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Soil Fertility Appraisal for Villupuram District of Tamil Nadu using GPS and GIS Techniques

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With a view to assess and map the soil fertility status of Villupuram district of Tamil Nadu, the present investigation was undertaken using GPS and GIS techniques. In this study, a systematic set of 864 georeferenced soil samples were collected from 144 selected villages, covering all the eight taluks and 22 blocks following multistage stratified random sampling approach. The soil samples were analyzed for 12 chemical parameters and the data along with GPS readings were used for the preparation of soil fertility maps using GIS. The soil fertility maps clearly revealed that a major area of the district was alkaline, non-saline, low in OC, low, high and medium in available N, P and K, respectively; with regard to available S and micronutrients, Zn was predominantly deficient and Cu was moderate while S, Fe, Mn and B were in sufficient status. As a whole, OC, available N, Zn and Cu are the major nutrient constraints in Villupuram district which warrants attention for implementing soil test crop response based nutrient recommendations through integrated plant nutrition system (STCR-IPNS) and application of corresponding micronutrients. Based on the soil fertility appraisal of the district, nutrient plan for various taluks has been furnished for implementation.

Key words: GPS and GIS techniques, soil fertility appraisal, STCR-IPNS

Green revolution has triggered to achieve higher production and nutritional security in the country. There has been a substantial increase in food production from about 50.8 million tonnes (Mt) in 1950 to about 275.11 Mt in 2016-17. To steer these agricultural achievements towards the path of an evergreen revolution, there is a need to blend the traditional knowledge with frontier technologies. Advances including the global positioning system (GPS) and geographic information system (GIS) facilitate soil fertility mapping and provide quantitative support for decision and policy making to improve agricultural approaches towards balanced nutrition. The GPS and GIS helps in collecting a systematic set of georeferenced samples and generating spatial data about the distribution of nutrients (Sharma 2004).

The GIS provides scientists, planners, managers and decision makers an efficient way of combining and analyzing georeferenced and descriptive data from different sources (soils, vegetation, geology, land covers and others) for better understanding and management of natural resources (Fernandaz *et al*. 1993). Georeferenced maps also help in monitoring changes in nutrient status over a period of time by revisiting with the help of GPS.

Intensive cultivation of high yielding varieties and hybrids coupled with decline in the use of organic manures and crop residue recycling which has resulted in depletion of native nutrients and occurrence of wide spread deficiencies of both macro and micronutrients. Though soil testing programme make desired impact in improving the crop production in the country, due to lack of awareness, most of the farmers are not fertilizing the crops as per soil tests. Hence, there is every necessity to create awareness among them about the soil test based fertilizer recommendation. At this juncture, soil testing along with GPS reading and GIS

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based mapping would enable to assess the soil fertility status of the particular location. With this background, the present study was carried out during 2011-2013 to assess the soil fertility status and to prepare soil fertility maps using GPS and GIS techniques for Villupuram district.

Villupuram district is the fourth largest district in Tamil Nadu which is predominantly an agrarian district. It is bounded by the Union Territory of Puducherry and Bay of Bengal in the east, Cuddalore district in the south, Dharmapuri and Salem districts in the west and Kancheepuram and Thiruvannamalai districts in the north. It is one of the highest fertilizer consumption districts of Tamil Nadu with rice-rice as one of the major cropping systems. It is located between 10°38′25″ N and 79°42′55″ E. The soil temperature is found to be hyperthermic. The total geographical area of the district is 7,22,203 ha with a mean annual rainfall of 989 mm and mean annual temperature of 27.7 °C. The major crops cultivated are rice, gingelly, turmeric, sugarcane, cashew, tapioca, eucalyptus, bengal gram, groundnut, maize and casuarina. Twelve soil series have been identified among which Arasanatham, Vadamadurai, Vadathesa-salur and Vanur form the major ones. This district has eight taluks *viz*., Gingee, Kallakkurichi, Sankarapuram, Tindivanam, Tirukkoyilur, Ulundurpettai, Vanur and Villupuram covering 22 blocks.

Materials and Methods

Collection of soil samples

A total of 864 samples were collected from 144 villages (10% of the total villages in the district) based on multistage stratified random sampling method during 2011-12. 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. The GPS data (Latitude ºN and Longitude ºE) were collected from each sampling site by using GPS - Garmin Etrex Vista HCX model.

