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Assessment of Spatial Variability of Soil Nutrient Status in Rice Ecosystem Using Nutrient Index in Anaimalai Block, Coimbatore

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A B S T R A C T

Geo referenced soil survey was undertaken in rice growing areas of Anaimalai Block, Coimbatore district of Tamil Nadu. The main aim of this study was to carry out the evaluation of soil fertility and fertilization practices being followed by the rice growing farmers of the selected villages in Anaimalai block. Soil samples were collected from 18 villages with an auger from a depth of 0-15 cm and analyzed for pH, electrical conductivity, organic carbon, available macro and micro nutrients using standard analytical methods. These data were used to spot the range of critical soil available nutrient and the relationships among the soil fertility parameters. Based on the results obtained, soil reaction was neutral to alkaline in nature. Electrical conductivity was found to be in safer limit (<1 dS m^{-1}) and almost 70 per cent of the villages fall under the medium category of soil organic carbon content. Results indicated that 70 percent of the samples are low to medium in available nitrogen; for Olsen P, it was 55 percent in medium status, 25 percent of the samples was under the highest P category (16-22 kg ha^{-1}); and about 80 per cent of the samples were medium in NH_4OAc – K. Except Cu, other micronutrients were deficient. From the nutrient index, Cu was above sufficiency range, P and Fe were found to be adequate and the other elements were deficit in soil.

Introduction

In the back drop of food crisis gripped India during 1960's the concept of green revolution was commenced to meet human need of fast growing population. Agriculture production was attentively considered as a main target to satisfy food constraints among the raising population. Traditional farming methods gave way to farming with high yield seeds, fertilizers and pesticides. Subsequently India has achieved a remarkable growth in agriculture, increasing food grain production from 83 mt in 1960-61 to about 252.23 mt in 2015-16. To augment food grain production, fertilizer consumption raised abruptly from 1 million tonnes (1960) to 25.6 million tonnes in 2016-2017 (FAI, 2017).

First of all, chemical fertilization was already crucial in the first half of the 1950s for the replenishment of soil nutrients. Without it soil nutrient balance would have been negative for both N and P although it would have remained positive for K. According to FAI (Fertilizer Association of India), the NPK ratio in India altered *viz.*, 4.6:2:1 in 2008-09, 4.3:2:1 in 2009-10, 6.5:2.9:1 in 2011-12, 8.2:3.2:1 in 2012-13 and 7.8:3.2:1 in 2015-2016 against the ideal ratio 4:2:1. Excessive use of fertilizers and associated chemical pesticides escort erosion of soil fertility, buildup of toxicity, loss of nutrients and deprivation of beneficial microbes.

Rice is the most important food crop around the world; in spite of its high domestic consumption. At present rice is grown in 158 million hectares throughout the world. China and India account for 55 percent of world rice production (FAO, 2017). In Anaimalai block of Tamil Nadu, rice is grown under larger area of 1500 ha. Presently, fluctuation in productivity and yield reduction is a flattering problem amongst farmers. Continuous cropping for enhanced yield removes substantial amounts of nutrients from soil in addition to that imbalanced use of chemical fertilizers, improper irrigation and various cultural practices also affect the soil quality rapidly (Medhe *et al.*, 2012). Inorganic fertilizer in improving fertility has been reported as futile owing to certain limitation such as decline in soil organic carbon, inappropriate use of chemical fertilizers, monocropping systems and reduction in beneficial microbial activity in soil (Shen *et al.*, 2010).

Hence soil fertility fluctuates throughout crop growing season each year due to alteration in quantity and availability of nutrients added by fertilizers, manure and compost. Evidence for rapidly changing nutrients in different ecosystems has also been reported (Bellamy *et al.*, 2005; Chen *et al.*, 2010). It was estimated that about 4.17 million tonnes of nitrogen, 2.13 million tonnes of phosphorus and 7.42 million tonnes of potassium are removed annually by agricultural cropping in India (Biswas and Mukerjee, 2001), thus affecting the soil nutrient availability (Zargar 2009). This has been aggravated by the negative nutrient balances of most cropping systems (Vlek *et al.*, 1997). Similar is the case with micronutrients like Zn, Fe, Cu and Mn deficiency can cause nutritional imbalance in the soils which may results in significant reduction in productivity (Wani *et al.*, 2014). Therefore, variation in soil properties should be continuously monitored and studied to understand the effects of different management systems on soils. The importance of reliable and timely information on soils cannot be overlooked in order to acquire spatial information of the soil properties, such information are necessary in the implementation of effective management strategies for sustainable agricultural production (Denton *et al.*, 2017). So, based on these views the survey has been conducted to assess the availability of the soil nutrient status in rice growing areas in Anaimalai Block, Coimbatore district of Tamil Nadu.

