerals present in these soils. Sangwan and Singh (1993) assessed that irregular distribution of Fe in soils of Naurangpura series might be due to weak pedogenic manifestation and alluvial nature of the soils.

The available iron content was ranging from 1.94 to 14.17 mg kg^{-1} soil. Pedons 1, 3, 4, 5 and 7 registered a decreasing trend with depth. Pedons 2 and 6 exhibited an irregular trend with depth. The mean values of available iron ranging from 2.60 to 12.68 mg kg^{-1} soil.

According to the critical limit (4.5 mg kg^{-1} soil) of Lindsay and Norvell (1978) the soils were **sufficient** in available iron whereas pedon 7 was found to be **deficient** in available iron (1.94 to 3.25 mg kg^{-1} soil). Surface horizons had higher concentration of DTPA-extractable Fe due to higher organic carbon (Prasad and Gajbhiye, 1999). The low iron content might be due to precipitation of Fe^{+2} by calcium carbonate concretions in calcareous soils and higher pH of these soils, which may decreased the availability of Fe (Kumar *et al.,* 2013).These results were further supported by positive correlation of available iron with organic carbon (r =0.298) and negative correlation with pH (r = -0.101). These findings were in good agreement with those of Sarkar *et al.* (2000).

4.10.2.4 Manganese

The total manganese content ranged from 58 to 472 mg kg^{-1} soil. Pedons 1, 3, 4 and 5 showed a regular decreasing trend with depth while the remaining pedons (2, 6 and 7) exhibited an irregular trend with depth. The mean values of total manganese content varied from 100 to 398 mg kg^{-1} soil.Wide variation in total Mn could be ascribed to the variation in the content of manganese bearing minerals, clay, organic carbon, CEC and other associated elements (Prasad, 1994).

Available manganese content varied from 1.10 to 6.24 mg kg^{-1} soil. All pedons exhibited a decreasing trend with depth while pedon 6 showed an irregular trend with depth. The mean values of available manganese content varied from 1.61 to 4.24 mg kg^{-1} soil. The available manganese content was **sufficient** because these values were well above the critical limit (1.0 mg kg^{-1}) of Lindsay and Norvell (1978). These observations were confirmed with the findings of Sarkar *et al*. (2000) and Bhaskar *et al*. (2004a) in soils of Bihar and in soils of Meghalaya.

The higher concentration of manganese in the surface horizon might be due to higher biological activity and the chelating of organic compounds, released during the decomposition of organic matter left after harvesting of crop. It was further supported by a significant positive correlation between available manganese and organic carbon (r = + 0.824**). Similar findings were also made by Murthy *et al*. (1997) and Verma *et al*. (2005).

In conclusion, the micronutrient analysis of soils in Chillakur mandal revealed that soils were **deficient** in available zinc whereas **sufficient** in available copper, iron (except pedon 7) and manganese.

4.11 SOIL CLASSIFICATION

The detailed taxonomic classification of soil resources of Chillakur mandal was given in Table. 4.24. Based on the morphological characters (Table. 4.4 and Appendix I), physical, physico-chemical and chemical properties, the soils of Chillakur mandal were classified up to family level as per soil taxonomy (Soil Survey Staff, 2014).

4.11.1 Taxonomic classification

CLASSIFICATION OF PEDONS 1, 3, 4 AND 7

At order level

a) Soils of recent origin. According to Rao *et al.* (1991), the alluvial deposits of Andhra Pradesh were of recent origin (2 million years old).

b) No development of pedons / horizonation.

c) Absence of any diagnostic sub-surface horizon.

Singh and Agarwal (2003) reported that absence of diagnostic sub-surface horizon in the profiles was one of the most important criteria for **Entisols**. Further, the soils in watershed area of Shikohpur, Gurgaon district, Haryana were also classified under Entisols due to very slight degree of soil formation either because of limited available time or because of unfavourable pedoenvironment (Sitanggang *et al.,* 2006).

Based on the above features these 4 pedons were classified under **Entisols** at order level.

At sub-order level

Pedons 1, 3 and 4 were characterized by

a) Did not permanently saturate with water and matrix was not reduced in all the horizons below 25 cm from the mineral soil surface.

b) 8 Depth of the pedon was less than 100 cm and 3 per cent or more (volume) fragments of diagnostic horizon were not observed.

c) Absence of rock fragments and a texture of loamy fine sand or coarser.

d) Not showed 0.2 per cent or more organic carbon of Holocene age at a depth of 125 cm below the mineral soil surface or an irregular decrease in the content of organic carbon.

e) Showed decrease in organic carbon with depth.

Hence, pedons 1, 3 and 4 were grouped under **Orthents** at sub-order level. Similar findings were also noticed by Thangasamy *et al*. (2005) who reported that soils of Sivagiri- micro watershed of Chittoor district in Andhra Pradesh were also classified into orthents at sub-order level.

Pedon 7 had sandy texture in the control section, not exhibited any diagnostic horizon and did not permanently saturate with water. Hence, this pedon was keyed out as **Psamments** at sub-order level. Verma *et al*. (2001) and Swarnam *et al*. (2004) classified the Entisols of Punjab and Shahibi basin of Haryana and Delhi into Psamments at sub-order level, respectively.

Table 4.22. Soil classification

Pedon No.	Order	Sub-order	Great group	Sub-group	Family	Tentative soil series
1.	Entisols	Orthent	Ustorthent	Typic Ustorthent	Fine-loamy, mixed, isohyperthermic, Typic Ustorthent	Oduru
2.	Inceptisols	Ustept	Haplustept	Typic Haplustept	Fine-loamy, smectitic, isohyperthermic, Typic Haplustept	Nelaballi
3.	Entisols	Orthent	Ustorthent	Typic Ustorthent	Fine-loamy, smectitic, isohyperthermic Typic Ustorthent	Kadivedu
4.	Entisols	Orthent	Ustorthent	Typic Ustorthent	Fine-loamy, kaolinitic, isohyperthermic, Typic Ustorthent	Thonukumala
5.	Inceptisols	Ustept	Haplustept	Typic Haplustept	Fine-loamy, smectitic, isohyperthermic, Typic Haplustept	Kalavakonda
6.	Entisols	Ustept	Haplustept	Typic Haplustept	Fine-loamy, mixed, isohyperthermic, Typic Haplustept	Udathavaripalem
7.	Entisols	Psamment	Ustipsamment	Typic Ustipsamment	Sandy, siliceous, isohyperthermic, Typic Ustipsamment	Yeruru

At great group level

Pedons 1, 3, and 4 had ustic moisture regime. Hence, these pedons were classified as **Ustorthents** at great group level. Thangasamy *et al*. (2005) reported that the soils of Sivagiri micro-watershed of Chittoor district in Andhra Pradesh were classified as Ustorthents at great group level.

Pedon 7 did not have aridic, xeric and udic moisture regimes but had ustic soil moisture regime. Hence, this pedon was classified under **Ustipsamments** at great group level. Shekhar *et al*. (2014) also classified the soils of central and eastern parts of Prakasam district in Andhra Pradesh as Ustipsamments.

At sub-group level

Pedons 1, 3 and 4 did not show the following characteristics

a) Lithic contact within 50 cm of the mineral soil surface.

b) 50 per cent or more (by volume) worm holes, worm casts and filled animal burrows in any horizon.

c) Frigid, mesic or thermic or hyper thermic, cracks within 125 cm of the mineral surface that were 5 mm or more wide to a thickness of 30 cm or more and linear extensibility of 6 cm or more.

d) Redox depletions of chroma 2 or less.

e) Durinodes

f) Cinders, pumice like fragments.

Due to the absence of above characteristics pedons 1, 3 and 4 were placed under **Typic Ustorthents** at sub-group level. Devi and Naidu (2014) classified sugarcane growing soils in chittoor district, Andhra Pradesh into **Typic Ustorthents.**

Pedon 7 was characterized by

a) Absence of lithic contact within 0.5 m of the mineral soil surface.

b) Not saturated with water within 1 m of the mineral soil surface.

c) Did not have prominent redox and aquic conditions.

d) Not had frigid or mesic or thermic or hyperthermic or isomesic soil temperature regimes.

e) Absence of lamellae within 2 m of the soil surface.

f) Not exhibited a munsell colour notation of 2.5 YR hue and value (moist) of 3 or less.

Hence, pedon 7 was grouped under **Typic Ustipsamments**. Based on the similar features Sekhar *et al.* (2014) classified the sandy soils of central and eastern parts of Prakasam district in Andhra Pradesh as Typic Ustipsamments at sub-group level.

