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GPS and GIS Based Soil Fertility Mapping for Cuddalore District of Tamil Nadu

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Geo referenced surface soil samples were collected from 79 villages of Cuddalore district, Tamil Nadu and about 474 soil samples were analysed for twelve chemical parameters. The fertility status revealed that the soils were acidic to alkaline in soil reaction, non - saline and low in organic carbon content. The macronutrient availability showed low available N (82.3%), high available P (61.8%), medium to high available K (49.3&31.8%) and sufficient in available S (84.4%). With regard to micronutrients, the soils were predominantly deficient in Zn (76.4%) followed by Cu (38%), B (10.6 %), Fe (1.8 %) and Mn (1.4 %). Using the geocoordinates, thematic maps for all the parameters were prepared, , which also indicated that major area of the district was acidic to alkaline in soil reaction, non-saline, low in OC, low, high and medium in available N, P and K, respectively. Zinc was predominantly deficient among the micronutrients, while all others were in sufficient status.

Key words: Cuddalore, Soil Properties, Macro and Micronutrient status, GIS, Soil fertility mapping

Soil fertility, compactability and erodibility are the elements of soil quality. Among these elements, decline in soil fertility endangers the maximum in productivity (Katyal, 2003, Reshma *et al.,* 2016). The indiscriminate use of fertilizers over a period of time has resulted in built-up of certain nutrient elements like phosphorus and deficiency of potassium and zinc in many locations (Raj Setia *et al.,* 2012). Depending upon the cropping pattern, leaching, erosion *etc.,* considerable amount of nutrients are lost from soil every year. If intensive cropping is continued over a period of time without balanced fertilization and restoring of nutrients in soil, reduction in soil fertility and loss in crop yields is inevitable. Hence, for sustainability of the present day agricultural system and balanced management of soil resources, it is imperative to emphasize on the rational management of soil fertility, which requires an understanding of how nutrients vary across the land. Soil testing provides information regarding nutrient availability in soils, which forms the basis for fertiliser recommendations to maximize the crop yields. Soil fertility maps are meant for highlighting the nutrient demand and obviously, it can be highly beneficial in guiding the farmers, manufactures and planners.

Material and Methods

Collection of soil samples

A total of 474 surface soil samples were collected from 79 villages (10 % of the total villages in the district) following multistage stratified random sampling method (Singh, 2010; Subba Rao and Muralidharudu, 2011). Six soil samples representing three different farmers' categories based on resource base *viz.,* large (>3 ha), medium (1-3 ha) and small (< 1 ha) were collected from each selected village in the district along with geo-coordinates (Latitude ºN and Longitude ºE) using GPS (Model-Garmin Etrex Vista HCX model).

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Analysis of samples

The collected soil samples were air dried, broken with wooden mallet and sieved through 2 mm sieve (0.2 mm sieve for organic carbon) and analysed for 12 chemical parameters *viz*. pH and EC (Jackson 1973), organic carbon (Walkley and Black, 1934), available N (Subbiah and Asija, 1956), available P (Olsen *et al.,*1954; Bray and Kurtz,1945), available K (Stanford and English, 1949), available S (Williams and Steinbergs, 1959), DTPA- Zn, Fe, Cu, and Mn (Lindsay and Norvell, 1978) and available Boron (Berger and Truog, 1944).

The analytical results of each soil sample was categorised as low, medium and high for organic carbon (OC) and major nutrients while for available S and micronutrients as deficient, moderate and sufficient based on the critical limits followed in Tamil Nadu. Making use of the number of samples in each category, the % sample category and Nutrient Index Values (NIV) were computed using the formulae furnished below.

$$\% \text{ sample category} = \frac{\text{No. of "low" or "medium" or "high" category}}{\text{Total number of samples}} \times 100$$

Nutrient index value was calculated from the proportion of soils under low, medium and high available nutrient categories, as represented by

$$NIV = \frac{[(P_H*3) + (P_M*2) + (P_L*1)]}{100}$$

Where,

NIV = Nutrient Index Value

P_L, P_M and P_H are the percentage of soil samples falling in low, medium and high nutrient status respectively and given weightage of one, two and three, respectively (Ramamoorthy and Bajaj, 1969). The index values are rated into various categories *viz*., low (<1.67), medium (1.67-2.33) and high (>2.33) for OC and available N,P&K. For available S and micronutrients, the ratings are very low (< 1.33), low (1.33-1.66), marginal (1.66-2.00), adequate (2.00-2.33), high (2.33-2.66) and very high (> 2.66). The taluks were categorized into different fertility ratings based on % sample category and NIV.