Analysis of samples

The collected soil samples were air-dried, ground with wooden pestle and mortar and sieved through 2-mm sieve (0.2 mm sieve for organic carbon), labelled and stored. The samples were analyzed for 12 chemical parameters *viz*., pH and electrical conductivity (EC) (Jackson 1973), organic carbon (OC) (Walkley and Black 1934), available nitrogen (N) (Subbiah and Asija 1956), available phosphorus (P) (Bray and Kurtz 1945; Olsen *et al.* 1954), available potassium (K) (Stanford and English 1949), available sulphur (S) (Williams and Steinbergs 1959), available zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn) (Lindsay and Norvell 1978) and available boron (B) (Berger and Truog 1944).

The analytical results of each soil sample was categorized as low, medium and high categories for OC and macronutrients and as deficient, moderate and sufficient based on the critical limits for available S and micronutrients as followed in Tamil Nadu. Making use of the number of samples in each category, the per cent sample category and nutrient index values (NIV) were computed using the formulae furnished below.

$$\text{Per cent sample category} = \frac{\text{No. of "low (L)" or "medium (M)" or "high (H)" category}}{\text{Total no. of samples}} \times 100$$

Nutrient index values and fertility rating

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

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

where, NIV = nutrient index value; P_L, P_M and P_H are the percentage of soil samples falling in the category of low, medium and high nutrient status 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 and 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 per cent 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 thematic maps on available nutrient status were generated during 2012-13 by categorizing the fertility status as 'low', 'medium' and 'high' by showing appropriate legend for OC and available N, P and K; 'deficient', 'moderate' and 'sufficient' for available S and micronutrients.

Results and Discussion

Soil Fertility Status, Per Cent Sample Categorisation and Nutrient Index Values

pH and electrical conductivity

The pH (Table 1) of the surface soil ranged from 5.15 to 9.60 with a mean of 7.78 and about 72.3% of the samples were found to be alkaline which might be due to the higher degree of base saturation (Waghmare *et al*. 2008; Sharma *et al*. 2008). The EC of the soil (Table 1) ranged from 0.01 to 0.98 dS m^{-1} with a mean of 0.23 dS m^{-1}**.** The non-saline nature of a major per cent of the soil samples might be due to proper management and inherent properties of soil as also reported by Sharma *et al*. (2008).

Organic carbon

The overall OC status of the soil (Table 1) ranged from 0.12 to 1.08% with a mean value of 0.43%. About 63.1 per cent of the soil samples were under low status with an overall fertility rating of 'low' which is primarily due to high temperature leading to higher rate of organic matter decomposition (Kameriya 1995) and also due to little or no organic matter additions (Rego *et al.* 2003).

Available N, P and K

The overall available N status (Table 1) ranged from 101 to 470 kg ha^{-1} with a mean value of 231 kg ha^{-1}. Similar to OC, a major percentage of soil samples (81.6%) were under low status with an overall fertility rating of 'low'. As majority of soils is alkaline in nature and having light texture along with 67% of calcareousness, the applied fertilizers would have been subjected to various losses which resulted in low amount of available N in the soil. The Olsen-P (Table 1) ranged from 7.0-69 kg ha^{-1} and Bray-P ranged from 16-89 kg ha^{-1} with an overall mean value of 25.4 and 34.9 kg ha^{-1}, respectively. The overall per cent sample category revealed 51.2% under high status with an overall fertility rating of 'high' which might be due to the continuous application of single superphosphate (SSP) for the crops that would have built-up soil available P status. The range of available K was 36 to 842 kg ha^{-1} with a mean of 209 kg ha^{-1} and the per cent sample category under low, medium and high was 13.9, 69.4 and 16.7, respectively with an overall medium fertility rating. 'Medium' available K in these soils may be attributed due to the continuous drain of K from the soil reserve over the years with inadequate supply of chemical fertilizers to meet the crop need,