CLASSIFICATION OF PEDONS 2, 5 AND 6

At order level

Following features in the sub-surface horizons within a depth of 0.18 to 1.90 m in pedons 2, 5 and 6 (with a thickness of >15 cm) were observed.

a) Texture was finer than very fine sand or loamy very fine sand.

b) Absence of rock structure.

c) Did not have anthropic, histic, melanic, mollic, plaggen and umbric epipedons.

d) Absence of duripan, fragipan, argillic, calcic, gypsic, natric, oxic, petrocalcic, petrogypsic, placic and spodic sub-surface horizons.

e) Absence of cementation or induration.

f) Regular decrease in the amount of organic carbon with depth.

The presence of cambic sub-surface diagnostic horizon in pedons 2, 5 and 6 were recognized by the above features. Prasad *et al.* (2001) reported that presence of cambic sub-surface horizon was the diagnostic criteria for Inceptisols.

Hence, pedons 2, 5 and 6 were keyed out as Inceptisols at order level. Kadao *et al.* (2003) classified the typical banana growing soils of Wardha district of Maharashtra into Inceptisols based on the presence of cambic horizon.

At sub-order level

The pedons 2, 5 and 6 have ustic soil moisture regime. Hence, these pedons were classified as **Ustepts** at this category. Sharma *et al.* (2004b) classified the soils of southern Rajasthan as Ustepts due to the presence of ustic soil moisture regime at great sub-order level.

At great group level

Pedons 2, 5 and 6 were not having either duripan or calcic horizon and the base saturation was more than 60 per cent at a depth between 0.25 to 0.75 m from the soil surface. These characters indicated these pedons represented the central concept of Ustepts. So, the pedons 2, 5 and 6 were grouped under Haplustepts at great group level. Patil and Prasad (2004) placed the *sal* supporting soils in Dindori district of Madhya Pradesh as Haplustepts at great group level.

At sub-group level

Pedons 2, 5 and 6 was characterized by

a) Did not have lithic contact within 50 cm from the soil surface

b) Absence of andic properties and acquic conditions within 75 cm depth from the surface.

c) Did not have umbric or mollic epipedons.

d) Not showed the vertic properties.

e) Absence of lamellae, calcic and gypsic sub-surface horizons.

f) Did not have aridic temperature regime and udic moisture regime.

g) Had more than 60 per cent base saturation in all the horizon of the profiles.

The above pedons did not exhibit intergradation with other taxa or an extragradation from the central concept. Hence, pedons 2, 5 and 6 were logically classified as **Typic Haplustepts** at sub-group level. Sugarcane growing soils of Chittoor district in Andhra Pradesh were classified under Typic Haplustepts at sub-group level (Devi and Naidu, 2014).

CLASSIFICATION AT FAMILY LEVEL

Particle size class

Pedons 1, 2, 3, 4, 5 and 6 contained more than 18 per cent and less than 35 per cent clay (weighted average) in the control section. Hence, the particle size class was Fine loamy.

Pedons 7 had less than 10 per cent clay (silt +1 ½ times clay ≤ 15) and high sand content (weighted average > 90%). So the particle size class was Sandy.

Mineralogy class

High CEC / Clay ratio (> 0.45) of the pedons 2, 3 and 5 indicated smectitic clay mineralogy, medium CEC/Clay ratio (0.24 to 0.45) of pedons 1 and 6 indicated mixed clay mineralogy and low CEC/Clay ratio (< 0.16 to 0.24) of pedon 4 indicated the kaolinitic mineralogy (Boul *et al.* 1998 ; Smith, 1980). However, pedon 7 recorded more than 80 per cent SiO_2 (91.75-94.16). Hence, the mineralogy class for pedon 7 was siliceous (Soil Survey Staff, 2014).

Temperature class

MAST was computed from the MAAT (28.78 °C) by adding 3.5°C. The Chillakur mandal was classified under megathermic temperature regime because of the prevailing mean annual soil temperature (32.28°C). MAST of 28°C was used as the limit to separate hyperthermic from megathermic (Sehgal, 1996).

MSST of the study area was 32.34°C which was computed by adding 2.5°C to the MSAT (30.66°C) and deducting the amplitudinal correction factor (0.82°C). The MWST of the study area was 26.91°C calculated by adding 2.5°C to the MWAT (25.23°C) and adding the amplitudinal correction factor (0.82°C). According to Sehgal (1996), the study area was placed under megathermic temperature regime.

Soil Survey Staff (2014) recognized March, April, May and June as summer months and November, December, January and February as winter months for the places in northern hemisphere. As per these criteria the difference between mean summer and winter temperatures was less than

6°C and mean annual temperature was more than 22°C. Therefore the temperature regime of the study area was classified as isohyperthermic.

Based on morphological, physical, physico-chemical, chemical, mineralogical and meteorological data, the soils of Chillakur mandal were classified as:

Pedon 1	:	Fine-loamy, mixed, isohyperthermic, Typic Ustorthent
Pedon 2	:	Fine-loamy, smectitic, isohyperthermic, Typic Haplustept
Pedon 3	:	Fine-loamy, smectitic, isohyperthermic, Typic Ustorthent
Pedon 4	:	Fine-loamy, kaolinitic, isohyperthermic, Typic Ustorthent
Pedon 5	:	Fine-loamy, smectitic, isohyperthermic, Typic Haplustept
Pedon 6	:	Fine-loamy, mixed, isohyperthermic, Typic Haplustept
Pedon 7	:	Sandy, siliceous, isohyperthermic, Typic Ustipsamment

4.12 LAND CAPABILITY CLASSIFICATION

The details of land capability classes and sub-classes assigned to the soils of Chillakur mandal were given in the Table. 4.23. Land capability sub-classes were assigned for the soils based on the kind and severity of limitations *viz.*, erosion risk (e), wetness (w), rooting zone (soils) limitations (s) and climatic limitations (c). Based on these criteria the soils of Chillakur mandal have been classified into different capability sub-classes and suitable land use plan has been suggested (Table 4.24).

IIIs	:	Moderately good cultivable lands (Pedons 5 and 6)
IIIws	:	Moderately good cultivable land (Pedon 2)
IVs	:	Fairly good cultivable lands (Pedon 7)
IVse	:	Fairly good cultivable lands (Pedons 1, 3 and 4)

Table 4.23. Land capability classification of soils of Chillakur mandal

Pedon No.	Tentative soil series	Soil characteristics										Land capability class with limitations
		Surface texture	Solum depth (m)	Drainage	Slope (%)	Erosion	Organic carbon (%)	Gavelliness	Stoniness	Salinity	Alkalinity	
1.	Oduru	scl	0.52+	Well drained	1-3	Moderate	<1%	–	–	–	–	IVse
2.	Nelaballi	sicl	1.50+	Somewhat poorly drained	0-1	Very slight	<1%	–	–	–	–	IIIws
3.	Kadivedu	sl	0.52+	Well drained	1-3	Slight	<1%	–	–	–	–	IVse
4.	Thonukumala	scl	0.55+	Well drained	1-3	Slight	<1%	–	–	–	–	IVse
5.	Kalavakonda	scl	1.00	Well drained	0-1	Very slight	<1%	–	–	–	–	IIIs
6.	Udathavaripalem	scl	1.50+	Well drained	0-1	Slight	<1%	–	–	–	–	IIIs
7.	Yeruru	s	1.90+	Well drained	0-1	Slight	<1%	–	–	–	–	IVs

Table 4.24. Interpretation of soils of Chillakur mandal

Pedon No.	Tentative soil series	Land capability class with limitations	Description	Major limitations	Suggested land use
1.	Oduru	IVse	Fairly good cultivable land for sustainable agriculture	Shallow depth, gentle slope, moderate erosion, poor nutrient status, moderate run-off and moderate water holding capacity.	Double cropping including legumes in rotation, addition of fertilizers and manures and adopting moderate soil conservation measures.
2.	Nelaballi	IIIws	Moderately good cultivable land for sustainable agriculture	Poor drainage, poor permeability, alkaline soil reaction and tillage problems.	Cultivation with precaution against permanent damage, moderate soil conservation measures, growing of leguminous crops in rotation and application of organic manures.
3.	Kadivedu	IVse	Fairly good cultivable land for sustainable agriculture	Low organic matter content, shallow depth, gentle slope, moderate erosion and moderate run-off,	Double cropping including legumes in rotation with special soil and water management practices and addition of organic manures.
4.	Thonukumala	IVse	Fairly good cultivable land for sustainable agriculture	Shallow depth, gentle slope, moderate erosion, moderate run-off, poor nutrient status and low organic matter content.	moderate soil conservation measures, very careful soil and water management practices could be followed and suitable for fruit crops like mango

Cont…

Table 4.24. (Cont.).

