CHARACTERIZATION AND CLASSIFICATION OF SOILS OF WARANGAL DISTRICT OF CENTRAL TELANGANA ZONE

BY

V.RAJAGOPAL
B. Sc. (Ag)

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ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
RAJENDRANAGAR, HYDERABAD-500 030, ANDHRA PRADESH

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CERTIFICATE

Mr. V. RAJAGOPAL has satisfactorily prosecuted the course of research and that the thesis entitled **"CHARACTERIZATION AND CLASSIFICATION OF SOILS OF WARANGAL DISTRICT OF CENTRAL TELANGANA ZONE"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University.

Date: 31.07.2009
Place: Hyderabad

(Dr. C. NAGENDER RAO)
MAJOR ADVISOR

LIST OF ABBREVIATIONS

%	:	Per cent
cm	:	Centimeter
cmol$(p^+)Kg^{-1}$	:	Centimol proton per kilogram
dS m^{-1}	:	Deci Siemen per meter
kg ha^{-1}	:	Kilogram per hectare
M ha	:	Million hectares
m	:	Meter
me	:	Milliequalent
mg kg^{-1}	:	Milligram per kilogram
Mg m^{-3}	:	Mega gram per meter cube
mm	:	Millimeter
ppm	:	Parts per million
ASWC	:	Available Storage Water Capacity
AWC	:	Available Water Content
BD	:	Bulk Density
BS	:	Base Saturation
$CaCO_3$	:	Calcium carbonate
CEC	:	Cation Exchange Capacity
Cu	:	Copper
EC	:	Electrical Conductivity
ESP	:	Exchangeable Sodium Percentage
et al.	:	Others
Fe	:	Iron
Fig	:	Figure
HC	:	Hydraulic Conductivity
K	:	Potassium
Mn	:	Manganese
MSL	:	Mean Sea Level
MWD	:	Mean Weight Diameter

N	:	Nitrogen
P	:	Phosphorus
PD	:	Particle Density
OC	:	Organic Carbon
Viz.	:	Namely
WR	:	Water Retention
Zn	:	Zinc

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(V.RAJAGOPAL)

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DECLARATION

I, **V.RAJAGOPAL,** hereby declare that the thesis entitled **"CHARACTERIZATION AND CLASSIFICATION OF SOILS OF WARANGAL DISTRICT OF CENTRAL TELANGANA ZONE"** submitted to Acharya N.G. Ranga Agricultural University for the degree of '**MASTER OF SCIENCE IN AGRICULTURE'** is the result of original research work done by me. I further declare that the thesis or any part thereof has not been published earlier in any manner.

Date: 31.07.2009 **(V.RAJAGOPAL)**
Place: Hyderabad

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AUTHOR	:	**V.RAJAGOPAL**
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ABSTRACT

The present investigation entitled “Characterization and Classification of Soils of Warangal district of Central Telangana Zone” was carried out during the year 2008-09.For this purpose, fourteen representative profiles from the district were chosen for the study. These were described morphologically, horizon-wise. Soil samples were collected horizon-wise and analysed for physical, physico-chemical and chemical properties. Soils were taxonomically classified based on these results. In addition, twenty surface samples were collected from each of nine Administrative Divisions separately and analysed for N, P and K based on which, the nutrient index was calculated. Physical rating index was calculated from eight physical properties.

The soil texture varied from sandy loam to sandy clay loam to clay loam in surface horizons and sandy clay loam to clay loam to clay in sub-surface horizons. Bulk density and particle density of soils varied from 1.32 to 1.71 and 2.42 to 2.61 Mg m^{-3}, respectively. The bulk density increased with depth. The per cent aggregates greater than 0.25 mm and per cent aggregate stability ranged from 48.36 to 64.64 and 61.86 to 77.94, respectively and decreased with depth.

Hydraulic conductivity of the soils ranged from 0.08 cm hr^{-1} in bottom layer of Warangal to 18.26 cm hr^{-1}in surface layer of Tadvai profile and it decreased with increase in depth. The infiltration was moderately rapid in Tadvai, Bachannapet, Eturunagaram, Wardhannapet and Raghunathapalli, moderate in Pakala, moderately slow in Malyal and slow in other profiles. The water retention at 33 and 1500 K Pa was low in surface layers and increased with depth. The available water content ranged from 4.66 per cent to 16.16 per cent and in general, it increased with depth. The available water storage capacity (cm m^{-1}) was low in Tadvai, Bachannapet and Eturunagaram profiles, medium in Nallabelli, Eleti Ramayapalli, Wardhannapet, Raghunthapalli, Pakala and Malyal profiles and high in Duggondi, Regonda, Ghanpur, Khanapur and Warangal RS profiles.

Soil reaction ranged from 6.31 to 8.71. It was slightly acidic to alkaline. The soils were non-saline. The soils of Nallabelli and Regonda were alkali soils. The cation exchange capacity (cmol(p+)kg^{-1}) varied from 8.30 to 46.33 and it increased with depth in Tadvai, Nallabelli, Wardhannapet, Pakala and Malyal profiles. The exchangeable complex was dominated by calcium followed by magnesium, sodium and potassium. ESP decreased with depth in Tadvai and Nallabelli profiles whereas it increased with depth in Wardhannapet profile. Base saturation percentage of soils varied from 72 to 94 per cent.

The soil organic carbon content of surface soils was high in Malyal and Warangal Research station profiles whereas in other profiles, it was medium. Soil calcium carbonate content varied from 1.42 to 13.67 per cent and it increased with depth in most of the profiles. The soils of Nallabelli, Duggondi, Regonda and Warangal Research station were calcareous. The available nitrogen and phosphorus content in the profiles varied from low to medium and decreased with depth. The potassium content of soils was medium to high and decreased with depth. The available micronutrient content was higher than critical limits and decreased with depth. In Regonda, iron content was low. The nutrient index calculated from the fertility status in surface (0-15 cm) soil samples was low in nitrogen (1.09), medium in phosphorus (1.98) and high in potassium (2.68).

As per Taxonomy, Eleti Ramayapalli, Wardhannapet, Pakala and Duggondi profiles were classified into Inceptisols: Tadvai, Nallabelli, Bachannapet, Eturunagaram and Raghunathapalli profiles into Alfisols and Regonda, Ghanpur, Khanapur and Warangal Research station profiles into Vertisols based on soil properties.

The major constraints identified were low available water storage capacity, slow infiltration, high sub surface bulk density, water logging, soil erosion, alkali soils and low nitrogen and phosphorus. No constraints for crop production were observed in Malyal. Management practices suggested to increase the productivity are contour cultivation, application of organic matter, deep ploughing, gypsum application and application of N and P fertilizers.

CHAPTER I

INTRODUCTION

India is very much dependent on agriculture for its economic stability and growth. In a whole, the soil is a basic and vital resource in the land for agriculture and non agriculture use. This is non-renewable resource and finite in quantity and degradation of soil has been increasing with improper land use plan and unscientific crop management pattern as influenced by human being over the years. Also the land availability for agriculture has been reduced from 0.40 ha in 1950 to 0.14 ha at present and is likely to touch the limit of 0.10 ha by 2025 (Sekhon and Velayutham, 2002) and we need to increase the food grain production to meet out the population requirement. Soil is dynamic, always changing as a result of the forces of nature and human influences. In this changing scenario, soil scientists have credit to recommend proper land use pattern and crop management to conserve and sustain the productivity of soil.

Characterization helps in determining the soil potential and identifying the constraints in crop production besides giving detailed information about different soil properties. This knowledge will help us to harvest the nutrients from the soil with sustainable replenishment of nutrients.

Classification of soil leads to identification of soil problems and envisages the alleviating the problems and this knowledge is essential for utilizing the productivity of soils. Lack of soil characterization becomes obstacle in exploiting the soil production potentials. Knowledge of soil helps in better management practice for increasing the productivity of the soil.

Warangal is one of the 10 districts of Telangana region of Andhra Pradesh extending over an area of 12834 Km^2.Warangal district lies between 17^o 19' & 18^o 36' N latitude and 78^o 49' & 80^o 43' E longitude. The district is bounded by Khammam district on the East, Karimnagar district on the North, Nalgonda on the South and Medak on the West. River Godavari serves as border on one side.

The topography of the district consists of isolated hills, rainfed tanks, lakes and shrubby forests. River Godavari forms the North Eastern border of the district, but is not yet tapped fully for irrigation. The climate in Warangal district is generally dry. Summers are hot with mercury sometimes touching 50^oC. The temperature dips to 13^oC in winters during the months of December and January.

Warangal district receives maximum rainfall through the South – West monsoon during the months of July, August and September. Normal annual rainfall is 994 mm. The areas of Cherial, Maddur, and Bachannapet receive only upto 750 mm rainfall and are classified as dry areas. Maximum rainfall is received in Mulug, Parkal, Mahabubabad and Narsampet Mandals.

The soils of Warangal district have been classified as red earths, black soils (shallow to deep) and forest soils. The characterization and classification is not based on systematic analysis of soils. Hence, the present study was taken up to characterize and classify the soils Warangal district of Central Telangana Zone, a newly created agro-climatic zone in Andhra Pradesh with the following objectives.

Objectives

1) To study the physical properties of the soils viz. mechanical composition, bulk density, particle density, water retention at different tensions, saturated hydraulic conductivity, soil aggregate analysis and infiltration rate.

2) To study the physico-chemical and chemical properties like soil reaction, electrical conductivity, CEC, exchangeable cations (Ca,Mg,Na and K), organic carbon, available-N,P and K and micro nutrients.

3) To classify the soils as per soil Taxonomical classification.

5) To compute the physical rating index and nutrient index.

4) To identify the soil constraints, if any for crop production and suggest ameliorative measures.

CHAPTER II

REVIEW OF LITERATURE

The information regarding morphological characters, physical, physico-chemical and chemical properties and classification of soils is reviewed in this chapter.

2.1 MORPHOLOGICAL CHARACTERS

2.1.1 Soil colour

The soil colour depends on the organic matter and ferric oxides (Simmonson, 1993). The colour of red soils ranges from red to yellow and is due to coatings of ferric oxide on the soil particles. Alluvial soils are grey or greyish brown in colour with low Chromas of one or two (Chakravarthy *et al.,* 1978).

Dipak Sarkar *et al.* (1997) reported that organic matter has effect on colour of the soil surface horizons. It varied from greyish brown to very dark greyish brown in soils developed on higher altitudes and brown to dark brown in soils developed on piedmont plain.

Khan and Chatterjee, (2001) reported that the moist matrix colour of all the horizons in uncultivated field was strong brown (Hue 7.5 YR) and mottle colour of the lower horizon was dark red (Hue 2.5 YR) but in rice cultivated soils it was brown (Hue 10 YR) and yellowish red (Hue 5 YR), respectively in West Bengal. These differences were mainly due to fluctuations of water table in rice growing pedon.

The colour of the Vertisols in Bapatla of Andhra Pradesh varied from dark greyish brown to very dark greyish brown in rice growing soils and from very dark grey to very dark greyish brown in non rice growing soils (Ratnam *et al.,* 2001).

The presence of very dark grey to very darkish brown mottles reflected impeded drainage in the sub soil pedons of Sivagiri watershed of Chittoor district (Thangasamy *et al.,* 2005).

Mini *et al.* (2007) observed the colour of soil surface layer in pedon of hill ranges to be 5 YR hue and with increased redness with depth with a hue of 2.5 YR due to decrease in organic matter content and increase in free iron oxide in soils of North Karnataka.

Vara Prasad Rao *et al.* (2008) reported that soil colour varied from very dark greyish brown (10 YR 3/2) to brown (7.5 YR 4/4) in plains, brown (10 YR 4/3) to dark red (2.5 YR 3/6) in uplands and very dark greyish brown (10 YR 3/2) to dark red (2.5 YR 3/6) in hill slopes.

2.1.2 Soil structure

Dadhwal *et al.* (1997) reported angular to sub angular blocky structure in jhum cultivated hill slopes of Mizoram. Sidhu *et al.* (2000) observed subangular blocky structure in moderately developed cambic and argillic horizons, while strong coarse structure was observed in the well expressed argillic horizons, the difference being attributed to plasma segregation.

The Vertisols in Nagpur district of Maharashtra had moderate medium sub angular blocky structure to moderate, strong sub angular to coarse strong angular blocky structure in sub surface soils (Jagdish Prasad *et al.,* 2001).The structure in the cultivated soils of Neogal watershed in North-West Himalayas was granular to sub-angular blocky in surface and sub-angular blocky in sub-surface horizons (Sharma *et al.* 2004).

Maji *et al.* (2005) reported that the structure of the soils over basaltic terrain in sub-humid tropics of Central India varied from sub angular blocky in surface horizon to angular blocky in sub-surface horizons, which might be due to swell-shrink phenomenon of smectitic clay minerals.

2.1.3 Consistency

Soil consistence is also an important physical and dynamic property which changes with variations in soil moisture.

Padole and Deshmukh (1998) reported slightly hard to very hard (dry), friable to very firm (moist) and sticky to very sticky and very plastic consistency in Vertisols of Purna Valley of Vidharbha. Patil *et al.* (1999) noticed that the consistence was hard (dry), firm (moist) and slightly sticky to slightly plastic (wet) in case of Entisols (Ustorthents). It was hard to very hard (dry), firm to very firm (moist) and very sticky to very plastic (wet) in case of Vertisols (Haplusterts).

The consistence of the soils in Chotanagpur plateau was slightly hard to hard (dry), friable to firm (moist) and slightly sticky to very sticky and non plastic to very plastic (wet) (Dipak Sarkar *et al.,* 2001). The dry consistence in sandy loam to loamy soils varied from soft to hard whereas loamy sand to silty clay loam soils, it was loose to extremely hard in Maulkhad catchment of Himachal Pradesh (Sharma and Anli Kumar, 2003).

Thangasamy *et al.* (2005) reported that the consistence was loose to very hard (dry), loose to very firm (moist) and non-sticky to very sticky and non-plastic to very plastic (wet) in soils of Sivagiri micro watershed in Chittoor district of Andhra Pradesh. Tripathi *et al.* (2006) found that the consistence was soft to hard, friable to firm, slightly sticky and slightly plastic in surface horizons in soils of Kiar Nagali Watershed area in North West Himalayas.

2.2 PHYSICAL PROPERTIES

2.2.1 Soil texture

Gangopadhyay *et al.* (2001) observed decrease in sand content with increase in soil depth. The content of clay in soil increased with increase in soil depth showing evidence of translocation of finer particles from surface to lower horizons.

Rajavel *et al.* (2002) reported increase in clay content in lower horizons in some soils of Uttar Pradesh due to illuviation of clay.

Seshagiri Rao *et al.* (2004) reported soil textures varying from sandy loam to sandy clay loam in Southern Coastal Agro-Eco sub region soils of Andhra Pradesh.

Tripathi *et al.* (2006) reported particle size distribution in Kiar Nagali Micro watershed in North – West Himalayas as 13.2 to 33.6 per cent for clay, 10.80 to 34.0 for silt and 38.4 to 73.1 for sand. In sub-surface horizons, the clay content was high due to illuvial movement of clay.

Mini *et al.* (2007) observed varying texture varied from sandy clay loam to sand clay in surface and clay loam to sandy loam in lower horizons in North Karnataka of Coastal Agro ecosystem. The particle size distribution in the Vertisols of Nagpur district of Maharastra, indicated that clay is dominant fraction throughout the profile. Lingade *et al.,* (2008).

2.2.2 Bulk density

The soils of Kuanria Irrigation project in Orissa had bulk density ranging from 1.46 to 1.87 Mg m^{-3} (Nanda *et al.,* 1997). Walia and Rao (1997) observed that the bulk density of soils in trans Yamuna plain of Uttar Pradesh varied from 1.46 to 1.96 Mg m^{-3} and increased with depth possibly due to enhanced compactness with depth, low organic matter and/or close packing of particles during settling of sediments.

