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Soil constraints and management in relation to the distribution of available macro and micronutrients in sugarcane growing soil profiles of semi arid tropical region of Telangana

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Abstract
The study was carried out to assess the nutrient status of sugarcane growing red, red laterite and black soils of Medak district of Telangana State for proper appraisal of their productivity potential and their rational use. The soil pH was ranging from neutral to strongly alkaline (6.5 to 9.2) and non-saline in nature. The organic carbon content varied from medium to high (4.3 to 8.4 g kg^{-1}) in surface horizons. The $CaCO_3$ was in the range of 1.3 to 7.8 per cent in surface horizons. The sub surface horizons were moderately calcareous. The CEC of soils was low to high (7.7 to 65.2 c mol (p^+) kg^{-1}). The exchangeable bases were in the order of $Ca^{+2} > Mg^{+2} > Na^+ > K^+$ on the exchange complex. Low exchangeable Na and K percentage was noticed in all the pedons as the exchange complex was dominated by divalent cations like Ca and Mg. The BSP ranged from 35.21 to 87.40% in surface and 21.17 to 95.52 per cent sub surface horizons. Profile wise nutrient status in sugarcane growing soils revealed that the soils were low to medium in available nitrogen (246.0 - 297 kg ha^{-1}), medium to high in available phosphorus (16.3 to 58.94 kg ha^{-1}) in red and black soils, high in available potassium (285 to 415 kg ha^{-1}) in surface horizons. The available phosphorus content was low to medium in red laterite soils pedons varied from 20.4 to 36.9 kg ha^{-1}. The available sulphur content of the pedons was high. The DTPA extractable available micronutrients Zn, Cu, Mn, and Fe were ranged from 0. 49 to 1.65 mg kg^{-1}, 0.94 to 2.80 mg kg^{-1}, 7.16 to 20.15 mg kg^{-1} and 7.66 to 25.30 mg kg^{-1} soil respectively. The hot water soluble B content varied from 0.51 to 1.99 mg kg^{-1}. Soils are deficient to sufficient in Zn and sufficient in available Cu, Fe and Mn in the surface layers of the soil profiles. Soil constraints were identified using soil test data which include texture, erosion, slope, depth, drainage and low organic carbon, low availability of N, P and micronutrients.

Keywords: sugarcane growing soils, distribution of available macro and micro nutrients

Introduction
The population in India is increasing steadily and as well the demand for sugar and other sweetening agents raising because of changing food habits. There is much scope to increase the area under sugarcane to meet the requirements but due to high cost of cultivation and lengthy growing periods farmers of the country are not coming forward. This envisages the adoption of better crop production and protection technologies for increased production per unit area and time apart from varietal improvement. Sugarcane (*Saccharum officinarum* L) is cultivated in the Medak district in an area of 22076 hectares producing 1721 thousand tonnes with an average productivity of 74.41 tha^{-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 per cent (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. It is also necessary to relate the information on crop requirements to units delineated on the soil map for agro technology transfer. Keeping this in view, a detailed study of profile wise distribution of available macro and micronutrient in of sugarcane growing soils in semi-arid tropical region was taken up for better scientific utilization of lands by identifying the potentials and limitations and to suggest suitable crop plan and management options for higher productivity under changing climate.

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 17^0 27' and 18^0 18' and East longitudes 77^0 28' and 79^0 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, fourteen geo-referenced pedons (Table 1) were selected in eight divisions of Medak district such as Aroor (Pedon 1), Paidigummal (Pedon 2), Burdipad (Pedon 3), Kuppanagar (Pedon 4), Basanthpur (Pedon 5), Kothur (Pedon 6), Budera (Pedon 7), Mamdipally (Pedon 8), Andole (Pedon 9), Kaudloor (Pedon 10), Antharam (Pedon 11), Pulakurty (Pedon 12), Mudguntal thanda (Pedon 13) and Ramakkapet (Pedon 14) The mandal wise sugarcane cultivated area (ha) of the district for the Year 2013-14 was given in Table 2. The selected pedons of the sugarcane growing area of the Medak district are broadly categorized into three groups based on the soil types *viz.* Black soils (1, 7, 9 and 12), Red laterite soils (2, 3, 4, 5 and 6) and Red soils (8, 10, 11, 13 and 14).

The climate is semi-arid. The mean annual rainfall is 870 mm of which 76 per cent is received during the southwest monsoon (June to September), 14 per cent during the northeast monsoon (October to December) and 8 per cent during the premonsoon period (March to May). The mean maximum and minimum temperature vary from 40° to 26 °C. Mean humidity varies from 65 per cent in July to 74 per cent 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 tomertosa and Acacia sp. 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.

Table 1: 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 (cmol (p+) kg^{-1})				Total Ex. Bases	BS (%)	CEC (cmol (p+) kg^{-1})	Free $CaCO_3$ (%)	CEC/ Clay ratio
							Ca	Mg	Na	K					
Sadasivpet division															
1	Aroor	Ap	0-25	8.1	0.24	7.5	18.6	11.6	0.55	1.70	32.45	80.32	40.4	5.6	0.68
		BA	25-52	8.2	0.28	5.4	21.4	12.4	0.66	1.52	35.96	84.61	42.5	7.4	0.68
		Bss1	52-79	8.3	0.33	5.1	22.4	12.5	0.73	1.53	37.13	78.83	47.1	8.3	0.74
		Bss2	79-115	7.9	0.33	3.7	22.1	12.8	0.75	1.55	37.25	77.28	48.2	9.3	0.75
		Bss3	115-155	8.5	0.34	1.7	22.4	13.1	0.81	1.50	37.81	76.69	49.3	11.6	0.81
		C	155+	Mixed with calcareous murram											
Zaheerabad division															
2	Paidigummal	Ap	0-16	6.0	0.17	4.9	2.2	1.3	0.1	0.81	4.41	50.11	8.8	-	0.17
		Bt1	16-43	5.9	0.13	3.6	2.0	1.7	0.1	0.78	4.58	49.25	9.3	-	0.16
		Bt2	45-68	6.4	0.11	2.2	1.5	1.3	0.1	1.17	4.07	39.90	10.2	-	0.18
		C	67+	Weathered Laterite hard pan											
3	Burdipad	Ap	0-16	5.8	0.10	5.5	2.0	1.5	0.14	0.96	4.60	41.07	11.2	-	0.46
		Bt1	16-38	6.4	0.10	4.3	2.4	1.9	0.15	0.86	5.31	43.88	12.1	-	0.31
		Bt2	38-70	6.3	0.11	2.2	2.7	1.3	0.16	0.57	4.73	35.83	13.2	-	0.32
		Bt3	70-95	6.0	0.10	2.6	2.8	1.2	0.15	0.37	4.52	32.06	14.1	-	0.34
		C	95+	Weathered Laterite hard pan											
4	Kuppanagar	Ap	0-14	5.6	0.08	5.7	2.4	1.8	0.11	0.45	4.76	53.48	8.9	-	0.22
		Bt1	14-30	6.1	0.09	4.9	2.2	1.2	0.16	0.69	4.25	41.67	10.2	-	0.20
		Bt1	30-50	6.4	0.08	2.7	2.0	1.2	0.15	0.65	4.00	25.81	15.5	-	0.26
		Bt2	50-81	6.5	0.09	2.6	1.7	0.9	0.12	0.54	3.26	21.17	15.4	-	0.29
		C	81+	Weathered Laterite hard pan											
5	Basanthpur	Ap	0-20	5.1	0.07	5.5	1.2	0.9	0.10	0.66	2.78	36.10	7.7	-	0.22
		Bt1	20-38	5.6	0.08	3.6	1.5	1.0	0.11	0.80	3.41	41.59	8.2	-	0.22
		Bt2	38-56	6.1	0.10	3.1	2.4	1.2	0.11	0.72	4.43	47.63	9.3	-	0.23
		Bt3	56-70	6.1	0.12	3.0	2.5	1.3	0.12	0.69	4.61	38.10	12.1	-	0.35
		C	70+	Hard lithic contact which roots cannot penetrated											
6	Kothur	Ap	0-15	5.4	0.06	4.9	2.0	1.1	0.10	0.85	4.05	35.21	11.5	-	0.32
		Bt1	15-45	5.9	0.11	2.7	2.4	1.6	0.10	0.77	4.87	36.07	13.5	-	0.24
		Bt2	45-75	6.3	0.09	2.5	2.9	1.8	0.15	0.87	5.72	39.18	14.6	-	0.24
		Bt3	75-105	6.5	0.09	1.5	3.0	1.8	0.15	0.65	5.60	38.10	14.7	-	0.25
		C	105+	Hard lithic contact which roots cannot penetrated											
7	Budera	Ap	0-14	6.5	0.21	6.6	11.4	6.0	0.14	0.76	18.30	75.00	24.4	2.8	0.63
		Bw1	14-41	6.8	0.26	4.5	12.2	6.0	0.15	0.52	18.87	66.68	28.3	3.2	0.71
		Bwss1	41-58	7.0	0.29	5.0	13.1	6.2	0.15	0.51	19.96	66.98	29.8	3.9	0.80
		Bwss2	58-79	6.7	0.31	3.5	13.2	6.4	0.20	0.55	20.35	81.08	25.1	4.7	0.64
		BC	79-100	7.0	0.34	2.4	13.3	6.5	0.21	0.55	20.56	83.92	24.5	4.7	0.58
Sangareddy division															
8	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	0.73
		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	0.71
		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	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	0.62
		C	95+ Weathered gneiss												
Jogipet division															
9	Andole	Ap	0-25	8.2	0.21	7.9	24.6	8.2	0.7	0.5	34.00	87.40	38.9	5.5	0.72
		BA	25-65	8.2	0.29	5.1	21.3	11.6	0.8	0.3	34.00	87.40	38.9	6.3	0.68
		Bss1	55-85	8.4	0.28	4.5	20.4	10.9	0.9	0.3	32.50	79.08	41.1	6.5	0.70