Pedon No.	Tentative soil series	Land capability class with limitations	Description	Major limitations	Suggested land use
5.	Kalavakonda	IIIs	Moderately good cultivable land for sustainable agriculture	Poor fertility status and low organic matter content.	Moderate soil conservation measures, application of organic manures and rice, groundnut and sesame could be grown.
6.	Udathavaripalem	IIIs	Moderately good cultivable land for sustainable agriculture	Poor nutrient status, moderate water holding capacity, low organic matter content and tillage problems	Special soil-conserving cropping systems, crop rotation that includes grasses and legumes, growing of green manure crops, stubble mulching and suitable for crops like groundnut, sunflower and sesame.
7.	Yeruru	IVs	Fairly good cultivable land for sustainable agriculture	Sandy texture, low water holding capacity, poor fertility status, low organic matter content and excessively drained.	Addition of tank silt (pond mud) is recommended and very careful soil and water management practices could be followed and groundnut and plantation crops like cashew could be grown.

Pedons 1, 3 and 4 are placed under capability sub-class IVse which were fairly good cultivable lands for sustainable agriculture with severe limitations of shallow depth, gentle slope, moderate erosion, poor nutrient status, low organic matter content and moderate water holding capacity. The management practices suggested for these pedons were addition of organic manures and fertilizers and by taking moderate soil conservation measures. Pulses, oilseeds and vegetables could be grown. Similar land capability classification was given by Rao *et al*. (2008) and Kharche and Pharande (2010) to the soils of Ramachandrapuram mandal in Chittoor district of Andhra Pradesh and soils (Entisols) of Mula command area of Maharashtra.

Pedon 2, is classified under capability sub-class IIIws which is moderately good cultivable land for sustainable agriculture with moderate limitations of poor drainage, poor permeability and tillage problems. The management practices suggested for this pedon is cultivation with precaution against permanent damage, moderate soil conservation measures, growing of leguminous crops in rotation and application of organic manures. Similarly, Sireesha and Naidu (2013b) placed the soils of Banaganapalle mandal in Kurnool district of Andhra Pradesh under land capability sub-class IIIws.

Pedons 5 and 6 are grouped under capability sub-class IIIs. These were moderately good cultivable lands with moderate limitations of poor nutrient status, moderate water holding capacity, low organic matter content, tillage problems and poor nutrient status. The management practices suggested for pedons 5 and 6 were application of organic manures, special soil-conserving cropping systems (contour farming), crop rotation that includes legumes, growing of green manure crops and stubble mulching. Groundnut, sunflower and sesame could be grown. Similarly Rao *et al*. (2008) placed the soils of Ramachandrapuram mandal in Chittoor district of Andhra Pradesh under land capability sub-class IIIs.

Pedon 7 had severe limitations of sandy texture and excessively drained. It is tentatively placed under land capability sub-class IVs. It is a fairly good cultivable land for sustainable agriculture with severe limitations of sandy texture, low water holding capacity, poor fertility, low organic matter content and excessively drained. Similar land capability classification was given by Leelavathi *et al*. (2009) to the soils of Yerpedu mandal in Chittoor district of Andhra Pradesh.The suggested land use plan for pedon 7 was addition of tank silt (pond mud) and very careful soil and water management practices could be followed. Crops like groundnut and cashew could be grown.

4.13 SOIL SITE SUITABILITY FOR CROPS

Each plant species requires definite soil and site conditions for its optimum growth. Although some plants may be found to grow under different soils and extreme agro-ecological condition yet not all plants can grow on the same soil and under the same environment. Since the availability of both water and plant nutrients was largely controlled by the physico-chemical and micro-environment of soils, therefore, the success and failure of any plant species, in a particular area, was largely determined by these factors.

The optimum requirement of a crop was always region specific. Climatic and soil parameters play a significant role to maximize crop yields. The depth wise soil characteristics used to arrive site-soil characteristics for assessing crop suitability were presented in the Table 4.25. The site-soil properties from the study area (Table 4.26) were matched with the soil-site suitability criteria (Appendix II) for rice, groundnut, sesame and sunflower crops that were grown in Chillakur mandal of SPSR Nellore district, Andhra Pradesh.

The kind and degree of limitations were evaluated (Table 4.27) and the suitability of different soils of study area for growing rice, groundnut, sesame and sunflower crops was given below.

The performance of any crop was largely dependent on soil parameters (depth, texture, drainage *etc.*) as conditioned by climate and topography. The study of soil-site characterization for predicting the crop performance of an area forms land evaluation. According to Wambeke and Rossiter (1987) land evaluation was the rating of soil for optimum returns per unit area.

Degree of suitability for various crops

Pedon No.	Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable-temporarily (N1)	Not suitable-permanently (N2)
Pedon 1	-	-	Rice, groundnut, sesame and sunflower	-	-
Pedon 2	-	-	Rice, groundnut, sesame and sunflower	-	-
Pedon 3	-	-	Rice, groundnut, sesame and sunflower	-	-
Pedon 4	-	-	Rice, groundnut, sesame and sunflower	-	-
Pedon 5	-	-	Rice, groundnut, sesame and sunflower	-	-
Pedon 6	-	-	Rice, groundnut, sesame and sunflower	-	-
Pedon 7	-	-	Groundnut, sesame and sunflower	Rice	-

The yield influencing factors for important crops have to be evaluated and the results obtained may be applied for higher production of these crops through proper utilization of similar soils occur elsewhere in same agro-climatic sub-region under scientific management practices (Khadse and Gaikwad, 1995).

Table 4.25. Depth wise soil characteristics used in assessing crop suitability

Pedon No.	Location	Horizon	Depth (m)	Physical characteristics (s)				Fertility characteristics (f)					Salinity and alkalinity (n)	
				Texture			$CaCO_3$ (%)							
				Sand (2-0.05%)	Silt (0.05 -0.002)	Clay (<0.002)		CEC [cmol (p+) kg^{-1} soil]	BS (%)	Sum of basis cations [cmol (p+) kg^{-1} soil]	pH (1:2.5 H_2O)	OC (%)	EC (dSm^{-1})	ESP
				—— % of <2 mm soil ——										
1	Oduru	Ap	0.00.-0.20	49.10	22.30	28.60	4.50	9.67	79.94	7.57	6.60	0.32	0.01	1.65
		A1	0.20-0.52	25.40	40.70	33.90	4.00	14.78	75.51	10.96	6.73	0.30	0.02	1.35
		Cr	0.52+	Weathered gneiss										
2	Nelaballi	Ap	0.00-0.18	15.70	53.80	30.50	9.50	16.52	72.76	11.69	7.43	0.61	0.08	2.00
		Bw1	0.18-0.33	43.70	27.70	28.60	11.50	14.78	79.84	11.48	7.93	0.57	0.02	2.17
		Bw2	0.33-0.55	41.60	25.80	32.60	10.00	17.93	70.50	12.21	8.40	0.46	0.03	2.40
		Bw3	0.55-0.80	37.70	24.00	38.30	12.00	20.87	64.21	13.05	8.50	0.43	0.05	1.68
		Bw4	0.80-1.15	38.00	29.70	32.30	15.00	21.84	69.96	14.99	8.20	0.38	0.03	1.33
		Bw5	1.15-1.50+	41.00	28.20	30.80	16.00	25.52	70.53	17.62	8.40	0.41	0.30	1.49
3	Kadivedu	Ap	0.00-0.20	54.00	33.60	12.40	6.00	5.15	85.44	4.28	7.70	0.28	0.03	2.33
		A1	0.20-0.33	49.80	23.80	26.40	6.50	14.34	74.97	10.57	7.58	0.26	0.02	1.26
		A2	0.33-0.52+	50.30	18.50	34.60	5.50	18.69	71.70	13.25	7.60	0.23	0.02	0.80
		Cr	0.52 +	Weathered gneiss										

Cont…

Table 4.25. (Cont.).