The bulk density in Vertisols of Majalgaon canal command area of Maharastra varied from 1.33 to 1.40 Mg m^{-3} and showed increasing trend with depth (Bharambe *et al.,* 1999). Jagdish Prasad *et al.* (2001) observed 1.52 to 1.72 g cm^{-3} bulk density in Inceptisols and Vertisols of Nagpur district. Bulk density of red soils was higher (1.63 Mg m^{-3}) than black soils (1.57 Mg m^{-3}) due to their coarser texture associated with lesser pore space (Ram Prakash and Seshagiri Rao, 2002).

Satyavathi and Suryanarayan, (2005) observed increased bulk density with depth from 1.81 to 1.97 Mg m^{-3} in black soils whereas in red soils, it was from 1.43 to 1.58 Mg m^{-3}.

Masri Sitanggang *et al.* (2006) stated that soils having higher percentage of sand (or) gravel had more bulk density than those having high clay content.

2.2.3 Particle density

Particle density is fairly constant for almost all soils that have no or have very little organic matter. The particle density of soils generally varies between 2.5 to 2.7 Mg m^3 with an average of 2.65 Mg m^3.according to Daji (1970) particle density of surface layers of the alluvial soils, black soils, laterite soils and red soils was 2.55, 2.20, 2.40 and 2.56 Mg m^3, respectively.

Madhusudhana Rao (1993) reported that particle density values of sandy soil in Chakicharla village of Andhara pradesh varied from 2.48 to 2.65 Mg m^{-3}.

Jawahar et al. (1999) studied particle density of the red coastal sand dune soils in Tamil Nadu varied from 2.12 to 2.97 Mg m^{-3}.

2.2.4 Aggregate stability

Yadav and Banerjee (1968) reported decrease in water stable aggregates with increasing depth under sal (*Shorea robusta)* plantations. There were large sized aggregates in the surface layer and small sized in the lower depths.

Water stable aggregates were more under teak (*Tectona grandis*) plantations when compared to Sal (*Shourea robusta*) and Chir (*Pinus roxburghii*) plantations. All these plantations showed a decreasing trend of water stable aggregates down the profile (Yadav and Singh, 1976).

Sushil Kumar *et al.* (2002) reported that aggregates having diameter greater than 0.25 mm were more in the surface soil under different land use system.

Kukal and Manmeet Kaur (2003) observed that the water stable aggregates were maximum (94.8%) in pasture soils followed by 42.3 % in forest soils and 40.4 % in agricultural soils.

2.2.5 Hydraulic conductivity

Hydraulic conductivity was found to be significantly negatively correlated with silt, clay, silt plus clay and CEC while it was significantly positively correlated with sand fraction and exchangeable calcium (Oswal and Khanna, 1981).

Rao and Krishnamurthy (1982) reported that the hydraulic conductivities of Alfisols and Vertisols soils of Hyderabad region to be 3.7 cm hr^{-1} and 2.5 cm s hr^{-1} respectively.

The hydraulic conductivity showed a very high significant positive correlation with sand ($r = 0.844$) and significant negative correlation with silt plus clay, EC, CEC, free $CaCo_3$ and bulk density (Venu Prasad, 1986). Non-significant correlation of saturated hydraulic conductivity with organic carbon in soils with low organic carbon content was reported by Singh *et al.* (1989).

Vani (1998) reported that hydraulic conductivity decreased with depth in Jambuga profile of Adilabad district. Similar result was also reported by Ramachandran (2006).

2.2.6 Infiltration

The steady state infiltration rate of Nagarjunasagar left canal area ranged from72 to 480 cm per day (Venu Prasad, 1986). Initial moisture content has notable influence on soil infiltration rate. Though the infiltration rate in the initial stages is slow, the steady state rate is obtained with time (Choudary, 1994).

Tillage operation has significant effect on soil infiltration. Khatik *et al*. (2003) reported lowest cumulative infiltration in unploughed land than ploughed land in Nala watershed area of Jabalpur district.

High infiltration rates were observed in soils having high organic matter (Rajyalakshmi, 2004).Ramachandran (2006) reported infiltration rates of 1.02 to 1.23 cm hr^{-1} in sandy clay loam soils of Hyderabad.

2.2.7 Water retention

Kaushal *et al.* (1996) observed that the water retention at 33 and 1500 K Pa had significant and positive relationship with clay, silt and organic carbon while it was negative with sand and bulk density in the temperate zone forest soils of Himalayas.

Bharambe *et al.* (1999) found that soils in Majalgaon canal command area of Maharastra were highly moisture retentive and moisture retained in surface layer at 33 K Pa tension varied from 39.6 to 42.1 per cent in deep Vertisols.

Ravinder Singh and Nayak (1999) studied the water retention characteristics of Mahi right bank canal command area of Gujarat. They concluded that the water retention capacity was in the order of Vertic Haplaquept > Typic Haplaquept > Fluventic Ustochrept > Typic Ustorthent.

Increase in the water held at 33 K Pa and 1500 K Pa with increase in depth and has been reported by Challa *et al. (*2000) in Vertisols of Maharastra.

Water retention capacity of soil varied with type and amount of clay as depicted by the varying amounts of 5.2 to 6.2 g kg^{-1} at 33 K Pa and 3.2 to 9.5 g kg^{-1} at 1500 K Pa in soils of Neogal watershed in North West Himalayas. (Sharma *et al.,* 2004).

Thangasamy *et al.* (2005) reported increase in water retention from surface (13.05 per cent) to lower horizons (58.99 per cent) in soils of Sivagiri watershed of Chittoor District of Andhra Pradesh. The increase in water retention was attributed to increased clay content with increase in depth. Maji *et al.* (2005) reported increased AWHC due to increase in clay with increased in depth in sub humid tropics of Central India.

Vara Prasad Rao *et al.* (2008) reported that higher clay content in lower depths increased water holding capacity (WHC) in uplands than in hill slopes.

2.3 PHYSIO-CHEMICAL PROPERTIES

2.3.1 Soil reaction (pH)

Singh *et al.* (2000) reported that pH values in old alluvial soils were found to be low in surface horizons, which might be due to high organic matter content as well as more biochemical weathering and upland physiography.

Rudramurthy and Dasog, (2001) reported that in red soil pedons, the pH ranged from strongly acidic to neutral and in black soils from neutral to strongly alkaline in northern Karnataka.

Sarkar *et al.* (2002) observed acidic soil reaction in Loktak catchment area of Manipur. They reported that pH increased with depth from 4.5 to 5.8 due to losses of bases.

Masri Sitaggang *et al.* (2006) reported that in hill top and hill side areas, the soils were slightly alkaline to alkaline with range of 7.55 to 8.57. Increase in pH is due to accumulation of leached bases from the hill top in watershed area of Shikohpuz, Gurgaon district of Haryana.

Taywade *et al.* (2008) reported that soil reaction of sewage irrigated soils ranged from 8.3 to 9.1 and that of non-irrigated soils from 7.9 to 8.7 in different horizons. Increase in pH was due to sewage effluents containing large quantities of alkaline salts in soils of Maharastra.

2.3.2 Electrical conductivity (EC)

Mishra and Ghosh (1995) stated that the soils derived from Mica rich parent material were very low in EC values. Rudramurthy and Dasog, (2001) reported low electrical conductivity in red soils (0.10 to 0.31 dS m^{-1}) as compared to black soils (0.24 to 1.10 dS m^{-1}).

In soils of Barne Nala Watershed, Jabalpur District, higher EC was observed in surface soil (Khatik *et al.*, 2003) which was attributed to poor infiltration causing accumulation of soluble salts in the surface soil.

Kawde *et al.* (2005) observed increase in EC with increase in depth in soils of Purna Valley of Keliveli.

Thangasamy *et al.* (2005) reported EC ranging from 0.02 to 0.36 dS m^{-1} in different horizons suggesting very low amount of soluble salts in Sivagiri Micro-watershed of Chittoor District of Andhra Pradesh. Masri Sitanggang *et al.* (2006) reported that EC of the soils of watershed area of Shikohpur, Haryana ranged from 1.05 to 1.40 dS m^{-1} in surface layer and 1.00 to 1.50 dSm^{-1} in sub-surface layers.

Tripathi *et al.* (2007) reported that EC of Vertisols of Kymore Plateau varied from 0.03 to 0.34 dS m^{-1}.

Verma *et al.* (2007) reported EC value of 10.14 dSm^{-1} in 0-15 cm depth and 24.5 dSm^{-1} in 5-36 cm depth in Alwai soils indicating increase in EC with increase in depth.

2.3.3 Cation exchange capacity (CEC)

The CEC of the soils in Lohit district of Arunachal Pradesh varied from 5 to 10 $cmol(p^+)kg^{-1}$ soil. The low values of CEC in proportion to their organic matter and/or clay content were assigned either due to dominance of illitic and kaolinitic clays as reported in this region or due to formation of complexes of clays and sesquioxides with organic matter which lead to blocking of exchange sites (Walia and Chamuah, 1996).

Chinchmalatpure *et al.* (2001) studied the salt affected areas of Gujarat and reported that the CEC of Orra and Vejalaka villages ranged from 28 to 40 cmol(p^+)kg^{-1} while that of Ralej and Zinzar villages ranged from 12 to 16 cmol(p^+)kg^{-1} .The higher CEC of former was due to dominance of smectitic mineralogy and lower CEC values of later was due to mixed mineralogy.

Sarkar *et al.* (2002) reported that in soils of Loktak catchment area, cation exchange capacity varied from 7.7 to 26.2 cmol(p+)kg^{-1} and decreased with depth.

Vacca *et al.* (2003) observed decrease in cation exchange capacity with depth in soils of South Central Italy.

The cation exchange capacity of both agricultural and cultivable waste lands of Raniganj Coal field area increased with depth (Ghose and Kundu, 2001).Tripathi *et al.* (2006) observed CEC ranging from 9.8 to 19.8 cmol (p^+) kg^{-1} in the soils of Kiar Nagali watershed of North West Himalayas which decreased with depth.

2.3.4 Exchangeable cations

Reddy *et al.* (1999) reported that exchange complex of soils in Karnataka was dominated by Ca (1.0 to 44.1 cmol(p^+)kg^{-1}) and was followed by Mg, Na and K with values ranging from 0.4 to 16.6, and 0.1 to 5.4 cmol(p^+)kg^{-1},respectively.

According to Chinchmalatpure *et al.* (2001) the salt affected soils of Gujarat showed the dominance of sodium cation followed by calcium, magnesium and potassium.

Exchangeable calcium and magnesium were found to be increasing with depth in the soils of Raniganj coalfield area (Ghose and Kundu, 2001).In Channapatna soils of Karnataka, calcium was noted to be dominant among the exchangeable cations followed by magnesium throughout the depth (Pillai and Natarajan, 2004).Thangasamy *et al.* (2005) reported that in most of the profiles in Sivagiri micro watershed in Chittoor district of Andhra Pradesh the exchangeable bases were in the order of Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} .

Patton *et al.* (2007) observed higher mean exchangeable Ca^{2+} (3.7 cmol(p^{+}) kg^{-1}) and Mg^{2+} (12.1 cmol (p^{+})kg^{-1}) in Jhum fields than terrace fields in Nagaland. Gangopadhyay *et al.* (2008) observed that Ca^{2+} was dominant among the bases in south Tripura District of North eastern India.

2.3.5 Base saturation

According to Walia and Rao (1996), the soil base saturations varied from 67.00 to 88.00 per cent in Bundelkhand. Base saturation of Epiaquepts of Banda plain region varied from 75.00 to 89.00 per cent (Walia and Rao, 1997).

Tamgadge *et al.* (1999) studied the soils of basaltic terrain in northern deccan plateau of Madhya Pradesh and reported that the base saturation of the soils ranged from 70 to 99 per cent. Dipak Sarkar *et al.* (2001) observed that the soils of lower Chotanagpur plateau had base saturation ranging from 49 to 77 per cent. The per cent base saturation of the soils in upper Maul Khad catchment of Himachal Pradesh ranged from 45 to 62 (Sharma and Anil Kumar 2003).

Satyavathi and Suryanarayan,(2005) reported that the base saturation ranged from 75 to 100 per cent in soils of Northern Telangana Zone of Andhra Pradesh. Tripathi *et al.* (2006) stated that in the soils of Kiar-Nagali Microwatershed in North-West Himalayas, the base saturation percentage varied from 58.5 to 66.3 and 56.6 to 74.3 per cent in surface and sub-surface horizons, respectively.

2.4 CHEMICAL PROPERTIES

2.4.1 Organic carbon

The organic carbon content of Vertisols and Alfisols of Maharastra decreased from the surface downwards, indicating the maturity of the profile developed on very stable land form and the surface soils registered fairly high amount of organic carbon (Jagdish Prasad *et al.,* 1995)

Dhaliwal *et al.* (1996) reported that the organic carbon content in flood plain soils of Punjab ranged from 0.06 to 0.87 per cent.

Sahrawat (1999) reported that in Vertisols of Patancheru, Andhra Pradesh the organic carbon content ranged from 0.50 to 5.0 g kg^{-1}. Sarkar *et al.* (2002) stated that the organic carbon content in the surface soils of Loktak catchment area in Manipur ranged from 24.7 to 45.4 g kg^{-1} and decreased with depth.

The organic carbon in surface horizons of banana growing soils in Wardha district of Maharastra ranged from 5.5 to 8.7 mg kg^{-1} and decreased in sub-surface soils to a minimum of 1.4 mg kg^{-1}(Kadao *et al.,* 2003).

Tripathi *et al.* (2006) studied that the soils of Kiar-Nagali Micro-watershed in North-West Himalayas. He reported that the organic carbon content of the surface and sub-surface soils ranged from 11.7 to 23.5 and 4.5 to 16.2 g kg^{-1}, respectively indicating decrease with increase in depth. Vara Prasad Rao *et al.* (2008) reported that in the soils of Ramachandrapuram mandal in Chittoor district of Andhra Pradesh, the organic carbon content varied from 1.2 to 5.6 g kg^{-1} and decreased with depth which might be due to the prevalence of tropical conditions.

2.4.2 Calcium carbonate

The $CaCO_3$ content of red and black soils of Tamil Nadu ranged from 2.0 to 2.93 per cent and 4.02 to 8.65 percent, respectively (Thiyagarajan, 1998). Sahu and Mishra (1996) reported the gradual increase of $CaCO_3$ in lower horizons.

Sahrawat, (1999) reported that Vertisols of Patancheru, Andhra Pradesh had $CaCO_3$ varying from 93 to 152 g kg^{-1}.Calcium carbonate content in soils of Udaipur and Chittaurgarh districts of Rajasthan ranged from 31.8 to 39.6 per cent and increased with depth. This could be due to limestone parent material (Singh *et al.,* 1999).

The $CaCO_3$ content in calcareous soils of Maharastra ranged from 57 to 167 g kg^{-1} and increased with depth. (Challa *et al.,* 2000). Increase in $CaCO_3$ with depth has also been reported by Sharma *et al.* (2004) and Bhasker *et al. (2005)*

Masri Sitanggang *et al.* (2006) reported that in the watershed area of Shikohpur, Gurgaon district, Haryana, the free $CaCO_3$ content ranged from

5.0 to 100.0 g kg^{-1}. The higher content might be due to ustic moisture regime of the area and deposition of $CaCO_3$ containing alluvium.

2.4.3 Available N P and K

The available nitrogen declined from 589 to 522 kg ha^{-1} and 567 to 511 kg ha^{-1} over a period of three years in soils under shifting cultivation in west and south Tripura, respectively (Datta *et al.,* 2001).The available phosphorus was low and available potassium was low to medium.

Ghose and Kundu, (2001) reported available N, P and K in agricultural fields ranging from 169.8 to 216.4, 7.6 to 9.4 and 239.4 to 266.6 kg ha^{-1} respectively.

Joshi *et al.* (2004) reported low available potassium (137 kg ha^{-1}) and total nitrogen (0.102 %) and high in available phosphorous (34.8 kg ha^{-1}) in soils of Bhetagad watershed of central Himalayas.

Thangasamy *et al.* (2005) observed decrease in available N, P and K in soils of Sivagari Watershed area from the surface soil to sub-surface soil.

Vara Prasad Rao *et al.* (2008) found nutrient status of Ramachandrapuram mandal of Chittoor district to be low in N, low to medium in P and medium to high in available K.