		Bss2	85-117	8.4	0.34	3.3	19.1	11.3	1.2	0.3	31.90	75.06	42.5	6.6	0.69
		Bss3	117-145	8.9	0.36	3.3	18.3	12.3	1.0	0.2	31.80	70.51	45.1	7.8	0.71
		Bss4	145-178	9.2	0. 40	2.9	18.1	8.4	1.3	0.3	28.10	60.69	46.3	9.9	0.75
Medak division															
10	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	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	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	0.71
		C	41+	Weathered gneiss											
Narsapur division															
11	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	0.71
		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	0.64
		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	0.43
		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	0.48
		C	90+	Weathered granite- gneiss											
Narayankhed division															
12	Pulkurty	Ap	0-27	7.9	0.16	8.4	25.2	16.3	0.81	0.80	43.11	76.71	56.2	7.8	0.79
		BA	27-55	8.1	0.18	6.7	26.6	18.5	0.86	0.60	46.56	82.85	60.2	8.4	0.82
		Bss1	55-87	8.0	0.20	4.8	29.2	19.6	0.89	0.60	50.29	83.54	64.7	8.6	0.86
		Bss2	88-124	8.2	0.22	4.6	30.5	20.1	1.11	0.60	52.31	80.85	64.2	10.1	0.85
		Bss3	124-150	8.4	0.23	3.6	30.9	20.6	1.13	0.50	53.13	82.76	65.2	11.2	0.86
13	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	0.65
		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	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	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	0.52
		C	65+	Weathered granite											
Dubbaka division															
14	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	0.65
		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	0.76
		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	0.61
		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	0.50
		C	70+	Weathered granite- gneiss											

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) [11]; cation exchange capacity (Chapman, 1965) [5]; organic carbon (Walkly and black, 1934) [43] and free $CaCO_3$ (Piper 1966) [26]. The available nitrogen was determined by kjeldal method (Subbiah and Asija, 1956) [41]; available phosphorus (Bray and Kurtz, 1945) [4]; potassium by flame emission method (Jackson, 1973) [11]; available sulphur (Williams and Steinbergs. 1959). The available micronutrients (Lindsay and Norvell, 1978) [15]; hot water soluble Boron was determined by using azomethine method as described by Jackson, (1958) [12].

Results and Discussion

Physico-Chemical Properties

The pedon wise physico-chemical properties of red, red laterite and black soils of sugarcane growing areas are described in (Table 1). Soil pH of the pedons showed wide variation with soil types. The black soil pedons was recorded higher pH values (6.5 to 9.2) followed by red soils (5.3 to 7.5) and red laterite soils (5.1 to 6.5). The pH value of black soils (pedon 1, 7, 9 and 12) found to vary from 6.5 (pedon 7) to 8.2 (pedon 1) in surface horizons whereas in subsurface horizons ranged from 6.7 in pedon 7 to 9.2 in pedon 9. The pH value of red soil (pedon 8, 10, 11, 13 and 14) ranged from 6.5 (pedon 8) to 6.9 (pedon 11) in surface horizons whereas in subsurface horizons ranged from 6.0 in pedon 10 to 7.5 in pedon 11. The pH value of red laterite soils (pedon 2, 3, 4, 5 and 6) ranged from 5.1 (pedon 5) to 6.0 (pedon 2) in surface horizons whereas in subsurface horizons ranged from 5.6 in pedon 5 to 6.5 in pedon 4. The results showed that the pedons of red laterite soils had lower pH values (moderately acidic to slightly acidic) followed by slightly acidic to neutral range in red soils and higher pH values in black soils (neutral to strongly alkaline). Similar trends was reported by Thangasamy *et al. (*2005) [42] and Gabhane *et al.* (2006) [9]. The pH increased with depth in the pedon 4, 5, 6, 8, 9, 11 and 14 might be due to increase in bases with depth and their complete downward leaching. The pedons 2, 10 and 13 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) [3]. The distribution was irregular in pedon 1, 2, 3, 7 and 12 which might be due to downward movement of bases and they get adsorbed at different layers irregularly (Rajeshwar and Mani, 2013) [30]. The lower pH values in surface layers of pedon 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12 and 14 which might be due to continuous removal of basic cations by crop plants and leaching (Nagassa and Gebrekidan, 2003) [19], movement of basic cations to deeper layers (Singh and Agarwal, 2003) [39] and/or due to precipitation of calcium carbonate (Balapande *et al.* 2007) [2]. The pH value of red laterite soils ranged from 5.1 to 6.0 in surface horizons whereas in subsurface horizons ranged from 5.5 to 6.5 and majority of these soils are moderately acidic in soil reaction and appeared to be related with acidic parent materials and leaching of bases such as calcium, magnesium, potassium and sodium from the soil leading to high hydrogen ion concentration caused by heavy precipitation during rainy season (Nayak *et al.* 2002 and Rajeshwar and Mani, 2014) [21, 29].

