

**CHARACTERISATION, CLASSIFICATION
AND EVALUATION OF SOILS IN
BANAGANAPALLE MANDAL OF
KURNOOL DISTRICT, ANDHRA PRADESH**

P.V. GEETHA SIREESHA

B.Sc. (Ag.)

**MASTER OF SCIENCE IN AGRICULTURE
(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)**



2012

**CHARACTERISATION, CLASSIFICATION
AND EVALUATION OF SOILS IN
BANAGANAPALLE MANDAL OF
KURNOOL DISTRICT, ANDHRA PRADESH**

BY

P.V. GEETHA SIREESHA

B.Sc. (Ag.)

**THESIS SUBMITTED TO THE
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF**

**MASTER OF SCIENCE IN AGRICULTURE
(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)**

CHAIRPERSON: Dr. M.V.S. NAIDU



**DEPARTMENT OF SOIL SCIENCE AND
AGRICULTURAL CHEMISTRY
SRI VENKATESWARA AGRICULTURAL COLLEGE, TIRUPATI
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
RAJENDRANAGAR, HYDERABAD – 500 030**

2012

DECLARATION

I, **P.V. GEETHA SIREESHA**, hereby declare that the thesis entitled **“CHARACTERISATION, CLASSIFICATION AND EVALUATION OF SOILS IN BANAGANAPALLE MANDAL OF KURNOOL DISTRICT, ANDHRA PRADESH”** submitted to the **Acharya N. G. Ranga Agricultural University**, Hyderabad for the award of 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.

Place :

(P.V. GEETHA SIREESHA)

Date :

I.D. No. TAM/2010-27

CERTIFICATE

This is to certify that the thesis entitled “**CHARACTERISATION, CLASSIFICATION AND EVALUATION OF SOILS IN BANAGANAPALLE MANDAL OF KURNOOL DISTRICT, ANDHRA PRADESH**” submitted in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE IN AGRICULTURE** to the Acharya N.G. Ranga Agricultural University, Hyderabad, is a record of the bonafide research work carried out by **Ms. P.V. GEETHA SIREESHA** under our guidance and supervision.

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

Thesis approved by the Student Advisory Committee:

Chairperson : **Dr. M.V.S. NAIDU** _____
Associate Professor (Direct)
Dept. Soil Science & Agril. Chemistry
S.V. Agricultural College
Tirupati – 517 502, A.P.

Member : **Dr. KEERTHI VENKAIAH** _____
Professor
Dept. Soil Science & Agril. Chemistry
S.V. Agricultural College
Tirupati – 517 502, A.P.

Member : **Dr. D.SUBRAMANYAM** _____
Subject Matter Specialist
Krishi Vigyan Kendra
Kalikiri – 517 234

Date of final viva-voce:

CERTIFICATE

Ms. P.V. GEETHA SIREESHA has satisfactorily prosecuted the course of research and that the thesis entitled “**CHARACTERISATION, CLASSIFICATION AND EVALUATION OF SOILS IN BANAGANAPALLE MANDAL OF KURNOOL 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 been previously submitted by her for a degree of any University.

Date :

Dr. M.V.S. NAIDU
Chairperson
Associate Professor
Dept. Soil Science and Agril. Chemistry
S. V. Agricultural College
Tirupati – 517 502.

Acknowledgements

*It gives me immense pleasure to express my deep sense of respect and gratitude to my major advisor **Dr. M.V.S. Naidu**, Associate Professor, Department of Soil Science and Agricultural Chemistry, S.V. Agricultural College, Tirupati for his encouragement, insightful guidance, constructive criticism and constant help at every step, during entire course of this study.*

*I humbly express my heartfelt thanks to **Dr. Keerthi Venkaiah**, Professor, Department of Soil Science and Agricultural Chemistry, Tirupati, member of my advisory committee for his wise counsel and help during my research work.*

*I humbly express my heartfelt thanks to **Dr. D. Subramanyam**, Subject Matter Specialist, Krishi Vigyan Kendra, Kalikiri, member of my advisory committee for his wise counsel and help during my research work.*

*I owe my effusive thanks to **Dr. K. Sreenivasulu Reddy**, Professor and Head, Department of Soil Science and Agricultural Chemistry, S.V. Agricultural College, Tirupati for his amiable suggestions, benevolent and noble ideas during my research work.*

*I wish to express my sincere gratitude to other staff members of the Department of Soil Science and Agricultural Chemistry, **Sri. C. Mastan Reddy**, Associate Professor, for their constructive advice and timely help during my research work.*

*I owe my effusive thanks to **Dr. A. Ramakrishna Rao**, Coordinator, DAATT Centre, Chittoor for his inspiring, meticulous and valuable guidance during the entire period of my investigation.*

*I thankfully recall the help rendered by **Dr. K. M. Manjaiah**, Senior Scientist, IARI, New Delhi and **Dr. Jagdish Prasad**, Principal Scientist, NBSS & LUP, Nagpur in carrying out X-ray diffraction analysis. My heartfelt thanks to **Dr. M. Sreenivasachari**, Scientist, ARS, Utukur, for interpretation of X-ray diffractograms.*

*I express my sincere gratitude to **Dr. M. Seshagiri Rao**, Professor (Rtd.), Agriculture College, Bapatla, for his valuable suggestions and guidance.*

*I am greatly beholden and accolade my highest respects with deep sense of honour to my most beloved parents **Smt. K. Lalithamma** and **Sri P.V. Subbarao**, and My brother **P.V. Sri Chakra**, for their everlasting love, persistent encouragement and inexorable efforts in moulding me as a responsible person.*

*Our little **Vinay** whose innocent and cute faces recoup my strength and rejoice me, need special mention in this context. My heartfull thanks are also due to **Smt. G. P. Leelavathi**, Assistant Professor, Agriculture polytechnic, Madakasira, for her continuous guidance and valuable suggestions.*

*The lack of vocabulary utterly fails me to express the stupendous weight of heartfelt gratitude to my beloved friends **Jyothi, Navata, Rama, Sharmila, Deepa, Keerthi, Jyosna, Nagaraju, Jayram, Safia, Radha, Mohan** and **Manireddy** for their endearment, encouragement, valuable moral support and pleasant cooperation rendered to me during the progress of the work.*

*I joyfully recollect the wonderful days I enjoyed in my life with my colleagues **Sagar, Parvathi** and **Manikhombha**, Seniors **Somasekhar, Seshagiri, Satish Kumar, Yasmin** and Juniors **Anita, Sravani, Chandana, Bharani** and **Radha**.*

*I place it on record my thanks to **Babu Raja Srinivas, Venkata Laxmi, Chandramma, Shekar, Ramana** and **Reddymuni** supporting staff, Department of Soil Science and Agricultural Chemistry for their timely help, co-operation and eager response during my research work.*

*I greatly acknowledge the **Acharya N.G. Ranga Agricultural University** and Government of Andhra Pradesh for their financial assistance provided in the form of stipend during my post graduate programme.*

*I express my special thanks to **Mr. Venkat** and **Mr. Ramu** for neat and timely execution of thesis work.*

It is by the unfathomable grace and blessings of the Almighty I have been able to complete two years in this college and present this humble piece of work for which I am eternally indebted.

I sincerely thank all who helped me directly and indirectly to bring out this humble piece of work.

***P.V. Geetha Sireesha...** *

LIST OF CONTENTS

Chapter No.	Title	Page No.
I	INTRODUCTION	1 – 2
II	REVIEW OF LITERATURE	3 – 46
III	MATERIAL AND METHODS	47 – 60
IV	RESULTS AND DISCUSSION	61 – 196
V	SUMMARY AND CONCLUSIONS	197 – 200
	LITERATURE CITED	201 – 221
	APPENDICES	222 – 239

LIST OF TABLES

Table No.	Title	Page No.
4.1	Meteorological data of the study area (2002-2011)	64
4.2	Vegetation and land use of the study area	67
4.3	Details of the pedons	72
4.4	Summary of the morphological characters of the pedons	77-78
4.5	Particle size analysis data of soils (< 2 mm size)	95
4.6	Range and mean of particle size analysis of the soils	96
4.7	Physical characteristics of the soils	103
4.8	Range and mean of physical properties of the soils	104
4.9	Physico-chemical properties of the soils	109
4.10	Range and mean of physico-chemical properties of the soils	110
4.11	Electro-chemical properties of the soils	114
4.12	Range and mean of electro-chemical properties of the soils	115
4.13	Per cent saturation of individual bases	121
4.14	Chemical composition of the soils (%)	124
4.15	Range and mean of chemical composition of the soils (%)	125
4.16	Molar concentrations and molar ratios of the soils	131
4.17	Range and mean of molar concentration and molar ratios of the soils	132
4.18	Available and total macronutrients content (mg kg^{-1}) of the soils	135
4.19	Range and mean of available and total macronutrients content (mg kg^{-1}) of the soils	136

Table No.	Title	Page No.
4.20	Available and total micronutrient status (mg kg ⁻¹) of the soils	143
4.21	Range and mean of available and total micronutrients content (mg kg ⁻¹) of the soils	144
4.22	d-spacings (nm) of X-ray diffractograms in clay fraction (less than 2 micron fraction)	151-152
4.23	Relative proportion of clay minerals	153
4.24	Soil classification	173
4.25	Land capability classification of soils of Banaganapalle mandal	182
4.26	Interpretation of soils of Banaganapalle mandal	183-184
4.27	Depth wise soil characteristics used in assessing crop suitability	189-190
4.28	Site and soil characteristics of studied profiles for crop suitability classification	191
4.29	Limitation levels of the land characteristics and land suitability classes	194
4.30	Simple correlations between different soil properties of profile soil samples	196

LIST OF ILLUSTRATIONS

Fig. No.	Title	Page No.
4.1	Location map of Banaganapalle mandal	62
4.2	Ombrothermic graph of study area (Banaganapalle mandal)	63
4.3	Profile diagrams of pedons	80
4.4	Profile diagrams of pedons	83
4.5	Profile diagrams of pedons	88
4.6	Profile diagram of pedon	93
4.7	Vertical distribution of soil particles	98
4.8	Vertical distribution of soil particles	99
4.9	Depth functions of electro-chemical characters	118
4.10	Depth functions of electro-chemical characters	119
4.11	Vertical distribution of silica and sesquioxides	127
4.12	Vertical distribution of silica and sesquioxides	128
4.13	Vertical distribution of available macronutrients	138
4.14	Vertical distribution of available macronutrients	139
4.15	Vertical distribution of available micronutrients	146
4.16	Vertical distribution of available micronutrients	147
4.17	X-ray diffractograms of pedon 1 (Vertic Haplustepts)	154
4.18	X-ray diffractograms of pedon 2 (Typic Ustorthents)	157
4.19	X-ray diffractograms of pedon 3 (Vertic Haplustepts)	160
4.20	X-ray diffractograms of pedon 4 (Typic Haplustepts)	162
4.21	X-ray diffractograms of pedon 5 (Fluventic Haplustepts)	165
4.22	X-ray diffractograms of pedon 6 (Lithic Ustorthents)	168
4.23	X-ray diffractograms of pedon 7 (Typic Ustifluvents)	170

LIST OF PLATES

Plate No.	Title	Page No.
4.1	Pedon 1	81
4.2	Pedon 2	84
4.3	Pedon 3	85
4.4	Pedon 4	86
4.5	Pedon 5	90
4.6	Pedon 6	91
4.7	Pedon 7	92

LIST OF ABBREVIATIONS AND SYMBOLS

%	:	Percentage
<	:	Less than
>	:	Greater than
°C	:	Degree Celsius
CEC	:	Cation Exchange Capacity
cm	:	Centimetre
cmol(p ⁺)kg ⁻¹	:	Centimole per kilogram
dS m ⁻¹	:	Deci Siemen per meter
EC	:	Electrolyte Conductivity
<i>et al.</i>	:	and others
<i>etc.</i>	:	and so on
Fig.	:	Figure
g kg ⁻¹	:	Gram per kilogram
<i>i.e.,</i>	:	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	:	Millimetre
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
nm	:	Nanometer
r	:	Correlation coefficient
USDA	:	United States Department of Agriculture
<i>viz.,</i>	:	Namely

ABSTRACT

- Name of the Author : **P.V. GEETHA SIREESHA**
- Title of the Thesis : **CHARACTERISATION, CLASSIFICATION AND EVALUATION OF SOILS IN BANAGANAPALLE MANDAL OF KURNOOL DISTRICT, ANDHRA PRADESH**
- Major Advisor : **Dr. M.V.S. NAIDU**
- Degree to which it is submitted : Master of Science
- Faculty : Agriculture
- Major field : Soil Science and Agricultural Chemistry
- University : Acharya N.G. Ranga Agricultural University
- Year of submission : 2012

The present investigation involves characterization, classification and evaluation of soils in Banaganapalle mandal of Kurnool district in 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 soil 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 confined to plains and very gently sloping topography. Pedon 3 was developed from dolomite while the remaining pedons were developed from granite-gneiss parent material.

The morphological features indicated the presence of AC (Pedons 2, 6 and 7) and ABC (Pedons 1, 3, 4 and 5) profiles. These soils were deep to very deep in depth, very dark grayish brown to dark brown in colour, sandy clay loam to clay in texture and had sub-angular blocky, angular blocky and crumb structure.

The clay content decreased with depth in pedons 1, 2 and 5. Pedons 3, 4, 6 and 7 had shown no specific trend with depth. Physical constants like water holding capacity, loss on ignition and volume expansion followed the trend of

clay content. Most of the pedons showed irregular trend of bulk density with depth, corresponding to decreasing organic carbon content with depth.

The pedons were slightly alkaline to strongly alkaline in reaction, non-saline and low in organic carbon. All the pedons registered medium to high per cent CaCO_3 . 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 nutrient status, the soils were low to medium in available nitrogen, medium to high in available phosphorus and low to high in available potassium and high in available sulphur. However, soils were deficient in available zinc and iron and sufficient in available copper and manganese.

As far as clay mineralogy is concerned, pedons 1, 2, 3, 4 and 6 showed the dominance of smectite clay mineralogy whereas pedons 5 and 7 exhibited the dominance of kaolinitic clay mineralogy.

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

- Pedon 1 : Fine-loamy, smectitic, isohyperthermic Vertic Haplustepts
- Pedon 2 : Fine-loamy, smectitic, isohyperthermic Typic Ustorthents
- Pedon 3 : Fine, smectitic, isohyperthermic Vertic Haplustepts
- Pedon 4 : Fine-loamy, smectitic, isohyperthermic Typic Haplustepts
- Pedon 5 : Fine-loamy, kaolinitic, isohyperthermic Fluventic Haplustepts
- Pedon 6 : Fine, smectitic, isohyperthermic Lithic Ustorthents
- Pedon 7 : Fine-loamy, kaolinitic, isohyperthermic Typic Ustifluvents

Based on the soil properties, the soils of the Banaganapalle mandal have been classified into land capability classes and sub-classes *viz.*, IIs (Pedon 1), IIIs (Pedons 2 and 5), IIIsw (Pedon 3), IIIes (Pedon 4) and IVes (Pedons 6 and 7).

The soil-site suitability evaluation of study area revealed that all the pedons were marginally suitable (S3) for growing sorghum crop. Pedons 1, 4, 6 and 7 were marginally suitable (S3) for growing rice, sorghum, chickpea and sunflower. Pedons 2 and 3 were temporarily not suitable (N1) whereas pedon 5 was marginally (S3) suitable for growing chickpea and sunflower crops. However, pedon 2 was marginally suitable (S3) and pedons 3 and 4 were temporarily not suitable (N1) for growing paddy crop.

Chapter ~ I

Introduction

Chapter I

INTRODUCTION

Normally soil is considered as static, but in reality it is dynamic, ever-changing and evolving. It is the continued response of the soil to its environment that determines its state of productivity. Since, all agricultural activities are directly or indirectly affected by ‘how the soil is to be handled’ hence its health become prime concern.

At global level out of total area of 134 billion ha, 3.03 billion ha (22%) is potentially cultivable, of which only 1.5 billion ha is actually cultivated at different productivity levels due to certain constraints. At the global level 2 billion ha land is degraded while among the developing countries India ranks very high (about 9.4%) in respect of relative per cent of soil degradation.

Agricultural intensification and massive infrastructural development in the recent years without considering the variability of entire production system enhanced the risk of soil erosion and fertility depletion (Singh *et al.*, 2007). Soil characterization in relation to evaluation of fertility status of the soils of an area or region is an important aspect in the context of sustainable agriculture.

An understanding of types of soils and their distribution, constraints and potentials are important for proper management to increase productivity. The state of soil health is governed by a number of physical, chemical and physico-chemical attributes. Prevalence of one or more unfavourable soil conditions for a long period leads to unsustainability of agricultural system. Soil survey data play a crucial role in defining sustainable management practices and also for harnessing the potential of varied agroecoregions for commercial commodity production.

The competing demands for finite soil resources by different sectors emphasize the need for appropriate land use planning. This is focused our attention to develop alternative suitable land use options for sustaining the increasing population with environmental security. Therefore, the knowledge on nature and properties of soils, their relationship with landforms and spatial distribution is very essential for developing a suitable land use plan.

Though sporadic information is available on characterization and classification of soils in Andhra Pradesh (Satyavathi and Suryanarayan Reddy, 2004b), no information is available on these aspects for the soils of Banaganapalle mandal in particular and Kurnool district, in general. A necessity is always felt for more soil database on mandal wise to take up various agricultural developmental plans in Andhra Pradesh.

Keeping these factors in mind, present investigation was undertaken with the following objectives:

1. To study the morphological features, physical, chemical and physico-chemical properties of each horizon of the soil profiles in Banaganapalle mandal of Kurnool district.
2. To study in detail the clay mineral composition and genesis responsible for the development of different soils in that mandal.
3. To classify the soils as per the USDA Soil Taxonomy up to family level and also for optimum land use planning.
4. To evaluate the suitability of soils for major crops (rice, sunflower, chickpea and sorghum) grown in the area to achieve suitable yields.

Chapter ~ II

Review of Literature

Chapter II

REVIEW OF LITERATURE

The natural resources of a country are of prime important for assessment of productivity of lands and sustainability of the eco-system. Among those resources soil was a natural resource on whose proper use depends on the life supporting systems of a country and socio-economic development of its people. No development 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. Management of soil resources is essential for both continued agricultural productivity and protection of the environment. Non availability of correct information on spatial extent of soils under various categories in Andhra Pradesh remains major constraint for overall development of the state and needs immediate attention. Hence, 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 combination 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 were 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 Govinda Rajan, 1971).

2.2 PEDOGENESIS

Dokuchaev (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.

Gupta and Tripathi (1992) stated that clay illuviation was an important soil forming process while studying pedogenesis in wet temperature and alpine climatic zones of north-west Himalayas. Reddy *et al.* (1993) revealed that plinthite layer was present in hills and hill range pedons indicating that soils were undergoing process of laterization. Changes in the land use system including deforestation could have brought significant pedogenic modification (Soloman *et al.*, 2002).

Anil Kumar (2002) reported that major coffee growing soils of Karnataka 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. The soil layer or pedosphere was essentially the skin of the terrestrial earth, regulating the biogeochemical and hydrological cycling of matter and energy with terrestrial surfaces

(Huete, 2004). Physiography influences soil formation through water, temperature, soil erosion and micro climate relations which in turn affects the pedogenic processes including varied soils (Verma *et al.*, 2005).

Irregular distribution of organic carbon indicated that pedogenesis was not strong enough to obliterate the mark of stratification (Mahesh Kumar *et al.*, 2009). Somasundaram *et al.* (2010) reported that high silt content in pedons of lower basin of Pudukottai district Tamil Nadu was attributed to weathering and advanced pedogenesis.

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.

Some Inceptisols of north-west India showed coarse texture in udic moisture regime due to deposition of alluvial parent material (Sharma *et al.*, 1997). Soils of Loktak catchment area of Manipur comprising of hills, ridges and furrows with shale as sedimentary parent rock (Sarkar *et al.*, 2002). 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

Jagdish Prasad, 2004). Satyavathi and Suryanarayan Reddy (2004b) reported that Inceptisols and Vertisols in Telangana region of Andhra Pradesh were originated from igneous rocks such as pink and grey granites and basalt and metamorphic rocks *viz.*, granite-gneiss and hornblende schists. According to Heluf and Mishra (2005) soils developed basaltic parent material showed moderate permeability. Predominant rock types exposed in the area of outer Himalayas were sandstone, shale and limestone, which were deposited as thin layers (Sanjeev *et al.*, 2005).

Singh and Agarwal (2005) assessed that parent materials range from recent alluvium to well weathered residual materials on 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 in 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.

The soils of Rajanukunte watershed have undulating surface with mounds, pediments and narrow valley on a granitic terrain (Ramesh Kumar *et al.*, 2006). Grape growing soils in Nasik district, Maharashtra developed over basalt (Balpande *et al.*, 2007). Soils were formed on alluvium of different sedimental deposits as showed by discontinuity in sand, silt and clay distribution along with depth (Sarade and Jagdish Prasad, 2008).

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. Jagdish Prasad *et al.* (1995) noticed that development of Typic Rhodustalfs under hot humid climate, Typic Ustropepts under sub-humid zone and Chromic Haplusterts in semi-arid climate of Maharashtra.

According to Dutta *et al.* (2001), deep weathering required a tropical climate with a rainfall of more than 1600 mm / month. Some red soils of Krishna district, Andhra Pradesh developed under semi-arid monsoonic climate with distinct summer, winter and rainy seasons with mean annual rainfall of 1090 mm (Ram Prakash and Seshagiri Rao, 2002). Climate of the study area of Nagpur Mandarin growing soils in Central India has tropical dry sub-humid with hot and dry summer and mild winter having mean annual rainfall of 1100 mm (Marathe *et al.*, 2003).

Satyavathi and Suryanarayan Reddy (2004b) stated that northern Telangana Zone falls under semi-arid (moist) tropics with an annual rainfall of around 1000 mm whereas southern Telangana 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 iso-hyperthermic. Soils of Chandragiri mandal of Chittoor district comes under semi-arid monsoonic climate with a mean annual soil temperature of 31.9°C and with a mean annual summer and winter soil temperatures of 32.1°C and 27.8°C, respectively which qualifies for iso-hyperthermic temperature regime with ustic soil moisture regime (Basavaraju *et al.*, 2005).

Entisols, Inceptisols and Alfisols were developed under semi-arid monsoonic climate with annual mean temperature of 31.5°C, falls under iso-hyperthermic with ustic moisture regime (Thangasamy *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, Maharashtra were located within the rainfall range of 477.3 to 753.1 mm with minimum and maximum temperatures of 10.2°C and 32.4°C, respectively (Balpande *et al.*, 2007). Ramchandrapuram mandal of Andhra Pradesh had a variety of soils developed under semi-arid monsoonic climate and qualifies for iso-hyperthermic soil temperature regime (Vara Prasad Rao *et al.*, 2008).

Ram *et al.* (2010) stated that flood-prone area soils 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 of Pulivendla region, Andhra Pradesh receives an average rainfall of 564 mm in which 55 per cent of annual rainfall received during south-west monsoon (Jun-Sept) and 31 per cent received during north-east monsoon (Oct-Dec).

Soils under Subarnarekha watershed in Ranchi district, Jharkhand receives annual rainfall ranging from 1400 to 1500 mm with a mean summer temperature of 22.9°C and mean winter temperature of 11.7°C falls under hyperthermic temperature regime (Deb and Sahu, 2011).

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.

Sand mineralogy of alluvium derived soils in southern bank of Bramhaputra river of Assam revealed that 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 deposition of sediments and hence could not get sufficient time for development.

2.3.4 Topography

Relief units are geomorphologically distinct areas, such as an undulating plain, sloping lands or an alluvial plain. It influences the micro-climate of the region ultimately the soil properties by altering soil forming processes. Topography refers to the differences in elevation of land surface on a broad scale.

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 of 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 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%) plains 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; 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. According to Sharma and Sanjeev (2008), soils of upper piedments belongs 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 gentle slopes 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, Tamil Nadu 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 silty loam in texture with alkaline pH range whereas high altitude soils were clay loam in texture with slightly acidic pH.

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.

Sarkar *et al.* (2002) stated that hilly terrain was mostly covered by mixed subtropical deciduous and evergreen forests with planted pine trees. However, the ground was covered with thick undergrowth of bushes, shrubs, tall grasses and other types of mixed vegetation. The higher exchangeable Ca in the surface soil may be due to redistribution of calcium by tree species (Patil and Jagdish Prasad, 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 neem (*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). According to Ram *et al.* (2010), the forest soils of the eastern plains of Rajasthan were classified under central India dry deciduous type with dhok (*Anogeious pendula*) and khair (*Acacia catechu*) as the main species of eastern part.

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

Sidhu *et al.* (1994) noticed Ap, C1, C2, C3 and C4 horizon sequence in Typic Ustorthents while Typic Ustipsamments showed Ap, C1, C2, C3 and C4 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 the 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, Andhra Pradesh showed Ap, B1, BC and C whereas black soils showed Ap, A12, A13, Ass1, Ass2 and AC in Lithic Haplustepts (Ram Prakash and Seshagiri 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 Anil 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 on Shivdi area soils exhibited Ap, AC, 2C1 and 2C2 and some of the horizons showed lithological discontinuity.

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. Vara Prasad 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.

2.4.3 Soil colour

Soil colour is one of the important basic properties which help to identify the kinds of soils and recognize the successions of soil horizons / layers in soil profiles. The soil colour of an area, often relates to specific chemical, physical and biological properties of the soils in that area. Soil colour indicates the soil forming process and reflects the mineralogy of the soil.

Soils on the upper pediplain were dark reddish brown to dark brown in colour whereas soils on the lower pediplain were very dark grayish brown to dark grayish brown colour (Ram Prakash and Seshagiri Rao, 2002). 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 Jagdish Prasad, 2004). Thangasamy *et al.* (2005) reported that soils on gently sloping topography have yellowish brown (10 YR 5/6) to dark red (2.5 YR 3/6) colour and becomes light yellowish brown (10YR 6/4) to very dark grayish brown (10 YR 3/2) in nearly level lands.

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.

The soil colour of some pedons under watershed area of Shikohpur was characterized by darker in chroma which may be attributed to formation of non-hydrated compounds (Sitanggang *et al.*, 2006). Mandal *et al.* (2006) observed soils under an area of micro-watershed in Nagpur, Maharashtra were grayish brown to dark brown in colour (10 YR). Low chroma in surface horizons of some pedons was due to the fact that surface horizons were moist than sub-surface horizons (Vara Prasad Rao *et al.*, 2008). Colour appears as a function of chemical and mineralogical composition of soil (Swarnam *et al.*, 2004).

Najar *et al.* (2009) confirmed that apple growing soils of Kashmir showed various shades of grey colour on southern aspect could be due to coagulation of iron and calcium with humus components rather than poor drainage conditions. Entisols and Alfisols of flood-prone soils of Rajasthan had a hue of soil matrix varied from 2.5 YR to 10 YR with a value ranging from 6 to 3 and a chroma from 6 to 2 under moist condition (Ram *et al.*, 2010).

2.4.4 Texture

Soil texture may be defined as the relative proportion of the various soil separates namely sand, silt and clay in a given soil. The proportion of each size group in a given soil cannot be altered easily, that is why texture is considered as a basic property of a soil.

The texture of Sunkesula series was clay whereas that of Velpula series was sandy clay. Clay content in soils of low hill and midland pedons increased with depth (Venugopal and Koshy, 1985). According to Sharma *et al.* (1997), soils of udic zone were comparatively coarser in texture in (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 separates (Manorama and Jose, 2000).

Sarkar *et al.* (2002) stated that soils developed from shale and colluviums had finer texture, it was due to sedimentary origin of parent materials. 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. The 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 10.0 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. In garden lands clay content was more in lower layers than in upper layers, as surface layers were subjected to mixing of lateritic gravels from the adjoining areas (Mini *et al.*, 2007). Verma *et al.* (2007) reported that sand content ranged from 95 to 96 per cent in dunes and 50 to 81 per cent in other soils of alluvial plains, however, reverse trend was observed in silt and clay content in semi-arid regions of Punjab.

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, movement of water and air 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 showed granular to sub-angular blocky structure while black soils distributed in lower pediplain exhibited angular blocky structure (Ram Prakash and Seshagiri Rao, 2002). Soils on foot hill slope of flat topped hills were characterized by sub-angular blocky structure (Patil and Jagdish Prasad, 2004).

The structure of the soils was 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). Outer Himalayas showed structural variations like granular in surface, angular blocky in sub-surface and C-horizon had predominately massive structure (Sanjeev *et al.*, 2005). Sub-surface horizons of Shikohpur watershed area of Haryana showed fine to medium, weak and 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 soil had weak to moderate structure whereas sub-surface soil 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. Surface horizons developed granular structure at higher altitudes on both northern and southern aspects in Apple growing soils of Kashmir (Najar *et al.*, 2009).

Soils in high hill slopes was weak to moderate, fine to medium and sub-angular blocky whereas soils of foot hill slopes had weak, medium and sub-angular blocky structure (Sahoo *et al.*, 2010). 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 (Lekhar and Jagdish Prasad, 2011).

2.4.6 Consistence

It is a term used to describe the action of physical forces of cohesion and adhesion on the attributes of soil material at various moisture contents that determines the resistance of soil material to crushing or rupture and its ability to change the shape or to be moulded.

Singh and Mishra (1996) reported that consistence of soils in higher topographic positions was non-sticky and non-plastic whereas the soils in lower topographic positions exhibited very sticky and very plastic consistence. 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 slightly 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).

According to Sarkar *et al.* (2001), the consistence of the soils in Chhotanagpur plateau was slightly hard to hard (dry), friable to firm (moist) and slightly sticky to very sticky and non-plastic to very plastic (wet). According to Sharma and Anil 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 the 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).

Mahesh Kumar *et al.* (2009) reported that lime and silica content slightly modified the moist and wet consistence in Chirai and Devas series of Rajasthan which were examined friable as moist and slightly sticky and slightly plastic as wet consistence.

2.4.7 Cracks

Venkateswarlu *et al.* (1995) studied the black soils of Kandukuru division of Andhra Pradesh which were sticky and plastic exhibiting cracks of about 2 to 5 cm wide and extending up to a depth of 65.0 cm. Sharma *et al.* (1996) observed the cracks of 1.0 to 3.0 cm wide and 0.60 m deep in soils developed on gently sloping plain to nearly level alluvial plain of basaltic terrain.

The Haplusterts occurring in the Chitravathi river basin of Andhra Pradesh had cracks of 2.5 to 5.0 cm wide and extended to a depth of 20.0 to 50.0 cm while the Ustropepts of same area exhibited cracks of 1.0 cm wide to a depth of 30.0 cm (Bhaskar and Nagaraju, 1998). Gupta *et al.* (1999) stated that presence of less than 1.0 cm wide cracks upto 37.0 cm, clay content more than 35.0 per cent and cambic B horizon in Garha soils necessitated its placement under Vertic Ustochrepts.

The Vertic Haplustepts of Kathiawar region of Gujarat had greater than 5.0 mm wide cracks through a depth of 30.0 cm (Sharma *et al.*, 2001a). The Vertic Haplustepts occurring in the Krishna district of Andhra Pradesh exhibited 0.5 to 1.0 mm wide cracks upto 52.0 cm depth (Ram Prakash and Seshagiri Rao, 2002). Vertic Haplustepts in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh showed 3.0 to 7.0 mm wide cracks extended upto 35.0 cm depth (Thangasamy *et al.*, 2005).

2.4.8 Slickensides

Subbaiah and Manickam (1992) noticed prominent and intersecting slickensides in Vertisols developed on different parent material. Gangapur soils (Chromic Haplusterts) of Nasik district, Maharashtra derived under semi-arid climate had 1.0 cm wide cracks extending upto 60.0 cm and also

showed intersecting slickensides (Jagdish Prasad *et al.*, 1995). Padole and Deshmukh (1998) observed well developed slickensides in the sub-surface horizons of Vertisols of Maharashtra. The soils (Haplusterts) of Chitravathi river basin of Andhra Pradesh exhibited vertic properties of intersecting slickensides in the deeper layers and presence of wedge shaped aggregates in the second layer (Bhaskar and Nagaraju, 1998).

Nagpur mandarin growing soils showed slickensides with wedge-shaped aggregates that broke into angular blocks indicating the pedoturbation as a result of shrink-swell property of the soils (Marathe *et al.*, 2003). Thick slickensides (6.0 to 84.0 cm) were observed in the Vertisols of Rajasthan. These were produced due to the abundance of smectite, high proportion of clay and deeper soil profile (Singh *et al.*, 2004).

Weak and indistinct slickensides were observed in lower horizons of Vertic Haplustepts in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh (Thangasamy *et al.*, 2005). Maji *et al.* (2005) assessed that sub-angular blocky structure was found in surface horizons of sub-humid tropics in central India was due to swell-shrink phenomenon of smectitic clay present in these soils resulting in the development of slickensides.

2.5 DIAGNOSTIC HORIZONS

2.5.1 Ochric epipedon

Ochric horizon was a light coloured surface horizon contains less than 1 per cent organic matter and is hard or very hard and massive when dry.

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 from Himachal Pradesh exhibited ochric horizon at the surface and lacked any evidence of soil development. Therefore, these soils were classified as Entisols at order level (Pardeep Kumar and Verma, 2005).

There was a little or no evidence of the development of pedogenic horizons other than an ochric epipedon of low land with shallow water table in soils of coastal argo-eco regions in north Karnataka (Mini *et al.*, 2007). Presence of ochric epipedon in some of the Apple growing soils of Kashmir were placed under the sub-order Ochrepts 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 hence classified under Inceptisols (Ashokkumar and Jagdish Prasad, 2010). Niranjana *et al.* (2011) reported that banana growing soils of Pulivendla region in Andhra Pradesh possess ochric epipedon followed by cambic sub-surface diagnostic horizon.

2.5.2 Cambic horizon

It is a coloured or structural B-horizon formed due to alteration by physical movement or by chemical weathering. The horizon is extremely variable in mineralogy because of its pedogenic youthness, occurs under

widely differing environments and may develop in the presence (or) absence of fluctuating ground water.

Sen *et al.* (1996) studied the soils of Manipur valley and observed cambic horizon as a diagnostic sub-surface horizon in Inceptisols. 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 depth 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. Pedons on hills and hill ranges and low lands with deep water table and garden lands located on hills and hill ranges were classified into Inceptisols owing to the presence of cambic horizon and absence of other diagnostic horizons in soils of coastal argo-eco regions in north Karnataka (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 (Shalima Devi and Anil Kumar, 2010).

2.6 PHYSICAL PROPERTIES

2.6.1 Particle size distribution

According to Vadivelu and Bandyopadhyay (1997) sand constitutes 90.00 per cent in soils (Psamments) of Minicoy Island, Lakshadweep. 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). Gravel (25 to 46 per cent) and sand (67 to 82 per cent) contents were higher in the soils of poorly managed terraces whereas silt and clay were higher in well managed terraces (Singh *et al.*, 1999).

Particle size distribution in Alfisols of some benchmark soils of West Bengal indicated that a distinct increase in clay content in sub-surface (Bt) horizons (Nayak *et al.*, 1999). According to Verma *et al.* (2001) the soils in different landscapes showed that sand and silt constitute major portion in mechanical composition. 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 Jagdish 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 occurring 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 clay content ranging from 34.4 to 73.4 per cent and it increased with depth. The silt content ranged from 12.8 to 40.0 per cent and sand content was less than 10.0 per cent in soils of micro-watershed in Vidarbha region of Maharashtra (Gabhane *et al.*, 2006).

2.6.2 Water holding capacity

Madhusudhana 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.

Ravender 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 Jagdish 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 in Andhra Pradesh varied from 19.36 to 55.40 per cent. The irregular trend with depth was due to illuviation and eluviation of finer fractions in different horizons.

2.6.3 Bulk density and particle density

Madhusudhana Rao (1993) studied the sandy soil profiles in Chakicharla village of Andhra Pradesh and observed that particle density and bulk density values ranged from 2.48 to 2.65 Mg m⁻³ and 1.46 to 1.61 Mg m⁻³, respectively. 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 in Giddalur mandal of 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. Yadav and Vyas (1998) studied the major soils (Entisols) in semi-arid eastern plains of Rajasthan and observed

that bulk density values of the soils ranged from 1.51 to 1.60 Mg m⁻³ and these values were increased with increase in depth.

The bulk density varied between 1.40 and 1.80 Mg m⁻³ in Inceptisols and ranged from 1.40 to 1.60 Mg m⁻³ in Alfisols of granitic terrain in Jabalpur district of Madhya Pradesh (Gupta *et al.*, 1999). Singh *et al.* (1999) found that bulk density varied from 0.83 to 1.22 Mg m⁻³ in the surface soils and increased with depth in soils of Ramganga catchment. Ram Prakash and Seshagiri 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 varied from 1.46 to 1.74 Mg m⁻³ and the bulk density was also 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 and texture (Sharma and Anil 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 Agrawal, 2005). The bulk density of the soils varied from 1.33 to 1.79 Mg m⁻³, in humid tropics of central India and variation in bulk density of these soils was attributed to the moisture content and high content of expanding type of clay minerals (Maji *et al.*, 2005).

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 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).

2.7 PHYSICO-CHEMICAL PROPERTIES

2.7.1 Soil reaction

The pH of red soils ranged from strongly acidic to slightly alkaline (pH 5.0 to 8.0) (Reddy *et al.*, 1993). Gurumurthy *et al.* (1996) stated that pH of soils in Giddalur mandal of Andhra Pradesh was neutral to moderately alkaline (6.8 to 9.1). Sharma *et al.* (1997) reported that pH of surface horizons varied from neutral (pH 7.3) to alkaline (pH 8.6) whereas in the sub-surface horizons it was neutral (pH 7.1) to strongly alkaline (pH 9.7) in Inceptisols of north-west India. The pH of soils (Entisols) in Minicoy Island, Lakshadweep varied from 7.9 to 8.7. However, the surface soil had lower pH values (7.9 to 8.0) probably due to the decomposition of organic matter (Vadivelu and Bandyopadhyay, 1997).

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). Soil pH varies from 4.5 to 5.8 and generally increased with depth. Loss of bases due to leaching and presence of Al^{3+} on exchange complex were largely responsible for low pH (Sarkar *et al.*, 2002). The soils of Maul Khad catchment in Himachal Pradesh were acidic in reaction with

pH varying from 5.1 to 5.7. The horizons with high clay content exhibited higher pH.

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 and 8.2 to 9.2 in piedmonts and narrow valleys of Degma and Mohgan villages of Nagpur district Maharashtra (Raghavendra 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 H₂O 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 CaCO₃ in the lower areas. Further, the KCl-pH values were lower than the water pH values and the difference between KCl-pH and H₂O-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, non-saline (Vara Prasad Rao *et al.*, 2008). According to Mustaq (2011), soils in low altitude were slightly alkaline in pH range whereas soils in high altitudes were slightly acidic in pH.

2.7.2 Electrical conductivity

The low EC (0.08 to 0.4 dS m⁻¹) in soils of Trans-Yamuna plains indicated the low amount of soluble salts (Walia and Rao, 1997). The EC of Vertisols and Inceptisols developed from different parent materials were normal with very low (< 1 dS m⁻¹) salt content (Chinchmalatpure *et al.*, 1998). Ravender Singh and Nayak (1999) stated that EC values of Typic Ustorthents ranged from 0.10 to 0.48 dS m⁻¹. Singh *et al.* (1999) noticed that electrical conductivity was low (0.01 to 0.27 dS m⁻¹) in soils of Ramganga catchment in Uttar Pradesh. Rudramurthy and Dasog (2001) observed that electrical conductivity was less in red soils (0.10 to 0.31 dS m⁻¹) as compared to their black counterparts (0.24 to 1.10 dS m⁻¹).

According to Pillai and Natarajan (2004), the electrical conductivity of the soils of Garakahalli watershed ranged from 0.02 to 0.20 dS m⁻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 dS m⁻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 dS m⁻¹ and has no salinity hazard. 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 dS m⁻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 dS m⁻¹ (Shamsudheen *et al.*, 2005).

The Entisols and Inceptisols of Shikohpur watershed of Gurgaon district, Haryana were non-saline with electrolyte concentration ranging from 1.05 to 1.40 dS m⁻¹ in surface layers and 1.00 to 1.50 dS m⁻¹ in sub-surface layers (Sitanggang *et al.*, 2006). 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 dS m⁻¹ (Leelavathi *et al.*, 2009). EC_e values were > 4 dS m⁻¹ in the surface horizons of flood-prone soils of eastern plains of Rajasthan, indicating saline-sodic nature of the soil (Ram *et al.*, 2010).

2.7.3 Calcium carbonate

Vertisols of Maharashtra had fairly high amount of free calcium carbonate (> 10 per cent) whereas Alfisols of the same area had very low CaCO₃ (Jagdish Prasad *et al.*, 1995). According to Singh and Mishra (1996), the CaCO₃ content in soils of Gandak command area of Bihar varied 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 CaCO₃ content (Jagdish 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 Maharashtra 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 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 receding water table and drainage conditions in soils of eastern region of Varanasi (Singh and Agrawal, 2005).

The free CaCO_3 was observed in all the soils of Shikohpur watershed area in Haryana was due to ustic 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 Maharashtra was 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 Jagdish Prasad, 2010). The CaCO_3 content varied from 88 to 205 g kg^{-1} in soils of Mula command of irrigated agroeco system in Maharashtra (Kharche and Pharanda, 2010).

2.7.4 Organic carbon

Singh *et al.* (1996) stated that great leaf fall and deep root system of leguminous crops left more biomass resulting increased organic carbon. Higher organic carbon content in northern profiles may be facilitated by wetter conditions and lower temperatures which were conducive to organic matter accumulation (Gupta and Chara, 1996). In surface soils organic carbon content ranged from 24.7 to 45.4 g kg⁻¹ and decreased with depth. High organic carbon content was due to slow microbial activity under low temperature and acidic environment in Loktak catchment area of Manipur (Sarkar *et al.*, 2002).

Organic carbon content ranged from 0.08 to 1.08 per cent in different horizons. Soils of subdued plateau had higher organic carbon content because these soils were under fallow grass-lands (Raghavendra 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). Sarade and Jagdish Prasad (2008) stated that organic carbon content of clayey soils was lower than coarse textured soils. Vara Prasad 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.

More than 90 per cent of soils were high in organic carbon having values more than 7.5 g kg^{-1} in Terai zone soils of West Bengal (Dabnath and Ghosh, 2009). 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 ranged from 0.3 to 7.6 g kg^{-1} in lower basin of Pudukkottai district in Tamil Nadu. Shalima Devi and Anil Kumar (2010) stated that coffee growing soils of Karnataka had organic carbon content from 1.47 to 5.29 per cent. High soil organic carbon content may be due to slow organic matter decomposition at higher altitudes where temperature was low and rainfall was high.

2.8 ELECTRO-CHEMICAL PROPERTIES

2.8.1 Cation exchange capacity

Fine loamy soils in the recent flood plains of Punjab had the highest CEC while those on sand dunes had the lowest CEC (Sidhu *et al.*, 1994). Mishra and Ghosh (1995) reported that CEC values of soils derived from mica-rich parent material varied between 6.00 and $15.90 \text{ cmol(p+)}\text{kg}^{-1}$ soil apparently due to variation in clay and organic matter contents. Walia and Chamuah (1996) noticed that values of CEC were in proportion to their organic matter or clay content in some Inceptisols of Arunachal Pradesh.

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 $22.80 \text{ cmol(p+)}\text{kg}^{-1}$ 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 $55.40 \text{ cmol(p+)}\text{kg}^{-1}$ soil which was mostly related to the clay content of soils. CEC of the soils of lower outlier in Chhotanagpur plateau varied from 2.00 to $18.00 \text{ cmol(p+)} \text{ kg}^{-1}$ soil (Sarkar *et al.*, 2001). Suresh Kumar *et al.* (2001) found that CEC of soils in residual

hills, denudational hills and pediments was low (11.70 to 16.37 $\text{cmol(p+)}\text{kg}^{-1}$ soil) whereas the soils of shallow and moderately buried pediments and valley fills had moderately high CEC [15.10 to 28.20 $\text{cmol(p+)}\text{kg}^{-1}$ soil]. The CEC of Entisols in Etawah district of Uttar Pradesh was low varying from 3.20 to 10.50 $\text{cmol(p+)}\text{kg}^{-1}$ 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 $\text{cmol(p+)}\text{kg}^{-1}$ soil] because of comparatively higher clay content (Verma *et al.*, 2001).

CEC of the soils ranged from 7.7 to 26.2 $\text{cmol(p+)}\text{kg}^{-1}$ 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 $\text{cmol(p+)}\text{kg}^{-1}$ soil and decreased with depth. Low CEC of these soils could be attributed to low content of clay and organic carbon.

Sharma *et al.* (2004b) stated that CEC in the soils of Neogal watershed in north-west Himalayas ranged from 4.9 to 14.3 $\text{cmol(p+)}\text{kg}^{-1}$ soil. The difference in CEC between the soils was due to the varied type / content of soil colloids and soil pH values. 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). CEC of the soils in Dindori district of Madhya Pradesh with smectitic mineralogy was higher [72.0 $\text{cmol(p+)}\text{kg}^{-1}$] as compared to the soils with mixed mineralogy [28.9 $\text{cmol(p+)}\text{kg}^{-1}$] (Patil and Jagdish Prasad, 2004).

The CEC values were higher in horizons containing high clay and/or high organic carbon content. Low values of CEC [9.0 to 11.5 $\text{cmol(p+)}\text{kg}^{-1}$] may be ascribed to the predominance of low CEC minerals, especially illite, in outer Himalayas (Sanjeev *et al.*, 2005). The CEC of the soils in Sivagiri

micro-watershed of Chittoor district in Andhra Pradesh ranged from 1.50 to 45.14 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil which corresponds to their clay content in the respective horizons (Thangasamy *et al.*, 2005).

The cation exchange capacity of soils varied from 51.16 to 62.98 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil and the soils which had lower amount of clay content had lowest CEC values in a micro-watershed of Vidharbha region in Maharashtra (Gabhane *et al.*, 2006). The CEC varied from 23.00 to 59.00 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ 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 in Nasik district of Maharashtra (Balpande *et al.*, 2007). The CEC values ranged from 16.60 to 38.10 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil and decreased with depth in coffee growing soils of Karnataka. (Shalima Devi and Anil Kumar, 2010).

2.8.2 Base saturation

The soils of Gandak command area of Bihar were highly base saturated and the cations on the exchange complex were in the order: $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ = \text{Na}^+$ (Singh and Mishra, 1996). 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 Chhotanagpur 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 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil while exchangeable magnesium varied between 0.5 and 6.5 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ 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 per cent indicating moderate soil fertility status. Among different cations, Ca^{2+} dominated the exchange complex followed by Mg^{2+} , K^+ and Na^+ (Sharma and Anil 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. Among the exchangeable cations Ca^{2+} dominates the exchange complex followed by Mg^{2+} , which dominates over Na^+ in the Entisols and Inceptisols of Rajasthan. Further, it was observed that with the increase in the finer fractions in the soil there was a corresponding increase in the content of exchangeable bases (Sharma *et al.*, 2004b). 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 Jagdish 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 $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ 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 varies 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 in Nasik district of 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 (Shalima Devi and Anil Kumar 2010). Sugarcane growing soils of Ahmadnagar district of Maharashtra were rich in base saturation (93.3 to 109.5 %) was due to the presence of base containing minerals such as Zeolite in these black soils (Ashokkumar and Jagdish Prasad, 2010).

2.8.3 Silica and sesquioxide

The sedentary soils developed on granite-gneiss were highly siliceous and had 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 per cent) increased with depth and sesquioxide content (3.45 to 30.75 per cent) 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 per cent) in benchmark 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). Ram Prakash and Seshagiri Rao (2002) stated that soils developed from granite-gneissic 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 $\text{SiO}_2 / \text{R}_2\text{O}_3$ molar ratios in surface soils. This indicates less siliceous substratum and thereby advanced stage of pedogenic development (Singh and Agrawal, 2005). The free Fe_2O_3 content ranged from 1.4 to 6.2 mg kg^{-1} . 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 Tamil Nadu 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 $\text{SiO}_2 / \text{R}_2\text{O}_3$ ratio of the pedons ranged from 3.16 to 14.07 and the ratio was wider in all the pedons. The low molar $\text{SiO}_2 / \text{R}_2\text{O}_3$ ratio indicated moderate weathering in soil whereas high molar ratio indicated *vice-versa* (Somasundaram *et al.*, 2010).

2.9 FERTILITY STATUS

2.9.1 Total and available macronutrients

Considering the fertility limits stated by Srivastava and Shyam Singh (2001) the available nitrogen was optimum in Ap horizon. All the hilly soils starting from high hill to foot hill were low in available phosphorus (Sarkar *et al.*, 2002). Rakesh Kumar *et al.* (2002) observed that total sulphur content in Entisols ranged from 282 to 470 mg kg^{-1} while it varied from 141 to 723 mg kg^{-1} in Alfisols of Jharkhand. 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. These nutrients were more in the surface horizons than in the sub-surface horizons.

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} and potassium ranged from 100 to 315 kg ha^{-1} in the surface soil and available sulphur content varied from 12.5 to 35.2 mg kg^{-1} , this could be due to higher amounts of organic matter in surface layers than deeper layers. The available P was medium to high (4.50 to 47.03 kg ha^{-1}), available K showed high range (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 which decreases with

depth in soils under Amethi area of Uttar Pradesh (Chaudhary *et al.* 2006). Available P content in the horizons of the pedons of Sivagiri micro watershed area varied from 4.5 to 29.3 kg ha⁻¹ (Thangasamy *et al.*, 2005).

Available P content said to be low to very high in status be (1.12 to 238 kg P ha⁻¹) and available K content said to be low to high in status (34 to 1193 Kg K ha⁻¹) (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 Mukhopadhyay (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 content of all the six pedons in banana growing soils of Pulivendla region in Andhra Pradesh was low (104 to 274 kg ha⁻¹). The available phosphorous content is medium to high (23 to 75 kg ha⁻¹) and potassium content was high in all the pedons (337 to 936 kg ha⁻¹) (Niranjana *et al.*, 2011).

2.9.2 Total and available micronutrients

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 2.0 to 219.0 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 soils of Loktak catchment (Sarkar *et al.*, 2000). Gently sloping 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 Jagdish Prasad (2004) reported that higher DTPA-extractable micronutrient cations in surface layers. According to Satyavathi and Suryanarayan Reddy (2004b), DTPA-extractable Zn, Cu, Fe and Mn were 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, Andhra Pradesh. 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.* (2005b) assessed that soils developed from alluvial plains had higher copper content (mean 0.61 mg kg^{-1}) than soils developed from micro basins (mean 0.50 mg kg^{-1}). Thangasamy *et al.* (2005) reported that 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. Total Fe was varied from 24668.4 to $28046.0 \text{ mg kg}^{-1}$ in surface soils and total Mn was varied from 358.8 to 591.0 mg kg^{-1} in some Vertisols of Rajasthan (Singh *et al.*, 2006).

The contents of available Zn, Cu, Fe and Mn were ranged from 0.31 to 4.70 , 0.30 to 2.80 , 8.20 to 50.20 and 2.70 to 56.40 mg kg^{-1} soil, respectively in soil series of lower Shiwaliks of Solan district in north-west Himalayas and (Sharma and Chaudhary, 2007). In general, alkali soils were low in fertility and deficient in DTPA-extractable micronutrients particularly Zn and Fe (Ashokkumar and Jagdish 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} , respectively 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 (Mahesh Kumar *et al.*, 2011).