2.4.4 Available Micronutrients

The available copper content ranged from 0.8 to 5.8 mg kg^{-1} in soils of Maharastra (Bharambe *et al.,* 1999). Entisols and Inceptisols of Mizoram registered 0.8 to 2.0 mg kg^{-1} of available copper (Misra and Saithantuannga, 2000).

Jassal *et al.* (2000) reported positive and significant correlation of Zn and Cu with clay and silt contents where as Mn showed positive correlation with sand and organic matter.

Bhaskar *et al.* (2005) observed that total Iron varied from 0.5 to 5.24 ppm in bil environ of Brahamaputra valley in Jorhat district of Assam. Thangasamy *et al.* (2005) reported that Sivagiri Micro watershed area in Chittor district was deficient in available Fe and suficient in Cu, Mn and Zn.

Balpande *et al.* (2007) reported Cu, Fe, Mn and Zn ranging from 1.16 to 22.0, 2.52 to 9.22, 0.06 to 3.06 and 3.44 to32.1 mg kg^{-1} respectively in soils of Maharastra.

Vara Prasad Rao *et al.* (2008) found that soils of Ramachandrapuram Mandal in Andhra Pradesh were deficient in available Fe and Zn and sufficient in Cu and Mn.

2.5 Soil Classification

Jagdish Prasad *et al.* (2001) classified shallow soils in Nagpur district of Maharastra into clayey hyperthermic Typic Ustothent by virtue of having ochric epipedon, thin solum, clay > 30 %, ustic moisture and hypherthermic soil temperature regimes.

Sarkar *et al.* (2002) classified the soils in to Inceptisols order due to the presence of cambic horizon, Udept in suborder level because of the prevailing Udic moisture regime and Dystrudept at great group level due to base saturation being less than 60 per cent within 25 to 75 cm depth in Loktak catchment area of Manipur.

Seshagiri Rao *et al.* (2004) classified the soils of Agro-eco sub region in Andhra Pradesh into fine montmorillonitic isohyperthermic based on criteria given USDA Taxonomic classification system. Maji *et al.* (2005) classified the landforms and soils developed over basaltic terrain in sub humid tropics of India into three orders *viz.,* Entisols, Inceptisols and Vertisols.

Thangasamy *et al.* (2005) classified the soils of Sivagiri micro watershed of Chittoor district into three orders,Viz; Entisol which do not have have any diagnostic horizon, Alfisols having argillic sub-surface diagnostic horizon and Inceptisols with cambic (BW) sub-surface diagnostic horizon. Tripathi *et al.* (2006) classified the soils of Kiar-Nagali Micro watershed in North West Himalayas into Inceptisols.

Mini *et al.* (2007) observed argillic horizon and base saturation more than 35 per cent in all horizons and classified the soils into Alfisols in pilot site of coastal agro eco system of Northern Karnataka.

The soils of Ramachandrapuram mandal of Chittoor District of Andhra Pradesh were classified into Entisols, Alfisols and Inceptisols (Vara Prasad Rao, 2008) based on soil properties.

2.6 Soil constraints

The constraints of very rapid permeability, poor permeability, high clay content, low organic carbon and nitrogen in soils of Srikakulam district of Andhra Pradesh were reported by Prabhu Prasadini and Singa Rao (1998).

High clay content of Indian black cotton soils poses problems during ploughing. Water logging of soils is also a major problem in these soils (Sehgal, 1996).

In Andhra Pradesh about 54 per cent of soils were degraded by water erosion, soil crusting and compaction, salinity, sodicity and flooding (NBSS&LUP, 1997).

Soil depth, poor drainage, sandy texture, alkalinity and low in nutrient status are the major constraints in soils of sugarcane growing areas of Kancheepuram, Tamil Nadu (Sellamuthu *et al.,* 2000).

Rajput *et al.* (2003) reported that physical, chemical and biological constraints influenced the productivity in soybean based cropping system in Central India.

Mukhopadhyay *et al.,* (2006) reported that constraints like moderate to steep slopes, shallow depth, light texture and high soil acidity resulted in poor productivity.

CHAPTER III

MATERIALS AND METHODS

The present study was carried out with the objectives of characterization and classification of soils of Warangal district of newly formed Central Telangana Zone in Andhra Pradesh.

3.1 LOCATION

The pedon locations are shown in Fig. 1. The area selected for the present study of Central Telangana Zone in Andhra Pradesh has total geographical area of 12,846 km^2 which lies between 17^o 19' & 18^o 36' N latitude and 78^o 49' & 80^o 43' East longitude. The district is surrounded by Khammam district of Andhra Pradesh on the East, Karimnagar district on the North, Nalgonda on the South and Medak on the West. River Godavari serves as border on one side. The site for profile study was selected with the use of topographical base maps.

3.2 PHYSIOGRAPHY

The Warangal district represents a variety of geological formations and contains rich deposits of economically important minerals. The rock formations are mainly divided into four geological formations, i.e., Archeans, Gondwanas, Puranas and Recent (Alluviums). Warangal is predominantly an agricultural district with a large number of artificial lakes and the river Godavari.

3.3 CLIMATE

3.3.1 Temperature

The climate in Warangal district is generally dry. Summers are hot with mercury sometimes touching 50^{o}C. The temperature dips to 13^{o}C in winters during the months of December and January.

3.3.2 Rainfall

Warangal district receives maximum rainfall through the South – West monsoon during the months of July, August and September. Normal annual rainfall is 994 mm. The areas of Cheriyal and Bachannapet receive only upto 750 mm rainfall and are classified as dry areas. Maximum rainfall is received in Mulug, Parkal, Mahabubabad and Narsampet Mandals.

3.4 VEGETATION

The predominant crop grown in the district is Paddy which accounts for 34% of the total cropped area. Cotton, maize, chilli, groundnut, green grams, castor and gingelly are other important crops grown in the district, The district represents two protected areas, namely Pakhal Wildlife Sanctuary and Eturnagaram Wildlife Sanctuary declared during 1952-53.

3.5 COLLECTION OF SOIL SAMPLES

3.5.1 Profile Samples

The profiles were studied in selected locations by digging pits up to required depth. Horizon-wise soil samples were collected from the profiles for analysis of soil properties. Samples for physical analysis as required were collected. Infiltration was studied *in situ.*

3.5.2 Surface samples

Twenty representative surface samples (0-15 cm) were collected from each of the nine Administrative divisions for preparation of nutrient index of nitrogen, phosphorus and potassium.

3.6 ANALYSIS OF SOIL SAMPLES

3.6.1 PHYSICAL PROPERTIES

3.6.1.1 Particle size analysis

The particle size analysis was carried out by hydrometer method. The textural classes were determined on the basis of different proportions of sand, silt and clay by using the textural triangle method of International Society of Soil Science (Piper, 1966).

3.6.1.2 Soil colour

Munsell's colour chart was used to find out Hue, Value and Chroma under dry and moist conditions (Soil Survey Staff, 1951).

3.6.1.3 Bulk density

Bulk density was determined by core sampler method (Blake and Hartge, 1986).

3.6.1.4 Particle density

Particle density was determined as per procedure given by Blake and Hartge (1986).

3.6.1.5 Aggregate analysis

Aggregate analysis was done by wet sieving method as described by Yoder (1937).The percentage aggregates more than 0.25 mm diameter and the per cent aggregate stability were calculated from the following equation

Per cent aggregates more than 0.25 mm

$$= \frac{\text{Weight of aggregates more than 0.25 mm diameter}}{\text{Weight of soil}} \times 100$$

Per cent aggregate stability

$$= \frac{\text{Weight of aggregates more than 0.25 mm diameter - weight of sand}}{\text{Weight of sample – weight of sand}} \times 100$$

3.6.1.6 Hydraulic conductivity

The hydraulic conductivity of the undisturbed samples was measured by the constant head method as per the procedure outlined by Klute and Dirksen (1986).

3.6.1.7 Infiltration rate

Infiltration rate was determined *in-situ* by using double ring infiltrometer as described by Jalota *et al*. (1998).

3.6.1.8 Water retention

Water retention capacity of soil samples at 33 K Pa and 15 K Pa tensions was determined using pressure plate apparatus (Klute, 1996) and expressed in terms of percentage on dry weight basis.

3.6.2 PHYSICO-CHEMICAL PROPERTIES

3.6.2.1 Soil reaction (pH)

pH of the soil samples was determined in 1:2.5 soil water suspension by using (DI-707) pH meter (Jackson, 1973).

3.6.2.2 Electrical conductivity (EC)

The electrical conductivity was determined in 1:2.5 soil water extract with help of (DI-909) digital conductivity meter (Jackson, 1973).

3.6.2.3 Exchangeable cations

The exchangeable cations were determined by extracting the soil with 1N neutral normal ammonium acetate. The exchangeable sodium and potassium were determined by flame photometer (Tandon, 1993). The exchangeable calcium and magnesium were determined by Versenate method (Chopra and Kanwar, 1991).

3.6.2.4 Cation exchange capacity (CEC)

The cation exchange capacity of the soil was determined as per procedure given by (Bower *et al.,* 1952).

3.6.2.5 Base saturation

Soil base saturation was calculated from the following equation (Tandon, 1993).

$$BS = \frac{R}{T}$$

Where,

BS – base saturation

S – me of basic cations per 100 g of soil

T – Total cation exchange capacity (me per 100 g of soil)

3.6.3 CHEMICAL PROPERTIES

3.6.3.1 Organic carbon

The organic carbon content was determined by Walkley and Black (1934) rapid titration method.

3.6.3.2 Free calcium carbonate ($CaCO_3$)

The free calcium carbonate content 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).

3.6.3.3 Available nitrogen (N)

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

3.6.3.4 Available phosphorus (P)

Available phosphorus in the soils was determined by using Olsen's extractant as described by Olsen *et al.* (1954).

3.6.3.5 Available potassium (K)

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

3.6.3.6 Available Micronutrients (Fe, Mn, Zn and Cu)

Twenty grams of soil was shaken with 30 ml of DTPA extractant of pH 7.3 for 2 hours. The contents were filtered and in the filtrate iron, manganese, zinc and copper were determined by using atomic absorption spectrophotometer (Tandon, 1993).

3.7 SOIL CLASSIFICATION

The soils were classified as per the Soil Taxonomy (Soil Survey Staff, 1998) based on climatic conditions, morphological, physical, physico-chemical and chemical properties of soils.

3.7.1 PHYSICAL RATING INDEX

Attempt was made to calculate numerically the physical index of the soils in relation to every profile as suggested by Gupta (1985). A product of eight soil physical properties ABCDEFGH were used to compute the physical rating index (PI). Based on PI, the suitability class was identified as shown in Table 1.

Physical rating index = ABCDEFGH

Where,

A - Soil depth (cm)
B - Bulk density (Mg $m^{-3)}$
C - Profile Water Storage Capacity (cm)
D - Infiltration Rate or hydraulic conductivity of soil (cm hr^{-1})
E - Aggregation in terms of organic matter content (%)
F - Non-capillary pore space (%)
G - Depth of water table (cm)
H - Slope (%)

Table 1. Physical rating index classes of soils

Class	Physical rating index	Suitability
I	>0.9	Highly suitable; very high crop yields
II	0.75-0.90	Suitable; expected yield is 75 % of the potential
III	0.50-0.75	Moderately suitable; expected yield is 50% of the potential
IV	0.25-0.50	Slightly suitable; low yield; can be improved by appropriate soil management practices
V	<0.25	Unsuitable

3.7.2 SOIL NUTRIENT INDEX

The surface soil samples were classified into low medium and high categories as per the limits suggested by Muhr *et al.* (1965) for available N, P and K. Nutrient index was calculated from the equation given below (Parker *et al.,*1951) and categorized (Table 2) as per Sekhon and Velayutham,2002.

$$\text{Nutrient index} = \frac{N_l + 2N_m + 3N_h}{N_l + N_m + N_h}$$

Where,

N_l - Number of soils falling under low category

N_m - Number of soils falling under medium category

N_h - Number of soils falling under high category

Table 2. Nutrient Index categories of soils

Category	NI value
Low	< 1.5
Medium	1.50 – 2.50
High	>2.50

3.7.3 Identification of constraints

Soil constraints were identified based on the field studies, laboratory analysis and suitable management practices are suggested.

CHAPTER IV

RESULTS

Soil profiles were dug up at the selected sites to required depth. Morphological features *viz.,* depth, horizons, boundaries, colour, structure *etc.* for each profile were recorded. Horizon-wise soil samples were collected from each profile and analysed for physical properties *viz.,* particle size distribution, bulk density, particle density, saturated hydraulic conductivity, moisture retention at 33 K Pa and 1500 K Pa tensions and aggregate stability, Physico-chemical properties *viz.,* soil reaction (pH), electrical conductivity (EC), cation exchange capacity and exchangeable cations and chemical properties *viz.,* organic carbon, available nitrogen, phosphorus and potassium and micro nutrients (Fe, Mn, Cu and Zn). Infiltration studies were made *in situ*. The results obtained are presented in this chapter.

4.1 SOIL MORPHOLOGICAL PROPERTIES

4.1.1 Depth of the profile

The depth of soils was moderately shallow to deep. It varied from 55 cm in Eleti Ramayapalli to 120 cm in Eturunagaram.

4.1.2 Soil horizons

Five horizons in Regonda, four horizons in Tadvai, Eturunagaram, Malyal, Ghanpur, Khanapur and Warangal research station and three horizons in Nallabelli, Bachannapet, Wardhannapet, Raghunathapalli, Pakala and Duggondi profiles were demarcated based on variation in colour and other properties.

4.1.3 Horizon boundary

In the surface horizons, the boundary was clear smooth in all the profiles. It varied from clear smooth to clear wavy to diffused wavy in other horizons.

4.1.4 Soil colour

The soil colour was yellowish red (Hue 10 YR to 2.5 YR) with Values between 3 and 5 and Chroma ranged from 1 to 8. The purity of colour decreased with depth.

4.1.5 Soil structure

In surface horizon, sub angular blocky structure was observed in all the profiles. The structure was sub angular blocky to angular blocky in sub - surface horizons of Duggondi, Regonda, Ghanpur, Khanapur and Warangal RS profiles.

4.1.6 Soil texture

Soil texture of profiles varied from sandy loam to sandy clay loam to clay loam in surface horizons and sandy clay loam to clay loam to clay in sub-surface horizons.

4.1.7 Consistency

Consistency of soils was recorded under dry, moist and wet conditions. The consistence was loose to very hard under dry, friable to very firm under moist and non-sticky to sticky and non-plastic to very plastic under wet conditions.

4.1.8 Slickensides

The polished shining surface was observed in Regonda, Khanapur and Warangal research station profiles in the sub-surface horizons.

4.1.9 Pores and Roots

The pores observed in the profiles varied from few (less than I %) to many (5% per unit area) with fine to medium in size.

Roots were observed in upper horizons of the profiles and number varied from few to many and sizes were from very fine (less than 0.5 mm) to medium (2.5 mm).

Morphological descriptions of the profiles are given in appendix.I and photographs are depicted in plates 1 to 7.

4.2 PHYSICAL PROPERTIES

4.2.1 Gravel

The gravel content in the soils varied from 2.82 per cent in surface horizon of Eturunagaram profile to 48.52 per cent in bottom layer of Bachannapet profile (Table 4). In general, there was increase in gravel content with the depth.

4.2.2 Mechanical composition

The data on mechanical composition of soils is presented in Table 4.

4.2.2.1 Sand

The sand content of the soils varied from 40.90 per cent in bottom layer of Ghanpur profile to 77.56 per cent in surface layer of Eturunagaram profile. Sand content decreased with depth in all the profiles.

4.2.2.2 Silt

The silt content varied from 7.91 per cent in surface layer of Eturunagaram profile to 19.87 per cent in bottom layer of Ghanpur profile. It increased with depth in Tadvai, Bachannapet, Eturunagaram, Eleti Ramaya Palli, Wardhannapet, Pakala and Ghanpur profiles and there was no definite trend with depth in other profiles.

4.2.2.3 Clay

The clay content of the soils varied from 12.48 per cent in surface layer of Bachannapet to 39.46 per cent in bottom layer of Regonda profile. Clay content was found to increase with depth in all the profiles except in Malyal profile where there was decrease in bottom layer.