The highest value of EC 0.40 dS m^{-1} was registered in pedon 9 and the lowest value of 0.06 dS m^{-1} were recorded in pedon 6 indicating that these soils were non saline in nature. The EC value of black soils (pedon 1, 7, 9 and 12) found to vary from

0.16 dS m^{-1} (pedon 12) to 0.24 dS m^{-1} (pedon 1) in surface horizons whereas in subsurface horizons ranged from 0.18 dS m^{-1} in (pedon 12) to 0.40 dS m^{-1} in pedon 9. The EC values of red soils (pedon 8, 10, 11, 13 and 14) ranged from 0.19 dS m^{-1} (pedon 8) to 0.24 (pedon 14) in surface horizons whereas in subsurface horizons ranged from 0.11 dS m^{-1} in pedon 10 to 0.29 in pedon 11. The EC values of red laterite soils (pedon 2, 3, 4, 5 and 6) ranged from 0.06 dS m^{-1} (pedon 6) to 0.17 dS m^{-1} (pedon 2) in surface horizons whereas in subsurface horizons ranged from 0.08 dS m^{-1} (pedon 5 and 4) to 0.13 dS m^{-1} in pedon 2. The EC was very low in red and red laterite soils even in lower horizons because they were formed on relatively higher elevations. The relatively high EC of black soils than red and red laterite soils could be due to the location and the high clay content resulting in accumulation of soluble salts (Masri Sitanggang *et al.* 2006 and Rajeshwar and Mani, 2013b) [17, 31]. The EC gradually increased with depth in majority of the pedons. This 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. These observations are in agreement with the findings of Renukadevi (2003) [34]. The EC values suggesting low amount of soluble salts which could be attributed to loss of bases (Sidhu *et al.* 1994) [38] due to heavy rainfall during monsoon.

The organic carbon showed wide variation. The highest value of OC 8.4 g kg^{-1} was registered in pedon 12 and the lowest value of 1.5 g kg^{-1} was recorded in pedon 6. The OC value of black soils (pedon 1, 7, 9 and 12) found to vary from 6.6 g kg^{-1} (pedon 7) to 8.4 g kg^{-1} (pedon 12) in surface horizons whereas in subsurface horizons ranged from 1.7 g kg^{-1} in pedon 1 to 6.7 g kg^{-1} in pedon 12. The OC values of red soils (pedon 8, 10, 11, 13 and 14) ranged from 4.3 g kg^{-1} (pedon 10) to 6.8 g kg^{-1} (pedon 14) in surface horizons whereas in subsurface horizons ranged from 2.1 g kg^{-1} in pedon 8 to 5.2 in pedon 14. The OC values of red Laterite soils (pedon 2, 3, 4, 5 and 6) ranged from 4.9 g kg^{-1} m^{-1} (pedon 2) to 5.7 g kg^{-1} (pedon 4) in surface horizons whereas in subsurface horizons ranged from 1.5 g kg^{-1} (pedon 6) to 4.9 g kg^{-1} in pedon 4. The depth wise distribution of organic carbon showed a decreasing trend in all the pedons except pedon 7. The organic carbon content ranged from low to medium in surface horizons of red and red laterite soils OC could be attributed to the rapid oxidation and decomposition of added organic matter under tropical condition (Saha *et al.* 1996, Mustapha *et al.* 2011) [36, 18]. Higher organic carbon content was recorded in surface soils as compared to subsurface soils. 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) [32] and Rajeshwar and Mani (2013b) [31].

The calcium carbonate content of red laterite soils (pedons 2, 3, 4, 5 and 6) was absent. The red soil pedons (8, 10, 11, 13 and 14) having 1.3 per cent (pedon 10) to 3.2 per cent (pedon 13) in surface horizons whereas, sub surface horizons 1.4 per cent (pedon 10) to 5.5 per cent (pedon 8). The $CaCO_3$ content of black soils (pedon 1, 7, 9 and 12) varying from 2.8 per cent (pedon 7) to 7.8 per cent (pedon 12) in surface horizon and 3.2 per cent (pedon 7) to 11.6 per cent (pedon 1) in subsurface horizon. The difference in the content among red and black soils was due to the variation in elevation, drainage and parent material. 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 (pedogenic and/or lithogenic) in soils of semi-arid regions (Pal *et al.* 2000). The high $CaCO_3$ content of black soils might be due to the soil developed over basaltic weathered parent materials mixed with calcareous murram on plain topography and had higher clay content resulting in the accumulation of calcium carbonate (Rajeshwar and Mani, 2013b) [31]. Increase in the calcium carbonate content down the depth was attributed to the leaching of bicarbonate from upper layer during rainy season and their subsequent precipitation as carbonate in the lower layer (Maji *et al.* 2005) [16].

Exchangeable properties

The cation exchange capacity was higher in black soil pedons varied from 24.4 c mol (p^+) kg^{-1} (pedon 7) to 56.2 c mol (p^+) kg^{-1} (pedon 12) in surface layers and 24.5 c mol (p^+) kg^{-1} (pedon 7) to 65.2 c mol (p^+) kg^{-1} (pedon 12) in sub surface layers than in red soils pedons varied from 7.8c mol (p^+) kg^{-1}(pedon 10) to 16.1 c mol (p^+) kg^{-1} (pedon 11) in surface layers and 11.1 c mol (p^+) kg^{-1}(pedon 10) to 20.1 c mol (p^+) kg^{-1}(pedon 8) in sub surface layers and red laterite soil pedons varied from 7.7 c mol (p^+) kg^{-1}(pedon 4) to 11.5 c mol (p^+) kg^{-1} (pedon 4) in surface layers and 8.2 c mol (p^+) kg^{-1}(pedon 4) to 15.4 c mol (p^+) kg^{-1}(pedon 4) in sub surface layers. Since CEC was the charge behaviour of soils, where clay was the fundamental block contributing towards cation exchange, the high CEC of the black soils was attributed to the high clay content and smectitic clay mineralogy (Pal and Deshpande, 1987) [22]. Confirming the above statement it showed the increasing trend of clay content with depth. Similar results were reported by Rudramurthy and Dasog (2001) [35]; Kadao *et al.* (2003) [14]; Gabhane *et al.* (2006) [9]; Balapande *et al.* (2007) [2].