Generation of thematic soil fertility maps

Database on soil available nutrient status was generated in Microsoft Excel package at TNAU and the Soil fertility maps were prepared at Indian Institute of Soil Science, Bhopal by using Arc-GIS software version 9.3. The linear directional semivariogram are constructed for the soil available nutrients in spatial dependent models by plotting the semi-variance r(h) is a function of log between neighboring observations. Inverse distance weighted model was fitted to semi variogram in order to create continuous surface for the estimated soil properties by using model fitting interface. Based on the percentage of nugget, spatial dependence classes were categorized in spatial variability map as 'low', 'medium' and 'high' nutrient status by showing colour difference on the maps

Results and Discussion

pH and electrical conductivity

The pH of the surface soil showed acidic to alkaline soil reaction (3.52 to 9.60) and non-saline to slightly saline (0.01 to 1.67 dS m^{-1} (Table 1). About 43.0 % of the samples were found to be alkaline, which might be due to higher degree of base saturation (Waghmare *et al.,* 2008; Resma *et al.*, 2016). The soils of Kurinjipadi taluk were predominantly acidic (83.3 %) whereas the soils of Titakudi, Cuddalore and Vridachalam taluks were alkaline in soil reaction (69.4, 58.3 and 55.6 %, respectively, Table 3). The soils of other taluks were predominantly neutral to alkaline. The variation in pH may be due to inherent heterogeneity of soils and also due to the nature of parent material and differences in cultural and fertiliser management practices (Vijayakumar *et al.,* 2015)

Table 1. Range and mean values of pH, EC, OC and available major nutrient status in the soils of Cuddalore district

Taluk	pH	EC (dS m^{-1})	OC (%)	N	P	K
				(kg ha^{-1})		
Chidambaram	5.87-8.27 (7.32)	0.02-1.67 (0.22)	0.03-0.53 (0.53)	101-333 (247)	7-51(106-325*) 26 (210*)	67-898 (328)
Cuddalore	5.11-8.50 (7.56)	0.02-0.74 (0.24)	0.09-0.86 (0.54)	185-308 (260)	7-27 (115-305*) 12 (210*)	90-341 (190)
Kattumannarkoil	4.95-9.00 (6.83)	0.01-0.84 (0.36)	0.03-1.13 (0.62)	126-364 (252)	7-50 ((19-330*) 19 (280*)	78-983 (319)
Kurinjipadi	3.83-8.45 (5.43)	0.01-1.18 (0.14)	0.03-0.86 (0.32)	109-283 (181)	24-33 (110-260*) 27 (179*)	53-464 (121)
Panruti	3.62-8.32 (7.11)	0.02-0.73 (0.15)	0.07-1.21 (0.57)	168-336 (246)	13-50 (122-328*) 34 (202*)	98-509 (214)
Titakudi	5.81-9.56 (7.81)	0.02-0.37 (0.09)	0.03-0.98 (0.36)	115-302 (219)	16-50 (100-151*) 26 (124*)	112-831 (287)
Vridachalam	3.52-9.60 (7.21)	0.01-0.71 (0.12)	0.03-0.96 (0.33)	115-302 (209)	6.4-32 (162-315*) 15 (257*)	79-612 (243)
Over all Range / Mean	3.52-9.60 (7.04)	0.01-1.67 (0.19)	0.03-1.21 (0.47)	101-364 (231)	6.4-51 (100-330*) 22.7 (208.9*)	53-983 (243.3)

* Bray- P

Electrical conductivity of the soil samples ranged from 0.01 to 1.67 dS m^{-1} with a mean of 0.19 dS m^{-1} indicating the non-saline nature of the soils. About 98.6 % of the soil samples analysed was found to be non-saline in nature, which might be attributed to light textured soils resulting in free drainage (Verma *et al.,* 2005; Vijayakumar *et al.,* 2015).