Table 1. Soil fertility status of Villupuram district of Tamil Nadu

Parameters / Nutrients	Range	Mean	Per cent sample category			NIV	Fertility rating	Per cent area based on soil fertility maps		
			Acidic/ Non-saline/ Low/ Deficient	Neutral/ Slightly saline/ Medium/ Moderate	Alkaline/ Saline/High/ Sufficient			D	M	S
pH	5.15-9.60	7.78	7.2	20.5	72.3	-	-	1	25	74
EC (dS m^{-1})	0.01-0.98	0.23	100.0	0.0	0.0	-	-	100	0	0
OC (%)	0.12-1.08	0.43	63.1	27.2	9.7	1.47	Low	68	32	0
Available N (kg ha^{-1})	101-470	231	81.6	18.2	0.2	1.19	Low	100	0	0
Available P (kg ha^{-1})	7-69	25.4	8.8	40.0	51.2	2.42	High	8	37	55
	16-89*	34.9*								
Available K (kg ha^{-1})	36-842	209	13.9	69.4	16.7	2.03	Medium	1	94	5
Available S (mg kg^{-1})	0.7-98.0	24.8	21.3	7.3	71.4	2.50	High	10	14	76
Available Zn (mg kg^{-1})	0.02-6.32	0.74	86.2	8.2	5.6	1.19	Very low	95	5	0
Available Fe (mg kg^{-1})	0.34-134.06	10.3	17.1	36.7	46.2	2.29	Adequate	0	32	68
Available Cu (mg kg^{-1})	0.07-8.68	1.55	40.2	27.9	31.9	1.92	Marginal	19	39	42
Available Mn (mg kg^{-1})	0.44-136.06	8.45	6.4	26.5	67.1	2.61	High	0	17	83
HWSB (mg kg^{-1})	0.10-6.90	1.41	5.2	33.3	61.5	2.56	High	0	12	88

*Bray-P; Acidic, neutral and alkaline for pH; Non-saline, slightly saline and saline for EC; Low, medium and high for OC and available N, P and K; Deficient, moderate and sufficient for available S and micronutrients.

mining of K has started appearing in the soils which is a matter of concern.

Available S

The available S status (Table 1) ranged from 0.7 to 98.0 mg kg^{-1} with a mean of 24.8 mg kg^{-1}. Sufficient status of S was noticed in 71.4% of the samples with an overall fertility rating of 'high'. This could be due to the continuous addition of S containing agrochemicals which contain sufficient amount of S to meet the requirement of the growing plants (Patel and Patel 2008).

Available micronutrients

The available Zn status (Table 1) ranged from 0.02 to 6.32 mg kg^{-1} with a mean of 0.74 mg kg^{-1}. About 86.2% of the soil samples were deficient in available Zn with an overall rating of "very low" and the present results are in line with the findings of Velu *et al*. (2008). The findings of Shyampura and Seghal (1995) and Katyal and Datta (2004) also subscribe to this view. Climatic conditions, parent materials, and management appeared to be largely responsible for the distribution of Zn in the soil. Coarse texture, high pH, calcareousness, diminishing OC and leaching often accentuated the Zn deficiency (Katyal and Rattan 1993). Zinc content in the investigated soils might be due to the low OC values in these blocks. The results of the present investigation are in the conformity with those of Takkar *et al*. (1997) who envisaged that when the soils are low in organic matter and not supplemented by mineral fertilization they are prone to Zn deficiency.

The available Fe status (Table 1) varied from 0.34 to 134.0 mg kg^{-1} with a mean of 10.3 mg kg^{-1}. Deficient, moderate and sufficient Fe status was noticed in 17.1, 36.7 and 46.2% of the samples, respectively with a mean fertility rating of adequate based on NIV. With reference to available Cu and Mn status, the values ranged from 0.07 to 8.68 mg kg^{-1} and 0.44 to 136.0 mg kg^{-1} with a mean of 1.55 and 8.45 mg kg^{-1}, respectively. The per cent deficiency of Cu was 40.2 with an overall fertility rating of marginal which might be due to low OC and alkaline pH of the soils. The per cent sufficiency of Mn was 67.1 with an overall rating of "high" in the soils of the study area which might be due to the fact that decomposition of organic matter releases micronutrients and also reduces the pH of the soil around the plant roots which helps in increasing the solubility of cationic micronutrients (Sharma and Chaudhary 2007).