Soil exchange complex was dominated with Ca in all the pedons compared to other exchangeable cations. The Exchangeable Calcium was higher in black soil pedons varied from 11.4 c mol (p^+) kg^{-1} (pedon 7) to 25.2 (pedon 12) in surface layers and 12.2 (pedon 7) to 30.9 (pedon 12) in sub surface layers than in red soils pedons (3.1 c mol (p^+) kg^{-1} (pedon 10) to 8.2 c mol (p^+) kg^{-1}(pedon 13) in surface layers and 5.5 c mol (p^+) kg^{-1} (pedon 10) to 9.5 c mol (p^+) kg^{-1}(pedon 11) in sub surface layers) and red laterite soil pedons varied from 1.1 c mol (p^+) kg^{-1} (pedon 5) to 2.4 c mol (p^+) kg^{-1} (pedon 4) in surface layers and 1.5 c mol (p^+) kg^{-1} (pedon 2) to 3.0 c mol (p^+) kg^{-1} (pedon 6) in sub surface layers. In general, exchangeable Ca content increased with depth in pedons 3, 5, 6, 7, 10, 11, 12, 13 and 14 and it was decreased with depth in pedon 2, 4 and 9. There was no regular pattern of distribution with depth was noticed in pedon 1 and 8. The Exchangeable magnesium higher in black soils varied from 6.0 c mol (p^+) kg^{-1} (pedon 7) to 16.3 c mol (p^+) kg^{-1}(pedon 12) in surface layers and 8.4 c mol (p^+) kg^{-1} (pedon 9) to 20.6 c mol (p^+) kg^{-1}(pedon 12) in sub surface layers than in red soils pedons (2.0 c mol (p^+) kg^{-1} in pedon 10) to 4.9 c mol (p^+) kg^{-1} in pedon 11 in surface layers and 2.7 c mol (p^+) kg^{-1} (pedon 14) to 6.8 c mol (p^+) kg^{-1} (pedon 11) in sub surface layers) and red laterite soil pedons 0.9 c mol (p^+) kg^{-1} (pedon 5) to 1.8 c mol (p^+) kg^{-1} (pedon 4) in surface and 0.9 c mol (p^+) kg^{-1} (pedon 4) to 1.9 c mol (p^+) kg^{-1} (pedon 3) in sub surface layers. Pedons 1, 5, 6, 7, 8, 11, 12 and 14 showed increasing trend with soil depth, while in the other pedons did not show a clear trend with depth.

The exchangeable sodium was higher in black soils varied from (1,7,9 and 12) varied from 0.7 c mol (p^+) kg^{-1} (pedon 9) to 0.81 c mol (p^+) kg^{-1} (pedon 12) in surface layers and 0.8 c mol (p^+) kg^{-1} (pedon 9) to 1.13 c mol (p^+) kg^{-1} (pedon 12) in sub surface layers. In the red soils pedons (8,10,11,13 and 14) the exchangeable sodium ranged from 0.1 c mol (p^+) kg^{-1} (pedon 10) to 0.14 c mol (p^+) kg^{-1} (pedon 8) in surface layers and 0.10 c mol (p^+) kg^{-1} (pedon 10) to 0.25 c mol (p^+) kg^{-1} (pedon 13) in sub surface layers. The red laterite soil pedons (2,3,4,5 and6) exchangeable sodium ranged from 0.10 c mol (p^+) kg^{-1} (pedon 2) to 0.14 c mol (p^+) kg^{-1} (pedon 3) in surface and 0.10 c mol (p^+) kg^{-1} (pedon 2) to 0.16 c mol (p^+) kg^{-1} (pedon 3) in sub surface layers. The exchangeable Na content increased with depth in pedons 1, 2, 5, 6. 7, 13 and 14. In the rest of the pedons, the depth wise distribution was irregular. The exchangeable potassium higher in black soils varied from 0.5 c mol (p^+) kg^{-1} (pedon 9) to 0.80 c mol (p^+) kg^{-1} (pedon 12) in surface layers and 0.2 c mol (p^+) kg^{-1} (pedon 9) to 1.6 c mol (p^+) kg^{-1} (pedon 1) in sub surface layers than in red soils pedons (0.3 c mol (p^+) kg^{-1} (pedon 11) to 0.96 c mol (p^+) kg^{-1} (pedon 13) in surface layers and 0.2 c mol (p^+) kg^{-1} (pedon 10) to 0.6 c mol (p^+) kg^{-1} (pedon 13) in sub surface layers and red laterite soil pedons (0.45 c mol (p^+) kg^{-1} (pedon 4) to 0.96 c mol (p^+) kg^{-1} (pedon 3) in surface and 0.37 c mol (p^+) kg^{-1} (pedon 3) to 0.87 c mol (p^+) kg^{-1}(pedon 6) in sub surface layers. The pedon 3, 10, 11, 12, 13 and 14 shows that the exchangeable K content decreased with depth and an increasing pattern was recorded in pedons 8. The remaining pedons showed inconsistent pattern with depth. The exchangeable cations were found to be low in red laterite soils when compared to red soils.

The exchangeable bases in the black and red 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) [42]. The exchangeable cations of red laterite soils (pedons 6 to 13), the exchangeable bases were in order $Ca^{+2} > Mg^{+2} > K^+ > Na^+$. Low exchangeable Na and K percentage was noticed in all the pedons as the exchange complex was dominated by divalent cations like Ca and Mg. The BS was higher in black soil pedons ranged from 75.0 per cent (pedon 7) to 87.4 per cent (pedon 9) in surface layers and 60.69 per cent (pedon 9) to 87.40 per cent (pedon 9) in sub surface layers. This could be due to the dominance of smectitic type of clays and moderate to strongly alkaline reaction. The high CEC of black soils was attributed to the smectitic clay mineralogy (Pal and Deshpande, 1987) [22]. These results were in accordance with the findings of Singh and Agarwal (2005) [40] and Gabhane *et al. (*2006) [9].

The BSP in red soils pedons was low to high and ranged from 62.50 per cent (pedon 10) to 85.09 per cent (pedon 11) in surface layers and 58.36 per cent (pedon 8) to 95.52 per cent (pedon 13) in sub surface layers might be due to either mixed or illitic mineralogy in clay fraction. The BSP was low to medium in red laterite soil pedons ranged from 28.66 per cent (pedon 6) to 53.48 per cent (pedon 4) in surface and 21.17 per cent (pedon 4) to 49.25 per cent (pedon 2) in sub surface layers might be due to kaolinite mineralogy in clay fraction and moderately acidic to slightly acidic reaction. An increasing trend with increased depth was noticed in pedons 10, while a reverse trend was observed in pedon 2, 4 and 9. The base saturation increased up to certain depth and then decreased in pedon 5, 6, 8, 11 and 12. Other pedons did not exhibit any regular pattern of distribution. These results were in accordance with the findings of Singh and Agarwal (2005) [40] and Gabhane *et al. (*2006) [9].

Available macro and micronutrients status

The pedon wise fertility status of respective soil pedons are described in table 2. The available nitrogen content of the pedons was low to medium and varied from 246.0 kg ha^{-1}(pedon 4) to 297.0 (pedon 7) kg ha^{-1} in surface horizons, whereas in subsurface horizons ranged from 88 kg ha^{-1} (pedon 4) to 253 kg ha^{-1} (pedon 9) (low). The availability of nitrogen in black soil is varied from 289 kg ha^{-1} (pedon 1) to 297 kg ha^{-1}(pedon 7) in surface layers and 88.0 kg ha^{-1} (pedon 9) to 253.0 kg ha^{-1} (pedon 9) in sub surface layers. The available N in red soils pedons ranged from 256 kg ha^{-1} (pedon 10) to 276 kg ha^{-1} (pedon 14) in surface layers and 92 kg ha^{-1} (pedon 14) to 232 kg ha^{-1}(pedon 13) in sub surface layers and in red laterite soil pedons ranged from 246.0 kg ha^{-1} (pedon 4) to 276 kg ha^{-1} (pedon 2) in surface layers and 88.0 kg ha^{-1} (pedon 4) to 193 kg ha^{-1}(pedon 2) in sub surface layers. The available N content was found to be relatively high in surface horizons and decreased in sub surface horizons, which might possibly be due to decreasing trend of organic carbon with depth. These observations are in accordance with the findings of Rajeshwar *et al.* (2009) [32].