4.2.3 Soil texture

Sandy loam, sandy clay loam, clay loam and clay textures were observed in different horizons of the profiles. In Tadvai, Nallabelli, Bachannapet, Eturunagaram, Wardhannapet and Raghunathapalli profiles, the texture of surface horizons was sandy loam. The texture in all the horizons of Nallabelli, Eleti Ramayapalli and Pakala profiles was sandy clay loam. In Duggondi and Khanapur profiles, all the horizons were clay loam. In Regonda, Ghanpur and Warangal research station profiles, the bottom layer was clay in texture while in the other upper layers, it was clay loam.

4.2.4 Bulk density

Bulk density of soils varied from 1.32 Mg m^{-3} in surface horizons of Regonda and Ghanpur profiles to 1.71 Mg m^{-3} in bottom layer of Nallabelli profile (Table 4). The bulk density of soil increased with the depth in all the profiles.

4.2.5 Particle density

The particle density of soils varied from 2.42 Mg m^{-3} in third layer of Eleti Ramaya Palli profile to 2.61 Mg m^{-3} in bottom layer of Pakala profile (Table 4). No definite trend was observed in particle density with increase in soil depth.

4.2.6 Aggregate stability

The per cent aggregates greater than 0.25 mm (Table 4) ranged from 61.86 in bottom layer of Tadvai profile to 77.94 in surface layer of Regonda. In general, the per cent of aggregates more than 0.25 mm decreased with depth.

The per cent aggregate stability ranged from 48.36 in bottom layer of Eturunagaram profile to 64.64 per cent in surface layer of Warangal RS profile (Table 4). The aggregate stability also decreased with depth.

4.2.7 Hydraulic conductivity (ks)

Saturated hydraulic conductivity (ks) varied from 0.08 cm hr^{-1} in bottom layer of Warangal profile to 18.26 cm hr^{-1} in surface layer of Tadvai profile (Table 5). There was large variation in ks in different profiles. The ks was higher in surface horizons and decreased with increase in depth in all the profiles.

4.2.8 Infiltration rate

The final infiltration rate (cm hr^{-1}) ranged from 0.30 in Khanapur and Warangal RS to 8.3 in Tadvai profiles (Table 6 and Fig 2). The infiltration was moderately rapid in Tadvai, Bachannapet, Eturunagaram, Wardhannapet and Raghunathapalli. In Pakala, it was moderate and in Malyal it was moderately slow. In other profiles, the infiltration rate was slow.

4.2.9 Water retention

Water retention at 33 K Pa and 1500 K Pa is presented in Table 5.

4.2.9.1 At 33 K Pa

Water retention at 33 K Pa varied from 9.52 per cent in surface layer of Wardhannapet profile to 32.86 per cent in bottom layer of Warangal RS profile. There was gradual increase in water retention with increase in depth in all the profiles.

4.2.9.2 At 1500 K Pa

Water retention at 1500 K Pa varied from 4.40 per cent in surface layer of Wardhannapet profile to 17.70 per cent in bottom layer of Warangal RS profile. It was lower in surface layers and increased gradually with increase in depth.

4.2.9.3 Available water content (AWC)

The available water content (Table 5) varied from 4.66 per cent in surface layer of Tadvai profile to 16.16 per cent in bottom layer of Regonda profile. In general, available water content increased gradually with increase in depth.

4.2.9.4 Available water storage capacity (AWSC)

Available water storage capacity (cm m^{-1}) varied from 9.06 in Bachannapet profile to 18.54 in Regonda profile (Table 6). It was low in Tadvai, Bachannapet, Eturunagaram profiles, medium in Nallabelli, Eleti Ramayapalli, Wardhannapet, Raghunathaplli, Pakala and Malyal and high in Duggondi, Regonda, Ghanpur, Khanapur and Warangal RS profiles.

4.3 PHYSICO-CHEMICAL PROPERTIES

4.3.1 Soil reaction (pH)

Soil reaction varied from 6.31 in second layer of Pakala profile to 8.7 in third layer of Khanapur profile (Table 7). In Wardhannapet, Raghunathapalli, Malyal and Khanapur profiles, pH increased with depth whereas in Nallabelli, Bachannapet and Pakala it decreased with depth. In other profiles, no definite trend was observed with increase in depth.

4.3.2 Electrical conductivity (EC)

Electrical conductivity of soils varied from 0.03 dS m^{-1} in bottom layer of Tadvai profile to 1.05 dS m^{-1} in bottom layer of Warangal RS profile and no definite trend in EC was observed with increase in depth (Table 7).

4.3.3 Cation exchange capacity (CEC)

Cation exchange capacity (cmol(p^{+})kg^{-1}) ranged from 8.30 in surface layer of Bachannapet profile to 46.33 in third layer of Regonda profile (Table 7). Increase in CEC with depth was observed in Tadvai, Nallabelli, Wardhannapet, Pakala and Malyal profiles whereas in other profiles no definite trend with depth was observed. However the CEC in lower most horizons was higher than the surface horizons in most of the profiles.

4.3.4 Exchangeable cations

The data on exchangeable cations is presented in Table 7. Calcium was the dominant cation on exchange complex followed by magnesium, sodium and potassium.

Calcium content (cmol$(p^+)kg^{-1}$) ranged from 4.35 in surface layer of Tadvai and second layer of Bachannapet to 24.3 in bottom layer of Ghanpur profile. Ca content increased with depth in Nallabelli, Pakala and Malyal whereas in other profiles, no definite trend was observed.

Magnesium (cmol$(p^+)kg^{-1}$) content in soils ranged from 1.2 in surface horizon of Bachannapet to 14.2 in surface horizon of Warangal RS. Increase in magnesium content with depth was observed in Nallabelli, Bachannapet and Wardhannapet profiles whereas in others, no definite trend was observed with depth.

Sodium (cmol$(p^+)kg^{-1}$) content in soils varied from 0.2 in bottom layer of Tadvai and second layer of Bachannapet to 8.1 in surface layer of Regonda. Increased sodium content with depth was observed in Eleti Ramayapalli, Wardhannapet and Pakala profiles whereas in other profiles, no definite trend was observed with depth.

Exchangeable sodium percentage varied from 1.09 in bottom layer of Tadvai to 21.39 in surface layer of Nallabelli. ESP decreased with depth in Tadvai and Nallabelli whereas it increased with depth in Wardhannapet. In others, no definite trend was observed with depth.

Potassium (cmol$(p^+)kg^{-1}$) content varied from 0.1 in bottom three layers of Tadvai and bottom layer of Malyal and Warangal RS profiles to 3.7 in second layer of Raghunathapalli profile. Increase in potassium content with depth was observed in Duggondi profile whereas in other profiles no definite trend was observed.

4.3.5 Base saturation percentage

Base saturation percentage ranged from 72 per cent in surface layer of Eletti Ramayapalli profile to 94 per cent in surface and bottom layer of Duggondi profile.

4.4 CHEMICAL PROPERTIES

4.4.1 Organic carbon

The organic carbon content of the soils in surface horizons ranged from 0.58 per cent in Raghunathapalli profile to 0.81 per cent in Malyal profile (Table 8). The rating for organic carbon was high in Malyal (0.81%) and Warangal Research Station (0.79%) whereas in other profiles, it was medium. Soil organic carbon decreased with increase in depth.

4.4.2 Free calcium carbonate

Free soil calcium carbonate ranged from 1.42 per cent in surface horizon of Bachannapet profile to 13.67 per cent in bottom layer of Duggondi profile (Table 8). No calcium carbonate was observed in Tadvai, Eturunagaram, Eleti Ramayapalli and Raghunathapalli. In general, calcium carbonate content increased with depth.

4.4.3. Available nitrogen

The available nitrogen (kg ha^{-1}) content varied from 256 (Eleti Ramayapalli and Raghunathapalli) to 360 (Ghanpur) in the surface horizons (Table 8). The available nitrogen was higher in surface horizons and decreased with depth.

4.4.4 Available phosphorus

The available phosphorus (Table 8) was higher in surface horizons and decreased with the depth. The available phosphorus content (Kg ha^{-1}) in surface horizons varied from 13.1 in Nallabelli to 35.8 in Warangal Research Station profiles.

4.4.5 Available potassium

The available potassium content was higher in surface horizons (Table 8). It ranged from 183 kg ha^{-1} in Nallabelli to 320 kg ha^{-1} in Wardhannapet profiles. In general, available potassium decreased with increase in depth.

4.4.6 Available Iron

The available iron (mg kg^{-1}) in soils ranged from 2.03 in last layer of Warangal RS profile to 58.86 in the surface layer of Pakala profile (Table 8).The available iron content decreased with depth in all the profiles.

4.4.7 Available Manganese

The available manganese (mg kg^{-1}) content ranged from 4.75 in the last layer of Warangal research station profile to 118.90 in the surface layer of Pakala profile (Table 8). In general, Manganese content decreased with depth in all the profiles.

4.4.8 Available copper

The available copper (mg kg^{-1}) content ranged from 1.01 in bottom horizon of Wardhannapet profile to 6.94 in surface layer of Duggondi profile (Table 8). The copper content decreased with increase in depth in all the profiles.

4.4.9 Available zinc

The available zinc content (mg kg^{-1}) in the soils ranged from 0.70 in last layer of Ghanpur profile to 6.20 in surface layer khanapur profile. Decrease in zinc content with depth was observed in all the profiles (Table 8).

4.5 Nutrient index (NI)

The data on available nutrients in surface soils (0-15 cm) is given in Appendix II.

4.5.1 Available nitrogen

The available nitrogen content of surface soils varied from 137 to 345 kg ha^{-1}. The calculated nutrient index (NI) was 1.09 indicating that the soils are low in available nitrogen.

4.5.2 Available phosphorus

The available phosphorus content of surface soils varied from 6.35 to 26.50 kg ha^{-1}. The calculated nutrient index was 1.98 indicating that the soils are medium in available phosphorus.

4.5.3 Available potassium

The available potassium content of surface soils varied from 121 to 392 kg ha^{-1}. The calculated nutrient index was 2.68 indicating that the soils are high in available potassium.

4.6 Soil classification

The classification of soils was done up to family level by following the procedure given by the Soil Taxonomy (Soil Survey Staff, 1998). The soils were classified into the three orders, viz. Alfisols, Inceptisols and Vertisols. The details are given in Table 9.

4.7 Production constraints

The production constraints identified and suitable management practices suggested are presented in Table 12 and discussed chapter V

Table 4. Physical properties of soils

Location	Depth (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Texture*	BD ($Mg\ m^{-3}$)	PD ($Mg\ m^{-3}$)	Per cent aggregates >0.25 mm	Aggregate stability (%)
1. Tadvai	0-15	5.40	75.69	7.97	16.34	sl	1.57	2.51	69.38	54.21
	15-37	9.40	66.18	8.61	25.21	scl	1.61	2.48	68.40	53.36
	37-55	7.90	64.25	9.00	27.65	scl	1.65	2.51	62.52	52.14
	55-70+	35.21	62.49	9.61	27.90	scl	1.65	2.48	61.86	49.25
2. Nallabelli	0-15	15.60	65.92	11.61	22.47	scl	1.60	2.53	70.74	54.63
	15-30	32.52	61.63	9.87	28.50	scl	1.65	2.48	69.54	54.51
	30-70+	36.28	60.16	10.21	29.63	scl	1.71	2.56	67.48	52.36
3. Bachannapet	0-8	30.25	76.87	10.65	12.48	sl	1.58	2.48	69.28	52.41
	8-50	42.52	65.41	11.84	22.75	scl	1.62	2.51	68.08	51.29
	50-65+	48.52	59.93	12.21	27.86	scl	1.69	2.49	68.06	48.75
4. Eturunagaram	0-15	2.82	77.56	7.91	14.53	sl	1.52	2.56	68.68	54.72
	15-47	8.36	68.07	8.32	23.61	scl	1.59	2.52	68.00	54.45
	47-80	5.40	63.02	8.65	28.33	scl	1.60	2.48	66.16	52.61
	80-120	31.22	61.48	9.87	28.65	scl	1.60	2.52	65.98	48.36
5. Eleti Ramavapalli	0-11	25.65	68.78	9.04	22.18	scl	1.53	2.46	73.10	55.61
	11-30	35.68	65.90	10.56	23.54	scl	1.59	2.44	72.20	55.23

contd..

Location	Depth (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Texture*	BD (Mg m^{-3})	PD (Mg m^{-3})	Per cent aggregates >0.25 mm	Aggregate stability (%)
	30-55	35.45	60.55	11.20	28.25	scl	1.61	2.42	69.38	55.16
	55+	36.12	58.69	12.15	29.16	scl	1.63	2.48	66.12	54.76
6. Wardhannapet	0-8	33.13	74.25	10.21	15.54	sl	1.58	2.56	71.06	54.65
	8-33	38.16	61.79	11.56	27.65	scl	1.67	2.58	70.66	52.15
	33-80+	40.62	59.67	12.01	28.32	scl	1.67	2.49	69.12	50.62
7.Raghunathapalli	0-25	23.43	74.95	9.73	15.32	sl	1.52	2.51	70.70	54.13
	25-55	32.57	61.87	8.57	24.56	scl	1.58	2.48	70.18	53.15
	55-75+	35.66	63.63	10.25	26.12	scl	1.62	2.52	69.72	50.62
8. Pakala	0-10	15.20	65.67	8.12	26.21	scl	1.59	2.58	71.50	53.67
	10-35	29.76	61.36	9.79	28.85	scl	1.60	2.52	70.80	53.31
	35-55+	40.26	60.43	9.92	29.65	scl	1.63	2.61	66.62	52.63
9. Malyal	0-20	12.40	56.20	14.22	29.58	scl	1.52	2.52	74.60	61.71
	20-40	16.24	52.25	17.10	30.65	cl	1.46	2.50	73.06	61.25
	40-65	19.42	56.35	12.38	31.27	cl	1.46	2.54	72.82	60.41
	65-95+	18.65	60.23	13.52	26.25	scl	1.48	2.53	70.12	60.27
10. Duggondi	0-15	18.08	55.98	10.34	33.68	cl	1.36	2.59	75.34	62.32

contd..