The mean available B status (Table 1) ranged from 0.10-6.90 mg kg^{-1} with an overall mean of 1.41 mg kg^{-1} exhibiting 61.5% sufficiency with an overall rating of high based on NIV which might be due to the occurrence of higher concentration of B in soils or continued use of irrigation water high in soluble salts including B (Bradford *et al*. 1996). The availability of boron is largely influenced by soil characteristics like pH, EC, OC, texture and calcium carbonate content (Keren and Bingham 1985).

Thematic Soil Fertility Maps

The per cent area based on soil fertility maps pertaining to all the 12 chemical parameters are depicted in fig. 1 to 12.

Soil pH and EC

With regard to soil pH, the soils are predominantly alkaline followed by neutral and acidic; out of the total geographical area, 74% of the area is under alkaline. In the case of EC, 100% of the area is under non-saline.

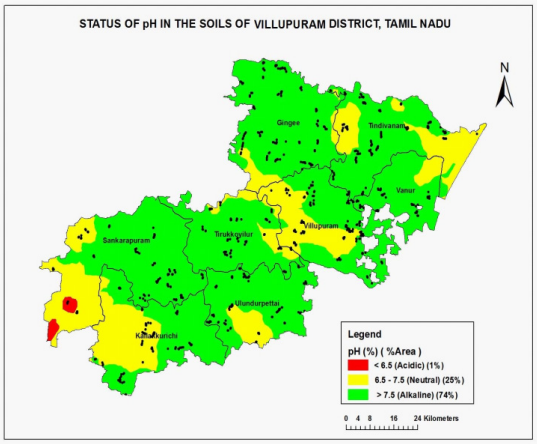

Fig. 1. pH

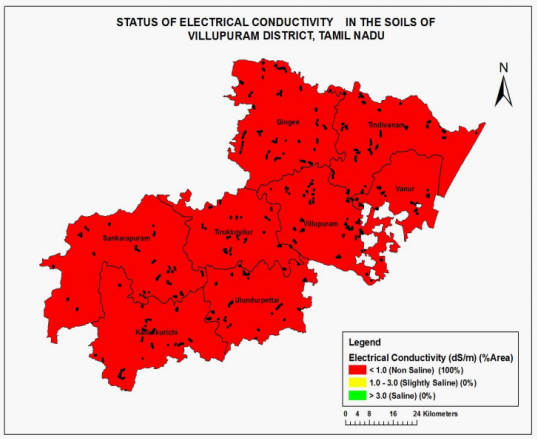