The available P content of soils was medium to high in black and red soils (pedon 1, 7, 8, 9, 10, 11, 12, 13 and 14) when compared to red laterite soils. The available phosphorus content of the pedons varied from 16.3 kg ha^{-1}(pedon 11) to 58.94 kg ha^{-1}(pedon 12) in surface horizons, whereas in subsurface horizons ranged from 8.11 (pedon 7) to 39.30 kg ha^{-1} (pedon 9) where the soil pH is 7.0 (Olsen method followed for estimation of P in neutral and calcareous soils). The reason for higher P in surface horizon might possibly be the confinement of crop cultivation to the rhizosphere and supplementing of the depleted phosphorus through external sources i.e. fertilizers. Similar results were reported by Thangasamy *et al.* (2005) [42]; Rajeshwar *et al.* (2009) [32]. The available phosphorus content was low to medium in red laterite soils pedons varied from 20.4 (pedon 4) to 36.9 kg ha^{-1} (pedon 3) in surface horizons, whereas in subsurface horizons ranged from 10.0 kg ha^{-1} (pedon 4) to 22.6 kg ha^{-1} (pedon 6) (Brays method followed for estimation of available P where the soil pH is less than 6.5). The availability of P in laterite soils was low which might be due to due to low CEC, clay content and low pH of these soils causes P fixation with Fe or Al ions and hydroxides resulting in deficiency of phosphorus in the form of insoluble compound of $Al_2 (H_2PO_4)_3$ and FeH_2PO_4. The results are in conformity with the findings of Pandey *et al.* (2000) [24]. However, relatively higher available P was observed in the surface horizons and decreased regularly with depth (Rajeshwar and Mani, 2013) [30].

The available potassium content of the pedons was high and ranged from 285 kg ha^{-1} (pedon 5) to 415 kg ha^{-1} (pedon 9) in surface horizons, whereas in subsurface horizons, it ranged from 121 kg ha^{-1} (pedon 3) to 395 kg ha^{-1} (pedon 9) (low). The availability of potassium in black soils was varied from 310 kg ha^{-1} (pedon 7) to 415 kg ha^{-1} (pedon 9) in surface layers and 181 kg ha^{-1} (pedon 7) to 395 kg ha^{-1} (pedon 9) in sub surface layers. The available K in red soils pedons 356 kg ha^{-1} (pedon 8) to 409 kg ha^{-1} (pedon 13) in surface layers and 195 kg ha^{-1} (pedon 14) to 379 kg ha^{-1}(pedon 13) in sub surface layers and red laterite soil pedons (285 kg ha^{-1} (pedon 5) to 384 kg ha^{1} (pedon 3) in surface layers and 121 kg ha^{-1} (pedon 3) to 321 kg ha^{-1} (pedon 2) in sub surface layers. The highest available K content was noticed in the surface horizons and showed decreasing trend with depth in all the pedons. The available K was more in surface horizons could be attributed to release of labile-K from organic residues, application of K fertilizers and upward translocation of K from lower depths along with capillary rise of ground water. Similar results were reported by Pal and Mukhopadyay (1992) [23] and Rajeshwar *et al.* (2009) [32].

The available sulphur content of the pedons was high and varied from 16.22 mg kg^{-1} (pedon 10) to 51.21 mg kg^{-1} (pedon 12) in surface horizons, whereas in subsurface horizons ranged from 5.56 kg ha^{-1} (pedon 6) to 31.98 mg kg^{-1} (pedon 9). The availability of sulphur in black soils is varied from 30.56 mg kg^{-1} (pedon 7) to 51.21 mg kg^{-1} (pedon 12) in surface layers and 6.23 mg kg^{-1} (pedon 9) to 31.98 mg kg^{-1} (pedon 9) in sub surface layers. The available S in red soil pedons varied from 16.22 mg kg^{-1} (pedon 10) to 32.12 mg kg^{-1} (pedon 11) in surface layers and 8.62 mg kg^{-1} (pedon 10) to 29.01 mg kg^{-1} (pedon 11) in sub surface layers and red laterite soil pedons (16.63 mg kg^{-1} (pedon 4) to 21.35 mg kg^{-1} (pedon 5) in surface layers and 5.56 mg kg^{-1} (pedon 5) to 20.78 mg kg^{-1} (pedon 5) in sub surface layers. The availability of S was more in surface horizon than the subsurface horizons might be due to soil sulphur is continuously cycled between inorganic and organic forms of sulphur (Ghosh *et al.* 2012) [10]. Similarly, the organic sulphur is also in equilibrium with inorganic counterpart and if there is any decline in inorganic SO_4-S level by means of crop uptake or leaching loss, it will be adequately replenished by the organic fraction (Pasricha and Fox, 1993) [25]. Surface layers contained more available sulphur content than sub-surface layers which could be due to higher amount of organic matter in surface layers than in deeper layers. Similar type of results was observed by Rao *et al.* (2008).

The DTPA extractable Zn content in all the pedons varied from 0.49 mg kg^{-1} (pedon 6) to 1.65 mg kg^{-1} (pedon 5) in surface horizons, whereas in subsurface horizons ranged from 0.20 mg kg^{-1} (pedon 6) to 0.80 mg kg^{-1} (pedon 7). The availability of Zn in black soil pedons varied from 0.86 mg kg^{-1} (pedon 1) to 1.36 mg kg^{-1} (pedon 9) in surface layers and 0.23 mg kg^{-1} (pedon 9) to 0.80 mg kg^{-1} (pedon 7) in sub surface layers. The available Zn in red soils pedons varied from 0.55 mg kg^{-1} (pedon 10) to 0.69 mg kg^{-1} (pedon 10) in surface layers and 0.21 mg kg^{-1} (pedon 10) to 0.58 mg kg^{-1} (pedon 13) in sub surface layers and red laterite soil pedons ranged from 0.49 mg kg^{-1} (pedon 6) to 1.65 mg kg^{-1} (pedon 5) in surface layers and 0.20 mg kg^{-1} (pedon 6) to 0.62 mg kg^{-1} (pedon 5) in sub surface layers. The available zinc content decreased with the depth in all pedons. The availability was more in surface soils which might be due to accumulation of comparatively more amount of organic matter and supplementing $ZnSO_4$ through external sources. Similar results were reported by Jalali *et al.* (1989) [13], Nayak *et al.* (2000) [20] and Rajeshwar *et al.* (2009) [32]. Considering 0.6 ppm as critical limit, 36.4 per cent of soils were found deficit in available zinc.