2.10 MINERALOGY OF CLAYS

Singh *et al.* (1991) found illite as the dominant clay mineral in the alluvial soils of the Varanasi district of eastern Uttar Pradesh. Illite is the dominant mineral in some Inceptisols of north-west India and other minerals present in the clay fraction were kaolinite, smectite and chlorite (Sharma *et al.*, 1997).

Mall and Mishra (2000) reported that clays in Alfisols of northern Bihar indicated the characteristic peaks of mica, kaolinite, vermiculite, chlorite, quartz, feldspar and intergrades. Investigation of some soils of A.konduru mandal in Andhra Pradesh revealed that smectite was the dominant mineral followed by illite and kaolinite (Suri Babu *et al.*, 2001). According to Patil and Jagdish Prasad (2004), X-ray diffraction analysis indicated the presence of smectite as the dominant clay mineral followed by kaolinite, mica and feldspars in Sal (*Shorea robusta*) supporting soils of Dindori district in Madhya Pradesh.

Jassal *et al.* (2004) investigated typical salt-affected soil of Punjab for their mineral assemblages and found that X-ray diffractograms of the clay fractions showed presence of illite, chlorite, smectite and kaolinite with small amounts of vermiculite. According to Jagmohan singh and Sawhney (2006), clay mineralogy investigation by X-ray diffraction techniques indicated that mica (illite) was the dominant clay mineral followed by kaolinite in salt effected soils of south-west Punjab. Raina *et al.* (2006) reported that soils of Uttar Pradesh constituted illite, mixed layer minerals and kaolinite in the clay fractions, in addition to quartz and small amounts of chlorite. Leelavathi *et al.* (2010a) reported that clay fraction of soils developed from granite-gneiss parent material exhibit clay fraction with characteristic peaks of smectite, mica and kaolinite. XRD of sand and silt fractions of the soils exhibited the dominance of quartz followed by feldspar and mica (Deb and Sahu, 2011).

2.11 CLASSIFICATION

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). Rice growing soils of Chattishgarh were classified into Udic Haplustepts (high WHC), Vertic Haplustepts and Typic Haplustepts (medium WHC) finally Lithic Haplustepts (low WHC) (Tamgadge *et al.*, 2002).

According to Sharma *et al.* (2004a), salt affected soils of southern Rajasthan were classified as Typic Haplustepts and Typic Calcustepts. Soils of topographic positions in Sivagiri micro watershed of Andhra Pradesh were grouped into Typic Ustipsamments, Typic Ustifluvents and Aquic Ustorthents (Thangasamy *et al.*, 2005). 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 of 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 grouped under Alfisols (Vara Prasad Rao *et al.*, 2008). According to Najjar *et al.* (2009), the soils 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). Based on the morphological and physico-chemical properties, of soils in Bharatpur and Dholpur districts of Rajasthan were classified under Alfisols those of Alwar district were also classified as Alfisols and those the soils of Sawai

Madhopur and Karauli were placed under Entisols (Ram *et al.*, 2010). Coffee growing soils of Karnataka were classified into Ustic Haplohumults, Dystric haplustepts, Ustic Paleustalfs, Ustic Palehumults Kanhaplic Haplustalfs and Ustic Haplustalfs (Shalima and Anil Kumar, 2010).

Ashokkumar and Jagdish Prasad (2010) classified some typical sugarcane growing soils of Ahmadnagar in Maharashtra as Lithic 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 Nadu as Typic Ustifluvents due to the absence of intergradation with other taxa or any extra gradation from central concept.

2.12 LAND CAPABILITY CLASSIFICATION

The land capability classification is an interpretative grouping of different soil units and plays an important role in land use planning to show the relative suitability of soils for cultivation of crops, pastures, forestry in addition to focussing the problems which need preventive measures.

According to Singh *et al.* (1992), soils of cold desert predominantly belongs to land capability classes IV-VIII with severe limitations of climate, soil and erosion. 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 the soil and crop management must give high research priority (Woldeamlak *et al.*, 2003).

Esther Shekinah *et al.* (2004) classified the soils of Sahaspur block in Uttaranchal into six land capability classes *viz.*, II, III, IV, VI, VII and VIII. 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). 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). Soils on upper and lower plateau of Medak district in Andhra Pradesh were grouped under land capability sub-classes of IIIws (Dhanorkar *et al.*, 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 classes *viz.*, IIs, IIIs and IIIes (Ram *et al.*, 2010). Soils of Mula command of irrigated agroeco system in Maharashtra classified as Lithic Ustorthents and it was grouped under land capability sub-class of IVse (Kharche and Pharanda, 2010).

2.13 SOIL-SITE SUITABILITY FOR DIFFERENT CROP

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).

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.*, 2004b). 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 in Telangana region of Andhra Pradesh (Satyavathi and Suryanarayan Reddy, 2004a). 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, Plinthustalfs, Udic Haplustalfs, Typic Haplustalfs and Typic Rhodustalfs were marginally suitable (S3), Lithic Haplustepts and Typic Ustorthents were not suitable temporarily (N1) and Lithic Ustorthents were not suitable permanently (N2) for growing paddy.

The land suitability evaluation revealed that soils of a micro-watershed in Vidarbha region of Maharashtra 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.* (2010b) 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 in Yerpedu mandal of Chittoor district in Andhra Pradesh.

Evaluation studies in Pulivendla region for growing banana revealed that 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 soil (Niranjana *et al.*, 2011).

Chapter ~ III

Material & Methods

Chapter III

MATERIAL AND METHODS

The present investigation was taken up to “characterize, classify and evaluate the soils in Banaganapalle mandal of Kurnool district, Andhra Pradesh”. The Banaganapalle mandal has a total geographical area of about 19843 ha.

Seven master profiles (Pedons) were examined in Banaganapalle mandal representing all major soil types 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 varied morphological characters of each horizon of all the pedons were described in field as per the guidelines laid down in USDA Soil Survey Manual (Soil Survey Division Staff, 2000). The detailed morphological description for all the seven pedons studied and climatic particulars of the study area were furnished in appendix-I. Horizon-wise soil samples were collected for analysis from each profile for physical, chemical and physico-chemical properties. Soil samples from control section (25 to 100 cm) were also collected for mineralogical study (Soil Survey Staff, 1998).

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 mechanical 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 CaCO₃ 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 Division Staff, 2000).

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)

This was estimated in soil samples 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. 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 $\text{cmol(p+)}\text{kg}^{-1}$ 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 $\text{cmol(p+)}\text{kg}^{-1}$ 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 and finally the volume was made upto 250 ml (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. Crucible along with the residue was cooled in a desiccator and then weighed. From the weight of the residue, the percentage of SiO₂ was calculated (Hesse, 1971).

3.3.3.3 Sesquioxides (R₂O₃)

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 aluminium was obtained by adding ammonium hydroxide in the presence of ammonium chloride, this precipitate was washed with warm distilled water till free of chlorides, residue along with the filter paper was dried, ignited and cooled in a desiccator and weighed. The results were expressed as per cent sesquioxides (Hesse, 1971).

3.3.3.4 Iron oxide (Fe₂O₃)

Iron concentration was determined by aspirating silica free acid extract into atomic absorption spectrophotometer (VARIAN AA240FS) and the results were expressed as per cent Fe₂O₃ (Hesse, 1971).

3.3.3.5 Alumina (Al₂O₃)

This was determined by deducting the Fe₂O₃ 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

Acid extract was directly aspirated to the flame photometer to estimate the total potassium content (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 Na₂O (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 $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ (Williams and Steinbergs, 1959) and estimated by turbidimetric method (Cottenie *et al.*, 1979).

3.3.4.1.5 Ratings for organic carbon and macronutrients

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, K and organic carbon. Available sulphur was classified based on the critical limits proposed by Tandon (1991).

S. No.	Nutrient	Low	Medium	High
1.	Organic carbon (%)	<5.0	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

Ratings 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 limit* (mg kg ⁻¹ soil)
Copper	0.2
Iron	4.5
Manganese	1.0
Zinc	0.6

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

3.4 CLAY MINERALOGY

3.4.1 Clay Separation

Clay in the soil sample collected from the control section of each pedon was separated by following the procedure outlined by Jackson (1969).

Twenty grams of soil was taken into a 500 ml beaker to which 200 ml of 1 N sodium acetate (pH 5.0) was added. The suspension was digested for 30 minutes on a water bath with intermittent stirring to destroy the carbonates, clear supernatant liquid was siphoned out and this procedure was repeated once again for black and calcareous soils. Then the suspension was treated with 5 ml of 30 per cent hydrogen peroxide and allowed for digestion overnight. The digestion was continued for 2-4 hours on a water bath by adding 10 ml more of hydrogen peroxide for complete oxidation of

organic matter. Later, the suspension was evaporated to thin paste and once again the contents in the beaker were stirred with 100 ml of sodium acetate (pH 7.0) to remove the soluble cations released from the organic matter. Then the suspension was subjected to CBD treatment to destroy the iron oxides. To achieve this, the suspension was treated with 40 ml of 0.3 *M* sodium citrate solution followed by 5 ml of 1 *M* sodium bicarbonate and heated on a water bath to 70 to 80°C. Then one gram of solid sodium dithionite salt was added and stirred well and heating was continued for further 15 to 20 minutes. Saturated NaCl solution of about 10 ml was added to promote flocculation. The supernatant liquid was siphoned out after settling, then the beaker was filled with distilled water. This process was repeated until the contents in the beaker remain in dispersed state. The suspension was stirred with an electrical stirrer and transferred to sedimentation cylinder and the volume was made upto 1000 ml. The contents were allowed to settle for specific time (6 hours and 20 minutes) and top layer was siphoned out upto 10 cm depth into a bottle and stored as sodium clay suspension after adding suitable quantity of sodium chloride.

3.4.2 Preparation of K-saturated clay

Suitable quantity of sodium clay suspension was transferred to a centrifuge tube and 30 ml of 1 *N* KCl solution was added. The contents were centrifuged for 5 minutes at 1500 rpm after shaking continuously for 5 minutes. This treatment was repeated twice. To remove the excess of potassium, the sample was washed once with distilled water, twice with methanol and once with acetone. The clay was transferred to a bottle using required quantity of distilled water to make 2 per cent clay suspension.

3.4.3 Preparation of Mg-saturated clay

Magnesium saturated clay was prepared in the same way as K-saturated clay using 1 *N* MgCl₂ solution instead of KCl solution.

3.4.4 Preparation of K and Mg-saturated clay slides

The slides of K and Mg-saturated clay were prepared by spreading 1 ml of 2 per cent clay suspension (Mg and K saturated separately) uniformly on clean microscopic slides and allowing them to dry at room temperature.

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

1. Mg-saturated clay at room temperature (25°C).
2. Mg-saturated ethylene glycol solvated clay.
3. K-saturated clay at room temperature (25°C).
4. K-saturated clay heated to 550°C.

3.4.5 X-Ray Diffraction analysis

The X-ray diffraction analysis was carried out on Phillips X'pert Pro PW 3040 / 60 XRD machine with the following scanning details.

Current	-	45 mA 40 kv
Scanning speed	-	2° 2 θ minute ⁻¹
Radiation	-	Cu K α

3.5 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 Banaganapalle mandal were

classified into different orders, sub-orders, great groups, sub-groups, families and finally into tentative series as per USDA Soil Taxonomy (Soil Survey Staff, 2003).

3.6 LAND CAPABILITY CLASSIFICATION

The land capability classes were fixed to the soils of Banaganapalle 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.

3.7 CROP SUITABILITY CLASSIFICATION

Seven dominant soils in the Banaganapalle mandal of Kurnool district in Andhra Pradesh were selected for evaluation and their morphometric characteristics were studied. Physical and chemical properties were estimated using standard procedures were presented in Table 4.27. 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 term of characteristics (Table 4.28). The following landscape and soil characteristics 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, CaCO₃), soil fertility characteristics [apparent CEC (cmol(p+)kg⁻¹ clay), per cent base saturation, sum of basic cation (cmol(p+)kg⁻¹ soil), pH (H₂O), per cent organic carbon, salinity (EC, dsm⁻¹) and alkalinity (ESP)]. The study area was almost plain 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 4.29). 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).

3.8 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 was located in Banaganapalle mandal of Kurnool district, Andhra Pradesh lies in between 15°08' and 15°24' North latitude and 78°12' and 78°16' East longitude (Figure 4.1).

4.2 SOIL FORMING FACTORS

4.2.1 Climate

The study area was confined to semi-arid monsoonic climate with distinct summer, winter and rainy seasons. The mean annual atmospheric temperature was 28.66°C and the mean annual rainfall was 775.43 mm of which 90.09 per cent was received during June to September (Table 4.1). The meteorological data were also depicted in ombrothermic diagram (Figure 4.2).

Climate was 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 (2002-2011) indicated that study area was confined to semi-arid monsoon type of climate with distinct summer (March to June), rainy (July to October) and winter (November to February) seasons. The overall climate of the study area was hot summer and mild winter. The Entisols, Inceptisols and Alfisols in Sivagiri micro-watershed area of Chittoor district in Andhra Pradesh were

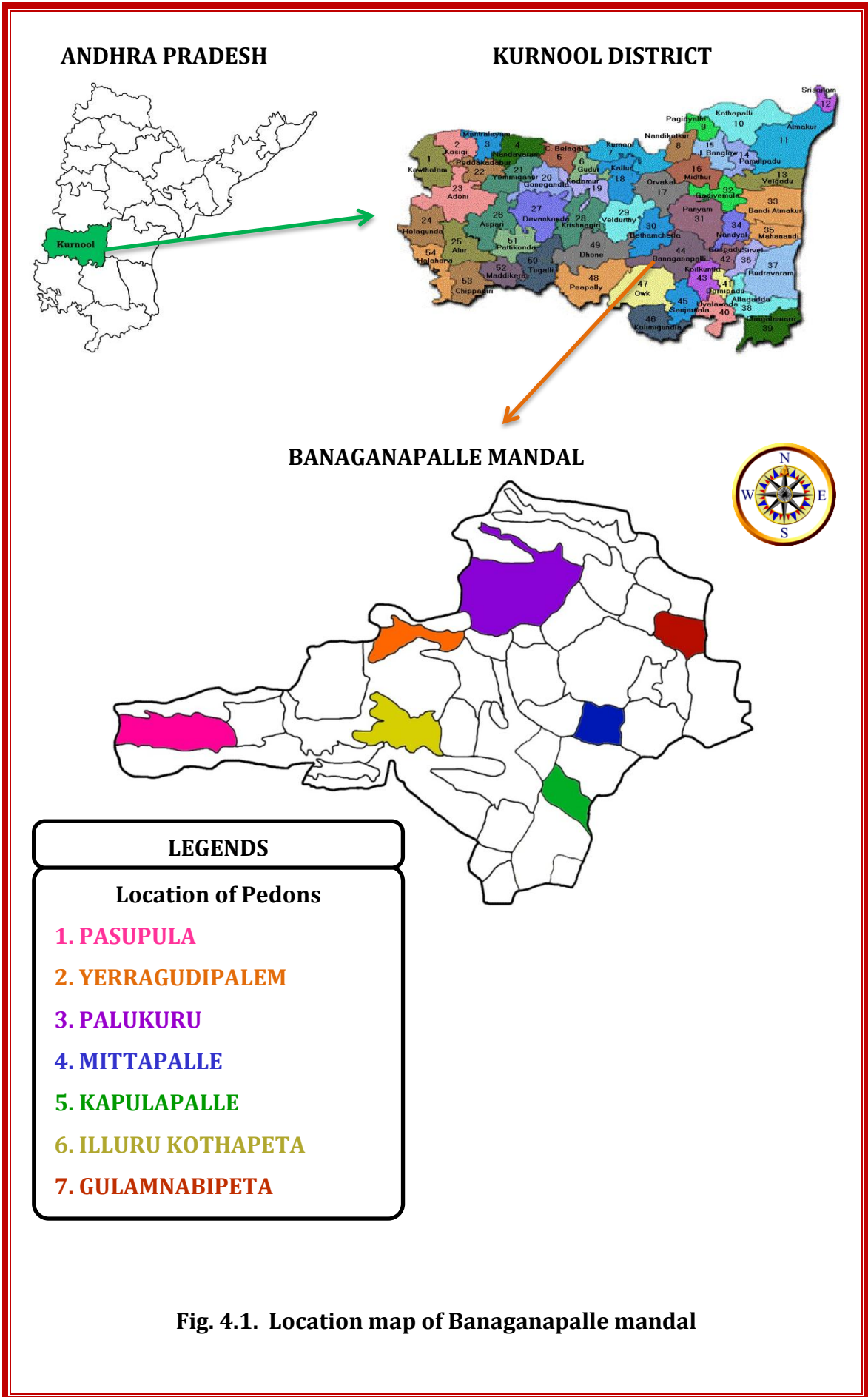


Fig. 4.1. Location map of Banaganapalle mandal

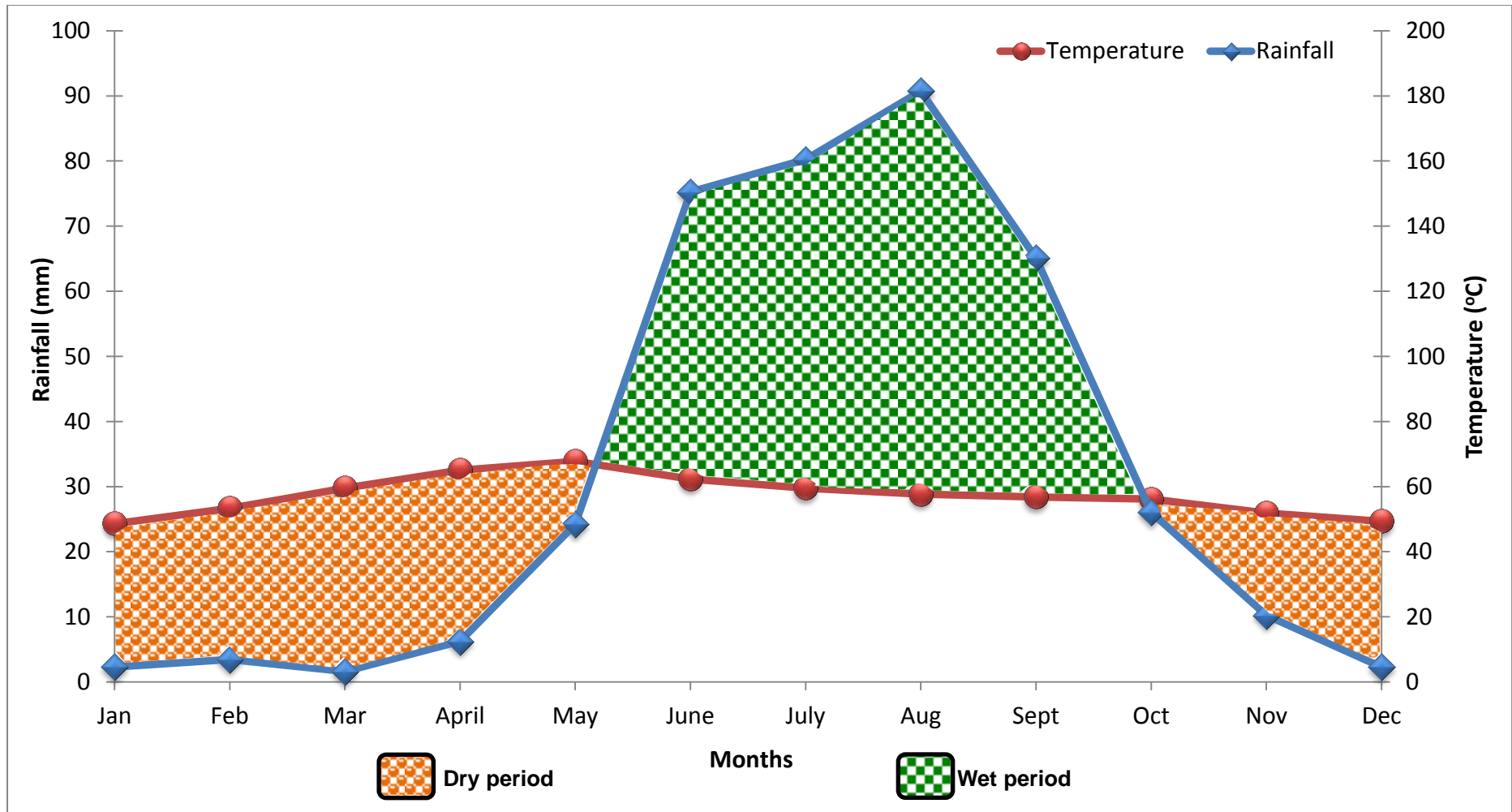


Fig. 4.2. Ombrothermic graph of study area (Banaganapalle mandal)

Table 4.1. Meteorological data of the study area (2002-2011)*

Month	Rainfall (mm)	Temperature (°C)			
		Maximum	Minimum	Mean	
January	4.58	31.7	16.9	24.30	
February	6.93	34.4	18.9	26.65	
March	3.20	37.3	22.2	29.75	
April	12.48	39.9	25.1	32.50	
May	48.43	40.4	27.3	33.85	
June	150.54	36.6	25.7	31.15	
July	160.43	34.7	24.8	29.75	
August	181.41	33.2	24.5	28.85	
September	130.22	32.7	24.1	28.40	
October	52.13	32.9	23.3	28.10	
November	20.46	31.2	20.7	25.95	
December	4.62	30.6	18.7	24.65	
Total	775.43	Mean	34.63	22.68	28.66

Mean annual rainfall = 775.43 mm
Mean annual air temperature = 28.66 °C
Langs precipitation factor = 27.06

* Mean values of ten years data from 2002 to 2011

developed under semi-arid monsoonic climate with an annual rainfall of 1215 mm and mean annual air temperature of 31.5°C (Thangasamy *et al.*, 2005). Ram Prakash and Seshagiri Rao (2002) also stated that red 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.

According to Ramesh Kumar (2002), different types of soils *viz.*, Entisols, Inceptisols, Alfisols and Vertisols were formed under semi-arid monsoonic climate in Singarayakonda mandal of Prakasam district in Andhra Pradesh. Similar findings were also reported by Vijay Kumar *et al.* (1994) in northern Telangana zone of Andhra Pradesh.

4.2.2 Parent material

Parent material was 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, 4, 5, 6 and 7 were developed from granite-gneiss parent material whereas pedon 3 developed from dolomite. The study area was comprised of mostly red, black and associated soils. 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 Suryanarayan Reddy (2004b) also stated that Inceptisols and Vertisols in Telangana region of Andhra Pradesh 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 (Ram Prakash and Seshagiri Rao, 2002).

4.2.3 Topography

The topography of Banaganapalle mandal varied from nearly level plains (0-1%) to very gently sloping uplands (1-3%) with very slight to slight erosion. Pedons 1, 2, 3 and 5 occurs on nearly level (0-1%) plains whereas the pedons 4, 6 and 7 lies on very gently 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. Seshagiri Rao *et al.* (2004) noticed that Inceptisols were formed on very gently to gently sloping uplands with a slope of 0 to 1 per cent.

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. The soils developed over granite-gneiss were comparatively younger with higher nutrient reserves followed by soils developed on granite, charnockites and laterites (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, sorghum, bajra, redgram, sunflower, cotton, tobacco and mango. The natural vegetation observed in the study area was *Parthenium hysterophorus*, *Lantana camara*, *Lucas aspera*, *Tridax*

Table 4.3. Details of the pedons

Pedon No.	Village	Location	Elevation above msl(m)	Horizon	Horizon thickness (m)
1	Pasupula	15°08'04.5" N 78°16'48.3" E	243	Ap	0.00-0.15
				2Bw1	0.15-0.41
				3Bw2	0.41-0.64
				4Bw3	0.64-0.90
				5Bw4	0.90-1.07
				Bw5	1.07-1.50+
2	Yerragudipalem	15°23'00.9" N 78°12'26.3" E	274	Ap	0.00-0.23
				A1	0.23-0.52
				A2	0.52-0.72
				Cr	0.72
3	Palukuru	15°24'00.1" N 78°12'03.9" E	287	Ap	0.00-0.18
				Bw1	0.18-0.43
				Bw2	0.43-0.67
				Bw3	0.67-0.91
				Cr	0.91
4	Mittapalle	15°18'57.4" N 78°14'37.1" E	233	Ap	0.00-0.19
				Bw1	0.19-0.48
				2Bw2	0.48-0.86
				3Bw3	0.86-1.10
				4Bw4	1.10-1.40
				Cr	1.40
5	Kapulapalle	15°18'12.6" N 78°14'56.4" E	230	A	0.00-0.21
				2 A1	0.21-0.61
				3Bw1	0.61-1.01
				4Bw2	1.01-1.40
				5Bw3	1.40-2.00
				Cr	2.00
6	Illuru Kothapeta	15°17'10.0" N 78°15'31.9" E	223	Ap	0.00-0.18
				A1	0.18-0.39
				A2	0.39-0.50
				Cr	0.50
7	Gulamnabipeta	15°15'44.3" N 78°15'37.9" E	216	Ap	0.00-0.20
				2A1	0.20-0.50
				3A2	0.50-0.87
				4A3	0.87-1.00
				Cr	1.00

procumbens, *Calotropis gigantia*, *Pongamia pinnata*, *Prosopis juliflora*, *Azadiracta indica*, *Acacia auriculiformis*, *Phyllanthus neruri*, *Cyperus rotundus* and *Cynadon 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, translocation and accumulation of mineral substances. Prasuna 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

An examination of soil profiles showed distinctive horizontal layers, some of which were highly visible. Significant changes occurred as the soils were developed from relatively unconsolidated parent material. Pedons 1, 2, 4, 5, 6 and 7 were developed from granite-gneiss parent material and pedon 3 was developed from dolomite.

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: 1) Weathering and organic matter break down by which some soil constituents were modified or destroyed and others were synthesized. 2) 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 and 3) 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 (Brady, 1995).

Simonson (1959) outlined the process of soil formation include a) addition of organic and mineral materials to the soil as solids, liquids and

gases b) losses of these from the soil c) translocation of materials from one point to another within the soil and d) transformation of mineral and organic substances within the soil.

In the present study as per the outlines given by Simonson (1959), the addition of organic matter was noticed due to accumulation of organic matter and humus on the surface soils and to certain depth of sub-soil was noticed in all the pedons (1, 2, 3, 4, 5, 6 and 7) of the study area. 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 1, 3, 4 and 5 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 2, 6 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 1, 3, 4 and 5. Smectite has been formed in these pedons through transformation from the weathering sequence of mica-vermiculite-smectite. However, kaolinite could be formed from montmorillonite by loss of alkalies and iron.

The study area has semi-arid climate with high summer temperatures with scarce rainfall and monsoonic type of climate. Natural vegetation in this area was 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 Banaganapalle mandal.

4.4 MORPHOLOGY OF TYPIFYING PEDONS

The detailed morphological and pedological features were presented in Appendix. 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 depth of different pedons studied was varied from 0.50 to 2.00 m and found to have deep to very deep solum. Solum depth was extended beyond 1.50 m in case of pedon 1 (1.50+ m) and pedon 5 (2.00 m) whereas the pedons 2, 3, 4, 6 and 7 extended upto 0.72, 0.91, 1.40, 0.50 and 1.00 m, respectively. Pedon 2 ended with weathered gneiss while pedons 4, 5, 6 and 7 ended with granite containing plagioclase with pegmatite veins. Pedon 3 ended with dolomite.

In general the AC profiles were very deep in depth whereas ABC profiles were deep to very deep in their depth. The physiography in the study area was almost plain [very gently sloping to plains]. Hence, all the profiles were deep to very deep in depth. These results were in accordance with the findings of Shyampura *et al.* (1993), who reported occurrence of deep pedons in plains in the soils of southern Rajasthan. The variation deep to very deep in depth of soils could be ascribed to differences in parent material and vegetation cover. Similar results were reported by Najar *et al.* (2009).

4.4.2 Number of horizons

Based on the different morphological features, pedons 1, 4 and 5 were distinguished into 6 horizons. Pedons 3 and 7 were distinguished into 5 horizons while pedons 2 and 6 were distinguished into 4 horizons. Similar

numbers of horizons were noticed in red, black and associated soils of Ramchandrapuram mandal in Chittoor district of Andhra Pradesh (Vara Prasad 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 Ap by taking into considerable change in colour and structure due to cultivation in all the profiles. Based on the macro morphological features, the 'A' horizon in pedons 2, 6 and 7 vertically sub divided into different sub-horizons. Pedons 1, 3, 4 and 5 exhibited ABC horizons with 'B' horizon differentiated into 2Bw1, 3Bw2, 4Bw3, 5Bw4 and Bw5 in pedon 1, Bw1, Bw2 and Bw3 in pedon 3, Bw1, 2Bw2, 3Bw3 and 4Bw4 in pedon 4 and 3Bw1, 4Bw2 and 5Bw3 in pedon 5 (Table 4.3).

The pedons studied were characterised by AB and ABC profiles. Horizonation was the main pedogenic process in Inceptisols. According to Simonsen (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 horizons.

Development of cambic horizon (Bw) was observed in pedons 1, 3, 4 and 5 as these pedons did not have rock structure, argillic, kandic, oxic and spodic horizons. Development of cambic (Bw) horizon in Inceptisols of Trans-Yamuna river and in Etawah district of Uttar Pradesh was observed by Sidhu *et al.* (1998) and Verma *et al.* (2001), respectively.

Further, the findings of the present investigation revealed that pedons 2, 6 and 7 did not exhibit any diagnostic sub-surface horizon, based on which they were characterized as Entisols. In Entisols, weak / no profile

Table 4.3. Details of the pedons

Pedon No.	Village	Location	Elevation above msl(m)	Horizon	Horizon thickness (m)
1	Pasupula	15°08'04.5" N 78°16'48.3" E	243	Ap	0.00-0.15
				2Bw1	0.15-0.41
				3Bw2	0.41-0.64
				4Bw3	0.64-0.90
				5Bw4	0.90-1.07
				Bw5	1.07-1.50+
2	Yerragudipalem	15°23'00.9" N 78°12'26.3" E	274	Ap	0.00-0.23
				A1	0.23-0.52
				A2	0.52-0.72
				Cr	0.72
3	Palukuru	15°24'00.1" N 78°12'03.9" E	287	Ap	0.00-0.18
				Bw1	0.18-0.43
				Bw2	0.43-0.67
				Bw3	0.67-0.91
				Cr	0.91
4	Mittapalle	15°18'57.4" N 78°14'37.1" E	233	Ap	0.00-0.19
				Bw1	0.19-0.48
				2Bw2	0.48-0.86
				3Bw3	0.86-1.10
				4Bw4	1.10-1.40
				Cr	1.40
5	Kapulapalle	15°18'12.6" N 78°14'56.4" E	230	A	0.00-0.21
				2 A1	0.21-0.61
				3Bw1	0.61-1.01
				4Bw2	1.01-1.40
				5Bw3	1.40-2.00
				Cr	2.00
6	Illuru Kothapeta	15°17'10.0" N 78°15'31.9" E	223	Ap	0.00-0.18
				A1	0.18-0.39
				A2	0.39-0.50
				Cr	0.50
7	Gulamnabipeta	15°15'44.3" N 78°15'37.9" E	216	Ap	0.00-0.20
				2A1	0.20-0.50
				3A2	0.50-0.87
				4A3	0.87-1.00
				Cr	1.00

development was observed due to inert nature of parent material. The horizons recognized were only A and C. Similar observations were made by Arun Kumar *et al.* (2002) and Sitanggang *et al.* (2006).

4.4.4 Horizon thickness and Horizon boundaries

The thickness of Ap horizon varied from 0.15 to 0.23 m for all the pedons whereas thickness of sub-surface horizons varied from 0.11 to 1.39 m. Surface horizons of all the pedons, 2Bw1 horizon in pedon 1 and 4Bw4 horizon of pedon 4 exhibited clear and smooth boundary whereas sub-surface horizons of all the profiles showed diffuse and wavy boundary. Similar results were reported by Vara Prasad Rao *et al.* (2008) and Leelavathi *et al.* (2009).

4.4.5 Soil colour

In pedons 1, 5 and 6 the colour varied from dark brown to very dark grayish brown with a hue varied from 7.5 YR to 10 YR, value of 3 to 4 and chroma in the range of 1 to 6. The pedons 2 and 7 exhibited brown to strong brown colour with a hue of 7.5 YR, value ranged from 3 to 4 and chroma varied from 2 to 6. In case of pedons 3 and 4, the colour varied from brown to dark brown with a hue of 10 YR, value ranged from 3 to 4 and chroma in between 1 and 4.

The Munsell colour notation of hue, value and chroma were more or less similar in both moist and dry conditions. 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).

Sarkar *et al.* (2002) stated that dark grayish colour in the lower layers of pedon indicates poor drainage condition. Occurrence of iron oxides at various hydrated forms might have resulted in dark brown colour to the soils (Ram Prakash and Seshagiri Rao, 2002). 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 gray 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 moist than sub-surface horizons (Vara Prasad 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. Pedon 7 showed fine, weak and crumb structure in the surface horizon. Pedon 1 exhibited coarse, strong and angular blocky structure and pedon 2 showed medium, moderate and sub- angular blocky. Pedons 4, 5 and 6 showed fine to medium, moderate and sub-angular blocky structure in surface horizons. All the pedons showed fine to coarse, weak to strong and sub-angular blocky to angular blocky structure in sub-surface horizons.

The variation in soil structure was a reflection of topographic position of the pedon (Singh and Agarwal, 2003). The structural variations in soils were useful to differentiate the horizon (Landay *et al.*, 1982). The study area had crumb, angular and sub-angular blocky 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; Leelavathi *et al.*, 2009). Weak structural development in pedon 7 might be due to low clay and organic carbon content. Similar results were obtained by Sitanggang *et al.* (2006).

4.4.7 Soil Texture

Texture of surface horizons and sub-surface horizons varied from sandy clay loam to clay. These variations were caused by topographic position, nature of parent material, *in-situ* weathering, translocation of clay and age of soils. 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), Giri Prakash (1997) and Leelavathi *et al.* (2009).

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 slightly hard to very hard, friable 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.

Sharma and Anil 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.*

(2004b) in soils of Neogal watershed in north-west Himalayas and Marathe *et al.* (2003) in Typic Ustorthents of mandarin orchards in Nagpur. 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 Sarkar *et al.* (2001) in soils of lower outlier of Chhotanagpur plateau.

4.4.9 Cracks

Cracks of 3 to 5 mm wide which extended to a depth of 35 cm were noticed in pedons 1 and 3. These cracks were evident in summer months. Development of cracks might be due to the presence of shrinking and swelling type of clay minerals. Further, the mineralogical study carried out in the present investigation confirmed the dominance of smectite clay mineral in this pedon which might be responsible for the development of cracks. Thangasamy *et al.* (2005) reported 3 to 7 mm wide cracks in Vertic Haplustepts of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh. Similar findings were also made by Sharma *et al.* (2001a) in soils of Kathiawar region of Gujarat and by Marathe *et al.* (2003) in Vertic Haplustepts of mandarin orchards in Nagpur.

4.4.10 Slickenslides

Indistinct and weak slickenslides were observed in pedons 1 and 3. The formation of slickensides might be due to the presence of high amount of expanding minerals, alternate wetting and drying cycles and soil depth more than 0.5 m (Soil Survey Staff, 1998). Thangasamy *et al.* (2005) observed weak indistinct slickensides in lower horizons of Vertic Haplustepts in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh. Sharma *et al.* (1997) observed slickensides in sub-surface horizons of Inceptisols having more than 30 per cent clay in north-west India.

Table 4.4. Summary of the morphological characters of the pedons

Pedon No.& Horizon	Depth (m)	Colour		Texture	Structure			Consistence			Effervescence	Boundary		Cutans			Pores		Roots		Remarks	
		Dry	Moist		S	G	T	Dry	Moist	Wet		D	T	T Y	TH	Q	S	Q	S	Q		
Pedon 1																						
Ap	0.00-0.15	10 YR 3/2	7.5YR 3/1	cl	c	3	abk	vh	vf	vsvp	es	c	s	-	-	-	f	c	f	f	Slickensides Cracks	
2Bw1	0.15-0.41	10YR 3/1	10 YR 3/1	c	c	3	abk	vh	vf	vsvp	es	c	s	-	-	-	m	m	f	f		
3Bw2	0.41-0.64	10YR 3/1	10 YR 3/1	sic	c	3	abk	vh	vf	vsvp	es	d	w	-	-	-	m	m	-	-		
4Bw3	0.64-0.90	10YR 3/1	10 YR 3/1	cl	c	3	abk	vh	vf	vsvp	es	d	w	-	-	-	-	-	-	-		
5Bw4	0.90-1.07	10YR 3/2	10 YR 3/2	cl	c	3	abk	vh	vf	vsvp	es	d	w	-	-	-	-	-	-	-		
Bw5	1.07-1.50+	7.5YR 4/3	10 YR 3/2	cl	c	3	abk	vh	vf	vsvp	es	d	w	-	-	-	-	-	-	-		
Pedon 2																						
Ap	0.00-0.23	7.5 YR3/3	7.5YR 3/3	scl	m	2	sbk	sh	fr	ssps	es	c	s	-	-	-	f	c	f	f	-	
A1	0.23-0.52	7.5 YR4/4	7.5YR 3/4	scl	m	2	sbk	sh	fr	ssps	es	d	w	-	-	-	-	-	-	-	-	
A2	0.52-0.72	7.5 YR3/3	7.5YR 3/2	scl	m	3	sbk	h	fi	ssps	es	d	w	-	-	-	-	-	-	-	-	
Cr	0.72	Weathered gneiss																				
Pedon 3																						
Ap	0.00-0.18	10 YR 3/1	10 YR 3/1	c	m	3	abk	h	fi	vsvp	ev	c	s	-	-	-	f	c	f	f	Slickensides Cracks	
Bw1	0.18-0.43	10 YR 3/2	10 YR 3/2	c	m	3	abk	h	fi	vsvp	ev	d	w	-	-	-	m	f	f	f		
Bw2	0.43-0.67	10 YR 4/1	10 YR 3/1	c	m	3	abk	h	fi	vsvp	ev	d	w	-	-	-	m	c	-	-		
Bw3	0.67-0.91	10 YR 4/1	10YR 4/1	c	m	3	abk	h	fi	vsvp	ev	d	w	-	-	-	-	-	-	-		
Cr	0.91	Dolomite																				
Pedon 4																						
Ap	0.00-0.19	10 YR 4/3	7.5YR 3/3	cl	f	2	sbk	sh	fi	sp	es	c	s	-	-	-	f	m	f	f	-	
Bw1	0.19-0.48	10 YR 3/3	7.5YR 3/4	cl	m	3	abk	h	fi	sp	es	d	w	-	-	-	f	f	c	f	-	
2Bw2	0.48-0.86	10 YR 4/3	7.5YR 3/2	l	m	3	abk	h	fi	ssps	es	d	w	-	-	-	-	-	f	f	-	
3Bw3	0.86-1.10	10 YR 3/2	7.5YR 3/3	scl	m	3	abk	h	fi	ssps	es	d	w	-	-	-	-	-	-	-	-	
4Bw4	1.10-1.40	10 YR 4/1	7.5YR 3/4	sc	m	3	abk	h	fi	sp	es	c	s	-	-	-	-	-	-	-	-	
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins																				

Table 4.4. (Cont.).

Pedon No.& Horizon	Depth (m)	Colour		Text ure	Structure			Consistence			Effer- vescenc e	Boundary		Cutans			Pores		Roots		Rem arks
		Dry	Moist		S	G	T	Dr y	Mois t	Wet		D	T	TY	TH	Q	S	Q	S	Q	
Pedon 5																					
Ap	0.00-0.21	10 YR 4/6	7.5YR 3/3	sicl	f	2	sbk	h	fi	sp	ev	c	s	-	-	-	f	f	f	f	-
2A1	0.21-0.61	10 YR 3/3	7.5YR 3/4	scl	f	2	sbk	h	fi	ssps	ev	d	w	-	-	-	f	m	f	f	-
3Bw1	0.61-1.01	7.5 YR 4/6	7.5YR 3/2	sil	f	2	sbk	sh	fr	sopo	ev	d	w	-	-	-	-	-	-	-	-
4Bw2	1.01-1.40	7.5 YR 4/6	7.5YR 3/3	sil	c	2	sbk	sh	fr	sopo	ev	d	w	-	-	-	-	-	-	-	-
5Bw3	1.40-2.00	7.5 YR 4/6	7.5YR 3/4	l	c	2	abk	h	fi	ssps	ev	d	w	-	-	-	-	-	-	-	-
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins																			
Pedon 6																					
Ap	0.00-0.18	10 YR 3/4	10YR 3/2	sicl	f	2	sbk	sh	fi	sp	ev	c	s	-	-	-	f	f	f	f	-
A1	0.18-0.39	10 YR 3/3	10YR 3/3	sicl	m	3	abk	h	vfi	sp	ev	d	w	-	-	-	m	f	f	f	-
A2	0.39-0.50	7.5YR 4/4	10YR 4/4	sicl	m	3	abk	h	vfi	sp	ev	d	w	-	-	-	-	-	-	-	-
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins																			
Pedon 7																					
Ap	0.00-0.20	7.5 YR 4/4	7.5YR 3/3	l	f	1	cr	sh	fr	ssps	ev	c	s	-	-	-	f	m	f	f	-
2A1	0.20-0.50	7.5 YR 3/4	7.5YR 3/4	scl	f	1	sbk	sh	fr	sp	ev	d	w	-	-	-	f	f	f	f	-
3A2	0.50-0.87	7.5 YR 3/3	7.5YR 3/6	l	m	2	sbk	sh	fr	ssps	ev	d	w	-	-	-	-	-	-	-	-
4A3	0.87-1.00	7.5 YR 3/4	7.5YR 4/6	l	m	2	sbk	sh	fr	ssps	ev	d	w	-	-	-	-	-	-	-	-
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins																			

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, 1 – 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

4.4.11 Porosity

The pores were fine to medium 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.

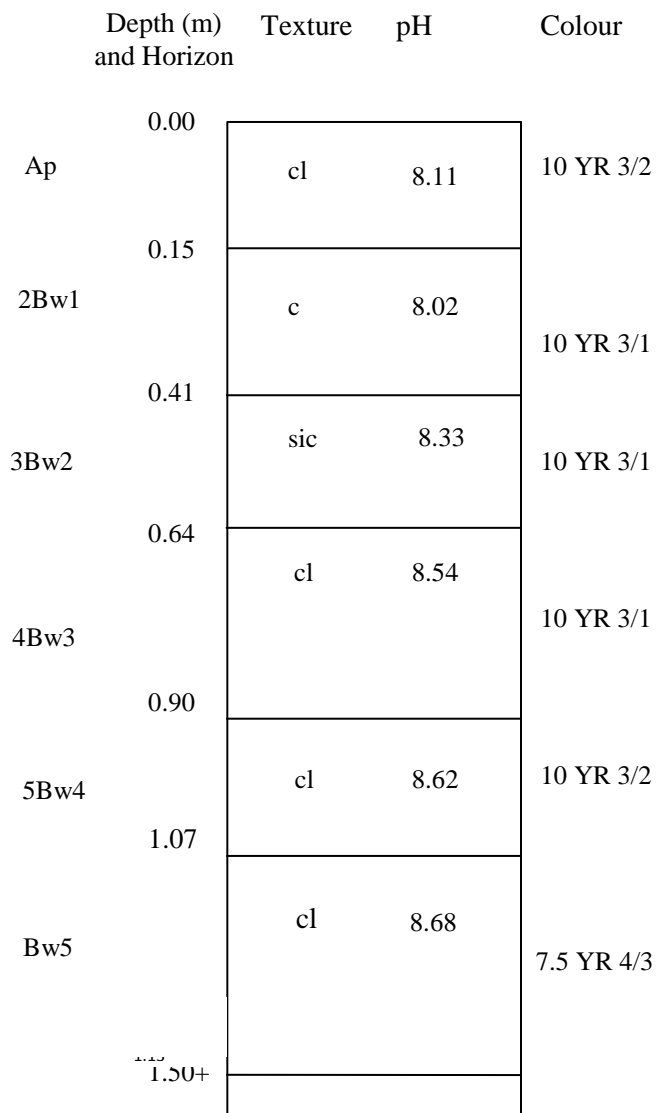
4.4.12 Roots

Roots were abundant in surface layers and decreased with depth. Further, the roots in different horizons of pedons were fine to coarse in size and few to common in quantity. The roots were almost absent below 1.00 m in pedons of 1, 4, 5 and 7. Root distribution indicated that vegetation of the area comprises of annuals and grasses.

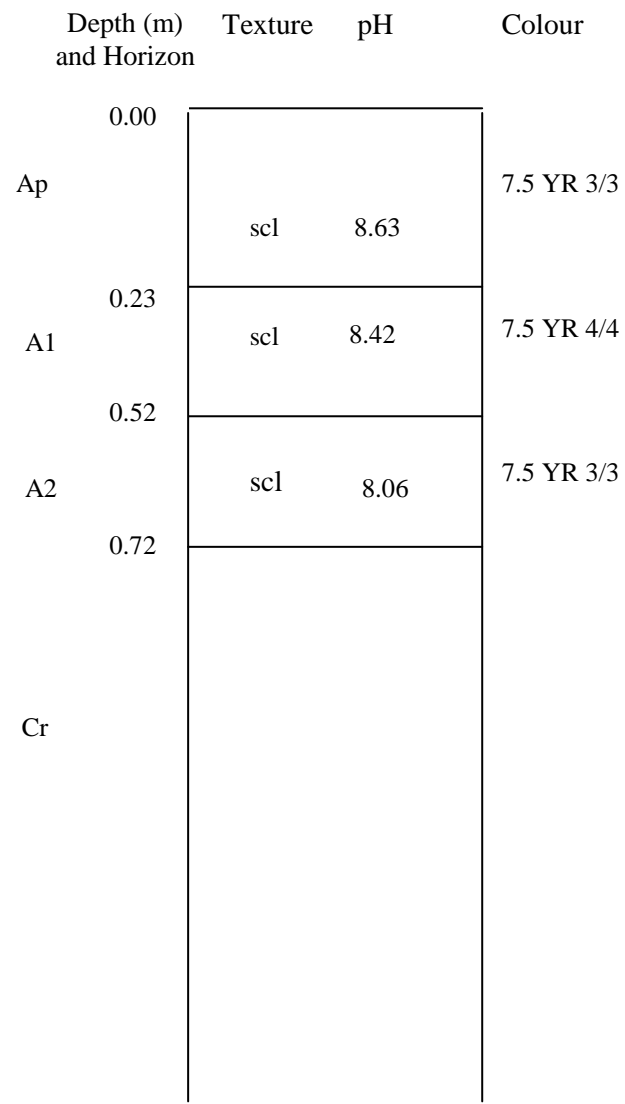
4.5 IMPORTANT MORPHOLOGICAL CHARACTERS OF THE TYPIFYING PEDONS

4.5.1 Pedon 1

This pedon was very deep in depth extending beyond 1.50 m with six horizons *viz.*, Ap, 2Bw1, 3Bw2, 4Bw3, 5Bw4 and Bw5. This pedon had very dark grayish brown to very dark gray in colour and silty clay to clay in texture. Further, surface and sub-surface horizons exhibited coarse, strong and angular blocky structure and very hard, very firm and very sticky and very plastic consistence in dry, moist and wet conditions, respectively. This pedon exhibited strong effervescence with diluted HCl treatment. Fine to medium and common to many pores were noticed. Few and fine roots were observed. The surface horizon showed clear and smooth boundary while sub-surface horizons exhibited clear to diffuse in distinctness and smooth to wavy in topography. Cracks of 3-5 mm wide and extended to a depth of 35 cm were observed. Slickenslides were noticed in sub-surface horizons (**Plate 4.1**).



Pedon 1



Pedon 2

Fig. 4.3: PROFILE DIAGRAMS



Fig. 4.1. Pedon 1

4.5.2 Pedon 2

This pedon was slightly deep extending beyond 0.55 m with four horizons *viz.*, Ap, A1, A2 and Cr. This pedon had brown to dark brown in colour and sandy clay loam texture in all the horizons. Further, surface and sub-surface horizons exhibited medium, moderate to strong and sub-angular blocky structure and slightly hard to hard, friable and slightly sticky and slightly plastic consistence in dry, moist and wet conditions, respectively. In surface horizon pores were fine and common. This pedon exhibited strong effervescence with diluted HCl treatment. Fine and few roots were also noticed in surface horizon only. The surface horizon showed clear and smooth boundary and sub-surface horizons exhibited diffuse and wavy boundary (**Plate 4.2**).

4.5.3 Pedon 3

This pedon was deep extending beyond 0.91 m with five horizons *viz.*, Ap, Bw1, Bw2, Bw3 and Cr. This pedon had dark gray to very dark gray in colour and clay in texture. Further, surface and sub-surface horizons exhibited medium, strong and angular blocky structure and hard, firm and very sticky and very plastic consistence in dry, moist and wet conditions, respectively. This pedon exhibited violent effervescence with diluted HCl treatment. Fine to medium and few to common pores and fine and few roots were observed in Bw3 horizon. The surface horizons showed clear and smooth boundary and sub-surface horizons exhibited diffuse and wavy boundary. Cracks of 3 to 5 mm wide and extended to a depth of 35 cm were observed. Slickenslides were noticed in sub-surface horizons (**Plate 4.3**).