Organic carbon

The organic carbon status of the surface soil ranged from 0.03 to 1.21 % with a mean value of 0.47 % (Table 1). The soils of Kattumannarkoil taluk recorded the highest mean organic carbon status (0.62 %) followed by Panruti taluk (0.57 %). About 55.5, 28.3 and 16.2 % of the soil samples were low, medium and high in organic carbon status, respectively (Table 3). Among various taluks, the soils of Kurinjipadi, Titakudi and Virdachalam were low in organic carbon status (>70%) and the fertility rating varied from low to medium with the overall rating in the soils were "low", which might be due to higher temperature prevailing

in the area and associated faster decomposition of organic matter, thus resulting in low organic carbon content of these soils (Verma *et al.,* 2005).

Available major nutrients status

The major nutrient status of soils in Cuddalore district was low in available N, high in available P and medium in available K. The overall available N status in the surface soils ranged from 101 to 364 kg ha^{-1} with a mean of 231 kg ha^{-1}. Among different taluks, soils collected from Kurinjipadi, showed the highest percentage of 'low' available N status (97.6%) followed by Titakudi (97.2%), Vridachalam (94.4 %) and Panruti (79.6 %, Table 4). The overall N fertility in the soils of Cuddalore district was low (Table 6). As majority of soils is alkaline in nature and having light texture along with 33.5 % of slightly calcareousness, the applied fertilizers would have been subjected to various losses and resulted in low available N in the

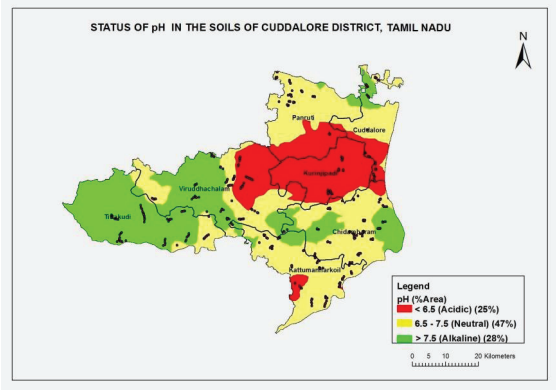

Fig.1a pH

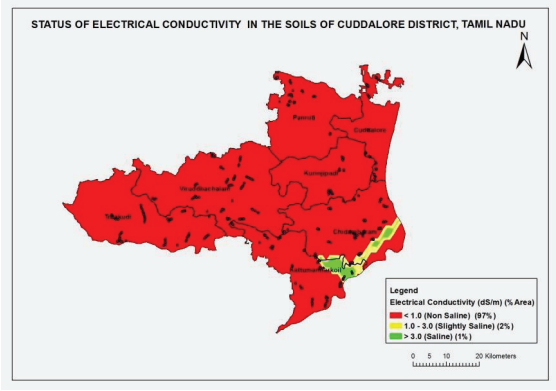

Fig.1b Electrical Conductivity

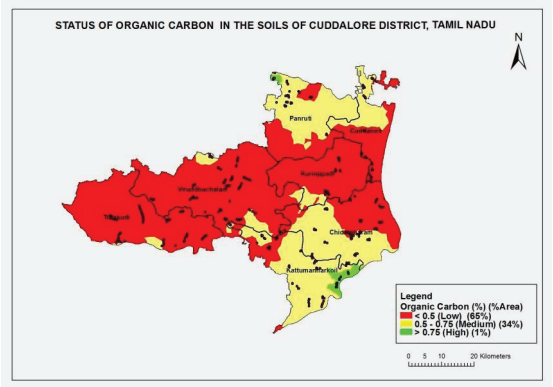

Fig.1c Organic Carbon

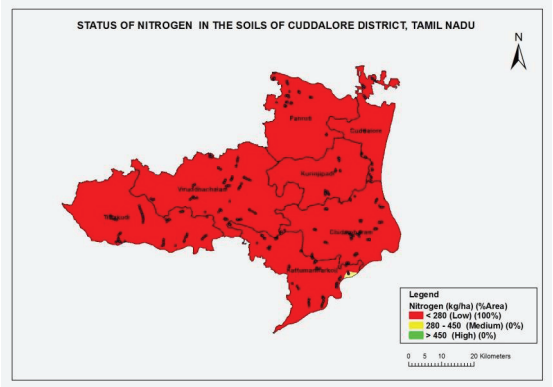

Fig.1dAvailable Nitrogen

Fig.1. Thematic maps for soil physico chemical properties and available N in Cuddalore district