The DTPA extractable Cu content in all the pedons varied from 0.94 mg kg^{-1} (pedon 7) to 2.80 mg kg^{-1} (pedon 8) in surface horizons, whereas in subsurface horizons ranged from 0.36 mg kg^{-1} (pedon 14) to 2.60 mg kg^{-1} (pedon 1). The availability of Cu in black soil pedons varied from 0.94 mg kg^{-1} (pedon 7) to 2.63 mg kg^{-1} (pedon 1) in surface layers and 0.38 mg kg^{-1} (pedon 7) to 2.60 mg kg^{-1} (pedon 1) in sub surface layers. The available Cu in red soils pedons varied from 1.81 mg kg^{-1} (pedon 10) to 2.80 mg kg^{-1} (pedon 8) in surface layers and 0.36 mg kg^{-1} (pedon 14) to 1.63 mg kg^{-1} (pedon 11) in sub surface layers and red laterite soil pedons ranged from 1.03 mg kg^{-1} (pedon 4) to 1.98 mg kg^{-1} (pedon 5) in surface layers and 0.50 mg kg^{-1} (pedon 6) to 1.81 mg kg^{-1} (pedon 2) in sub surface layers. A decreasing trend with depth was noticed in all the pedons except 1, 3, 6, 11 and 12, which were showing irregular trend with depth. The available copper was more in surface layers and decreases with depth. The available copper was more in surface layers and decreases with depth. Dipak Sarkar and Sahoo (2000) [7] and Rajeshwar *et al.* (2009) [32] also reported similar findings. As per the critical limit of 0.2 ppm (Lindsay and Norvel, 1978) [15], all soils were well above the critical limit.

The available Mn content of all the pedons varied from 7.16 (pedon 10) to 20.15 mg kg^{-1} (pedon 12) in surface horizons, whereas in subsurface horizons ranged from 4.26 mg kg^{-1} (pedon 13) to 24.26 mg kg^{-1} (pedon 5). The availability of Mn in black soil pedons varied from 7.69 mg kg^{-1} (pedon 1) to 13.80 mg kg^{-1} (pedon 12) in surface layers and 4.8 mg kg^{-1} (pedon 12) to 11.1 mg kg^{-1} (pedon 12) in sub surface layers. The available Mn in red soils pedons varied from 7.16 mg kg^{-1} (pedon 10) to 10.88 mg kg^{-1} (pedon 8) in surface layers and 2.19 mg kg^{-1} (pedon 11) to 9.80 mg kg^{-1} (pedon 8) in sub surface layers and red laterite soil pedons ranged from 13.93 mg kg^{-1} (pedon 6) to 20.15 mg kg^{-1} (pedon 5)in surface layers and 8.63 mg kg^{-1} (pedon 6) to 24.26 mg kg^{-1} (pedon 5) in sub surface layers. A decreasing trend with depth was noticed in pedons 2, 6, 8, 9, 12, 13 and 14 and the remaining pedons showing irregular trend with depth. The remaining pedons showing irregular trend with depth where decrease in manganese content up to certain depth and decreased in its bottom layer. The higher Mn status in the surface soils may be attributed to the lower oxidation, acidic nature of the soils and also due to the release of chelated Mn from the organic compounds. Similar findings were reported by Sharma and Chaudhary (2007) [37], Rajeshwar and Ariff Khan (2007) and Arokiyaraj *et al.* (2011) [1]. All the soils analyzed well above the critical limit of 2ppm (Lindsay and Norvel 1978) [15].

The DTPA extractable Fe content ranged from 7.66 (pedon 8) to 25.30 mg kg^{-1} (pedon 5) in surface horizons whereas in subsurface horizons ranged from 3.27 mg kg^{-1} (pedon 8) to 24.60 mg kg^{-1} (pedon 5). The availability of Fe in black soil pedons varied from 8.94 mg kg^{-1} (pedon 1) to 15.8 mg kg^{-1} (pedon 7) in surface layers and 3.27 mg kg^{-1} (pedon 1) to 14.4 mg kg^{-1} (pedon 7) in sub surface layers. The available Fe in red soils pedons varied from 7.66 mg kg^{-1} (pedon 8) to 15.96 mg kg^{-1} (pedon 14) in surface layers and 3.27 mg kg^{-1} (pedon 8) to 14.60 mg kg^{-1} (pedon 14) in sub surface layers and red laterite soil pedons ranged from 18.18 mg kg^{-1} (pedon 6) to 25.30 mg kg^{-1} (pedon 5) in surface layers and 13.9 mg kg^{-1} (pedon 5) to 24.60 mg kg^{-1} (pedon 5) in sub surface layers. A decreasing trend with depth was noticed in pedons 1, 2, 3, 5, 6, 8, 10, 11, 12, 13 and 14. The pedon 4, 7 and 9 showed irregular trend with depth. It was high in the surface horizon when compared to the subsurface layers which might be due to accumulation of humic material in the surface soils besides prevalence of reduced conditions in subsurface soils. The findings were in agreement with the findings of Prasad and Sakal (1991) [27]. As per the critical limit of 4.0 ppm (Lindsay and Norvel, 1978) [15], all soils were well above the critical limit.

The hot water soluble B content varied from 0.51 (pedon 2) to 1.99 mg kg^{-1} (pedon 9 and 5) in surface horizons whereas in subsurface horizons ranged from 0.18 mg kg^{-1} (pedon 2) to 1.86 mg kg^{-1} (pedon 7). The availability of B in black soil pedons varied from 1.85 mg kg^{-1} (pedon 1) to 1.99 mg kg^{-1}

(pedon 9) in surface layers and 0.39 mg kg^{-1} (pedon1) to 1.74 mg kg^{-1} (pedon 7) in sub surface layers. The available B in red soils pedons varied from 1.66 mg kg^{-1} (pedon 14) to 1.86 mg kg^{-1} (pedon 11) in surface layers and 1.33 mg kg^{-1} (pedon 14) to 1.71 mg kg^{-1} (pedon 8) in sub surface layers and red laterite soil pedons ranged from 0.51 mg kg^{-1} (pedon 2) to 0.61 mg kg^{-1} (pedon 6) in surface layers and 0.18 mg kg^{-1} (pedon 2) to 0.59 mg kg^{-1} (pedon 4) in sub surface layers may be due to parent material. A decreasing trend with depth was noticed in all the pedons and it was high in the surface horizons when compared to the sub surface horizons which might be due to accumulation of organic matter.

Table 2: Available nutrient status of Sugarcane growing soil pedons of the Medak district

