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Pedogenesis and land evaluation of some sugarcane growing red soils in semi-arid tropical region of Telangana

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Abstract
To characterise and classify the sugarcane growing red soils of Medak district of Telangana State and assess the suitability for growing sugarcane and develop strong soil resource database for proper appraisal of their productivity potential and their rational use. Based on the morphological characteristics and land elevation, five geo referenced pedons were selected. The area was under the influence of semi-arid monsoon type climate. The selected red soils were developed on weathered granite-gneiss parent material at gently sloping lands. The texture was ranging from gravelly sandy loam (coarse) and sandy clay loam (medium) in the surface horizons and sandy loam and sandy clay loam in sub-surface horizons. The clay content ranged from 13.2 to 22.6 percent in surface horizons and 14.6 to 31.4 percent in subsurface horizons. The sand content varied from 72.3 to 75.1 percent in surface horizons and 56.4 to 77.1 in subsurface horizons. The silt clay ratio ranged from 0.19 to 0.82 indicating the moderate to high weathering. The soils were developed weak pedality with granular structure in the surface horizons and sub-angular blocky peds in sub-surface layers. Soil pH was moderately acidic to neutral (6.0 to 7.5) and non-saline. The organic carbon content was low to medium (4.3 to 6.8 g kg^{-1}) in surface horizons and in subsurface horizons it was low to medium ranged from 2.1 to 5.2 g kg^{-1}. The exchangeable bases of soil pedons were in order of $Ca^{+2} > Mg^{+2} > Na^{+} > K^{+}$ on the exchange complex. Based on the morphology, physical, physico-chemical and chemical properties of the soils, the soil pedons were classified as per USDA soil taxonomy. Soils were classified into orders *viz*., Alfisols and Entisols.

Keywords: Sugarcane growing red soils, morphological, physical, physico-chemical properties, soil classification, soil formation and land evaluation

Introduction

Land is a finite natural resource and there is little scope to increase the areas under cultivation. The efforts made in the past to bring new areas under cultivation which results the reduction forests to 20% of total geographical area of the country. For decades, advancement in agricultural practices has been a necessity due to ever increasing demand caused by growing population. Sugarcane (*Saccharum officinarum* L) is being cultivated in India in an area of 42.45 lakh ha in the states of Karnataka, Maharashtra, Madhya Pradesh, Telangana, Andhra Pradesh, Tamil Nadu, Goa and Kerala with total sugar production of 192.67 lakh tones. India is one of the largest producers of sugar and shares about 41.11% and 13.25% of Asian and Worlds sugar production respectively. The population in India is increasing steadily and as well the demand for sugar and other sweetening agents because of changing food habits. There is no scope to increase the area under sugarcane to meet the requirements. This envisages the adoption of better crop production and protection technologies for increased production per unit area and time apart from varietal improvement. Sugarcane is cultivated in the Medak district in an area of 22076 hectares producing 1721 thousand tonnes with an average productivity of 74.41 t ha^{-1}.

Telangana state being under a semi-arid tropical monsoon climate, has a number of soil types which are found in all types of climates, occupying 3.5 percent (114, 840 sq km or 114.84 lakh ha or 11.484 m.ha) of the country’s geographical area. Hence their management varies from place to place besides the crop variation. Maintaining the soil with high productivity on sustainable basis is important to meet basic needs of the people. Hence delineating the sugarcane growing soils for their fertility helps in understanding the soil related constraints and their intensity which is essential to develop site specific management strategies.

Classification of sugarcane growing soils in a taxonomic perspective provides information on the nature and its potential production capabilities. The characterization and classification of soils helps in determining the soil potential, identifying constraints and giving detailed

Information on different soil properties of the sugarcane growing areas. The present investigation is aimed to assess the characteristics of soils and land resources to comprehend the potential capability of sugarcane growing soils of Medak district in the perspective of developed land use decision for effective utilization of resources.

Materials and Methods

Location and brief description of the study area

Medak district of Telangana state is with a geographical area of 9,519 km^2 forms a part of Deccan Plateau under Godavari basin and lies between North Latitudes 17^o 27' and 18^o 18' and East longitudes 77^o 28' and 79^o 10'. Sugarcane is cultivated in the district in an area of 22076 hectares producing 1721 thousand tonnes with an average productivity of 74.41 t ha^{-1} (Centre for Monitoring Indian Economy, 2014-15). Based on the morphological characteristics and physiography, five geo-referenced pedons (Table 1) were selected in four divisions of Medak district such as Mamdipally (Pedon 1), Kaudloor (Pedon 2), Antharam (Pedon 3), Mudguntal thanda (Pedon 4) and Ramakkapet (Pedon 5). The district forms part of South Deccan Plateau. It is an ancient plateau exposed for long ages to denudation. Sheet-wash and retreat of hill slopes are the major geomorphic processes responsible for sculpturing of the present day landforms under semi-arid conditions. The plateau has two erosional surfaces with altitudes of 150-600 m and 300-900 m above MSL.

The Medak district represents a variety of geological formations. It has been divided into three physiographic regions, *viz.*, granite and granite-gneiss landform, basalt landform and laterite landform. The important rock types are Peninsular Gneissic complex, Dharwar super group associated with Younger intrusive of Achaean age separated unconformably with overlying Basaltic flows of late Cretaceous to early Eocene age with sub-Recent to Recent alluvium along the stream courses. The Archaean or Peninsular gneisses occur all over the district in 6,86,853 ha area (70.7%). They are partially metamorphosed igneous rocks. They remained stable as a "Shield" area for a very long time. The rocks are composed of grey or pink feldspars, quartz and muscovite mica (NBSS & LUP, 2005) [24].

The climate is semi-arid. The mean annual rainfall is 870 mm of which 76 percent is received during the southwest monsoon (June to September), 14 percent during the northeast monsoon (October to December) and 8 percent during the premonsoon period (March to May). The mean maximum and minimum temperature vary from 40° to 26 °C. Mean humidity varies from 65 percent in July to 74 percent in December. The soil moisture content is dry for more than 90 cumulative days or 45 consecutive days in the months of summer solstice. The soil moisture and temperature regimes of the study area are Ustic and Isohyperthermic, respectively. The natural vegetation existing in the study area are grasses, shrubs, thorny bushes such as *Cynodon dactylon, Cyprus rotundus, Butea frondosa, Dalbergia latifolia, Azadirachta indica, Tectona grandis, Terminalia tomertose* and *Acacia* spp. *Prosopis juliflora, Cacia* sp, broad leaf weeds such as *Selotia, Parthenium, Eucalyptus, Euforbia* sps., etc. The principal crops cultivated are Rice, Maize, Sugarcane, cotton, redgram, Greengram, Blackgram, Groundnut and Potato.