Pedon No.	Location	Horizon	Depth (m)	Physical characteristics (s)			$CaCO_3$ (%)	Fertility characteristics (f)					Salinity and alkalinity (n)	
				Texture										
				Sand (2-0.05%)	Silt (0.05 -0.002)	Clay (<0.002)		CEC [cmol (p+) kg^{-1} soil]	BS (%)	Sum of basis cations [cmol (p+) kg^{-1} soil]	pH (1:2.5 H_2O)	OC (%)	EC (dSm^{-1})	ESP
				—— % of <2 mm soil ——										
4	Thonukumala	Ap	0.00-0.25	33.30	32.10	31.20	4.50	6.30	84.29	5.25	6.10	0.24	0.02	0.95
		A1	0.25-0.55	62.30	15.60	22.10	3.50	5.10	98.24	4.94	6.33	0.22	0.03	1.37
		Cr	0.55+	Weathered gneiss										
5	Kalavakonda	Ap	0.00-0.21	55.20	21.10	23.70	5.50	13.80	59.06	8.06	6.20	0.57	0.03	0.65
		A1	0.21-0.35	51.50	19.10	29.40	6.00	14.24	66.64	9.32	6.21	0.54	0.03	1.19
		Bw1	0.35-0.57	33.20	28.50	32.10	7.50	14.56	60.99	8.70	6.38	0.49	0.03	1.24
		Bw2	0.57-0.78	42.30	25.60	38.30	6.50	22.82	60.65	13.69	6.17	0.46	0.03	0.66
		Bw3	0.78-1.00	40.60	28.40	31.00	7.00	15.43	72.33	11.07	6.60	0.41	0.03	0.58
		Cr	1.00+	Weathered gneiss										
6	Udathavaripalem	Ap	0.00-0.27	58.70	18.20	23.10	8.50	10.22	66.93	6.74	6.30	0.46	0.32	0.98
		A1	0.27-0.37	54.80	20.40	24.10	7.00	6.74	88.43	5.79	6.80	0.43	0.02	2.52
		A2	0.37-0.58	52.40	21.70	25.90	5.50	9.46	67.34	6.19	7.12	0.42	0.03	1.90
		Bw1	0.58-0.78	18.70	50.40	30.90	6.50	12.06	66.42	7.88	7.24	0.32	0.06	1.08
		Bw2	0.78-0.91	17.40	52.60	30.00	6.00	10.00	63.50	6.20	7.28	0.35	0.02	1.50
		Bw3	0.91-1.20	15.20	53.40	31.40	8.00	10.90	61.56	6.60	7.20	0.22	0.21	1.01
		Bw4	1.20-1.50+	14.30	55.00	30.70	8.50	9.45	70.26	6.46	6.90	0.20	0.02	1.90
7	Yeruru	Ap	0.00-0.30	88.4	5.30	6.30	1.50	5.40	57.59	3.04	6.23	0.24	0.05	1.30
		A1	0.30-0.58	90.6	4.20	5.20	2.00	4.70	61.91	2.84	6.40	0.22	0.04	1.49
		A2	0.58-0.80	90.5	3.70	5.80	2.00	5.10	76.67	3.83	6.45	0.18	0.03	1.57
		A3	0.80-0.98	90.6	3.20	6.20	2.50	5.30	71.51	3.71	6.50	0.14	0.03	1.51
		A4	0.98-1.27	89.6	4.30	6.10	2.00	5.10	65.10	3.26	6.20	0.16	0.31	1.18
		A5	1.27-1.48	90.6	3.70	5.70	2.00	4.90	55.10	2.64	6.10	0.12	0.02	1.22
		A6	1.48-1.90+	91.2	3.30	5.50	2.50	4.80	53.96	2.54	7.50	0.12	0.31	1.04

Table 4.26. Site and soil characteristics of studied profiles for crop suitability classification

Pedon No.	Soil	Land form	Parent material	Wetness (W) drainage	Physical soil characteristics (s)				Soil fertility characteristics (f)					Salinity and alkalinity (n)	
					Texture	Coarse fragments Volume (%)	Soil depth (m)	$CaCO_3$ (%)	Apparent CEC [c mol (p+) kg^{-1} soil]	Sum of basic cations [c mol (p+) kg^{-1} soil]	BSP	pH 1:2.5	OC (%)	EC (dSm^{-1})	ESP
1	Oduru	Upland	Weathered gneiss	Well drained	scl	Nil	0.52+	4.19	39.68	8.25	77.21	6.63	0.32	0.02	1.65
2	Nelaballi	Plain	Weathered gneiss	Somewhat poorly drained	sicl	Nil	1.50+	11.64	53.70	11.63	70.63	7.57	0.60	0.04	2.40
3	Kadivedu	Upland	Weathered gneiss	Well drained	sl	< 15	0.52+	5.94	49.10	5.54	77.80	7.68	0.28	0.02	2.33
4	Thonukumala	Upland	Weathered gneiss	Well drained	scl	Nil	0.55+	3.95	21.64	5.25	91.90	6.20	0.24	0.02	1.37
5	Kalavakonda	Plain	Weathered gneiss	Well drained	scl	Nil	1.00+	6.55	51.63	8.26	63.80	6.20	0.57	0.02	1.24
6	Udathavaripalem	Plain	Weathered gneiss	Well drained	scl	Nil	1.50+	6.95	38.98	6.74	68.13	6.3	0.46	0.12	2.52
7	Yeruru	Plain	Coastal alluvium	Excessively drained	s	Nil	1.90+	1.94	87.58	3.04	65.65	6.23	0.24	0.04	1.57

Topography (Slope) : 0-1%, 1-3%
Flooding : Fo

The soil site characteristics of the study area were matched with soil site suitability criteria for a few important crops *viz.,* rice, groundnut, sesame and sunflower (Appendix II) given by Sys *et al.* (1993).

The kind and degree of limitation and suitability class were determined and evaluated. The studied soils vary in their suitability for different crops according to the criteria for the determination of the land suitability classes.

Pedons1, 3 and 4, which were classified under Typic Ustorthents were marginally suitable (S3) for rice, groundnut, sesame and sunflower crops. The major limiting factors for growth of rice, groundnut, sesame and sunflower in these soils were wetness, texture, shallow depth and low organic carbon. The texture can be improved by mixing with tank silt year after year and organic carbon status in these soils can be improved by the application of farm yard manure, green manuring and inclusion of legumes in rotation. Kumar and Naidu (2012b) reported that Typic Ustorthents were marginally suitable for growing rice crop in Vadamalapeta mandal of Chittoor district in Andhra Pradesh.

Pedons 2, 5 and 6 were grouped under Typic Haplustepts. All pedons were marginally suitable (S3) for crops like rice, groundnut, sesame and sunflower. Soil fertility characteristics *viz.,* pH and organic carbon and physical soil characteristics like texture and drainage were the limitations. Organic carbon and pH were major limitations for all the crops whereas soil texture was a limitation for rice crop. However, heavy texture and improper drainage were found to be important soil related constraints in growing these crops. Organic carbon status in these soils can be improved by the application of farm yard manure, green manuring and inclusion of legumes in rotation. pH can be controlled by application of organic manures and sulphur and texture can be improved by mixing with tank silt year after year. Leelavathi *et al.* (2010) reported that Typic Haplustepts were marginally

Table 4.27. Limitation levels of the land characteristics and land suitability classes