Table 2. Range and mean values of available sulphur and micronutrients in the soils of Cuddalore district (mg kg^{-1})

Taluk	S	Zn	Fe	Cu	Mn	B
Chidambaram	3.75-58.75 (34.65)	0.22-4.06 (1.01)	4.19-62.70 (32.2)	0.62-6.30 (3.25)	0.96-30.02 (18.4)	0.70-8.70 (3.27)
Cuddalore	31.25-63.00 (41.21)	0.43-3.46 (1.26)	7.89-51.20 (30.2)	0.72-4.55 (2.65)	8.82-22.57 (15.39)	0.10-3.90 (0.57)
Kattumannarkoil	2.25-50.00 (23.70)	0.15-2.45 (0.84)	1.48-64.66 (33.47)	0.30-6.80 (2.34)	2.99-29.52 (17.61)	0.10-6.50 (3.76)
Kurinjipadi	0.75-41.25 (16.32)	0.09-2.38 (0.90)	5.76-63.47 (48.63)	0.74-7.63 (4.01)	3.25-29.97 (21.40)	2.50-7.30 (3.80)
Panruti	7.25-54.75 (33.31)	0.17-3.50 (1.18)	2.41-52.22 (19.60)	0.18-7.71 (1.54)	5.34-27.08 (13.38)	0.70-6.50 (2.23)
Titakudi	17.75-39.25 (28.68)	0.03-1.85 (0.27)	13.20-42.56 (27.48)	0.24-20.09 (1.92)	0.04-14.23 (7.80)	1.00-3.70 (2.65)
Vridachalam	26.65-54.50 (35.07)	0.02-1.90 (0.79)	2.16-51.8 (16.98)	0.01-4.29 (0.99)	1.32-46.32 (8.85)	0.10-7.70 (2.51)
Over all Range / Mean	0.75-63.00 (30.42)	0.02-4.06 (0.89)	1.48-64.66 (29.85)	0.01-20.09 (2.39)	0.04-46.32 (14.69)	0.10-8.7 (2.69)

Table 3. % sample category of soil pH, EC and organic carbon in different taluks of Cuddalore district

Taluk	pH			EC (dS m^{-1})			OC (%)		
	Acidic	Neutral	Alkaline	Non - Saline	Slightly Saline	Saline	Low	Medium	High
Chidambaram	15.7	37.3	47.1	97.1	2.9	0.0	48.0	25.5	26.5
Cuddalore	8.3	33.3	58.3	100.0	0.0	0.0	45.8	37.5	16.7
Kattumannarkoil	38.9	41.1	20.0	100.0	0.0	0.0	30.0	34.4	35.6
Kurinjipadi	83.3	7.1	9.5	92.9	7.1	0.0	71.4	23.8	4.8
Panruti	20.4	38.9	40.7	100.0	0.0	0.0	46.3	37.0	16.7
Titakudi	4.2	26.4	69.4	100.0	0.0	0.0	75.0	16.7	8.3
Vridachalam	28.9	15.6	55.6	100.0	0.0	0.0	72.2	23.3	4.4
Over all Range / Mean	28.5	28.5	43.0	98.6	1.4	0.0	55.5	28.3	16.2

soil. These results are in confirmation with the findings of Sharma *et al.* (2008). The low organic carbon content in the soils is also an indicator of low available nitrogen status (Verma *et al.,* 2005).

The Olsen - P status varied from 6.4 to 51 kg ha^{-1} and Bray-P ranged from 100 to 330 kg ha^{-1} with an overall mean of 22.7 and 208.9 kg ha^{-1}, respectively (Table 1). The overall % sample category under low,

Table 4. % sample category of soil available macro nutrients in different taluks of Cuddalore district