Collection and processing of soil samples

The division wise geo-referenced pedons were selected on the basis of soil heterogeneity and land forms in different locations of sugarcane growing areas of the district. Horizon wise soil samples were collected from the representative pedons for laboratory analysis. The soil samples were air-dried in shade, processed and screened through a 2 mm sieve. Particles greater than 2mm were considered as gravel. The samples were air dried and ground to pass through 2 mm sieve. Relevant physical and chemical properties were determined by following standard analytical procedures. The Soil pH, EC (1:2.5 soil water suspension); exchangeable cations (Jackson 1973); cation exchange capacity (Chapman, 1965) [9]; organic carbon (Walkly and Black, 1934) [48]; free $CaCO_3$ (Piper 1966) [29]; bulk density (Blake and Hartze 1986); COLE (Soil Survey Staff, 2010) [43]; water holding capacity and volume expansion (Sankaram, 1966); gravel by gravimetry method (Govindarajan and Koppar, 1975) [17]; Soil texture by International Pipette Method (Piper, 1966) [29]. The soils were characterized and classified as per Keys to Soil Taxonomy (Soil Survey Staff, 2010) [43].

Results and Discussion

Morphological properties

The details of the morphological properties of the soils were presented in Table 1. The landforms of pedon were classified under gently sloping and well drained with respect to drainage condition. Thin clay films were noticed in pedon 1, 3, 4 and 5. Soil depth of the pedon 2 was shallow (25-50 cm), pedon 4 and 5 were moderate (50-75 cm), pedon 1 and 3 was moderately deep (75-100 cm). Soil depth was shallow in moderate steep slope whereas moderately deep soils were found in nearly level to very gently sloping plain. The variation of depth in relation to physiography, mainly because of non-availability of adequate amount of water for prolonged period on upland soils associated with removal of finer particles and their deposition at lower pediplain have resulted in shallow soils in uplands and deeper soils in lowland physiographic units. The same types of findings were reported by Meena *et al*. (2009) [20] and Rajeshwar and Mani (2013) [30].

In pedon 1, 2, 4 and 5 five horizons and in pedon 2 four horizons were demarcated. All the pedons were characterized as A-B-C horizons except pedon 2 (A-C). The thickness of the surface horizons varied from 11.0 (pedon 10) to 27.0 (pedon 12) cm and sub-surface horizons ranged from 11.0 (pedon 10) to 40.0 cm (pedon 9). Pedon 8, 11, 13 and 14 showed considerable homogeneity in soil pedon development (A-Bt-C) and pedon 10 do not have any diagnostic horizons. The boundary between the horizons varied from smooth, wavy, clear and abrupt. The surface horizon was designated as 'Ap' horizon at all the location because of the ploughed and/or disturbed condition due to cultivation (Rajeshwar *et al*., 2009) [30]; Ashok kumar and Jagadish Prasad (2010) [2]. The surface horizon was characterized as 'ochric' epipedon because of less organic matter content and light colour as per the requirements specified by Soil Survey Staff (1999) [43]. Argillic horizon was developed in the subsurface layers (pedon 1, 3, 4 and 5) might be due to illuviation of clay from the surface horizon. Clay orientation had taken place in the 'B' horizon. That resulted in the formation of clay cutans or clay skins. The broken to common and moderately thick argillans were noticed in between 12 and 95 cm depth in the pedon 1, 3, 4 and 5 (Nagassa and Gebrekidan, 2003; Singh and Agarwal, 2005) [22, 30]. Due to sufficient clay illuviation in argillic horizon (Bt) from the overlying horizons, the texture had become finer. Hence, the boundary between Bt horizon and overlying horizon was clear (Thangasamy *et al.*, 2005) [45].

The soil colour of pedon 1, 2, 3, 4 and 5 had varying from dark reddish brown (5YR3/3) to brown (7.5YR5/4) under dry condition and dark reddish brown (5YR3/2) to brown (7.5YR4/4) under moist condition might be due to the release of iron, its degree of oxidation, hydration might have given the soil brownish to reddish / red colour. The dark reddish brown colour was due to better drainage conditions in higher slopes. Similar observations of red soils were corroborated with those of Dutta *et al.* (2001) [14]; Rajeshwar and Mani (2013) [30].

The soil developed weak pedality with granular structure in the surface horizons and sub-angular blocky peds in sub-surface layers. The surface horizons were generally granular type because of organic matter and inter-cultivation operations. The strength of the peds was weak to moderate whereas, the size of the peds was very fine to medium. This type of weak pedality was attributed to less clay content, low CEC and dominance of illite/kaolinite type of clay (Singh and Agarwal (2005) [22]; Rajeshwar and Mani (2013) [30]. The texture was widely ranging from gravelly sandy loam (coarse) and sandy clay loam (medium) in the surface horizons and sandy loam and sandy clay loam (fine) in sub-surface horizons. As the red soils were derived from acidic coarse to medium grained granite-gneissic parent material, the red soils were exhibiting these textural classes. Gupta *et al.* (2003) [18]; Singh and Agarwal (2005) [22]; Rajeshwar and Mani (2013) [30] reported similar textural classes. This wide variation in soil texture was caused by topographic position, nature of parent material, in-situ weathering, and translocation of clay and age of the soils (Vara Prasada Rao *et al*., 2008) [2].

The consistence varied from loose, slightly hard to hard, friable to firm and non-sticky and non-plastic to slightly sticky and slightly plastic in dry, moist and wet conditions, respectively. This physical behaviour of soils influenced by the textural make up but also due to type of clay minerals present in these soils. The C horizon of all the pedons had shown non-sticky, non-plastic, slightly sticky and slightly plastic consistence, which might be due to less amount of clay (Thangasamy *et al.*, 2005) [45]. The effervescences were slight to moderate in different horizons. Few lime concretions and nodules of different sizes were observed in the upper layers of pedons 3, 4 and 5 (Rajeshwar and Mani, 2013) [30].