Location	Depth (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Texture*	BD (Mg m^{-3})	PD (Mg m^{-3})	Per cent aggregates >0.25 mm	Aggregate stability (%)
	15-37	21.40	48.94	15.85	35.21	cl	1.44	2.54	74.88	62.15
	37-65+	22.42	48.30	14.27	37.43	cl	1.44	2.56	72.34	61.35
11. Regonda	0-11	15.16	52.74	16.63	30.63	cl	1.32	2.49	77.94	64.27
	11-35	26.22	50.57	17.21	32.22	cl	1.35	2.47	76.74	63.27
	35-55	15.04	51.06	15.21	33.73	cl	1.38	2.52	76.14	61.29
	55-75	13.86	48.86	17.01	34.13	cl	1.40	2.59	73.80	61.27
	75+	12.39	47.12	13.42	39.46	c	1.41	2.52	73.64	59.27
12. Ghanpur	0-17	18.62	57.79	11.65	27.56	cl	1.32	2.47	76.74	63.27
	17-45	10.17	54.23	13.52	32.25	cl	1.34	2.58	75.78	61.32
	45-60	18.62	48.18	18.01	33.81	cl	1.34	2.56	75.06	61.25
	60-65+	29.38	40.90	19.87	39.23	c	1.38	2.52	73.78	60.25
13. Khanapur	0-12	13.12	47.85	18.89	33.26	cl	1.37	2.46	76.80	64.17
	12-30	11.36	51.54	12.92	35.54	cl	1.42	2.57	76.20	62.47
	30-45	15.88	44.65	19.15	36.20	cl	1.46	2.55	75.96	62.31
	45-65+	19.27	43.21	18.23	38.56	cl	1.48	2.48	75.62	60.32
14. Warangal RS	0-15	16.53	54.63	15.03	30.34	cl	1.41	2.53	76.16	64.64
	15-55	19.22	48.76	15.28	35.96	cl	1.41	2.49	75.52	62.76
	55-72	18.88	49.63	14.16	36.21	cl	1.45	2.51	75.18	62.17
	72+	19.27	48.20	12.59	39.21	c	1.48	2.53	74.88	60.15

* sl- sandy loam, scl- sandy clay loam, cl- clay loam, c- clay

Table 7. Physico-chemical properties of soils

Location	Depth (cm)	pH (1:2.5)	EC (dS m^{-1})	Exchangeable bases ($cmol(p^+)kg^{-1}$)				CEC ($cmol(p^+)kg^{-1}$)	ESP (%)	Base saturation (%)
				Ca^{2+}	Mg^{2+}	Na^+	K^+			
1. Tadvai	0-15	6.88	0.13	4.3	2.8	1.4	0.2	12.50	11.20	87
	15-37	6.82	0.63	5.6	3.2	1.2	0.1	15.20	7.80	79
	37-55	6.83	0.06	8.1	4.3	0.3	0.1	18.80	1.59	81
	55-70+	6.83	0.03	7.3	3.6	0.2	0.1	18.20	1.09	75
2. Nallabelli	0-15	8.64	0.28	7.4	4.7	4.6	2.1	21.50	21.39	87
	15-30	8.42	0.26	8.6	5.8	3.8	2.6	26.30	14.44	79
	30-70+	8.39	0.28	12.8	8.4	2.3	0.8	28.50	8.07	85
3. Bachannapet	0-8	6.88	0.19	5.0	1.2	0.3	0.2	8.30	3.61	80
	8-50	6.44	0.14	4.3	1.5	0.2	0.3	7.40	2.70	85
	50-65+	6.74	0.13	3.6	2.6	0.4	0.2	10.30	3.88	66
4. Eturunagaram	0-15	6.75	0.19	13.5	8.4	2.3	0.8	29.30	7.84	85
	15-47	6.51	0.10	10.6	6.4	2.0	1.1	26.60	7.51	75
	47-80	6.46	0.05	11.0	5.7	2.2	0.6	24.32	9.04	80
	80-120	6.74	0.29	8.7	7.6	2.8	1.6	28.27	9.90	73
5. Eleti Ramayapalli	0-11	7.47	0.20	8.8	2.3	1.3	0.9	18.56	7.08	72

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Location	Depth (cm)	pH (1:2.5)	EC (dS m^{-1})	Exchangeable bases (cmol(p^+)kg^{-1})				CEC (cmol(p^+)kg^{-1})	ESP (%)	Base saturation (%)
				Ca^{2+}	Mg^{2+}	Na^+	K^+			
	11-30	7.62	0.30	14.4	5.3	1.3	0.6	24.93	5.21	87
	30-55	7.60	0.26	12.2	4.1	1.3	0.6	24.52	5.30	74
	55+	7.46	0.24	14.2	3.9	1.42	0.5	21.12	6.72	76
6. Wardhannapet	0-8	6.45	0.10	9.2	6.6	1.8	0.7	21.32	8.44	85
	8-33	6.69	0.07	11.2	7.1	2.1	0.8	24.87	8.44	85
	33-80+	6.62	0.13	10.8	8.2	3.4	0.6	26.31	12.90	87
7.Raghunathapalli	0-25	7.08	0.90	8.4	3.3	2.1	0.8	18.32	11.46	80
	25-55	7.62	0.25	10.3	4.6	1.8	3.7	21.42	8.40	95
	55-75+	7.75	0.28	8.2	3.3	2.4	0.7	19.21	12.40	76
8.Pakala	0-10	6.94	0.10	6.8	2.4	1.6	0.8	15.32	10.44	75
	10-35	6.31	0.07	9.2	6.3	1.9	0.9	20.23	9.39	90
	35-55+	6.33	0.11	11.2	4.5	2.5	0.5	21.61	11.56	86
9. Malyal	0-20	7.61	0.26	10.3	2.1	0.4	0.2	14.00	2.85	92
	20-40	7.92	0.22	10.4	4.9	0.6	0.3	16.50	3.63	98
	40-65	7.97	0.15	11.1	4.4	0.3	0.2	18.20	1.64	87
	65-95+	8.01	0.13	12.1	5.1	0.3	0.1	21.00	1.42	83

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Location	Depth (cm)	pH (1:2.5)	EC (dS m^{-1})	Exchangeable bases (cmol(p^+)kg^{-1})				CEC (cmol(p^+)kg^{-1})	ESP (%)	Base saturation (%)
				Ca^{2+}	Mg^{2+}	Na^+	K^+			
10. Duggondi	0-15	8.00	0.33	8.7	4.7	2.1	0.8	17.32	12.12	94
	15-37	7.91	0.44	11.2	5.8	3.1	0.9	23.21	13.35	90
	37-65+	8.01	0.27	10.3	4.2	1.8	1.0	18.46	9.75	94
11. Regonda	0-11	8.60	0.20	15.6	10.1	8.1	1.2	39.59	20.45	88
	11-35	8.55	0.13	13.2	9.2	5.6	1.3	37.98	14.94	77
	35-55	8.43	0.17	22.1	8.3	7.2	1.4	46.63	15.44	84
	55-75	8.61	0.18	20.2	7.2	6.5	2.0	41.94	15.49	86
	75+	8.58	0.17	23.6	8.5	6.4	2.2	43.74	14.63	93
12. Ghanpur	0-17	7.60	0.27	16.3	4.2	2.1	0.2	25.42	8.26	89
	17-45	7.49	0.10	15.0	2.3	1.0	0.2	23.42	4.26	79
	45-60	7.65	0.05	16.2	3.4	1.2	0.2	26.10	4.59	80
	60-65+	7.17	0.13	24.3	3.6	1.2	0.2	32.38	3.70	90
13. Khanapur	0-12	7.77	0.27	14.7	8.3	3.4	0.8	34.68	9.80	78
	12-30	8.44	0.27	23.1	8.1	4.2	0.8	39.32	10.68	92
	30-45	8.70	0.36	13.2	5.9	3.2	0.7	32.21	9.90	71
	45-65+	8.66	0.05	13.2	8.3	4.4	1.2	32.21	13.16	84

contd…

Table 8. Chemical properties of soils

Location	Depth (cm)	OC (%)	$CaCO_3$ (%)	Available macronutrients kg ha^{-1}			Available micronutrients mg kg^{-1}			
				N	P_2O_5	K_2O	Fe	Mn	Cu	Zn
1. Tadvai	0-15	0.72	_	294	14.1	250	25.46	61.59	2.87	5.19
	15-37	0.60	_	252	11.3	232	23.12	25.61	2.87	3.52
	37-55	0.58	_	222	8.6	180	12.46	7.32	2.10	2.31
	55-70+	0.58	_	174	7.8	118	6.98	5.42	1.91	1.43
2. Nallabelli	0-15	0.60	5.20	275	13.1	183	17.60	30.78	3.28	1.38
	15-30	0.62	6.20	256	8.2	142	12.65	14.32	2.96	1.38
	30-70+	0.50	6.80	219	7.3	130	5.95	10.27	2.48	1.16
3. Bachannapet	0-8	0.65	1.42	269	16.1	186	9.06	27.33	1.93	1.55
	8-50	0.52	1.82	219	8.2	143	8.21	15.31	1.55	1.27
	50-65+	0.43	2.26	189	7.3	122	7.53	6.29	1.35	1.04
4. Eturunagaram	0-15	0.67	_	275	26.9	308	23.27	88.39	1.97	1.66
	15-47	0.62	_	235	14.1	232	19.21	77.91	1.87	1.60
	47-80	0.35	_	125	7.3	180	17.31	72.15	1.40	1.50
	80-120	0.25	_	122	6.3	132	12.85	72.06	1.23	1.25
5. Eleti Ramayapalli	0-11	0.62	_	256	24.8	312	17.46	58.21	5.07	2.14
	11-30	0.51	_	219	16.1	230	13.08	28.74	3.68	1.44
	30-55	0.51	_	174	11.2	180	12.21	26.41	3.21	1.28

contd..

Location	Depth (cm)	OC (%)	$CaCO_3$ (%)	Available macronutrients kg ha^{-1}			Available micronutrients mg kg^{-1}			
				N	P_2O_5	K_2O	Fe	Mn	Cu	Zn
	55+	0.36	_	158	5.3	142	11.87	25.63	2.65	1.11
6.Wardhannapet	0-8	0.72	1.60	276	24.6	320	21.11	40.47	1.82	5.36
	8-33	0.65	2.52	264	12.3	235	19.34	36.97	1.62	4.21
	33-80+	0.63	3.10	172	7.8	180	18.15	18.79	1.01	3.15
7. Raghunathapalli	0-25	0.58	_	256	22.4	220	8.67	73.89	4.99	4.78
	25-55	0.51	_	189	12.3	180	5.76	43.67	3.54	4.78
	55-75+	0.44	_	162	5.3	132	5.59	36.87	2.10	1.94
8. Pakala	0-10	0.71	1.68	296	27.8	292	58.86	118.90	6.26	5.71
	10-35	0.68	2.52	253	16.1	210	45.34	117.69	5.36	3.98
	35-55	0.63	2.72	185	8.2	192	22.64	116.72	4.54	2.86
9. Malyal	0-20	0.81	1.60	296	31.4	270	13.93	31.16	4.76	4.77
	20-40	0.66	2.50	235	18.9	210	10.21	16.23	4.15	3.10
	40-65	0.56	3.10	178	14.3	185	7.65	12.87	3.65	2.20
	65-95+	0.31	3.80	164	6.5	160	6.65	10.91	2.75	1.64
10.Duggondi	0-15	0.71	11.48	288	25.2	308	28.20	10.15	6.94	6.34
	15-37	0.51	12.15	262	17.9	235	27.15	10.11	6.84	3.21
	37-65+	0.44	13.67	235	9.2	196	26.46	9.78	4.87	2.08
11..Regonda	0-11	0.72	5.40	329	31.4	280	4.15	9.87	2.17	1.65

contd..

Location	Depth (cm)	OC (%)	$CaCO_3$ (%)	Available macronutrients kg ha^{-1}			Available micronutrients mg kg^{-1}			
				N	P_2O_5	K_2O	Fe	Mn	Cu	Zn
	11-35	0.51	6.80	256	15.3	192	3.54	9.42	1.97	1.56
	35-55	0.31	7.30	175	7.5	156	2.94	8.25	1.76	1.42
	55-75	0.25	8.50	163	6.4	132	2.56	1.72	1.21	1.34
	75+	0.19	6.70	153	5.4	110	2.03	6.84	1.69	0.91
12. Ghanpur	0-17	0.71	2.76	360	28.7	308	29.96	111.61	5.09	4.21
	17-45	0.54	2.94	262	11.6	210	27.86	100.35	4.87	3.51
	45-60	0.39	3.25	184	8.6	136	18.65	71.61	4.07	1.35
	60-65+	0.28	3.60	168	7.8	110	11.53	70.55	3.98	0.70
13. Khanapur	0-12	0.68	2.26	298	30.5	314	33.30	26.94	4.50	6.20
	12-30	0.52	2.84	198	17.9	232	33.21	24.81	3.47	5.87
	30-45	0.45	3.12	164	11.3	184	32.97	21.34	2.56	5.79
	45-65+	0.36	3.96	157	5.4	142	27.60	20.15	1.70	5.66
14. Warangal RS	0-15	0.79	5.30	282	35.8	312	6.94	12.04	2.30	3.29
	15-55	0.58	5.60	257	18.9	231	6.69	5.31	1.86	1.57
	55-72	0.46	7.30	175	10.9	192	6.32	5.16	1.53	1.17
	72+	0.44	7.68	163	7.9	165	5.81	4.75	1.16	0.92

Table 9. Classification of soils

Location	Order	Sub-order	Great group	Subgroup	Family
1.Tadvai	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalfs	Fine loamy superactive isohyperthermicTypic Haplustalfs
2.Nallabelli	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalfs	Fine loamy superactive isohyperthermicTypic Haplustalfs
3.Bachannapet	Alfisols	Ustalfs	Natrustalfs	Natrustalfs	Fine loamy semiactive calcareous isohyperthermicTypic Natrustalfs
4.Eturunagaram	Alfisols	Ustalfs	Rhodustalfs	Typic Rhodustalfs	Fine loamy super active isohyperthermic Typic Rhodustalfs
5.Eleti Ramayapalli	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Fine loamy superactive isohyperthermicTypic Haplustepts
6.Wardhannapet	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Fine loamy superactive, isohyperthermicTypic Haplustepts
7.Raghunathapalli	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalfs	Fine Loamy superactive Isohyperthermic Typic Haplustalfs

contd..

CHAPTER V

DISCUSSION

The results obtained on morphological, physical, physico-chemical and chemical properties of soils of Warangal district are discussed in this chapter.

5.1 MORPHOLOGICAL PROPERTIES

5.1.1 Soil colour

The colour of soil was yellowish red (Hue 10YR to 2.5YR) with Value between 3 and 5 and Chroma ranging between 1 to 8 (Table 3). The purity of colour decreased with depth. The differences in colour in different horizons and in different profiles could be attributed to various pedological processes being accelerated in the profile. The differences in organic matter and iron contents and the degree of oxidation and imperfect hydration due to poor drainage might add to the changes in colour. Gangopadhyay *et al.* (1986) reported similar findings. The colour changes were attributed to be the function of chemical and mineralogical composition of the soils (Simmonson, 1993 and Swarnam *et al*., 2004).

5.1.2 Soil structure

The soil structure was sub angular blocky in surface horizons and sub angular blocky to angular blocky in sub-surface horizons (Table 3). The variation in soil structure is a reflection of physiographic position of the profile (Singh and Agarwal, 2003). Vara Prasad Rao *et al*. (2008) also reported well developed structural variations in soils of Chittoor district of Andhra Pradesh.

5.1.3 Consistency

The consistency of soils varied from loose to very hard (dry), friable to very firm (moist) and non-sticky and non-plastic to sticky and very plastic (Table 3). Variations in consistence could be attributed to variation in clay content of profiles situated on different topographic positions. Variations in consistence due to clay content has been reported by Patil (1999) and Vara Prasad Rao *et al*. (2008).

5.2 PHYSICAL PROPERTIES

5.2.1 Mechanical composition

Sand constitutes the bulk of mechanical fractions which varied from 40.90 to 77.36 per cent in the horizons of the profiles (Table 4). Higher fractions of sand could be attributed to dominance of physical weathering. The sand content was higher in surface horizons and decreased with increase in depth which is in conformity with the results reported by Gangopadhyay *et al*. (2001).

The silt content of the soils varied from 7.91 per cent to 19.87 in the horizons of the profiles (Table 4). There was no definite trend with depth. In some profiles, there was increase in silt content with depth while in some others, the trend was irregular.

The clay content of the soils varied from 12.48 to 39.46 per cent in the profiles (Table 4). The clay content, in general increased with depth. The clay content increases with increase in depth showing evidence of translocation of finer particles from surface to sub-surface horizons (Gangopadhyay *et al*., 2001). The increase in clay content in lower horizons could also be attributed to vertical migration of clay (Sarkar *et al*., 2002).

5.2.2 Texture

The texture of soils varied from sandy loam to sandy clay loam to clay loam to clayey (Table 4) in different horizons of the profiles. Seshagiri Rao *et al.* (2004) reported soil textures varying from sandy loam to sandy clay loam in Southern Coastal Eco-sub region of Andhra Pradesh. The variations in texture could be due to variations in weathering which is influenced by landscape position, soil environment and translocation of clay (Buol *et al*., 1998).

5.2.3 Bulk density

Bulk density of soils varied from 1.32 to 1.71 Mg m^{-3} in the horizons of the profiles (Table 4). In general, surface layers had lower bulk density and it was found to increase with depth. This might be due to more compaction of finer particles in deeper layers caused by overhead weight of surface soils (Jewitt *et al*., 1979). Low bulk density in surface layers could also be attributed to higher organic matter content (Walia and Rao, 1996).

5.2.4 Particle density

The particle density of soils varied from 2.42 to 2.61 Mg m^{-3} in the horizons of profiles. No definite trend was observed in particle density with depth. Madhusudhana Rao (1993) reported particle density varying from 2.48 to 2.65 Mg m^{-3} in soils of chikicharla village of Andhra Pradesh.