Soil	Crop	Wetness (w) drainage	Physical soil characteristics (s)			$CaCO_3$ (%)	Soil fertility characteristics (f)			Alkalinity (n)	Actual land suitability sub-class	Potential land suitability sub-class
			Texture	Coarse fragments (Vol. %)	Soil depth (cm)		Sum of basis cations [cmol (p+) kg^{-1} soil]	pH 1:2.5	OC (%)	ESP		
Typic Ustorthents	Rice	2	2	0	2	1	0	0	3	0	S3wsf	S2ws
	Groundnut	0	0	0	2	0	0	0	3	0	S3sf	S2s
	Sesame	0	0	0	2	-	0	1	3	0	S3sf	S2s
	Sunflower	0	1	0	3	0	0	0	3	0	S3sf	S3s
Typic Haplustepts	Rice	2	2	0	0	1	0	1	3	0	S3wsf	S2ws
	Groundnut	1	1	0	0	0	0	2	3	0	S3sf	S1
	Sesame	2	0	0	0	-	0	3	3	0	S3wf	S1w
	Sunflower	2	0	0	0	1	0	2	3	0	S3wsf	S1w
Typic Ustorthents	Rice	2	3	2	2	1	1	1	3	0	S3wsf	S3ws
	Groundnut	0	0	2	2	0	0	2	3	0	S3sf	S2s
	Sesame	0	0	1	2	-	1	2	3	0	S3sf	S2s
	Sunflower	0	2	1	3	0	0	2	3	0	S3sf	S3s
Typic Ustorthents	Rice	2	2	0	2	1	0	0	3	0	S3wsf	S2ws
	Groundnut	0	0	0	2	0	0	1	3	0	S3sf	S2s
	Sesame	0	0	0	2	-	0	0	3	0	S3sf	S2s
	Sunflower	0	1	0	3	1	0	1	3	0	S3sf	S3s
Typic Haplustepts	Rice	2	2	0	0	2	0	0	3	0	S3wsf	S2ws
	Groundnut	0	0	0	1	0	0	1	3	0	S3f	S1
	Sesame	0	0	0	1	-	0	0	3	0	S3f	S1
	Sunflower	0	1	0	2	1	0	1	3	0	S3sf	S2s
Typic Haplustepts	Rice	2	2	0	0	2	0	0	3	0	S3wsf	S2ws
	Groundnut	0	0	0	0	0	0	1	3	0	S3f	S1
	Sesame	0	0	0	0	-	0	1	3	0	S3f	S1
	Sunflower	0	1	0	0	1	0	1	3	0	S3f	S1
Typic Ustisamments	Rice	2	4	0	0	0	2	1	3	0	N1wsf	N1ws
	Groundnut	0	3	0	0	0	1	1	3	0	S3sf	S3s
	Sesame	0	3	0	0	-	2	1	3	0	S3sf	S3s
	Sunflower	0	3	0	0	0	1	1	3	0	S3sf	S3s

Limitations: 0- No; 1-Slight; 2-Moderate; 3-Severe, 4-Very severe. Suitability classes: f-Soil fertility limitations; s-Physical soil limitations; w-Wetness limitations; n-Salinity (and / or alkalinity) limitations.

suitable (S3) for growing paddy crop in Yerpedu mandal of Chittoor district in Andhra Pradesh.

Pedon 7 was grouped under Typic Ustipsamments was marginally suitable (S3) for growing groundnut, sesame and sunflower crops and temporarily not suitable (N1) for rice crop. This soil had limitations of excessively drained, physical characteristics like sandy texture and fertility characteristics like low sum of basic cations and low organic carbon. Soil texture can be improved by mixing with tank silt year after year, organic carbon status in these soils can be improved by the application of farm yard manure, green manuring and inclusion of legumes in rotation. Sekhar *et al*. (2014) stated that Typic Ustipsamments were temporarily not suitable (N1) for growing rice crop in soils of central and eastern parts of Prakasam district in Andhra Pradesh.

The soil-site suitability for different crops (rice, groundnut, sesame and sunflower) revealed that shallow depth in pedon 1, 3 and 4, low organic carbon in all pedons (1, 2, 3, 4, 5, 6 and 7) and sandy texture in pedon 7 are the major limitations for growing these crops on these soils. By correcting the limitations as suggested above, sustainable yields can be achieved in rice, groundnut, sesame and sunflower crops.

Table 4.28. Simple correlations between different soil properties (Relation among chemical and physical properties)

Variables			r-values
pH	vs	$CaCO_3$	0.725**
pH	vs	Base saturation	-0.075
pH	vs	Available Zn	-0.110
pH	vs	Available Cu	0.113
pH	vs	Available Fe	-0.109
pH	vs	Available Mn	-0.138
Organic carbon	vs	Total N	0.939**
Organic carbon	vs	Total P	0.497**
Organic carbon	vs	Total S	0.742**
Organic carbon	vs	Available N	0.907**
Organic carbon	vs	Available P	0.819**
Organic carbon	vs	Available K	0.791**
Organic carbon	vs	Available S	0.789**
Organic carbon	vs	Available Zn	0.601**
Organic carbon	vs	Available Cu	0.621**
Organic carbon	vs	Available Fe	0.298
Organic carbon	vs	Available Mn	0.824**
Clay	vs	R_2O_3	0.884**
Clay	vs	Available Zn	0.350*
Clay	vs	Available Cu	0.440*
Clay	vs	Available Fe	0.469**
Clay	vs	Available Mn	0.375*
Clay	vs	CEC	0.773**
Sand	vs	Silica	0.889**
Bulk density	vs	Pore space	0.340
Bulk density	vs	Organic carbon	-0.329
Water holding capacity	vs	Clay	0.799**
Water holding capacity	vs	Sand	-0.721**
Loss on ignition	vs	Clay	0.942**
Loss on ignition	vs	Sand	-0.834**
Volume expansion	vs	Clay	0.828**

* Values significant at 5 per cent level
** Values significant at 1 per cent and 5 per cent level

Chapter ~ V

Summary & Conclusions

Chapter – VI

SUMMARY AND CONCLUSIONS

The present investigation involves characterization, classification and evaluation of soils in Chillakur mandal of SPSR Nellore district in Andhra Pradesh.

Seven representative pedons were selected in seven different locations of Chillakur mandal covering all types of soils. The pedons were studied in detail and described for their morphological characteristics. The horizon-wise soil samples collected from these pedons were processed and analyzed for physical properties *viz.*, particle size class, soil density, water holding capacity, volume expansion, pore space and LOI; physico-chemical properties like pH, EC, organic carbon and $CaCO_3$; electro-chemical characteristics such as CEC, exchangeable bases and base saturation; chemical composition (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, P_2O_5, Na_2O and K_2O) and total and available nutrients (N, P, K, S, Zn, Cu, Fe and Mn) status.

The climate of the Chillakur mandal was semi-arid monsoonic climate with a mean annual rainfall and air temperature of 1113.25 mm and 28.78°C, respectively. However, distinct summer, rainy and winter seasons were existing in the Chillakur mandal.

Pedons 2, 3, 4, 5, and 6 were developed from granite-gneiss parent material whereas pedon 7 was originated from alluvium. These pedons were occurring on nearly plain (0-1%) to gently sloping (1-3%) topography with moderately deep to very deep in depth. These pedons were characterized by AC (Pedons 1, 3, 4 and 7) and ABC (Pedons 2, 5 and 6) profiles. The colour varied from yellowish red to dark reddish brown in pedons 1, 3 and 4, brown to yellow colour in pedons 5, 6 and 7 and pale brown to dark yellowish brown in pedon 2.

The morphological features indicated that these pedons in general had the texture ranged from sand to silty clay loam in surface horizons and sand to clay loam in sub-surface horizons. The soil structure varied from fine to coarse, structureless to strong and crumb to angular blocky in size, grade and type, respectively. Consistence varied from loose to very hard, loose to very firm and non-sticky and non-plastic to very sticky and very plastic in dry, moist and wet conditions, respectively.

The clay content in pedons 1 and 4 exhibited a decreasing trend with depth while pedons 5 and 6 showed an increasing trend up to Bw2 and Bw3 horizons, respectively and later on a decreasing trend with depth. Pedon 3 showed an increasing trend with depth. However, no specific trend with depth was observed in pedons 2 and 7. Physical constants like water holding capacity, loss on ignition and volume expansion followed the trend of clay content. All pedons exhibited an irregular trend in bulk density while pedon 1 showed a decreasing trend with depth.

All the pedons were slightly acidic to moderately alkaline in reaction, non-saline and low to medium in organic carbon content. All the pedons exhibited low $CaCO_3$ status. CEC values of these pedons were low to medium and pedon 4 exhibited a decreasing trend with depth, pedons 1 and 3 exhibited an increasing trend with depth and pedon 5 showed an increasing trend up to Bw2 horizon later on decreased. However, remaining pedons did not show any particular trend with depth.

The exchange complex was dominated by Ca^{2+} followed by Mg^{2+}, Na^{+} and K^{+}.

The silica content exhibited a decreasing trend with depth in case of pedons 1 and 3 whereas pedon 5 showed a decreasing trend up to Bw1 horizon later on an increasing trend. Pedon 4 had shown an increasing trend with depth. However, remaining pedons did not show any particular trend with depth. Further, SiO_2 / R_2O_3, SiO_2 / Al_2O_3, SiO_2 / Fe_2O_3, Al_2O_3 / R_2O_3 ratios were higher in all the soils indicating the siliceous nature of the parent material.

Regarding the fertility status, the soil samples were low to medium in available nitrogen and available phosphorus, low to high available potassium and high in available sulphur. As far as cationic micronutrients (DTPA-extractable) status is concerned, the soils were deficient in available zinc and sufficient in available copper, iron (except pedon 7) and manganese.