Physical properties

The data on fine earth fractions of the soil pedons are presented in Table 2. The clay content of the soils ranged from 13.2 percent (pedon 2) to 22.6 percent (pedon 3) in surface horizons whereas in subsurface horizons it ranged from 14.6 percent (pedon 2) to 32.4 percent (pedon 1). The distribution of clay varied widely both within the pedon and among the pedons. All the Pedon had showed increasing trends with increased soil depth except pedon 3, showed irregular trend with soil depth due to the illuviation process occurring during soil development. Similar observations were also made by Tripathi *et al.* (2006) [46]. The clay content was found gradually increased in pedon 1, 4 and 5. The increased clay content with depth was an evidence of pedogenic development as their formation and distribution is time dependent (Bhaskar *et al.*, 2009) [4]. These variations could be attributed to the parent material, topography, *in situ* weathering and pedogenesis (Rudramurthy and Dasog, 2001; Gabhane *et al*., 2006; Rajeshwar and Mani, 2013) [35, 16, 30]. The silt content of the pedon varied from 4.1 (pedon 5) to 10.8 (pedon 2) percent in surface horizons, whereas in subsurface horizons ranged from. 4.6 (pedon 5) to 12.5 (pedon 5) percent. There was a gradual increase in silt content with depth in pedons 3 and 4 and 5. Whereas reverse trend was noticed in pedon 10 might be due to coarse nature of silt than clay, which restricts its movement with percolating water (Sharma *et al.*, 2001; Rajeshwar and Mani, 2013) [30, 40]

The sand content varied from 72.3 (pedon 3) to 75.1 (pedon 5) percent in surface horizons and 57.3 (pedon 5) to 77.1 (pedon 2) percent in subsurface horizons. A decreasing trend in sand content with depth was observed in pedon 3, 4 and 5, whereas an increasing trend was observed in pedon 2. The remaining pedons did not exhibit any regular trend with depth due to the translocation / migration of finer particles into the lower layers and surface erosion. These observations were in agreement with those of Bhaskar and Subbaiah (1995) [4], Sarkar *et al.* (2001) [38] and Monday *et al.* (2003) [21]. The high sand content in all pedon were indicative of high degree of transportation of fine fraction of the soil from higher topography to lower topography. To confirm the presence or absence of lithological discontinuity among adjacent horizons in different soil pedons, the ratios of fine earth fractions were computed (Table 3). The ratio of sand and silt varied from 4.58 (pedon 5) to 18.32 (pedon 5), silt/clay (0.19 (pedon 1) to 0.82 (pedon 2) and sand/(silt + clay) (1.06 (pedon 4) to 3.38 (pedon 2). The silt and clay ratio ranging from 0.19 (pedon 1) to 0.82 (pedon 2) which indicating the moderate to high weathering. Similar finding was reported by Rajeshwar and Mani (2013) [30]. Gravel content was observed in all the horizons**.** An increasing trend of gravel content with depth was observed in all the pedons. The gravels of the red soils were found to be very hard probably due to periodic wetting and drying favoured concretion formation and more permanent wetting leads to mottling (Manickam *et al.*, 1973) [19]; Rajeshwar and Mani (2013) [30].

The bulk density of the soils ranged from 1.38 Mg m^{-3} (pedon 1) to 1.46 Mg m^{-3} (pedon 1) in surface horizons whereas in subsurface horizons ranged from1.39 Mg m^{-3} in (pedon 1) to 1.56 Mg m^{-3} in (pedon 5). Bulk density increased with increasing depth in all pedons. The increase in bulk density with depth might be due to decrease in organic matter content, more compaction, and less aggregation (Rajeshwar and Mani, 2013) [30]. The water holding capacity was found to vary from 21.0 percent (pedon 4) to 36.0 percent (pedon 1) in surface horizons whereas in subsurface horizons ranged from 23.0 to 42.0 percent in pedon 3 and pedon 1 respectively. The water holding capacity showed increasing trend with soil depth in pedon 4 and 5. The other pedons were exhibited an irregular trend with depth. In all the locations these values showed increasing trend with increasing clay content in general. These types of trends were in accordance with those of Rudramurthy and Dasog (2001) [35] and Bhaskar *et al.* (2005) [4]. The pore space varied from (38.0 percent pedon 1 to 51.0 percent pedon 4). An increase in porosity with depth was observed in pedon 1, 2, 3 and 4. There was no trend in the distribution pattern in other pedons. Similar trend was noticed by Rajeshwar and Mani (2013) [30]. The volume of expansion (2.90 pedon 4 to 5.75 percent pedon 4). The lower volume of expansion was found due to presence of illitic or kaolinitic types of non-expanding clay minerals showed increasing trend with soil depth in pedon 4 and 5.

Physico-chemical properties

The pedon wise physico-chemical properties of of black soils of sugarcane growing areas are described in (Table 4). The pH value ranging from 6.5 (pedon 2) to 6.9 (pedon 3) in surface horizons whereas in subsurface horizons ranging from 6.0 (pedon 2) to 7.5 (pedon 3). The pH increased with depth in the pedon 1, 3 and 5 might be due to increase in bases with depth and their complete downward leaching. The pedons 2 and 4 showed decreasing trend which might be due to the chemical weathering which leads to accumulation of exchangeable H^+, Al^{3+}, Fe and Al oxides and clay minerals (Bipul Deka *et al.*, 2009) [6]. The lower pH values in surface layers of pedon 1, 3 and 5 which might be due to continuous removal of basic cations by crop plants and leaching (Nagassa and Gebrekidan, 2003) [22], movement of basic cations to deeper layers (Singh and Agarwal, 2003) [22] and due to precipitation of calcium carbonate (Balapande *et al.*, 2007). The EC values ranging from 0.19 dS m^{-1} (pedon 1) to 0.24 (pedon 5) in surface horizons whereas in subsurface horizons ranged from 0.11 dS m^{-1} (pedon 2) to 0.29 (pedon 3). The EC was very low even in lower horizons because they were formed on relatively higher elevations. The EC gradually increased with depth in majority of the pedons might be due to the leaching of electrolytes to the lower depth and also due to foraging of nutrient ions by the vegetation in the surface layer (Renukadevi (2003) [34].