Fig. 2. Electrical conductivity

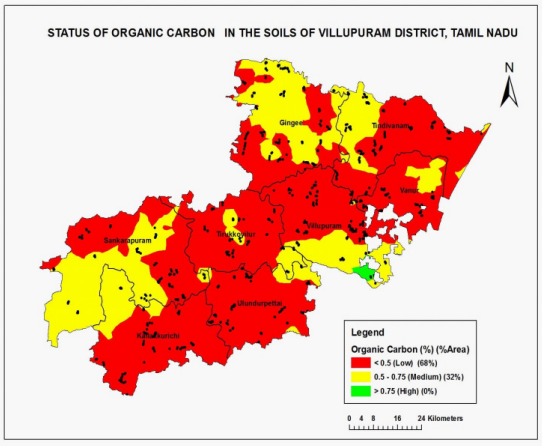

Fig. 3. Organic carbon

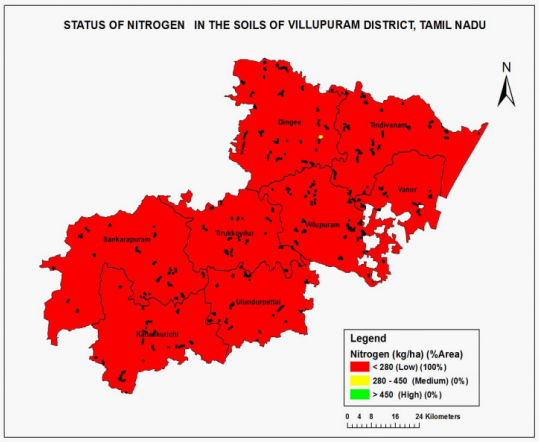

Fig. 4. Available nitrogen

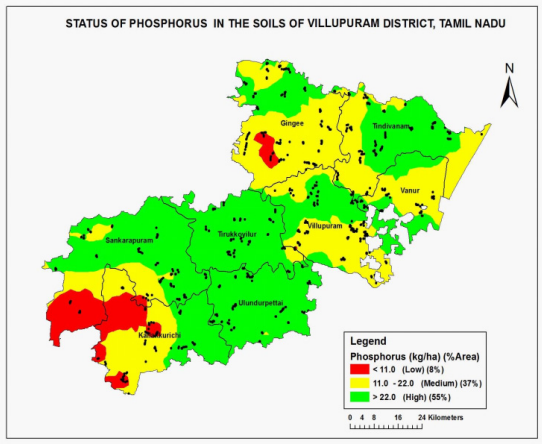

Fig. 5. Available phosphorus

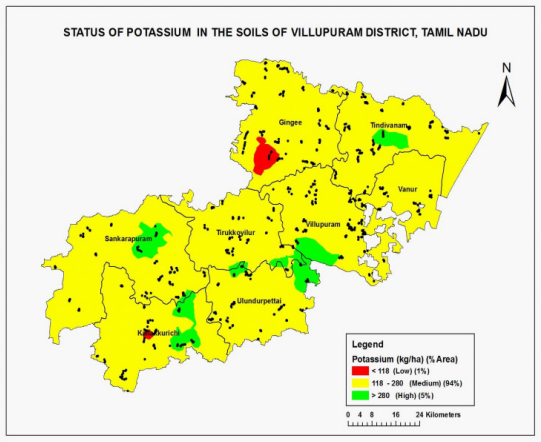

Fig. 6. Available potassium

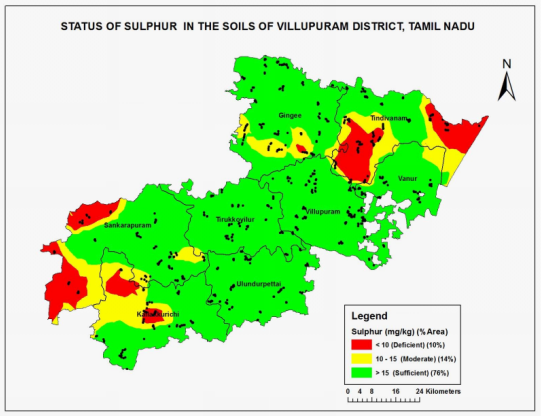

Fig. 7. Available sulphur

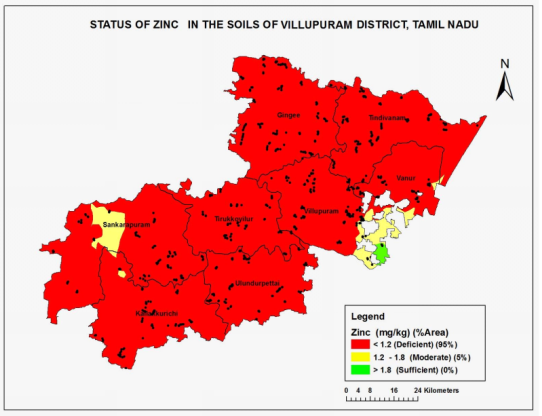

Fig. 8. Available zinc

Organic Carbon and Available Nutrients

The OC status was predominantly low accounting 68% of the total geographical area followed by medium (32%). With regard to available N, about 100% was under low category. In the case of available P, 55, 37 and 8% of the total area was under high, medium and low category, respectively. With respect to available K, 94% of the area was under medium, 5% under high and only 1% under low category. In case of available S, it was in sufficient range in 76% of the area, moderate in 14% and deficient in 10% of the total geographical area.