Pedon	Location	Horizon	Depth (cm)	Available Macronutrients (kg ha^{-1})			Available S (mg kg^{-1})	Available Micronutrients (mg kg^{-1})				
				N	P	K		Zn	Cu	Mn	Fe	B
Sadasivpet division												
1	Aroor	Ap	0-25	289	41.8	401	44.6	0.86	2.63	7.69	8.94	1.85
		BA	25-52	210	24.1	383	31.1	0.73	2.32	7.25	7.05	1.12
		Bss1	52-79	189	19.6	281	26.2	0.54	2.60	6.65	5.52	0.56
		Bss2	79-115	168	15.2	241	16.2	0.51	1.89	5.24	4.85	0.39
		Bss3	115-155	101	10.2	222	13.3	0.36	1.48	5.44	3.27	0.42
		C	155+	Mixed with calcareous murram								
Zaheerabad division												
2	Paidigummal	Ap	0-16	276	28.8	382	19.63	0.56	1.94	15.69	22.26	0.51
		Bt1	16-43	193	18.4	321	12.96	0.42	1.81	14.29	21.06	0.46
		Bt2	45-68	132	16.4	296	8.72	0.36	0.67	12.04	18.89	0.18
		C	67+	Weathered Laterite hard pan								
3	Burdipad	Ap	0-16	261	36.9	384	21.35	0.51	1.81	14.02	23.6	0.59
		Bt1	16-38	188	15.6	264	16.34	0.44	1.05	12.24	22.4	0.52
		Bt2	38-70	96	12.1	132	9.74	0.34	1.01	9.03	18.5	0.46
		Bt3	70-95	90	10.1	121	7.57	0.25	1.03	10.03	20.3	0.34
		C	95+	Weathered Laterite hard pan								
4	Kuppanagar	Ap	0-14	246	20.4	356	16.33	0.66	1.03	19.27	23.79	0.60
		Bt1	14-30	163	15.6	246	15.23	0.54	0.95	14.23	22.67	0.59
		Bt1	30-50	106	11.5	195	11.41	0.51	0.85	16.81	12.13	0.55
		Bt2	50-81	88	10.0	184	8.68	0.48	0.71	10.40	14.0	0.45
		C	81+	Weathered Laterite hard pan								
5	Basanthpur	Ap	0-20	268	24.6	285	21.32	1.65	1.98	20.15	25.3	0.54
		Bt1	20-38	163	14.9	265	20.78	0.62	1.92	19.60	24.6	0.49
		Bt2	38-56	125	14.3	186	15.62	0.43	1.64	22.54	14.2	0.35
		Bt3	56-70	95	12.6	187	12.36	0.22	1.62	24.26	13.9	0.26
		C	70+	Hard lithic contact which roots cannot penetrated								
6	Kothur	Ap	0-15	268	24.6	286	15.63	0.49	1.58	13.93	18.18	0.61
		Bt1	15-45	151	22.6	265	14.23	0.33	0.50	13.24	17.02	0.59
		Bt2	45-75	108	21.5	186	7.69	0.20	0.46	9.81	15.54	0.47
		Bt3	75-105	92	11.3	151	5.56	0.20	0.50	8.63	15.32	0.33
		C	105+	Hard lithic contact which roots cannot penetrated								
7	Budera	Ap	0-14	277	21.03	310	30.56	0.88	0.94	12.36	15.8	1.94
		Bw1	14-41	184	20.62	281	18.52	0.80	0.86	10.60	11.6	1.86
		Bwss1	41-58	152	14.80	267	15.47	0.42	0.66	10.25	14.4	1.51
		Bwss2	58-79	96	11.23	210	10.75	0.36	0.39	9.57	12.6	1.36
		BC	79-100	92	8.11	181	9.23	0.31	0.38	10.98	11.1	1.22
Sangareddy division												
8	Mamdipally	Ap	0-15	270	20.6	356	19.66	0.61	2.80	10.88	7.66	1.84
		Bt1	15-40	174	14.1	308	13.42	0.45	1.60	9.80	6.54	1.71
		Bt2	40-65	161	12.9	303	11.12	0.44	1.40	9.11	6.42	1.63
		Bt3	65-95	109	10.3	294	9.96	0.23	0.70	5.26	3.27	1.53
		C	95+	Weathered gneiss								
Jogipet division												
9	Andole	Ap	0-25	296	42.1	415	48.56	1.36	1.05	10.60	10.2	1.99
		BA	25-65	253	39.3	395	31.98	0.69	1.02	10.23	8.1	1.84
		Bss1	55-85	165	29	336	24.52	0.48	0.96	9.63	5.2	1.74
		Bss2	85-117	168	18.91	358	19.23	0.37	0.62	9.51	6.2	1.58
		Bss3	117-145	96	18.52	321	9.65	0.34	0.61	8.86	6.6	1.41
		Bss4	145-178	88	16.4	294	6.23	0.23	0.61	5.45	5.2	1.23
Medak division												
10	Kaudloor	A	0-11	25	19.1	396	16.22	0.55	1.81	7.16	13.70	1.75
		A21	11-22	189	10.3	364	11.23	0.32	1.02	4.13	11.69	1.61
		A22	22-41	123	9.02	351	8.62	0.21	0.60	5.17	9.64	1.52
		C	41+	Weathered gneiss								
11	Antharam	Ap	0-18	265	16.3	394	32.12	0.58	1.91	8.11	14.11	1.86
		Bt1	18-35	194	15.2	286	29.01	0.45	1.63	4.17	13.23	1.63

		Bt2	35-50	127	15.2	291	20.16	0.32	1.54	2.19	10.25	1.51
		Bt3	50-90	98	11.6	231	14.52	0.25	1.57	2.26	5.31	1.38
		C	90+	Weathered granite-gneiss								
Narayankhed division												
12	Pulkurty	Ap	0-27	289	58.94	404	51.21	0.96	2.34	13.8	9.5	1.89
		BA	27-55	178	27.66	384	26.25	0.72	2.14	11.1	9.1	1.74
		Bss1	55-87	165	20.02	348	18.29	0.52	2.51	6.5	8.3	1.68
		Bss2	88-124	129	16.56	334	15.52	0.41	1.63	5.2	8.2	1.51
		Bss3	124-150	113	16.21	256	10.31	0.36	1.61	4.8	4.9	1.42
13	Mudguntal thanda	A	0-13	266	18.32	409	23.26	0.66	2.14	9.99	11.72	1.72
		Bt1	13-25	232	15.0	392	20.21	0.61	1.21	8.03	10.85	1.69
		Bt2	25-46	130	11.16	379	19.65	0.58	1.10	7.22	10.66	1.63
		Bt2	46-65	140	9.90	368	12.32	0.33	0.91	4.26	9.60	1.56
		C	65+	Weathered granite								
Dubbaka division												
14	Ramakkapet	A	0-12	276	17.16	356	16.32	0.69	2.30	7.30	15.96	1.66
		Bt2	35-46	226	11.82	308	15.23	0.48	1.30	6.33	14.60	1.53
		Bt3	46-70	126	9.93	292	11.75	0.41	0.41	6.32	13.55	1.49
		Bt3	46-70	92	9.81	195	11.11	0.35	0.36	5.23	10.49	1.33
		C	70+	Weathered granite-gneiss								

Major soil constraints and management options to improve the crop productivity

Soil constraints were identified using soil test data (Table 3) which include texture, erosion, slope, depth, drainage and low organic carbon, low availability of N, P and micronutrients. Similar observations were made by Reddy *et al*. (1998) [33] and Francis Conant *et al*. (1983). Major constraints for crop production in red soils are shallow (pedon10) to moderately deep with coarse loamy texture, slope, erosion, high coarse fragments, low to medium OC, low availability of N and Zn (pedon 10 and 11). As the rainfall is high during rainy season, runoff and erosion are the main problems. Improved soil management practices by green manuring, application of organic manures such as farmyard manures, composted coir pith; pressmud at 25 t ha^{-1} per year conserves soil moisture and crop rotation with legumes to enhance the crop productivity on these soils. These soils are deficient in nutrients like N followed by Zn. High soil productivity could be achieved by enrichment of organic matter and maintenance of enhanced soil fertility.