The OC values ranging from 4.3 g kg^{-1} (pedon 2) to 6.8 g kg^{-1} (pedon 5) in surface horizons whereas in subsurface horizons ranged from 2.1 g kg^{-1} (pedon 1) to 5.2 (pedon 5). The depth wise distribution of organic carbon showed a decreasing trend in all the pedons. The organic carbon content ranged from low to medium in surface horizons could be attributed to the rapid oxidation and decomposition of added organic matter under tropical condition (Saha *et al.*, 1996, Mustapha *et al.*, 2011). The organic carbon content relatively higher in surface horizons than sub-surface horizons in all the pedons and it decreased with depth. This was attributed to the addition of farmyard manure and plant residues to surface horizons which resulted in higher organic carbon content in surface horizons than that of lower horizons. These observations are in accordance with results of Rajeshwar *et al.* (2009) [30]. The calcium carbonate content of soil pedon ranging from 1.3 percent (pedon 2) to 3.2 percent (pedon 4) in surface horizons whereas, sub surface horizons 1.4 percent (pedon 2) to 5.5 percent (pedon 1). The content was relatively higher in deeper layers than in surface layers might be due to the downward movement of it along with percolating water in soils of semi-arid regions (Pal *et al.*, 2000) [26].

Exchangeable properties

The cation exchange capacity red soils pedons varied from 7.8c mol (p^+) kg^{-1} (pedon 2) to 16.1 c mol (p^+) kg^{-1} (pedon 3) in surface layers and 11.1 c mol (p^+) kg^{-1} (pedon 2) to 20.1 c mol (p^+) kg^{-1} (pedon 1) in sub surface layers. The CEC was the charge behaviour of soils, where clay was the fundamental block contributing towards cation exchange. Similar results were reported by Rudramurthy and Dasog (2001) [35]. The CEC/clay ratios were found to vary from 0.43 (pedon 3) to 0.77 (pedon 2). The CEC values are indicating that the red soils are moderate to highly weathered (Rajeshwar and Mani, 2013) [30].

Soil exchange complex was dominated with Ca in all the pedons compared to other exchangeable cations. The Exchangeable Ca in soil pedons varying from 3.1 c mol (p^+) kg^{-1} (pedon 2) to 8.2 c mol (p^+) kg^{-1}(pedon 4) in surface layers and 5.5 c mol (p^+) kg^{-1} (pedon 2) to 9.5 c mol (p^+) kg^{-1}(pedon 3) in sub surface layers. The exchangeable Ca content increased with depth in pedons 2, 3, 4 and 5. There was no regular pattern of distribution with depth was noticed in pedon 1. The Exchangeable magnesium ranging from 2.0 c mol (p^+) kg^{-1} (pedon 2) to 4.9 c mol (p^+) kg^{-1} (pedon 3) in surface layers and 2.7 c mol (p^+) kg^{-1} (pedon 5) to 6.8 c mol (p^+) kg^{-1} (pedon 3) in sub surface layers. Pedons 1, 3 and 5 showed increasing trend with soil depth, while in the other pedons did not show a clear trend with depth**.**

The exchangeable sodium ranging from 0.1 c mol (p^+) kg^{-1} (pedon 2) to 0.14 c mol (p^+) kg^{-1} (pedon 1) in surface layers and 0.10 c mol (p^+) kg^{-1} (pedon 2) to 0.25 c mol (p^+) kg^{-1}(pedon 4) in sub surface layers. The exchangeable Na content increased with depth in pedons 4 and 5. In the rest of the pedons, the depth wise distribution was irregular**.** The exchangeable potassium ranging from 0.3 c mol (p^+) kg^{-1} (pedon 3) to 0.96 c mol (p^+) kg^{-1} (pedon 4) in surface layers and 0.2 c mol (p^+) kg^{-1} (pedon 2) to 0.6 c mol (p^+) kg^{-1} (pedon 4) in sub surface layers. The pedon 2, 4 and 5 shows that the exchangeable K content decreased with depth and an increasing pattern was recorded in pedon 1.

The exchangeable bases of soil pedons were in order of $Ca^{+2} > Mg^{+2} > Na^+ > K^+$ on the exchange complex. From the distribution of Ca^{+2} and Mg^{+2}, it is evident that Ca^{+2} shows the strongest relationship with all the species, comparing these ions (Ca^{+2}, Mg^{+2}, K^+ and Na^+) it was clear that Mg^{+2} was present in low amount than Ca^{+2} because of its higher mobility. These results are in conformity with findings of Thangasamy *et al.*, (2005) [45]. The BSP was low to high and ranging from 62.50 percent (pedon 2) to 85.09 percent (pedon 3) in surface layers and 58.36 percent (pedon 1) to 95.52 percent (pedon 4) in sub surface layers might be due to either mixed or illitic mineralogy in clay fraction. The base saturation increased up to certain depth and then decreased in pedon 1 and 3. The remaining pedon did not exhibit any regular pattern of distribution. These results were in accordance with the findings of Singh and Agarwal (2005) [22] and Gabhane *et al.* (2006) [16]. The ESP ranging from 0.62 (pedon 3) to 1.14 (pedon 2) in surface layers and 0.66 (pedon 2) to 1.48 (pedon 4) in sub surface layers. The pedons 3 and 4 was found to follow an increasing trend with the increase in depth. All other pedons exhibited an irregular distribution pattern with the increase in depth. Similar observations reported by Patel *et al.* (2012) [27]. The SAR was ranges between 0.03 (pedon 3) to 0.05 (pedon1) in surface horizons, whereas in subsurface horizons ranged from 0.03 (pedon 2) to 0.08 (pedon 4). The pedons 3, and 4 were found to follow an increasing trend with the increase in depth. All other pedons exhibited an irregular distribution pattern with the increase in depth. These observations are in accordance with results of Rajeshwar *et al.* (2009) [30].