4.5.4 Pedon 4

This pedon was very deep extending beyond 1.40 m with six horizons *viz.*, Ap, Bw1, 2Bw2, 3Bw3, 4Bw4 and Cr. This pedon had brown to dark brown in colour and sandy clay loam to clay loam in texture. Further,

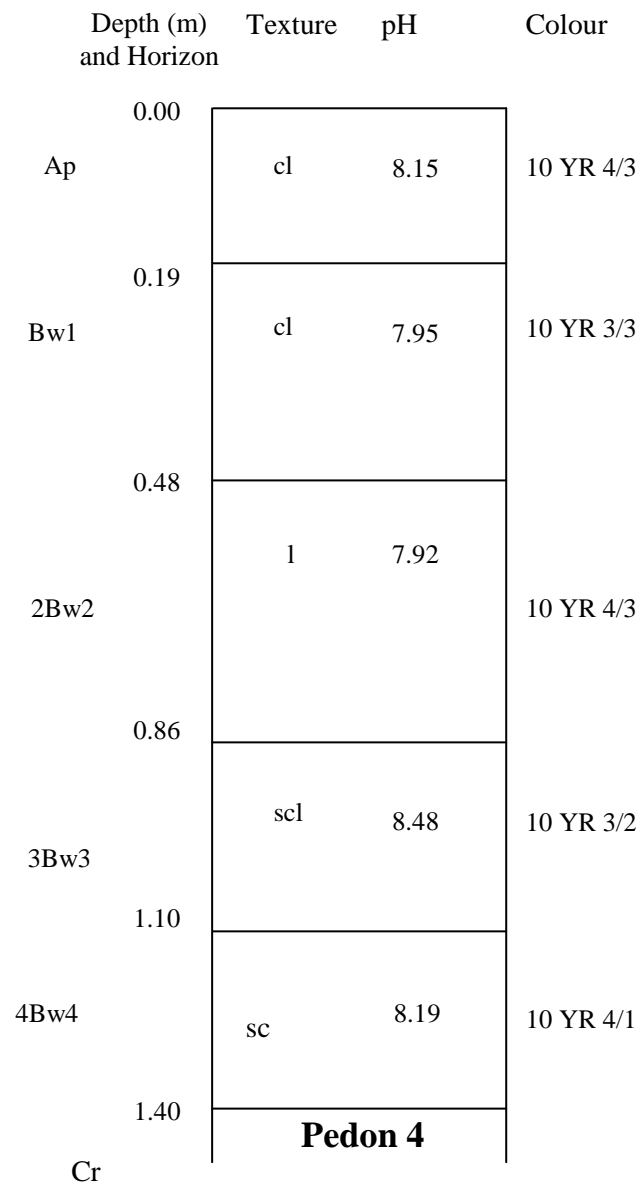
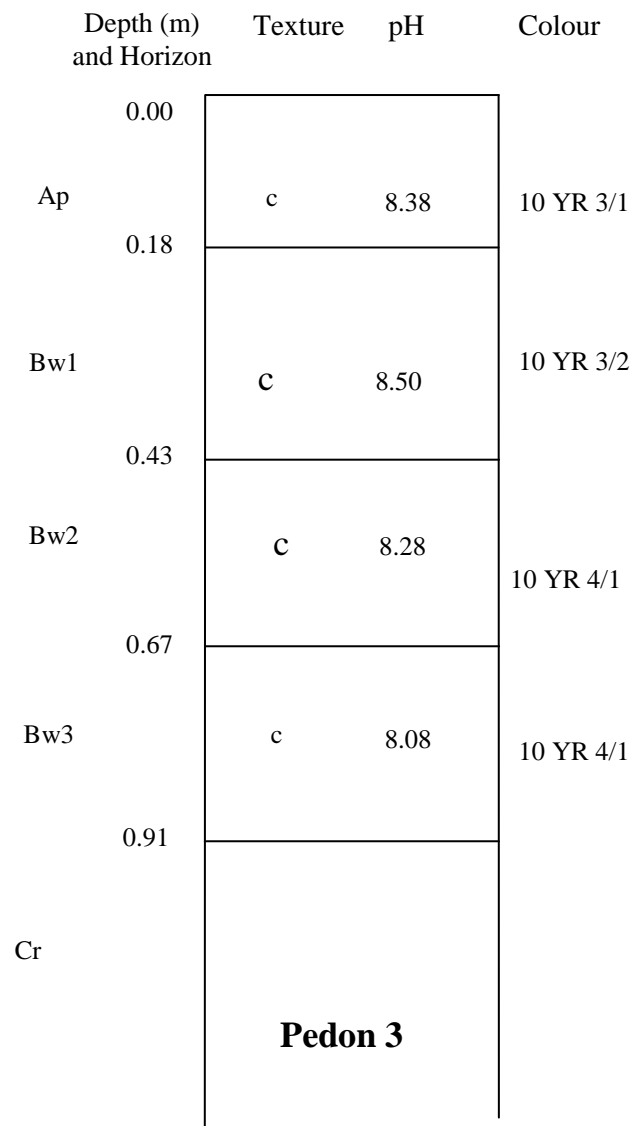


Fig.4.4: PROFILE DIAGRAMS

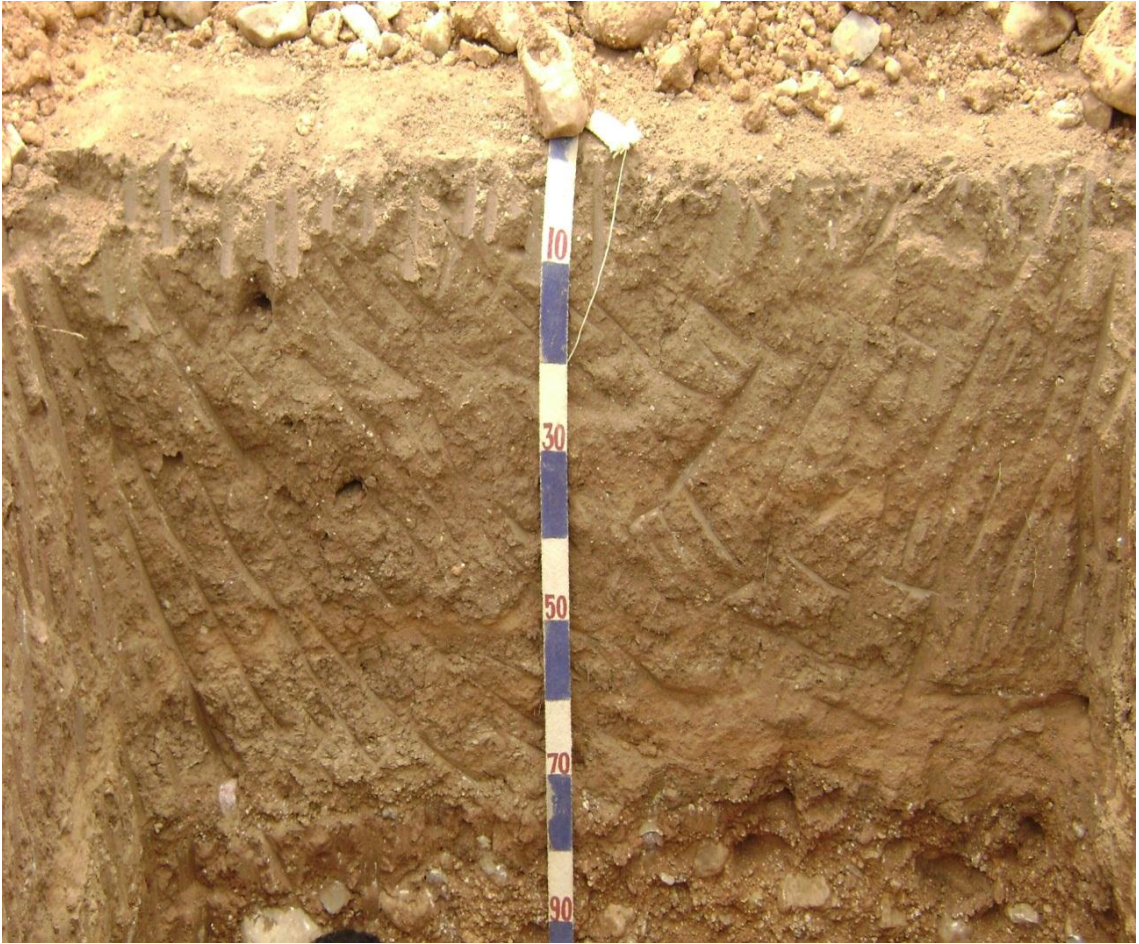


Fig. 4.2. Pedon 2

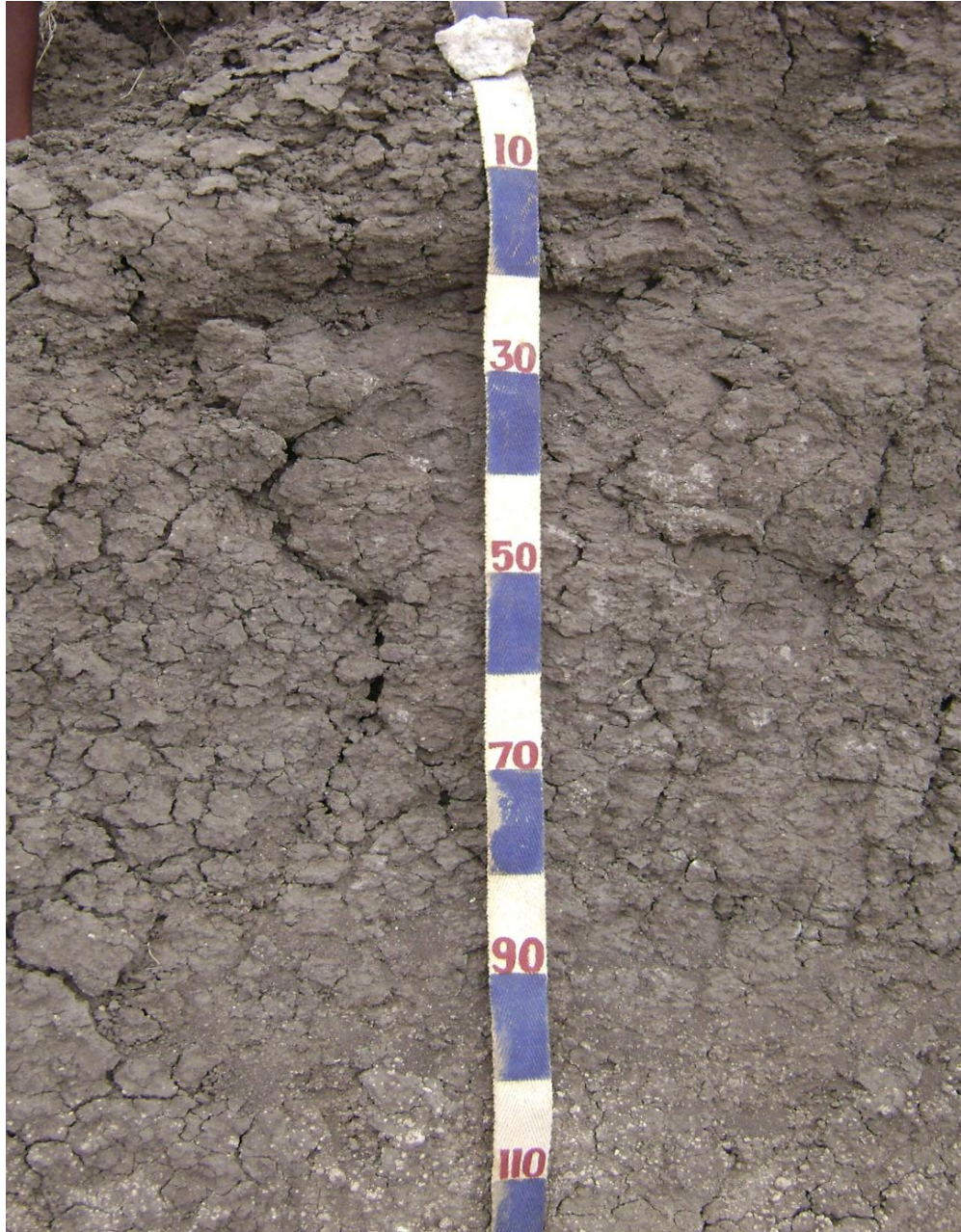


Fig. 4.3. Pedon 3



Fig. 4.4. Pedon 4

surface horizon showed fine, moderate and sub-angular blocky whereas sub-surface horizons exhibited medium, strong and 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. This pedon exhibited strong effervescence with diluted HCl treatment. Fine and few to many pores and fine to coarse and few roots were noticed up to 3Bw3 horizon. The surface horizon showed clear and smooth boundary while the boundary in sub-surface horizons exhibited clear to diffuse in distinctness and smooth to wavy in topography (**Plate 4.4**).

4.5.5 Pedon 5

This pedon was very deep extending beyond 2.00 m with six horizons *viz.*, Ap, 2A1, 3Bw1, 4Bw2, 5Bw3 and Cr. This pedon had dark yellowish brown to dark brown in colour and sandy clay loam to loam in texture. Further, surface horizons showed medium, moderate and sub-angular blocky structure and sub-surface horizons exhibited medium to fine, moderate and sub-angular blocky to angular blocky structure and slightly hard to hard, friable to firm and non-sticky and non-plastic to slightly sticky and slightly plastic consistence in dry, moist and wet conditions, respectively. This pedon exhibited violent effervescence with diluted HCl treatment. Fine and few to many pores and fine and few roots were noticed. The surface horizon showed clear and smooth boundary and sub-surface horizons exhibited diffuse and wavy boundary (**Plate 4.5**).

4.5.6 Pedon 6

This pedon was deep extending beyond 0.50 m with four horizons of *viz.*, Ap, A1, A2 and Cr. This pedon had dark yellowish brown to brown in colour and silty clay loam in texture. Further, surface horizons exhibited medium, moderate and sub-angular blocky structure and sub-surface horizons showed medium, strong and angular blocky structure. Slightly hard

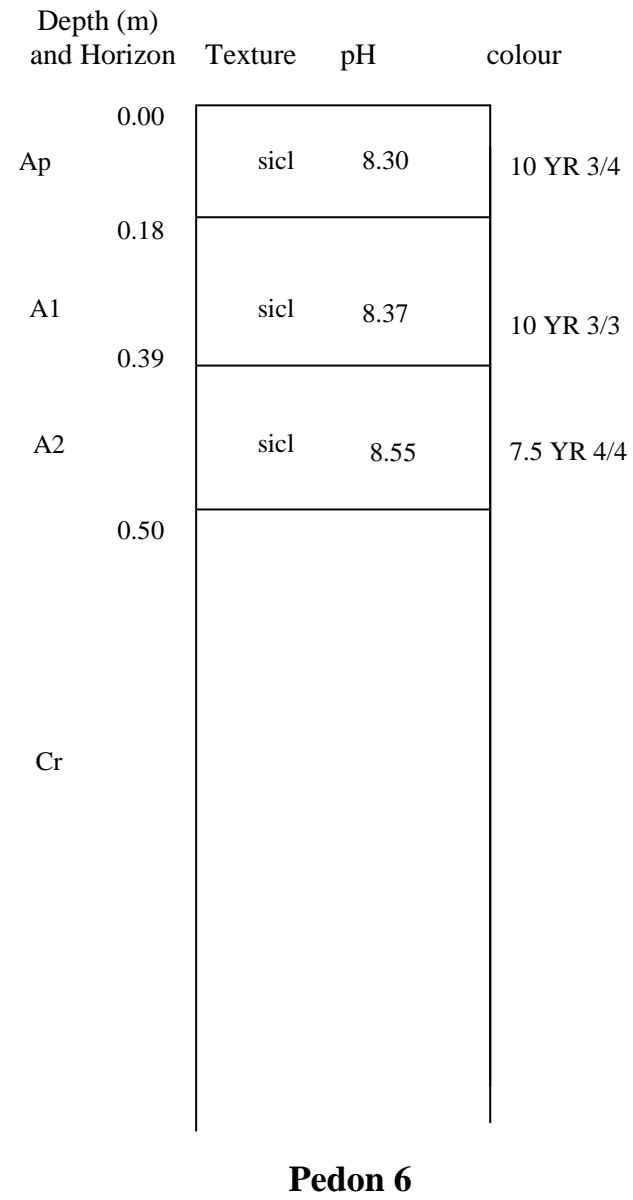
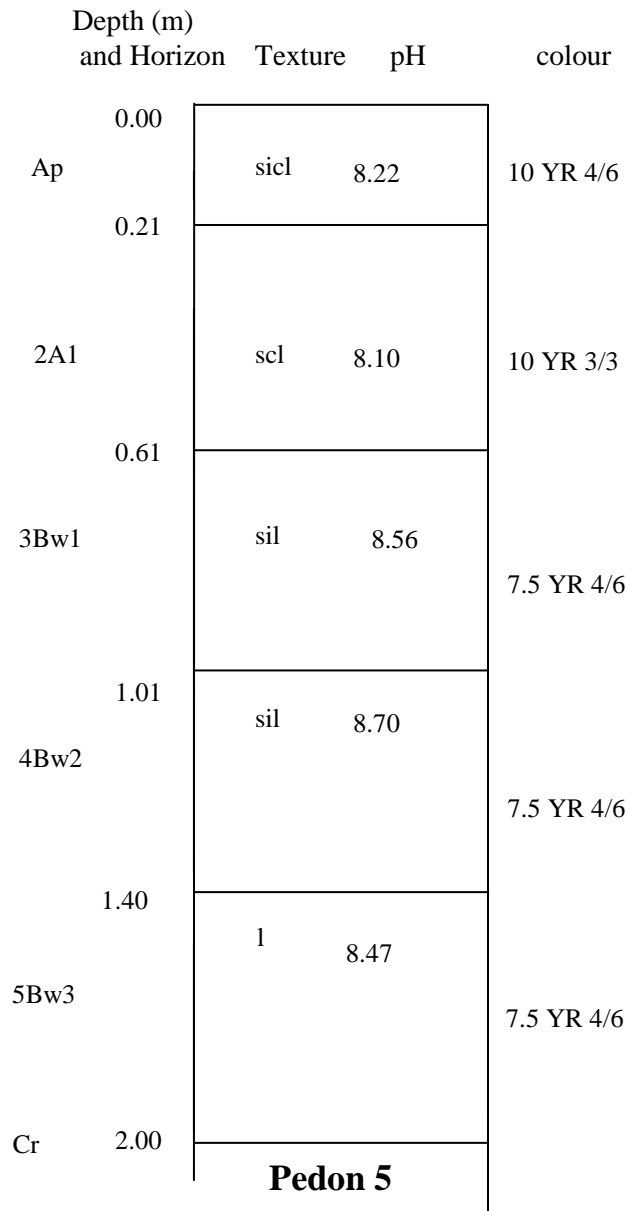


Fig. 4.5: PROFILE DIAGRAMS

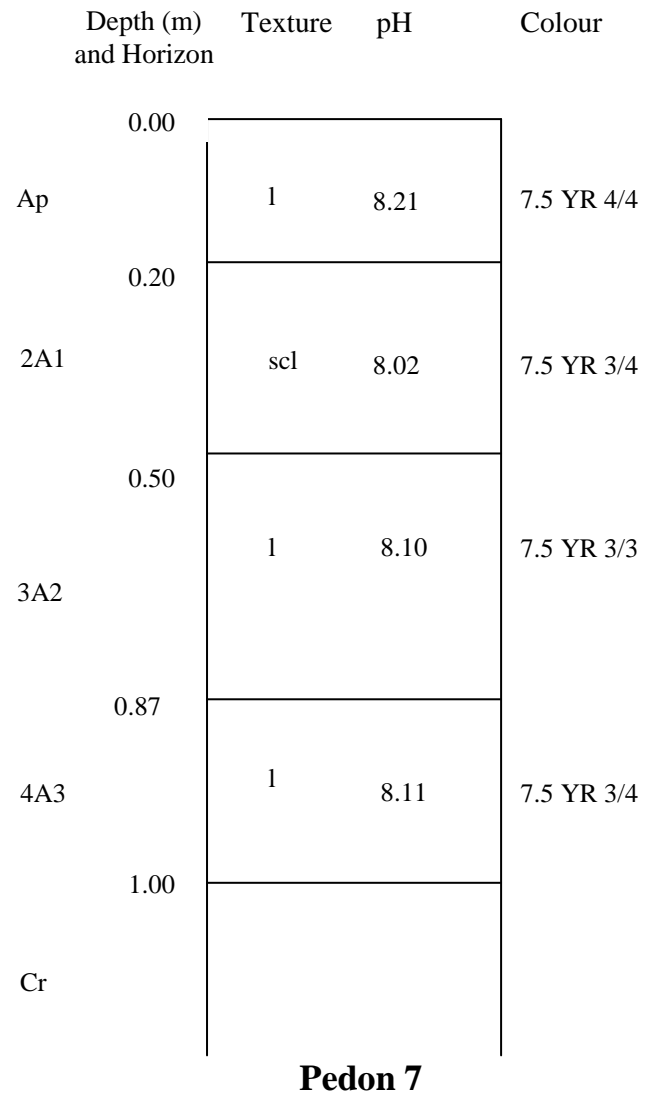


Fig. 4.6: PROFILE DIAGRAM



Fig. 4.5. Pedon 5

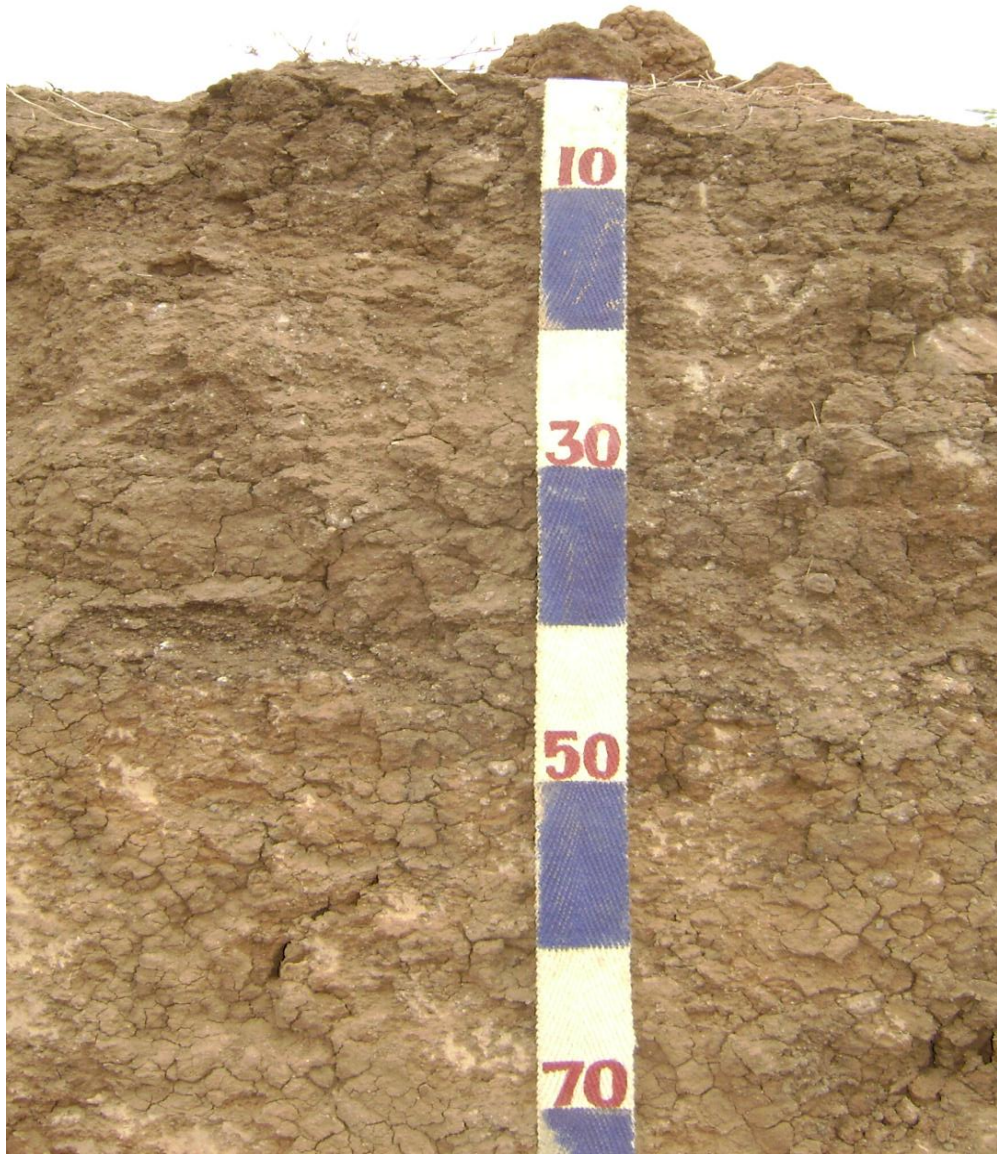


Fig. 4.6. Pedon 6



Fig. 4.7. Pedon 7

to hard, firm to very firm and sticky and plastic consistence in dry, moist and wet conditions, respectively. This pedon exhibited violent effervescence with diluted HCl treatment. Fine to medium and few pores and fine and few roots were noticed. The surface horizon showed clear and smooth boundary and sub-surface horizons exhibited diffuse and wavy boundary (**Plate 4.6**).

4.5.7 Pedon 7

This pedon was deep extending beyond 1.00 m with five horizons viz., Ap, 2A1, 3A2, 4A3 and Cr. This pedon had strong brown to dark brown colour and sandy clay loam to loam in texture. Further, surface horizons exhibited fine, weak and crumb structure and sub-surface horizons showed fine to medium, weak to moderate and sub-angular blocky structure. Slightly hard, fraible to firm and sticky and plastic to slightly sticky and slightly plastic consistence in dry, moist and wet conditions, respectively. This pedon exhibited violent effervescence with diluted HCl treatment. Fine and few to many pores and fine and few roots were noticed. The surface horizon showed clear and smooth boundary and sub-surface horizons exhibited diffuse and wavy boundary (**Plate 4.7**).

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.

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

Pedon No. & Horizon	Depth (m)	Sand	Silt (%)	Clay	Textural class	<u>Sand</u> <u>Silt</u>	<u>Silt</u> <u>Clay</u>	<u>Sand</u> <u>Silt+ clay</u>
Pedon 1								
Ap	0.00-0.15	25.65	30.96	43.39	cl	0.83	0.71	0.34
2Bw1	0.15-0.41	26.79	34.58	38.63	c	0.77	0.90	0.37
3Bw2	0.41-0.64	20.20	45.40	34.40	sic	0.44	1.32	0.25
4Bw3	0.64-0.90	28.57	38.17	33.26	cl	0.75	1.15	0.40
5Bw4	0.90-1.07	28.74	40.86	25.40	cl	0.70	1.61	0.43
Bw5	1.07-1.50+	30.15	42.57	27.28	cl	0.71	1.56	0.43
Pedon 2								
Ap	0.00-0.23	50.85	21.37	27.78	scl	2.38	0.77	1.03
A1	0.23-0.52	51.54	23.34	25.12	scl	2.21	0.93	1.06
A2	0.52-0.72	51.78	30.69	17.53	scl	1.69	1.75	1.07
Cr	0.72	Weathered gneiss						
Pedon 3								
Ap	0.00-0.18	19.79	31.33	48.88	c	0.63	0.64	0.25
Bw1	0.18-0.43	23.42	25.16	51.42	c	0.93	0.49	0.31
Bw2	0.43-0.67	27.79	21.66	50.55	c	1.28	0.43	0.38
Bw3	0.67-0.91	18.86	32.71	48.43	c	0.58	0.68	0.23
Cr	0.91	Dolomite						
Pedon 4								
Ap	0.00-0.19	36.21	24.70	39.09	cl	1.47	0.63	0.57
Bw1	0.19-0.48	38.43	29.48	32.09	cl	1.30	0.92	0.62
2Bw2	0.48-0.86	32.41	47.11	20.48	l	0.69	2.30	0.48
3Bw3	0.86-1.10	49.21	26.41	24.38	scl	1.86	1.08	0.97
4Bw4	1.10-1.40	44.21	14.47	41.32	sc	3.06	0.35	0.79
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 5								
Ap	0.00-0.21	16.62	46.78	36.60	sicl	0.36	1.28	0.20
2A1	0.21-0.61	45.65	23.91	30.44	scl	1.91	0.79	0.84
3Bw1	0.61-1.01	21.69	50.59	27.72	sil	0.43	1.83	0.28
4Bw2	1.01-1.40	28.13	48.70	23.17	sil	0.58	2.10	0.39
5Bw3	1.40-2.00	46.63	32.03	21.34	l	1.46	1.50	0.87
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 6								
Ap	0.00-0.18	20.97	46.10	32.93	sicl	0.45	1.40	0.27
A1	0.18-0.39	17.91	44.37	37.72	sicl	0.40	1.18	0.22
A2	0.39-0.50	19.96	46.34	33.70	sicl	0.43	1.38	0.25
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 7								
Ap	0.00-0.20	43.64	30.24	26.12	l	1.44	1.16	0.77
2A1	0.20-0.50	52.79	24.80	22.41	scl	2.13	1.11	1.12
3A2	0.50-0.87	42.55	31.26	26.19	l	1.36	1.19	0.74
4A3	0.87-1.00	43.05	36.19	20.76	l	1.19	1.74	0.76
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins						

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

Pedon No.	Range & Mean	Sand (%)	Silt (%)	Clay (%)	Sand/Silt	Silt/Clay	$\frac{\text{Sand}}{\text{Silt} + \text{Clay}}$
1	Range	20.20-30.15	30.96-45.40	25.4-43.39	0.44-0.83	0.71-1.61	0.25-0.43
	Mean	26.68	38.76	33.73	0.70	1.21	0.37
2	Range	50.85-51.78	21.37-30.69	17.53-27.78	1.69-2.38	0.77-1.75	1.03-1.07
	Mean	51.39	25.13	23.48	2.09	1.15	1.05
3	Range	18.86-27.79	21.66-32.71	48.43-51.42	0.58-1.28	0.43-0.68	0.23-0.38
	Mean	22.47	27.72	49.82	0.85	0.56	0.29
4	Range	32.41-49.21	14.47-47.11	20.48-41.32	0.69-3.06	0.35-2.30	0.48-0.97
	Mean	40.09	28.43	31.47	1.68	1.06	0.69
5	Range	16.62-46.63	23.91-50.59	21.34-36.60	0.36-1.91	0.79-2.10	0.20-0.87
	Mean	31.74	40.40	27.85	0.95	1.50	0.52
6	Range	17.91-20.97	44.37-46.34	32.93-37.72	0.40-0.45	1.18-1.40	0.22-0.27
	Mean	19.61	45.60	34.78	0.43	1.32	0.27
7	Range	42.55-52.79	24.80-36.19	20.76-26.19	1.19-2.13	1.10-1.74	0.74-1.12
	Mean	45.51	30.62	23.87	1.53	1.29	0.85

4.6.1.1 Clay (< 2 microns) fraction

The clay content ranged from 17.53 to 51.42 per cent. The highest amount of clay was observed in Bw1 horizon of pedon 3 while the lowest amount of clay was recorded in A2 horizon of pedon 2. Pedon 1, 2 and 5 exhibited a decreasing trend with depth whereas pedon 4 showed a decreasing trend up to 2Bw2 horizon and later on an increasing trend with depth. However, no specific trend with depth was observed in pedons 3, 6 and 7. The mean clay content in all these pedons varied from 23.48 (Pedon 2) to 49.82 (Pedon 3) per cent.

The decrease in clay content with depth in pedons 1, 2 and 5 might be due to variability of weathering in different horizons. These results were in accordance with the findings of Giri Prakash (1997) who reported an irregular decrease of clay content with depth in soils of Gudiyatham taluk in Tamil Nadu.

4.6.1.2 Silt (0.002 to 0.05 mm) fraction

The silt content ranged from 14.47 to 50.59 per cent. The highest amount of silt was observed in 3Bw1 horizon of pedon 5 while the lowest amount of silt was recorded in 4Bw4 horizon of pedon 4. Pedon 2 exhibited an increasing trend with depth whereas pedon 3 showed a decreasing trend up to Bw2 horizon and later on an increasing trend with depth. However, irregular trend with depth was observed in pedons 1, 4, 5, 6 and 7. The mean silt content in all these pedons varied from 25.13 (Pedon 2) to 45.60 (Pedon 6) per cent.

Irregular distribution of silt with depth might be due to variation in weathering of parent material or *in-situ* formation. These results were in agreement with the findings of Satish Kumar and Naidu (2012), who noticed an irregular trend in silt content with depth in Vadamalapeta mandal of chittoor district, Andhra Pradesh. Similar results were also reported by Arun Kumar *et al.* (2002).

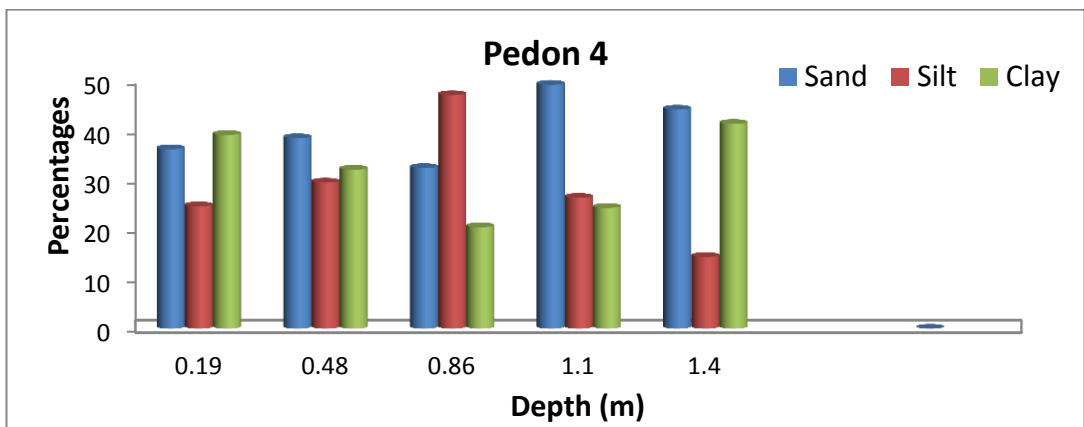
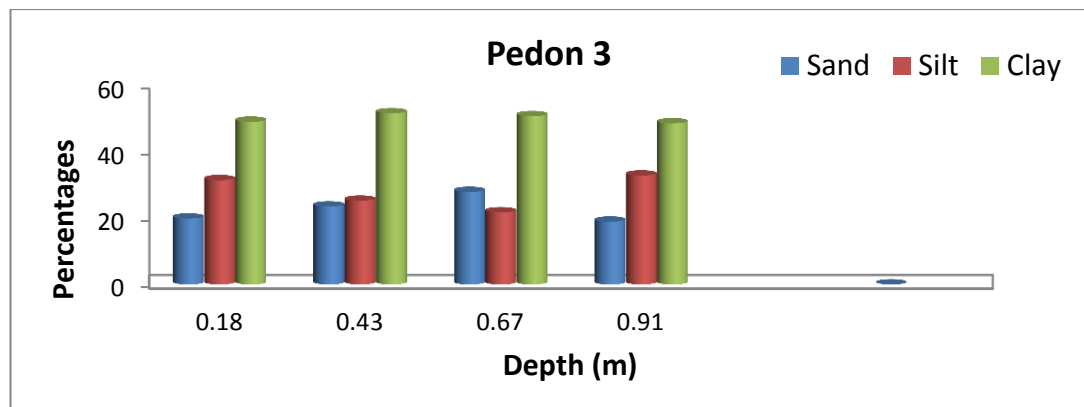
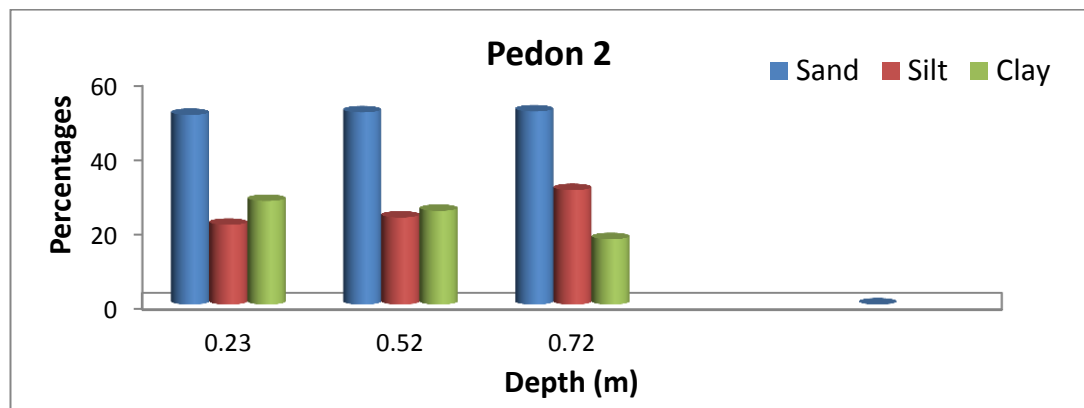
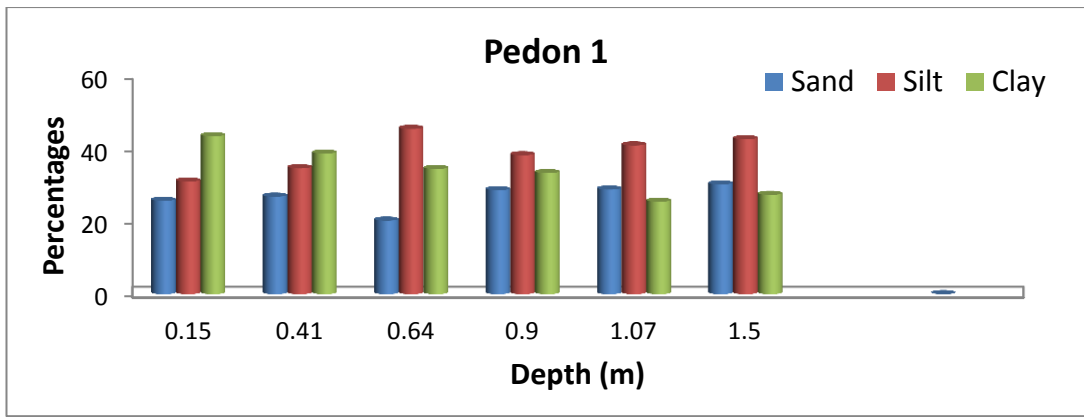


Fig.4.7. Vertical distribution of soil particles

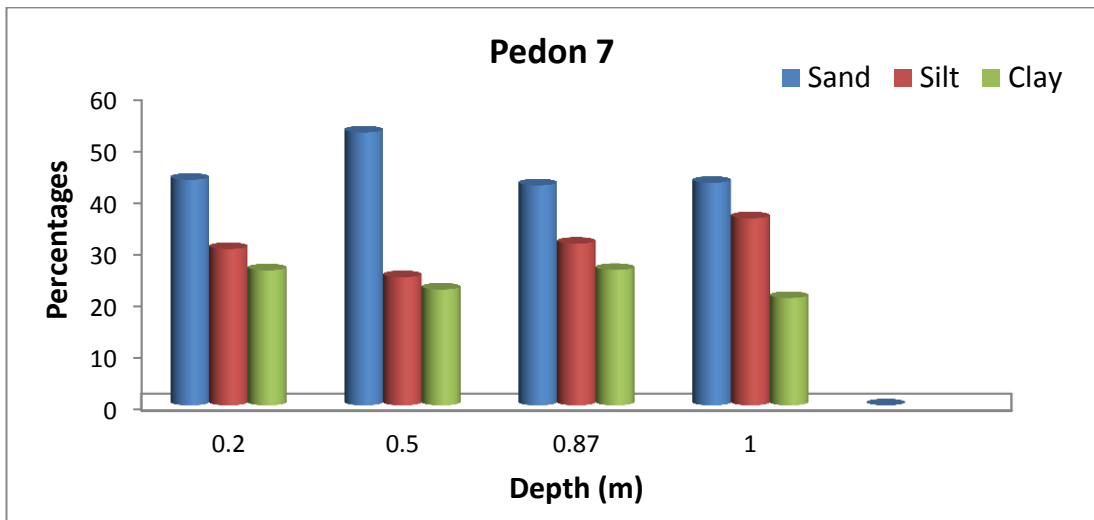
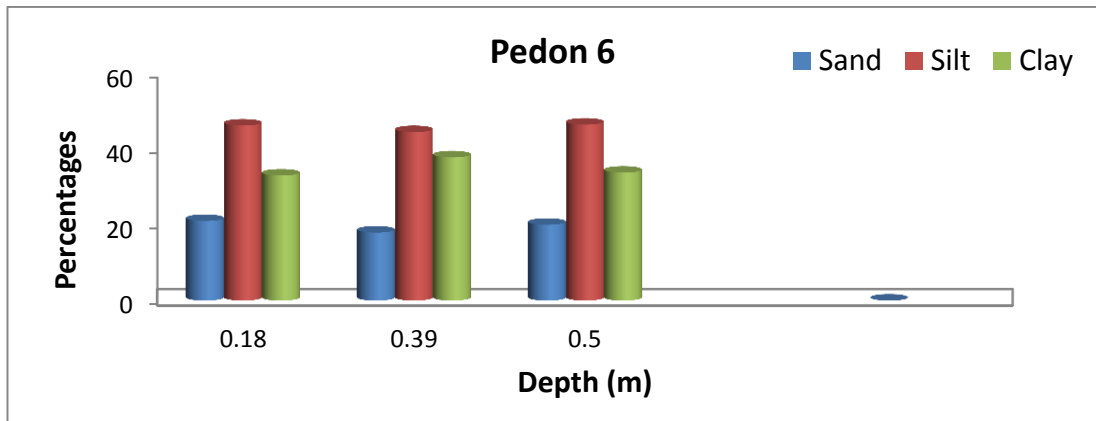
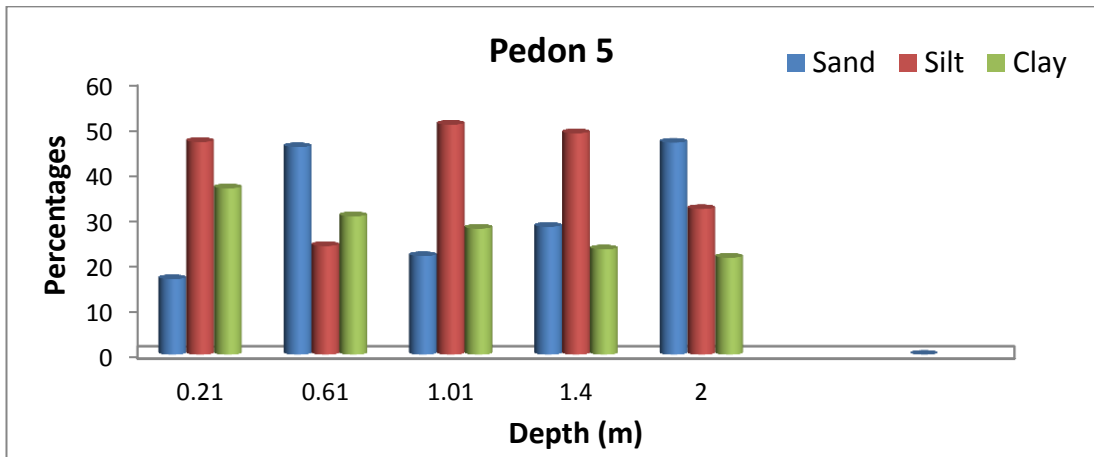


Fig.4.7. Vertical distribution of soil particles

4.6.1.3 Sand (0.05 to 2.00 mm) fraction

The sand content ranged from 16.62 to 52.79 per cent. The highest amount of sand was observed in 2A1 horizon of pedon 7 while the lowest amount of sand was recorded in Ap horizon of pedon 5. Pedon 2 exhibited an increasing trend with depth whereas pedon 3 showed an increasing trend up to Bw2 horizon and later on a decreasing trend with depth. The mean sand content in all these pedons varied from 19.61 (Pedon 6) to 51.39 (Pedon 2) per cent. However, no specific trend with depth was observed in pedons 1, 4, 5, 6 and 7. This might be due to lithological discontinuities in the profiles. These results were in accordance with the findings of Bhaskar *et al.* (2004a).

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 0.36 to 3.06. The mean values of sand / silt ratio *i.e.*, 0.43 to 2.09 were recorded in pedon 6 and pedon 2, respectively. In pedon 2, the values showed a decreasing trend with depth. Pedon 3 exhibited an increasing trend with depth up to Bw2 horizon and later on decreased with depth. The pedons 1, 4, 5, 6 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 0.35 to 2.30. The mean values of silt / clay ratio *i.e.*, 0.56 to 1.49 were registered in pedon 3 and pedon 5, respectively. Pedons 1 and 2 exhibited an increasing trend with depth. However, the pedons 3, 4, 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 0.20 to 1.12. The mean values ranged from 0.27 to 0.85 were registered in pedon 6 and pedon 7, respectively. Pedons 2 and 6 exhibited a decreasing trend with depth whereas pedon 3 showed an increasing trend with depth up to Bw2 horizon later on decreased. However, pedons 1, 4, 5 and 7 did not show any specific trend with depth.

The sand / silt ratio increased with depth in pedon 3 was due to deposition of alluvial materials. The wider sand / silt ratio in soils of Brahmaputra valley of Assam indicated lithological discontinuity due to deposition of alluvial materials in fluvial cycles (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. Raghuwanshi *et al.* (2011) higher silt / clay ratio revealed slightly higher rate of weathering due to the presence of soil water for fairly long time in sub-surface horizon as compared to the surface horizons.

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 1.15 to 1.78 Mg m⁻³. The highest value of 1.78 Mg m⁻³ was recorded in Bw1 horizon of pedon 3 whereas 3Bw1 horizon of pedon 5 exhibited the lowest value of 1.15 Mg m⁻³. The mean values ranged from 1.31 to 1.54 Mg m⁻³ and were registered in pedon 4 and pedon 2, respectively. All the pedons showed more or less an increasing trend with depth.

Variation in bulk density of these soils attributed to the moisture content and high content of expanding type of clay minerals. Similar results were obtained by Swarnam *et al.* (2004) in the Entisols and Inceptisols of

Shahibi basin in Haryana and Delhi and in the soils of Chandragiri mandal in Chittoor district Basavaraju *et al.* (2005) of Andhra Pradesh, respectively. Kadao *et al.* (2003) reported that bulk density values in banana growing soils of Wardha district of Maharashtra ranged from 1.49 to 1.79 Mg m⁻³ in Inceptisols.

Most of the pedons had shown an increasing trend with depth. This might be due to more compaction of finer particles in deeper layers caused by over-head weight of the surface soil. Similar results were reported by Jewitt *et al.* (1979). Low bulk density of surface soils could be attributed to higher organic matter content. This was evident from the significant negative correlation ($r = -0.404$) 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. Similar results were reported by Walia and Rao (1996) in Bundelkhand region of Uttar Pradesh.

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 pore space. Similar results were reported by Ram *et al.* (2010).

4.6.2.2 Particle density

Particle density values of different layers in these seven pedons varied from 2.06 to 2.70 Mg m⁻³. The highest value of 2.70 Mg m⁻³ was recorded in Bw5 horizon of pedon 1 whereas 3Bw1 horizon of pedon 5 exhibited the lowest value. The mean values ranged from 2.22 to 2.48 Mg m⁻³ were registered in pedon 4 and pedon 6, respectively. Pedon 7 exhibited a decreasing trend with depth whereas pedon 1 exhibited a decreasing trend with depth up to 4Bw3 horizon later on it was increased with depth. Pedons 2, 4, 5 and 6 did not show any specific 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	0.00-0.15	1.40	2.52	38.12	54.43	07.92	0.88	5.88
2Bw1	0.15-0.41	1.21	2.50	47.03	60.83	11.13	1.22	7.18
3Bw2	0.41-0.64	1.59	2.36	59.77	46.81	15.15	1.73	8.55
4Bw3	0.64-0.90	1.57	2.14	48.37	48.66	10.94	1.45	9.14
5Bw4	0.90-1.07	1.36	2.60	70.35	59.60	10.65	2.77	9.39
Bw5	1.07-1.50+	1.59	2.70	49.20	40.36	14.32	1.80	3.85
Pedon 2								
Ap	0.00-0.23	1.52	2.68	37.37	42.07	5.59	1.35	4.60
A1	0.23-0.52	1.62	2.23	36.89	38.72	5.23	1.47	3.14
A2	0.52-0.72	1.47	2.30	34.34	44.76	4.99	1.96	7.23
Cr	0.72	Weathered gneiss						
Pedon 3								
Ap	0.00-0.18	1.69	2.32	53.65	47.16	11.42	1.10	9.14
Bw1	0.18-0.43	1.78	2.36	56.86	34.80	12.82	1.10	6.81
Bw2	0.43-0.67	1.70	2.50	55.39	36.02	10.87	1.09	6.19
Bw3	0.67-0.91	1.26	2.35	58.86	49.07	13.87	1.22	8.37
Cr	0.91	Dolomite						
Pedon 4								
Ap	0.00-0.19	1.21	2.36	46.66	33.09	8.71	1.19	3.69
Bw1	0.19-0.48	1.26	2.07	46.68	32.24	9.62	1.45	6.33
2Bw2	0.48-0.86	1.19	2.14	45.11	33.16	9.10	2.20	5.54
3Bw3	0.86-1.10	1.44	2.17	41.57	32.05	6.07	1.70	8.42
4Bw4	1.10-1.40	1.44	2.38	40.98	31.95	6.48	0.99	4.04
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 5								
Ap	0.00-0.21	1.32	2.50	36.43	33.08	4.97	0.99	5.89
2A1	0.21-0.61	1.61	2.20	40.60	27.10	7.91	1.33	8.26
3Bw1	0.61-1.01	1.15	2.06	38.48	37.46	6.97	1.38	5.32
4Bw2	1.01-1.40	1.51	2.60	30.25	27.94	5.18	1.30	5.18
5Bw3	1.40-2.00	1.38	2.18	32.28	31.60	6.35	1.51	4.02
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 6								
Ap	0.00-0.18	1.29	2.57	49.13	33.54	10.24	1.49	7.97
A1	0.18-0.39	1.28	2.45	35.92	34.03	5.75	0.95	4.32
A2	0.39-0.50	1.59	2.43	48.22	29.28	8.83	1.43	5.91
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 7								
Ap	0.00-0.20	1.43	2.53	27.43	19.72	4.56	1.05	3.69
2A1	0.20-0.50	1.25	2.50	33.16	39.46	5.48	1.48	3.58
3A2	0.50-0.87	1.52	2.36	36.98	17.05	5.98	1.41	4.22
4A3	0.87-1.00	1.35	2.34	37.48	32.36	4.51	1.80	5.23
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins						

Table 4.8. Range and means 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	1.21-1.59	2.14-2.70	38.12-70.35	40.36-60.83	7.92-15.15	0.88-2.77	3.85-9.39
	Mean	1.46	2.47	52.14	51.78	11.69	1.64	7.33
2	Range	1.47-1.62	2.23-2.68	34.34-37.37	38.72-44.76	4.99-5.59	1.35-1.96	3.14-7.23
	Mean	1.54	2.40	36.20	41.85	5.27	1.59	4.99
3	Range	1.26-1.78	2.32-2.50	53.65-58.86	34.80-49.07	10.87-13.87	1.10-1.21	6.19-9.14
	Mean	1.61	2.38	56.19	41.76	12.24	1.13	7.63
4	Range	1.19-1.44	2.07-2.38	40.98-46.68	31.95-33.16	6.07-9.62	0.99-2.20	3.69-8.42
	Mean	1.31	2.22	44.20	32.50	8.00	1.51	5.60
5	Range	1.15-1.61	2.06-2.60	30.25-40.60	27.10-37.46	4.97-7.91	0.99-1.51	4.02-8.26
	Mean	1.40	2.30	35.61	31.44	6.28	1.30	5.73
6	Range	1.28-1.59	2.43-2.57	35.92-49.13	29.28-34.03	5.75-10.24	0.95-1.49	4.32-7.97
	Mean	1.38	2.48	44.42	32.28	8.27	1.29	6.07
7	Range	1.25-1.52	2.34-2.53	27.43-37.48	17.05-39.46	4.51-5.98	1.05-1.80	3.58-5.23
	Mean	1.39	2.43	33.76	27.15	5.13	1.43	4.18

Further, there was no significant variation in textural components 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 17.05 to 60.83 per cent. The mean values *i.e.*, 27.15 to 51.78 were registered in pedon 7 and pedon 1 respectively. All the pedons did not show any specific trend with depth. This corroborates the study of Gurumurthy *et al.* (1996). Walia and Rao (1996) stated that decrease in pore space with depth might be due to increase in coarse fraction or coarse fragments in Inceptisols and Entisols and filling up of pores by eluvial materials in Alfisols.

4.6.2.4 Water holding capacity

The values of water holding capacity varied from 27.43 to 70.35 per cent. Pedon 1 exhibited relatively higher values ranging from 38.12 to 70.35 per cent whereas pedon 7 had shown lower values ranging from 27.43 to 37.48 per cent. Pedon 1 and 4 exhibited a decreasing trend with depth whereas pedon 7 showed an increasing trend with depth. However, pedons 1, 3, 5 and 6 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 and Thangasamy *et al.* (2005) in soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh.

In general surface soil had the higher water holding capacity than sub-surface horizons which might be due to presence of higher clay and organic matter content in the surface soil. Water holding capacity was very less in sandy soils due to high sand and less clay content as evidenced by

negative correlation ($r = -0.513$) between water holding capacity and sand content. Singa Rao and Prabhu Prasadini (1998) also observed similar type of negative correlation between water holding capacity and sand.

The water holding capacity showed irregular trend with depth in pedons 1, 3, 5 and 6. This irregular trend was due to the illuviation and eluviation of finer fractions in different horizons of the pedons.