5.2.5 Soil aggregates > 0.25 mm

The per cent aggregates greater than 0.25 mm was higher in the surface horizons (Table 4). In general, the percentage decreased with depth. Higher percent aggregates greater than 0.25 mm in surface soils could be attributed to higher organic carbon status. Rajyalakshmi (2004) reported significant correlation of organic carbon with per cent aggregates greater than 0.25 mm (r = 0.983).

5.2.6 Aggregate stability

The per cent aggregate stability (Table 4) in the soils also decreased with depth. Since aggregate stability is derived from the aggregates > 0.25 mm, similar trend with depth was observed. The factors discussed earlier which influenced aggregates > 0.25 mm also influenced aggregate stability.

5.2.7 Hydraulic conductivity (Ks)

Saturated hydraulic conductivity (Ks) of soils varied from 0.08 to 18.26 cm hr^{-1} in the horizons of profiles (Table 5). The Ks was higher in surface horizons and decreased with increase in depth. This could be attributed to increase in bulk density and clay content with increase in soil depth. Decrease in hydraulic conductivity with depth has been reported by Rajyalakshmi (2004) and Ramachandran (2006).

5.2.8 Infiltration

The final infiltration rate in the soils varied from 0.3 to 8.3 c m hr^{-1} in the profiles (Table 6 and Fig.2). Infiltration was moderately rapid in Tadvai, Bachannapet, Eturunagaram, Wardhannapet and Raghunathapally soils, moderate in Nallabelli, Eleti Ramayapalli and Pakala soils, moderately slow in Malyal and slow in other soils.

Infiltration reached more or less steady rate after 2 hours in all the profiles. The infiltration rates were high in the beginning but decreased with time. The decrease in infiltration could be attributed to higher clay content in sub-surface layers. Mathur (1991) observed similar trend in infiltration rate with increasing clay content down the depth. The decrease in infiltration rate with depth could also be attributed to increased bulk density in the sub- surface horizons as observed by Jaggi and Bisen (1986) and Singa Rao *et al.* (1995).

5.2.9 Water retention

Water retention at 33 k Pa varied from 9.52 to 32.86 per cent (Table 5). The water retention was low in surface horizons and increased with increase in depth. The low water retention in surface horizons could be attributed to less clay content, more sand fraction, less CEC. With increase in clay content with depth, the water retention increased. Gajbhiye (1990) and Sushil Kumar *et al*. (2002) observed positive correlation between water retention and clay content.

The water retention at 1500 K Pa varied from 4.40 to 17.70 per cent in the soils. The water retention in the lower horizons increased with the increase in depth. This could be attributed to increase in clay content with depth (Gajbhiye, 1990),Vara Prasad Rao *et al.* (2008) and Lingade *et al.* (2008) reported higher water retention due to increase in clay content with depth.

5.2.9.1 Available water

The available water content (Table 5) varied from 4.66 to 16.16 per cent in the soils. Available water content was low in surface horizons and increased with depth in almost all the profiles. This could be attributed to increase in clay content with depth (Gajbhiye, 1990 and Vara Prasad Rao *et al.,* 2008).

5.2.9.2 Available water storage capacity (AWSC)

The available water storage capacity of the profiles varied from 9.06 to 18.54 cm m^{-1} (Table 6 and Fig. 3). The AWSC (cm m^{-1} depth) of the profiles was low (5-10) in Tadvai, Bachannapet and Eturunagaram, medium (10-15) in Nallabelli, Eleti Ramayapalli, Wardannapet, Raghunathapally, Pakala and Malyal and high (15-20) in Duggondi, Regonda, Ghanpur, Khanapur and Warangal RS. The soils high in clay content have exhibited high available water storage capacity. Maji *et al*. (2005) reported higher available water storage capacity with increase in clay, organic matter and depth in sub humid tropics of Central India.

5.3 PHYSICO-CHEMICAL PROPERTIES

5.3.1 Soil reaction (pH)

Soil reaction varied from 6.31 to 8.70 (Table 7) in the soils. They were slightly acidic to neutral to alkaline in reaction. An increase in pH with depth was observed in some profiles. This could be attributed to accumulation of exchangeable Na and Ca. As mobility of calcium was more than other elements, calcium which had been translocated to lower depths might have led to higher pH values. Similar observations were reported by Mathan and Kannan (1993), Maji and Bandopadhyay (1995) and Singh *et al*. (2000).

5.3.2 Electrical conductivity (EC)

The electrical conductivity (dS m^{-1}) of the soils varied from 0.03 to 1.05 (Table 7). There was no definite trend in EC with depth.

5.3.3 Cation exchange capacity (CEC)

Increase in CEC was observed in Tadvai, Nallabelli, Wardhannapet, Pakala and Malyal profiles whereas in other profiles, no definite trend with depth was observed. However, the CEC in lower most horizons was higher than the surface horizons in most of the profiles. The increase in CEC from surface to lower layers could be due to the increase in clay content with depth in the soil. Similar observations were reported by Sahu and Misra (1996) and Surekha *et al*. (1997).

5.3.4 Exchangeable cations

Calcium was the dominant cation on exchange complex followed by magnesium, sodium and potassium (Table 7). The exchangeable cations increased with the depth in certain profiles and no definite trend was observed in other profiles. Increase in exchangeable cations with depth was reported by Chakraborty and Sinha (1983) and Ghose and Kundu (2001).

Exchangeable sodium percentage (ESP) varied from 1.09 to 21.39 (Table 7). However, no definite trend was observed in ESP with depth of soil. The soils of Nallabelli and Regonda with ESP more than 15 per cent come under alkali soils and require special reclamation methods.

5.3.5 Base saturation

Base saturation percentage varied from 72 to 94 per cent in the soils which was a factor in classification of soils. Sathyawathy and Suryanarayan (2005) reported base saturation ranging from 75 to 100 % in soils of Northern Telangana Zone of Andhra Pradesh.

5.4 CHEMICAL PROPERTIES

5.4.1 Organic carbon

The organic carbon content was medium to high in surface soils varying from 0.58 to 0.81 per cent (Table 8). The soil organic carbon decreased with increase in depth. The general decrease in organic carbon content with depth could be due to organic matter accumulation in the surface soil as a result of nutrient recycling by biomass (Gangopadhyay *et al*., 1986 and Vara Prasad Rao *et al.,* 2008).

5.4.2 Free calcium carbonate

Free calcium carbonate content of soils varied from 1.42 to 13.67 per cent (Table 8). The soils of Nallbelli, Duggondi, Regonda and Waranga Research station were calcareous having more than five per cent of calcium carbonate. The calcium carbonate increased with depth which might be due to calcification and/ or inheritance from Parent material. Singh and Khera (2007) observed similar results.

5.4.3 Available Nitrogen

The available nitrogen (kg ha^{-1}) of the soils varied from 256 in surface layer of Eleti Ramayapalli profile to 360 in the surface horizon of Ghanpur profile (Table 8). The available nitrogen was medium in Tadvai, Pakala, Malyal, Duggondi, Regonda, Ghanpur, Khanapur and Warangal research station profiles. In other profiles, it was low. The nitrogen content in all the profiles decreased with depth. Ahuja (1990), Kaistha *et al.* (1990) and Thangasamy *et al.* (2005) also found decease in available nitrogen with increase in depth.

5.4.4 Available phosphorus

The available phosphorus content in surface soils varied from low (13.1 kg ha^{-1}) in Nallabelli to medium (35.8 kg ha^{-1}) in Warangal RS (Table 8). The available phosphorus in sub-surface horizons was lower than surface horizons indicating decrease with depth. Decrease in available phosphorus content with depth was reported by NBSS and LUP (1997) and Vara Prasad Rao *et al.* (2008).

5.4.5 Available potassium

The available potassium content was high in surface horizons. It varied from 183 kg ha^{-1} in Nallabelli profile to 320 kg ha^{-1} in Wardhannapet profile (Table 8). The potassium content also decreased with depth. Higher potassium in surface soils might be due to intensive weathering, release of labile K from organic residues and translocation of element from lower depths with capillary rise of ground water as reported by Pal and Mukhopadhyay (1992). It could also due to more weathering of potassium bearing minerals as influenced by biotic and abiotic factors as reported by Kumara Sastry and Balakran Mathur (1972) and NBSS and LUP (1997).

5.4.6 Available Iron

The available iron (mg kg^{-1}) in soils ranged from 2.03 in last layer of Warangal Research station profile to 58.86 in the surface layer of Pakala profile (Table 8). The available iron content was higher than the critical limit in all the profiles except Regonda where it was low. It decreased with depth. This trend of decrease in iron content with depth was also observed by Verma *et al.* (2007) and Vara Prasad Rao *et al.* (2008).

5.4.7 Available Manganese

The available Mn content (mg kg^{-1}) in soils varied from 4.75 in the last layer of Warangal Rs profile to 118.90 in the surface layer of Pakala profile (Table 8). The soils are sufficiently high in Mn when compared to critical limitof 1 ppm (Lindsay and Norvell, 1978).

In general, Manganese decreased with depth. The higher availability in the soil surface might be due to higher biological activity (or) organic carbon in surface horizons.

These results are in conformity with the results reported by Murthy *et al*. (1997) and Dipak Sarkar *et al.* (2000).

5.4.8 Available Copper

The available copper content ranged from 1.01 mg kg^{-1} in bottom layer of Wardhannapet profile to 6.94 mg kg^{-1} in surface layer of Duggondi profile (Table 8). These soils are sufficiently high in available copper compared to critical limit of 0.2 ppm. The available copper content also decreased with depth in all the profiles. This could be due to decrease in organic carbon content of soil with depth and also due to high biological activity in surface soil. Similar observations were reported by Tripathi *et al.* (1994) in soils of Himachal Pradesh and Sharma *et al*. (2005) in Alfisols of Punjab.

5.4.9 Available Zinc

The available zinc content in the soils varied from 0.70 mg kg^{-1} in last layer of Ghanpur profile to 6.20 in surface layer of Khanapur profile (Table 8). Decrease in zinc content with depth was observed in all the profiles.

The zinc content of soil was sufficiently high as compared to critical limit of 0.6 mg kg^{-1} (Lindsay and Norvell, 1978). This could be due to low amount of organic carbon in the deeper layers. Similar results were reported by Dipak Sarkar *et al*. (2002) and Setia *et al.* (2007).

5.5 SOIL CLASSIFICATION

Based on morphological, physical, physico-chemical and chemical properties of the soils and the climate of the district, the profiles of Warangal district were classified upto family level (Table 9) as per the specification given by Soil Taxonomy (Soil Survey Staff,1998).The soils of Warangal district were classified into Alfisols, Inceptisols and Vertisols at order level. Similar findings were earlier reported by Satyavathi and suryanarayn (2005) in some soils of Warangal district. Bharathi (2008) reported Entisols, Inceptisols and Alfisols in the soils of adjoining district of Khammam.

5.6 NUTRIENT INDEX

The nutrient index of soils Warangal district is given in Table 10.

The available nitrogen content in surface soils of Warangal district was rated as low (NI < 1.5). The low nitrogen status in soils could be attributed to low organic carbon in these soils (Prasuna Rani *et al.*, 1992).

The available phosphorus content in surface soils was rated as medium. This could be attributed to the fixation of released phosphorus by clay minerals and sesquioxides (Vijay Kumar *et al.,* 1994).

Table 10. Nutrient index of soils

S.No.	Nutrients	Nutrient index	Nutrient critical value	Category
1.	N	1.09	< 1.50	Low
2.	P_2O_5	1.98	1.50 – 2.50	Medium
3.	K_2O	2.68	> 2.50	High

The available potassium content in the surface soils in rated as high. This could be attributed to more intense weathering, release of potassium from organic residues and application of potassium fertilizers. Similar results were reported by Anil Kumar (2003) in soils of Himachal Pradesh and Vara Prasad Rao *et al*. (2008) in Chittoor district of Andhra Pradesh.

5.6 PHYSICAL RATING INDEX (PI)

To characterize the soil physical environment in relation to crop growth, soil physical index developed by Gupta (1985) is used. It is generally more suitable for the soils under cultivation of different crops. Physical rating index was computed from the product of weightages assigned to 8 soil physical properties. The components are soil depth, bulk density, moisture storage capacity, infiltration, aggregation in terms of organic matter, non capillary pore space, water table depth and slope. The PI, calculated for different properties varied from 0.47 to 0.62 (Table 11 and Appendix III). The properties with least weightage were the main soil physical constraints for crop production. The suitability classes based on soil physical index is given in Table 11. Out of 14 profiles studied, two profiles were classified as category IV while all the other profiles were under category III. The lower PI values indicate that these soils require suitable management practices to alleviate soil physical constraints (with lowest weightage value) and improve the soil productivity. Several workers have used this as a guide to identify the major soil physical constraints for crop production (Prabhu Prasadini and Singa Rao, 1997 and Rajyalakshmi, 2004).

5.7 PRODUCTION CONSTRAINTS

Soil constraints were identified using physical rating index and chemical index based on soil fertility status. The major constraints identified were low available water storage capacity, slow infiltration, high sub-surface bulk density, soil erosion, and low nitrogen and phosphorus. No constraints for crop production were observed in Malyal (Table 12). Management practices suggested to increase the productivity are application of organic matter, deep ploughing, contour cultivation and gypsum application of N and P fertilizers. Similar constraints and management practices were suggested by Rajya Lakshmi (2004) under different land use systems.

Table 11. Soil physical rating index classes of soils

S.No	Location	Physical index	Suitability class	Suitability
1	Tadvai	0.51	III	Moderately suitable; expected yield is 50% of potential
2	Nallabelli	0.59	III	Moderately suitable; expected yield is 50% of potential
3	Bachannapet	0.47	IV	Slightly suitable; low yield; can be improved by appropriate management practices
4	Eturunagram	0.54	III	Moderately suitable; expected yield is 50% of potential
5	Eleti Ramayapalli	0.62	III	Moderately suitable; expected yield is 50% crop yield
6	Wardhannapet	0.50	IV	Slightly suitable; low yield; can be improved by appropriate management practices
7	Raghunathapalli	0.51	III	Moderately suitable; expected yield is 50% of potential
8	Pakala	0.73	III	Moderately suitable; expected yield is 50% of potential
9	Malyal	0.62	III	Moderately suitable; expected yield is 50% of potential
10	Duggondi	0.53	III	Moderately suitable; expected yield is 50% of potential
11	Regonda	0.56	III	Moderately suitable; expected yield is 50% of potential
12	Ghanpur	0.53	III	Moderately suitable; expected yield is 50% of potential
13	Khanapur	0.53	III	Moderately suitable; expected yield is 50% of potential
14	Warangal RS	0.53	III	Moderately suitable; expected yield is 50% of potential

Table 12. Soil productivity constraints and their management

Location	Identified soil constraints for crop production	Soil management practices suggested to increase the productivity
1. Tadvai	Low AWSC and high sub soil BD	Addition of OM and deep ploughing
2. Nallabelli	Alkali soil, High sub soil BD and low N & P	Gypsum application, deep ploughing and N & P fertilizers application
3. Bachannapet	Low AWSC and low N & P	Addition of OM and N & P fertilizers application
4. Eturunagaram	Slopy land, low AWSC, high sub soil BD and low N	Contour cultivation, addition of OM, deep ploughing and N fertilizer application
5. Eleti Ramayapalli	High sub soil BD and low N	Deep ploughing and application of N fertilizers
6. Wardhannapet	High sub soil BD	Deep ploughing
7. Raghunathapalli	High sub soil BD and low N	Deep ploughing and application of N fertilizer
8.Pakala	High subsoil BD	Deep ploughing
8. Malyal	No constraints identified	----
10. Duggondi	Slow infiltration	Provision of drainage
11. Regonda	Alkali soil and slow infiltratio	Gypsum application and provision of drainage
12. Ghanpur	Slow infiltration	Provision of drainage
13. Khanapur	Slow infiltration	Provision of drainage
14. Warangal RS	Slow infiltration	Provision of drainage

CHAPTER VI

SUMMARY AND CONCLUSIONS

The present investigation entitled “Characterization and Classification of Soils of Warangal district of Central Telangana Zone” was carried out during 2008-09 at Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad.