Soil classification

Sugar cane growing red soils of Medak district were classified based on morphological, physical, physico-chemical, chemical and meteorological data, according to revisions of USDA Soil Taxonomy (Soil Survey Staff. 2010) [44]. The pedon 1, 3, 4 and 5 were classified under Alfisols because of the presence of an argillic horizon. And the base saturation was more than 35 percent. As the moisture regime is Ustic, the pedons 1, 3, 4 and 5 were classified as Ustalfs at sub order level. The pedon 3 and 4 classified as Lithic Haplustalfs at sub group level due to lithic contact within 50 cm of the mineral soil surface. The pedon 1 and 5 was classified as Typic Haplustalfs at sub group level due to presence of argillic horizon and that do not have a lithic contact within 50 cm of the mineral soil surface. The pedons 1, 3 and 4 had showed less than 35 percent (by volume) rock fragments and clay content less than 35 percent on weighted average in fine earth fraction. Hence qualified for "Loamy" particle size class. The pedon 5 had showed 35 percent or more (by volume) rock fragments and clay content less than 35 percent on weighted average in fine earth fraction. Hence qualified for "Loamy-skeletal" particle size class at family category level. The difference between mean summer and winter temperatures was less than 6 ^{O}C and the mean annual soil temperature was more than 22 ^{O}C. Therefore, the study area was classified as "Iso-hyperthermic" temperature regime (Thangasamy *et al.*, 2005) [45]. The pedon 10 was classified under Entisols because of the slight degree of soil formation and presence of less than 30 percent clay in sub horizons within depth of 50 cm and classified as Orthents at sub order level (Ahuja *et al.*, 1997) [1]. As the moisture regime is Ustic, the pedon 10 was classified as Ustorthents at great group level and Typic Ustorthents at sub group level because of no appreciable cementation with silica and there is no lithic contact within 50 cm of the mineral soil surface. The pedon had showed 35 percent or more (by volume) rock fragments and clay content less than 35 percent on weighted average in fine earth fraction. Hence, qualified for "Loamy-skeletal" particle size class.

Pedogenesis

The temperature and rainfall pattern of the study area indicated that the climate is semi-arid monsoon type with distinct and well-defined dry season and wet season. The soil moisture control section is dry for more than 90 cumulative days or 45 consecutive days in the months of summer solstice. The soil moisture and soil temperature regimes of the study area are Ustic and Isohyprerthermic, respectively. The soils of the study area were influenced and formed under semi-arid type of climate. Dutta *et al.* (2001) [14] noticed the occurrence of red soils under semi-arid climate in south India. The formation and development of red soils were occurring under the semi-arid climate (Rudramurthy *et al.*, 1997; Reddy and Shivaprasad, 1999) [36, 2]. Eastern Ghats (south) of Deccan trap had been divided into three landforms *viz.*, granite and granite-gneiss, dharawars, and cuddapahs and kurnools (Reddy *et al.*, 1996). The first landform was characterized by hills to gently sloping plains and valleys. The eroded soil constituents and soluble constituents were washed/leached down the slope. In the very gently sloping lands and valleys, the finer factions and calcium carbonate were accumulating with weathered granitic gneiss. Hence, the parent material for the development of these red soils was weathered granite-gneiss at higher elevations in very gently sloping lands, plains and valleys (Rao *et al.*, 1995) [32]. Red soils (pedon 1, 2, 3, 4 and 5) were formed and developed on weathered granite-gneiss of studied area.

Red soils were formed near the foothills of granitic-gneiss at higher topographic positions with the slope varying from 3 to 8 percent on gently sloping lands. Many scientists in different locations also reported formation of red soils on higher elements of topography. Similar findings were reported by Nagelschmidt *et al.*, (1940) [23]; Curi and Franzmeir (1984) [12]; Nagassa and Gebrekidan (2003) [22]; Thangasamy *et al.* (2005) [45]; Gabhane *et al.* (2006) [16] also observed the occurrence of red soils on higher elements of topography. Undulating and gently sloping lands had developed deep to very deep, well drained and moderately eroded Haplustalfs in south of Eastern Ghats on granite-gneiss landform (Reddy *et al.*, 1996). Occurrence of red soils in gently sloping and undulating uplands was observed by Dutta *et al.* (1999) [15]; Sarkar *et al.* (2001) [38]; Chunale (2004) [10]; Singh and Agarwal (2005) [22]; Nikam *et al.* (2006) [25].

The natural vegetation in the study area included *Cynodon dactylon*, *Cyprus rotundus*, *Azadirata indica*, *Prosopis juliflora*, *cacia sps*,. *Manjifera indica*, *Tectona grandis*, *Tamarindus indica*, *Palmyra*, *Tadipalm*, broad leaf weeds such as *Selotia*, *Parthenium*, *Euforbia* spp., and shrubs etc. Similar type of vegetation was reported by Satish (2003) [39] and Bhaskar (2005) [4]. Though vegetation served as a good sign of indication of soil properties, the influence of natural vegetation on soil formation and development was not observed, as the natural vegetation was sparse in different locations of the study area. The red soils of the study area have been formed during Archean period about 3800 million years back (Rao *et al.*, 1995) [32]. Digar and Barde (1982) [13] reported that it was during Archean period, the red soils were formed, whereas the black soils were developed during Cenozoic era, which included tertiary and quaternary period (Coulombe *et al.*, 1996) [11].

Soil Forming Processes

Argillic horizons (textural clay enriched 'B' horizons) were recognized in the sub-surface of red soils and red laterite soils (pedon 8, 10 11, 13 and 14) due to presence of clay cutans (argillans). There was a translocation of clay and iron oxides from 'Ap' horizon to 'B' horizon in the solum. The clay enrichment due to illuviation was sufficient enough to meet the requirement of argillic horizon (Bt). The texture was finer than the overlying horizon. Thus illuviation was the main pedogenic process in these pedons. Similar observations were also reported by Peterschmitt *et al.* (1996) [28]; Dutta *et al.* (1999) [15], Singh and Agarwal (2005) [22].