Major constraints for crop production in sugar cane growing black soils are very deep soils, calcareous, clayey and poorly drained with slow permeability and low hydraulic conductivity. Leaching of soluble weathering products were limited hence the contents of available calcium and magnesium were high. The pH was above 8.0 with low to medium availability of N. Soils have swell shrink characteristic and cracks during summer. The moisture retention capacity of the soil was high. The early rainfall enters into the soils through cracks and once the cracks are closed the water stagnation occurs due to slow permeability. As the rainfall is high during rainy season, runoff and erosion are the main problems. Soils are prone to water erosion due to their slow infiltration. Once the soil is thoroughly wetted and the cracks are closed the rate of water infiltration becomes almost zero. These soils need proper surface drainage during rainy season. As the available moisture capacity of the surface and subsurface soils was high, the soils have potential for double cropping. Improved management practices have good potential to enhance productivity on these soils. Some of these soil management suggested are:

Addition of river sand @ 100 t ha^{-1} and application of 100 cart loads of red loam soil ha^{-1} deep ploughing with mould board plough or disc plough during summer can be recommended to enhance the infiltration and percolation. To overcome the problem of water logging during rainy season, the broad bed and furrow system is suggested. Broad bed and furrow system manage the surface drainage during rainy season cropping. The raised beds should be 1.2 m wide and 15 cm high with two furrows of 30 cm width on either side to drain out excess water. The broad bed and furrow system needs a graded slope of land, 0.8 to 2.0% and it should be formed across the slope. The furrows should lead to a main drain at the end of the field. Pre monsoon sowing of green manures and incorporation at flowering stage will enhance the nitrogen availability and improves the soil physical, chemical and biological environment. Application of farmyard manure or pressmud @ 25 t ha^{-1} $year^{-1}$ conserves soil moisture, adds micronutrients, enhances aeration and improves the soil physical properties; crop rotation with legume crops tend to take up more cations in proportion to anions which aids in reduction of soil pH.

The soil constraints for sugar cane in red laterite soils were light to medium in surface texture, shallow, moderately deep to deep rooting depth and gravelliness with kaolinite clay mineralogy resulting in poor water holding capacity. Surface crusting is common problem in this soil. The low water holding capacity does not permit post-rainy season cropping without irrigation. They are denuded and subject to serious erosion problems (Plate 20 & 21). Intensive leaching causes nutrient losses and release of free iron and aluminium oxides. The free iron and aluminum causes toxicity and nutrient imbalances in terms of N, K, P and Zn. Due to low pH of these soils, acidification causes P fixation with Fe or Al ions and hydroxides resulting in deficiency of phosphorus in the form of insoluble compound of $Al_2\ (H_2PO_4)_3$ and FeH_2PO_4; reduced availability of K, Ca, Mg and toxicity due to high availability of Mn, Fe, B and Mo. Improved management practices have good potential to enhance productivity on these soils.

Application of lime is the most effective remedy for soil acidity. It is the only cost-effective option for acidic agricultural soils. Liming may result in substantial crop yield responses for several years, as well as allowing or improving crop production. Recommended quantity of FYM with enriched rock phosphate and zinc sulphate has to be applied to enhance the phosphorous and zinc use efficiency and maintain the soil quality; pre monsoon sowing of green manures and incorporation at flowering stage will enhance the nitrogen availability and reduce surface crusting problem by creating favourable soil physical environment. Application of organic manures such as farmyard manure, composted coirpith or pressmud @ 25 t ha^{-1} per year conserves soil moisture, adds micronutrients, enhances aeration and improves the physical properties of the soil, therefore 15-20 tonnes of well decomposed farmyard manure is added while preparing the land a month before sowing the seed.

Maintenance of surface pH above 6.5 is essential in acidic soils for optimum soil productivity. More than one application of 1.0-1.5 t/ha of lime is likely to be required over a number of years. Application of higher rates of lime (2-5 t/ha) to reach the desired surface pH may expose crops to nutrient deficiencies, particularly manganese and zinc. Rising of soil pH decreases the level of available aluminium and manganese in the soil and at the same time increases the availability of phosphorus, magnesium, calcium and molybdenum. To overcome the leaching of Nitrogen, split application of nitrogen fertilizers along with phosphorus and Zn for maximizing the crop yield; can be recommended to use lower rates of less acidifying fertilizers; application of acidifying fertilizers such as mono ammonium phosphate or sulphate of ammonia to be avoided. Continuous cultivation of legumes crops in acid soils tend to take up more cations in proportion to anions. As a consequence, H^+ ions are excreted from their roots to maintain the electrochemical balance within their tissues. This leads to a rise in soil acidification. Hence crop rotation with cereals crop is mandatory.

Table 3: Comparative evaluation of productivity of soils in the study area along with the management options

Soil type	Pedon	Location	Suitability	Major limitations	Management suggested
Black Soils	1	Aroor	Moderately suitable to highly suitable	Drainage, texture, runoff, erosion and $CaCO_3$, high pH, sub surface hard pan	Addition of river sand at 100 t ha^{-1}; application of 100 cart loads of red loam soil; summer deep ploughing; furrow system to manage the surface drainage; raised beds should be 1.2 m wide and 15 cm hight with two furrows of 30 cm width on either side to drain out excess of water; pre monsoon sowing of green manures; application of farmyard manures, composted coir pith or press mud at 25 t ha^{-1} per year and crop rotation. Follow site-specific nutrient management.
	9	Andole	Moderately suitable to highly suitable	Drainage, texture, runoff, erosion and high $CaCO_3$, high pH in subsurface horizon	
	12	Pulakurty	Moderately suitable to highly suitable	Drainage, texture, runoff, erosion and high $CaCO_3$, high pH, sub surface hard pan	
	7	Budera	Moderately suitable to highly suitable	Slope, medium OC and N and Low Zn	Pre monsoon sowing of green manures; application of farmyard manures, composted coir pith or press mud at 25 t ha^{-1} per year and crop rotation. Follow site-specific nutrient management.
Red Soils	8	Mamdipally	Marginally suitable to Moderately suitable	Texture, slope, Low N and Zn	Application of black soils/ tank silt; pre monsoon sowing of green manures; application of farmyard manure, composted coir pith or press mud at 25 t ha^{-1} per year and crop rotation. Follow site-specific nutrient management.
	11	Antharam	Marginally suitable to Moderately suitable	Texture, slope, Low N and Zn	
	13	Mudguntal thanda	Marginally suitable to Moderately suitable	Texture, slope, low OC, Low N and Zn	
	14	Ramakkapet	Marginally suitable to Moderately suitable	Texture, slope, low OC, Low N and Zn	
	10	Kaudloor	Marginally suitable to Moderately suitable	Depth, Slope, Erosion, Texture, Coarse fragments, OC, Low N & low Zn	Application of black soils/ tank silt; pre monsoon sowing of green manures; application of farmyard manures, composted coir pith or press mud at 25 t ha-1 per year and crop rotation. Follow site-specific nutrient management to overcome the nutrients deficiencies.
Red Laterite Soils	2	Paidigummal	Marginally suitable to Moderately suitable	Texture, slope, Low WHC, Moderately acidic, coarse fragments, OC, Low N, Sub surface hardening, insitu crusting, indurate laterite layer, massive and tough	Deep ploughing, sub-soiling or chiseling up to a depth of 50 - 75 cm at 90 cm; Application of black soils/ tank silt; application of Lime (1.0-1.5 t ha^{-1}); application of FYM enriched rock phosphate and zinc sulphate; Green manuring; application of organic manures; application of bio char @ 5 -10; maintenance of surface pH; split application of nitrogen to reduce leaching; use lower rates of less acidifying fertilizers; avoid acidifying fertilizers such as mono ammonium phosphate or sulphate of ammonia; crop rotation with legumes. Follow site-specific nutrient management.
	3	Burdipad	Marginally suitable to Moderately suitable		
	4	Kuppanagar	Marginally suitable to Moderately suitable		
	5	Basanthpur	Marginally suitable to Moderately suitable		
	6	Kothur	Marginally suitable to Moderately suitable		

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