4.6.2.5 WHC / clay

The ratio between water holding capacity (WHC) and clay ranged from 0.88 to 2.77 per cent which were registered in pedon 1. Pedon 2 exhibited an increasing trend with depth. However, remaining pedons did not show any particular trend with depth. The values of WHC / clay varied in accordance with clay content. This was supported by significant positive correlation ($r = +0.490$) between clay and WHC.

4.6.2.6 Volume expansion

The per cent volume expansion varied from 4.51 to 15.15 per cent. Pedon 1 recorded the higher mean values (11.69%) and pedon 7 showed lower mean values (5.13%). Pedon 2 exhibited a decreasing trend with depth whereas pedon 7 showed an increasing trend with depth up to 3A2 horizon and later on decreased. Further, the remaining pedons 1, 3, 4, 5 and 6 did not show any particular trend with depth.

The volume expansion had significant positive correlation ($r = +0.531$) 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.

4.6.2.7 Loss on ignition

These values varied from 3.14 to 9.39 per cent. The highest value of 9.39 per cent was observed in 5Bw4 horizon of pedon 1 and the lowest value of 3.14 per cent was noticed in A2 horizon of pedon 2. An increasing trend with depth was observed in pedon 1 up to 5Bw4 horizon later on decreased. Pedon 3 showed a decreasing trend with depth up to Bw3 horizon and later on increased. Further, the remaining pedons 2, 4, 5, 6 and 7 did not show any particular trend with depth.

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 possessed negative correlation ($r = -0.403$) with LOI. Similarly, Sharma *et al.* (1996) noticed 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 7.92 to 8.70 indicating slightly alkaline to strongly alkaline in reaction. Pedon 6 exhibited an increasing trend with depth while pedon 2 showed a decreasing trend with depth. The remaining pedons did not show any particular trend with depth.

This 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 Shalima Devi and Anil Kumar (2010). An increasing trend of pH with depth might be due to release of organic acids during decomposition of organic matter and these acids might have brought down the pH in the surface soils. Similar results were obtained by Arun Kumar *et al.* (2002), Basavaraju *et al.* (2005) and Thangasamy *et al.* (2005). Higher pH in soils on gently sloping plain may be due to deposition of exchangeable bases brought by runoff water in surface horizons (Sarkar *et al.*, 2002) and also prevalence of higher temperature during most part of the year resulted in accumulation of soluble salts indicating high pH in surface soils (Ram *et al.*, 2010).

The pH values of 1:2.5 soil 1 N KCl suspension ranged from 7.23 to 8.30. The lowest value of 5.34 was observed in Bw1 horizon of pedon 4 and the highest value of 8.30 was observed in Bw5 horizon of pedon 1. Pedons 1 and 3 exhibited an increasing trend with depth whereas pedon 2 showed a decreasing trend with depth. The 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_{H_2O} values ($\Delta pH = pH_{kcl} - pH_{H_2O}$) with large negative value (more than -0.5) indicated a high negative surface density of these soils. 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 varied from 0.12 to 0.93 dS m⁻¹. The lowest value of 0.12 dS m⁻¹ was noticed in Ap horizon of pedon 7 and the highest value of 0.93 dS m⁻¹ was registered in Ap horizon of pedon 1. Pedon 2 exhibited decreasing trend with depth while pedon 1 exhibited a decreasing trend with depth up to 5Bw4

Table 4.9. Physico-chemical properties of soils

Pedon No. & Horizon	Depth (m)	Organic carbon (%)	Total nitrogen (%)	C/N ratio	CaCO ₃ (%)	pH (1:2.5)		EC (dSm ⁻¹)
						H ₂ O	1N KCl	
Pedon 1								
Ap	0.00-0.15	0.43	0.098	4.39	5.5	8.11	7.73	0.93
2Bw1	0.15-0.41	0.34	0.084	4.05	14.5	8.02	7.89	0.78
3Bw2	0.41-0.64	0.22	0.084	2.62	15.5	8.33	8.04	0.78
4Bw3	0.64-0.90	0.18	0.070	2.57	18.5	8.54	8.19	0.77
5Bw4	0.90-1.07	0.16	0.070	2.29	2.5	8.62	8.23	0.74
Bw5	1.07-1.50+	0.21	0.056	3.75	7.5	8.68	8.30	0.85
Pedon 2								
Ap	0.00-0.23	0.18	0.056	3.21	5.5	8.63	8.20	0.89
A1	0.23-0.52	0.13	0.053	2.45	6.5	8.42	8.05	0.20
A2	0.52-0.72	0.10	0.042	2.38	15.5	8.06	8.05	0.12
Cr	0.72	Weathered gneiss						
Pedon 3								
Ap	0.00-0.18	0.40	0.112	3.57	33.5	8.38	7.88	0.12
Bw1	0.18-0.43	0.31	0.084	3.69	21.5	8.50	7.86	0.28
Bw2	0.43-0.67	0.09	0.084	1.07	37.5	8.28	7.85	0.49
Bw3	0.67-0.91	0.35	0.070	5.00	25.5	8.08	7.62	0.59
Cr	0.91	Dolomite						
Pedon 4								
Ap	0.00-0.19	0.75	0.114	6.67	6.5	8.15	7.33	0.29
Bw1	0.19-0.48	0.66	0.084	7.86	7.5	7.95	7.23	0.66
2Bw2	0.48-0.86	0.21	0.112	1.88	7.5	7.92	7.74	0.57
3Bw3	0.86-1.10	0.12	0.072	1.67	8.5	8.48	7.80	0.35
4Bw4	1.10-1.40	0.27	0.056	4.82	8.5	8.19	7.84	0.25
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 5								
Ap	0.00-0.21	0.58	0.099	5.86	27.5	8.22	7.72	0.25
2A1	0.21-0.61	0.20	0.083	2.17	26.5	8.10	7.93	0.35
3Bw1	0.61-1.01	0.25	0.071	3.52	25.5	8.56	8.05	0.28
4Bw2	1.01-1.40	0.04	0.071	0.56	22.5	8.70	8.06	0.22
5Bw3	1.40-2.00	0.07	0.055	1.27	28.5	8.47	7.90	0.24
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 6								
Ap	0.00-0.18	0.44	0.058	7.59	19.5	8.30	8.08	0.27
A1	0.18-0.39	0.32	0.042	7.62	17.5	8.37	8.27	0.24
A2	0.39-0.50	0.04	0.028	1.43	10.5	8.55	8.29	0.48
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins						
Pedon 7								
Ap	0.00-0.20	0.29	0.097	2.99	17.5	8.21	7.98	0.12
2A1	0.20-0.50	0.14	0.073	1.92	16.5	8.02	7.91	0.13
3A2	0.50-0.87	0.16	0.054	2.96	16.5	8.10	8.00	0.14
4A3	0.87-1.00	0.13	0.045	2.89	14.5	8.11	8.05	0.14
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins						

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 ₂ O	1 N KCl	
1	Range	0.16-0.43	0.056-0.098	2.29-4.39	2.50-15.50	8.02-8.68	7.73-8.30	0.74-0.93
	Mean	0.26	0.077	3.28	10.67	8.38	8.06	0.81
2	Range	0.10-0.18	0.042-0.056	2.38-3.21	5.50-15.50	8.06-8.63	8.05-8.20	0.12-0.89
	Mean	0.14	0.050	2.68	9.17	8.37	8.10	0.40
3	Range	0.09-0.40	0.070-0.112	1.07-5.00	21.50-37.50	8.08-8.50	7.62-7.88	0.12-0.59
	Mean	0.29	0.088	3.33	29.50	8.31	7.80	0.37
4	Range	0.12-0.76	0.072-0.114	1.67-7.80	6.50-8.50	7.92-8.48	7.23-7.84	0.25-0.66
	Mean	0.40	0.087	4.58	7.70	8.14	7.59	0.42
5	Range	0.04-0.58	0.055-0.099	0.56-5.86	22.50-28.50	8.10-8.70	7.72-8.06	0.22-0.35
	Mean	0.22	0.076	2.68	26.10	8.41	7.93	0.27
6	Range	0.04-0.44	0.028-0.058	1.43-7.62	10.5-19.5	8.30-8.55	8.08-8.29	0.24-0.48
	Mean	0.27	0.042	5.55	15.83	8.41	8.21	0.33
7	Range	0.13-0.29	0.045-0.097	1.92-2.99	14.5-17.5	8.02-8.21	7.91-8.05	0.12-0.14
	Mean	0.18	0.07	2.69	16.25	8.11	7.99	0.13

horizon later on increased. Pedon 7 showed an increasing trend with depth. However, pedons 3, 4 and 6 did not show any particular trend with depth.

Electrical conductivity values in pedon 7 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 0.04 to 0.75 per cent indicating **low to medium** in organic carbon status. The highest value was registered in Ap horizon of pedon 4 and the lowest value was noticed in A2 horizon of pedon 6. Pedons 2 and 6 showed a decreasing trend with depth while pedons 1, 3 and 4 exhibited a decreasing trend with depth up to 5Bw4, Bw2 and 3Bw3 horizons, respectively. The remaining pedons showed an irregular 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.

Relatively high organic carbon in the surface horizons as compared to sub-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 sub-surface 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 0.56 to 7.86. The lowest ratio of 0.56 was observed in 4Bw2 horizon of pedon 5 and the highest ratio of 7.86 was noticed in Bw1 horizon of pedon 4. Pedon 3 exhibited an increasing trend with depth whereas pedon 2 showed a decreasing 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 Ram Prakash and Seshagiri Rao (2002) in red soils of Krishna district, Andhra Pradesh.

4.7.5 Calcium carbonate

The calcium carbonate content ranged from 2.50 to 37.50 per cent. Higher mean value of 29.50 per cent was registered in pedon 3 while lower mean value of 7.70 per cent was observed in pedon 4. Pedons 2 and 4 exhibited an increasing trend with depth whereas pedons 6 and 7 showed a decreasing trend with depth. The remaining pedons did not show any particular trend with depth.

The free CaCO₃ was observed in all the soils. It could be due to ustic soil moisture regime of the area, which was quite congenial for carbonate formation. The highest CaCO₃ content was noticed in the lower horizons of pedons 3 and 5. This might be due to high clay content which led to impeded leaching, consequently accumulation of CaCO₃ in the lower horizon. Similar results were reported by Ram Prakash and Seshagiri Rao (2002) in soils of Krishna district, Andhra Pradesh.

The CaCO₃ content of the pedons 4, 6 and 7 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 CaCO₃ content in pedons 1 and 3 showed an irregular distribution with depth. This may either be 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 Agrawal (2005) who reported an irregular distribution of CaCO₃ with depth was attributed to differential dissolution by CO₂ rich water which was moderated by physiography, rising and receding water table and drainage conditions.

4.8 ELECTRO-CHEMICAL PROPERTIES

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 21.84 to 51.24 cmol (p⁺) kg⁻¹ soil. The highest value of 51.24 cmol (p⁺) kg⁻¹ soil was noticed in the Ap horizons of pedon 1 and the lowest value of 21.84 cmol (p⁺) kg⁻¹ soil was observed in A2 horizon of pedon 2. Further, the data on mean values revealed that mean CEC values were ranged from 27.52 to 46.61 cmol (p⁺) kg⁻¹ soil. Pedons 1 and 2 exhibited a decreasing trend with depth whereas pedons 4, 5 and 7 showed a decreasing trend with depth up to 3Bw3, 4Bw2 and 3A2 horizons, respectively. The remaining pedons did not show any particular trend with depth.

The high CEC values were due to illuvial accumulation of clay. These results were in accordance with the results of Sitanggang *et al.* (2006). Further the CEC values showed more or less a decreasing trend with depth in pedons 1 and 2, where the CEC corresponds to clay content,

Table 4.11. Electro-chemical properties of the soil

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	0.00-0.15	51.24	39.70	8.73	1.75	0.41	98.72	4.54	1.18
2Bw1	0.15-0.41	44.45	33.50	8.22	0.71	0.37	96.29	4.07	1.15
3Bw2	0.41-0.64	43.15	30.75	9.63	1.23	0.31	97.15	3.19	1.25
4Bw3	0.64-0.90	42.11	28.50	10.95	1.87	0.18	98.54	2.60	1.27
5Bw4	0.90-1.07	40.97	24.00	14.70	1.70	0.16	98.99	1.63	1.61
Bw5	1.07-1.50+	40.80	24.60	9.42	1.88	0.19	88.46	2.60	1.50
Pedon 2									
Ap	0.00-0.23	42.54	35.00	7.20	0.13	0.14	99.84	4.86	1.53
A1	0.23-0.52	33.58	21.70	2.73	0.04	0.43	74.15	7.94	1.34
A2	0.52-0.72	21.84	15.40	4.26	0.08	0.44	92.40	3.61	1.25
Cr	0.72	Weathered gneiss							
Pedon 3									
Ap	0.00-0.18	42.28	32.75	6.45	0.62	0.44	95.22	5.07	0.86
Bw1	0.18-0.43	42.33	30.75	6.75	0.66	0.39	91.07	4.56	0.82
Bw2	0.43-0.67	41.89	36.75	3.75	0.98	0.33	99.80	9.80	0.83
Bw3	0.67-0.91	42.65	37.75	3.45	1.15	0.26	99.90	10.94	0.88
Cr	0.91	Dolomite							
Pedon 4									
Ap	0.00-0.19	42.55	35.00	5.55	0.01	0.57	96.66	6.31	1.09
Bw1	0.19-0.48	41.68	32.50	3.00	0.12	0.25	86.06	10.83	1.30
2Bw2	0.48-0.86	38.36	24.50	4.38	0.18	0.12	76.06	5.60	1.87
3Bw3	0.86-1.10	40.37	22.80	2.10	0.11	0.23	62.52	10.86	1.66
4Bw4	1.10-1.40	50.10	28.70	2.16	0.09	0.24	62.26	13.29	1.21
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 5									
Ap	0.00-0.21	50.97	30.10	2.46	0.08	0.85	65.70	12.20	1.39
2A1	0.21-0.61	44.72	28.60	7.80	1.34	0.42	85.33	3.67	1.47
3Bw1	0.61-1.01	37.03	22.90	9.38	2.91	0.28	95.78	2.44	1.34
4Bw2	1.01-1.40	28.31	21.20	2.46	2.94	0.42	95.44	8.62	1.22
5Bw3	1.40-2.00	38.63	26.80	3.42	2.43	0.39	85.53	7.84	1.81
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 6									
Ap	0.00-0.18	41.78	27.60	4.44	1.84	0.88	83.19	6.21	1.27
A1	0.18-0.39	51.18	21.50	2.82	1.42	0.13	50.55	7.62	1.36
A2	0.39-0.50	46.89	20.80	3.00	1.29	0.05	53.61	6.93	1.39
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 7									
Ap	0.00-0.20	30.15	26.5	2.76	0.16	0.36	98.77	9.60	1.15
2A1	0.20-0.50	28.58	23.4	2.40	1.00	0.30	94.82	9.75	1.28
3A2	0.50-0.87	25.10	21.8	2.16	0.18	0.29	97.33	10.09	0.96
4A3	0.87-1.00	26.24	20.4	2.70	0.62	0.27	91.41	7.56	1.26
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins							

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	CEC/clay
			Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺			
1	Range	40.80-51.24	24.00-39.70	8.22-14.70	0.71-1.88	0.16-0.41	88.46-98.99	1.63-4.54	1.15-1.61
	Mean	43.78	30.17	10.27	1.52	0.27	96.36	3.10	1.33
2	Range	21.84-42.54	15.40-35.00	2.73-7.20	0.04-0.13	0.14-0.44	74.15-99.84	3.61-7.94	1.25-1.53
	Mean	32.65	24.03	4.73	0.08	0.34	88.79	5.47	1.37
3	Range	41.89-42.65	30.75-37.75	3.45-6.75	0.62-1.15	0.26-0.44	91.07-99.89	4.56-10.94	0.82-0.88
	Mean	42.29	34.5	5.10	0.85	0.36	96.50	7.59	0.85
4	Range	38.36-50.10	22.80-35.00	2.10-5.55	0.01-0.18	0.12-0.57	62.25-96.87	5.60-13.29	1.09-1.87
	Mean	42.61	28.70	3.44	0.10	0.28	76.71	9.38	1.43
5	Range	28.31-50.97	21.20-30.10	2.46-9.38	0.08-2.94	0.28-0.85	65.70-95.78	2.44-12.20	1.22-1.81
	Mean	39.88	25.92	5.10	1.94	0.47	84.66	6.95	1.45
6	Range	41.78-51.18	20.80-27.60	2.82-4.44	1.29-1.84	0.05-0.88	50.55-83.19	6.21-7.62	1.27-1.39
	Mean	46.61	23.30	3.42	1.52	0.35	62.45	6.92	1.34
7	Range	25.10-30.15	20.40-26.50	2.16-2.76	0.16-1.00	0.27-0.36	91.40-98.74	7.56-10.09	0.96-1.28
	Mean	27.52	23.02	2.50	0.49	0.30	95.58	9.25	1.16

organic carbon content and type of clay mineral present in these soils. A significant positive correlation ($r = +0.631$) observed between clay and CEC in the present study suggested that clay was the main contributor CEC in soils. Similar results were also reported by Thangasamy *et al.* (2005). These findings were further supported by the findings of Arun 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.

4.8.2 Base saturation

The per cent base saturation on the exchange complex was in between 50.55 and 99.90. The highest value of 99.90 was observed in Bw3 horizon of pedon 3 and the lowest value of 50.55 was noticed in A1 horizon of pedon 6. Pedon 4 exhibited a decreasing trend with depth and 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. Similar results were reported by Basavaraju *et al.* (2005).

The higher base saturation observed in the pedons might also be due to higher amount of Ca^{2+} occupying 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. Similar results were reported by Shalima Devi and Anil Kumar (2010). 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).

4.8.3 Exchangeable bases

The exchangeable bases in all the pedons were in the order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ 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 15.40 to 39.70 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil. The lowest value of 15.40 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil was noticed in A2 horizon of pedon 2 while the highest value of 39.70 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil was observed in Ap horizon of pedon 1. The per cent saturation of calcium varied from 42.01 to 88.51 on the exchange complex (Table 4.13). Further, the exchangeable calcium had shown a decreasing trend with depth in pedons 1, 2, 6 and 7 while an irregular increase with depth was noticed in remaining pedons.

4.8.3.2 Magnesium

Next to calcium, magnesium was the dominant cation on the exchange complex. Magnesium contributed 4.31 to 35.88 per cent on the exchange complex. Magnesium content was ranged from 2.10 to 14.70 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil. The lowest value of 2.10 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil was recorded in 3Bw3 horizon of pedon 4 and the highest value of 14.70 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil was recorded in 5Bw4 horizon of pedon 1. Pedon 5 exhibited an increasing trend with depth up to 3Bw1 horizon later on decreased. However, the 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 0.01 to 2.94 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil. The highest value of 2.94 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil was noticed in Bw2 horizon of pedon 5 while the lowest value of

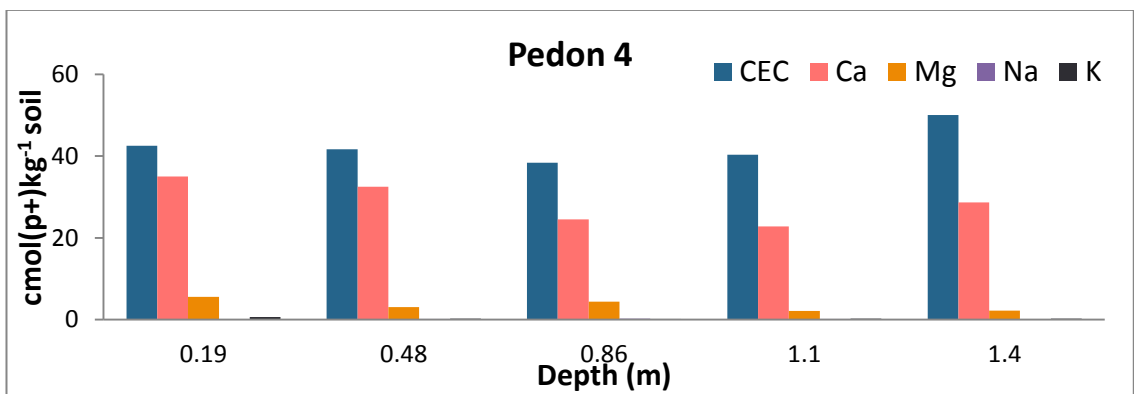
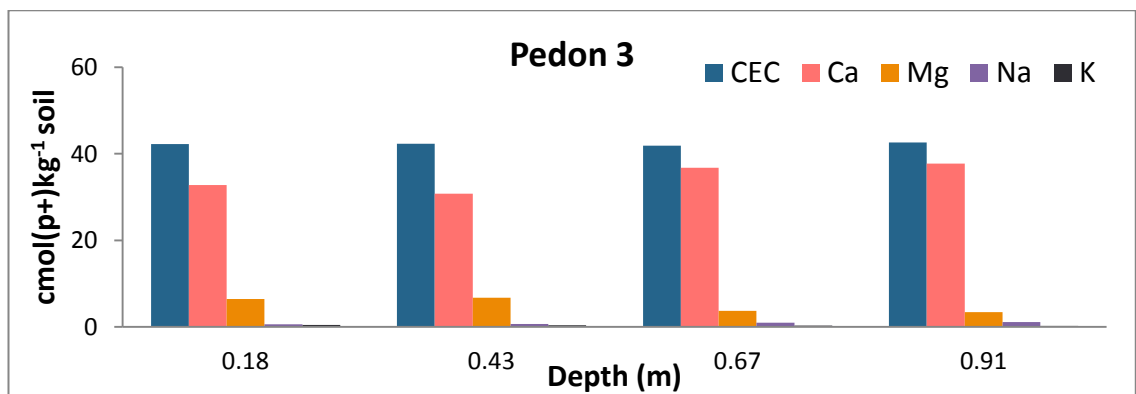
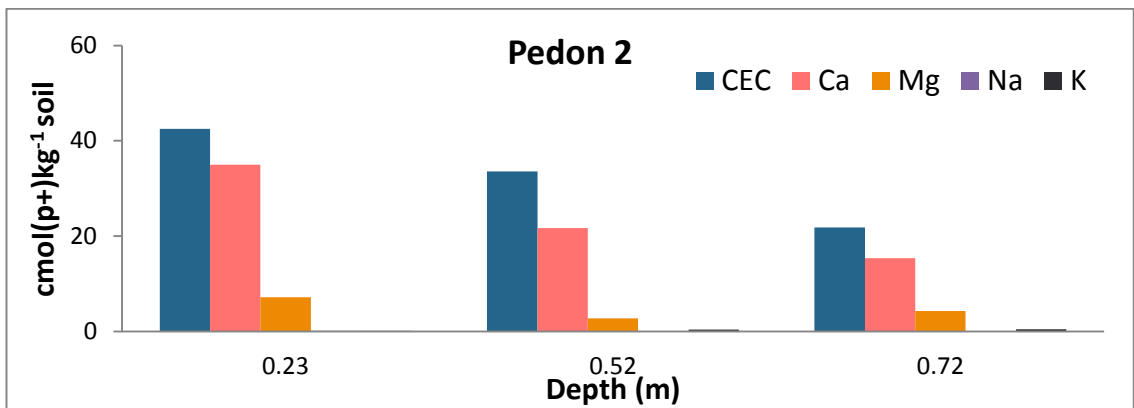
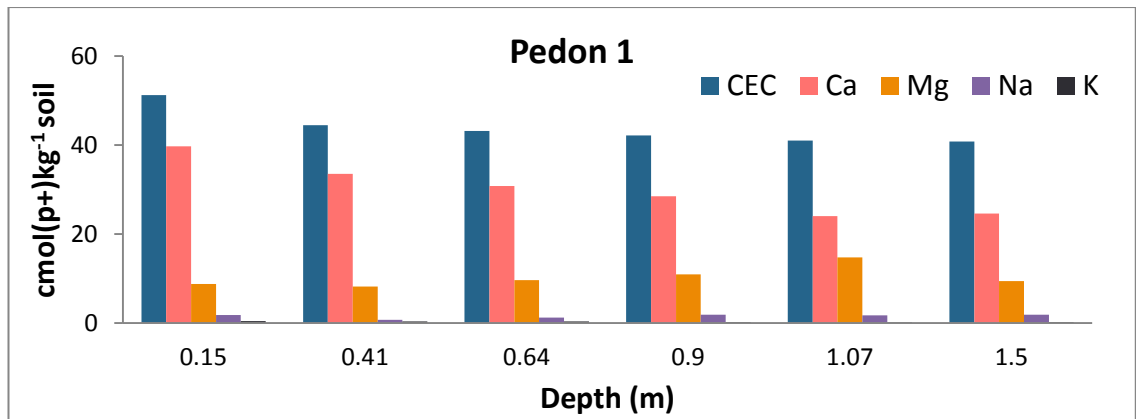


Fig.4.9. Depth functions of electro-chemical properties

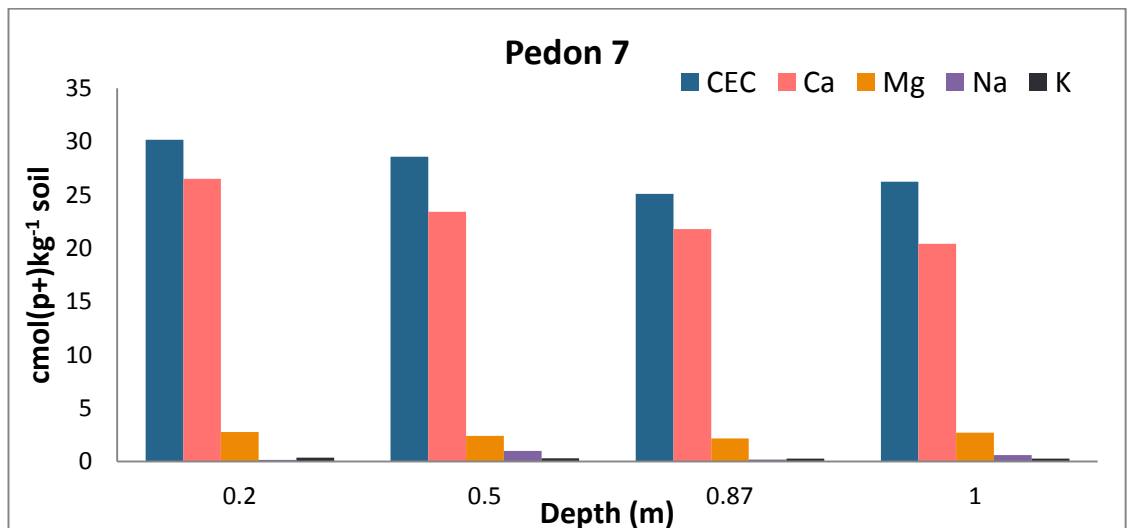
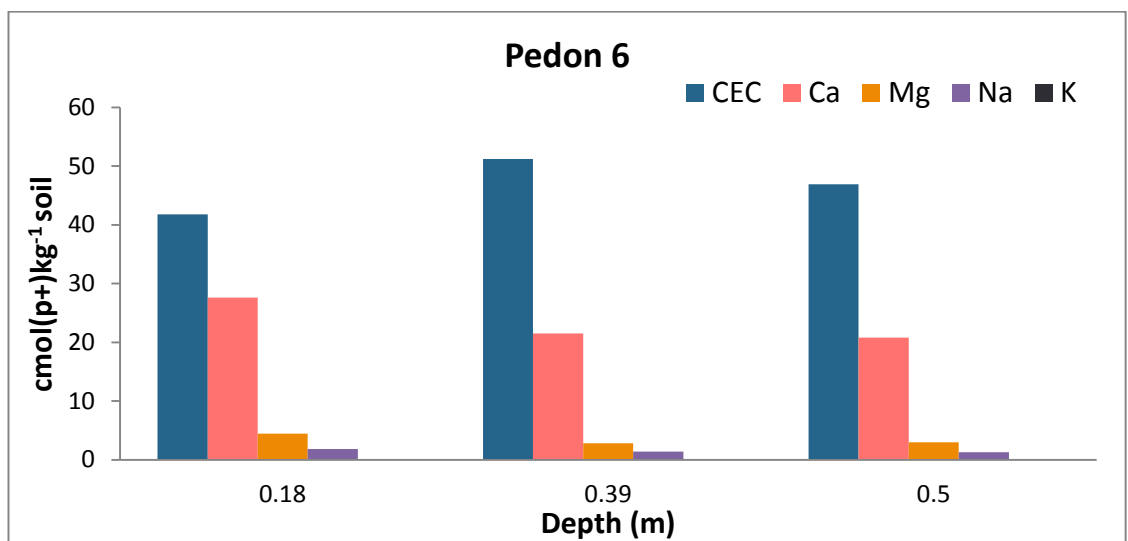
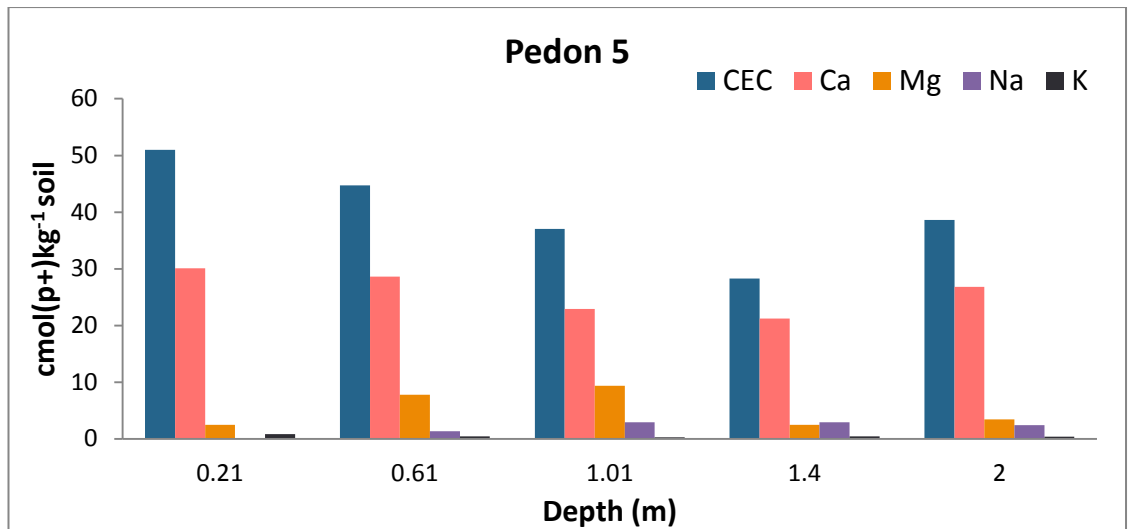


Fig.4.9. Depth functions of electro-chemical properties

0.01 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil was recorded in Ap horizon of pedon 4. Pedon 3 exhibited an increasing trend with depth. The remaining pedons did not show any particular trend with depth. The sodium was adsorbed to an extent of 10.38 per cent on the exchange complex in pedon 5.

4.8.3.4 Potassium

The exchangeable potassium content of different horizons in pedons ranged from 0.05 to 0.88 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil. The highest value of 0.88 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil was noticed in Ap horizon of pedon 6 and the lowest value of 0.05 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil was noticed in A2 horizon of pedon 6. Pedon 1 showed an irregular increasing trend with depth up to 5Bw4 horizon, later on increased. Pedon 2 exhibited an increasing trend with depth while pedon 7 showed a decreasing trend with depth. However, pedons 3, 4, 5 and 6 did not show any particular trend with depth. As high as 2.10 per cent saturation of K in Ap horizon and as low as 0.11 per cent saturation of K in A2 horizon of pedon 6 was noticed.

The exchangeable bases in all the pedons were in the order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ on the exchange 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 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 tree species (Patil and Jagdish Prasad, 2004).

Table 4.13. Percent saturation of individual bases

Pedon No. & Horizon	Depth (m)	Exchangeable bases (%)			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
Pedon 1					
Ap	0.00-0.15	77.48	17.04	3.41	0.80
2Bw1	0.15-0.41	75.36	18.49	1.59	0.83
3Bw2	0.41-0.64	71.26	22.32	2.85	0.72
4Bw3	0.64-0.90	67.68	26.00	4.44	0.43
5Bw4	0.90-1.07	58.58	35.88	4.14	0.39
Bw5	1.07-1.50+	60.29	23.09	4.61	0.46
Pedon 2					
Ap	0.00-0.23	82.27	16.92	0.30	0.33
A1	0.23-0.52	64.62	8.13	0.12	1.28
A2	0.52-0.72	70.51	19.50	0.36	2.01
Cr	0.72	Weathered gneiss			
Pedon 3					
Ap	0.00-0.18	77.46	15.25	1.47	1.04
Bw1	0.18-0.43	72.64	15.95	1.56	0.92
Bw2	0.43-0.67	87.73	8.95	2.34	0.78
Bw3	0.67-0.91	88.51	8.09	2.70	0.60
Cr	0.91	Dolomite			
Pedon 4					
Ap	0.00-0.19	82.26	13.04	0.02	1.34
Bw1	0.19-0.48	77.98	7.19	0.29	0.59
2Bw2	0.48-0.86	63.87	11.42	0.47	0.31
3Bw3	0.86-1.10	56.47	5.20	0.27	0.57
4Bw4	1.10-1.40	57.28	4.31	0.18	0.48
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins			
Pedon 5					
Ap	0.00-0.21	59.05	4.82	0.15	1.66
2A1	0.21-0.61	63.95	17.44	2.99	0.93
3Bw1	0.61-1.01	61.83	25.33	7.86	0.75
4Bw2	1.01-1.40	74.88	8.68	10.38	1.48
5Bw3	1.40-2.00	69.36	8.85	6.28	1.01
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins			
Pedon 6					
Ap	0.00-0.18	66.06	10.63	4.40	2.11
A1	0.18-0.39	42.01	5.50	2.77	0.25
A2	0.39-0.50	44.36	6.39	2.75	0.11
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins			
Pedon 7					
Ap	0.00-0.20	87.89	9.15	0.53	1.19
2A1	0.20-0.50	81.88	8.39	3.49	1.05
3A2	0.50-0.87	86.85	8.60	0.71	1.15
4A3	0.87-1.00	77.74	10.28	2.36	1.03
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins			

Similar results were reported by Sharma *et al.* (1997) who reported that Ca and Mg were the dominant bases followed by Na and K in some Inceptisols of north-west India.

4.8.4 Ratio between Ca and Mg

The ratio between Ca and Mg ranged from 13.29 to 1.63 which was registered in pedon 4 and pedon 1, respectively. Pedon 1 showed a decreasing trend with depth whereas pedon 7 exhibited an increasing trend with depth. However, remaining pedons did not show any particular trend with depth.

Narrower $\text{Ca}^{2+} / \text{Mg}^{2+}$ ratio was due to 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) and Sharma *et al.* (2011).

4.8.5 Ratio between CEC and Clay

The ratio between CEC and clay ranged from 1.87 to 0.82 which was registered in pedon 4 and pedon 3, respectively. Pedons 1 and 6 showed an increasing trend with depth whereas pedon 2 exhibited a decreasing trend with depth. Remaining pedons did not exhibit any particular trend with depth.

The CEC : clay ratio was used to identify the mineralogy. If ratio was more than 0.7 indicated presence of smectite mineral. Similar results were reported by Ashokkumar and Jagdish Prasad (2010) and Suri Babu *et al.* (2001) in soils of Ahmadnagar district of Maharashtra and A.Konduru mandal in Krishna district of Andhra Pradesh, respectively.

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 81.06 to 92.40 per cent. The highest value of 92.40 per cent was noticed in 5Bw3 horizon of pedon 5 and the lowest value of 81.06 was noticed in A2 horizon of pedon 6. The pedons 2 and 3 exhibited a decreasing trend with depth. However, remaining pedons 4, 5, 6 and 7 did not show any particular trend with depth.

The variation in silica was mainly associated with the variations in chemical composition of parent material and also relative amount of sand fraction. Pedons 2 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 Leelavathi *et al.* (2010a) in soils of Chittoor district, 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). Similar increase in sand content with depth in soils located on active flood plain was noticed in Etawah district of Uttar Pradesh (Verma *et al.*, 2001). Siliceous nature of the parent material, decrease in sand content with depth has resulted in trends showed by silica in different soils (Ram Prakash and Seshagiri Rao, 2002).

4.9.2 Sesquioxides (R_2O_3)

The values of sesquioxides varied in between 4.63 and 10.17 per cent. The highest value of 10.17 per cent was observed in A2 horizon of pedon 6

Table 4.14. Chemical composition of the soils (%)

Horizon	Depth (m)	SiO ₂	R ₂ O ₃	Fe ₂ O ₃	Al ₂ O ₃	P ₂ O ₅	K ₂ O	Na ₂ O	CaO	MgO
Pedon 1										
Ap	0.00-0.15	85.11	7.83	5.89	1.94	0.19	0.98	0.20	3.99	1.44
2Bw1	0.15-0.41	84.82	8.79	7.38	1.41	0.18	0.95	0.19	3.92	1.00
3Bw2	0.41-0.64	83.79	8.91	7.64	1.27	0.17	0.90	0.60	3.85	0.96
4Bw3	0.64-0.90	82.95	9.86	8.46	1.40	0.17	0.96	0.14	3.99	1.24
5Bw4	0.90-1.07	84.10	9.89	6.84	3.05	0.16	1.10	0.30	2.80	1.10
Bw5	1.07-1.50+	85.93	6.66	5.46	1.20	0.17	1.08	0.73	3.43	1.49
Pedon 2										
Ap	0.00-0.23	84.46	9.88	7.64	2.24	0.19	0.55	0.16	3.50	0.10
A1	0.23-0.52	83.25	9.73	5.91	3.82	0.18	0.45	0.15	2.31	0.37
A2	0.52-0.72	83.04	8.31	4.93	3.38	0.19	0.33	0.18	2.80	1.45
Cr	0.72	Weathered gneiss								
Pedon 3										
Ap	0.00-0.18	87.32	7.16	6.33	0.83	0.17	0.05	0.25	4.76	0.29
Bw1	0.18-0.43	84.63	7.27	5.55	1.72	0.16	0.08	0.20	6.51	0.82
Bw2	0.43-0.67	82.39	7.17	5.71	1.46	0.20	0.09	0.23	8.40	1.06
Bw3	0.67-0.91	81.80	7.39	6.11	1.28	0.17	0.05	0.27	7.00	0.91
Cr	0.91	Dolomite								
Pedon 4										
Ap	0.00-0.19	83.16	9.43	4.41	5.02	0.27	0.47	0.25	4.48	1.10
Bw1	0.19-0.48	83.55	9.47	7.38	2.09	0.24	0.36	0.26	2.03	1.29
2Bw2	0.48-0.86	84.17	9.06	7.02	2.04	0.20	0.18	0.18	3.15	0.91
3Bw3	0.86-1.10	86.89	8.14	3.43	4.71	0.18	0.25	0.19	2.94	0.48
4Bw4	1.10-1.40	86.38	8.78	4.51	4.27	0.23	0.20	0.25	2.59	0.86
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins								
Pedon 5										
Ap	0.00-0.21	87.69	6.89	5.52	1.09	0.21	0.66	0.21	3.50	0.53
2A1	0.21-0.61	86.18	6.33	5.82	0.51	0.20	0.42	0.14	2.45	0.58
3Bw1	0.61-1.01	85.39	8.59	6.61	1.98	0.22	0.72	0.30	2.80	0.24
4Bw2	1.01-1.40	85.98	7.32	6.26	1.06	0.20	0.70	0.29	2.52	0.24
5Bw3	1.40-2.00	92.40	4.63	3.29	1.34	0.25	0.31	0.18	1.54	0.10
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins								
Pedon 6										
Ap	0.00-0.18	82.34	9.89	7.84	2.05	0.26	1.10	0.28	3.29	0.34
A1	0.18-0.39	88.52	4.92	3.80	1.12	0.21	0.98	0.25	4.20	0.87
A2	0.39-0.50	81.06	10.17	4.40	5.77	0.24	0.66	0.21	4.00	0.91
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins								
Pedon 7										
Ap	0.00-0.20	87.46	7.55	6.04	1.51	0.27	0.63	0.16	2.24	0.15
2A1	0.20-0.50	88.01	5.01	5.95	1.06	0.24	0.57	0.15	2.10	0.14
3A2	0.50-0.87	89.79	5.56	4.91	0.65	0.14	0.43	0.14	1.40	0.38
4A3	0.87-1.00	89.67	4.90	3.51	1.39	0.07	0.37	0.12	1.26	0.29
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins								

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

Pedon No.	Range & Mean	SiO₂	R₂O₃	Fe₂O₃	Al₂O₃	P₂O₅	K₂O	Na₂O	CaO	MgO
1	Range	82.95-85.93	6.66-9.89	5.46-8.46	1.20-3.05	0.16-0.19	0.90-1.10	0.14-0.73	2.80-3.99	0.96-1.49
	Mean	84.45	8.65	6.94	1.71	0.17	0.99	0.36	3.66	1.20
2	Range	83.04-84.46	8.31-9.88	4.93-7.64	2.24-3.82	0.18-0.19	0.33-0.55	0.15-0.18	2.31-3.50	0.10-1.45
	Mean	83.58	9.30	6.16	3.14	0.18	0.44	0.16	2.87	0.64
3	Range	81.80-87.32	7.16-7.39	5.55-6.33	0.83-1.72	0.16-0.20	0.05-0.09	0.20-0.27	4.76-8.40	0.29-1.06
	Mean	84.03	7.24	5.92	1.32	0.17	0.06	0.23	6.66	0.77
4	Range	83.16-86.89	8.14-9.47	3.43-7.38	2.04-5.02	0.18-0.27	0.18-0.47	0.18-0.26	2.03-4.48	0.48-1.29
	Mean	84.83	8.97	5.35	3.62	0.22	0.29	0.22	3.03	0.92
5	Range	85.39-92.40	4.63-8.59	3.29-6.61	0.51-1.98	0.20-0.25	0.31-0.72	0.14-0.30	1.54-3.50	0.10-0.58
	Mean	87.53	6.75	5.50	1.20	0.22	0.56	0.22	2.56	0.34
6	Range	81.06-88.52	4.92-10.17	3.80-7.84	1.12-5.77	0.21-0.26	0.66-1.10	0.21-0.28	3.29-4.20	0.34-0.91
	Mean	83.97	8.33	5.35	2.98	0.24	0.91	0.24	3.83	0.71
7	Range	87.46-89.79	4.90-7.55	3.51-6.04	0.65-1.51	0.07-0.27	0.37-0.63	0.12-0.16	1.26-2.24	0.14-0.38
	Mean	88.73	5.75	5.10	1.15	0.18	0.50	0.14	1.75	0.24

and the lowest value of 4.63 per cent was noticed in 5Bw3 horizon of pedon 5. Pedon 2 exhibited a decreasing trend with depth and the remaining pedons (1, 3, 4, 5, 6 and 7) 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 varied in accordance with clay. These findings were further supported by Gurusurthy *et al.*, (1996) who reported positive correlation between clay and sesquioxides. Similar results were earlier reported by Subbaiah and Manickam (1992) in soils of Andhra Pradesh. Sesquioxide content of the soils varied in accordance with clay content (Ram Prakash and Seshagiri Rao, 2002).

4.9.3 Aluminium oxide (Al_2O_3)

The aluminum oxide content was in between 0.51 and 5.77 per cent. The highest value of 5.77 was noticed in A2 horizon of pedon 6 while the lowest value of 0.51 was observed in 2A1 horizon of pedon 5. All the 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. The results were in corroboration with the findings of Ramalakshmi *et al.* (2001). Further, sandy soils had very less alumina content because they were major contributors of silica.

4.9.4 Iron oxide (Fe_2O_3)

The iron oxide content was in between 3.29 and 8.46 per cent. The highest value of 8.46 per cent was observed in 4Bw3 horizon of pedon 1 and the lowest value of 3.29 per cent was noticed in 5Bw3 horizon of pedon 5. Pedons 2 and 7 exhibited a decreasing trend with depth. The remaining pedons showed an irregular distribution of iron oxide with depth.

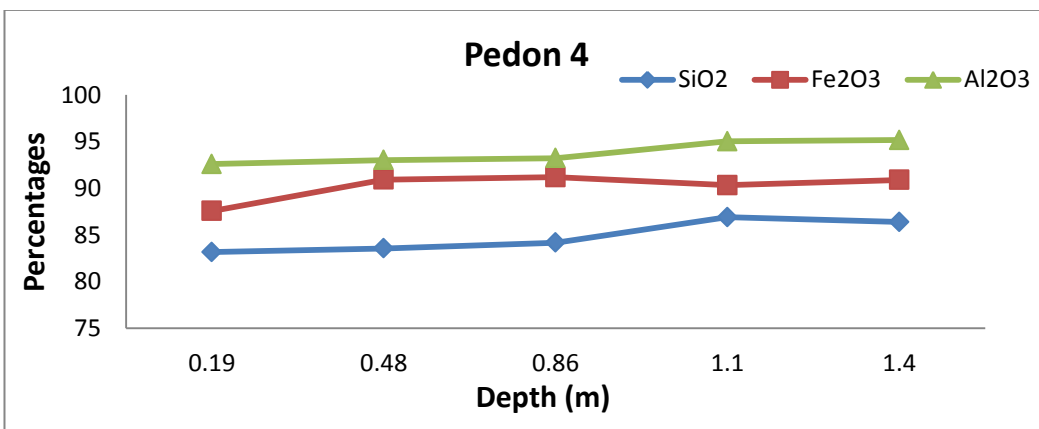
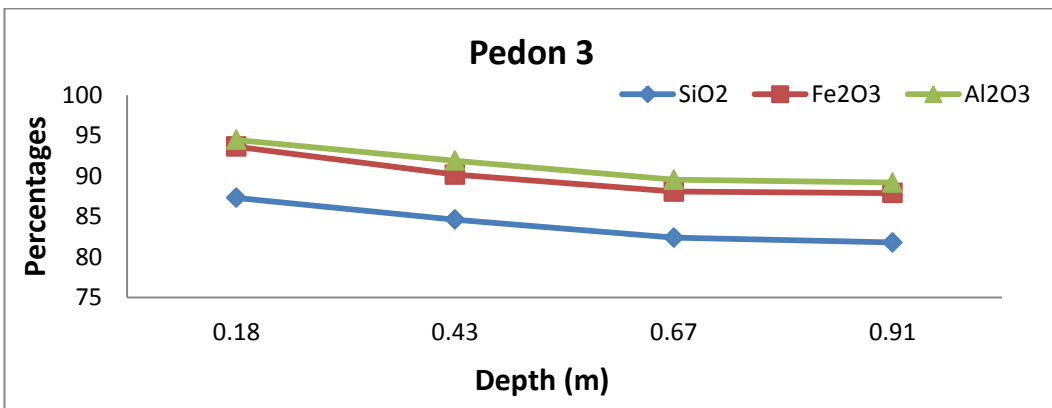
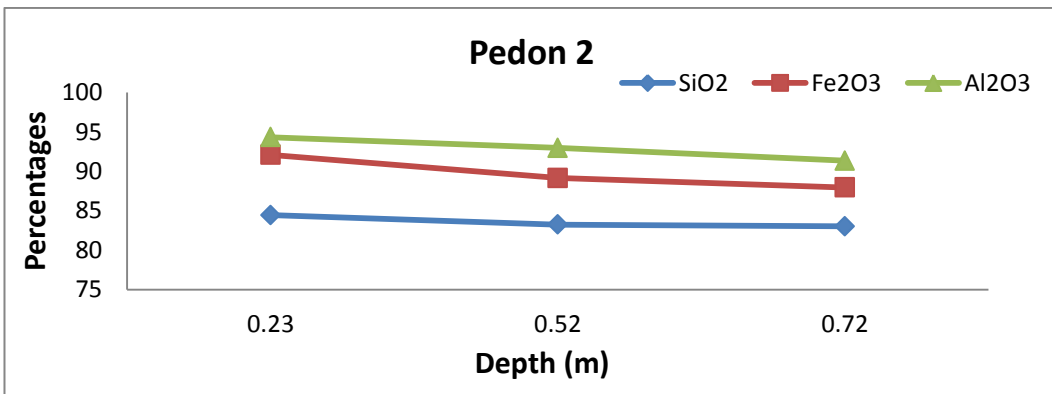
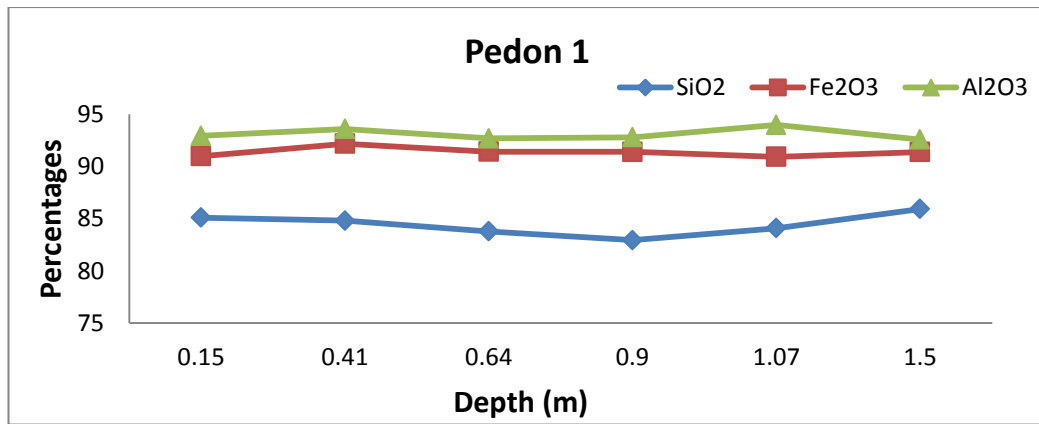


Fig.4.11. Vertical distribution of silica and sesquioxides

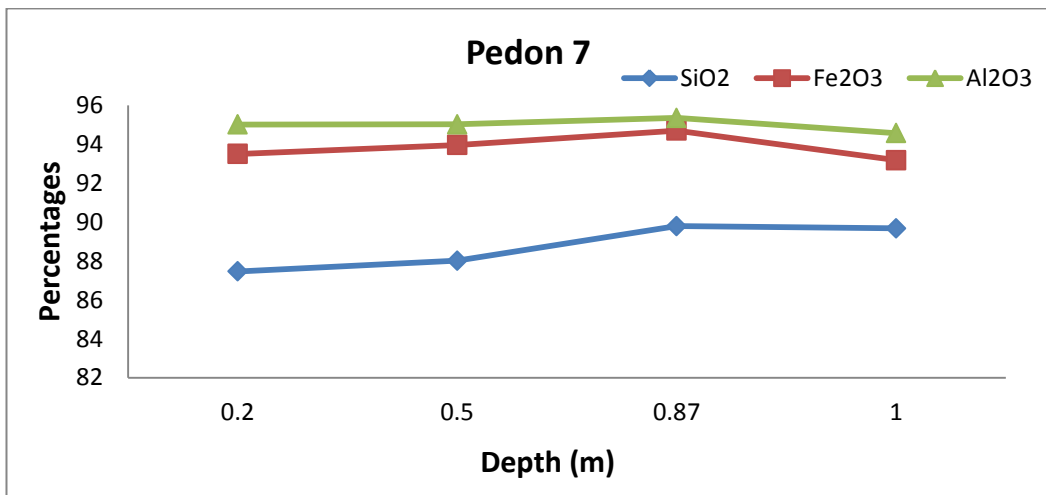
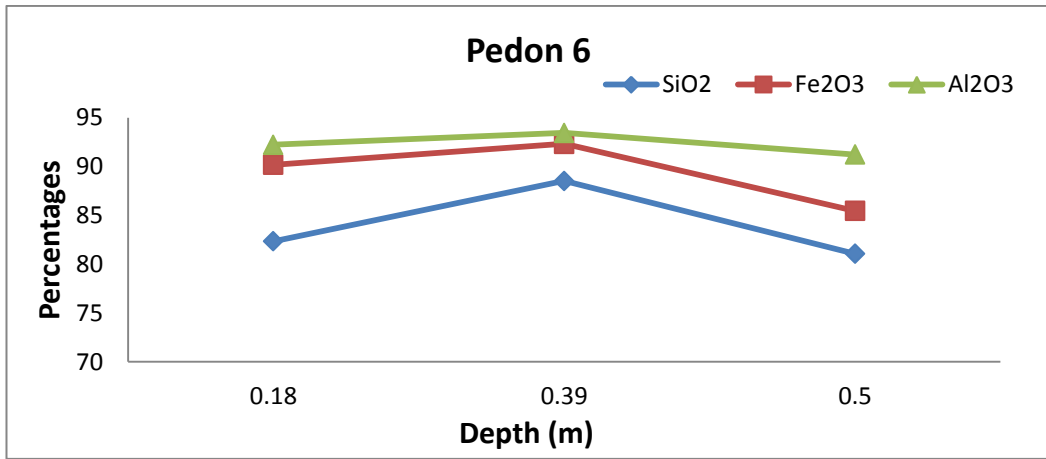
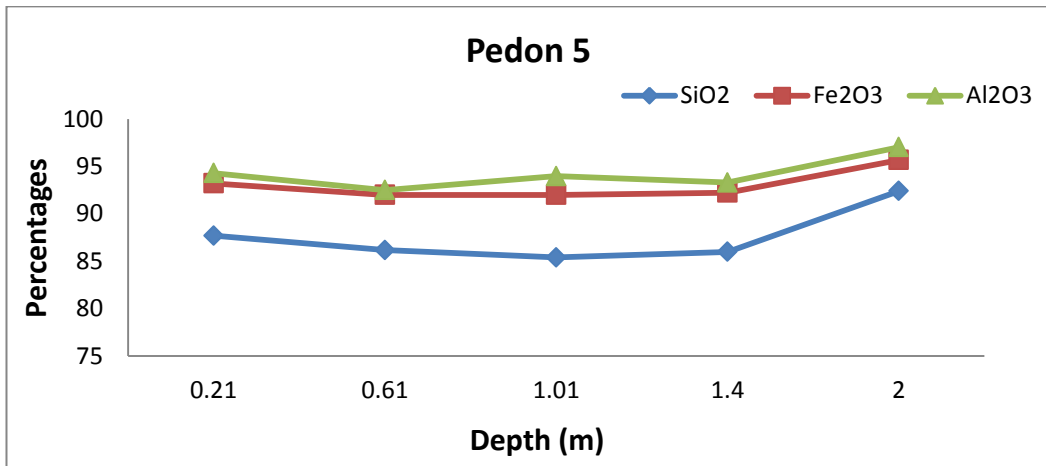


Fig.4.11. Vertical distribution of silica and sesquioxides

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).