Based on morphological, physical, physico-chemical, mineralogical and meteorological data, the soils of Chillakur mandal were classified as:

Pedon 1 : Fine-loamy, mixed, isohyperthermic, Typic Ustorthent

Pedon 2 : Fine-loamy, smectitic, isohyperthermic, Typic Haplustept

Pedon 3 : Fine-loamy, smectitic, isohyperthermic, Typic Ustorthent

Pedon 4 : Fine-loamy, kaolinitic, isohyperthermic, Typic Ustorthent

Pedon 5 : Fine-loamy, smectitic, isohyperthermic, Typic Haplustept

Pedon 6 : Fine-loamy, mixed, isohyperthermic, Typic Haplustept

Pedon 7 : Sandy, siliceous, isohyperthermic, Typic Ustipsamment

Tentative interpretative grouping of soils into land capability sub-classes as follows:

Pedons 1, 3 and 4 were placed under capability sub-class IVse which were a fairly good cultivable lands for sustainable agriculture with severe limitations of shallow depth, gentle slope, moderate erosion, poor nutrient status, low organic matter content, and moderate water holding capacity

Pedon 2 was grouped under land capability sub-class IIIws. It is a moderately good cultivable lands with moderate limitations such as poor drainage, slight erosion, poor soil aeration, low organic carbon, soil tillage problems and poor nutrient status.

Pedons 5 and 6 classified under land capability sub-class IIIs. These are moderately good cultivable lands with moderate limitations of shallow depth and poor nutrient status. Pedon 7 was grouped under land capability sub-class IVs, which was a fairly good cultivable land with severe limitation of texture and excessively drained and low organic carbon content.

The soil-site suitability evaluation of study area revealed that all pedons were marginally suitable (S3) for rice, groundnut, sesame and sunflower crop and pedon 7 was temporarily not suitable (N1) for rice crop.

In conclusion, the analysis of soils of the Chillakur mandal revealed that soils were low to medium in organic carbon, available N and available P, low to high in available K and high in available S whereas deficient in available Zn and sufficient in available Cu, available Fe (except pedon 7) and available Mn. Hence, using organics in combination with inorganics not only sustains crop yield but also soil health for future generations.

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*Originals not seen

Appendices

APPENDIX I

PEDON 1

I. Soil site description

a.	Village	:	Oduru
b.	Physiography	:	Uplands
c.	Slope	:	Degree : 1-3% (very gently sloping) Class – B Aspect : NW – NE
d.	Parent material	:	Granite-gneiss
e.	Natural vegetation	:	*Borassuss flaciflora* *Cynodon dactylon* and *Pongamia pinneta etc.*
f.	Land use	:	Maize, Groundnut and Tomato
g.	Erosion	:	Moderate
h.	Drainage	:	Well drained
i.	Ground water depth	:	Below 50 m
j.	Location	:	Near to Telugu - Ganga canal in the Oduru village. [14º02′44.6″ N, 79º52′36.3″ E]

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.20	Reddish brown (5 YR 4/4) dry, dark reddish brown (5 YR 3/4) moist; sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, firm, slightly sticky and slightly plastic; few fine pores; clear smooth boundary.
A1	0.20-0.52	Reddish brown (5YR 5/4) dry, reddish brown (5 YR 4/4) moist; clay loam; medium, moderate, sub-angular blocky; hard, firm, sticky and plastic; few fine pores; clear smooth boundary
Taxonomic Unit	:	Fine loamy, siliceous, isohyperthermic, Typic Ustorthent
LCC (tentative interpretative grouping)	:	IVse (Fairly good cultivable land with severe limitations)

PEDON 2

I. Soil site description

a.	Village	:	Nelaballi
b.	Physiography	:	Plain
c.	Slope	:	Degree : 0-1% (Nearly level) Class – A Aspect : SW – SE
d.	Parent material	:	Granite- gneiss
e.	Natural vegetation	:	*Parthenium hysterophorus* *Acacia nilotica* and *Cynodon dactylon, etc.*
f.	Land use	:	Rice and Sesame
g.	Erosion	:	Very slight
h.	Drainage	:	Some what poorly drained
i.	Ground water depth	:	Below 20 m
j.	Location	:	Left side of the road that proceeds to the Nelaballi village and near to village water tank [14º05′26.3″ N, 79º53′02.5″ E]

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.18	Dark yellowish brown (10 YR 4/6) dry, dark yellowish brown (10 YR 3/4) moist; silty clay loam; medium, moderate, sub-angular blocky; hard, firm, sticky and plastic; few fine pores; strong effervescence; clear smooth boundary.
Bw1	0.18-0.33	Dark yellowish brown (10 YR 4/6) dry, dark yellowish brown (10 YR 4/6) moist; clay loam; medium, moderate, sub-angular blocky; hard, firm, slightly sticky and slightly plastic; few fine pores; strong effervescence; diffuse wavy boundary.
Bw2	0.33-0.55	Brown (10 YR 4/3) dry, brown (10 YR 4/3) moist; clay loam; coarse, moderate, angular blocky; very hard, very firm, very sticky and very plastic; violent effervescence; clear smooth boundary.
Bw3	0.55-0.80	Brown (10 YR 5/3) dry, greyish brown (10 YR 5/2) moist; clay loam; coarse, moderate, angular blocky; very hard, very firm, very sticky and very plastic; violent effervescence; clear smooth boundary.
Bw4	0.80-1.15	Pale brown (10 YR 6/3) dry, dark greyish brown (10 YR 4/2) dark greyish brown moist; clay loam; coarse, moderate, angular blocky; very hard, very firm, very sticky and very plastic; violent effervescence; clear smooth boundary.
Bw5	1.15-1.50+	Brown (10 YR 4/3) dry, dark grey (10 YR 4/1) moist; clay loam; coarse, moderate, angular blocky; very hard, very firm, very sticky and very plastic; violent effervescence; clear smooth boundary.
Taxonomic Unit	:	Fine-loamy, smectitic, isohyperthermic, Typic Haplustept
LCC (tentative interpretative grouping)	:	IIIws (Moderately good cultivatable with moderate limitations)

PEDON 3

I. Soil site description

a.	Village	:	Kadivedu
b.	Physiography	:	Upland
c.	Slope	:	Degree : 1-3% (very gently sloping) Class – B Aspect : NE – NW
d.	Parent material	:	Granite-gneiss
e.	Natural vegetation	:	*Cyprus rotundas,* *Cyanodon dactylon* and *Calotropis gigantia etc.*
f.	Land use	:	Citrus orchard and Leafy vegetables
g.	Erosion	:	Slight
h.	Drainage	:	Well drained
i.	Ground water depth	:	Below 25 m
j.	Location	:	In citrus orchard and near silica factory of the village. [14º04′42.8″ N, 79º53′54.8″ E]

II. Brief description of the typifying pedon

Horizon	Depth(m)	Morphometric characters
Ap	0.00 – 0.20	Reddish brown (5 YR 5/3) dry, yellowish red (5 YR 4/2) moist; sandy loam; fine weak crumb; slightly hard, friable, slightly sticky and slightly plastic; fine and few pores; clear and smooth boundary.
A1	0.20-0.33	Reddish brown (5 YR 5/3) dry, reddish brown (5 YR 4/3) moist; sandy clay loam; medium moderate, sub-angular blocky; slightly hard, firm, sticky and plastic; few and fine pores; clear and smooth boundary.
A2	0.33-0.52	Reddish brown (5 YR 5/4) dry, reddish brown (5 YR 4/4) moist; clay loam; coarse strong angular blocky; hard, very firm, very sticky and very plastic; few and fine pores; clear and smooth boundary.
Taxonomic Unit	:	Fine-loamy, smectitic, isohyperthermic, Typic Ustorthent
LCC (tentative interpretative grouping)	:	IVse (Fairly good cultivable land with severe limitations)

PEDON 4

I. Soil site description

a.	Village	:	Thonukumala
b.	Physiography	:	Upland
c.	Slope	:	Degree : 1-3% (Very gently sloping) Class – B Aspect : SE – SW
d.	Parent material	:	Granite-gneiss
e.	Natural vegetation	:	*Parthenium hysterophorus* *Cyprus rotundus* and *Tephrosia purpurea etc.*
f.	Land use	:	Mango orchard
g.	Erosion	:	Slight
h.	Drainage	:	Well drained
i.	Ground water depth	:	Below 50 m
j.	Location	:	Right side of the road, proceeding to Thonukumala. [14º06′35.6″ N, 79º57′16.5″ E]