Table 1: Morphological characteristics of Sugarcane growing soil pedons of the Medak district

Pedon	Location	Horizon	Depth (cm)	Colour		Texture	Structure	Consistency			Effervescence	Pores	Roots	Boundary	Cutans	Other features
				Dry	Moist			Dry	Moist	Wet						
Sangareddy division																
1	Mamdipally	Loamy, Mixed, Superactive, Isohyperthermic Typic Haplustalfs (17 º 36'12.54"N,78 º 08'59.68"E, 514 m MSL)														
		Ap	0-15	5YR4/6	5YR4/6	sl	f1gr	sh	fr	so&po	-	ff	cf	cs	-	Argillic horizon
		Bt1	15-40	5YR3/4	5YR3/4	sl	m2 sbk	sh	fr	ss&sp	-	ff	ff	gs	-	
		Bt2	40-65	5YR4/6	5YR4/6	scl	m2sbk	sh	fr	ss&sp	-	ff	ff	gs	t tn p	
		Bt3	65-95	5YR4/6	5YR4/6	gscl	m2sbk	h	fr	ss	-	ff	ff	gs		
		C	95+	Weathered gneiss												
Medak division																
2	Kaudloor	Loamy-Skeletal, Mixed, Superactive, Isohyperthermic Typic Ustorthents (17 º 57'04.04"N, 78 º 00'36.82"E,489 m MSL)														
		Ap	0-11	7.5YR 3/4	7.5YR4/6	sl	f1gr	l	vfr	so&po	-	ff	mf	gs	-	-
		A21	11-22	7.5YR3/4	7.5YR4/6	gsl	f2gr	l	vfr	so&po	-	ff	ff	gs	t tn p	
		A22	22-41	5YR4/4	5YR6/6	gsl	f2gr	sh	fr	so&po	-	ff	-	gs	t tn p	

		C	41+	Weathered granite												
Narsapur division																
3	Antharam	Loamy, Mixed, Active, Isohyperthermic Lithic Haplusalfs (17 º 51’52.75”N 78 º 11’17.34” 539 m MSL)														
		Ap	0-18	7.5YR3/4	7.5YR4/4	sl	m1gr	l	vfr	so&po	ms	ff	mf	as	-	Argillic horizon
		Bt1	18-35	5 YR5/3	5YR4/3	scl	m1sbk	sh	fr	ss&sp	ms	ff	cf	gs	t tn p	
		Bt2	35-50	5 YR5/4	5YR4/4	scl	m2sbk	sh	fr	ss&sp	ms	ff	cf	gs	t tn p	
		Bt3	50-90	5 YR5/6	5YR4/6	scl	m2sbk	h	fr	ss	ms	ff	-	cs	-	
		C	90+	Weathered granite-gneiss												
Narayankhed division																
4	Mudguntal thanda	Loamy, Mixed, Active, Isohyperthermic Lithic Haplustalfs (18 º 03’34.95”N, 77 º 49’20.43”E, 484 m MSL)														
		Ap	0-13	7.5YR5/4	7.5YR4/4	sl	m1gr	l	fr	ss&po	m	ff	cf	cs		Argillic horizon
		Bt1	13-25	5YR4/4	5YR3/4	scl	m2sbk	sh	fi	ss&sp	m	ff	cf	cs	t tn p	
		Bt2	25-46	5YR4/3	5YR3/4	gscl	m2sbk	h	fi	ss&sp	m	ff	ff	ab		
		Bt2	46-65	5YR4/4	5YR3/3	gscl	m2sbk	h	fi	ss&sp	m	ff	-	ab		
		C	65+	Weathered granite												
Dubbaka division																
5	Ramakkapet	Loamy Skeletal, Mixed, Superactive, Isohyperthermic Typic Haplustalfs (18 º 11’10.10”N, 78 º 37’47.53”E 509 m MSL)														
		Ap	0-12	7.5YR5/4	7.5YR4/4	sl	f1gr	l	fr	ss	m	ff	cf	cs		Argillic horizon
		Bt1	12-35	5YR4/4	5YR4/3	scl	m1sbk	sh	vfr	ss&sp	m	ff	mf	cs	t tn p	
		Bt2	35-46	5YR5/6	5YR4/6	gscl	m2sbk	h	vfr	ss&sp	ms	ff	ff	cw	t tn p	
		Bt3	46-70	5YR5/6	5YR4/6	gscl	m2sbk	h	vfr	ss&sp	ms	ff	-	cw		
		C	70+	Weathered granite												

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

Table 2: Physical characteristics of Sugarcane growing soil pedons of the Medak district

Pedon	Location	Horizon	Depth (cm)	Gravel (%)	Particle size distribution (%)			B.D (Mg m-3)	Pore space (%)	W.H.C (%)	Volume expansion (%)
					Sand	Silt	Clay				
	Sangareddy division										
1	Mamdipally	Ap	0-15	15.6	73.6	6.1	19.8	1.38	38.0	36.0	2.91
		Bt1	15-40	23.1	66.4	6.5	26.5	1.39	41.0	39.0	3.36
		Bt2	40-65	32.4	63.9	5.8	29.9	1.42	46.0	42.0	3.90
		Bt3	65-95	36.3	59.4	7.8	32.4	1.44	49.0	41.0	3.75
		C	95+	Weathered gneiss							
	Medak division										
2	Kaudloor	Ap	0-11	26.8	74.6	10.8	13.2	1.46	41.0	31.0	2.94
		A21	11-22	38.9	76.5	8.1	14.6	1.43	46.0	30.0	2.98
		A22	22-41	45.3	77.1	7.2	15.6	1.49	47.0	36.0	3.13
		C	41+	Weathered gneiss							
	Narsapur division										
3	Antharam	Ap	0-18	23.0	74.3	4.6	19.6	1.44	39.0	22.0	3.60
		Bt1	18-35	25.5	66.4	7.9	25.6	1.46	41.0	23.0	4.10
		Bt2	35-50	29.1	60.1	8.2	31.2	1.49	44.0	27.0	4.22
		Bt3	50-90	33.2	59.6	11.6	28.7	1.49	46.0	29.0	4.35
		C	90+	Weathered granite-gneiss							
4	Mudguntalthanda	Ap	0-13	22.5	74.2	5.4	19.4	1.41	43.0	21.0	2.90
		Bt1	13-25	26.3	65.1	6.8	27.4	1.43	45.0	25.0	4.10
		Bt2	25-46	35.3	60.1	9.3	29.9	1.49	47.0	29.0	5.22
		Bt2	46-65	45.9	56.4	11.1	32.2	1.51	51.0	33.0	5.75
		C	65+	Weathered granite							
	Dubbaka division										
5	Ramakkapet	Ap	0-12	17.9	75.1	4.1	19.8	1.42	46.0	25.0	2.96
		Bt1	12-35	35.9	72.1	4.6	23.2	1.45	45.0	28.0	3.25
		Bt2	35-46	51.1	67.1	7.3	25.4	1.52	46.0	30.0	3.65
		Bt3	46-70	60.2	57.3	12.5	27.1	1.54	47.0	31.0	5.21
		C	70+	Weathered granite-gneiss							