4.9.5 Phosphorus pentoxide (P_2O_5)

The P_2O_5 content of the pedons ranged from 0.07 to 0.27 per cent. The highest value of 0.27 per cent was observed in Ap horizons of pedon 4 and 7 while lowest value of 0.07 per cent was noticed in 4A3 horizon of pedon 7. However, all pedons did not show any specific trend with depth.

Relatively higher values of P_2O_5 in soil might be due to the presence of P-bearing minerals such as calcium apatite and also due to use of higher dose of phosphatic fertilizers. Similar results were also reported by Leelavathi *et al.* (2010).

4.9.6 Potassium oxide (K_2O)

These values ranged from 0.05 to 1.10 per cent. Relatively lower value of 0.05 per cent was noticed in pedon 3 whereas higher value of 1.10 per cent was recorded in pedons 1 and 6. The pedons 2, 6 and 7 exhibited a decreasing trend with depth while the remaining pedons did not show any particular trend with depth. Low quantity of K_2O suggested the presence of small amount of micaceous minerals and low amount of K-bearing minerals.

4.9.7 Sodium oxide (Na_2O)

The Na_2O content ranged from 0.12 to 0.73 per cent. The higher value of 0.73 per cent was noticed in Bw5 horizon of pedon 1 whereas the lower value of 0.12 per cent was recorded in 4A3 horizon of pedon 7. Pedons

6 and 7 showed a decreasing with depth. However, remaining pedons did not exhibit any specific trend with depth. The Na₂O content in this soil might be derived from parent material containing sodium bearing minerals.

4.9.8 Calcium oxide (CaO)

These values ranged from 1.26 to 8.40 per cent. Highest value of 8.40 per cent was noticed in pedon 3 whereas the lowest value of 1.26 per cent was recorded in pedon 7. Pedons 2 and 7 exhibited a decreasing trend with depth. Further, calcium oxide exhibited an increasing trend with depth up to Bw₂ and A₁ horizons in pedons 3 and 6, respectively. The remaining pedons did not show any specific depth function. Higher values of CaO indicates the presence of minerals rich in calcium (Mall and Mishra, 2000).

4.9.9 Magnesium oxide (MgO)

The magnesium oxide content varied from 0.10 to 1.49 per cent. The highest value of 1.49 per cent was recorded in Bw₅ horizon of pedon 1 whereas the lowest value of 0.10 per cent was registered in Ap horizon of pedon 2 and Bw₃ horizon of pedon 5. Pedons 2 and 6 showed an increasing trend with depth while pedon 4 exhibited an irregular decrease with depth. Further, remaining pedons did not show any particular trend with depth.

Higher values of MgO indicate the presence of minerals rich in magnesium. 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 SiO₂ ranged from 1.33 to 1.54 in between the horizons of all the pedons while the molar concentration of

Table 4.16. Molar concentrations and molar ratios of the soils

Pedon No. & Horizon	Depth (m)	Molar concentration				Molar ratio			
		SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	R ₂ O ₃	SiO ₂ /R ₂ O ₃	SiO ₂ /Al ₂ O ₃	SiO ₂ /Fe ₂ O ₃	Al ₂ O ₃ /Fe ₂ O ₃
Pedon 1									
Ap	0.00-0.15	1.42	0.037	0.019	0.056	25.33	74.44	38.40	0.52
2Bw1	0.15-0.41	1.41	0.046	0.014	0.060	23.51	102.07	30.54	0.29
3Bw2	0.41-0.64	1.39	0.048	0.012	0.060	27.13	111.94	29.15	0.26
4Bw3	0.64-0.90	1.38	0.053	0.014	0.066	20.69	100.53	26.05	0.25
5Bw4	0.90-1.07	1.40	0.043	0.030	0.073	19.24	46.78	32.67	0.69
Bw5	1.07-1.50+	1.43	0.034	0.012	0.046	31.11	121.50	41.82	0.34
Pedon 2									
Ap	0.00-0.23	1.41	0.048	0.022	0.070	20.13	63.97	29.38	0.45
A1	0.23-0.52	1.39	0.037	0.080	0.074	18.60	36.98	37.43	1.01
A2	0.52-0.72	1.38	0.030	0.033	0.064	21.58	41.68	44.76	1.07
Cr	0.72	Weathered gneiss							
Pedon 3									
Ap	0.00-0.18	1.45	0.039	0.008	0.047	30.85	181.25	37.17	0.21
Bw1	0.18-0.43	1.41	0.035	0.017	0.052	27.28	83.48	40.52	0.49
Bw2	0.43-0.67	1.37	0.036	0.014	0.050	27.40	97.85	38.05	0.38
Bw3	0.67-0.91	1.36	0.038	0.013	0.051	26.79	108.43	35.58	0.32
Cr	0.91	Dolomite							
Pedon 4									
Ap	0.00-0.19	1.38	0.028	0.050	0.077	18.00	28.10	50.11	1.78
Bw1	0.19-0.48	1.39	0.046	0.020	0.067	20.84	67.83	30.08	0.44
2Bw2	0.48-0.86	1.40	0.043	0.020	0.063	22.22	33.70	32.55	0.46
3Bw3	0.86-1.10	1.45	0.021	0.046	0.068	21.36	31.30	67.32	2.15
4Bw4	1.10-1.40	1.44	0.028	0.042	0.070	20.50	34.32	50.90	1.48
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 5									
Ap	0.00-0.21	1.46	0.035	0.011	0.045	32.24	136.50	42.22	0.30
2A1	0.21-0.61	1.43	0.036	0.005	0.041	34.60	286.72	39.35	0.13
3Bw1	0.61-1.01	1.42	0.041	0.019	0.061	23.36	73.17	34.36	0.46
4Bw2	1.01-1.40	1.40	0.039	0.010	0.050	28.17	134.43	35.65	0.26
5Bw3	1.40-2.00	1.54	0.020	0.013	0.034	45.57	117.00	74.64	0.63
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 6									
Ap	0.00-0.18	1.37	0.049	0.020	0.069	19.80	68.15	27.91	0.40
A1	0.18-0.39	1.47	0.024	0.011	0.035	42.35	134.11	61.90	0.46
A2	0.39-0.50	1.35	0.028	0.057	0.084	16.03	23.84	48.96	2.05
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 7									
Ap	0.00-0.20	1.46	0.038	0.015	0.053	27.55	97.33	38.42	0.39
2A1	0.20-0.50	1.36	0.037	0.010	0.047	28.93	136.00	36.75	0.27
3A2	0.50-0.87	1.33	0.031	0.006	0.037	35.94	221.67	42.90	0.19
4A3	0.87-1.00	1.49	0.022	0.013	0.035	42.57	114.61	67.75	0.59
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins							

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 ₂ O ₃	Al ₂ O ₃	R ₂ O ₃	SiO ₂ / R ₂ O ₃	SiO ₂ / Al ₂ O ₃	SiO ₂ / Fe ₂ O ₃	Al ₂ O ₃ / Fe ₂ O ₃
1	Range	1.38-1.43	0.034-0.053	0.012-0.030	0.046-0.073	19.24-31.11	46.78-121.50	26.05-41.82	0.25-0.69
	Mean	1.40	0.044	0.017	0.060	24.50	92.87	33.10	0.39
2	Range	1.38-1.41	0.030-0.048	0.022-0.080	0.064-0.074	18.60-21.58	36.98-63.97	29.38-44.76	0.45-1.07
	Mean	1.39	0.038	0.045	0.069	20.10	47.54	37.19	0.84
3	Range	1.36-1.45	0.035-0.039	0.008-0.017	0.047-0.052	26.79-30.85	83.48-181.25	35.5-40.52	0.21-0.49
	Mean	1.40	0.037	0.013	0.050	28.08	117.75	37.83	0.35
4	Range	1.38-1.45	0.021-0.046	0.020-0.050	0.063-0.077	18.00-22.22	28.10-67.80	30.08-67.32	0.44-2.15
	Mean	1.41	0.033	0.035	0.069	20.58	39.05	46.19	1.26
5	Range	1.40-1.54	0.020-0.041	0.005-0.019	0.034-0.061	23.36-45.57	73.17-286.72	34.33-74.64	0.13-0.63
	Mean	1.45	0.034	0.012	0.046	32.79	149.56	45.24	0.35
6	Range	1.35-1.47	0.024-0.049	0.011-0.057	0.035-0.084	16.03-42.35	23.84-134.11	27.91-61.90	0.40-2.05
	Mean	1.40	0.034	0.029	0.063	26.06	75.37	46.26	0.97
7	Range	1.33-1.49	0.022-0.038	0.006-0.015	0.035-0.053	27.55-42.57	97.33-221.67	36.75-67.72	0.19-0.59
	Mean	1.41	0.032	0.011	0.043	33.75	142.40	46.46	0.36

R_2O_3 ($Fe_2O_3 + Al_2O_3$) contents ranged from 0.034 to 0.084. Molar concentration of SiO_2 in pedons 2 and 3 showed a decreasing trend with depth. Molar concentration of R_2O_3 in pedon 7 exhibited a decreasing trend with depth. However, remaining pedons did not show any specific trend with depth.

The silica / sesquioxide values were varying from 16.03 to 45.57. The highest value of 45.57 was observed in 5Bw3 horizon of pedon 5 whereas the lowest value of 16.03 was noticed in A2 horizon of pedon 6. Pedon 3 exhibited a decreasing trend with depth. However, remaining pedons did not show any specific depth function.

The silica / alumina ratios varied from 23.84 to 286.72. The highest value of 286.72 was observed in 2A1 horizon of pedon 5 whereas the lowest value of 23.84 was noticed in A2 horizon of pedon 6. All pedons had shown an irregular trend with depth.

The silica / iron oxide ratio ranged from 26.05 to 74.64. The highest value of 74.64 was recorded in 5Bw3 horizon of pedon 5 while the lowest value of 26.05 was noticed in 4Bw3 horizon of pedon 1. All the pedons showed an irregular trend with depth.

The ratios (Al_2O_3 / Fe_2O_3) were ranging from 0.13 to 2.15. The lowest value of 0.13 was exhibited by 2A1 horizon of pedon 5 while the highest value of 2.15 was recorded in 3Bw3 horizon of pedon 4. An increasing trend with depth was observed in pedons 6 whereas the remaining pedons exhibited an irregular trend with depth.

The irregular trend of SiO_2 / R_2O_3 , SiO_2 / Al_2O_3 and Al_2O_3 / Fe_2O_3 could be attributed to heterogeneous nature of parent materials (Khan *et al.*, 1997). These findings were in conformity with the findings of Walia and Rao (1996) in red soils of Uttar Pradesh. 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 $\text{SiO}_2 / \text{R}_2\text{O}_3$ and $\text{SiO}_2 / \text{Al}_2\text{O}_3$ ratios with depth might be due to decrease in sand content and increase in clay content. This was in conformity with the studies of Mahesh Babu (1992) and Anitha (1996). Similar findings were also reported by Ratnam *et al.* (2000) in the soils of Kakumanu mandal of Guntur district, Andhra Pradesh.

The ratios of $\text{SiO}_2 / \text{R}_2\text{O}_3$, $\text{SiO}_2 / \text{Al}_2\text{O}_3$, $\text{SiO}_2 / \text{Fe}_2\text{O}_3$ and $\text{Al}_2\text{O}_3 / \text{Fe}_2\text{O}_3$ 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 Ram Prakash and Seshagiri Rao (2002) in red soils of Krishna district, Andhra Pradesh. The soils of eastern region of Varanasi were fairly high in SiO_2 and $\text{SiO}_2 / \text{R}_2\text{O}_3$ molar ratios in surface soils. This indicates less siliceous substratum and advanced stage of pedogenic development (Singh and Agrawal, 2005). The low molar $\text{SiO}_2 / \text{R}_2\text{O}_3$ 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 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.

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	0.00-0.15	196.00	14.07	91.50	37.50	980	813	8175	1563
2Bw1	0.15-0.41	161.00	16.08	145.00	30.00	840	775	7900	1282
3Bw2	0.41-0.64	147.00	20.01	122.50	22.50	840	763	7500	969
4Bw3	0.64-0.90	134.40	20.63	69.50	45.00	760	750	8075	531
5Bw4	0.90-1.07	112.00	17.33	60.50	47.50	760	687	9225	531
Bw5	1.07-1.50+	98.70	18.00	75.50	25.00	560	750	9050	938
Pedon 2									
Ap	0.00-0.23	143.50	14.67	54.50	17.50	560	813	4600	719
A1	0.23-0.52	127.40	29.34	68.00	22.50	530	788	3750	500
A2	0.52-0.72	117.60	32.67	72.50	21.25	420	850	2775	469
Cr	0.72	Weathered gneiss							
Pedon 3									
Ap	0.00-0.18	174.30	16.08	173.50	23.75	1120	725	475	844
Bw1	0.18-0.43	156.80	17.34	150.50	26.25	840	688	675	938
Bw2	0.43-0.67	141.40	18.00	129.00	37.50	840	875	750	593
Bw3	0.67-0.91	130.90	24.00	102.50	17.50	700	750	450	438
Cr	0.91	Dolomite							
Pedon 4									
Ap	0.00-0.19	166.60	20.66	124.00	27.50	1140	1188	3900	1031
Bw1	0.19-0.48	153.30	34.88	96.50	20.00	840	1063	3025	1000
2Bw2	0.48-0.86	137.90	25.34	47.50	21.25	1120	875	1550	532
3Bw3	0.86-1.10	128.10	31.50	88.00	20.25	720	775	2075	625
4Bw4	1.10-1.40	113.40	18.09	92.50	27.50	560	1000	1725	844
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 5									
Ap	0.00-0.21	140.00	26.13	182.50	67.50	990	900	5475	1094
2A1	0.21-0.61	124.60	22.01	163.00	45.00	830	938	3525	813
3Bw1	0.61-1.01	112.70	20.01	108.50	57.50	710	975	6025	1031
4Bw2	1.01-1.40	105.00	19.43	158.00	41.25	710	888	5825	750
5Bw3	1.40-2.00	168.00	17.33	151.00	42.00	550	1125	2475	906
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 6									
Ap	0.00-0.18	130.90	25.33	128.00	45.00	580	1150	9175	1281
A1	0.18-0.39	99.40	14.76	51.00	30.00	420	938	8175	1156
A2	0.39-0.50	84.70	21.34	19.50	55.00	280	1063	5725	1063
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 7									
Ap	0.00-0.20	138.60	16.75	138.50	22.00	970	1163	5300	656
2A1	0.20-0.50	124.60	16.08	116.00	19.25	730	1063	4750	625
3A2	0.50-0.87	121.10	7.37	112.50	19.75	540	622	3625	594
4A3	0.87-1.00	98.70	6.00	106.50	12.50	450	313	3075	438
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins							

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	98.70-196.00	14.07-20.63	60.50-145.00	22.50-47.50	560-980	687-8123	7500-9225	531-1563
	Mean	141.52	17.69	94.08	34.58	790	756	8320	969
2	Range	117.60-143.50	14.67-32.67	54.50-72.50	17.50-22.50	420-560	788-850	2775-4600	469-719
	Mean	129.50	25.56	65.00	20.42	503	817	3708	562
3	Range	130.90-174.30	16.08-24.00	102.50-173.5	17.50-37.50	700-1120	688-875	450-750	438-938
	Mean	150.85	18.86	138.88	26.25	875	759	588	703
4	Range	113.40-166.60	18.09-34.88	47.50-124.00	20.00-27.50	560-1140	775-1188	1550-3900	532-1031
	Mean	139.86	26.09	89.70	23.30	876	980	2455	806
5	Range	105.00-168.00	17.33-26.13	108.50-182.50	41.25-67.50	550-990	888-1125	2475-6025	750-1094
	Mean	130.06	20.98	152.60	50.65	758	965	4665	919
6	Range	84.70-130.90	14.76-25.33	19.50-128.00	30.00-55.00	280-580	938-1150	5725-9175	1063-1281
	Mean	104.90	20.48	66.17	43.33	427	1050	7392	1167
7	Range	98.70-138.60	6.00-16.75	106.50-138.50	12.50-22.00	450-970	313-1163	3075-5300	438-656
	Mean	120.75	11.55	118.38	18.38	673	790	4188	578

4.10.1.1 Nitrogen

The total nitrogen content ranged from 280 to 1140 mg kg⁻¹ soil. Except pedon 4, all the pedons exhibited a decreasing trend with depth. This might be due to decreasing trend of organic carbon with depth, as evident from significant positive correlation of total nitrogen ($r = +0.551$) with organic carbon. The mean values of the total nitrogen varied from 503 to 876 mg kg⁻¹ soil.

The available nitrogen ranged in between 84.70 and 196.00 mg kg⁻¹ soil and these soils were found to be **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 104.90 to 150.08 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 ($r = +0.509$) with organic carbon. This observation was in accordance with the results of Satish Kumar and Naidu (2012).

The semi-arid condition of the area might have favoured rapid oxidation and lesser accumulation of organic matter, releasing more NO₃-N which could have been lost by leaching (Finck and Venkateswarlu, 1982). The reason for the maximum available nitrogen content observed in the surface 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 was supplemented by the external addition of fertilizers during crop cultivation.

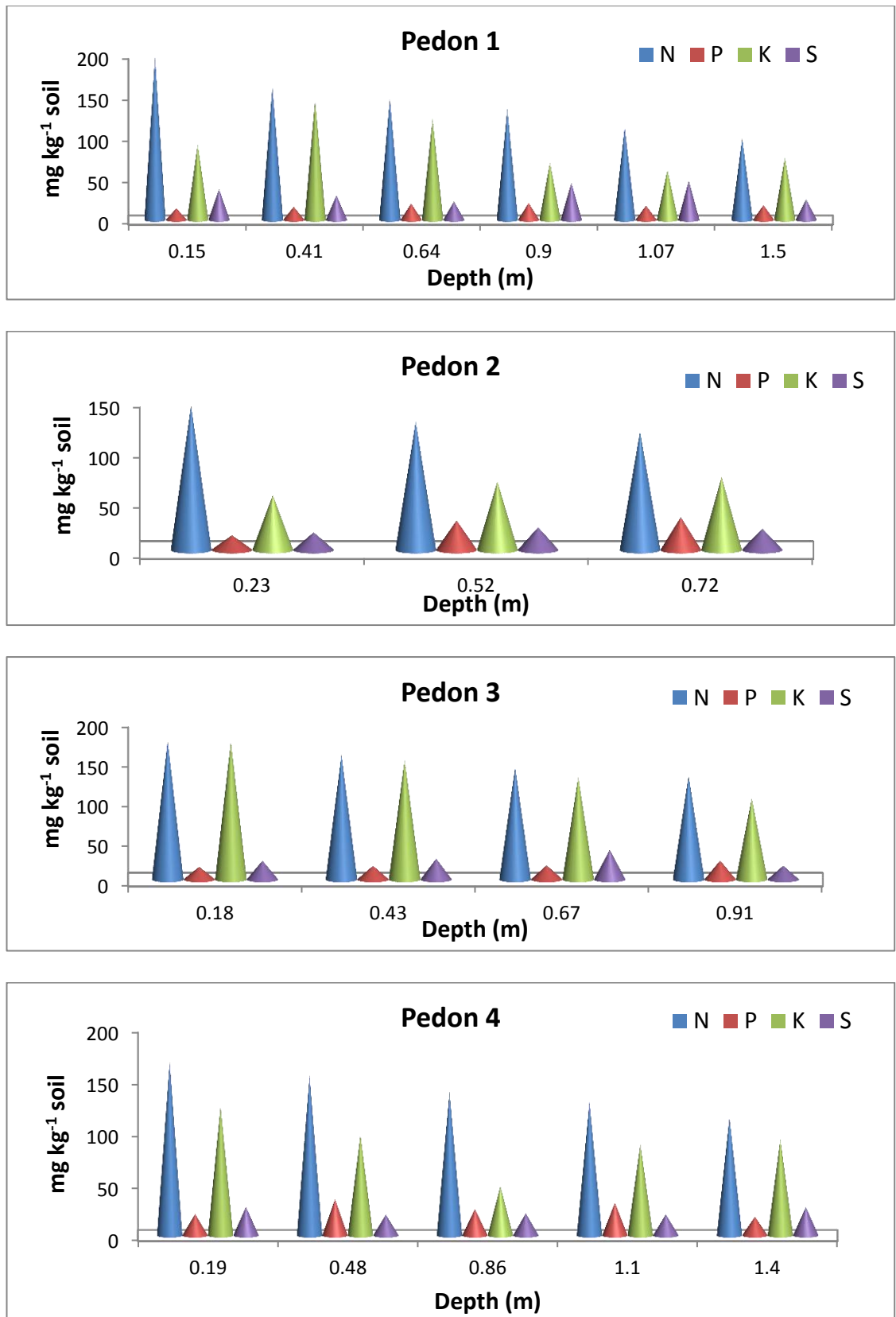


Fig.4.13. Vertical distribution of available macronutrients

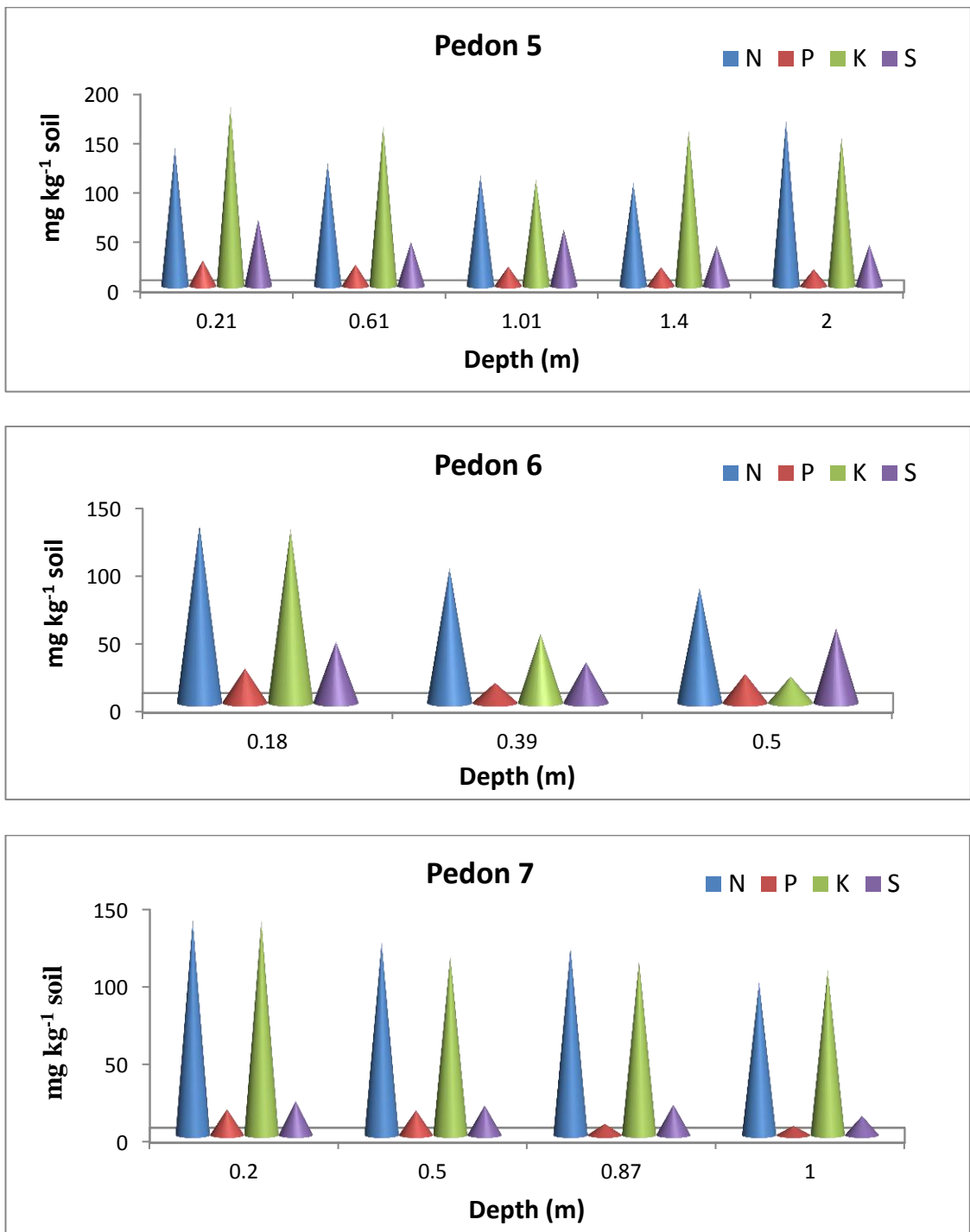


Fig.4.13. Vertical distribution of available macronutrients

4.10.1.2 Phosphorus

The total phosphorus content varied from 313 to 1188 mg kg⁻¹ soil. Pedons 1 and 4 exhibited an irregular decreasing trend with depth whereas the pedon 7 showed a decreasing trend with depth. However, the remaining pedons did not show any specific depth function. Mean values for total phosphorus in these soils were ranging from 756 to 1050 mg kg⁻¹ soil.

Relatively higher values of phosphorus in these soils could be due to the occurrence of P-bearing minerals. Similar results were also recorded by Mall and Mishra (2000) and Thangasamy *et al.* (2005) in Alfisols of northern Bihar and in soils of Sivagiri micro-watershed of Chittoor district in Andhra Pradesh. In general, more or less a decrease in total phosphorus content with increase in depth was noticed. High organic matter in the surface and addition of phosphoric fertilizers to soils were the causes for high phosphorus content in the surface soils.

The available phosphorus varied from 6.00 to 34.88 mg kg⁻¹ soil and these soils were **medium to high** in available phosphorus. Pedons 5 and 7 showed a decreasing trend with depth whereas the pedons 2 and 3 exhibited an increasing trend with depth. However, remaining pedons did not show any particular trend with depth. The mean values of available phosphorus varied from 11.55 to 26.09 mg kg⁻¹ soil.

The higher available phosphorus was observed in the surface horizons. Available phosphorus decreased regularly with depth. The reason for higher available 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 free iron oxide and exchangeable Al³⁺ in smaller amounts (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 (Prasuna Rani *et al.*, 1992).

4.10.1.3 Potassium

The total potassium content varied from 450 to 9225 mg kg⁻¹ soil. Pedons 2, 6 and 7 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 587 to 8320 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 Prasuna Rani *et al.* (1992) in red soils of Nellore district in Andhra Pradesh.

The available potassium in different pedons varied from 19.50 to 182.50 mg kg⁻¹ soil and these soils were **low to high** in available potassium. The mean values of available potassium were ranging from 43.30 to 257.70 mg kg⁻¹ soil. Slow weathering of mica and fixation of released potassium might have resulted in low exchangeable potassium status (Ram Prakash and Seshagiri Rao, 2002). Pedons 3, 6 and 7 showed 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.

However, the remaining pedons did not show any particular trend with depth. Similar findings were reported by Sharma and Anil Kumar (2003) who noticed an irregular trend of K with soil depth and 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 438 to 1563 mg kg⁻¹ soil. Pedons 2, 6 and 7 exhibited a decreasing trend with depth. However, the remaining pedons did not show any specific trend with depth. Mean values for total sulphur in these soils were ranging from 562 to 1167 mg kg⁻¹ soil. 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 a decreasing trend with increasing depth was also 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 12.50 to 67.50 mg kg⁻¹ soil and the available sulphur content in these soils was found to be **high**. All the pedons did not show any particular trend with depth. The mean values of available sulphur ranged from 18.38 to 50.65 mg kg⁻¹ soil.

Surface layers contained almost more available sulphur than sub-surface layers which might be due to higher amount of organic matter in surface layers than in deeper layers. Similar results were reported by Thangasamy *et al.* (2005).

4.10.2 Micronutrients

The results pertaining to micronutrients were presented in Tables 4.20 and 4.21 and depicted in Figures 4.15 and 4.16.

4.10.2.1 Zinc

Total zinc was ranging from 42.50 to 144.25 mg kg⁻¹ soil. Pedon 6 exhibited a regular decreasing trend with depth. Further, the remaining pedons did not show any particular trend with depth. The mean values of total zinc were between 53.78 to 103.50 mg kg⁻¹ soil. Parent materials and

Table 4.20. Available and total micronutrient status (mg kg⁻¹) of the soils

Pedon No. & Horizon	Depth (m)	Available micro nutrients				Total micronutrients			
		Zn	Cu	Fe	Mn	Zn	Cu	*Fe (%)	Mn
Pedon 1									
Ap	0.00-0.15	0.57	2.69	2.70	10.36	144.25	52.50	4.21	128.25
2Bw1	0.15-0.41	0.35	1.38	0.93	05.25	105.00	51.50	5.27	66.75
3Bw2	0.41-0.64	0.31	2.03	0.83	03.91	99.25	40.50	5.45	76.00
4Bw3	0.64-0.90	0.57	1.89	1.31	03.14	86.75	44.30	6.04	79.50
5Bw4	0.90-1.07	0.31	1.32	1.92	02.14	88.00	54.80	4.88	74.50
Bw5	1.07-1.50+	0.23	1.69	0.91	03.92	97.75	20.30	3.90	69.30
Pedon 2									
Ap	0.00-0.23	0.31	0.77	0.58	3.94	62.75	17.50	5.46	79.75
A1	0.23-0.52	0.25	0.46	0.56	3.47	56.30	16.75	4.22	40.50
A2	0.52-0.72	0.20	0.22	0.42	2.70	60.30	12.75	3.52	30.50
Cr	0.72	Weathered gneiss							
Pedon 3									
Ap	0.00-0.18	0.30	1.11	1.11	2.36	47.50	24.50	3.80	132.00
Bw1	0.18-0.43	0.40	1.19	0.81	5.12	72.30	21.75	1.82	111.00
Bw2	0.43-0.67	0.44	1.32	0.56	4.25	52.80	15.50	2.65	153.25
Bw3	0.67-0.91	0.50	0.99	0.62	2.98	42.50	43.75	4.36	134.75
Cr	0.91	Dolomite							
Pedon 4									
Ap	0.00-0.19	0.36	1.81	0.67	6.13	89.50	39.25	3.15	509.30
Bw1	0.19-0.48	0.31	1.29	0.49	5.88	84.50	18.75	5.27	246.00
2Bw2	0.48-0.86	0.28	1.42	0.56	2.76	48.50	23.00	5.01	339.00
3Bw3	0.86-1.10	0.22	1.75	0.73	3.44	65.30	39.00	2.45	184.00
4Bw4	1.10-1.40	0.31	0.85	0.43	6.16	72.50	31.75	3.22	131.00
Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 5									
Ap	0.00-0.21	0.48	1.26	0.77	6.47	63.80	34.00	3.94	194.00
2A1	0.21-0.61	0.43	0.72	0.38	5.04	64.00	40.00	4.15	168.50
3Bw1	0.61-1.01	0.34	1.09	0.52	5.44	82.00	38.00	4.72	143.50
4Bw2	1.01-1.40	0.27	0.93	0.55	5.17	72.00	19.70	4.48	184.50
5Bw3	1.40-2.00	0.19	0.70	0.53	2.62	59.00	49.25	2.39	102.75
Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 6									
Ap	0.00-0.18	0.32	2.12	0.99	9.76	102.30	49.00	5.60	119.00
A1	0.18-0.39	0.31	1.98	0.67	9.26	79.25	34.00	2.73	96.25
A2	0.39-0.50	0.28	1.52	0.60	8.80	69.75	30.50	3.14	53.75
Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins							
Pedon 7									
Ap	0.00-0.20	0.36	0.59	0.59	6.90	67.50	28.00	5.03	146.00
2A1	0.20-0.50	0.23	0.50	0.43	3.87	72.30	29.00	3.55	121.75
3A2	0.50-0.87	0.16	0.68	0.63	4.35	62.80	24.50	4.22	62.00
4A3	0.87-1.00	0.20	0.32	0.39	2.48	50.00	23.30	3.93	60.75
Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins							

* Total iron status 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	0.23-0.57	1.32-2.69	0.83-2.70	2.14-10.36	86.75-144.25	20.30-54.80	3.82-5.92	66.75-128.25
	Mean	0.53	1.83	1.43	4.79	103.50	43.98	4.86	82.38
2	Range	0.20-0.31	0.22-0.77	0.42-0.58	2.70-3.94	56.30-62.75	12.75-17.50	3.45-5.35	30.50-79.75
	Mean	0.25	0.48	0.52	3.37	59.78	15.67	4.31	50.25
3	Range	0.30-0.50	0.99-1.32	0.56-1.11	2.36-5.12	42.50-72.30	15.50-43.75	1.79-4.27	111.00-153.25
	Mean	0.41	1.15	0.78	3.67	53.78	26.37	3.10	132.75
4	Range	0.22-0.36	0.85-1.81	0.43-0.73	2.76-6.16	48.50-89.50	18.75-39.25	2.40-5.17	131.00-509.3
	Mean	0.30	1.42	0.58	4.87	72.06	30.35	3.74	281.86
5	Range	0.19-0.48	0.70-1.26	0.38-0.77	2.62-6.47	59.00-82.00	19.70-49.25	2.30-4.62	102.75-194.00
	Mean	0.34	0.94	0.55	4.95	68.16	36.19	3.85	158.65
6	Range	0.28-0.32	1.52-2.12	0.60-0.99	8.80-9.76	69.75-102.30	30.50-49.00	2.67-5.40	53.75-119.00
	Mean	0.30	1.87	0.75	9.27	83.77	37.83	3.74	89.67
7	Range	0.16-0.36	0.32-0.68	0.39-0.63	2.48-6.90	50.00-72.30	23.30-29.00	3.48-4.93	60.75-146.00
	Mean	0.24	0.52	0.51	4.40	63.15	26.20	4.10	97.62

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 0.16 to 0.57 mg kg⁻¹ soil. Pedons 2, 5 and 6 exhibited a regular decreasing trend with depth whereas pedon 3 showed an increasing trend with depth and the remaining pedons showed an irregular trend with increasing depth. The mean values of available zinc were between 0.24 to 0.53 mg kg⁻¹ soil. Considering 0.6 mg kg⁻¹ soil as critical level (Lindsay and Norvell, 1978) for available zinc, all the soils were below the critical limit and 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 (Jagdish Prasad *et al.*, 2009). Zinc deficiency was wide spread in the high pH, low organic matter and calcareous soils (Rattan and Sharma, 2004).

4.10.2.1 Copper

The total copper content of the horizons in different pedons varied from 12.75 to 54.80 mg kg⁻¹ soil. Pedons 2 and 6 exhibited a regular decrease with depth. Further, remaining pedons did not show any particular trend with depth. The mean values of the total copper content varied from 15.67 to 43.98 mg kg⁻¹ soil. The variation in total copper content among the pedons might be due to variation in copper bearing minerals in the soils.

The available copper content varied from 0.22 to 2.69 mg kg⁻¹ soil. Pedon 5 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 0.48 to 1.87 mg kg⁻¹ soil.

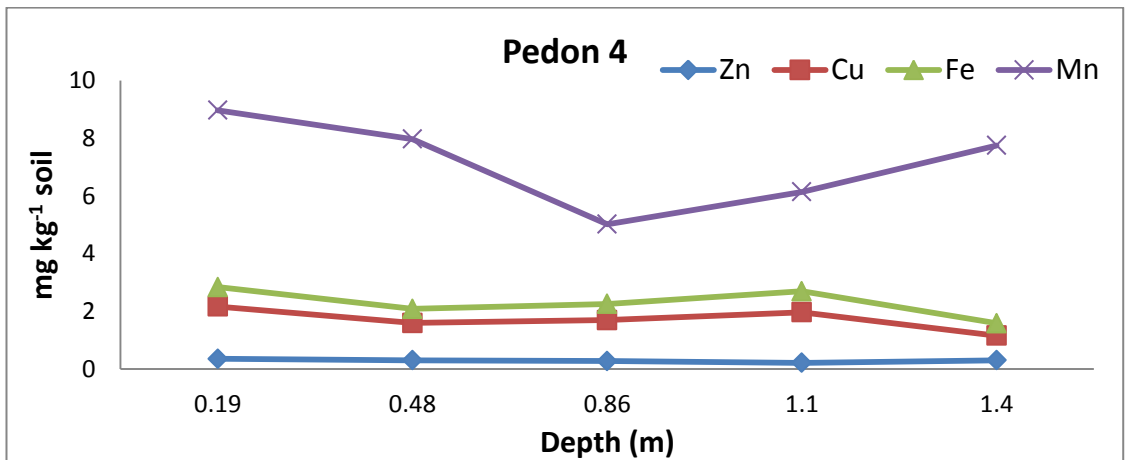
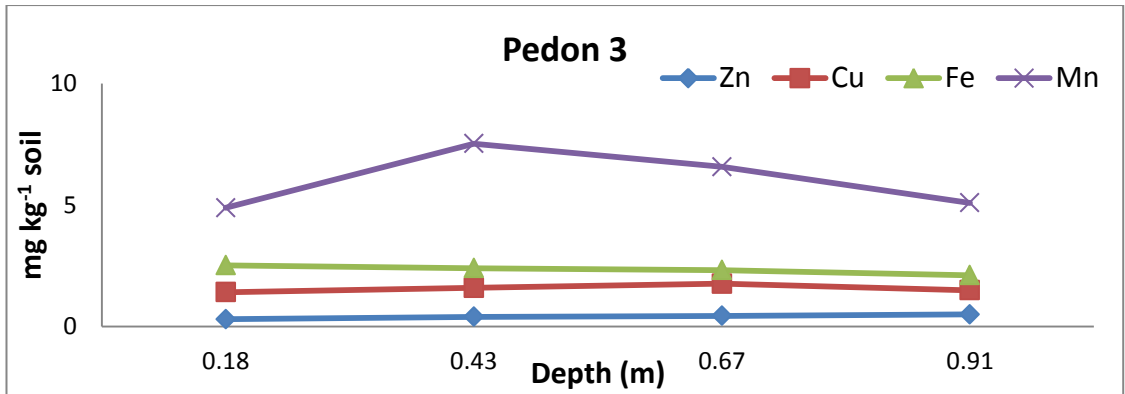
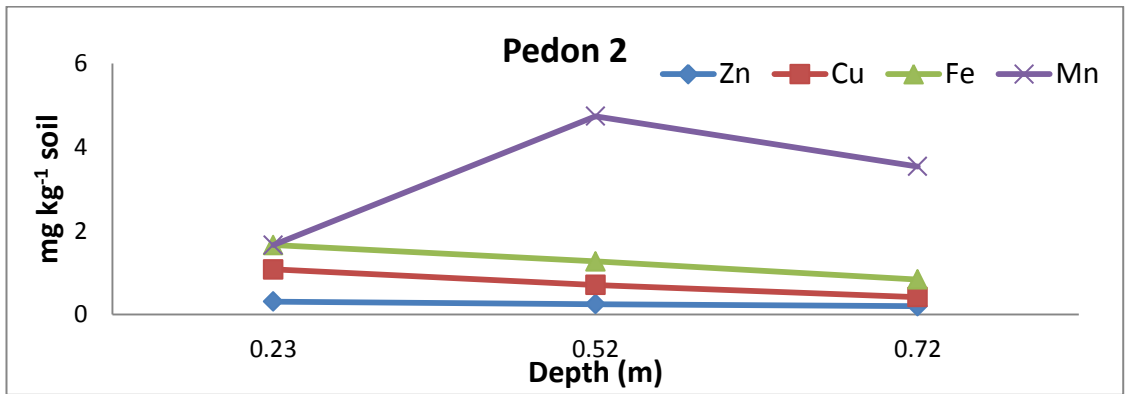
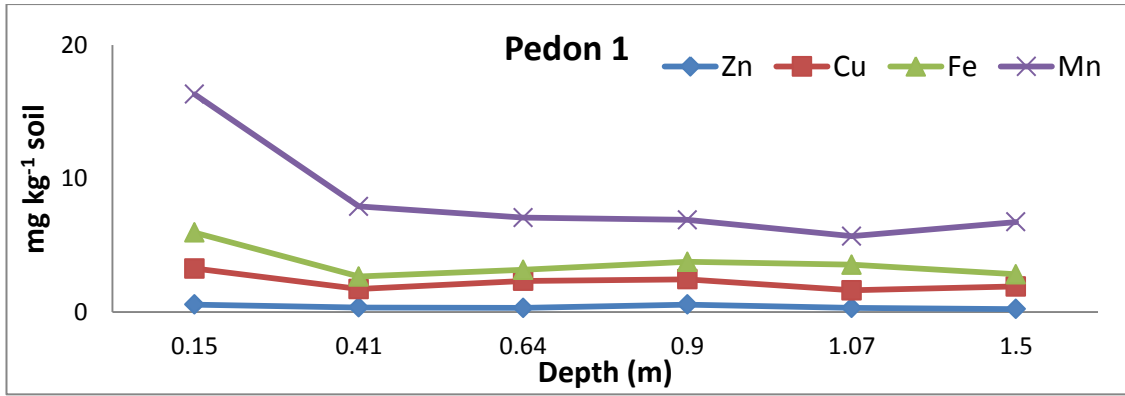


Fig.4.15. Vertical distribution of available micronutrients

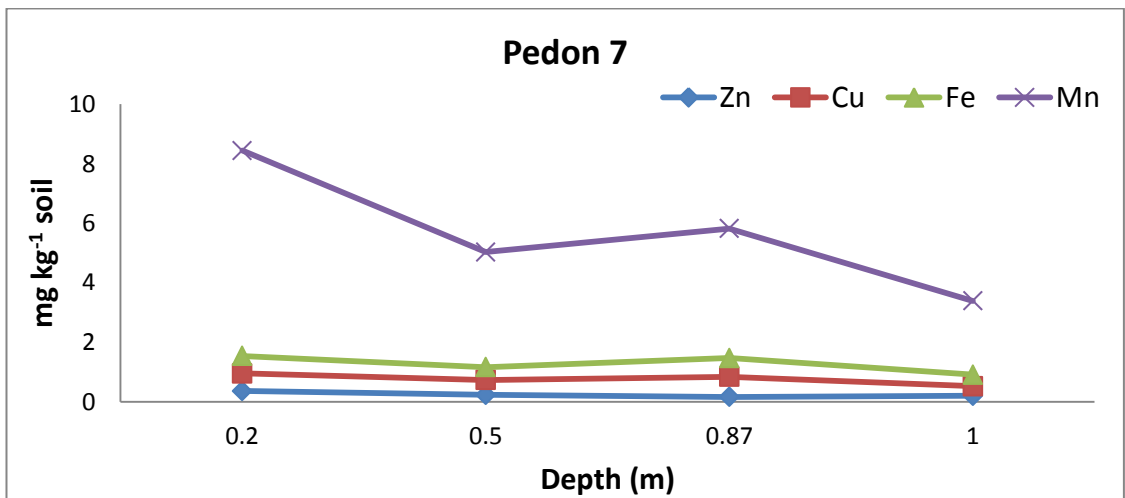
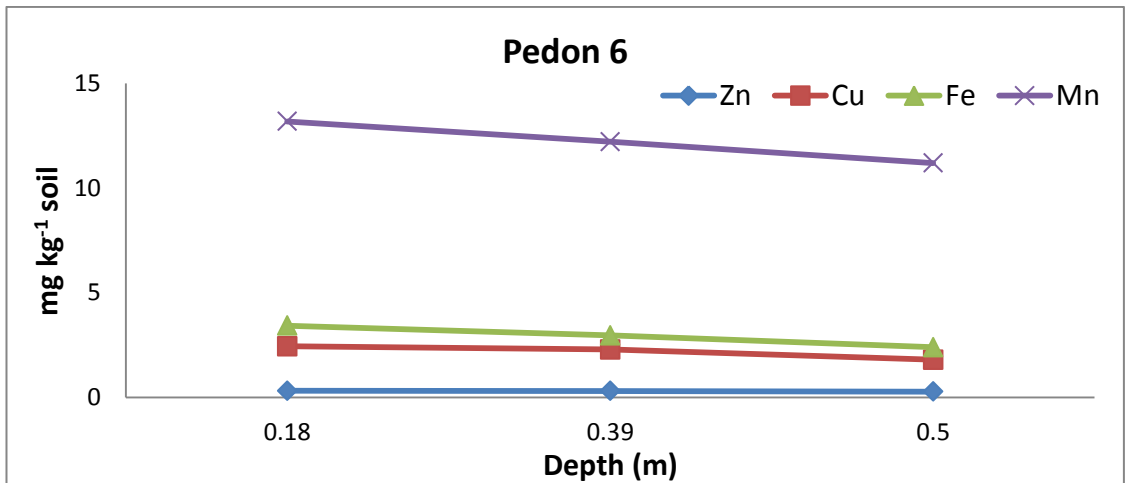
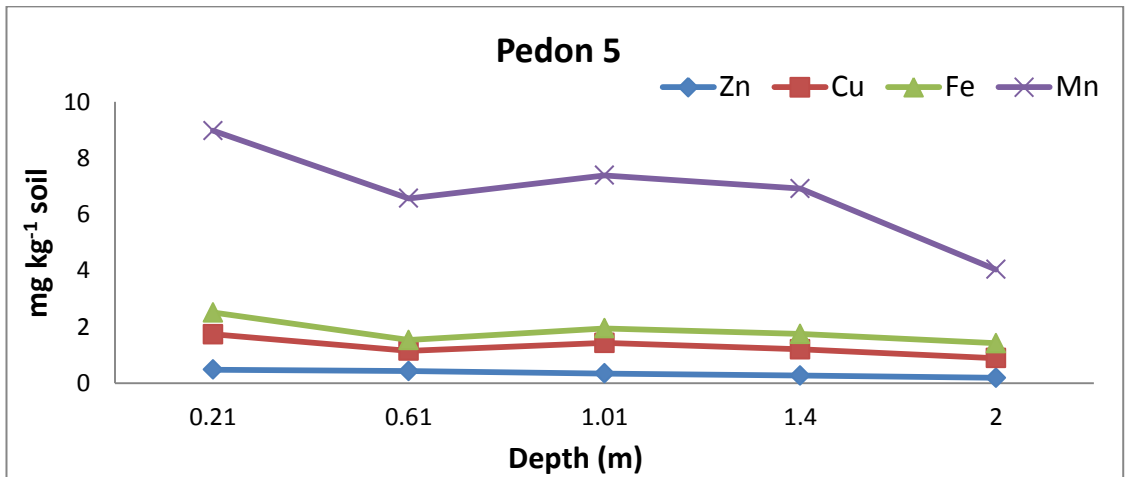


Fig.4.15. Vertical distribution of available micronutrients

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). Similar results were expressed by Sarkar *et al.* (2000) and Verma *et al.* (2005b) in soils of Madhubani district in Bihar and in soils developed on different physiographic units of Fatehgarh Sahib district of Punjab, respectively.

4.10.2.3 Iron

The total iron content ranged from 1.82 to 5.92 per cent. Pedon 2 showed a regular decreasing trend with depth. However, the remaining pedons exhibited an irregular trend with depth. The mean values of the total iron content varied from 3.10 to 4.86 per cent. Variation in total iron among the pedons could be attributed to variation in ferromagnesium 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 0.38 to 2.70 mg kg^{-1} soil. Pedons 2 and 6 exhibited a regular decreasing trend with depth while pedon 3 exhibited an irregular decreasing trend with depth. However, remaining pedons did not show any specific depth function. The mean values of available iron ranging from 0.51 to 1.43 mg kg^{-1} soil.

According to the critical limit (4.5 mg kg^{-1} soil) of Lindsay and Norvell (1978) the soils were **deficient in available iron**. The distribution of available iron in all the pedons did not show a definite pattern. Surface horizons had higher concentration of DTPA-extractable Fe due to higher organic carbon (Jagdish Prasad and Gajbhiye, 1999).

4.10.2.4 Manganese

The total manganese content ranged from 30.50 to 509.30 mg kg⁻¹ soil. Pedons 2, 6 and 7 showed regular decreasing trend with depth while the remaining pedons (1, 3, 4 and 5) exhibited an irregular trend with depth. The mean values of total manganese content varied from 50.25 to 281.86 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 (Ramakrishna Prasad, 1994).

Available manganese content varied from 2.14 to 10.36 mg kg⁻¹ soil. Pedons 2 and 6 showed a regular decreasing trend with depth while pedon 1 exhibited a regular decreasing trend with depth except last horizon. However, remaining pedons showed irregular trend with depth in all the pedons. The mean values of available manganese content varied from 3.37 to 9.27 mg kg⁻¹ soil. The available manganese content was **sufficient to high** 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, respectively.

The higher concentration of available 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 ($r = + 0.402$). Similar findings were also made by Singh *et al.* (2006) and Verma *et al.* (2005a).

In conclusion, the micronutrient analysis of the Banaganapalle mandal revealed that soils were **deficient** in **available zinc** and **iron** whereas **sufficient** in **available copper** and **manganese**.

4.11 CLAY MINEROLOGY

The X-ray diffraction analysis was carried out in the clay fraction (< 2 micron) collected from control section (25-100 cm depth) of the pedons. The d-spacings of different clay minerals observed in X-ray diffractograms were presented in Table 4.22 and the relative proportion of clay minerals was given in Table 4.23.