Fourteen representative profiles from the district were chosen for the study. These were described morphologically, horizon-wise. Soil samples were collected horizon-wise and analysed for physical, physico-chemical and chemical properties. Soils were taxonomically classified based on these results. In addition, twenty surface samples were collected from each of nine Administrative Divisions separately and analysed for N, P and K based on which, the nutrient index was calculated. Physical rating index was calculated from eight physical properties. Based soil properties, crop production constraints were identified and ameliorative measures suggested. Findings from the study are summarized below.

- The depth of soil varied from 55 cm (Shallow) in Eleti Ramayapalli profile to 120 cm (Deep) in Eturunagaram profile.
- Sand, silt and clay contents of soils were found to vary from 40.90 to 77.56 per cent, 7.91 to 19.87 per cent and 12.48 to 39.46 per cent, respectively.

- Texture of the soils varied from sandy loam to sandy clay loam to clay loam in surface soils and from sandy clay loam to clay loam to clay in sub-surface soils.
- Bulk density and particle density of soils varied from 1.32 to 1.71 and 2.42 to 2.61 Mg m^{-3}, respectively. The bulk density increased with depth.
- The per cent aggregates greater than 0.25 mm decreased with depth. The per cent aggregate stability of soil also showed similar trend with the depth.
- There was large variation in hydraulic conductivity of the soils. It varied from 0.08 cm hr^{-1} to 18.26 cm hr^{-1}. Hydraulic conductivity was higher in surface horizons and decreased with increase in depth.
- The infiltration was found to be moderately rapid in Tadvai, Bachannapet, Eturunagaram, Wardhannapet and Raghunathapalli, moderate in Pakala, moderately slow in Malyal and slow in other profiles.
- The available water content (cm m^{-1}) increased gradually with depth. It varied from 4.66 per cent in Tadvai profile to 16.16 per cent in Regonda profile.
- The available water storage capacity (cm m^{-1}) of the profiles varied from 9.06 in Bachannapet profile to 18.54 in Regonda profile. It was low in Tadvai, Bachannapet and Eturunagaram profiles, medium in Nallabelli, Eleti Ramayapalli, Wardhannapet, Raghunathapalli, Pakala and Malyal

profiles and high in Duggondi, Regonda Ghanpur, Khanapur and Warangal RS profiles.

- Soil reaction varied from 6.31 to 8.71. It increased with depth in Wardhannapet, Raghunathapalli, Malyal and Khanapur profiles and decreased with depth in Nallabelli, Bachannapet and Pakala profiles. The soils of Nallabelli and Regonda were alkali soils.
- Electrical conductivity (dS m^{-1}) varied from 0.03 to 1.05 and no definite trend was observed with depth.
- The exchangeable complex was dominated by calcium followed by magnesium, sodium and potassium.
- Cation exchange capacity was observed to increase with depth in Tadvai, Nallabelli, Wardhannapet, Pakala and Malyal profiles whereas in other profiles, no definite trend was observed.
- ESP was found to decrease with depth in Tadvai and Nallabelli profiles, whereas it increased with depth in Wardhannapet profiles and in others, no definite trend was observed with depth. Base saturation percentage of soils varied from 72 to 94 per cent.
- The organic carbon content of surface soils varied from 0.58 to 0.81 per cent. Higher soil organic carbon content was observed in surface soils and it decreased with depth. The rating for organic carbon was high in Malyal and Warangal Research station profiles whereas in other profiles, it was medium.

- Soil calcium carbonate content was found to vary from 1.42 to 13.67 per cent and it increased with depth. The soils of Nallabelli, Duggondi, Regonda and Warangal Research Station were calcareous.
- The available nitrogen, phosphorus and potassium contents of soils varied from 256 to 360, 13.1 to 35.8 and 183 to 320 kg ha^{-1}, respectively and decreased with increase in depth.
- The available iron, manganese, copper and zinc contents were sufficiently high. In Regonda, the iron content was low. The micronutrient content was found to decrease with depth.
- Eleti Ramayapalli, Wardhannaapet, Pakala and Duggondi profiles were classified into Inceptisols. Tadvai, Nallabelli, Bachannapet, Eturunagaram , malyal and Raghunathapalli profiles were classified into Alfisols and Regonda, Ghanpur, Khanapur and Warangal Research station profiles were classified into Vertisols based on soil properties.
- The available nitrogen, phosphorus and potassium content in surface (0-15 cm) samples varied from 137 to 345, 6.35 to 26.50 and 121 to 392 kg ha^{-1} and the nutrient index rating was low, medium and high, respectively.
- Based on soil physical rating index, Bachannapet and Wardhannapet profiles were classified as class IV which is slightly suitable. The yield could be increased by appropriate soil management practices. Other profiles were classified as class III which are moderately suitable where the expected yield is 50 per cent of yield potential. The yield could be further increased by soil management practices.

- Soil constraints were identified using physical rating index and chemical index based on soil fertility status. The major constraints identified were low available water storage capacity, slow infiltration, high sub surface bulk density, water logging, soil erosion, alkali soils and low nitrogen and phosphorus. No constraints for crop production were observed in Malyal. The management practices suggested to increase the productivity are application of organic matter, deep ploughing, contour cultivation, gypsum application and application of N and P fertilizers.

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APPENDIX I

Description of Profiles

The soil profiles were studied for morphological features of the horizons as per the methods and nomenclature used by (Soil Survey Staff, 1998). The description of the profiles is given below.

Profile	**:**	**1**
Location	**:**	**Tadvai**
Mandal	**:**	**Tadvai**

Soils are moderately shallow in depth, moderately rapid in drainage condition with undulating topography.Natural vegetation includes shrubs and forest tree species such as *Acacia nilotica, Tectonis grandis etc.*

Depth (cm)	Description
0-15	Reddish brown (2.5YR 4/3 D), dark reddish brown (5YR 3/3 M); sandy loam; fine weak sub angular blocky; loose, friable, non-sticky and non-plastic; medium pores are many; few fine roots; no effervescence with diluted HCl; clear smooth boundary.
15-37	Reddish brown (2.5YR 4/4 D), dark red (2.5YR 3/6 M); sandy clay loam; fine weak sub angular blocky; slightly hard, friable, slightly sticky with no plasticity; medium pores are common; no effervescence with diluted HCl; clear smooth boundary.
37-55	Red (2.5YR 4/6 D), dark red (2.5YR 3/6 M); sandy clay loam; fine moderate sub angular blocky; slightly hard, friable, slightly sticky and slightly plastic; few medium pores; very few fine roots; no effervescence with diluted HCl; diffused wavy boundary.

55-70+	Red (2.5YR 4/8 D), dark red (2.5YR 3/6 M), sandy clay loam; fine moderate sub angular blocky; slightly hard, friable, slightly sticky and slightly plastic; very few medium pores; no effervescence with diluted HCl; diffused wavy boundary.

Profile	**:**	**2**
Location	**:**	**Nallabelli**
Mandal	**:**	**Nallabelli**

Soils are moderately shallow in depth, poor in drainage condition and the topography is nearly level (<1%). Maize and sorghum are the major crops grown.

Depth (cm)	Description
0-15	Yellowish brown (10YR 5/4 D), dark yellowish brown (10YR 4/4 M); sandy clay loam; medium moderate sub angular blocky; slightly hard, friable, slightly sticky and non plastic; medium size pores are many; few fine roots; violent effervescence observed with diluted HCl; more calcium carbonate nodules; clear smooth boundary.
15-30	Dark yellowish brown (10YR 4/4 D), dark yellowish brown (10YR 3/4 M); sandy clay loam; medium moderate sub-angular blocky; slightly hard, firm, slightly sticky and slightly plastic; fine pores are common; very few very fine roots; violent effervescence with diluted HCl; more calcium carbonate nodules; clear smooth boundary.
30-70+	Dark yellowish brown (10YR 4/6 D), dark yellowish brown (10YR 3/6 M); sandy clay loam; medium moderate sub angular blocky; very hard, firm, slightly sticky and plastic; fine pores are few; violent effervescence with diluted HCl; more calcium carbonate nodules; diffused wavy boundary.

Profile : 3
Location : Bachannapet
Mandal : Bachannapet

Soils are moderately shallow in depth, poor in drainage condition and the topography is nearly level (<1%).Maize and cotton are the major crops grown.

Depth (cm)	Description
0-8	Red (2.5YR 4/6 D), dark red (2.5YR 3/6 M); sandy loam; fine weak sub angular blocky ; loose, firm, slightly sticky and slightly plastic; medium pores are common; few fine pores; slight effervescence with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
8-50	Red (2.5YR 4/8 D), dark red (2.5YR 3/6 M); sandy clay loam; fine moderate sub angular blocky; slightly hard, firm, slightly sticky and slightly plastic; medium pores are many. Very fine roots; slight effervescence with diluted HCl; few calcium carbonate nodules; clear and wavy boundary.
50-65+	Yellowish red (5YR 4/6 D), dark reddish brown (2.5YR 3/4 M); sandy clay loam; fine weak sub angular blocky; slightly hard, firm, sticky and plastic; medium size pores are many; slight effervescence with diluted HCl; few calcium carbonate nodules; clear wavy boundary.

Profile : 4
Location : Eturunagaram
Mandal : Eturunagaram

Soils are deep to very deep in depth, moderately rapid in drainage condition and the topography is nearly level (<1%). Natural vegetation includes forest tree species and shrubs.

Depth (cm)	Description
0-15	Yellowish red (5YR 4/6 D), dark reddish brown (2.5YR 3/3 M); sandy loam; fine weak sub angular blocky; loose, firm, non-sticky and non-plastic; medium size pores are many; few fine roots; no effervescence with diluted HCl; clear smooth boundary.
15-47	Red (5YR 4/6 D), dark reddish brown (2.5YR 3/4 M); sandy clay loam; fine weak sub angular blocky; slightly hard, friable, slightly sticky and non-plastic; medium pores are many; few fine roots; no effervescence with diluted HCl; clear smooth boundary.
47-80	Red (2.5YR 4/8 D), dark red (2.5YR 3/6 M); sandy clay loom; medium moderate sub angular blocky; slightly hard, friable, sticky and plastic; fine pores are common; no effervescence with diluted HCl; diffused wavy boundary.
80-120	Red (2.5YR 4/6 D); dark red (2.5 YR 3/6 M); sandy clay loam; medium moderate sub angular blocky; hard, firm, sticky and plastic; few fine pores; no effervescence with diluted HCl; diffused wavy boundary.

Profile : 5
Location : Eleti Ramayapalli
Mandal : Chityal

Soils are moderately shallow in depth, poor in drainage condition and the topography is nearly level (<1%).Cotton and sorghum are the major crops grown.

Depth (cm)	Description
0-11	Brown (7.5YR 4/4 D), dark brown (7.5YR 3/4 M); sandy clay loam; fine weak sub angular blocky; loose, friable, slightly sticky and non plastic; medium pores are common; few fine roots; no effervescence with HCl; clear smooth boundary.
11-30	Strong brown (7.5YR 4/6 D), dark brown (7.5YR 3/4 M); sandy

	clay loam; medium moderate sub angular blocky; slightly hard, firm, slightly sticky and slightly plastic; medium size pores are many; very few fine roots; no effervescence with diluted HCl; clear smooth boundary.
30-55	Strong brown (7.5YR 4/6 D), dark brown (7.5YR 3/4 M); sandy clay loam; medium moderate sub angular blocky; slightly hard, firm, sticky and slightly plastic; few fine pores; few fine roots; no effervescence with diluted HCl; diffused wavy boundary.
55+	Strong brown (7.5YR 4/6 D), dark brown (7.5YR 3/4 M); sandy clay loam; moderate medium sub angular blocky; slightly hard, firm, sticky and slightly plastic; fine pores are few; no effervescence with diluted HCl; diffused wavy boundary.

Profile : 6
Location : Wardhannapet
Mandal : Wardhannapet

Soils are moderately deep in depth, moderately rapid in drainage condition and the topography (undulation) is nearly level (<1%).Cotton, maize and sorghum are the major crops grown.

Depth (cm)	Description
0-8	Yellowish brown (10YR 5/4 D), dark yellowish brown (10YR 4/4 M); sandy loam; medium weak sub angular blocky; loose, friable, non-sticky and non-plastic; medium pores are many; few fine roots; slight effervescence with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
8-33	Yellowish red (5YR 5/6 D), red (2.5YR 4/6 M); sandy clay loam; medium moderate sub angular blocky; slightly hard, firm, slightly sticky and slightly plastic; fine size pores are common; very fine roots are few; slight effervescence with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
33-80+	Yellowish brown (10YR 5/4 D), strong brown (7.5YR 4/6 M);

sandy clay loam; medium moderate sub angular blocky; slightly hard, firm, sticky and plastic; very fine pores are few; slight effervescence with diluted HCl; few calcium carbonate nodules; diffused wavy boundary.

Profile : 7
Location : Raghunathapalli
Mandal : Raghunathapalli

Soils are moderately shallow in depth, moderately rapid in drainage condition and the topography is nearly level (<1%). Cotton, maize and sorghum are the major crops grown.

Depth (cm)	Description
0-25	Reddish brown (5YR 4/4 D), dark brown (7.5YR 3/4 M); sandy loam; fine weak sub angular blocky; slightly hard, friable, no-sticky and no-plastic; medium pores are many; fine pores are few; no effervescence with diluted HCl; clear smooth boundary.
25-55	Yellowish red (5YR 4/6 D), dark reddish brown (5 YR 3/3 M); sandy clay loam; medium strong angular blocky ; slightly hard, firm, slightly sticky and slightly plastic, fine pores are common; very fine pores are few; no effervescence with diluted HCl; clear wavy boundary.
55-75+	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M); sandy clay loam; medium moderate sub angular blocky; hard, firm, sticky and plastic; very fine pores are few; no effervescence with diluted HCl; diffused wavy boundary.

Profile : 8
Location : Pakala
Mandal : Narasmpet

Soils are moderately shallow in depth, moderate in drainage condition and the topography is nearly level (<1%).Cotton, maize and sorghum are the major crops grown.

Depth (cm)	Description
0-10	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/3 M); sandy clay loam; fine weak sub angular blocky; loose, friable, non sticky and slightly plastic; medium pores are many; slight effervescence with diluted HCl; few calcium carbonate nodules; diffused wavy nature boundary.
10-35	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/3M); sandy clay loam; medium moderate angular blocky; slightly hard, friable, slightly sticky and slightly plastic, fine pores are few; slight effervescence with diluted HCl; few calcium carbonate nodules; diffused wavy boundary.
35-55+	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/3 M); sandy clay loam; medium moderate sub angular blocky; slightly hard, friable, slightly sticky and slightly plastic; fine pores are few; slight effervescence with diluted HCl; few calcium carbonate nodules; diffused wavy boundary.

Profile : 9
Location : Malyal
Mandal : Malyal

Soils are moderately deep in depth, moderately slow in drainage condition and the topography is nearly level (<1%).Rice and cotton are the major crops grown.

Depth (cm)	Description
0-20	Dark greyish brown (10YR 4/2 D), dark brown (10YR 4/3 M); sandy clay loam; medium moderate sub angular blocky; loose, friable, non sticky and slightly plastic; medium pores are many; fine roots are very few; slight effervescence with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
20-40	Brown (10YR 4/3 D), dark yellowish brown (10YR 4/4 M); clay loam; medium moderate sub angular blocky; slightly hard, firm, slightly sticky and slightly plastic; fine pores are common; fine roots are few; slight effervescence with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
40-65	Dark yellowish brown (10YR 4/4 D), dark greyish brown (10YR 4/2 M); clay loam; medium strong angular blocky; hard, firm, slightly sticky and slightly plastic; fine pores are few; few fine roots; violent effervescence with diluted HCl; few calcium carbonate nodules; diffused wavy boundary.
65-95+	Dark yellowish brown (10YR 4/4 D), dark greyish brown (10YR 4/2 M); sandy clay loam; fine strong angular blocky; hard, firm, slightly sticky and slightly plastic; fine pores are few; violent effervescence with diluted HCl; few calcium carbonate nodules; diffused wavy boundary.