As far as available micronutrients are concerned, the Zn status was deficient in 95% of the area and a

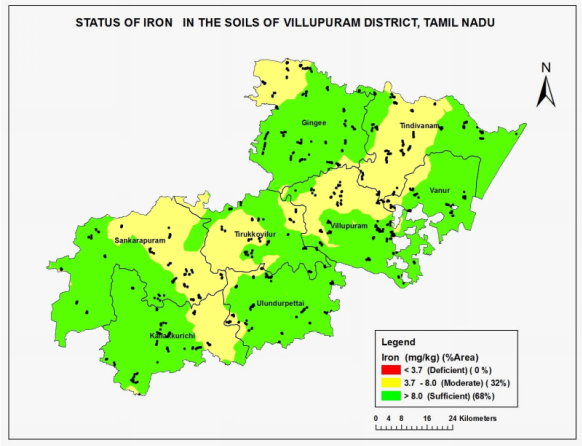

Fig. 9. Available iron

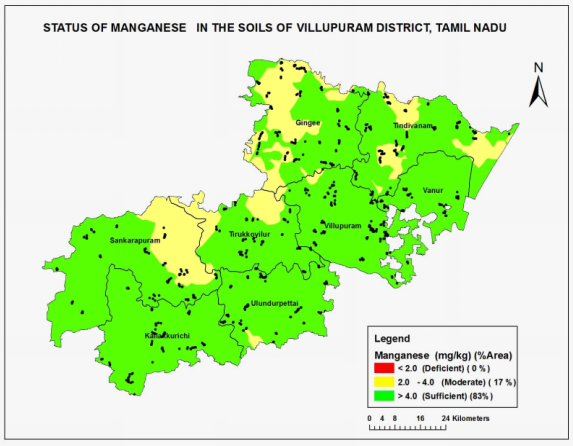

Fig. 11. Available manganese

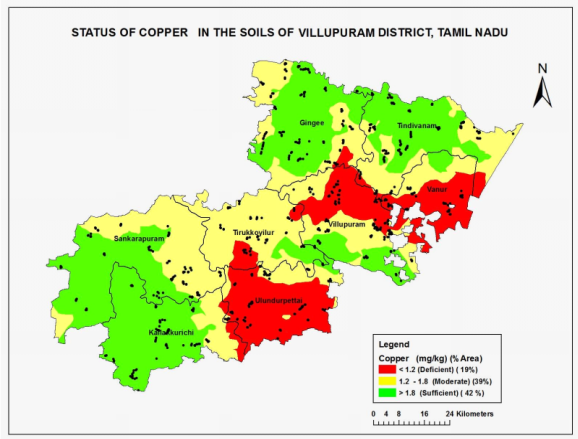

Fig. 10. Available copper

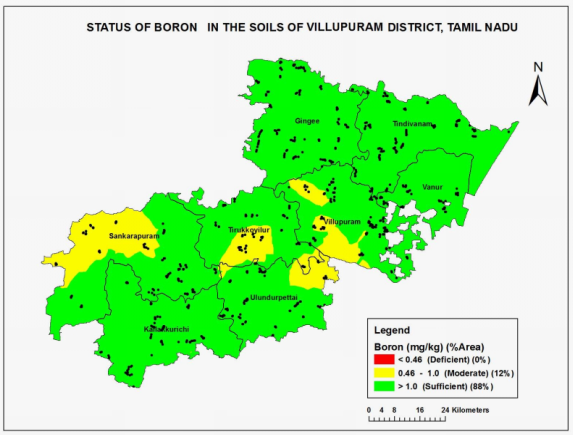

Fig. 12. Available boron

Table 2. Proposed nutrient plan for Villupuram district

Strategies	Taluks	Remedial measures
Soil amendment Acidity	Parts of Sankarapuram taluk	Incorporation of lime as per lime requirement. Acid tolerant crops *viz.,* millets, groundnut, sweet potato, cauliflower *etc.* can be grown.
Sodicity (pH>8.5, EC<4 dS m^{-1} and ESP >15)	Entire district is alkaline (except parts of Kallakkurichi, Sankarapuram, Gingee, Villupuram, Ulundurpettai, Tirukkoyilur, Vanur and Tindivanam taluks)	In these areas, where the sodicity exists, incorporation of daincha @ 5 t ha^{-1} and application of gypsum as per gypsum requirement is recommended. Provision of drainage for the removal of replaced sodium is suggested. Sodicity tolerant crops *viz*., rice, amla, eucalyptus, tamarind *etc*. can be grown. After reclamation, follow the STCR-IPNS recommendations for the particular crop.
Application of manures, microbial culture like *Trichoderma viride* for decomposition *etc.* for enhancing the organic carbon status	Whole district	Application of green manures / green leaf manures @ 6.25 t ha^{-1}/locally available organic manures *viz.,* FYM @ 12.5 t ha^{-1} /vermicompost @ 5 t ha^{-1}. *In-situ* crop residue incorporation along with *Trichoderma viride* (@ 4g kg^{-1}).
Recommendations for NPK	Whole district	As per STCR-IPNS recommendation for various crops and soils (Santhi *et al*. 2016; http://www.stcr.gov.in &http://www.soilhealth.dac.gov.in).