Mineralogical studies by X-ray diffractograms of soil clay were obtained with the following four treatments.

1. Mg-saturated at room temperature (25°C)
2. Mg-saturated and ethylene glycol solvated
3. K-saturated at room temperature (25°C)
4. K-saturated and heated at 550°C

Pedon 1

X-ray diffractograms of clay fraction for pedon 1 were presented in Figure 4.17.

1. Presence of smectite was identified by an intense large peak at 1.724 nm d-spacing on Mg-saturated with ethylene glycol solvation and a sharp peak at 1.486 nm d-spacing in Mg-saturated sample at room temperature (25°C) indicated the presence of smectite. Further, a peak at 1.233 nm d-spacing in K-saturated sample at room temperature (25°C) followed by peak at 0.990 nm d-spacing in K-saturated and heated at 550°C treatments indicated the presence of smectite.
2. Small peaks were observed at 0.723 and 0.716 nm d-spacings in Mg-saturated with ethylene glycol solvation and Mg-saturated at room temperature treatment. The peak persisted at 0.721 nm

Table 4.22. d-spacing (nm) of X-Ray diffractograms in clay fraction (less than 2 micron fraction)

Pedon No.	Calcium saturated		K-saturated		Clay mineral
	Ethylene glycol	Room temperature	Room temperature	550°C	
1.	1.724	1.486	1.233	0.990	} Smectite
	1.005	1.013	1.006	0.990	
	0.500*	0.499*	0.501*	0.496*	} Illite
	0.334*	–	0.334*	0.334*	
	0.723	0.716	0.721	–	} Kaolinite
	0.356*	–	0.356*	–	
	0.425	0.426	0.426	–	} Quartz
	0.402	0.402	0.401	–	
	0.325	–	0.324	0.319	} Feldspars
	0.319	–	0.319	0.315	
2.	1.654	1.228	1.227	0.952	} Smectite
	1.013	0.997	0.998	0.952	
	–	0.495*	0.501*	0.494*	} Illite
	0.334*	0.331*	0.334*	0.329*	
	0.717	0.717	0.720	–	} Kaolinite
	0.355*	0.357*	0.356*	–	
	0.303	0.303	–	0.311	} Feldspars
–	–	–	–		
3.	1.629	1.469	1.006	0.999	} Smectite
	0.993	–	1.006	0.999	
	0.501*	0.502*	–	0.502*	} Illite
	0.334*	–	0.333*	0.331*	
	0.724	0.729	0.729	–	} Kaolinite
	0.357*	0.358*	0.358*	–	
	–	–	–	–	} Feldspars
	–	–	–	–	

* Higher order peaks

Table 4.22.(Cont.).

4.	1.682	1.549	1.129	1.183	} Smectite	
	0.995	1.002	0.998	0.992		
	0.498*	0.500*	0.499*	—		} Illite
	0.332*	0.333*	0.333*	0.332*		
	0.722	0.724	0.726	—		
	0.358*	0.356*	0.358*	—		} Kaolinite
	0.415	—	—	—		
	—	—	—	—		} Quartz
	—	—	0.315	—		
	—	—	—	—		} Feldspars
—	—	—	—			
5.	1.699	1.720	0.997	0.986	} Smectite	
	1.006	0.999	0.997	0.986		
	0.500*	0.499*	0.500*	0.493*		} Illite
	0.335*	0.334*	0.332*	0.333*		
	0.734	0.717	0.719	—		
	0.357*	0.357*	0.352*	—		} Kaolinite
	0.425	—	0.426	—		
	—	—	—	—		} Quartz
	0.335	0.319	0.308	0.325		
	—	—	—	—		} Feldspars
—	—	—	—			
6.	1.654	1.228	1.227	0.952	} Smectite	
	1.013	0.997	0.998	0.952		
	—	0.495*	0.501*	0.494*		} Illite
	0.334*	0.331*	0.334*	0.329*		
	0.717	0.717	0.720	—		
	0.355*	0.357*	0.356*	—		} Kaolinite
	0.303	0.303	—	0.311		
	—	—	—	—		} Feldspars
	—	—	—	—		
	7.	1.668	1.484	0.999		1.000
0.995		1.019	0.999	1.000		
0.499*		0.499*	0.500*	0.498*	} Illite	
0.334*		0.334*	0.334*	0.333*		
0.726		0.721	0.722	—		
0.357*		0.356*	0.356*	—	} Kaolinite	
0.424		0.425	0.425	0.425		
0.401		0.401	0.402	0.400	} Quartz	
0.325		0.324	0.325	0.324		
0.319		0.319	0.319	0.319	} Feldspars	
—	—	—	—			

*Higher order peaks

Table 4.23. Relative proportion of clay minerals (from X-ray diffractograms of soil clay)

Pedon No.	Tentative soil series	Smectite	Kaolinite	Illite	Feldspars	Quartz
1.	Pasupula	76	11	6	4	3
2.	Yerragudipalem	52	23	10	15	-
3.	Palukuru	86	10	4	-	-
4.	Mittapalli	67	16	13	Tr	4
5.	Kapulapalle	40	46	4	8	2
6.	Illuru Kothapeta	53	25	6	16	-
7.	Gulamnapipeta	37	49	10	3	1

'-' : refers to nil

Tr : Traces refers to less than 1%

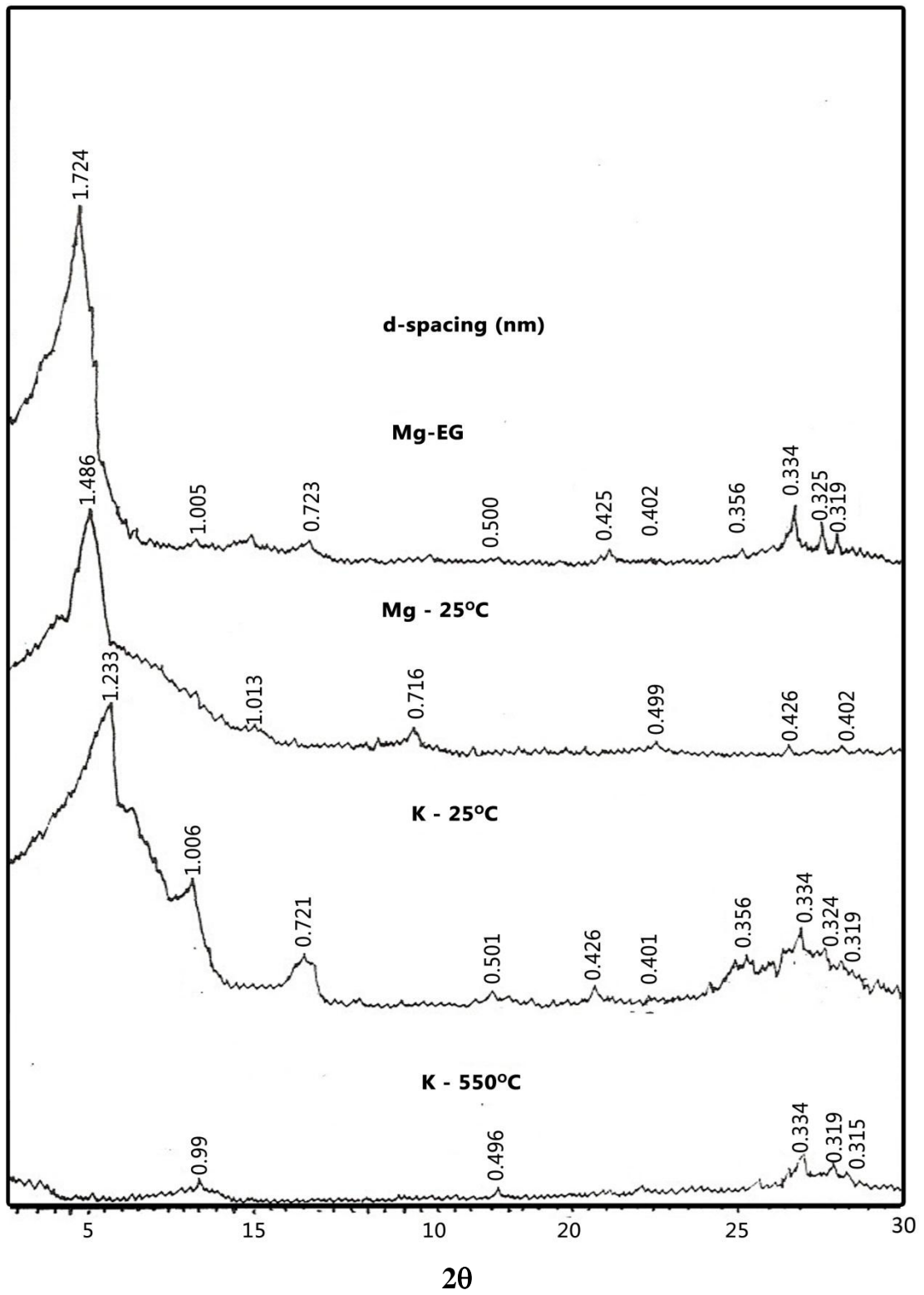


Fig. 4.17. X-ray diffractograms of pedon 1 (Vertic Haplustepts)

d-spacing in K-25°C but disappeared in K-saturated and heated to 550°C indicated the presence of kaolinite.

3. Illite had shown small peaks at 1.005 and 1.013 nm d-spacings in Mg-saturated with ethylene glycol solvation and Mg-saturated sample at room temperature (25°C) treatments, respectively. Illite also showed sharp peaks at 1.006 and 0.990 nm d-spacings in K-saturated at room temperature and K-saturated and heated to 550°C treatments, respectively.

Second order peaks were noticed at 0.500 and 0.499 nm d-spacings in Mg-saturated ethylene glycol solvation and Mg-saturated sample at room temperature treatments, respectively. Further, small peaks at 0.501 and 0.496 nm d-spacings in K-saturated sample at room temperature (25°C) and K-saturated and heated at 550°C treatments, respectively.

Third order peaks at 0.334 nm d-spacings were observed in Mg-saturated with ethylene glycol solvation, K-25°C and K-550°C treatments, confirmed the presence of illite.

4. A significant quantity of feldspars was identified by their small peaks at 0.325 and 0.319 nm d-spacings in Mg-saturated with ethylene glycol solvation and similar peaks were also observed at 0.324 and 0.319 nm d-spacings in K-25°C and at 0.319 and 0.315 nm d-spacings in K-550°C treatments.
5. Quartz was identified by small peaks at 0.425 and 0.426 nm d-spacing in Mg-saturated with ethylene glycol solvated and Mg-saturated at room temperature treatments. Similar peaks were also noticed in K-25°C treatments.

In this pedon smectite mineral was dominant (76%) followed by kaolinite (11%), illite (6%), feldspars (4%) and quartz (3%).

Pedon 2

X-ray diffractograms of clay fraction for pedon 2 were presented in Figure 4.18.

1. Presence of smectite was identified by the following reflections.
 - a. Mg-saturation with ethylene glycol solvation : A strong peak at 1.654 nm d-spacing.
 - b. Mg-saturation at room temperature : A sharp peak at 1.228 nm d-spacing.
 - c. K-saturated at 25°C : Conspicuous peaks at 1.227 nm d-spacing.
 - d. K-saturated at 550°C : Sharp peak at 0.952 nm d-spacing.
2. Kaolinite was identified by the following peaks at different d-spacings.
 - a. A strong first order peak at 0.717 nm d-spacing in Mg-saturated ethylene glycol solvation and Mg-saturated at room temperature treatments. Similar peak in K-25°C treatment and disappearance of the same peak in K-saturated and heated to 550°C treatment indicated the presence of kaolinite.
 - b. Small second order peaks at 0.355, 0.357 and 0.356 nm d-spacings in Mg-saturated with ethylene glycol solvation Mg-saturated at room temperature and K-25°C treatments, respectively and collapse of the same peak in K-550°C treatment confirmed the presence of kaolinite.

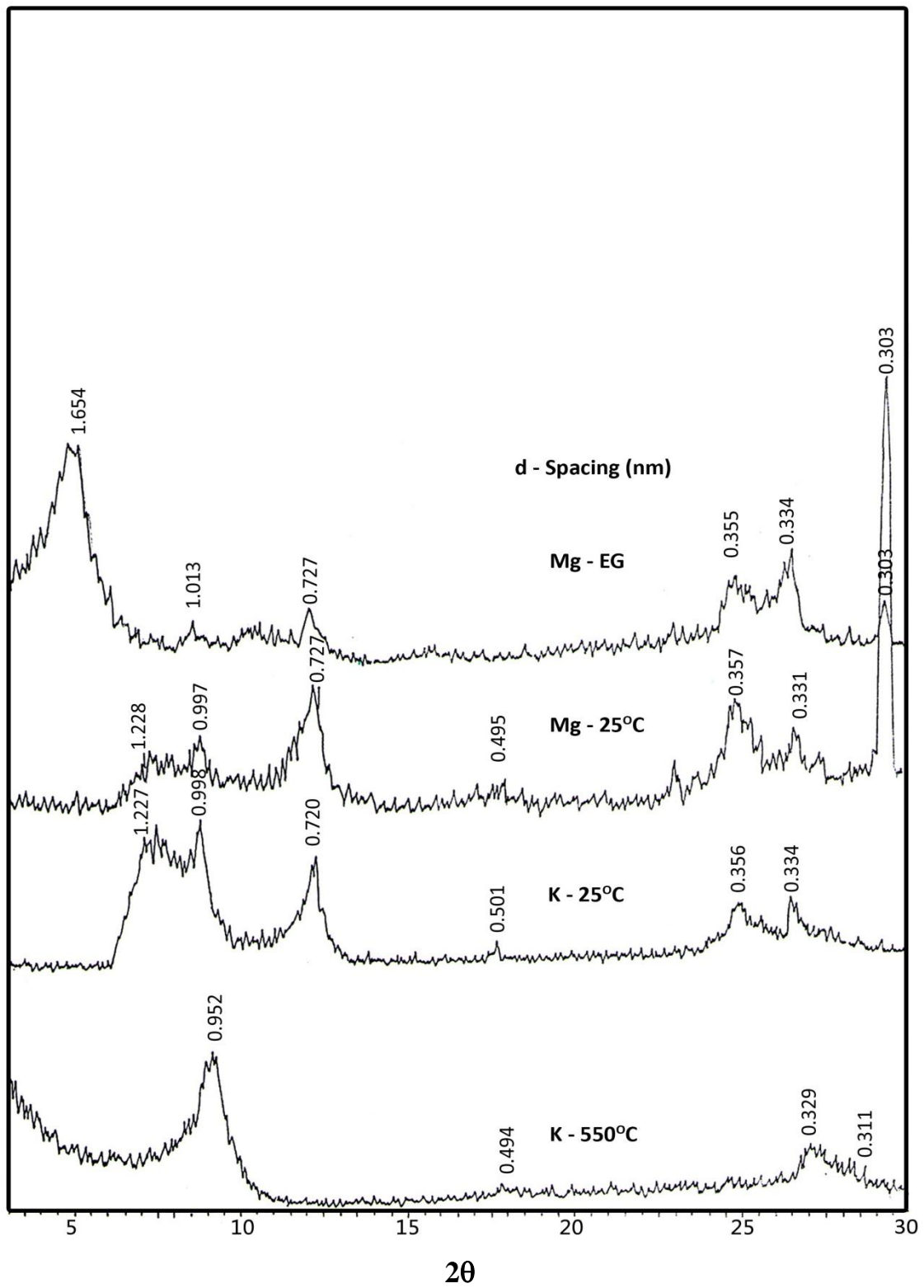


Fig. 4.18. X-ray diffractograms of pedon 2 (Typic Ustorthents)

3. A significant quantity of feldspars was identified by their characteristic peak at 0.303 nm d-spacing in Mg-saturated with ethylene glycol solvation and Mg-saturated at room temperature treatments. Further, similar peak at 0.311 nm d-spacing in K-550°C treatment proved the presence of feldspars.
4. Presence of illite in the clay fraction was identified by following peaks with different treatments.
 - a. First order peaks at 0.993 and 0.997 nm d-spacings were observed in both Mg-saturated with ethylene glycol solvation and Mg-saturated at room temperature treatments. Further, similar peaks were observed at 0.998 and 0.952 nm d-spacings in K-25°C and K-550°C treatments, respectively.
 - b. Second order peaks were also observed at 0.495, 0.501 and 0.494 nm d-spacings with Mg-25°C, K-25°C and K-550°C treatments, respectively.
 - c. Third order peaks at 0.334 and 0.331 nm d-spacings were noticed in Mg-saturated with ethylene glycol solvation treatment and Mg-saturated at room temperature treatments, respectively. Furthermore, the third order peaks were also observed at 0.334 and 0.329 nm d-spacings in K-25°C and K-550°C treatments, respectively.

All the above characteristic peaks indicated the presence of illite.

Semi quantitative estimates had shown that smectite (52%) was the dominant clay mineral followed by kaolinite (23%), feldspars (15%) and illite (10%).

Pedon 3

X-ray diffractograms of clay fraction from pedon 3 were presented in Figure 4.19.

1. Presence of smectite was detected by a large peak at 1.469 nm d-spacing in Mg-saturated at room temperature treatment which expanded to 1.629 nm d-spacing in Mg-saturated ethylene glycol solvation treatment. Further, the peak was shifted to 1.006 nm d-spacing with K-saturation at room temperature and at 0.999 nm d-spacing with K-saturation and heated at 550°C treatments.
2. The X-ray diffractograms of clay exhibited an intense large peak at 0.724 nm d-spacing followed by a higher order peak at 0.357 nm d-spacing in Mg-saturated ethylene glycol solvation treatment indicated the presence of “Kaolinite”. These peaks were persisted on Mg-saturation at room temperature and K-saturation at room temperature but collapsed in K-saturated sample heated to 550°C treatment, confirmed the presence of Kaolinite.
3. A sharp large peak observed at 0.993 nm d-spacing followed by higher order peaks at 0.501 nm and 0.334 nm d-spacings in Mg-saturated with ethylene glycol solvation treatment and persistence of these peaks in all other treatments indicated the presence of illite clay mineral.

Semi quantitative estimates had shown that smectite (86%) was the dominant clay mineral followed by kaolinite (10%) and illite (4%).

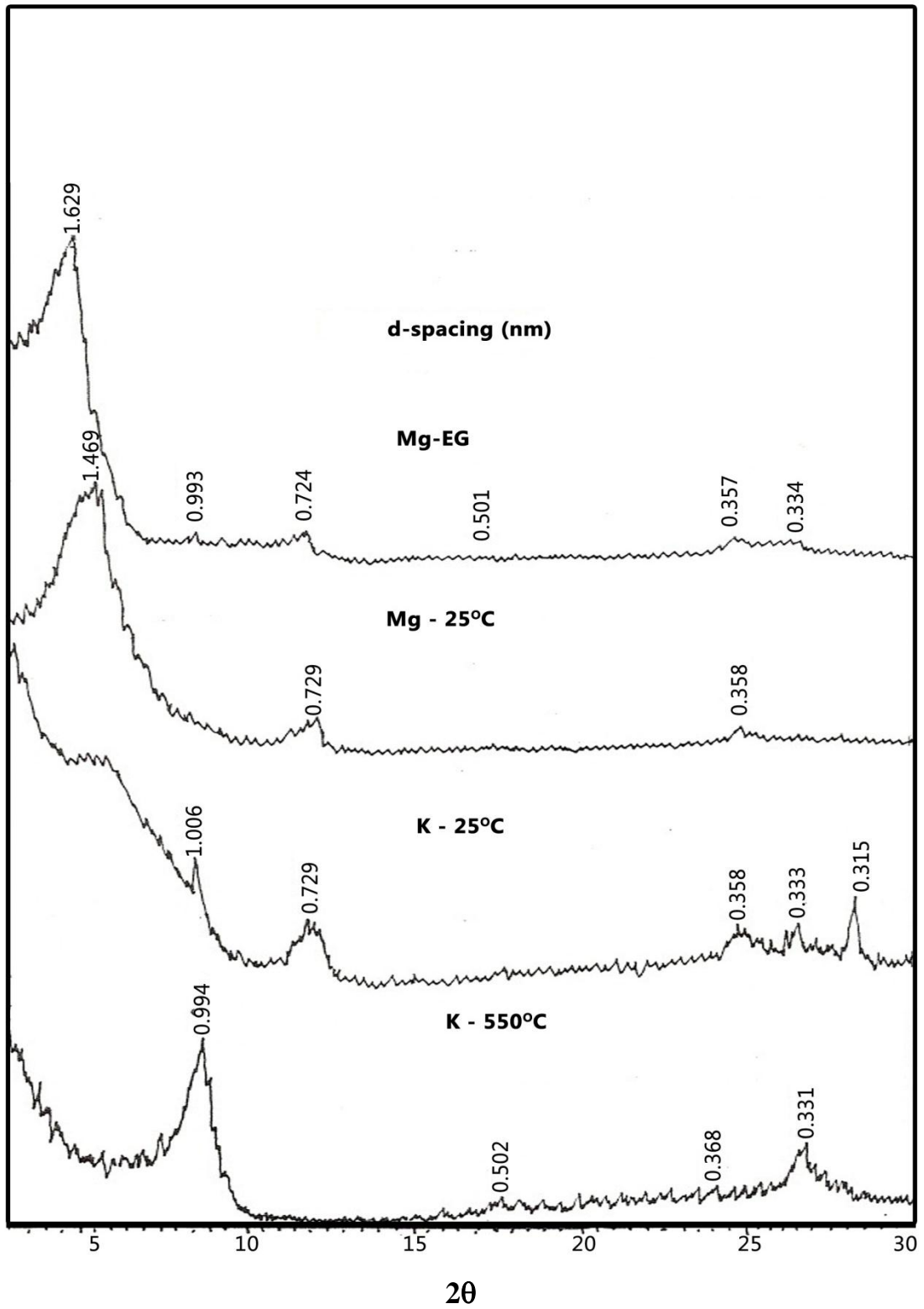


Fig. 4.19. X-ray diffractograms of pedon 3 (Vertic Haplustepts)

Pedon 4

X-ray diffractograms of clay fraction for pedon 4 were presented in Figure 4.20.

1. Presence of smectite was identified by the following reflections.
 - a. Mg-saturated with ethylene glycol solvation : A strong peak at 1.682 nm d-spacing.
 - b. Mg-saturation at room temperature : A sharp peak at 1.549 nm d-spacing.
 - c. K-saturated at 25°C : Conspicuous peak at 1.129 nm d-spacing.
 - d. K-saturated and heated to 550°C : A peak at 1.183 nm d-spacing.
2. Kaolinite was identified by following peaks at different d-spacings.
 - a. Strong first order peaks at 0.772 and 0.724 nm d-spacings in Mg-saturated ethylene glycol solvation and Mg-saturated at room temperature treatments. Similar peak in K-25°C treatment and disappearance of the same peak in K-saturated and heated to 550°C treatment indicated the presence of kaolinite.
 - b. Small second order peaks at 0.358, 0.356 and 0.358 nm d-spacings in Mg-saturated with ethylene glycol solvated, Mg-saturated at room temperature and K-25°C treatments, respectively and collapse of the same peak at K-550°C treatment confirmed the presence of kaolinite.
3. Sharp peaks at 0.995 nm (first order), 0.498 nm (second order) and 0.332 nm (third order) d-spacings in Mg-saturated ethylene glycol solvated treatment and persistence of these peaks in all other treatments indicated the presence of illite.

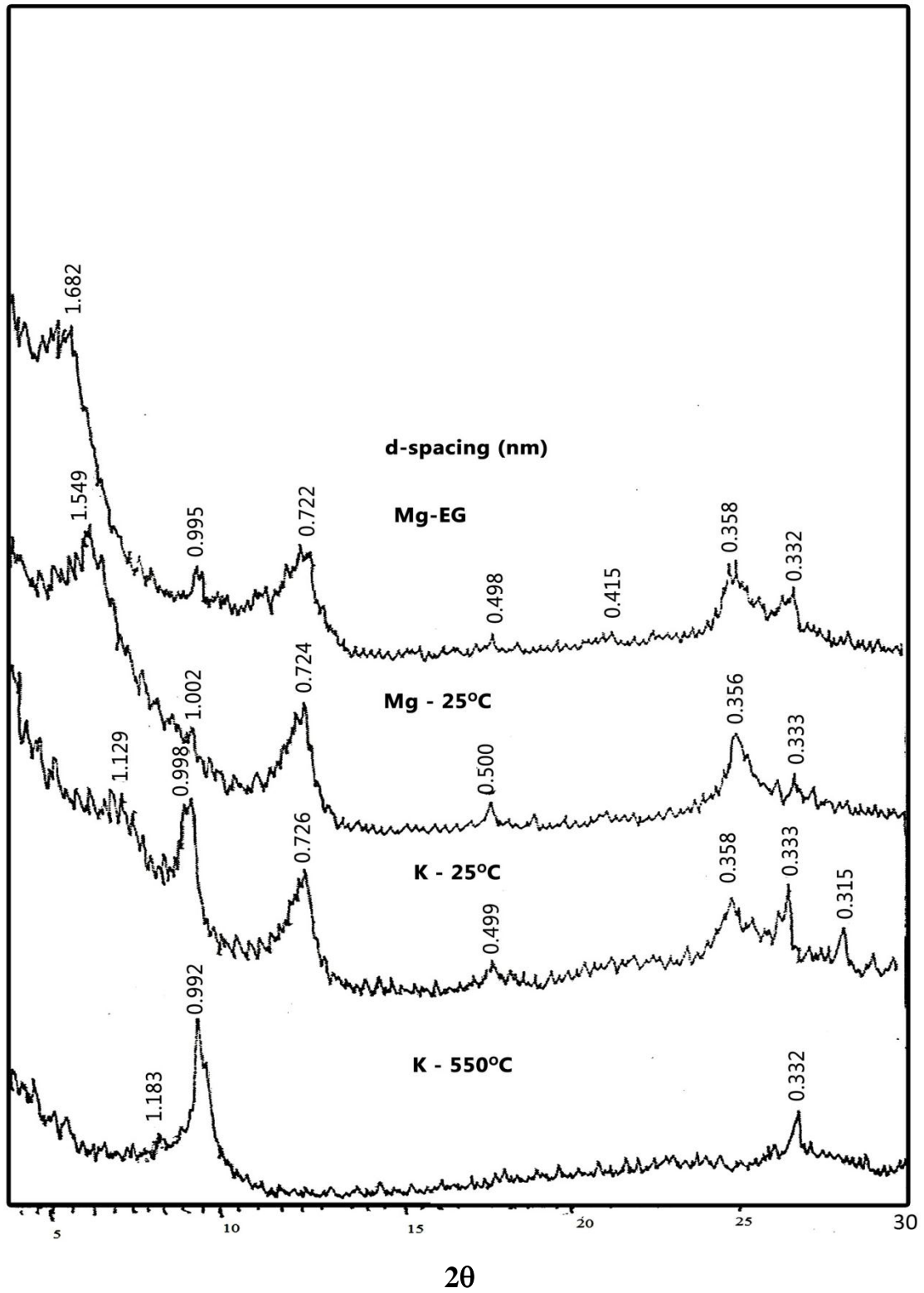


Fig. 4.20. X-ray diffractograms of pedon 4 (Typic Haplustepts)

4. Very small peak was observed at 0.415 nm d-spacing in Mg-saturated with ethylene glycol solvation treatment indicated the presence of quartz.
5. Traces of feldspars (<1%) was observed by a small peak at 0.315 nm d-spacing in K-saturated at room temperature treatment.

Semi quantitative estimates had shown that smectite (67%) was the dominant clay mineral followed by kaolinite (16%), illite (13%) and quartz (4%).

Pedon 5

X-ray diffractograms of clay fraction for pedon 5 were presented in Figure 4.21.

1. Kaolinite was identified by the following peaks at different d-spacings.
 - a. Strong first order peaks at 0.734, 0.717 and 0.719 nm d-spacings in Mg-saturated ethylene glycol solvation treatment, Mg-25°C and K-25°C treatments, respectively. Disappearance of the same peak in K-saturated and heated to 550°C treatment indicated the presence of kaolinite.
 - b. Small second order peaks at 0.357, 0.357 and 0.352 nm d-spacings were observed in Mg-saturated with ethylene glycol solvation, Mg-25°C and K-25°C treatments, respectively. However, the peak vanished in K-550°C treatment, which confirmed the presence of kaolinite.
2. Presence of smectite was detected by an intense large peak at 1.699 nm d-spacing in Mg-saturated with ethylene glycol solvation and a peak at 1.159 nm d-spacing in Mg-saturated

sample at room temperature. Further, similar peaks were observed at 0.997 and 0.986 nm d-spacing in K-25°C and K-550°C treatments, respectively.

3. The presence of feldspars were identified by a small peak at 0.335 nm d-spacing in Mg-saturated with ethylene glycol solvated sample and a small peak at 0.319 nm d-spacing in Mg-saturated at room temperature. Further, existence of small peaks at 0.308 and 0.325 nm d-spacing in K-25°C and K-550°C treatments, respectively, which proved the presence of feldspars.
4. Presence of illite in the clay fraction was identified by following peaks with different treatments.
 - a. The first order peaks at 1.006 and 0.999 nm d-spacings were observed in Mg-saturated with ethylene glycol solvation and Mg-saturated at room temperature treatments, respectively. Further, similar peaks were also observed at 0.997 and 0.986 nm d-spacings in K-25°C and K-550°C treatments, respectively.
 - b. Second order peaks were also observed at 0.500, 0.499, 0.500, and 0.493 nm d-spacings with Mg-saturated with ethylene glycol solvation, Mg-25°C, K-25°C and K-550°C treatments, respectively.
 - c. Third order peaks at 0.335, 0.334, 0.332 and 0.333 nm d-spacing were noticed in Mg-saturated with ethylene glycol solvation, Mg-25°C, K-25°C and K-550° treatments, respectively. All the above characteristic peaks indicated the presence of illite.
5. Very small peak was observed at 0.425 nm d-spacing in Mg-saturated with ethylene glycol solvated treatment and a small peak

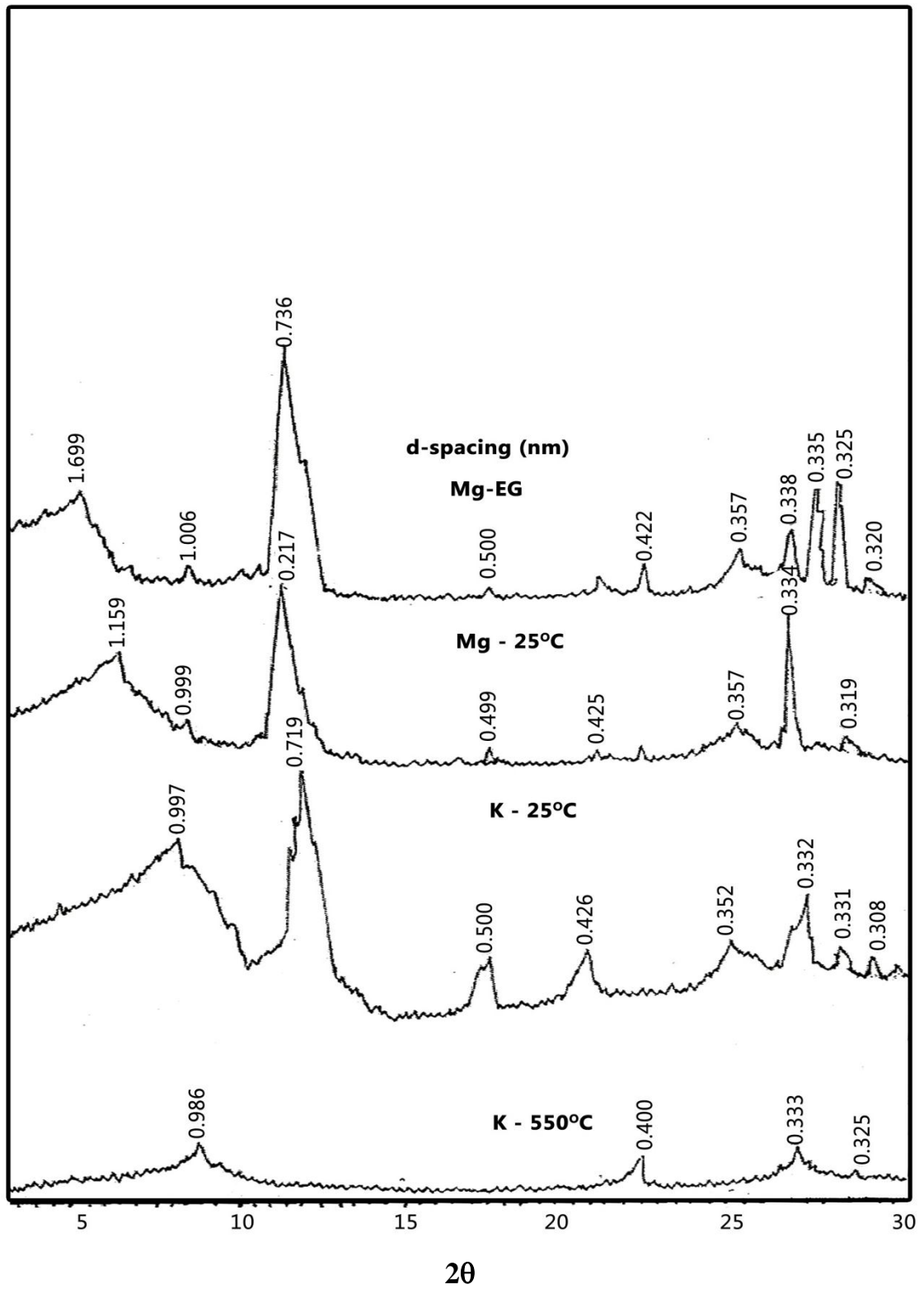


Fig. 4.21. X-ray diffractograms of pedon 5 (Fluventic Haplustepts)

was observed at 0.426 nm d-spacing with K-saturated at room temperature, treatment indicated the presence of quartz.

Semi-quantitative estimates had shown that kaolinite (46%) was the dominant clay mineral followed by smectite (40%), feldspars (8%), illite (4%) and quartz (2%).

Pedon 6

X-ray diffractograms of clay fraction for pedon 6 were presented in Figure 4.22.

1. Presence of **smectite** was identified by the following reflections.
 - a. Mg-saturation with ethylene glycol solvation : A strong peak at 1.654 nm d-spacing.
 - b. Mg-saturation of room temperature : A sharp peak at 1.228 nm d-spacing.
 - c. K-saturated at 25°C : Conspicuous peak at 1.227 nm d-spacing.
 - d. K-saturated and heated to 550°C : Sharp peak at 0.952 nm d-spacing.
2. **Kaolinite** was identified by the following peaks at different d-spacings.
 - a. A strong first order peak at 0.717 nm d-spacings in Mg-saturated ethylene glycol solvated treatment and Mg-saturated at room temperature. Similar peak in K-25°C treatment and disappearance of the same peak in K-saturated and heated to 550°C treatment indicated the presence of kaolinite.
 - b. Small second order peaks were noticed at 0.355, 0.357 and 0.356 nm d-spacings in Mg-saturated with ethylene glycol solvation, Mg-saturated at room temperature and K-25°C

treatments, respectively. Collapse of the peak at K-550°C treatment confirmed the presence of kaolinite.

3. A significant quantity of feldspars was identified by their characteristic peaks at 0.303 nm d-spacings in Mg-saturated with ethylene glycol solvation and Mg-saturated at room temperature treatments. Further, similar peak at 0.311 nm d-spacing in K-550°C treatment proved the presence of feldspars.
4. Presence of illite in the clay fraction was identified by following peaks with different treatments.
 - a. First order peaks at 1.013 and 0.997 nm d-spacings were observed in both Mg-saturated with ethylene glycol solvation and Mg-saturated at room temperature treatments, respectively. Further, similar peaks were observed at 0.998 and 0.952 nm d-spacings in K-25°C and K-550°C treatments, respectively.
 - b. Second order peaks were also observed at 0.495, 0.501 and 0.494 nm d-spacings with Mg-25°C, K-25°C and K-550°C treatments, respectively.
 - c. Third order peaks at 0.334 and 0.331 nm d-spacings were noticed in Mg-saturated with ethylene glycol solvated treatment and Mg-saturated at room temperature treatments, respectively. Furthermore, the third order peaks were also observed at 0.334 and 0.329 nm d-spacings in K-25°C and K-550°C treatments, respectively.

All the above characteristic peaks indicated the presence of illite.

Semi quantitative estimates had shown that smectite (53%) was the dominant clay mineral followed by kaolinite (25%), feldspars (16%) and illite (6%).

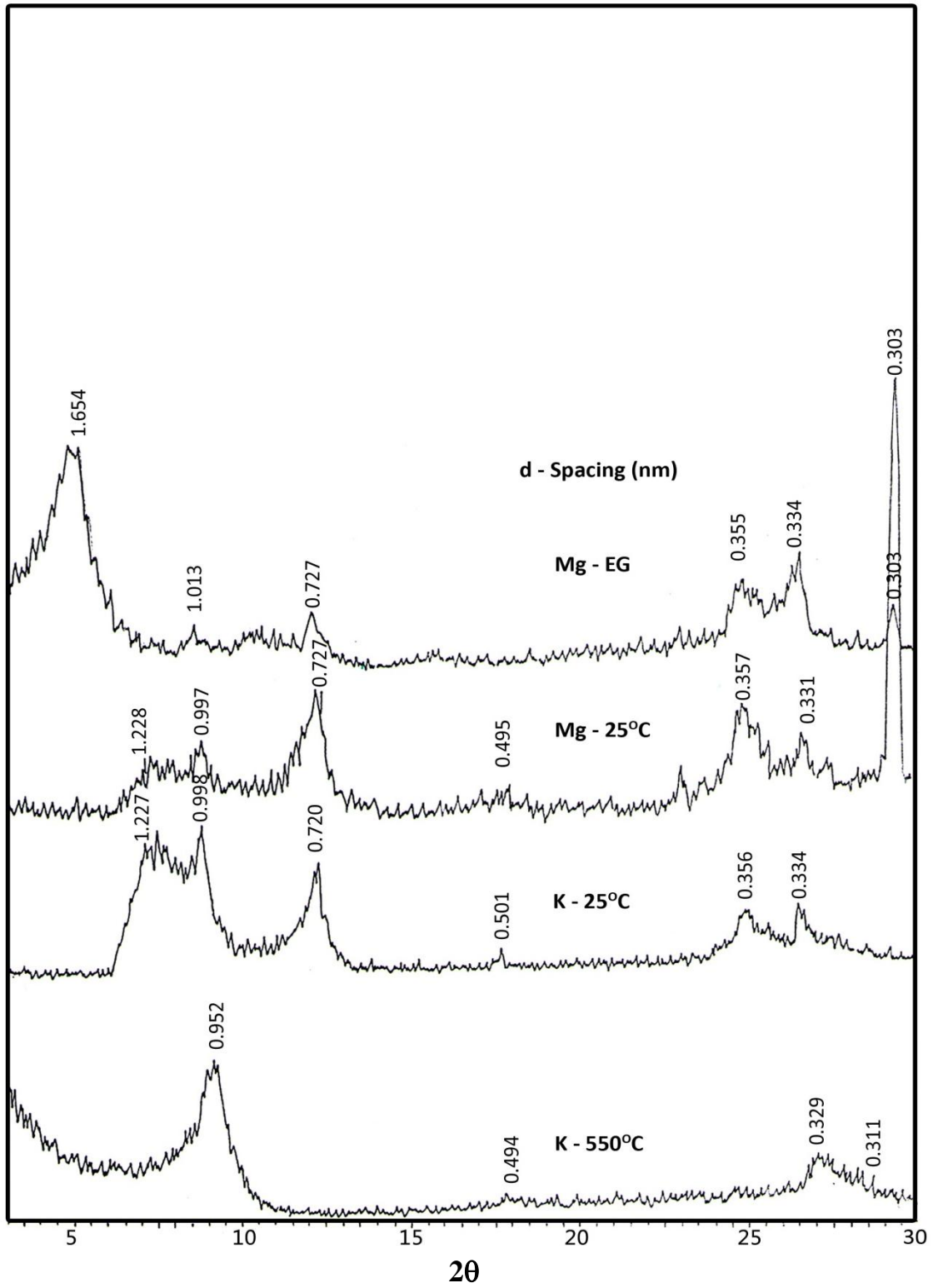


Fig. 4.22. X-ray diffractograms of pedon 6 (Lithic Ustorthents)

Pedon 7

The diffraction patterns of clay fraction for pedon 7 were depicted in Figure 4.23.

1. The X-ray diffractograms of clay exhibited an intense large peak at 0.726 nm d-spacing followed by a higher order peak at 0.357 nm d-spacing in Mg-saturated ethylene glycol solvation treatment. These peaks were persisted on Mg-saturation at room temperature and K-saturation at room temperature but collapsed in K-saturated and heated to 550°C treatment, confirmed the presence of kaolinite.
2. Presence of smectite was detected by an intense large peak at 1.668 nm d-spacing in Mg-saturated with ethylene glycol solvated treatment and a peak at 1.484 nm d-spacing in Mg-saturated sample at room temperature. Further, the peaks were shifted to 0.999 and 1.003 nm d-spacing with K-saturation at room temperature and K-saturation and heated to 550°C treatments, respectively.
3. A sharp large peak observed at 0.995 nm d-spacing followed by higher order peaks at 0.499 nm and 0.334 nm d-spacings in Mg-saturated with ethylene glycol solvation treatment and persistence of these peaks in all other treatments indicated the presence of illite clay mineral.
4. The presence of feldspars was identified by peaks at 0.325 and 0.319 d-spacings in Mg-saturated with ethylene glycol solvation and Mg-saturated at room temperature treatments, respectively and persistence of these peaks in all other treatments indicated the presence of feldspars.

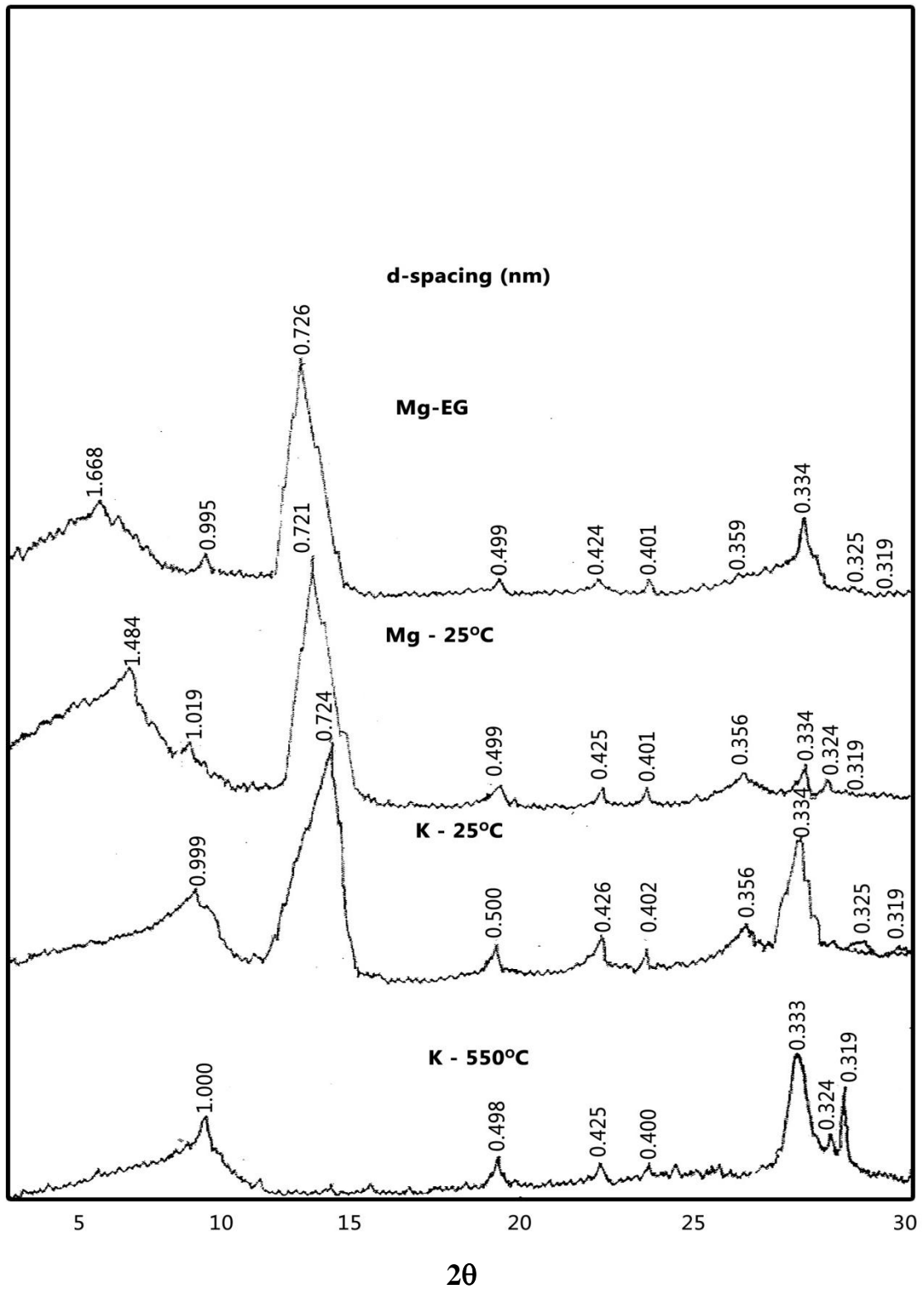


Fig. 4.23. X-ray diffractograms of pedon 7 (Typic Ustifluvents)

5. Very small peaks were observed at 0.424 and 0.425 nm d-spacings in both Mg-saturated with ethylene glycol solvated and Mg-saturated at room temperature treatments. Further, small peaks observed at 0.425 nm d-spacings with K-saturated at room temperature and K-saturated and heated at 550°C treatments indicated the presence of small amounts of quartz.

Semi-quantitative estimates had shown that kaolinite (49%) was relatively dominant clay mineral followed by smectite (37%), illite (10%), feldspars (3%) and quartz (1%).

The clay fraction of soils in the present study was found to be a mixture of three clay minerals *viz.*, smectite, illite and kaolinite.

Semi-quantification of X-RDA diffractograms of clay fraction showed 40 to 86 per cent of smectite, 10 to 49 per cent of kaolinite, 4 to 13 per cent of illite, 3 to 16 per cent of feldspars and 1 to 4 per cent of quartz. Smectite was the single most dominant mineral in pedons 1, 2, 3, 4 and 6 than other minerals whereas kaolinite was the dominant mineral in pedons 5 and 7.

Transformation and neo-formation are the principal processes in the genesis of clay minerals. Transformation modifies a clay mineral without altering its structure while neo-formation leads to formation of new mineral. The process of elimination and recombination led to formation of 2:1 (or) 1:1 type minerals (Padro *et al.*, 1969).

Smectite was the single dominant mineral in pedons 1, 2, 3, 4 and 6 than other minerals. It is quite unlikely that such a high amount of smectite in these soils could be produced during the low rainfall period of the present semi-arid conditions (Bhattacharyya *et al.*, 1993). Smectite was also formed possibly from plagioclase during earlier geologic period and is an ephemeral in humid environment (Tardy *et al.*, 1973; Bhattacharyya *et al.*, 1993), however its retention is possible because of climate change from humid to

semi-arid during Pliopleistocene transition period (Pal *et al.*, 1989). Similar results were reported by Leelavathi *et al.* (2010a).

Kaolinite is the dominant clay mineral in pedons 5 and 7. Kaolinite present in these pedons might have been formed from smectite (Bhattacharyya *et al.*, 1993). Kaolinite minerals could be formed by neosynthesis from the products of hydrolytic decomposition of feldspars and other primary minerals (Murali *et al.*, 1978; Rengasamy *et al.*, 1978) and by conversion of smectite or vermiculite to kaolinite following hydroxy interlayering in the expandable mineral or mixed layering between 2:1 and 1:1 layers (Pal *et al.*, 1989; Bhattacharyya *et al.*, 1993, 2000). Further, the kaolinite was formed in an earlier geological period with more rainfall and greater fluctuations in temperature (Pal and Deshpande, 1987). However, the study area is also experiencing the above conditions, which may lead to the synthesis of kaolinite mineral in the pedons 5 and 7.

Illite was present in small quantities in all the pedons. Illite present in the clay might have been derived by alteration of micas from the parent material. Potassium bearing minerals of rocks under the prevailing conditions of the soil formation had led to formation of illitic type of minerals (Satyanarayana and Biswas, 1970).

Feldspars and Quartz were present in traces in all the pedons which might have been derived from coarser alluvial sediments by physical weathering.

4.12 SOIL CLASSIFICATION

The detailed taxonomic classification of soil resources of Banaganapalle mandal was given in Table 4.24. Based on the morphological characters (Table 4.4 and Appendix), physical, physico-chemical and chemical properties, the soils of Banaganapalle mandal were classified up to family level as per soil taxonomy (Soil Survey Staff, 2003).

Table 4.24. Soil classification

Pedon No.	Order	Sub-order	Great group	Sub-group	Family	Tentative soil series
1.	Inceptisols	Ustepts	Haplustepts	Vertic Haplustepts	Fine-loamy, smectitic, isohyperthermic Vertic Haplustepts	Pasupula
2.	Entisols	Orthents	Ustorthents	TypicUstorthents	Fine-loamy, smectitic, isohyperthermic Typic Ustorthents	Yerragudipalem
3.	Inceptisols	Ustepts	Haplustepts	Vertic Haplustepts	Fine, smectitic, isohyperthermic Vertic Haplustepts	Palukuru
4.	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Fine-loamy, smectitic, isohyperthermic Typic Haplustepts	Mittapalle
5.	Inceptisols	Ustepts	Haplustepts	Fluventic Haplustepts	Fine-loamy, kaolinitic, isohyperthermic Fluventic Haplustepts	Kapulapalle
6.	Entisols	Orthents	Ustorthents	Lithic Ustorthents	Fine, smectitic, isohyperthermic Lithic Ustorthents	Illuru kothapeta
7.	Entisols	Fluvents	Ustifluvents	Typic Ustifluvents	Fine-loamy, kaolinitic, isohyperthermic, Typic Ustifluvents	Gulamnapeta

4.12.1 Taxonomic classification

CLASSIFICATION OF PEDONS 2, 6 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 Agrawal (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 three pedons were classified under Entisols at order level.

At sub-order level

Pedon 7 exhibited the following features:

- a) Slope less than 25 per cent
- b) An irregular decrease in the organic carbon from 25 cm to lithic contact.
- c) Warmer than cryic.

Based on the above features, the pedon 7 was classified as Fluvents at suborder level. Dhaliwal *et al.* (1996) classified the flood plain soils of Punjab into Fluvents as they showed an irregular decrease of organic carbon.

Pedons 2 and 6 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) 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 2 and 6 were grouped under Orthents at sub-order level. Similar findings were reported by Thangasamy *et al.* (2005) who reported that soils of Sivagiri-micro watershed of Chittoor district in Andhra Pradesh were classified into orthents at sub-order level.

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 placed under Ustifluvents at great group level. Ram *et al.* (2010) reported that some flood-prone soils of eastern plains in Rajasthan were classified under Ustifluvents at great group level.

Pedons 2 and 6 also had ustic moisture regime. Hence, these pedons were classified as Ustorthents at great group level. Thangasamy *et al.* (2005) stated that the soils in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh were classified as Ustorthents at great group level.