Taluk	N			P			K			S		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Chidambaram	77.5	22.5	0.0	12.7	16.7	70.6	9.8	31.4	58.8	5.9	3.9	90.2
Cuddalore	58.3	41.7	0.0	62.5	25.0	12.5	16.7	79.2	4.2	0.0	0.0	100.0
Kattumannarkoil	71.1	28.9	0.0	15.6	24.4	60.0	10.0	32.2	57.8	21.1	16.7	62.2
Kurinjipadi	97.6	2.4	0.0	0.0	0.0	100.0	66.7	26.2	7.1	45.2	14.3	40.5
Panruti	79.6	20.4	0.0	0.0	9.3	90.7	11.1	63.0	25.9	1.9	0.0	98.1
Titakudi	97.2	2.8	0.0	0.0	38.9	61.1	1.4	66.7	31.9	0.0	0.0	100.0
Vridachalam	94.4	5.6	0.0	30.0	32.2	37.8	13.3	50.0	36.7	0.0	0.0	100.0
Over all Range / Mean	82.3	17.7	0.0	17.3	20.9	61.8	18.9	49.3	31.8	10.6	5.0	84.4

medium and high was 17.3, 20.9 and 61.8 % respectively. Among the seven taluks, all the soils in Kurinjipadi taluk (100%) were higher in available P and none of the soil samples collected from Kurinchipadi, Titakudi and Panruti was deficient in available P. However, the soils of Cuddalore taluk

Table 5. % sample category of soil available micronutrient status in different taluks of Cuddalore district

Taluk	Zinc			Iron			Copper			Manganese			HWSB		
	D	M	S	D	M	S	D	M	S	D	M	S	D	M	S
Chidambaram	76.5	12.7	10.8	0.0	4.9	95.1	11.8	14.7	73.5	2.0	1.0	97.1	5.9	3.9	90.2
Cuddalore	50.0	45.8	4.2	0.0	4.2	95.8	25.0	4.2	70.8	0.0	0.0	100.0	0.0	0.0	100.0
Kattumannarkoil	81.1	16.7	2.2	2.2	4.4	93.3	38.9	12.2	48.9	0.0	1.1	98.9	21.1	16.7	62.2
Kurinjipadi	81.0	11.9	7.1	0.0	2.4	97.6	16.7	11.9	71.4	0.0	4.8	95.2	45.2	14.3	40.5
Panruti	66.7	16.7	16.7	9.3	11.1	79.6	55.6	13.0	31.5	0.0	0.0	100.0	1.9	0.0	98.1
Titakudi	98.6	1.4	0.0	0.0	0.0	100.0	51.4	23.6	25.0	1.4	1.4	97.2	0.0	0.0	100.0
Vridachalam	81.1	17.8	1.1	1.1	6.7	92.2	66.7	14.4	18.9	6.7	10.0	83.3	0.0	0.0	100.0
Over all Range / Mean	76.4	17.6	6.0	1.8	4.8	93.4	38.0	13.4	48.6	1.4	2.6	96.0	10.6	5.0	84.4

(62.5 %) had the highest % category of “low” P status. The available P in different taluks is generally medium to high status with the overall rating of high (Table 6) and only 17.3 % of the samples tested were low in available P. Higher available P status is attributed to regular application of phosphatic fertilizers and the immobile nature of phosphate ions in soils, which might have resulted in the accumulation of P in soils (Verma *et al.* 2005).

The available potassium status in the surface soils of different taluks ranged from 53 to 983 kg ha^{-1} with an overall mean value of 243.3 kg ha^{-1}. The highest mean available K (328 kg ha^{-1}) was recorded in Chidambaram taluk and the lowest mean value of 121 kg ha^{-1} was noticed in the soils of Kurinjipadi taluk (Table1). The % sample category under low, medium and high status varied between 1.40 to 66.7, 26.2 to 79.2 and 4.20 to 58.8, respectively. The available potassium is generally medium to high in the soils of Cuddalore district and only 18.9 % of soil samples tested were low in available K. The fertility rating varied from low to high with an overall mean of medium K fertility. The soils of Chidambaram and Kattumanakoil taluks were high in available K fertility,

while the soils of Kurinchipadi taluk has low K fertility. The higher K status could be attributed to the prevalence of Illite – a potassium rich mineral in these soils (Patil *et al.*, 2011).