II. Brief description of the typifying pedon

Horizon	Depth (m)		Morphometric characters
Ap	0.00-0.25		Reddish brown (5 YR 5/4) dry, reddish brown (5 YR 4/4) moist; sandy clay loam; fine, weak, crumb; smooth, friable, slightly sticky and slightly plastic; few and fine pores; clear and smooth boundary.
A1	0.25-0.55		Yellowish red (5 YR 5/6) dry, Yellowish red (5 YR 4/6) moist; sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, firm, slightly sticky and slightly plastic; few and fine pores; clear and smooth boundary.
Taxonomic Unit		**:**	Fine- loamy, kaolinitic isohyperthermic, Typic Ustorthent
LCC (tentative interpretative grouping)		**:**	IVse (Fairly good cultivable land with severe limitations)

PEDON 5

I. Soil site description

a.	Village	:	Kalavakonda
b.	Physiography	:	Plain lands
c.	Slope	:	Degree : 0-1% (Nearly level) Class – A Aspect : NW – SW
d.	Parent material	:	Granite-gneiss
e.	Natural vegetation	:	*Azadiracta indica* *Cyprus rotundas*, *Cyanodon dactylon* and *Parthenium hysterophorus etc.*
f.	Land use	:	Rice and Mango orchard
g.	Erosion	:	Very slight
h.	Drainage	:	Well drained
i.	Ground water depth	:	Below 20 m
j.	Location	:	In paddy field under Venkatrao water tank and at west side of SBQ steel factory. [14º′0748.5″ N, 79º58′07.7″ E]

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.21	Yellowish brown (10 YR 5/4) dry, Yellowish brown (10 YR 5/4) moist; sandy clay loam; fine, weak, crumb; slightly hard, friable, slightly sticky and slightly plastic; few fine pores; clear smooth boundary.
A1	0.21-0.35	Light yellowish brown (10 YR 6/4) dry, dark yellowish brown (10 YR 4/4) moist; sandy clay loam; fine, moderate, sub-angular blocky; slightly hard, firm, sticky and plastic; few and fine pores; clear smooth boundary.
Bw1	0.35 -0.57	Brown (7.5 YR 5/4) dry, brown (7.5 YR 4/4) moist; clay loam; medium, strong, angular blocky; hard, very firm, very sticky and very plastic; diffuse wavy boundary.
Bw2	0.57 -0.78	Brown (7.5 YR 5/4) dry, brown (7.5 YR 4/3) moist; clay loam; medium, strong, angular blocky; hard, very firm, very sticky and very plastic; diffuse wavy boundary.
Bw3	0.78 -1.00+	Brown (7.5 YR 5/4) dry, brown (7.5 YR 4/4) moist; clay loam; medium, strong, angular blocky; hard, very firm, very sticky and very plastic; diffuse wavy boundary.
Taxonomic Unit	:	Fine-loamy, smectitic, isohyperthermic, Typic Haplustept
LCC (tentative interpretative grouping)		IIIws (Moderately good cultivable land with moderate limitations)

PEDON 6

I. Soil site description

a.	Village	:	Udathavaripalem
b.	Physiography	:	Palain
c.	Slope	:	Degree : 0-1% (Nearly level) Class – A Aspect : NE – SE
d.	Parent material	:	Granite- gneiss
e.	Natural vegetation	:	*Calotropis gigantia,* *Cyprus rotundas* and *Cyanodon dactylon etc.,*
f.	Land use	:	Rice and Groundnut
g.	Erosion	:	Slight
h.	Drainage	:	Moderately well drained
i.	Ground water depth	:	Below 15 m
j.	Location	:	On the right side of the road that near Chennayya water canal. [14º08′23.6″ N, 80º00′33.5″ E]

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.27	Brownish yellow (10 YR 6/6) dry, brownish yellow (10 YR 6/6) moist; sandy clay loam; fine, weak, crumb; slightly hard, firm, sticky and plastic; few fine pores; clear smooth boundary.
A1	0.27-0.37	Brownish yellow (7.5 YR 5/2) dry, brownish yellow (10 YR 7/4) moist; sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, firm, sticky and plastic; few fine pores; clear smooth boundary.
A2	0.37 -0.58	Light yellowish brown (10 YR 6/4) dry, Light yellowish brown (10 YR 6/4) moist; sandy clay loam; coarse, strong, angular blocky; hard, firm, sticky and plastic; diffuse wavy boundary.
Bw1	0.58-0.78	Very pale brown (10 YR 7/4) dry, light yellowish brown (10 YR 6/4) moist; silty clay loam; coarse, strong, angular blocky; very hard, very firm, sticky and plastic; clear smooth boundary.
Bw2	0.78-0.91	Pale brown (10 YR 6/3) dry, light brownish grey (10 YR 6/2) moist; silty clay loam; coarse, strong, angular blocky; very hard, very firm, sticky and plastic; clear smooth boundary.
Bw3	0.91-1.20	Brown (7.5 YR 5/4) dry, light grey (10 YR 7/2) moist; silty clay loam; coarse, strong, angular blocky; very hard, very firm, sticky and plastic; clear smooth boundary.
Bw4	1.20-1.50+	Pale brown (10 YR 6/3) dry, pale brown (10 YR 6/3) moist; silty clay loam; coarse, strong, angular blocky; very hard, very firm, sticky and plastic; clear smooth boundary.
Taxonomic Unit	:	Fine-loamy, mixed, isohyperthermic, Typic Haplustept
LCC (tentative interpretative grouping)	:	IIIs (Moderately good cultivable land with moderate limitations)

PEDON 7

I. Soil site description

a.	Village	:	Yeruru
b.	Physiography	:	Plain
c.	Slope	:	Degree : 0-1% (Nearly level) Class – A Aspect : NE – SE
d.	Parent material	:	Alluvium
e.	Natural vegetation	:	*Azadiracta indica,* *Borassuss flaciflora* and *Eucalyptus* spp *etc.*
f.	Land use	:	Groundnut
g.	Erosion	:	Slight
h.	Drainage	:	Well drained
i.	Ground water depth	:	Below 10 m
j.	Location	:	In groundnut cultivated area eastern side of the village. [14º10′16.6″ N, 80º02′34.7″ E]

II. Brief description of the typifying pedon

Horizon	Depth (m)		Morphometric characters
Ap	0.00-0.30		Light brown (7.5 YR 5/4) dry, dark brown (7.5 YR 7/6) moist; sandy; fine, structureless, single grain; loose, non- sticky and non-plastic; few medium pores; clear smooth boundary.
A1	0.30-0.58		Light brown (7.5 YR 5/4) dry, light yellowish brown (10 YR 6/4) moist; sandy; fine, structureless, single grain; loose, non- sticky and non-plastic; few fine pores; clear smooth boundary.
A2	0.58 -0.80		Light yellowish brown (10 YR 6/4) dry, light yellowish brown (10 YR 6/4) moist; sandy; fine, structureless, single grain; loose, non-sticky and non-plastic; diffuse wavy boundary.
A3	0.80 -0.98		Light yellowish brown (10 YR 6/4) dry, light brownish grey (10 YR 6/2) moist; sandy; fine, structureless, single grain; loose, non- sticky and non-plastic; diffuse wavy boundary.
A4	0.98-1.27		Light yellowish brown (10 YR 6/4) dry, light brown (10 YR 6/1) moist; sandy; fine, structureless, single grain; loose, non- sticky and non-plastic; diffuse wavy boundary.
A5	1.27-1.48		Very pale brown (10 YR 7/4) dry, light grey (10 YR 7/1) moist; sandy; fine, structureless, single grain; loose, non- sticky and non-plastic; diffuse wavy boundary.
A6	1.48-1.90+		Very pale brown (10 YR 7/4) dry, light grey (10 YR 7/1) moist; sandy; fine, structureless, single grain; loose, non- sticky and non-plastic; diffuse wavy boundary.
Taxonomic Unit		:	sandy, siliceous, isohyperthermic, Typic Ustipsamment.
LCC (tentative interpretative grouping)		:	IVs (Fairly good cultivable land with severe limitations)