At sub-group level

Pedon 7 did not show intergradation with any other taxa or any extra gradation from the central concept. It was logically classified under Typic Ustifluvents at sub-group level. Kannan *et al.* (2011) classified soils of Cauvery delta region of Tamil Nadu as Typic Ustifluvents due to the absence of intergradation with other taxa or any extra gradation from central concept.

Pedon 2 did not show the following characteristics

- a) Lithic contact within 50 cm of the mineral soil surface.
- b) 50% 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 pedon 2 was placed under Typic Ustorthents at sub-group level. Balpande *et al.* (2007) classified grape growing soils in Nasik district, Maharashtra into Typic Ustorthents.

Pedon 6 was characterized by

- a) Did not have aquic condition or redox depletions with a chroma of 2 or less
- b) Presence of Lithic contact within 50 cm of the mineral soil surface

Based on the above characteristics this pedon was placed under “Lithic Ustorthents” at sub-group level. Soils of Mula command of irrigated agroeco-system in Maharashtra, were grouped under Lithic Ustorthents by Kharche and Pharanda (2010).

CLASSIFICATION OF PEDONS 1, 3, 4 AND 5

At order level

Following features in the sub-surface horizons within a depth of 0.15 to 1.58 m in pedons 1, 3, 4 and 5 (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 1, 3, 4 and 5 were recognized by the above features. Jagdish Prasad *et al.* (2001) reported that presence of cambic sub-surface horizon was the diagnostic criteria for Inceptisols.

Hence, pedons 1, 3, 4 and 5 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 1, 3, 4 and 5 have ustic soil moisture regime. Hence, these pedons were classified as Ustepts at this category. Sharma *et al.* (2004a) 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 1, 3, 4 and 5 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 1, 3, 4 and 5 grouped under Haplustepts at great group level. Patil and Jagdish Prasad (2004) placed the *sal* supporting soils in Dindori district of Madhya Pradesh as Haplustepts at great group level.

At sub-group level

Pedons 1 and 3 had vertic features like cracks of 3 to 5 mm wide to a depth of 35 cm and slickensides in the lower horizons. Due to the presence of these vertic characters, these pedons were classified under Vertic Haplustepts. Satyavathi and Suryanarayan Reddy (2004b) classified the soils of Madhira, Khammam and Sangareddi in Andhra Pradesh as Vertic Haplustepts due to the presence of cracks and slickensides.

Pedon 4 was characterized by

- a) Did not have lithic contact within 50 cm from the soil surface
- b) Absence of andic properties and acqic 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.

Hence pedon 4 did not exhibit intergradation with other taxa or an extrgradation from the central concept. Hence, pedon 4 was logically classified as “Typic Haplustepts” at sub-group level. Soils of Mula command of irrigated agroeco-system, Maharashtra, wereclassified under Typic Haplustepts at sub-group level (Kharche and Pharanda, 2010).

Pedon 5 was characterized by

- a) Soils have a slope of 25 per cent
- b) At a depth of 125 cm below the mineral soil surface, an organic carbon content of 0.2 per cent or more and no densic, lithic or paralithic contact within that depth
- c) An irregular decrease in organic carbon content (Holocene age) between a depth of 25 cm and either a depth of 125 cm below the mineral soil surface or densic, lithic or paralithic contact, whichever was shallower.

Based on the above characteristics the pedon 5 was placed under “Fluventic Haplustepts” at sub-group level. Muthumanickam *et al.* (2010)

classified soils of Kangeyam tract, Tamil Nadu as Fluventic Haplustepts on very gently sloping uplands.

CLASSIFICATION AT FAMILY LEVEL

Particle size class

Pedon 3 contained more than 35 per cent and less than 60 per cent clay (weighted average) in the control section, which led the soils to be grouped under Fine particle size class.

Pedons 1, 2, 4, 5, 6 and 7 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.

Mineralogy class

The mineralogy class for pedons 5 and 7 was kaolinitic, since kaoliniteclay mineral contributed to more than 40 per cent in the clay fraction of the pedons. Pedons 1, 2, 3, 4 and 6 showed the dominance of smectite clay mineral (more than 40%) in the clay fraction. Hence, the mineralogy class for these pedons was smectitic (Soil Survey Staff, 1999).

Temperature class

MAST was computed from the MAAT (28.66°C) by adding 3.5°C. The Banaganapalle mandal was classified under megathermic temperature regime because of the prevailing mean annual soil temperature (32.16 °C). MAST of 28°C was used as the limit to separate hyperthermic from megathermic (Sehgal, 1996).

MSST of the study area was 33.49°C which was computed by adding 2.5°C to the MSAT (31.81°C) and deducting the amplitudinal correction factor (0.82°C). The MWST of the study area was 28.71°C calculated by adding 2.5°C to the MWAT (25.39°C) and adding amplitudinal correction

factor (0.82°C). According to Sehgal (1996), the study area was placed under megathermic temperature regime.

Soil Survey Staff (1998) 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 **isohypethermic**.

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

- Pedon 1 : Fine-loamy, smectitic, isohyperthermic Vertic Haplustepts
- Pedon 2 : Fine-loamy, smectitic, isohyperthermic Typic Ustorthents
- Pedon 3 : Fine, smectitic, isohyperthermic Vertic Haplustepts
- Pedon 4 : Fine-loamy, smectitic, isohyperthermic Typic Haplustepts
- Pedon 5 : Fine-loamy, kaolinitic, isohyperthermic Fluventic Haplustepts
- Pedon 6 : Fine, smectitic, isohyperthermic Lithic Ustorthents
- Pedon 7 : Fine-loamy, kaolinitic, isohyperthermic Typic Ustifluvents

4.13 LAND CAPABILITY CLASSIFICATION

The details of land capability classes and sub-classes assigned to the soils of Banaganapalle mandal were given in the Table 4.25. 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 Banaganapalle mandal have been classified into different capability sub-classes and suitable land use plan has been suggested (Table 4.26).

Table 4.25. Land capability classification of soils of Banaganapalle 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.	Pasupula	cl	1.50	Somewhat poorly drained	0-1	Nil	<1%	–	–	–	–	IIs
2.	Yerragudipalem	scl	0.72	Moderately well drained	0-1	Nil	<1%	–	–	–	–	IIIs
3.	Palukuru	c	1.00	Poor	0-1	Nil	<1%	–	–	–	–	IIIws
4.	Mittapalle	cl	1.40	Somewhat poorly drained	1-3	Slight	<1%	–	–	–	–	IIIes
5.	Kapulapalle	sicl	2.00	Somewhat poorly drained	0-1	Nil	<1%	–	–	–	–	IIIs
6.	Illuru Kothapeta	sicl	0.70	Somewhat poorly drained	1-3	Slight	<1%	–	–	–	–	IVes
7.	Gulamnapeta	l	0.87	Well drained	1-3	Slight	<1%	–	–	–	–	IVes

Table 4.26. Interpretation of soils of Banaganapalle mandal

Pedon No.	Tentative soil series	Land capability class with limitations	Description	Major limitations	Suggested land use
1.	Pasupula	IIs	Good cultivable land for sustainable agriculture	Did not have any major limitations except low organic carbon and low nutrient status.	Double cropping including legumes in crop rotation with the addition of fertilizers and manures. Groundnut, redgram, sugarcane and paddy could also be grown
2.	Yerragudipalem	IIIs	Moderately good cultivable land for sustainable agriculture	Poor drainage, poor permeability and high water holding capacity.	Cultivation with precaution against permanent damage, moderate soil conservation measures, growing of leguminous crops in rotation and application of organic manures.
3.	Palukuru	IIIsw	Moderately good cultivable land for sustainable agriculture	Fine texture, high shrink-swell potential, poor drainage, very low hydraulic conductivity, poor soil aeration, alkaline soil reaction and soil tillage problems.	Double cropping including legumes in rotation with special soil and water management practices. Paddy and sugarcane could be grown.

Table 4.26. (Cont.).

Pedon No.	Tentative soil series	Land capability class with limitations	Description	Major limitations	Suggested land use
4.	Mittapalle	IIIes	Moderately good cultivable land for sustainable agriculture	Gentle slope, moderate erosion, moderate run-off, high permeability and poor nutrient status.	Suitable for mango, pulses, oil seeds and vegetables.
5.	Kapulapalle	IIIs	Moderately good cultivable land for sustainable agriculture	Poor drainage, poor permeability and high water holding capacity.	Cultivation with precaution against permanent damage. Moderate soil conservation measures, growing of leguminous crops in rotation and application of organic manures.
6.	Illuru Kothapeta	IVes	Fairly good cultivable land for sustainable agriculture	Gentle slope, moderate erosion, shallow depth, moderate run-off and poor nutrient status	Addition of tank silt (pond mud) is recommended and very careful soil and water management practices could be followed, fruit crops like pomegranate can be grown.
7.	Gulamnapipeta	IVes	Fairly good cultivable land for sustainable agriculture	Gentle slope, moderate erosion, shallow depth, moderate run-off, high permeability and poor nutrient status.	Addition of tank silt (pond mud) is recommended and very careful soil and water management practices could be followed, fruit crops like pomegranate can be grown.

- IIs : Good cultivable lands (Pedon 1)
- IIIs : Moderately good cultivable lands (Pedons 2 and 5)
- IIIs_w : Moderately good cultivable land (Pedon 3)
- IIIs_e : Moderately good cultivable land (Pedon 4)
- IVs_e : Fairly good cultivable lands (Pedons 6 and 7)

Pedon 1 had slight limitations of soil hence, tentatively placed under land capability sub-class IIs. Further, similar land capability classification was suggested to the soils developed from basaltic terrain (Sharma *et al.*, 1996). Singh and Mishra (1996) had also given the tentative classification of IIs for Entisols (Typic Ustorthents) and Inceptisols (Typic Eutrochrepts) of Gandak command area of Bihar. The suggested land use plan for pedon 1 was double cropping including legumes in rotation with the addition of manures and fertilizers and need moderate soil and water management practices. Groundnut, redgram and sugarcane crops can be grown in these soils.

Pedons 2 and 5 were placed under capability sub-class IIIs which were moderately good cultivable lands for sustainable agriculture with moderate limitations such as excessively drained, low organic carbon and low water holding capacity. The management practices suggested for pedons 2 and 5 were growing of leguminous crops in rotation and application of organic manures. Similarly, Vara Prasad Rao *et al.* (2008) placed the soils of Ramachndrapuram mandal in Chittoor district of Andhra Pradesh under land capability sub-class IIIs.

Pedon 3 was grouped under capability sub-class IIIs_w. These were moderately good cultivable lands with moderate limitations of soil and wetness (Fine texture, high shrink-swell potential, poor drainage, poor soil aeration and alkaline soil reaction). The management practices suggested for pedon 3 was double cropping including legumes in rotation with special soil

and water management practices. Paddy and sugarcane could be grown. Similar land capability classification was given by Thangasamy *et al.* (2005) to the soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh.

Pedon 4 was classified into land capability sub-class IIIse which was moderately good cultivable land for sustainable agriculture with moderate limitation of erosion due to very gentle slope, moderate runoff and low permeability. Similarly Thangasamy *et al.* (2005) placed the soils of Sivagiri micro-watershed in Chittoor district of Andhra Pradesh under land capability sub-class IIIse. The suggested land use plan for pedon 2 is growing of horticultural crops like mango, sapota, guava, custard apple *etc.* Similar views were expressed by Sarkar *et al.* (2002) in Loktak catchment area of Manipur.

Pedons 6 and 7 were classified into land capability sub-class IVse. These were fairly good cultivable lands for sustainable agriculture with severe limitation of erosion and soils (shallow depth, gentle slope, moderate erosion, low organic carbon, low nutrient status and poor drainage). The suggested land use plan for pedons 6 and 7 was addition of tank silt to improve the soil texture, very careful soil and water management practices could be followed and vegetables, pulses and oil seeds can be preferred in these soils. These soils also require proper conservation measures like contour bunding and contour farming to protect the soils against erosion. Similar land capability classification was given by Vara Prasad Rao *et al.* (2008) to the soils of Ramachandrapuram mandal in Chittoor district of Andhra Pradesh.

4.14 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 agroecological conditions, 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 requirements of a crop were 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 4.27. The site-soil properties from the study area (Table 4.28) were matched with the soil-site suitability criteria (Appendix-II) for rice, sorghum, chick pea and sun flower crops that were grown in Banaganapalle mandal of Kurnool district, Andhra Pradesh. The kind and degree of limitations were evaluated (Table 4.29) and the suitability of different soils of study area for growing rice, sorghum, chick pea and sun flower crops were 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 Van 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, Sorghum, Chick pea and Sun flower	-	-
Pedon 2	-	-	Rice, Sorghum	Chick pea and Sun flower	-
Pedon 3	-	-	Sorghum	Rice, Chick pea and Sun flower	-
Pedon 4	-	-	Rice, Sorghum, Chick pea and Sun flower	-	-
Pedon 5	-	-	Sorghum, Chick pea and Sun flower	Rice	-
Pedon 6		-	Rice, Sorghum, Chick pea and Sun flower		-
Pedon 7		-	Rice, Sorghum, Chick pea and Sun flower		-

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 that occur elsewhere in same agro-climatic subregion under scientific management practices (Khadse and Gaikwad, 1995).

The soil site characteristics of the study area were matched with soil site suitability criteria for a few important crops *viz.*, rice, sorghum, chickpea and sunflower (Appendix II) given by Sys *et al.* (1993). The kind and degree of limitation and suitability class was 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.

Table 4.27. Depth wise soil characteristics used in assessing crop suitability

Ped on No.	Location	Hori- zon	Depth (m)	Physical characteristics (s)				Fertility characteristics (f)					Salinity and alkalinity (n)	
				Sand (2- 0.05%)	Texture		CaCO ₃ (%)	CEC [cmol (p+) kg ⁻¹ soil]	BS (%)	Sum of basis cations [cmol (p+) kg ⁻¹ soil]	pH (1:2.5 H ₂ O)	OC (%)	EC (dSm ⁻¹)	ESP
					Silt (0.05 - 0.002)	Clay (<0.002)								
1	Pasupula	Ap	0.00-0.15	25.65	30.96	43.39	5.5	51.24	98.73	48.84	8.11	0.43	0.93	0.80
		2Bw1	0.15-0.41	26.79	34.58	38.63	14.5	44.45	96.29	42.09	8.02	0.34	0.78	0.83
		3Bw2	0.41-0.64	20.20	45.40	34.40	15.5	43.15	97.15	40.69	8.33	0.22	0.78	0.72
		4Bw3	0.64-0.90	28.57	38.17	33.26	18.5	42.11	98.54	39.63	8.54	0.18	0.77	0.43
		5Bw4	0.90-1.07	28.74	40.86	25.40	2.5	40.97	98.99	38.86	8.62	0.16	0.74	0.39
		Bw5	1.07-1.50+	30.15	42.57	27.28	7.5	40.80	88.46	34.21	8.68	0.21	0.85	0.47
2	Yerragudi Palem	Ap	0.00-0.23	50.85	21.37	27.78	5.5	42.54	99.84	42.34	8.63	0.18	0.89	0.33
		A1	0.23-0.52	51.54	23.34	25.12	6.5	33.58	74.15	24.86	8.42	0.13	0.20	1.28
		A2	0.52-0.72	51.78	30.69	17.53	15.5	21.84	92.40	20.10	8.06	0.10	0.12	2.01
		Cr	0.72	Weathered gneiss										
3	Palukuru	Ap	0.00-0.18	19.79	31.33	48.88	33.5	42.28	95.22	39.64	8.38	0.40	0.12	1.04
		Bw1	0.18-0.43	23.42	25.16	51.42	21.5	42.33	91.07	37.89	8.50	0.31	0.28	0.92
		Bw2	0.43-0.67	27.79	21.66	50.55	37.5	41.89	99.80	40.83	8.28	0.09	0.49	0.79
		Bw3	0.67-0.91	18.86	32.71	48.43	25.5	42.65	99.90	41.46	8.08	0.35	0.59	0.61
		Cr	0.91	Dolomite										

Table 4.27. (Cont.).

Ped on No.	Location	Hori- zon	Depth (m)	Physical characteristics (s)			CaCO ₃ (%)	Fertility characteristics (f)					Salinity and alkalinity (n)	
				Sand (2-0.05%)	Texture 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 ₂ O)	OC (%)	EC (dSm ⁻¹)	ESP
				— % of <2 mm soil —										
4	Mittapalle	Ap	0.00-0.19	36.21	24.70	39.09	6.5	42.55	96.66	41.12	8.15	0.76	0.29	1.34
		Bw1	0.19-0.48	38.43	29.48	32.09	7.5	41.68	86.06	35.75	7.95	0.66	0.66	0.60
		2Bw2	0.48-0.86	32.41	47.11	20.48	7.5	38.36	76.06	29.00	7.92	0.21	0.57	0.31
		3Bw3	0.86-1.10	49.21	26.41	24.38	8.5	40.37	62.52	25.13	8.48	0.12	0.35	0.57
		4Bw4	1.10-1.40	44.21	14.47	41.32	8.5	50.10	62.26	31.10	8.19	0.27	0.25	0.48
		Cr	1.40	Granite containing plagioclase feldspars with pegmatite veins										
5	Kapulapalle	Ap	0.00-0.21	16.62	46.78	36.60	27.5	50.97	65.70	33.41	8.22	0.58	0.25	1.67
		2A1	0.21-0.61	45.65	23.91	30.44	26.5	44.72	85.33	36.82	8.10	0.18	0.35	0.94
		3Bw1	0.61-1.01	21.69	50.59	27.72	25.5	37.03	95.78	32.56	8.56	0.25	0.28	0.76
		4Bw2	1.01-1.40	28.13	48.70	23.17	22.5	28.31	95.44	24.08	8.70	0.04	0.22	1.48
		5Bw3	1.40-2.00	46.63	32.03	21.34	28.5	38.63	85.53	30.61	8.47	0.07	0.24	1.01
		Cr	2.00	Granite containing plagioclase feldspars with pegmatite veins										
6	Illuru Kothapeta	Ap	0.00-0.18	20.97	46.10	32.93	19.5	41.78	83.19	32.92	8.30	0.44	0.27	2.11
		A1	0.18-0.39	17.91	44.37	37.72	17.5	51.18	50.55	24.45	8.37	0.32	0.24	0.25
		A2	0.39-0.50	19.96	46.34	33.70	10.5	46.89	53.61	23.85	8.55	0.04	0.48	0.11
		Cr	0.50	Granite containing plagioclase feldspars with pegmatite veins										
7	Gulamnapipeta	Ap	0.00-0.20	43.64	30.24	26.12	17.5	30.15	98.77	29.62	8.21	0.29	0.12	1.19
		2A1	0.20-0.50	52.79	24.80	22.41	16.5	28.58	94.82	26.10	8.02	0.14	0.13	1.05
		3A2	0.50-0.87	42.55	31.26	26.19	16.5	25.10	97.33	24.25	8.10	0.16	0.14	1.16
		4A3	0.87-1.00	43.05	36.19	20.76	14.5	26.24	91.41	23.37	8.11	0.13	0.14	1.03
		Cr	1.00	Granite containing plagioclase feldspars with pegmatite veins										

Table 4.28. 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	Fine-loamy, smectitic, iso-hyperthermic, Vertic Haplustepts	Plain	Granite gneiss	Somewhat poorly drained	cl	Nil	1.50	13.22	117.84	46.14	97.01	8.07	0.39	0.80	0.83
2	Fine-loamy, smectitic, iso-hyperthermic, Typic Ustorthents	Plain	Granite gneiss	Moderately well rained	scl	Nil	0.72	8.68	142.63	40.94	87.43	8.60	0.18	0.40	2.01
3	Fine, smectitic, iso-hyperthermic, Vertic Haplustepts	Plain	Dolomite	Poor	c	Nil	1.00	29.15	83.90	39.15	96.52	8.41	0.37	0.39	1.04
4	Fine-loamy, smectitic, iso-hyperthermic, Typic Haplustepts	Very gently sloping	Granite gneiss	Somewhat poorly drained	cl	Nil	1.40	7.45	124.19	39.83	80.98	8.10	0.73	0.51	1.34
5	Fine-loamy, kaolinitic, iso-hyperthermic, Fluventic Haplustepts	Plain	Granite gneiss	Somewhat poorly drained	sicl	Nil	2.00	26.32	143.70	33.96	85.28	8.20	0.52	0.30	1.67
6	Fine, smectitic, iso-hyperthermic, Lithic Ustorthents	Very gently sloping	Granite gneiss	Somewhat poorly drained	sicl	Nil	0.70	16.68	132.51	30.55	62.97	8.32	0.41	0.21	2.11
7	Fine-loamy, kaolinitic, iso-hyperthermic, Typic Ustifluvents	Very gently sloping	Granite gneiss	Well drained	l	Nil	0.87	16.44	122.69	28.92	96.10	8.17	0.26	0.13	1.19

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

Pedons 1 and 3 were grouped under Vertic Haplustepts. Pedon 1 was marginally suitable (S3) for crops like rice, sorghum, chickpea and sunflower whereas pedon 3 was marginally (S3) suitable for sorghum and temporarily not suitable (N1) for rice, chickpea and sunflower. Soil fertility characteristics *viz.*, pH and organic carbon and physical soil characteristics like texture and depth were the limitations. For all four crops organic carbon and pH were major limitations. Texture (clay loam) was a limitation for rice (pedon 1) and chickpea (pedon 3). 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. Vertic Haplustepts were found to be marginally suitable (S3) for growing chickpea (Satyavathi and Suryanarayan Reddy, 2004a).

Pedon 2, which was classified under Typic Ustorthents was marginally suitable (S3) for rice and sorghum and temporarily not (N1) suitable for chickpea and sunflower. The major limiting factors for the growth of chickpea and sunflower in this soil were pH (8.13) and organic carbon (0.16). It can be improved by reducing soil pH through application of organic manures and amendments like sulphur. Organic carbon status in this soils can be improved by the application of farm yard manure, green manuring and inclusion of legumes in crop rotation. The other limiting factors were the texture and depth. The texture can be improved by mixing with tank silt year after year. Satish Kumar (2007) reported that Typic Ustorthents were marginally suitable for growing rice crop.

Pedon 4, which was grouped under Typic Haplustepts was marginally suitable (S3) for crops like rice, sorghum, chickpea and sunflower and these crops suffer from the soil constraints like texture, pH and organic carbon.

The soil characteristics viz., texture, soil reaction and organic carbon were constraints for sorghum crop. The texture can be improved by mixing with tank silt year after year. The pH can be controlled by application of organic manures and sulphur. The organic carbon status in these soils can be improved by the application of farm yard manure, green manuring and inclusion of legumes in crop rotation. Leelavathi *et al.* (2010b) reported that Typic Haplustepts were marginally suitable (S3) for growing paddy crop in Yerpedu mandal of Chittoor district, Andhra Pradesh.

Pedon 5 was classified under Fluventic Haplustepts, was marginally suitable (S3) for growing sorghum, chickpea and sun flower crops and temporarily not suitable (N1) for rice. This soil has limitations of wetness and soil characteristics like texture and fertility characteristics like pH and organic carbon. Alkalinity was not a limitation for all crops. Hence, the pH can be controlled by application of organic manures and sulphur. The organic carbon status in these soils can be improved by the application of farm yard manure, green manuring and inclusion of legumes in crop rotation and texture can be improved by mixing with tank silt year after year.

Pedon 6 grouped under Lithic Ustorthents, was marginally suitable (S3) for rice, sorghum, chickpea and sunflower. These soils had slight limitations of wetness (drainage) and physical soil characteristics like texture, soil depth and fertility characteristics like pH and organic carbon. Alkalinity was not a limitation for all crops.

Pedon 7 which was grouped under Typic Ustifluvents, was marginally suitable (S3) for rice, sorghum, chickpea and sunflower. The limitations were physical soil characteristics (texture and depth) and soil fertility characteristics (pH and organic carbon). So the organic carbon status in these soils can be improved by the application of farm yard manure, green manuring and inclusion of legumes in crop rotation. Texture was a limitation for all crops and this can be improved by mixing the soil

Table 4.29. 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) ESP	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 (%)			
Vertic Haplustepts	Rice	2	1	0	0	2	0	1	3	0	S3wsf	S1ws
	Sorghum	2	0	0	0	0	0	3	2	0	S3wf	S1w
	Chickpea	2	0	0	0	1	0	3	3	0	S3wf	S1w
	Sunflower	2	0	0	0	1	0	3	3	0	S3wf	S1w
Typic Ustorthents	Rice	0	1	0	2	2	0	3	3	0	S3sf	S2s
	Sorghum	0	1	0	1	0	0	3	2	0	S3sf	S1s
	Chickpea	0	1	0	2	0	0	4	3	0	N1sf	S2s
	Sunflower	0	1	0	3	1	0	4	3	0	N1sf	S3s
Vertic Haplustepts	Rice	2	0	0	0	4	0	2	3	0	N1wf	S1w
	Sorghum	2	0	0	0	1	0	3	2	0	S3wf	S1w
	Chickpea	2	1	0	1	2	0	4	3	0	N1wsf	S1ws
	Sunflower	2	0	0	1	3	0	4	3	0	N1wsf	S1ws
Typic Haplustepts	Rice	2	1	0	0	2	0	1	3	0	S3sf	S1s
	Sorghum	2	2	0	0	0	0	3	2	0	S3sf	S2s
	Chickpea	2	0	0	1	0	0	2	3	0	S3sf	S1s
	Sunflower	2	0	0	1	1	0	3	3	0	S3sf	S1s
Fluventic Haplustepts	Rice	2	1	0	0	4	0	1	3	0	N1wsf	S1s
	Sorghum	2	0	0	0	1	0	3	2	0	S3wf	S1
	Chickpea	2	1	0	0	2	0	2	3	0	S3wsf	S1s
	Sunflower	2	0	0	0	3	0	3	3	0	S3wf	S1
Lithic Ustorthents	Rice	2	1	0	2	3	0	2	3	0	S3wsf	S2s
	Sorghum	2	0	0	1	0	0	3	2	0	S3wsf	S1s
	Chickpea	2	1	0	2	1	0	3	3	0	S3wsf	S2s
	Sunflower	2	0	0	3	2	0	3	3	0	S3wsf	S3s
Typic Ustifluvents	Rice	0	2	0	1	3	0	1	3	0	S3sf	S2s
	Sorghum	0	1	0	1	0	0	3	2	0	S3sf	S1s
	Chickpea	0	1	0	1	1	0	2	3	0	S3sf	S1s
	Sunflower	0	1	0	2	2	0	3	3	0	S3sf	S2s

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.

with tank silt year after year. Alkalinity was not a limiting factor for growing all four crops. Satyavathi and Suryanarayana Reddy (2004a) reported that Entisols were marginally suitable for growing chickpea in Telangana region of Andhra Pradesh.

The soil-site suitability for different crops (rice, sorghum, chickpea and sun flower) revealed that all the pedons (1, 2, 3, 4, 5, 6 and 7) exhibited organic carbon content and pH as severe limitations. Improper drainage was the limitation for pedons 1 and 3. Texture was a limitation in pedons 2, 4 and 7. Shallow depth was a major limitation for pedons 2 and 6. By correcting the above limitations sustainable yields can be achieved in rice, sorghum, chickpea and sun flower crops.

**Table 4.30. Simple correlations between different soil properties
(Relation among chemical and physical properties)**

Variables		r-values
pH	vs	CaCO ₃ 0.019
pH	vs	Base saturation -0.066
pH	vs	Available Zn -0.144
pH	vs	Available Cu 0.226
pH	vs	Available Fe 0.137
pH	vs	Available Mn -0.065
Organic carbon	vs	Total N 0.551**
Organic carbon	vs	Total P 0.304
Organic carbon	vs	Total S 0.521**
Organic carbon	vs	Available N 0.509**
Organic carbon	vs	Available P 0.201
Organic carbon	vs	Available K 0.187
Organic carbon	vs	Available S 0.084
Organic carbon	vs	Available Zn 0.317
Organic carbon	vs	Available Cu 0.255
Organic carbon	vs	Available Fe 0.206
Organic carbon	vs	Available Mn 0.402*
Clay	vs	R ₂ O ₃ 0.051
Clay	vs	Available Zn 0.459**
Clay	vs	Available Cu 0.389*
Clay	vs	Available Fe 0.267
Clay	vs	Available Mn 0.305
Clay	vs	CEC 0.631**
Sand	vs	Silica 0.299
Bulk density	vs	Pore space -0.091
Bulk density	vs	Organic carbon -0.404*
Water holding capacity	vs	Clay 0.490**
Water holding capacity	vs	Sand -0.513**
Loss on ignition	vs	Clay 0.286
Loss on ignition	vs	Sand -0.403*
Volume expansion	vs	Clay 0.531**

* 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 Banaganapalle mandal of Kurnool district in Andhra Pradesh.

Seven representative pedons were selected in seven different locations of Banaganapalle 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 CaCO₃; electro-chemical characteristics such as CEC, exchangeable bases and base saturation; chemical composition (SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, P₂O₅, Na₂O and K₂O) and total and available nutrients (N, P, K, S, Zn, Cu, Fe and Mn) status. Clay mineral analysis was also carried out to identify relative proportion of various clay minerals in the soil samples collected from the control section of each pedon.

The climate of the Banaganapalle mandal was semi-arid monsoonic climate with a mean annual rainfall and air temperature of 775.43 mm and 28.66°C, respectively. However, distinct summer, rainy and winter seasons were existing in the Banaganapalle mandal.

Pedons 1, 2, 4, 5, 6 and 7 were developed from granite-gneiss parent material and pedon 3 was developed from dolomite parent material. These pedons were occurring on plains to very gently sloping topography with deep to very deep in depth. These pedons were characterized by AC (Pedons 2, 6 and 7) and ABC (Pedons 1, 3, 4 and 5) profiles. The colour varied from

dark yellowish brown to brown in pedons 2, 6 and 7, dark gray to very dark grayish brown in pedons 1 and 3, dark brown to strong brown in pedons 4 and 5.

The morphological features indicated that these pedons in general had fine to coarse texture and sub-angular blocky to angular blocky structure. Consistence varied from slightly hard to very hard, fraible to very firm and non-sticky and non-plastic to very sticky and very plastic in dry, moist and wet conditions, respectively. Cracks of 3 to 5 mm wide up to a depth of 35 cm and indistinct and weak slickensides were observed below 0.70 m in the pedons 1 and 3.

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

All the pedons were slightly alkaline to strongly alkaline in reaction, non-saline and low in organic carbon content. All these pedons exhibited higher CaCO_3 status. CEC values of these pedons were low to medium. A decreasing trend was observed in pedons 1 and 2 with depth whereas pedons 3, 4 and 6 showed a decreasing trend with depth except in the last horizon and the 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 was decreased in pedons 2 and 3 along with depth while pedon 1 showed a decreasing trend with depth up to 4Bw3 horizon and later on increased. All other pedons did not show any particular trend with depth. Further, $\text{SiO}_2 / \text{R}_2\text{O}_3$, $\text{SiO}_2 / \text{Al}_2\text{O}_3$, $\text{SiO}_2 / \text{Fe}_2\text{O}_3$, $\text{Al}_2\text{O}_3 / \text{R}_2\text{O}_3$

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, medium to high in available phosphorus and low to high in available potassium and high in available sulphur. As far as cationic micronutrients (DTPA-extractable) status was concerned, the available iron and zinc were deficient while the available copper and manganese were sufficient.

X-ray diffraction analysis of clay samples revealed that the pedons 1, 2, 3, 4 and 6 showed the dominance of smectite clay mineralogy whereas pedons 5 and 7 exhibited the dominance of kaolinitic clay mineralogy.

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

- Pedon 1 : Fine-loamy, smectitic, isohyperthermic Vertic Haplustepts
- Pedon 2 : Fine-loamy, smectitic, isohyperthermic Typic Ustorthents
- Pedon 3 : Fine, smectitic, isohyperthermic Vertic Haplustepts
- Pedon 4 : Fine-loamy, smectitic, isohyperthermic Typic Haplustepts
- Pedon 5 : Fine-loamy, kaolinitic, isohyperthermic Fluventic Haplustepts
- Pedon 6 : Fine, smectitic, isohyperthermic Lithic Ustorthents
- Pedon 7 : Fine-loamy, kaolinitic, isohyperthermic Typic Ustifluvents

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

Pedon 1 classified under land capability sub-class IIs. These are good cultivable lands with slight limitations of soil (low organic carbon, low nutrient status and high permeability). Pedons 2 and 5 were grouped under land capability sub-class IIIs. These were moderately good cultivable lands with moderate limitations of soil (poor drainage, poor permeability, low

organic carbon content and high water holding capacity). Pedon 3 was placed under land capability sub-class IIIsw. These were moderately good cultivable lands with moderate limitations of soil and wetness (fine texture, high shrink-swell potential, poor drainage, poor soil aeration, alkaline reaction and soil tillage problems).

Pedon 4 was placed under land capability sub-class IIIes. These were moderately good cultivable lands for sustainable agriculture with severe limitations of erosion and low nutrient status. Pedons 6 and 7 grouped under land capability sub-class IVes. These were fairly good cultivable lands with severe limitation of erosion and soil *i.e.* gentle slope, moderate erosion and shallow depth.

The soil-site suitability evaluation of study area revealed that all the pedons were marginally suitable (S3) for growing sorghum crop. Pedons 1, 4, 6 and 7 were marginally suitable (S3) for growing rice, sorghum, chickpea and sunflower. Pedons 2 and 3 were temporarily not suitable (N1) whereas pedon 5 was marginally (S3) suitable for growing chickpea and sunflower crops. However, pedon 2 was marginally suitable (S3) and pedons 3 and 4 were temporarily not suitable (N1) for growing paddy crop.

In conclusion, the analysis of soils of the Banaganapalle mandal revealed that the soils were low to medium in organic carbon, low to medium in available N, medium to high in available P, low to high in available K and deficient in Zn and Fe. Hence, integrated use of organic manures in combination with inorganic fertilizers not only helps to achieve sustainable yields of crops but also sustains the soil health.

Literature Cited

LITERATURE CITED[#]

- Anil Kumar, K.S. 2002. Characterization, classification and suitability evaluation of coffee - growing soils of Karnataka. *Ph.D Thesis*, University of Agricultural Sciences, Bangalore.
- Anitha, G. 1996. Characterisation and classification of black soils in Gurazala mandal in Guntur district of Andhra Pradesh. *M.Sc. (Ag.) Thesis*, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad.
- Arun Kumar, V., Natarajan, S and Sivasamy, R. 2002. Characterisation and classification of soils of lower Palar - Manimuthar watershed of Tamil Nadu. *Agropedology*. 12: 97-103.
- Ashok Kumar, H.P and Jagdish Prasad. 2010. Some typical sugarcane growing soils of Ahmadnagar district of Maharashtra. Their characterization, classification and nutritional status of soils and plants. *Journal of the Indian Society of Soil Science*. 58(3): 257-266.
- Bali, S.K., Raj, K., Hundal, H.S., Singh, K and Singh, B. 2010. GIS-aided mapping of DTPA extractable zinc and soil characteristics in the state of Punjab. *Journal of the Indian Society of Soil Science*. 58(2): 235-240.
- Balpande, H.S., Challa, O and Jagdish Prasad. 2007. Characterization and classification of grape growing soils in Nasik district of Maharashtra. *Journal of the Indian Society of Soil Science*. 55(1): 80-83.
- Basavaraju, D., Naidu, M.V.S., Ramavatharam, N., Venkaiah, K., Rama Rao, G and Reddy, K.S. 2005. Characterisation, classification and evaluation of soils in Chandragiri mandal of Chittoor district, Andhra Pradesh. *Agropedology*. 15: 55-62.
- Bhaskar, B.P and Nagaraju, M.S.S. 1998. Characterisation of some salt affected soils occurring in Chitravathi river basin of Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 46: 416-421.
- Bhaskar, B.P and Subbaiah, G.V. 1995. Genesis, characterisation and classification of laterites and associated soils along the east coast of Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 45: 107-112.

[#] As per the thesis format guidelines (2010) prescribed by Acharya N.G.Ranga Agricultural University, Rajendranagar, Hyderabad 500030 for thesis presentation.

- Bhaskar, B.P., Saxena, R.K., Vadivelu, S., Baruah, U., Butte, P.S and Dutta, D.P. 2004a. Soils on *Jhum* cultivated hill slopes of Narang – Kongripara watershed in Meghalaya. *Journal of the Indian Society of Soil Science*. 52: 125-133.
- Bhaskar, B.P., Saxena, R.K., Vadivelu, S., Baruah, U., Butte, P.S and Dutta, D.P. 2004b. Pedogenesis in high attitude soils of Meghalaya Plateau. *Agropedology*. 14: 9-23.
- Bhatnagar, R.K., Bansal, K.N and Trivedi, S.K. 2003. Distribution of sulphur in some profiles of Shivpuri district of Madhya Pradesh. *Journal of the Indian Society of Soil Science*. 51: 74-76.
- Bhattacharyya, T., Pal, D.K and Deshpande, S.D. 1993. Genesis and transformation of minerals in the formation of red (Alfisols) and black (Inceptisols and Vertisols) soils on Deccan basalt in the Western Ghats, India. *Journal of Soil Science*. 44: 159-171.
- Bhattacharyya, T., Pal, D.K and Srivastava, P. 2000. Formation of gibbsite in the presence of 2:1 minerals: An example from Ultisols of northern India. *Clay Minerals*. 35: 847-850.
- *Black, G.R and Hartge, K.H. 1986. *Bulk density and particle density In: Methods of soil analysis, part-1* Ed. by Arnold klyte Monograph No.9 Agronomy series American Society of Agronomy Inc., Madison, Wisconsin, USA. 363-382.
- *Bower, C.A., Reitemeier, R.F and Fireman, M. 1952. Exchangeable cations analysis of saline and alkali soils. *Soil Science*. 73: 251-261.
- Brady, N.C. 1990. *The Nature and Properties of Soils*. Tenth edition, Prentice Hall of India Limited, New Delhi pp 65.
- Brady, N.C. 1995. *The Nature and Properties of Soils*. Tenth edition, Prentice Hall of India Limited, New Delhi. pp 65.
- Buol, S.W., Hole, F.D., Mc Cracken, R.J and Southard, R.J. 1998. *Soil Genesis and Classification*. Fourth edition, Panima Publishing Corporation, New Delhi. 1-380.
- Chakravathy, D.N., Sehgal, J.L and Dev, G. 1979. Sand mineralogy of alluvium derived soils of southern bank of the river Brahmaputra in Assam. *Journal of the Indian Society of Soil Science*. 27: 417-426.
- Chaudhary, D.R., Arupghosh, Sharma, M.K and Chikara, J. 2006. Characterization of some salt - affected soils of Amethi, Uttar Pradesh. *Agropedology*. 16(2): 126-129.

- Likhar, K.C and Jagdish Prasad. 2011. Characteristic and classification of orange - growing soils developed from different parent material in Nagpur district in Maharashtra. *Journal of the Indian Society of Soil Science*. 59(3): 209-217.
- Chinchmalatpure, Anil, R., Gowrisankar, D., Challa, O and Sehgal, J.L. 1998. Soil site suitability of micro - watershed of Wunna catchment near Nagpur. *Journal of the Indian Society of Soil Science*.46: 657-661.
- Chopra, S.L and Kanwar, J.S. 1991. *Analytical Agricultural Chemistry*. Kalyani Publishers, New Delhi. pp 279.
- *Cottenie, A., Virloo, M., Velghe, G and Kiekens, L. 1979. *Analytical Method for plants and Soils*. State University, Ghent, Belgium.
- Deb, S and Sahu, S.S. 2011. Soil minerology in relation to physiography in Jumar sub-watershed, Jharkhand. *Agropedology*. 21(1): 1-7.
- Debnath, P and Ghosh, S.K. 2009. Determination of critical limit of available boron for rice in terai zone soils of West Bengal. *Journal of the Indian Society of Soil Science*. 59(1): 82-86.
- Dhaliwal, S.S., Sidhu, P.S and Sharma, B.D. 1996. Morphological, physical and chemical characteristics and taxonomy of flood - plain soils. *Agropedology*. 6: 13-22.
- Dhanokar, B.A., Niranjana, K.V., Arti Koyal, Naidu, L.G.K., Reddy, R.S and Sarkar, D. 2010. Soils resources inventory of lateritic terrain of Medak district, Andhra Pradesh for sustainable crop planning. *Agropedology*. 20(2): 97-102.
- *Dokuchaiev, V.V. 1886. *Report to the Provincial Zensstvo (local authority of Nizhimi-Norgorod (now gorki) No.1*. Main phases in the history of land assessment in European Russia with classification of Russian soils. In Acad. Sci., USSR. Collected writings (Sochineniya) vol. 4 Moscow, 1950.
- Dutta, D., Ray, S.K., Reddy, R.S and Budihal, S.L. 2001. Characterisation and classification of Paleosols in part of south India. *Journal of the Indian Society of Soil Science*. 49: 726-734.
- Dutta, D., Sah, K.D., Sarkar, D and Reddy, R.S. 1999. Quantitative evaluation of soil development in some Alfisols of Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 47: 311-315.

- Elahi, S.F., Hossain, M.F and Kamal, A.S.M. 1996. Characteristics of some soils developed on Madhupur clay in Bangladesh. *Journal of the Indian Society of Soil Science*. 44: 482-488.
- Esther Shekinah, D., Saha, S.K and Rejaur Rahman. 2004. Land capability evaluation for land use planning using GIS. *Journal of the Indian Society of Soil Science*. 52: 232-237.
- Fink, A and Venkateswarlu, J. 1982. Chemical properties and fertility management of vertisols. *In vertisols and rice soils on the tropics. Symposia of 12th International Congress of Soil Science*, New Delhi held on 8-16 February, 1982.
- Gabhane, V.V., Jadhao, V.O and Nagdeve, M.B. 2006. Land evaluation for land use planning of a macro - watershed in Vidarregion of Maharashtra. *Journal of the Indian Society of Soil Science*. 54(3): 307-315.
- Gangopadhyay, S.K., Walia, C.S., Chamuah, G.S and Baruah, U. 1998. Rice growing soils of upper Brahmaputra valley of Assam - their characterstics and suitability. *Journal of the Indian Society of Soil Science*. 46: 103-109.
- Giri Prakash, P. 1997. Soil Resource Appraisal of Gudiyatham Taluk, Pembar - Vagavathi Agram watershed using Remote sensing techniques. *M.Sc. (Ag.) Thesis*, Tamil Nadu Agricultural University, Coimbatore.
- *Glinka, K.D. 1931. *Treatise on soils science (Pochvovedenie) 4th or Fourth edition Isreal programme for science*. Trans, Jerusalem 1963 Transl. from Russian by A Gourevich. Available from the United States, Department of Commerce Washington, DC.
- Gomez, K.A and Gomez, A.A. 1984. *Statistical procedures for Agricultural Research*. Second edition, Wiley - Inter Science Publications, New York.
- Gupta, G.P., Tembhare, B.B and Mishra, S.R 1999. Characterisation and classification of soils of granitic terrain in Jabalpur district of Madhya Pradesh. *Agropedology*. 9: 77-81.
- Gupta, R.D and Tripathi, B.R. 1992. Genesis of soil in wet temperate and sub-alpine / moist alpine climatic zones of north - west Himalayas. *Journal of the Indian Society of Soil Science*. 40: 505-512.
- Gupta, S.K and Chara, R.S. 1996. Soil characteristics as influenced by slope aspects in middle Siwaliks. *Agropedology*. 6: 43-48.

- Gurumurthy, P., Seshagiri Rao, M., Bhanu Prasad, V., Pillai, R.N and Lakshmi, G.V. 1996. Characterisation of red, black and associated soils of Giddalur mandal of Andhra Pradesh. *The Andhra Agricultural Journal*. 43: 123-127.
- Heluf, G and Mishra, B.B. 2004. Synthesis of working papers. *Soil Science Technical Bulletin No.1*, Alemaya University, Alemaya, Ethiopia.
- Heluf, G and Mishra, B.B. 2005. Characterization of soils of Amensis sub-catchment of Hirna watershed in western Hararghe region, Ethiopia. *Agropedology*. 15(1): 7-15.
- Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis*, John Murray Publishers, London. pp 101.
- Huete, A. 2004. *Remote sensing of soils and soil processes*. In Remote Sensing for Natural Resources Management and Environmental Monitoring Manual of Remote Sensing, 3rd edition, volume 4 (Susan Ustin, Ed), John Wiley and Sons, Inc, New York.
- Jackson, M.L. 1969. *Soil Chemical Analysis - advanced course*. second edition, published by the Author, Department of Soil Science, University of Wisconsin, Madison, Wisconsin.
- Jackson, M.L. 1973. *Soil Chemical Analysis*. Oxford IBH Publishing House, Bombay. pp 38.
- Jagdish Prasad and Gajbhiye, K.S. 1999. Vertical distribution of micronutrient cations in some Vertisol profiles occurring in different eco-regions. *Journal of the Indian Society of Soil Science*. 4: 151-153.
- Jagdish Prasad, Ray, S.K., Gajbhiye, K.S and Singh, S.R. 2009. Soils of selsura research farm in wardha district, Maharashtra and their suitability for crops. *Agropedology*. 19(2): 84-91.
- Jagdish Prasad, Satyavathi, P.L.A., Rajeev Srivastava and Nair, K.M. 1995. Characterisation and classification of soils of Nasik district, Maharashtra. *Agropedology*. 5: 25-28.
- Jagdish Prasad, Nagaraju, M.S.S., Rajeev Srivastava, Ray, S.K and Chandran, P. 2001. Characteristics and classification of some orange growing soils in Nagpur district of Maharashtra. *Journal of the Indian Society of Soil Science*. 49: 735-739.
- Jagmohan Singh and Sawhney, J.S. 2006. Clay mineralogy of some salt-affected soils of South-West Punjab. *Journal of the Indian Society of Soil Science*. 54(4): 461-464.

- Jassal, H.S., Singh, J., Sawhney, J.S and Sharma, B.D. 2004. Geochemical environment and clay mineral formation of some salt - affected soils of Punjab. *International Conference on Sustainable Management of Sodic lands held at Luknow*. 156-158.
- Jenny. 1941. *A text book of pedology, concept and application*, 1st Edition Kalyani Publication.
- Jewitt, T.N., Law, R.D and Virgo, K.J. 1979. Outlook on agriculture as quoted by W A Blockhuis morphology and genesis of Vertisols. *In Vertisols and rice soils of tropics. Symposia of 12th International Congress of soils*.
- Kadao, S.H., Jagdish Prasad and Gajbhiye, K.S. 2003. Characterization and classification of some typical banana growing soils of Warda district of Maharashtra. *Agropedology*. 13(2): 28-34.
- Kannan, P., Natrajan, S., Sivasamy, R and Kukarperumal, R. 2011. Soil resource information and alternative crop planning for Cauvery Delta region of Tiruvarur district, Tamil Nadu. *Journal of the Indian Society of Soil Science*. 59(2): 109-120.
- Khadse, G.K and Gaikwad, S.T. 1995. Soil based Agro-technology transfer: A case study. *Agropedology*. 5: 91-96.
- Khan, Z.H., Mazumdar, A.R., Hussain, M.S and Saheed, S.M. 1997. Chemical and mineralogical properties of some benchmark soils in the flood plains of Bangladesh. *Journal of the Indian Society of Soil Science*. 45: 362-369.
- Khan, Z.H., Mazumdar, A.R., Mohiuddin, A.S.M., Hussian, M.S and Saheed, S.M. 1998. Physical properties of some benchmark soils from the flood plains of Bangladesh. *Journal of the Indian Society of Soil Science*. 46: 442-446.
- Kharche, V.K and Pharanda, A.L. 2010. Land degradation assessment and land evaluation in Mula command of irrigated agro-ecosystem of Maharashtra. *Journal of the Indian Society of Soil Science*. 58(2): 221-227.
- *Klingebiel, A.A and Montgomery, P.H. 1966. *Agricultural Hand Book* No. 210, USDA, Washington.
- Krishnan, P., Nair, K.M., Naidu, L.G.K., Srinivas, S., Artikoyal, Nasre, R.A., Ramesh, M and Gajbhiye, K.S. 2004. Land, soil and land use of Lakshadweep coral islands. *Journal of the Indian Society of Soil Science*. 52: 226-231.

- Landey, R.J., Hirekerur, L.R and Krishnamurthy, P. 1982. Morphology, genesis and classification of black soils. *In: Review of soil research in India. Symposia of 12th International Congress of Soil Science*, New Delhi, Held on 8-16, February 1982.
- Leelavathi, G.P., Naidu, M.V.S., Ramavatharam, N and Karuna Sagar, G. 2009. Studies on genesis, classification and evaluation of soils for sustainable land use planning in Yerpedu mandal of Chittoor district, Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 57: 109-120.
- Leelavathi, G.P., Naidu, M.V.S., Ramavatharam, N and Karuna Sagar, G. 2010a. Clay mineralogy of soils formed on granite - gneiss of Chittoor district, Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 58(4): 376-383.
- Leelavathi, G.P., Naidu, M.V.S., Ramavatharam, N and Karuna Sagar, G. 2010b. Soil-ste suitability evaluation for commonly growing crops in Yerpedu mandal of Chittoor district, Andhra Pradesh. *Agropedology*. 20(2): 133-138.
- Lekha, V.S., Raja, P., Sehgal, J.L and Gajbhiye, K.S. 1998. Sand mineralogical investigations and mineral weathering index (MWI) of some selected soils of Kerala. *Journal of the Indian Society of Soil Science*. 46: 675-682.
- *Lindsay, W.L and Norvell, W.A. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal*. 43: 421-428.
- Madhusudhana Rao, M. 1993. Characterisation and classification of soils of Ulavapadu mandal of Prakasam district in Andhra Pradesh. *M.Sc. (Ag.) Thesis*, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad.
- Mahesh Babu, B. 1992. Characterisation and classification of black soils under Polavaram Project left canal area in East Godavari and Visakhapatnam districts of Andhra Pradesh. *M.Sc. (Ag.) Thesis*, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad.
- Mahesh Kumar, Singh, S.K., Raina, P and Sharma, B.K. 2009. Characterization, classification and evaluation of soils of Churu district. *Journal of the Indian Society of Soil Science*. 57(1): 253-261.

- Mahesh Kumar, Singh, S.K., Raina, P and Sharma, B.K. 2011. Status of available major and micronutrients in arid soils of Churu district of western Rajasthan. *Journal of the Indian Society of Soil Science*. 59(2): 188-192.
- Maji, A.K., Obi Reddy, G.P., Jhayalan, S and Walke, N.J. 2005. Characterization and classification of landforms and soils over basaltic terrain in sub-humid tropics of central India. *Journal of the Indian Society of Soil Science*. 53(2): 154-162.
- Maji, B and Bandyopadhyay, B.K. 1995. Characterisation and classification of coastal soils of various pH groups in Sundarbans of West Bengal. *Journal of the Indian Society of Soil Science*. 43: 103-107.
- Mall, J and Mishra, B.B. 2000. Identification and genesis of clay minerals of some Alfisols of northern Bihar. *Journal of the Indian Society of Soil Science*. 48: 586-593.
- Mandal, G.K., Pal, S.K and Roy, A. 2006. Characterization of acidity under different land use patterns in Tarai soils of West Bengal. *Agropedology*. 16(1): 21-25.
- Manorama, T.K.C and Jose, A.I. 2000. Characterization of acid saline rice based wetland ecosystem of Kuttanad, Kerala and their salinity protection by Thanneermukkom regulator. *Agropedology*. 10: 108-115.
- Marathe, R.A., Mohanty, S and Shyam Singh. 2003. Soil characterisation in relation to growth and yield of Nagpur mandarin (*Citrus reticulata* Blanco). *Journal of the Indian Society of Soil Science*. 51: 70-73.
- Meena, H.B., Giri, J.D and Mishra, H.K. 2009. Suitability assessment of soils occurring on different landforms of Chittorgarh district, Rajasthan. *Agropedology*. 19(2): 75-83.
- Meena, H.P., Sharma, R.P and Rawat, U.S. 2006. Status of macro and micronutrient in some soils of Tonk district of Rajasthan. *Journal of the Indian Society of Soil Science*. 54(4): 508-512.
- Mehta, S.E., Meel, P.K., Grewal, K.S and Giridhar, K.K. 1996. Kinetics of desorption of ammonium acetate extractable potassium in Entisols. *Journal of the Indian Society of Soil Science*. 44:60-65.
- Mini, V., Patil, P.L and Dasog, G.S. 2007. Characterization and classification of soils of pilot site in coastal agro-ecosystem of north Karnataka. *Agropedology*. 17(1): 59-67.