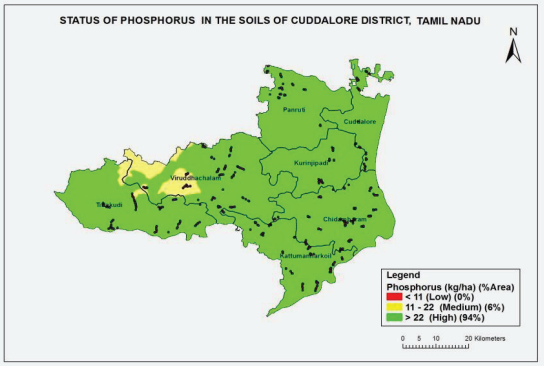

Fig.2a Available Phosphorus

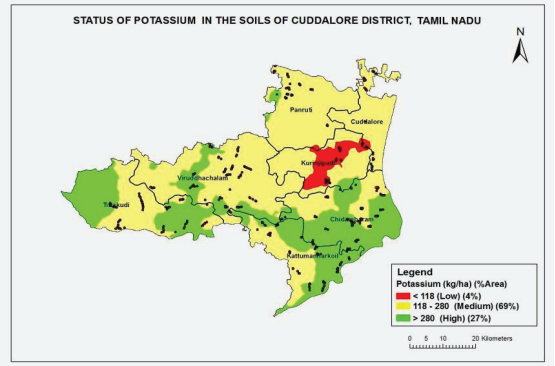

Fig.2b Available Potassium

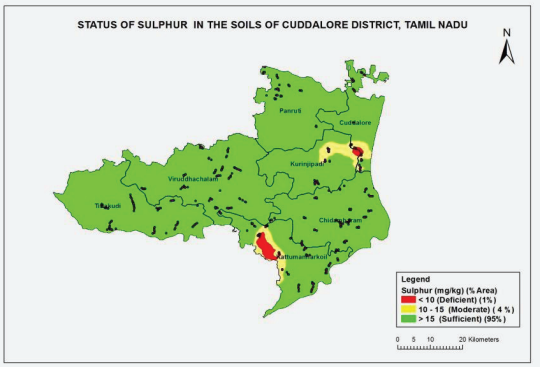

Fig.2c Available Sulphur

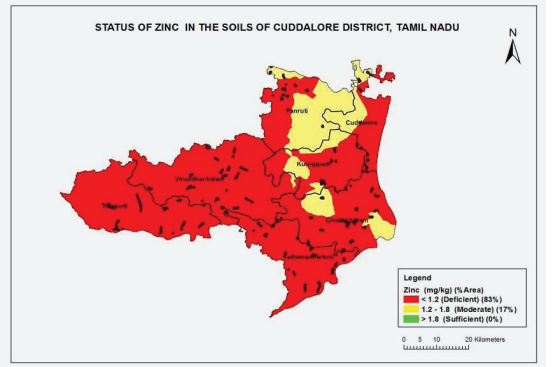

Fig.2d Available Zinc

Fig.2. Fertility maps of soil nutrient status in Cuddalore district

Available sulphur and micronutrients status

The soils of Cuddalore district were very high in available S, Fe, Mn and B fertility while adequate in Cu and very low in Zn fertility (Tables 2 to 6). The available S status ranged from 0.80 to 63.0 mg kg^{-1} with an overall mean of 30.4 mg kg^{-1} indicating the sufficiency status. About 10.6 % samples alone were deficient in available S and 5.0 and 84.4 % of the samples were moderate and high in status, respectively. None of the soils collected from Cuddalore, Titakudi and Vridachalam taluks were deficient in S availability. However, 21.1- 45.2% of the soil samples collected from Kattumannarkoil and Kurinchipadi taluks were deficient in S. The fertility rating in all the taluks ranged from marginal to very high and the overall rating for available sulphur in the district was very high. The very high status of S may be due to the continuous addition of S through super phosphate and also through ground water, which contains sufficient amount of S to meet the requirement of the growing plants and the results are in confirmation with the findings of Pasricha *et al.* (2001).