Profile : 10
Location : Duggondi
Mandal : Duggondi

Soils are moderately shallow in depth, poor drainage in condition and the topography is nearly level (<1%). Rice and maize and sorghum are the major crops grown.

Depth (cm)	Description
0-15	Greyish brown (10YR 5/2 D), reddish brown (2.5YR 4/3 M); clay

	loam; medium moderate sub angular blocky; slightly hard, firm, slightly sticky and slightly plastic; medium pores common; few fine roots; violent effervescence with diluted HCL; more calcium carbonate nodules; clear smooth boundary.
15-37	Brown (10YR 5/3 D), dark reddish brown (10YR 3/3 M); clay loam; medium moderate sub angular blocky; hard, firm, slightly sticky and slightly plastic; medium size pores are many; few very fine roots; violent effervescence with diluted HCl; more calcium carbonate nodules observed; diffused wavy boundary.
37-65+	Yellowish brown (10YR 5/4 D), dark yellowish brown (10YR 3/4 M); clay loam; weak fine angular blocky; hard, firm, sticky and plastic; few fine pores; violent effervescence with diluted HCl; more calcium carbonate nodules; diffused smooth boundary.

Profile : 11
Location : Regonda
Mandal : Regonda

Soils are moderately in deep, poor in drainage condition and the topography is nearly level (<1%). Rice and cotton are the major crops grown.

Depth (cm)	Description
0-11	Very dark grey (7.5YR 3/1 D), black (7.5YR 2.5/1 M); clay loam; medium moderate sub angular blocky; hard, firm, slightly sticky and slightly plastic; medium pores are many; few fine roots; violent effervescence with diluted HCl; more calcium carbonate nodules; clear smooth boundary.
11-35	Very dark grey (7.5YR 3/1 D), black (7.5YR 2.5/1 M); clay loam; medium moderate angular blocky; hard, firm, slightly sticky and slightly plastic; fine pores are common; few fine size roots; violent effervescence with diluted HCl; more calcium carbonate nodules observed; diffused wavy boundary.
35-55	Very dark grey (7.5YR 3/1 D), black (7.5YR 2.5/1 M); clay loam; fine, moderate angular blocky; slightly hard, firm, sticky and

	plastic; fine pores are common; violent effervescence with diluted HCl; more calcium carbonate nodules; diffused smooth boundary.
55-75	Very dark grey (7.5YR 3/1 D), black (7.5YR 2.5/1M); clay loam; fine, strong angular blocky; slightly hard, firm sticky and plastic; fine pores are common; violent effervescence with diluted HCl; more calcium carbonate nodules; diffused smooth boundary.
75+	Very dark grey (7.5YR 3/1 D), black (7.5YR 2.5/1M); clay; fine, strong angular blocky; slightly hard, very firm, sticky and very plastic; violent effervescence with diluted HCl; more calcium carbonate nodules; diffused smooth boundary.

Profile : 12
Location : Ghanpur
Mandal : Ghanpur

Soils are moderately shallow, poor in drainage condition and the topography is nearly level. Maize and cotton are the major crops grown.

Depth (cm)	Description
0-17	Brown (7.5YR 5/2 D), dark brown (7.5YR 3/3 M); clay loam; medium weak sub angular blocky; hard, firm, slightly sticky and non-plastic; medium size pores are many; few fine roots; slight effervescence with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
17-45	Brown (7.5YR 5/2 D), dark brown (7.5YR 3/3 M); clay loam; medium moderate angular blocky; slightly hard, firm, slightly sticky and slightly plastic; very fine pores are few; few fine roots; slight effervescence with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
45-60	Brown (7.5YR 5/2 D), dark brown (7.5YR 3/3 M); clay loam; medium moderate angular blocky; slightly hard, firm, sticky and plastic; few very fine pores; few fine roots; slight effervescence with diluted HCl; few calcium carbonate nodules; diffuse wavy

	boundary.
60-65+	Brown (7.5YR 5/2 D), dark brown (7.5YR 3/3 M); clay; medium weak angular blocky; slightly hard, firm, sticky and plastic; few very fine pores; slight effervescence with diluted HCl; few calcium carbonate nodules; diffused wavy boundary.

Profile : 13
Location : Khanapur
Mandal : Khanapur

Soils are moderately shallow, poor in drainage condition and the topography is nearly level plain. Rice is the major crops grown.

Depth (cm)	Description
0-12	Yellowish brown (10YR 5/4 D), dark yellowish brown (10YR 4/6 M); clay loam; medium weak sub angular blocky; hard, firm slightly sticky and plastic; medium pores are many; few fine roots; slight effervescence observed with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
12-30	Yellowish brown (10YR 5/6 D), dark yellowish brown (10YR 4/6 M); clay loam; medium weak sub angular blocky; hard, firm, slightly sticky and plastic; medium pores are common; few fine roots; slight effervescence with diluted HCl; few calcium carbonate nodules; clear smooth boundary.
30-45	Dark yellowish brown (10YR 4/4 D), yellowish brown (10YR 3/4 M); clay loam; medium weak angular blocky; slightly hard, very firm, sticky and plastic; few and very fine pores; slight effervescence with diluted HCl; few calcium carbonate nodules; diffused wavy boundary.
45-65+	Dark yellowish brown (10YR 4/6 D), dark yellowish brown (10YR 3/6 M); clay loam; medium strong angular blocky; slightly hard, very firm, sticky and plastic; very fine pores are few; slight effervescence with diluted HCl; few calcium carbonate nodules;

diffused wavy boundary.

Profile	**:**	**14**
Location	**:**	**Warangal Research Station**
Mandal	**:**	**Warangal**

Soils are moderately shallow, poor in drainage condition and the topography is nearly level. Cotton, maize, pulses and fodder sorghum are the major crops grown.

Depth (cm)	Description
0-15	Very dark greyish brown (10YR 3/2 D), very dark grey (10YR 3/1 M); clay loam; medium weak sub angular blocky; hard, firm, slightly sticky and slightly plastic; medium pores are common; fine roots are very few; violent effervescence with diluted HCl; more calcium carbonate nodules; clear smooth boundary.
15-55	Very dark greyish brown (10YR 3/2 D), very dark grey (10YR 3/1 M); clay loam; medium strong angular blocky; hard, firm, sticky and plastic; medium pores are common; very fine roots are very few; violent effervescence with diluted HCl; more calcium carbonate nodules; clear smooth boundary.
55-72	Very dark greyish brown (10YR 3/2 D) very dark grey (10YR 3/1 M); clay loam; medium strong angular blocky; slightly hard, very firm, very sticky and very plastic; few very fine roots; violent effervescence with diluted HCl; more calcium carbonate nodules; diffused wavy boundary.
72+	Very dark greyish brown (10 YR 3/2 D) very dark grey (10 YR 3/1 M); clay; medium strong angular blocky; slightly hard, very firm, very sticky and very plastic; very fine pores; few very fine roots; violent effervescence with diluted HCl; more calcium carbonate nodules; diffused wavy boundary.

Appendix II

Available N, P & K in surface soils

Administrative division	Mandals	Number of soil samples	Available major nutrients (kg ha^{-1})		
			N	P_2O_5	K_2O
Hanamakonda	1. Hanamakonda	1	185	12.50	232
		2	183	14.20	346
		3	179	18.60	357
		4	345	13.50	343
	2. Hasanparthy	1	158	21.20	295
		2	172	10.50	304
		3	169	14.65	321
	3. Geezugonda	1	220	20.50	298
		2	295	19.55	289
		3	187	20.20	296
	4. Sangam	1	179	19.87	294
		2	163	18.73	325
		3	323	9.80	185
	5) Wardhannapet	1	172	16.20	308
		2	210	18.75	302
		3	215	18.35	317
		4	315	15.65	333
	6) Parvathagiri	1	225	16.40	326
		2	240	17.20	318
		3	260	18.25	309
2. Ghanpur	1. Dharmasagar	1	136	6.35	305
		2	142	7.75	292
		3	157	23.75	288
	2. Raghunathapalli	1	137	8.25	312
		2	167	9.50	323
		3	152	10.73	195
		4	295	26.50	316
	3. Zaffargath	1	154	10.65	325
		2	182	6.95	332
		3	174	7.25	318
		4	163	8.16	319
	4. Palakurthi	1	312	9.23	296
		2	198	11.32	325

Administrative division	Mandals	Number of soil samples	Available major nutrients (kg ha^{-1})		
			N	P_2O_5	K_2O
		3	251	10.81	317
	5. Ghanapur station	1	182	7.42	360
		2	247	22.65	205
		3	325	6.93	322
	6. Devaruppala	1	245	7.72	341
		2	265	8.51	339
		3	255	7.99	355
3. Janagaon	1.Cherial	1	168	12.75	165
		2	155	13.65	180
		3	172	10.50	215
	2. Maddur	1	180	16.35	220
		2	210	15.25	245
		3	195	18.25	163
		4	205	12.35	182
	3. Narmeta	1	232	18.64	310
		2	212	16.32	332
		3	243	17.25	291
	4. Bachannapet	1	261	12.52	185
		2	235	16.36	163
		3	241	15.21	176
		4	252	17.32	335
	5. Jangaon	1	218	14.25	232
		2	261	19.35	212
		3	237	20.50	242
	6. Lingal ghanpur	1	218	14.50	265
		2	195	6.25	218
		3	178	13.25	247
4. Mahabubabad	1. Kothagudem	1	189	12.50	132
		2	210	11.73	121
		3	176	15.83	260
	2. Gudur	1	192	20.84	346
		2	265	22.75	332
		3	215	23.63	318
	3. Kesamudram	1	265	12.35	119.26
		2	235	13.25	121.12

Administrative division	Mandals	Number of soil samples	Available major nutrients (kg ha^{-1})		
			N	P_2O_5	K_2O
		3	272	17.67	295.35
		4	295	18.32	162.72
	4.Mahabubabad	1	310	23.25	119.22
		2	260	15.32	212.35
		3	193	18.16	254.54
	5. Korivi	1	212	20.15	262.50
		2	218	15.12	230.10
		3	241	19.32	210.50
		4	251	17.15	189.50
	6. Dornakal	1	271	18.12	192.35
		2	242	17.32	240.50
		3	239	16.15	212.16
5. Maripeda	1. Raiparthi	1	218	12.50	315
		2	212	13.25	392
		3	236	14.50	372
		4	252	18.0	286
	2. Kodakundla	1	237	19.50	225
		2	255	21.50	293
		3	263	18.75	265
		4	273	17.75	235
	3. Torur	1	246	9.30	272
		2	252	18.20	232
		3	261	7.65	200
	4. Nellikudur	1	248	13.20	207
		2	272	14.16	310
		3	265	20.50	214
		4	232	11.50	217
	5. Narasimhulapeta	1	195	13.50	265
		2	210	12.54	257
		3	225	17.53	236
		4	218	18.12	241
	6. Marripeda	1	243	19.76	275
		2	212	18.75	268
		3	235	20.32	263

Administrative division	Mandals	Number of soil samples	Available major nutrients (kg ha^{-1})		
			N	P_2O_5	K_2O
6.Narsampet	1. Nallabelli	1	196	7.25	2.90
		2	218	13.50	312
		3	235	14.25	316
	2. Duggondi	1	276	12.50	321
		2	238	23.50	216
		3	241	15.25	333
	3. Warangal	1	216	20.50	285
		2	222	18.50	296
		3	231	16.75	313
	4. Narsampet	1	205	20.15	316
		2	214	18.95	298
		3	221	17.25	333
	5. Khanapur	1	218	12.15	356
		2	221	13.25	322
		3	236	14.10	318
	6. Chennaraopet	1	245	16.50	295
		2	216	14.22	205
		3	227	17.55	312
	7. Nekkonda	1	236	20.50	307
		2	225	19.32	309
7. Parkal	1. Chityal	1	188	11.25	221
		2	220	24.50	336
		3	219	18.32	396
		4	235	12.50	351
	2. Mogulapalli	1	242	12.30	319
		2	256	14.51	286
		3	237	16.32	329
	3. Regonda	1	263	24.50	291
		2	272	16.51	292
		3	261	17.21	273
	4. Parkal	1	225	18.50	265
		2	198	16.32	316
		3	220	17.21	323
	5. Shyampet	1	255	16.50	345
		2	243	17.20	326

Administrative division	Mandals	Number of soil samples	Available major nutrients (kg ha^{-1})		
			N	P_2O_5	K_2O
		3	222	19.35	316
	6. Atmakur	1	218	20.25	309
		2	210	21.50	318
		3	226	19.65	321
		4	235	21.0	332
8. Mulug	1. Bhoopalpally	1	226	23.50	299
		2	235	14.50	321
		3	232	13.21	360
		4	218	16.50	335
		5	195	18.32	342
	2. Ghanpur	1	240	12.50	275
		2	198	13.20	296
		3	232	14.50	299
		4	256	16.32	305
		5	232	17.21	312
	3. Venkatapur	1	280	13.65	321
		2	262	14.35	275
		3	259	15.25	296
		4	261	17.21	236
		5	236	18.31	342
	3. Mulug	1	245	19.21	351
		2	237	20.50	363
		3	243	21.50	345
		4	255	19.65	352
		5	261	20.25	363
9. Akulavari Ghanapur	1. Eturunagaram	1	262	11.0	292
		2	255	12.55	265
		3	243	15.65	296
		4	236	17.32	310
		5	223	18.21	305
	2. Govindraopet	1	295	9.65	310
		2	301	10.25	312
		3	265	12.50	316
		4	254	13.10	321
		5	243	14.54	325

Administrative division	Mandals	Number of soil samples	Available major nutrients (kg ha^{-1})		
			N	P_2O_5	K_2O
		6	262	16.32	328
		7	271	19.50	331
		8	269	20.61	338
	3. Tadvai	1	252	18.50	269
		2	261	17.63	272
		3	258	15.43	292
		4	272	12.63	298
		5	276	8.95	305
		6	295	11.95	310

Nutrient index ;

$$\text{Nutrient index} = \frac{N_l + 2N_m + 3N_h}{N_l + N_m + N_h}$$

$$\text{Nitrogen} = \frac{1 \text{ X } 163 + 2 \text{ X } 17 + 3 \text{ X } 0}{180}$$

= **1.09**

$$\text{Phosphorus} = \frac{1 \text{ X } 12 + 2 \text{ X } 158 + 3 \text{ X } 10}{180}$$

= **1.98**

$$\text{Potassium} = \frac{1 \text{ X } 0 + 2 \text{ X } 158 + 3 \text{ X} 10}{180}$$

= **2.68**

Appendix III. Physical Rating Index of soils

Location	Soil depth	BD	WSC	IR	Aggregation	Non capillary pore space	Water table depth	Slope	PI
1.Tadvai	0.90	1.00	0.80	0.80	0.95	0.95	1.0	1.00	0.51
2.Nallabelli	0.90	1.00	0.90	0.90	0.95	0.95	1.0	0.90	0.59
3.Bachannapet	0.90	1.00	0.80	0.80	0.95	0.95	1.0	0.90	0.47
4.Eturunagaram	0.95	1.00	0.80	0.80	0.95	0.95	1.0	1.00	0.54
5.Eleti Ramayapalli	0.90	1.00	0.90	0.90	0.95	0.95	1.0	0.95	0.62
6.Wardhannapet	0.90	1.00	0.85	0.80	0.95	0.95	1.0	0.90	0.50
7.Raghunathapalli	0.90	1.00	0.80	0.80	0.95	0.95	1.0	1.00	0.51
8.Pakala	0.90	1.00	0.90	1.00	0.95	0.95	1.0	1.00	0.73
9.Malyal	0.95	1.00	0.80	0.95	0.95	0.95	1.0	0.95	0.62
10.Duggondi	0.90	0.85	0.95	0.90	0.95	0.95	1.0	0.90	0.53
11.Regonda	0.95	0.85	0.90	0.90	0.95	0.95	1.0	0.95	0.56
12.Ghanpur	0.90	0.85	0.90	0.90	0.95	0.95	1.0	0.95	0.53
13.Khanapur	0.90	0.85	0.95	0.90	0.95	0.95	1.0	0.90	0.53
14.Warangal RS	0.90	0.85	0.90	0.90	0.95	0.95	1.0	0.95	0.53