- Mishra, B.B and Ghosh, S.K. 1995. Characterisation of soils derived from mica rich parent materials in two toposequences. *Journal of the Indian Society of Soil Science*. 43: 92-98.
- Mishra, B.B., Heluf, G and Kibert, K. 2004. Soils of Ethiopia: concept, appraisal and perspective in relation to food security. *Journal of Food, Agriculture and Environment* (in press), Finland.
- Muhr, G.R., Datta, N.P., Sankarasubramoney, H., Laley, V.K and Donahue, R.L. 1965. Critical soil test values for available N, P and K in different soils. *In soil testing in India*. 2nd Edition, USAID mission to India, New Delhi. 52-56.
- Murali, V., Krishna Murti, G.S.R and Sarma, V.A.K. 1978. Clay minerals distribution in two toposequences of tropical soils of India. *Geoderma*. 20: 257-269.
- Murthy, I.Y.L.N., Sastry, T.G., Datta, S.C., Narayanasamy, G and Rattan, R.K. 1997. Distribution of micronutrient cations in Vertisols derived from different parent materials. *Journal of the Indian Society of Soil Science*. 45: 577-580.
- Mushtaq, A.W. 2011. Relationship between the Quantity / Intensity parameters of potassium in rice soils of lesser Himalayas. *Journal of the Indian Society of Soil Science*. 59(1): 48-53.
- Muthumanickam, D., Kannan, P., Nataranjan, S., Sivasamy, R and Kumarperumal, R. 2010. Soil resource inventory using remote sensing and GIS. A case study in Erode district in Tamil Nadu. *Agropedology*. 20(2): 89-96.
- Naidu, L.G.K and Hunsigi, G. 2001. Application and validation of FAO-framework and soil potential ratings for land suitability evaluation of sugarcane soils of Karnataka. *Agropedology*. 11: 91-100.
- Najar, G.R., Akhtar, F., Singh, S.R and Wani, J.A. 2009. Characterization and classification of some Apple growing soils of Kashmir. *Journal of the Indian Society of Soil Science*. 57(1): 81-84.
- Natasa, J., Vidic Franc and Lobnik. 1997. Role of soil development of the chronosequences in the Ljubljana basin, Solvenia. *Geoderma*. 76: 35-64.
- Nayak, D.C., Sarkar, D., Das, K and Chatterjee, S. 1999. Studies on pedogenesis in a soil chronosequence in West Bengal. *Journal of the Indian Society of Soil Science*. 47:322-328.

- Nayak, R.K., Sahu, G.C and Nanda, S.K. 2002. Characterization and classification of the soils of central research station, Bhubaneswar. *Agropedology*. 12: 1-8.
- NBSS and LUP 1994. In: Soil Survey of India. Edited by Sohanlal, Deshpande S B and Sehgal J L. National Bureau of Soil Survey and Land Use Planning, Nagpur. 1-385.
- Niranjana, K.V., Ramamurthy, V., Rajendra Hegde, Srinivas, S., Arti Koyal, Naidu, L.G.K and Sarkar, D. 2011. Characterization, classification and suitability evaluation of banana growing soils of Pulivendla region of Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 59(1): 1-5.
- *Olsen, S.R., Cole, C.V., Watanabe, F.S and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *Circular of United States Department of Agriculture*. pp. 939.
- Padole, V.R and Deshmuck, P.W. 1998. Soil survey interpretation for land use planning in salt - affected soils of Purna valley fo Virdarbha, Maharashtra. *Journal of the Indian Society of Soil Science*. 46: 489-493.
- Padro C, Jamagne, M and Begon, J.C. 1969. Mineral interactions and transformations in relation to pedogenesis during the quarternary. *Soil Science*. 17: 462-469.
- Pal, D.K and Deshpande, S.B. 1987. Genesis of clay minerals in red and black soil complex of southern India. *Clay Research*. 6: 6-13.
- Pal, D.K, Deshpande, S.B., Venugopal, K.R and Kalbande, A.R. 1989. Formation of di and tri-octahedral smectites as evidence for paleo-climatic changes in southern and central Peninsular India. *Geoderma*. 45: 75-184.
- Pannu, B.S., Sangwan, B.S., Goyal, V.P and Panwar, B.S. 1999. Comparative study of the morphology and characteristics of soils used for rice and non-rice based cropping sequence in Haryana. *Journal of the Indian Society of Soil Science*. 47: 105-109.
- Pati, R and Mukhopadhyay, D. 2011. Distribution of cationic micronutrients in some acid soils of west Bengal. *Journal of the Indian Society of Soil Science*. 59(2): 125-133.
- Patil, M.N., Khandare, N.C and Puranik, R.B. 1999. Evaluation of pedological development of orange garden soils of Akola district through field morphology rating system. *Journal of the Indian Society of Soil Science*. 47: 180-182.

- Patil, R.B and Jagdish Prasad. 2004. Characteristics and classification of some *Sal (Shorea robusta)* supporting soils in Dindori district of Madhya Pradesh. *Journal of the Indian Society of Soil Science*. 52: 119-124.
- Pillai, M.Y and Natarajan, A. 2004. Characterisation and classification of dominant soils of parts of Garakahalli watershed using remote sensing technique. *Mysore Journal of Agricultural Science*. 38: 193-200.
- Piper, C.S. 1966. *Soil and Plant Analysis*. Hans Publications, Bombay. pp. 59.
- Powar, S.L and Mahta, V.B. 1999. Characterization of soils of the Konkan coast. *Journal of Indian Society of Soil Science*. 47: 334-337.
- Pradeep Kumar and Verma, T.S. 2005. Characterization and classification of some rice growing soils of Palam valley of Himachal Pradesh. *Agropedology*. 15(2): 80-85.
- Prasuna Rani, P., Pillai, R.N., Bhanu Prasad, V and Subbaiah, G.V. 1991. Characterisation and classification of red and associated soil of Kavali canal area under Somasila project of Andhra Pradesh. *The Andhra Agricultural Journal*. 38: 368-374.
- Prasuna Rani, P., Pillai, R.N., Bhanu Prasad, V and Subbaiah, G.V. 1992. Nutrient status of some red and associated soil of Nellore District under Somasila Project in Andhra Pradesh. *The Andhra Agricultural Journal*. 39: 1-5.
- Raghavendra Reddy, M.G., Obi Reddy, G.P., Maji, A.K and Nageswararao, K. 2004. Land evaluation for cotton suitability in parts of eastern Maharastra plateau using remote sensing and GIS. *Agropedology*. 14(1): 25-31.
- Raghuwanshi, S.R.S., Tiwari, S.C., Prabha, S., Raghuwanshi, O.P.S., Sasode, D.S and Umat, R. 2011. Characterization of salt-affected soils of Bhind district of Madhya Pradesh. *Journal of the Indian Society of Soil Science*. 59(4): 388-391.
- Raina, A.K., Sharma, S.D and Jha, M.N. 2006. Sand and clay mineralogy of salt-affected soils of Uttar Pradesh. *Journal of the Indian Society of Soil Science*. 54(1): 65-74.
- Rakesh Kumar, Singh, K.P and Surendra Singh. 2002. Vertical distribution of sulphur fractions and their relationships among carbon, nitrogen and sulphur in acidic soils of Jharkhand. *Journal of the Indian Society of Soil Science*. 50: 502-505.

- Ram Prakash, T and Seshagiri Rao, M. 2002. Characterisation and classification of some soils in a part of Krishna district, Andhra Pradesh. *The Andhra Agricultural Journal*. 49: 228-236.
- Ram, D., Ram, T and Subhash, C. 2010. Characterization and classification of flood - prone soils of eastern plains of Rajasthan for their corrective measures. *Journal of the Indian Society of Soil Science*. 58 (2): 228-232.
- Ramakrishna Prasad, P. 1994. Characterisation, classification and mineralogy of predominant soil types in commands of Krishna, Godavari and Sarada rivers of Andhra Pradesh. *Ph.D. Thesis*, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad.
- Ramalakshmi, S., Seshagiri Rao, M and Bhanu Prasad, V. 2001. Horizon - wise chemical composition of Haplustepts, Haplusterts and Ustipsamments of Baptna Kalapalem region of Guntur district of Andhra Pradesh. *The Andhra Agricultural Journal*. 48: 111-113.
- Ramesh Kumar, Bhanu Prasad, V and Seshagiri Rao, M. 2002. The morphology, clay mineralogy and taxonomy of some soil of Singarayakonda mandal in Prakasam district of Andhra Pradesh. *The Andhra Agricultural Journal*. 49: 237-240.
- Ramesh Kumar, S.C., Vadivelu, S., Reddy, R.S., Naidu, L.G.K, Rajendra, H and Srinivas, S. 2006. Land suitability for grape cultivation and its economics in Rajanukunte watershed, Karnataka. *Agropedology*. 16(2): 98-104.
- Rao, B.R.M., Venkataratnam, L., Thammappa, S.S and Sreenivas, K. 1991. *SPOT data of soil resource mapping*. Project report, NRSA, Hyderabad.
- Ratnam, B.V., Seshagiri Rao, M and Sankara Rao, V. 2000. Chemical composition (Total elemental analysis) and molar ratio of black soils of Kakumanu mandal (A.P). *The Andhra Agricultural Journal*. 47: 319-321.
- Rattan, R.K and Sharma, P.D. 2004. Main micronutrients available and their method of use. *Proceedings IFA International symposium on micronutrients*. 1-10.
- Ravender Singh and Nayak, A.K. 1999. Water retention and transmission characteristics of Mahi right bank canal command area of Gujarat. *Journal of the Indian Society of Soil Science*. 47: 9-15.
- Rayachaudhuri, S.P and Govinda Rajan, S.V. 1971. *Review of soils research in India*. In: Soil genesis and classification. ICAR, New Delhi.

- Reddy, D.R., Vasudeva Rao, A.E and Raghu Mohan, N.G. 1993. Morphology and physico-chemical properties of red soils of Nagarjuna Project area of Andhra Pradesh. In : Red and Laterite Soils of India, Resource Appraisal and Management, NBSS & LUP, Nagpur, India Publications 37: 106-110.
- Rengasamy, P., Sarma, V.A.K., Murthy, R.S and Krishnamurthy, G.S.R. 1978. Mineralogy, genesis and classification of ferruginous soils of eastern Mysore plateau. *Journal of Soil Science*. 29: 431-445.
- Rudramurthy, H.V and Dasog, G.S. 2001. Properties and genesis of associated red and black soils in north Karnataka. *Journal of the Indian Society of Soil Science*. 49(2): 301-309.
- Sahoo, A.K., Dipak Sarkar, Baruah, U and Butte, P.S. 2010. Characterization, classification and evaluation of soils of Langol hill Manipur for rational land use planning. *Journal of the Indian Society of Soil Science*. 58(4): 355-362.
- Samanta, A., Chatterjee, A.K., Mete, P.K and Biswapati Mandal. 2002. Status of total and available iron and zinc in soils of west Bengal under continuous cultivation of mulberry. *Journal of the Indian Society of Soil Science*. 50: 35-42.
- Sangwan, B.S and Singh, K. 1993. Vertical distribution of Zn, Mn, Cu and Fe in the semi - arid soils of Haryana and their relationship with soil properties. *Journal of the Indian Society of Soil Science*. 41(3): 463-467.
- Sanjeev, K., Chaudhary, Karan Singh, Tripathi, D and Bhandari, A.R. 2005. Morphology, genesis and classification of soils from two important land use in outer Himalayas. *Journal of the Indian Society of Soil Science*. 53(3): 394-398.
- *Sankaram, A. 1966. *A Laboratory Manual for Agricultural Chemistry*. Published by Jaya Singer Asia Publishing House, Bombay. 56-57.
- Sarade, S.D and Jagdish Prasad. 2008. Characterization and classification of guava-growing soils of Bhandara district in Maharashtra. *Journal of the Indian Society of Soil Science*. 56(3): 300-304.
- Sarkar, D., Abhijit Halder, Alok Majumdar and Velayutham, M. 2000. Distribution of micronutrient cations in some Inceptisols and Entisols of Madhubani district, Bihar. *Journal of the Indian Society of Soil Science*. 48: 202-205.
- Sarkar, D., Baruah, U., Gangopadhyay, S.K., Sahoo, A.K and Velayutham, M. 2002. Characteristics and classification of soils of Loktak

- command area of Manipur for sustainable land use planning. *Journal of the Indian Society of Soil Science*. 50: 196-204.
- Sarkar, D., Gangopadhyay, S.K and Velayutham, M. 2001. Soil toposequence relationship and classification in lower outlier of Chhotanagpur plateau. *Agropedology*. 11: 29-36.
- Satish Kumar, Y.S and Naidu, M.V.S. 2012. Characteristics and classification of soils representing major landforms in Vadamalapeta mandal of Chittoor district, Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 60: 63-67.
- Satish Kumar, Y.S. 2007. Genesis, classification and evaluation of soils in Vadamalapeta mandal of Chittoor district, Andhra Pradesh. *M.Sc. (Ag) Thesis*. Acharya N.G. Ranga Agricultural University, Hyderabad, India.
- Satyanarayana, T and Biswas, T.D. 1970. Chemical and mineralogical studies of associated black and red soils. *The Mysore Journal of Agricultural Science*. 3: 253-264.
- Satyavathi, P.L.A and Suryanarayan Reddy, M. 2004a. Soil-ste suitability for six major crops in Telengana, Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 52(2): 220-225.
- Satyavathi, P.L.A and Suryanarayan Reddy, M. 2004b. Distribution of DTPA extractable micronutrients in soils of Telengana, Andhra Pradesh. *Agropedology*. 14: 32-44.
- Saxena, P.K. 1992. Characterisation and classification of soils of Ghaggar plains of Patiala, Punjab. *Agropedology*. 2: 81-91.
- Sehgal, J.L. 1996. *Pedology Concepts and Applications*. Kalyani Publishers, New Delhi. 176-185.
- Sen, T K., Nayak, D.C., Singh, R.S., Dubey, P.N., Maji, A.K, Chamuah, G.S and Sehgal, J.L. 1997. Pedology and edaphology of bench mark acid soils of north - eastern India. *Journal of the Indian Society of Soil Science*. 45: 782-790.
- Sen, T.K., Nayak, D.C., Dubey, P.N., Chamuah, G.S and Sehgal, J.L. 1996. Highly leached mineral soils of Manipur : Their pedology, characteristics, problems and management. *Journal of the Indian Society of Soil Science*. 44: 123-126.

- Seshagiri Rao, M., Prasuna Rani, P., Ramesh, K and Vikram, D. 2004. Morphology and classification of southern coastal agro-eco sub-region soils of Andhra Pradesh. *The Andhra Agricultural Journal*. 51: 71-76.
- Shalima Devi, G.M and Anil Kumar, K.S. 2010. Characterization and classification of coffee growing soils of Maharashtra. *Journal of the Indian Society of Soil Science*. 58(1): 125-131.
- Shamsudheen, M., Dasog, G.S and Patil, P.L. 2005. Characterisation and classification of some forest soils of north Karnataka. *Agropedology*. 15(2): 86-89.
- Sharma, B.D., Jassal, H.S, Sawhney, J.S and Sidhu, P.S. 1999. Micronutrient distributions in different physiographic units of the Shiwalik hills of the semi - arid tracts of Punjab. *Arid Soil Research and Rehabilitation*. 13: 189-200.
- Sharma, B.D., Sidhu, P.S., Raj Kumar and Sawhney, J.S. 1997. Characterization, classification and landscape relationships of Inceptisols in north -west India. *Journal of the Indian Society of Soil Science*. 45: 167-173.
- Sharma, J.C and Choudhary, S.K. 2007. Vertical distribution of micronutrient cations in relation to soil characteristics in lower shiwaliks of Solan district in north - west Himalayas. *Journal of the Indian Society of Soil Science*. 55: 40-44.
- Sharma, J.C and Sanjeev, K.C. 2008. Land productivity and site-suitability assessment for crop diversification using remotely sensed data and GIS techniques. *Agropedology*. 18(1): 01-11.
- Sharma, J.P., Landey, R.J., Kalbande, A.R and Mandal, C. 2001a. Characteristics and classification of soils of Kathiawar region of Gujarat as influenced by topography. *Agropedology*. 11: 83-90.
- Sharma, R.K., Swami, B.N., Giri, J.D., Singh, S.K and Shyampura, R.L. 2001b. Soils of Haldi Ghati region of Rajasthan and their suitability for different land uses. *Agropedology*. 11: 23-28.
- Sharma, R.C., Mandal, A.K., Singh, R and Singh, Y.P. 2011. Characteristics and use potential of sodic and associated soils in CSSRI experimental farm, Luknow, Uttar Pradesh. *Journal of the Indian Society of Soil Science*. 59(4): 381-387.
- Sharma, S.P., Sharma, P.D., Singh, S.P and Minhas, R.S. 1993. Characterisation of Soan river valley soils in lower Siwaliks of Himachal Pradesh-I Hill Soils. *Journal of the Indian Society of Soil Science*. 41: 714-720.

- Sharma, S.S., Totawat, K.L and Shyampura, R.L. 1996. Characterisation and classification of soils of toposequence over basaltic terrain. *Journal of the Indian Society of Soil Science*. 45: 480-485.
- Sharma, S.S., Totawat, K.L and Shyampura, R.L. 2004a. Characterization and classification of salt - affected soils of southern Rajasthan. *Journal of the Indian Society of Soil Science*. 52(3): 203-213.
- Sharma, V.K., Sharma, P.D., Sharma, S.P., Acharya, C.L and Sood, R.K. 2004b. Characterisation of cultivated soils of Neogal watershed in north - west Himalayas and their suitability for major crops. *Journal of the Indian Society of Soil Science*. 52: 63-68.
- Sharma, V.K and Anil Kumar. 2003. Characterisation and classification of the soil of upper Maul Khad catchment in wet temperate zone of Himachal Pradesh. *Agropedology*. 13: 39-49.
- Shashi, S.Y., Swami, B.N., Shyampura, R.L and Giri, J.D. 2005. Soil-site suitability evaluation of hot arid western plain soils of Rajasthan. *Agropedology*. 15(1): 76-79.
- Shivaramu, H.S., Raghu Mohan, N.G., Chakraborty, N.M., Niranjaya, K.V and Artikoyal. 1998. Soil survey and land evaluation for fresh water aquaculture. *Journal of the Indian Society of Soil Science*. 46: 708-710.
- Shyampura, R.L., Giri, J.D., Krishna, N.D.R and Sehgal, J.L. 1993. Genesis and classification of red soils of Durgapur district, Rajasthan. *Agropedology*. 3: 39-47.
- Sibirtsev, N.M. 1901. *Soil Science. In selected works (Izbrannye Sochineniya) Vol. 1 Israel Prog. for Sci. Transl. Jerusalem 1996 Transal from Russian by N. Kanar Avail. from US Department. Commerce Spring field, VA.*
- Sidhu, G.S., Manjaiah, K.M and Ghosh, S.K. 1998. Characterisation of pedological development in some soils of central Aravallies - Yamuna river transect, Haryana. *Journal of the Indian Society of Soil Science*. 46: 481-484.
- Sidhu, P.S., Raj Kumar and Sharma, B.D. 1994. Characterisation and classification of Entisols in different soil moisture regimes of Punjab. *Journal of the Indian Society of Science*. 42: 633-640.
- *Simonson, R.W. 1959. Outline of a generalized theory of soil genesis. *Soil Science Society of American Proceedings*. 23: 152-156.

- Singa Rao, M and Prabhu Prasadini, R. 1998. Profile water storage capacity of soils of scarce rainfall zone of Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 46: 351-353.
- Singh, H.N., Sharma, A.K and Om Prakash. 1999. Characterisation and classification of some cultivated soils of Ramganga catchment in the soils of Uttar Pradesh. *Agropedology*. 9: 41-46.
- Singh, I.S and Agrawal, H.P. 2003. Characterization and classification of some rice soils of Chandauli district of Uttar Pradesh. *Agropedology*. 13: 11–16.
- Singh, I.S and Agrawal, H.P. 2005. Characterization, genesis and classification of rice soils of Eastern region of Varanasi, Uttar Pradesh. *Agropedology*. 15 : 29–38.
- Singh, K., Goyal, V.P and Singh, M. 1991. Distribution of micronutrient cations in semi-arid alluvial soil profiles. *Journal of the Indian Society of Soil Science*. 38: 736-737.
- Singh, Karan., Sharma, P.D and Bhandari, A.R. 1992. Land capability classes and managent needs for sustained productivity in semi - arid regions of north - west Himalayas. *Agropedology*. 2: 51-57.
- Singh, R.A. 1980. *Soil Physical Analysis*. Kalyani Publishers, New Delhi. 64-87.
- Singh, R.N., Diwakar, D.P.S and Singh, A.K. 1993. A comparative study of acid soils developed in granite - gneiss and Mahananda alluvium. *Journal of the Indian Society of Soil Science*. 41: 125-132.
- Singh, R.S., Singh, S.K., Dubey, P.N and Shyampura, R.L. 2006. Pedogenic distribution of iron and manganese in some vertisols of Rajasthan. *Agropedology*. 16(2): 77-85.
- Singh, S.K., Baser, B.L., Shyampura, R.L and Pratap Narain. 2004, variations in morphometric characteristics of Verisols in Rajasthan, *Journal of the Indian Society of Soil Science*. 52: 214-219.
- Singh, S.K., Mahesh, K., Sharma, B.K and Tarafdar, J.C. 2007. Depletion of organic carbon, phosphorus and potassium stock under pearl millet-based cropping sequence in arid environment of India. *Arid Land Research Management*. 21: 119-131.
- Singh, V.N and Mishra, B.B. 1996. Pedogenic characterisation of some typical soils of Gandak command area of Bihar for evaluation of land suitability. *Journal of the Indian Society of Soil Science*. 44: 136-142.

- Singh, Y., Chaudhary, D.C., Singh, S.P., Bharadwaj, A.K and Singh, D. 1996. Sustainability of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) sequential cropping through introduction of legume crop in system. *Indian Journal of Agronomy*. 41: 510-514.
- Sitanggang, M., Rao, Y.S., Nayan Ahmed and Mahapatra, S.K. 2006. Characterization and classification of soils of watershed area of Shikopur in Gurgaon district of Haryana. *Journal of the Indian Society of Soil Science*. 54(1):106-110.
- Soil Survey Division Staff. 2000. *Soil Survey Manual* (Indian Print), USDA Handbook 18, Us Govt. Printing Office, Washington.
- Soil Survey Staff. 1998. *Keys to Soil Taxonomy*. Eighth edition, Natural Resource Conservation Service, USDA, Blacksburg, Virginia.
- Soil Survey Staff. 1999. *Soil Taxonomy*. Second edition, Agricultural Hand Book No.436, USDA, Natural Resources Conservations Service, Washington, DC pp 1-782.
- Soil Survey Staff. 2003. *Keys to soil taxonomy*, 9th edition, USDA, Natural Resource Conservation Service, Washington, DC.
- Soloman, D., Lehmann, J., Mamo, T., Fritzsche, F and Zceh, W. 2002. Phosphorus form and dynamics as influenced by landuse changes in sub-humid Ethiopian soils. *Geoderma*. 105: 21-48.
- Somasundaram, J., Nataranjan, S., Mathan, K.K., Arun Kumar, V and Sivasamy, R. 2010. Characterization of some typical pedons in lower Vellar basin of Pudukottai district in Tamil Nadu. *Agropedology*. 20(2): 103-111.
- Sridhar, A and Ananthanarayana, R. 1996. Vertical distribution of sulphur in base un-saturated rice fallow profiles of Karnataka. *Journal of the Indian Society of Soil Science*. 44: 650-656.
- Srivastava, A.K and Shyam Singh. 2001. Citrus nutrition research in india. Current status and future strategies. *Indian Journal of Agricultural Sciences*. 78: 3-16.
- Subbaiah, G.V and Manickam, T.S. 1992. Genesis and morphology of Vertisols developed on different parent materials. *Journal of the Indian Society of Soil Science*. 40: 150-155.
- *Subbiah, B.V and Asija, C.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*. 25: 32.

- Suresh Kumar, L.M., Pande, and Patel, N.R. 2001. Pedogenic characterisation and productivity of some lateritic soils developed on different geomorphic conditions. *Agropedology*. 11: 37-44.
- Suri Babu, K., Bhanu Prasad, V., Seshagiri rao, M and Prasuna rani, P. 2001. Clay mineralogy of some soils of A. Konduru mandal in Krishna district of A.P. *The Andhra Agriculture Journal*. 48(3&4): 243-247.
- Swarnam, T.P., Velmurugan, A and Rao, Y.S. 2004. Characterisation and classification of some soils from Shahibi basin in parts of Haryana and Delhi. *Agropedology* 14: 114-122.
- Sys, C., Van Ranst, E and Debaveye, J.C. 1991. *Land evaluation, Part-II Methods in land evaluation*. Agricultural Publications No.7, Belgium.
- Sys, C., Van Ranst, E., Debaveye, J and Beernaert, F. 1993. *Land evaluation, Part-III Crop requirements*. Agricultural Publications, No. 7, Belgium.
- Tamgadge, D.B., Gaikawad, S.T and Gajbhiye, K.S. 1999. Soils of Madhya Pradesh: Part I - An inventory and soil physiographic relationship. *Journal of the Indian Society of Soil Science*. 47: 109-114.
- Tamgadge, D.B., Gajbhiye, K.S and Bankar. W.V. 2002. Evaluation of soil suitability for paddy cultivation in Chattisgarh – A parametric approach. *Journal of the Indian Society of Soil Science*. 50: 81-88.
- Tandon, H.L.S. 1991. *Sulphur research and agricultural production in India*. 3rd edition, the sulphur institute, Washington, D.C. 140-148.
- Tardy, Y., Boqcquie,r G., Paquet, H and Millot, G. 1973. Formation of clay from granite and its distribution in relation to climate and topography. *Geoderma*. 10: 271-284.
- Thangasamy, A., Naidu, M.V.S and Ramavatharam, N. 2004. Clay mineralogy of soils in the Sivagiri micro - watershed of Chittoor district, Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 52(4): 454-461.
- Thangasamy, A., Naidu, M.V.S., Ramavatharam, N and Raghava Reddy, C. 2005. Characterization, classification and evaluation of soil resources in Sivagiri micro - watershed of Chittoor district in Andhra Pradesh for sustainable land use planning. *Journal of the Indian Society of Soil Science*. 53(1): 11–21.

- Tiwary, J.R and Mishra, B.B. 1992. Clay mineralogy of some yellow soils developed on Rajmahal trap of Bihar. *Journal of the Indian Society of Soil Science*. 40: 406-408.
- Tiwary, J.R, Jha, P.P and Mishra, B.B. 1989. Characteristics and classification of red, black and yellow soils of Rajmahal trap of Bihar. *Journal of the Indian Society of Soil Science*. 37: 518-523.
- Tripathi, D., Verma, J.R., Patial, K.S and Karan Singh. 2006. Characteristics, classification and suitability of soils for major crops of Kiar - Nagali micro-watershed in north - west Himalayas. *Journal of the Indian Society of Soil Science* 54(2): 131–136.
- Vadivelu, S and Bandyopadhyay, A.K. 1997. Characteristics, genesis and classification of soils of Minicoy island, Lakshadweep. *Journal of the Indian Society of Soil Science*. 45: 796-801.
- *Van Wambeke, A and Rossiter, D. 1987. Automated land evaluation systems as a focus for soil research. *IBSRAM Newsletter* 6, October, 1987.
- Vara Prasad Rao, A.P., Naidu, M.V.S., Ramavatharam, N and Rama Rao, G. 2008. Characterization, classification and evaluation of soils on different landforms in Ramchandrapuram mandal of Chittoor district in Andhra Pradesh for sustainable land use planning. *Journal of the Indian Society of Soil Science*. 56(1): 23-33.
- Venkatesu, T., Venkaiah, K and Naidu, M.V.S. 2002. Depth wise distribution of nutrients in groundnut growing soils of Nellore district in Andhra Pradesh. *Journal of Oil Seeds Research*. 19 (2): 185-189.
- Venkateswarlu, M., Seshagiri Rao, M., Bhanu Prasad, V and Pillai, R.N. 1995. Classification of black soils of Kandukuru division of Andhra Pradesh. *The Andhra Agricultural Journal*. 42: 38-42.
- Venugopal, V.K and Koshy, M.M. 1985. Morphology and particle-size distribution in the soil profiles from a catena in Kerala. *Agricultural Research Journal of Kerala*. 23: 9-16.
- Verma, T.P., Sudhakar Rao, R.V., Mahapatra, S.K and Tarsemlal. 2001. Studies on soil variability across different landscapes in Etawah district of Uttar Pradesh - A case study. *Journal of the Indian Society of Soil Science*. 49: 309-325.
- Verma, V.K., Setia, R.K and Sharma, P.K. 2007. Distribution of micronutrient cations in different physiographic units of semi-arid region of Punjab. *Agropedology*. 18(1): 58-65.

- Verma, V.K., Setia, R.K., Sharma, P.K., Singh, C and Kumar, A. 2005a. Pedospheric variations in distribution of DTPA-extractable micronutrients in soils developed on different physiographic units in central parts of Punjab, India. *International Journal of Agriculture and Biology*. 7: 243-246.
- Verma, V.K., Setia, R.K., Sharma, P.K., Charanjit Singh and Ashok Kumar 2005b. Micronutrient distribution in soils developed on different physiographic units of Fatehgrah Sahib district of Punjab. *Agropedology*. 15(1): 70-75.
- Vijay Kumar, T., Suryanarayana Reddy, M and Gopalakrishna, V. 1994. Characteristics and classification of soils of high rainfall zone of Andhra Pradesh. *Agropedology*. 4:31-43.
- Walia, C.S and Chamuah, G.S. 1996. Characterisation of some Inceptisols of Arunachal Hills. *Journal of the Indian Society of Soil Science*. 44: 179-182.
- Walia, C.S and Rao, Y.S. 1996. Genesis, characteristics and taxonomic classification of some red soils of Bundelkhand region of Uttar Pradesh. *Journal of the Indian Society of Soil Science*. 44: 476-481.
- Walia, C.S and Rao, Y.S. 1997. Characteristics and classification of some soils of Trans - Yamuna plains. *Journal of the Indian Society of Soil Science*. 45: 156-162.
- *Watanabe, F.S and Olsen, S.R. 1965. Test of ascorbic acid method for determining phosphorous in water and sodium bicarbonate extracts of soils. *Proceedings of Soil Science Society of America*. 29: 677-678.
- *Williams, C.H and Steinbergs, A. 1959. In: *Methods and analysis of soils, plants, water and fertilizers*, FDCO, New Delhi. India, pp. 58.
- *Woldeamalk, Bewet and Leostroosnijder. 2003. Effect of agro ecological land use succession on soil properties in chemonga watershed, Blue Nile basin, Ethiopia. *Geoderma*. 111: 85-98.
- Yadav, B.L and Vyas, K.K. 1998. Water retention characteristics of some soils of the semi - arid eastern plain of Rajasthan. *Journal of the Indian Society of Soil Science* 46: 439-441.

Appendices

APPENDIX - I

PEDON – 1

I. Soil site description

- a. Village : Pasupula
- b. Physiography : Plain lands
- c. Slope : Degree : 0-1%
(Nearly level)
Class – A
Aspect : NW – NE
- d. Parent material : Granite-gneiss
- e. Natural vegetation : *Azadiracta indica*,
Cynodon dactylon,
Parthenium hysterophorus etc.
- f. Land use : Mango, Cotton and Paragrass
- g. Erosion : Very slight
- h. Drainage : Somewhat poorly drained
- i. Ground water depth : Below 20 m
- j. Location : On the left side of the main road
that proceeds to Pasupula bus
station.

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.15	Very dark grayish brown (10 YR 3/2) dry, very dark gray (7.5 YR 3/1) moist; clay loam; coarse, strong, angular blocky; very hard, very firm, very sticky and very plastic; strong effervescence; common fine pores; clear smooth boundary.
2Bw1	0.15-0.41	Very dark gray (10 YR 3/1) dry and moist; clay; coarse, strong, angular blocky; very hard, very firm, very sticky and very plastic; strong effervescence; many medium pores; clear smooth boundary.
3Bw2	0.41-0.64	Very dark gray (10 YR 3/1) dry and moist; silty clay; coarse, strong, angular blocky; very hard, very firm, very sticky and very plastic; strong effervescence; many medium pores; diffuse wavy boundary.
4Bw3	0.64-0.90	Very dark gray (10 YR 3/1) dry and moist; clay loam; coarse, strong, angular blocky; very hard, very firm, very sticky and very plastic; strong effervescence; diffuse wavy boundary.
5Bw4	0.90-1.07	Very dark grayish brown (10 YR 3/2) dry and moist; clay loam; coarse, strong, angular blocky; very hard, very firm, very sticky and very plastic; strong effervescence; diffuse wavy boundary.
Bw5	1.07-1.50+	Brown (7.5 YR 4/3) dry, very dark grayish brown (10 YR 3/2) moist; clay loam; coarse, strong, angular blocky; very hard, very firm, very sticky and very plastic; strong effervescence; diffuse wavy boundary.
Other features	:	a) Cracks of 3 to 5 mm wide to a depth of 35 cm b) Indistinct and weak slickensides were present in 2Bw1 horizon.
Taxonomic Unit	:	Fine-laomy, smectitic, isohyperthermic Vertic Haplustepts
LCC (tentative interpretative grouping)	:	IIs (Good cultivatable land with slight limitations)

PEDON – 2

I. Soil site description

- a. Village : Yerragudipalem
- b. Physiography : Plain lands
- c. Slope : Degree : 0-1%
(Nearly level)
Class – A
Aspect : NW – SE
- d. Parent material : Granite-gneiss
- e. Natural vegetation : *Azadiracta indica*,
Cynodon dactylon,
Parthenium hysterophorus etc.
- f. Land use : Sorghum and Bajra
- g. Erosion : Very slight
- h. Drainage : Moderately well drained
- i. Ground water depth : Below 20m
- j. Location : In sorghum field, 1 km from
village

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.23	Dark brown (7.5 YR 3/3) dry and moist; sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, friable, slightly sticky and slightly plastic; few coarse pores; strong effervescence; clear smooth boundary.
A1	0.23-0.52	Brown (7.5 YR 4/4) dry, dark brown (7.5 YR 3/4) moist; sandy clay loam; medium, moderate, sub-angular blocky; slightly hard, friable, slightly sticky and slightly plastic; strong effervescence; diffuse wavy boundary.
A2	0.52-0.72	Dark brown (7.5 YR 3/3) dry, dark brown (7.5 YR 3/2) moist; sandy clay loam; medium, strong, sub-angular blocky; hard, friable, slightly sticky and slightly plastic; strong effervescence; diffuse wavy boundary.
Taxonomic Unit	:	Fine-loamy, smectitic, iso-hyperthermic Typic Ustorthents
LCC (tentative interpretative grouping)	:	IIIs (Moderately good cultivable lands with slight limitations)

PEDON – 3

I. Soil site description

- a. Village : Palukuru
- b. Physiography : Plain lands
- c. Slope : Degree : 0-1%
(Nearly level)
Class – A
Aspect : NW – SE
- d. Parent material : Dolomite
- e. Natural vegetation : *Tridax procumbens* and
Calotropis gigantia etc.
- f. Land use : Sunflower, Paddy and Redgram
- g. Erosion : Very slight
- h. Drainage : Poor
- i. Ground water depth : Below 20 m
- j. Location : In fallow lands located in Palukuru
village.

II. Brief description of the typifying pedon

Horizon	Depth(m)	Morphometric characters
Ap	0.00 – 0.18	Very dark gray (10 YR 3/1) dry and moist; clay; medium strong angular blocky; hard, firm, very sticky and very plastic; violent effervescence; common fine pores; clear smooth boundary.
Bw1	0.18-0.43	Very dark grayish brown (10 YR 3/2) dry and moist; clay; medium strong angular blocky; hard, firm, very sticky and very plastic; violent effervescence; few medium pores; diffuse and wavy boundary.
Bw2	0.43-0.67	Dark gray (10 YR 4/1) dry, very dark gray (10 YR 3/1) moist; clay; medium strong angular blocky; hard, firm, very sticky and very plastic; violent effervescence; common medium pores; diffuse and wavy boundary.
Bw3	0.67-0.91	Dark gray (10 YR 4/1) dry and moist; clay; medium strong angular blocky; hard, firm, very sticky and very plastic; violent effervescence; diffuse and wavy boundary.
Other features		: a) Cracks of 3 to 5 mm wide to a depth of 35 cm b) Indistinct and weak slickensides were present in Bw1 horizon.
Taxonomic Unit		: Fine, smectitic, isohyperthermic Vertic Haplustepts
LCC (tentative interpretative grouping)		: IIIsw (Moderately good cultivable land with moderate limitations)

PEDON – 4

I. Soil site description

- a. Village : Mittpalle
- b. Physiography : Very gently sloping uplands
- c. Slope : Degree : 1-3%
(Very gently sloping)
Class – B
Aspect : NW – SE
- d. Parent material : Granite-gneiss
- e. Natural vegetation : *Parthenium hysterophorus* and
Lantana camera etc.
- f. Land use : Sunflower, Paddy and Redgram
- g. Erosion : Slight
- h. Drainage : Somewhat poorly drained
- i. Ground water depth : Below 20 m
- j. Location : Right side of the road proceeding to
Mittapalle village

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.19	Brown (10 YR 4/3) dry, dark brown (7.5YR 3/3) moist; clay loam; fine, moderate, sub-angular blocky; slightly hard, firm, sticky and plastic; few fine pores; strong effervescence; many fine pores; clear smooth boundary.
Bw1	0.19-0.48	Dark brown (10 YR 3/3) dry dark brown (7.5 YR 3/4) moist; clay loam; medium, strong, angular blocky; hard, firm, sticky and plastic; strong effervescence; few fine pores; diffuse wavy boundary.
2Bw2	0.48-0.86	Brown (10 YR 4/3) dry dark brown (7.5 YR 3/2) moist; loam; medium, strong, angular blocky; hard, firm, slightly sticky and slightly plastic; strong effervescence; diffuse wavy boundary.
3Bw3	0.86-1.10	Very dark grayish brown (10 YR 3/2) dry, dark brown (7.5 YR 3/3) moist; sandy clay loam; medium, strong, angular blocky; hard, firm, slightly sticky and slightly plastic; strong effervescence; diffuse wavy boundary.
4Bw4	1.10-1.40	Dark gray (10 YR 4/1) dry dark brown (7.5 YR 3/4) moist; sandy clay; medium, strong, angular blocky; hard, firm, sticky and plastic; strong effervescence; diffuse wavy boundary.
Taxonomic Unit		: Fine-loamy, smectitic, isohyperthermic Typic Haplustepts
LCC (tentative interpretative grouping)		: IIIse (Moderately good cultivable land with moderate limitations)

PEDON – 5

I. Soil site description

- a. Village : Kapulapalle
- b. Physiography : plain lands
- c. Slope : Degree : 0-1%
(Nearly level)
Class – A
Aspect : NW – NE
- d. Parent material : Granite-gneiss
- e. Natural vegetation : *Acacia nilotica* and
Prosopis juliflora etc.
- f. Land use : Sorghum, Tobacco and Paddy
- g. Erosion : Very slight
- h. Drainage : Somewhat poorly drained
- i. Ground water depth : Below 20 m
- j. Location : In the mango orchard, 1km away
from Kapulapalle.

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.21	Dark yellowish brown (10 YR 4/6) dry, dark brown (7.5 YR 3/3) moist; silty clay loam; medium, moderate, sub-angular blocky; hard, firm, sticky and plastic; violent effervescence; few fine pores; clear smooth boundary.
Bw1	0.21-0.61	Dark brown (10 YR 3/3) dry, dark brown (7.5 YR 3/4) moist; sandy clay loam; medium, moderate, sub-angular blocky; hard, firm, slightly sticky and slightly plastic; violent effervescence; diffuse wavy boundary.
2Bw2	0.61-1.01	Strong brown (7.5 YR 4/6) dry, dark brown (7.5 YR 3/2) moist; silty loam; fine, moderate, sub-angular blocky; slightly hard, fraible, non-sticky and non-plastic; violent effervescence; diffuse wavy boundary.
3Bw3	1.01-1.40	Strong brown (7.5 YR 4/6) dry, dark brown (7.5 YR 3/3) moist; silty loam; fine, moderate, sub-angular blocky; slightly hard, fraible, non-sticky and non-plastic; violent effervescence; diffuse wavy boundary.
4Bw4	1.40-2.00	Strong brown (7.5 YR 4/6) dry, dark brown (7.5 YR 3/4) moist; loam; fine, moderate, sub-angular blocky; hard, firm, slightly sticky and slightly plastic; violent effervescence; diffuse wavy boundary.
Taxonomic Unit	:	Fine-loamy, kaolinitic, isohyperthermic Fluventic Haplustepts
LCC (tentative interpretative grouping)		IIIs (Moderately good cultivable lands with slight limitations)

PEDON – 6

I. Soil site description

- a. Village : Illuru Kothapeta
- b. Physiography : Very gently sloping uplands
- c. Slope : Degree : 1-3%
(Very gently sloping)
Class – B
Aspect : NW – NE
- d. Parent material : Granite – gneiss
- e. Natural vegetation : *Calotropis gigantia*,
Cyperus rotundus etc.
- f. Land use : Paddy
- g. Erosion : Slight
- h. Drainage : Somewhat poorly drained
- i. Ground water depth : Below 20 m
- j. Location : 1 km away from Illuru Kothapeta.

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.18	Dark yellowish brown (10 YR 3/4) dry very dark grayish brown (10 YR 3/2) moist; silty clay loam; medium, moderate, sub-angular blocky; slightly hard, firm, sticky and plastic; violent effervescence; few fine pores; clear smooth boundary.
A1	0.18-0.39	Dark brown (10 YR 3/3) dry and moist; silty clay loam; medium, strong, angular blocky; hard, very firm, sticky and plastic; violent effervescence; few medium pores; diffuse wavy boundary.
A2	0.39-0.50	Brown (7.5 YR 4/4) dry dark yellowish brown (10 YR 4/4) moist; silty clay loam; medium, strong, angular blocky; hard, very firm, sticky and plastic; violent effervescence; diffuse wavy boundary.
Taxonomic Unit		: Fine, smectitic, isohyperthermic Lithic Ustorthents.
LCC (tentative interpretative grouping)		: IVes (Fairly good cultivable land with severe limitations)

PEDON – 7

I. Soil site description

- a. Village : Gulamnabipeta
- b. Physiography : Very gently sloping uplands
- c. Slope : Degree : 1-3%
(Very gentle sloping)
Class – B
Aspect : NW – SE
- d. Parent material : Granite – gneiss
- e. Natural vegetation : *Cynodon dactylon* and
Cyperus rotundus etc.
- f. Land use : Sorghum, bajra and Redgram
- g. Erosion : Slight
- h. Drainage : Well drained
- i. Ground water depth : Below 20 m
- j. Location : In the fallow land, 1 km away from
Gulamnabipeta

II. Brief description of the typifying pedon

Horizon	Depth (m)	Morphometric characters
Ap	0.00-0.20	Brown (7.5 YR 4/4) dry dark brown (7.5 YR 3/3) moist; loam; fine, weak, crumb; slightly hard, fraible, slightly sticky and slightly plastic; violent effervescence; few medium pores; clear smooth boundary.
2A1	0.20-0.50	Dark brown (7.5 YR 3/4) dry and moist; sandy clay loam; medium, weak, sub-angular blocky; slightly hard, fraible, sticky and plastic; violent effervescence; few fine pores; diffuse wavy boundary.
3A2	0.50-0.87	Dark brown (7.5 YR 3/3) dry, strong brown (7.5 YR 3/6) moist; loam; fine, moderate, sub-angular blocky; slightly hard, fraible, slightly sticky and slightly plastic; diffuse wavy boundary.
4A3	0.87-1.00	Dark brown (7.5 YR 3/4) dry, strong brown (7.5 YR 4/6) moist; loam; fine, moderate, sub-angular blocky; slightly hard, fraible, slightly sticky and slightly plastic; diffuse wavy boundary.
Taxonomic Unit		: Fine-loamy, kaolinitic, isohyperthermic Typic Ustifluents
LCC (tentative interpretative grouping)		IVse (Fairly good cultivable lands with severe limitations)

APPENDIX – II

**LANDSCAPE AND SOIL REQUIREMENTS –
RICE CULTIVATION UNDER NATURAL FLOODS**

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)	Can only be practiced in flat flood plains						
Slope (%)							
Wetness (w)	F32	F31	F42, F41	F22, F21	–	F11, F12	
Flooding			F43, F33	F23, F24 F34, F44		F13, F14 F15, F25 F45, F35	
Drainage	Very poor	Poor	Imperf.	Moderate		Good	
Physical soil Characteristics (S)	Cm, SiCm,	C-60v,	Co	Sil	–	L and lighter	
Surface texture (*)	C+60v,	C-60s,	SiCL	SC			
(**)	C+60s	SiCs	Cl,Si				
	Cm, SiCm,	C-60v	SiL, SC,	SL, LfS,	–	S, cS	
	C+60v	C-60s	L, SCL	LS, LcS,			
	C+60s	SiCs, Co,		fS			
		SiCL, CL,					
		Si					
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	–	> 20	
Gypsum (%)	< 1	1 – 3	3 – 10	10 – 15	–	> 15	
Soil fertility characteristics (f)							
Apparent CEC (cmol(+)/kg clay)	> 24	24 – 16	< 16(–)	< 16 (+)	–	–	
Base saturation (%)	> 50	50 – 35	35 – 20	< 20	–	–	
Sum of basic cations (cmol(+)/kg soil)	>4	4.0 – 2.8	2.8 – 1.6	< 1.6	–	–	
pH H ₂ O	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 – 8.8	–	> 8.8	
Organic carbon (%)	> 2	2.0 – 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 filtration rate of less than 0.1 cm/hour and / or groundwater is present within 50 cm for the soil surface

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)	F0	–	–Imperfect	F1	–	F2+	
Flooding Drainage (4)	Good	Moderate	Good	Poor and	Poor, but	Poor, not	
(5)	imperf.	Moderate		aeric	drainab	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	LcS, fs, S	–	Cm, SiCm	
Coarse fragm (Vol%)	0 – 3	3-15	15-35	35-55	–	> 55	
Soil depth (cm)	> 150	150-100	100-75	75-50	–	<50	
CaCO ₃	0-6	6-15	15-25	25-35	–	>35	
Gypsum (%)	0 – 2	2 – 4	4 – 10	10 – 20	–	> 20	
Soil fertility characteristics (f)							
Apparent CEC (cmol(+)/kg clay)	> 24	24-16	< 16(-)	< 16 (+)	–	–	
Base saturation (%)	> 50	50 – 35	35-20	<20	–	–	
Sum of basic cations (cmol(+)/kg soil)	>4	4.0 – 2.8	2.8 – 1.6	< 1.6	–	–	
pH H ₂ O	6.6-6.2 6.6-7.0	6.2-6.0 7.0-7.5	6.0-5.5 7.5-8.0	5.5-5.0 8.0-8.5	<5.0 –	– >8.5	
Organic carbon (%)	> 2.0	2.0 – 1.2	1.2 – 0.8	< 0.8	–	–	
Salinity and Alkalinity (n)							
E _{Ce} (dS/m)	0 – 2	2 – 4	4 – 6	6 – 8	9 – 12	> 12	
ESP	0 – 8	8 – 10	10 – 15	15 – 20	20 – 25	> 25	

LANDSCAPE AND SOIL REQUIREMENTS – SORGHUM

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)	F0	–	F1	F2	–	F3+	
Flooding Drainage (4)	Good	Moderate	Imperf.	Poor and	Poor, but	Poor, not	
(5)	imperf.	Moderate	Good	aeric	drainab	drainab	
Physical soil Characteristics (S)							
Texture / Structure	C <60s, SiC, Co, SiL, Cl, Si, SiCL	C <60v, C > 60s, L, SCL	C>60v,SL,	LfS, fS, LS, S, LcS	–	Cm, SiCm, cS	
Coarse fragm (Vol%)	0 – 3	3 – 15	15 – 35	35 – 55	–	> 55	
Soil depth (cm)	>90	90-50	50-20	20-10	-	<10	
CaCO ₃	3-20	20-30	30-45	45-75	-	>75	
	3-2	2-0	-	-	-	-	
Gypsum (%)	0 – 3	3-5	5-10	10-20	–	> 20	
Soil fertility characteristics (f)							
Apparent CEC (cmol(+)/kg clay)	> 24	24 – 16	< 16(–)	< 16 (+)	–	–	
Base saturation (%)	> 50	50 – 35	35-15	<15	–	–	
Sum of basic cations (cmol(+)/kg soil)	>5	5.0-3.5	3.5-2.0	<2	–	–	
pH H ₂ O	6.5 – 6.0	6.0 – 5.5	5.5 – 5.0	5.0 – 4.5	< 4.5	–	
	6.5 – 7.0	7.0 – 7.5	7.5 – 8.0	8.0 – 8.5	–	–	
Organic carbon (%)							
(6)	> 1.5	1.5 – 0.8	<0.8	–	–	–	
(8)	> 0.8	0.8 – 0.4	< 0.4	–	–	–	
Salinity and Alkalinity (n)							
ECe (dS/m)	0 – 4	4-8	8-12	12-16	16-20	> 20	
ESP	0 – 10	10-20	20-28	28-35	–	> 35	

LANDSCAPE AND SOIL REQUIREMENTS – CHICKPEA

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)	F0	–	–	F1	–	F2+	
Flooding Drainage (4)	Good	Moderate	Imperf.	Poor and	Poor, but	Poor, not	
(5)	imperf.	Moderate	Good	aeric	drainab	drainab	
Physical soil Characteristics (S)							
Texture / Structure	SiL, CL	SiCL, SC, L, SCL	CS, SL, SiCs	LfS, LS, Co, SiCm	–	Cm, 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	0-10	10-25	25-35	35-50	–	> 50	
Gypsum (%)	0.0-0.1	0.1-0.3	0.3-3.0	3-15	–	> 15	
Soil fertility characteristics (f)							
Apparent CEC (cmol(+)/kg clay)	> 24	24 – 16	< 16(–)	< 16 (+)	–	–	
Base saturation (%)	>80	80-50	50-35	<35	–	–	
Sum of basic cations (cmol(+)/kg soil)	> 8	8-5	5.0-3.5	3.5-2.0	<2	–	
pH H ₂ O	6.8 – 6.5	6.5 – 6.0	6.0 – 5.6	5.6 – 5.2	< 5.2	–	
	6.8 – 7.0	7.0 – 7.6	7.6 – 8.0	8.0 – 8.2	–	>8.2	
Organic carbon (%)	>2	2.0-1.2	1.2-0.8	<0.8	–	–	
Salinity and Alkalinity (n)							
ECe (dS/m)	0 – 1	1-2	2-3	3-6	–	> 6	
ESP	0 – 5	5-8	10-12	12-15	–	> 15	