Sand (0.02-2.0 mm); Silt (0.002-0.02mm) and Clay (<0.002mm)

Table 3: Ratios of fine earth fractions of pedons (Particle size-analysis)

Pedon	Location	Horizon	Depth (cm)	Sand+ Silt	Silt + Clay	Sand / Silt	Silt / Clay	Sand/(Sand + Silt)	Sand/(Silt + Clay)
Sangareddy division									
1	Mamdipally	Ap	0-15	79.7	25.9	12.07	0.31	0.92	2.84
		Bt1	15-40	72.9	33.0	10.22	0.25	0.91	2.01
		Bt2	40-65	69.7	35.7	11.02	0.19	0.92	1.79
		Bt3	65-95	67.2	40.2	7.62	0.24	0.88	1.48
		C	95+	Weathered gneiss					
Medak division									

2	Kaudloor	Ap	0-11	85.4	24.0	6.91	0.82	0.87	3.11
		A21	11-22	84.6	22.7	9.44	0.55	0.90	3.37
		A22	22-41	84.3	22.8	10.71	0.46	0.91	3.38
		C	41+	Weathered gneiss					
Narsapur division									
3	Antharam	Ap	0-18	76.9	27.2	15.72	0.20	0.94	2.66
		Bt1	18-35	74.3	33.5	8.41	0.31	0.89	1.98
		Bt2	35-50	68.3	39.4	7.33	0.26	0.88	1.53
		Bt3	50-90	71.2	40.3	5.14	0.40	0.84	1.48
		C	90+	Weathered granite-gneiss					
4	Mudguntal thanda	Ap	0-13	78.6	24.8	16.86	0.22	0.94	2.99
		Bt1	13-25	71.9	34.2	9.57	0.25	0.91	1.90
		Bt2	25-46	69.4	39.2	6.46	0.31	0.87	1.53
		Bt2	46-65	67.5	43.3	5.08	0.34	0.84	1.30
		C	65+	Weathered granite					
Dubbaka division									
5	Ramakkapet	Ap	0-12	79.2	24.3	18.32	0.20	0.95	3.09
		Bt1	12-35	76.7	27.8	15.67	0.20	0.94	2.59
		Bt2	35-46	74.4	32.7	9.19	0.29	0.90	2.05
		Bt3	46-70	69.8	39.6	4.58	0.46	0.82	1.45
		C	70+	Weathered granite-gneiss					

Table 4: Physico-chemical characteristics Sugarcane growing soil pedons of the Medak district

Pedon	Location	Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	OC (g kg^{-1})	Exchangeable Cations (c mol (p+) kg^{-1})				Total Ex. Bases	BS (%)	CEC (cmol (p+) kg^{-1})	Free $CaCO_3$ (%)	ESP (%)	SAR	CEC/Clay ratio
							Ca	Mg	Na	K							
Sangareddy division																	
1	Mamdipally	Ap	0-15	6.6	0.19	5.3	6.5	3.9	0.14	0.20	10.74	74.58	14.4	3.2	0.97	0.05	0.73
		Bt1	15-40	6.8	0.15	2.7	6.8	3.8	0.13	0.30	11.03	58.36	18.9	4.6	0.69	0.04	0.71
		Bt2	40-65	7.1	0.16	2.3	8.8	4.1	0.20	0.34	13.44	68.57	19.6	5.2	1.02	0.06	0.66
		Bt3	65-95	7.3	0.12	2.1	7.5	4.9	0.20	0.35	12.95	64.43	20.1	5.5	1.00	0.06	0.62
		C	95+	Weathered gneiss													
Medak division																	
2	Kaudloor	Ap	0-11	6.5	0.19	4.3	3.1	2.0	0.1	0.3	5.50	62.50	7.8	1.3	1.14	0.05	0.59
		A21	22-Nov	6.3	0.16	3.5	5.5	3.7	0.2	0.2	9.60	67.13	11.3	1.4	1.40	0.07	0.77
		A22	22-41	6.0	0.11	2.5	7.2	2.9	0.1	0.2	10.4	68.87	11.1	1.4	0.66	0.03	0.71
		C	41+	Weathered gneiss													
Narsapur division																	
3	Antharam	Ap	0-18	6.9	0.20	5.9	6.5	4.9	0.1	0.3	13.70	85.09	16.1	3.1	0.62	0.03	0.71
		Bt1	18-35	7.1	0.22	4.6	7.2	5.1	0.15	0.3	12.95	79.45	16.3	3.8	0.92	0.05	0.64
		Bt2	35-50	7.3	0.26	4.5	7.4	5.3	0.14	0.2	14.54	94.42	13.4	4.3	0.91	0.04	0.43
		Bt3	50-90	7.5	0.29	2.4	9.5	6.8	0.19	0.2	9.89	71.67	13.8	4.8	1.38	0.05	0.48
		C	90+	Weathered granite-gneiss													
4	Mudguntal thanda	Ap	0-13	6.8	0.22	6.6	7.6	2.3	0.12	0.96	10.98	83.18	13.2	1.8	0.91	0.04	0.65
		Bt1	13-25	6.7	0.19	4.9	8.2	3.6	0.15	0.60	12.55	95.08	14.3	3.2	1.05	0.05	0.52
		Bt2	25-46	6.6	0.16	4.1	8.3	4.6	0.21	0.55	13.66	95.52	16.5	3.4	1.27	0.06	0.55
		Bt2	46-65	6.5	0.13	3.9	8.6	4.8	0.25	0.30	13.95	84.55	16.9	5.1	1.48	0.08	0.52
		C	65+	Weathered granite													
Dubbaka division																	
5	Ramakkapet	Ap	0-12	6.8	0.24	6.8	7.6	2.5	0.11	0.25	10.46	79.24	13.2	2.1	0.83	0.04	0.65
		Bt1	Dec-35	7.1	0.21	5.2	8.0	2.7	0.13	0.36	11.19	63.58	17.6	2.8	0.74	0.04	0.76
		Bt2	35-46	7.2	0.19	4.5	8.7	2.9	0.15	0.36	12.11	77.63	15.6	3.2	0.96	0.05	0.61
		Bt3	46-70	7.4	0.21	2.9	8.7	3.1	0.15	0.28	12.23	90.59	13.5	4.5	1.11	0.05	0.50
		C	70+	Weathered granite-gneiss													