Table 6. Fertility ratings of major and micronutrients in the soils of different taluks in Cuddalore district

Taluk	Fertility Rating									
	OC	N	P	K	S	Zn	Fe	Cu	Mn	HWSB
Chidambaram	Medium	Low	High	High	Very high	Low	Very high	High	Very high	Very high
Cuddalore	Medium	Low	Low	Medium	Very high	Low	Very high	High	Very high	Very high
Kattumannarkoil	Medium	Low	High	High	High	Very low	Very high	Adequate	Very high	High
Kurinjipadi	Low	Low	High	Low	Marginal	Very low	Very high	High	Very high	Marginal
Panruti	Medium	Low	High	Medium	Very high	Low	Very high	Marginal	Very high	Very high
Titakudi	Low	Low	High	Medium	Very high	Very low	Very high	Marginal	Very high	Very high
Vridachalam	Low	Low	Medium	Medium	Very high	Very low	Very high	Low	Very high	Very high
Over all Range / Mean	Low	Low	High	Medium	Very high	Very low	Very high	Adequate	Very high	Very high

All the micronutriments status in the soils of Cuddalore district were very high in availability except Zn, which was low to very low in availability. The overall DTPA-Zn status ranged from 0.02 to 4.06 mg kg^{-1} with a mean of 0.89 mg kg^{-1} and the soils of almost all the taluks had deficient Zn status. The DTPA-Fe status varied from 1.48 to 64.66 mg kg^{-1} with a mean of 29.85 mg kg^{-1} and found to be very high in all the taluks. The availability of Cu varied from 0.01 to 20.09 mg kg^{-1} with a mean of 2.39 mg kg^{-1}. The mean Cu status in the soils of Vridachalam taluk was deficient, while rest of the taluks showed moderate to higher Cu

status. The Mn availability in the soils varied from 0.04 to 46.32 mg kg^{-1} with a mean of 14.69 mg kg^{-1} and the lowest Cu availability was observed in Titakudi taluk. Similar to Fe, Mn was also found to be very high in the soils of all the taluks. The mean HWSB availability in the soils of all the taluks indicated deficient to sufficient B status and varied from 0.10 to 8.7 mg kg^{-1} with a mean of 2.69 mg kg^{-1}.

The % sample deficiency worked out for all the taluks indicated the predominant Zn deficiency in all the taluks (76.4 %) followed by Cu (38 %), B (10.6 %), Fe (1.8 %) and Mn (1.4 %). Among the taluks, 98.6 % of the samples collected from Titakudi taluk showed Zn deficiency, which increased with increase in pH and decreased with increase in organic carbon, $CaCO_3$, and clay content. Similar observations were made by