APPENDIX – II

LANDSCAPE AND SOIL REQUIREMENTS – RICE CULTIVATION UNDER IRRIGATION

Land Characteristics	Class, degree of limitation and rating scale					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
	100 95	85	60	40	25	0
Topography (t)						
Slope (%)	0	<1	1-2	2-4	-	>4
Wetness(w)						
Flooding	F0,F11,F12	F21,F23 F31,F32	F13, F23 F33, F41 F42,F43	F14, F24 F34, F44	-	F15, F25 F34, F45
Drainage	Imperf.	moderate	poor good	Very poor	-	-
Physical soil characteristics (S)						
Surface texture (*)	Cm, SiCm, C+60v, C+60s	C-60v, C-60s, SiCs	Co SiCL CL,Si	SiL SC	-	L and lighter
(**)	Cm, SiCm, C+60v, C+60s	C-60v, C-60s, SiCs,Co, SiCL, CL, Si	SiL,Sc, L,SCL	SL,LFS, LS,LcS fS	-	S, cS
Coarse fragm (vol%)	0	< 3	3-15	15-35	-	> 35
Soil depth (cm)	> 90	90-75	75-50	50-20	-	< 20
$CaCo_3$	< 3	3-6	6-15	15-25	-	> 25
Gypsum (%)	< 1	1-3	3-10	10-15	-	> 15
Soil fertility characteristics (f)						
Apparent CEC $(cmol(p^+)kg^{-1}$ clay)	> 24	24-16	< 16 (-)	< 16 (+)	-	-
Base saturation (%)	> 80	80-50	50-35	35-20	< 20	-
Sum of basic cations $(cmol(p^+)kg^{-1}$ clay)	> 6.5	6.5-4	4-2.8	2.8-1.6	< 1.6	-
pH H_2O	6.5-6.0	6.0-5.5	5.5-5.0	5.0-4.5	-	< 4.5
	6.5-7.0	7.0-8.2	8.2-8.5	8.5-9.0	-	> 9.0
Organic carbom (%)	> 2	2-1.5	1.5-0.8	< 0.8	-	-
Salinity and Alkalinity (n)						
ECe (dS/m)	0-1	1-2	2-4	4-6	6-12	> 12
ESP	0-10	10-20	20-30	30-40	-	> 40

(*) Subsoil has an infiltration rate of more than 0.1 cm/ hour and no groundwater is present within 50 cm from the soil surface.

(**) Subsoil has an infiltration rate of more than 0.1 cm/ hour and no groundwater is present within 50 cm from the soil surface.

LANDSCAPE AND SOIL REQUIREMENTS-GROUNDNUT

Land Characteristics	Class, degree of limitation and rating scale					
	S1		S2	S3	N1	N2
	0	1	2	3	4	
	100 – 95	95 – 85	85 – 60	60 – 40	40 – 25	25 – 0
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	> 6
(2)	0-2	2-4	4-8	8-16	-	> 16
(3)	0-4	4-8	8-16	16-30	30-50	> 50
Wetness(w)						
Flooding	Fo	-	-	-	-	-
Drainage (4)	good	-	moderate	imperf.	poor,	poor,
(5)	imperf.	moder.	good		drainab	not drainab
Physical soil characteristics (S)						
Texture /structure	L, SCL, SL	SiCl, SiL Co, Si, SC CL	C < 60s, Lfs, LS, SiCs	C > 60v, C < 60v, fs C > 60s, S	-	Cm, SiCm
Coarse fragm (vol%)	0-1	1-3	3-15	15-35	-	> 35
Soil depth (cm)	> 100	100-75	75-50	50-25	-	< 25
$CaCo_3$ (%)	0-12	12-25	25-35	35-50	-	> 50
Gypsum (%)	0-2	2-4	4-10	10-20	-	> 15
Soil fertility characteristics (f)						
Apparent CEC ($cmol(p^+)kg^{-1}$ clay)	> 16	< 16 (-)	< 16 (+)	-	-	-
Base saturation (%)	> 50	50-35	< 35	-	-	-
Sum of basic cations ($cmol(p^+)kg^{-1}$ clay)	> 4	4-2.8	2.8-1.6	< 1.6	-	-
pH H_2O	6.8-6.5	6.5-6.0	6.0-5.6	5.6-5.4	< 5.4	-
	6.8-7.0	7.0-7.5	7.5-8.0	8.0-8.2	-	> 8.2
Organic carbom (%)						
(6)	> 2.0	2.0-1.2	1.2-0.8	< 0.8	-	-
(7)	> 1.2	1.2-0.8	0.8-0.5	< 0.5	-	-
(8)	> 0.8	0.8-0.4	<0.4	-	-	-
Salinity and Alkalinity (n)						
ECe (dS/m)	0-2	2-4	4-6	6-8	8-12	> 12
ESP	0-8	8-20	10-15	15-20	-	> 20

LANDSCAPE AND SOIL REQUIREMENTS- SUNFLOWER

Land Characteristics	**Class, degree of limitation and rating scale**					
	S1		S2	S3	N1	N2
	0	1	2		3	4
	100 95	85	60	40	25	0
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	> 6
(2)	0-2	2-4	4-8	8-16	-	> 16
(3)	0-4	4-8	8-16	16-30	30-50	> 50
Wetness(w)						
Flooding	Fo	-	-	F1	-	F2+
Drainage (4)	good	moderate	imperf.	imperf.	poor,	poor,
(5)	imperf.	moderate	good		drainab	not drainab
Physical soil characteristics (S)						
Texture /structure	C<60s, SiC, Co, SiL, Si, SiCL, CL	C>60s, SC, L, SCl, C<60v	C>60v, SL, Lfs, LS	C > 60v, C < 60v, fs C > 60s, S	-	Cm, SiCm
Coarse fragm (vol%)	0-3	3-15	15-35	35-55	-	> 35
Soil depth (cm)	> 150	150-100	100-75	75-100	-	< 25
$CaCo_3$ (%)	0-6	6-15	15-25	25-35	-	> 50
Gypsum (%)	0-2	2-4	4-10	10-20	-	> 15
Soil fertility characteristics (f)						
Apparent CEC ($cmol(p^+)kg^{-1}$ clay)	> 24	24-16	< 16(-)	-	-	-
Base saturation (%)	> 50	50-35	< 35	-	-	-
Sum of basic cations ($cmol(p^+)kg^{-1}$ clay)	> 4	4-2.8	2.8-1.6	< 1.6	-	-
pH H_2O	6.8-6.5	6.5-6.0	6.0-5.6	5.6-5.4	< 5.4	-
	6.8-7.0	7.0-7.5	7.5-8.0	8.0-8.5	-	> 8.5
Organic carbom (%) (6)	> 2.0	2.0-1.2	1.2-0.8	< 0.8	-	-
Salinity and Alkalinity (n)						
ECe (dS/m)	0-2	2-4	4-9	9-12	-	> 12
ESP	0-8	8-15	15-20	20-25	-	> 25

LANDSCAPE AND SOIL REQUIREMENTS- SESAME

Land Characteristics	Class, degree of limitation and rating scale					
	S1 0 (100–95)	S1 1 (95–85)	S2 2 (85–60)	S3 3 (60–40)	N1 4 (40–25)	N2 (25–0)
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	> 6
(2)	0-2	2-4	4-8	8-16	-	> 16
(3)	0-4	4-8	8-16	16-30	30-50	> 50
Wetness(w)						
Flooding	Fo	-	F1	F2	-	F3+
Drainage (4)	well	moderate s. exces	imperf. s.imperf	poor and aeric	Poor but drained	Poor not drained
(5)	imperf.. s.imperf	moder.	well			
Physical soil characteristics (S)						
Texture /structure	L, SCL, SL, SiCL,CL	SiCls SiL SC	Cs, Co, LS,	C > 60, S	-	Cm, SiCm,cS
Coarse fragm (vol%)	0-3	3-15	15-35	35-55	-	> 55
Soil depth (cm)	> 100	100-75	75-50	50-30	-	< 30
$CaCo_3$ (%)						
Gypsum (%)						
Soil fertility characteristics (f)						
Apparent CEC (cmol(p^+)kg^{-1} clay)	> 24	24-16	< 16(-)	< 16 (+)	-	-
Base saturation (%)	> 80	80-50	50-35	<35	-	-
Sum of basic cations (cmol(p^+)kg^{-1} clay)	> 6.5	6.5-4	4-2.8	2.8-1.6	<1.6	-
pH H_2O	6.3-6.2	6.2-5.8	5.8-5.5	5.5-5.2	<5.2	-
	6.3-6.5	6.5-7.0	7.0-7.5	7.5-8.2	-	> 8.2
Organic carbom (%) (6)	> 2.0	2.0-1.2	1.2-0.8	< 0.8	-	-
Salinity and Alkalinity (n)						
ECe (dS/m)	0-2	2-4	4-6	6-8	-	> 8
ESP						