Table 5: Land capability classification of Sugarcane growing soil pedons of Medak District based on soil characteristics

Physiographic unit	Location	Topography			Physical soil characteristics				Pedon development	Soil fertility factors			LCC
		Slope	Erosion	Drainage	Texture	Sur. coarse fragments	Sub. sur. coarse fragments	Soil Depth		CEC	BS	OC	
Pedon1	Mamdipally	III	IV	I	III	III	III	III	II	I	III	III	IIIstef
Pedon 2	Kaudloor	III	VI	I	III	III	III	IV	V	IV	III	IV	IIItsdef
Pedon 3	Antharam	II	IV	I	III	III	III	III	II	I	III	III	IIIstef
Pedon 4	Mudguntal thanda	II	IV	I	III	III	III	III	II	I	IV	III	IIIstef
Pedon 5	Ramakkapet	II	IV	I	III	III	III	III	II	I	III	III	IIIstef

Table 6: Soil-site characteristics for land evaluation of Sugarcane growing Soils of Medak District

Physiographic unit	Location	Climate				Land form characteristics			Physico-chemical characteristics(weighted averages)						
		Rain fall (mm)	Max. temp (oC)	Min. temp (oC)	RH (%)	Slope (%)	Erosion	Drainage	Depth (cm)	Sur. coarse fragments (vol %)	Texture	pH (1:2.5)	OC (g kg-1)	CEC (Cmol (p+)/kg)	B.S (%)
Pedon 1	Mamdipally	855	40.0	26.2	74.0	3-8	Severe	Well	95	15.6	sl	6.6	5.3	14.4	74.58
Pedon 2	Kaudloor	855	40.0	26.2	74.0	3-8	Severe	Well	41	24.6	gsl	6.5	4.3	7.8	62.50
Pedon 3	Antharam	855	40.0	26.2	74.0	3-8	Severe	Well	90	23.0	sl	6.9	5.9	16.1	85.09
Pedon 4	Mudguntal thanda	855	40.0	26.2	74.0	3-8	Severe	Well	65	22.5	sl	6.8	6.6	13.2	83.18
Pedon 5	Ramakkapet	855	40.0	26.2	74.0	3-8	Severe	Well	70	17.9	sl	6.8	6.8	13.2	79.24

Table 7: Actual and potential soil suitability for Sugarcane growing Soils of Medak District

Pedon No	Location	Max. temp (c)	Min. Temp (c)	RH (c)	Slope (t)	Drainage (w)	Texture (s)	Depth (s)	$CaCO^3$ (s)	EC (n)	ESP (n)	pH (n)	BSP (f)	CEC (f)	OC (f)	Actual Suitability	Potential Suitability
Pedon 1	Mamdipally	S1	S1	S1	S3	S1	S2	S2	S2	S1	S1	S2	S2	S2	S2	S3	S2
Pedon 2	Andole	S1	S1	S1	S1	S3	S3	S1	S1	S1	S1	S2	S1	S1	S1	S2	S1
Pedon 3	Kaudloor	S1	S1	S1	S3	S1	S2	N1	S3	S1	S1	S2	S1	S3	S3	S3	S2
Pedon 4	Antharam	S1	S1	S1	S3	S1	S2	S2	S2	S1	S1	S2	S1	S1	S2	S3	S2
Pedon 5	Mudguntal thanda	S1	S1	S1	S3	S3	S2	S3	S2	S1	S1	S3	S3	S2	S2	S3	S2
Pedon 6	Ramakkapet	S1	S1	S1	S3	S1	S2	S3	S2	S1	S1	S2	S2	S2	S2	S3	S2

Soil Suitability class : S_1-Highly suitable; S_2-Moderately suitable; S_3-Marginally suitable
Not Suitability class : N_1-Temporarily not suitable N_2-Permanently not suitable AS-Actual Suitability PS-Potential Suitability

Land evaluation

Land capability classification is an interpretive grouping of soils mainly based on the inherent soil characteristics, external land features and environmental factors that limits the use of land. The classification of units provide information on the physiography, colour, texture, structure of soil, type of clay mineral, consistence, permeability, depth of soil and soil reaction (Appendix I). Each of above factor have definite role to play in behaviour of soil and its management. Based on soil properties, the red soils, red laterite soils and black soils were classified into land capability classes III. Similar observations were also made by Sarkar *et al.* (2002) [37]. Pedon wise land capability classification of the sugarcane growing soils of Medak district is given in table 5 and table 6. The soil (pedon 1, 3, 4 and 5) were classified into 'III tsef' land capability sub-class due to the limitations of slope, texture, soil depth, erosion and soil fertility whereas the pedon 10 classified as 'III tsdef' capability sub-class due to the limitations of slope, texture, soil depth, severe erosion, coarse fragments and soil fertility limitations. Similar interpretation was also made by Rajeshwar and Mani, (2013) [30]. Soil site suitability in red soils found to be marginally and moderately suitable for sugar cane cultivation (Table 7). However this fertility related constraints can be managed through appropriate management practices. Slope, texture and depth, fertility and erosion and surface crusting were the major limitations. Therefore to realize the full potential, these soils should be properly managed, supplemented with organic manures and inorganic fertilizers and be provided with assured irrigation. If these improvements could be done, the marginally suitable land could be converted to the moderately suitable lands and moderately suitable lands become highly suitable for sugar cane cultivation.

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