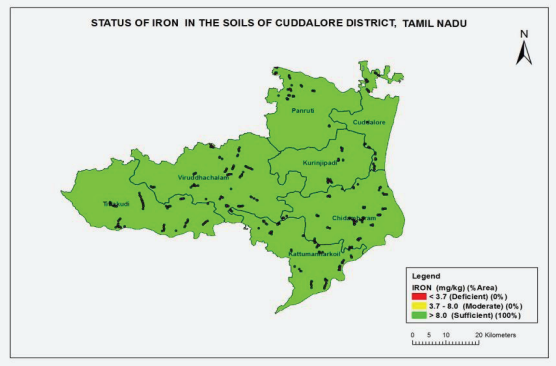

Fig.3a Available Iron

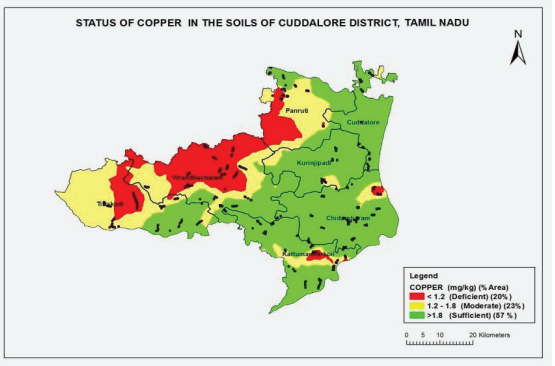

Fig.3b Available Copper

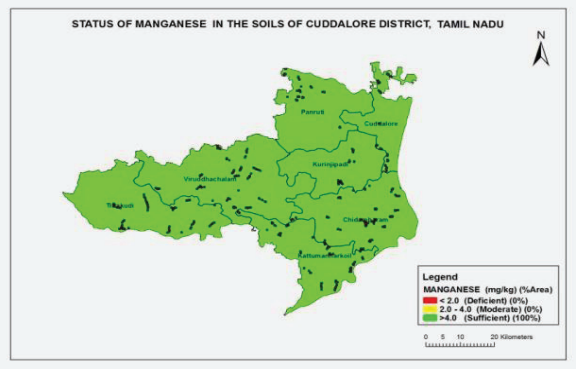

Fig.3c Available Manganese

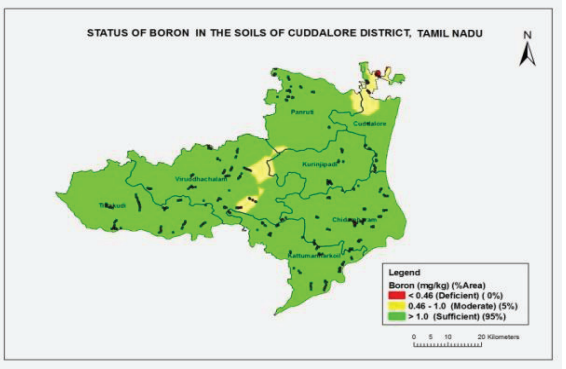

Fig.3d Available Boron

Fig.3. Fertility maps of micro nutrient status in the soils of Cuddalore district

Takkar *et al*. (1977) and Sood *et al.* (2009). Almost all the taluks had sufficient Fe and Mn availability. No Mn deficiency was noticed in the soils of Cuddalore, Kattumannarkoil, Kurinjipadi and Panruti taluks. With reference to Cu, Vridachalam (66.7 %), Panruti (55.6 %) and Titakudi (51.4 %) taluks had higher Cu deficiency as compared to other taluks. The soils of Cuddalore, Titakudi and Vridachalam taluks had no B deficiency except Kurinjipadi, , which had 45.2 % B deficiency.

Notably, very low fertility rating was recorded for Zn in most of the taluks, low to high Cu, very high Mn and Fe in all the taluks and marginal to very high HWSB availability. The overall fertility rating for micronutrients in the soils of Cuddalore district revealed very low Zn, very high Fe, Mn and B and adequate Cu status.

Thematic soil fertility maps

The thematic maps depicting the soil fertility status of Cuddalore District were generated using sampling point data and by krigging. The soil fertility maps pertaining to all the 12 chemical parameters are depicted in Fig. 1 to 3. Out of the total geographical area in the district 25, 47 and 28 % of the area is having acidic, neutral and alkaline in soil reaction, respectively. Most of the areas were non-saline (97 %) and only 2 % of the area is under slightly saline category. The organic carbon status was predominantly low accounting for 65 % of the total area followed by medium (34 %) and high (1 %) carbon status. About 100 % of the total area was predominantly low in available N status and none of the samples falls under high and medium category. In contrary, the available P was predominantly high (94 % of the total area) and medium in only 6 % of the area. About 69 % of the area was medium in available K, 27 % under high and only 4 % under low category. The available S was sufficient in 95 % of the area, moderate in 4 % and deficient in only 1 % of the total area in the district.

As far as available micronutrients were concerned, the Zn status was deficient in 83 % of the area and 100 % of the entire area was sufficient in Fe and Mn status. The available Cu status was observed to be sufficient in 57 % of the area, moderate in 23 % and

deficient in 20 % area. Boron availability was sufficient in 95 % of the area and only negligible area was under moderate status (5%) and no samples under deficient category.

Conclusion

It can be concluded that the soils of Cuddalore district were acidic to alkaline in soil reaction, non-saline and low in organic carbon content. The soil fertility for various major, secondary and micronutrient status indicated that, the soils were low in N, high in P, medium in K, very high in S, Fe, Mn, and B, adequate in Cu and very low in Zn status. Therefore, based on soil fertility mapping, reclamation measures are to be followed in problem soil areas; over usage of fertilizers in high fertile areas and under usage of fertilizers in low fertile areas are to be avoided. At this juncture, adopting Soil Test Crop Response based Integrated Plant Nutrition System (STCR-IPNS) including secondary and micronutrients to various crops / cropping sequences could result on increased productivity, fertilizer use efficiency and profitability with sustained soil health over long run. This information will be useful to researchers, planners, policy makers, extension personnel of the State Department of Agriculture, fertilizer industries and farmers.

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