Contd...

Strategies	Taluks	Remedial measures
	High P areas – Whole district (except parts of Kallakkurichi, Sankarapuram, Gingee, Villupuram, Tindivanam and Vanur taluks).	50% of the recommended of P_2O_5 isrecommended as maintenance dose.
Recommendations for secondary/ micronutrients	S-Parts of Kallakkurichi, Sankarapuram, Tindivanam, Gingee and Vanur taluks.	Instead of DAP, application of SSP /gypsum is recommended
	Zn- Whole district	Recommended dose of $ZnSO_4$ can be applied according to crop and varieties (*e.g.* rice - $ZnSO_4$ @ 25 kg ha^{-1}).
	Fe- Parts of Sankarapuram, Kallakkurichi, Tirukkoyilur, Gingee, Villupuram, Tindivanam, Vanur and Ulundurpettai taluks.	Recommended dose of $FeSO_4$ can be applied according to crop and varieties (*e.g.* Sugarcane - $FeSO_4$ @ 100 kg ha^{-1}).
	Cu- Whole district (except parts of Kallakkurichi, Sankarapuram, Tirukkoyilur, Gingee, Tindivanam and Villupuram taluks).	Recommended dose of $CuSO_4$ can be applied according to crop and varieties (*e.g.* rice - $CuSO_4$ @ 5 kg ha^{-1}).
	Mn- Parts of Sankarapuram, Gingee, Tindivanam and Tirukkoyilur taluks.	Recommended dose of $MnSO_4$ can be applied according to crop and varieties (*e.g.* pearl millet - $MnSO_4$ @ 12.5 kg ha^{-1}).
	B- Parts of Sankarapuram, Tirukkoyilur, Villupuram and Ulundurpettai taluks.	Recommended dose of borax can be applied according to crop and varieties (*e.g.* groundnut - borax @ 10 kg ha^{-1}).

negligible area was under moderate (5%) and no sufficient area was reported. With regard to Fe status, predominantly sufficiency was recorded in 68% of the area followed by medium in 32% of the area and no deficiency status was reported. In case of available Cu, sufficiency was observed in 42% of the area while moderate and deficiency status was reported in 39 and 19% area, respectively. With regard to available Mn, predominantly sufficiency was recorded in 83% of the area followed by medium in 17% of the area and no deficiency status was reported. In the case of available B, sufficiency was reported in 88% of the area followed by medium in 12% of the area and no deficient status was reported.

Proposed nutrient plan for Villupuram district

Based on the soil fertility appraisal of the district nutrient plan for various taluks has been furnished in table 2 for implementation.

Conclusions

It can be concluded that based on thematic maps, a major area of Villupuram district was alkaline, non-saline, low in OC, low, high and medium in available N, P and K, respectively; with regard to available S and micronutrients, Zn was predominantly deficient and Cu was moderate while S, Fe, Mn and B were in sufficient status. As a whole, OC, available N, Zn and Cu are the major nutrient constraints in Villupuram district. Therefore, adoption of soil test crop response based integrated plant nutrition system (STCR-IPNS) and micronutrient recommendations to various crops/ cropping systems would enhance the crop productivity, fertilizer use efficiency and alleviate the deficiencies over long run. Based on the soil fertility appraisal of the district nutrient plan for various taluks has been furnished for implementation. By following the nutrient plan there would be balanced nutrition to crops and optimization of yields. The georeferenced sampling sites can be revisited with the help of GPS, which helps in monitoring the soil fertility changes over long run. Further, it will be useful to the researchers, planners, policy makers, extension workers of the State Department of Agriculture, fertilizer industries and farmers.

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