Materials and Methods

Description of the study area

Anaimalai Block situated in Coimbatore district of Tamil Nadu with latitude 10˚34’57.29”N and longitude of 76˚57’10.02”. It is positioned at a junction of Eastern Ghats and Western Ghats and has a general northwest-southeast trend with tropical climate. The summer receives high and winter receives very minimum rainfall with average precipitation of 1348mm. The average annual temperature in Anaimalai is 27.0 °C. Canal irrigation is the major source of irrigation.

Cropping pattern

In Anaimalai block, rice is cultivated under three different seasons *viz.*, Kar (May-June), Samba (Aug) and Navarai (Dec-Jan). The major cropping pattern of Rice-Rice-Pulses and Rice-Rice-Green manures were being followed by the farmers and routinely they grow green manure as offseason crop and incorporate it into the soil at the time of flowering stage.

Soil sampling and analysis

The accuracy and utility of soil test results depends on soil sampling precision. To fulfill the objective, 72 surface soil samples (15 cm depth) were collected at the rate of four samples per village, from 18 villages in Anaimalai block with latitude and longitude values by Global Positioning System (GPS).

Fertilizer packages followed in sampled area

Based on the collected information, the fertilizer practice for rice followed in eighteen villages revealed that nitrogen was excessively used (150-230 kg N ha^{-1}) than the recommended dose. With regard to phosphorus, more than 70 percent of the farms received sufficient phosphorus and it was supplied in the form of complex fertilizers and DAP and 15 per cent of the farms were applied with excess P (20-30 kg of P_2O_5 ha^{-1}) but regarding potassium the trend was reverse that most of the farms received 35 percent lesser than the recommended dose (50 kg ha^{-1}). Requirement of micronutrients is met through the micronutrient mixtures.

Physicochemical analysis of soil samples

Totally seventy soil samples were collected randomly with soil auger from a depth of 0-15 cm in Anaimalai block which belongs to the Irugur and Palladam soil series. The soil physico-chemical parameters *viz.,* pH, electrical conductivity (EC), organic carbon, available nitrogen, phosphorus, potassium and DTPA Fe, Zn, Mn and Cu were analyzed by using standard analytical methods. Soil pH was measured in a 2:1 water/soil ratio with a shaking time of about 30 minutes (ELICO – LI615 pH meter). Salinity was determined by measuring the electrical conductivity of the saturated soil extract given by Jackson (1967) EC (ELICO CM 180 Conductivity meter). Organic carbon was estimated by Chromic acid wet digestion method given by Walkley and Black (1934). Available N in soil was determined by alkaline permanganate method (Subbiah and Asija, 1956) and available P was analysed by 0.5 M $NaHCO_3$ (pH 8.5) Colorimetric with ascorbic acid reduction method by (Olsen 1954). Exchangeable K was estimated by flame photometer following soil extraction with Neutral Normal NH_4OAc (Standford and English, 1949). Sulphur ($CaCl_2$ method), Boron (Hot water soluble method) and Micronutrients (DTPA extract and Atomic Absorption Spectrometry method, Jackson (1973)) were analysed.

Nutrient availability index (NAI)

To appraise the fertility status of soils in the study area, different soil properties affecting nutrient availability including pH, electrical conductivity, organic carbon, available N, P, K, iron, manganese, zinc and copper were included. Here the nutrient index was worked out based on the formula given by Bajaj and Ramamurthy *et al.,* (1969). The nutrient index with respect to organic carbon, available N, P, and K, S, B, and micronutrients were used to evaluate the fertility status of soils in the 18 villages. Nutrient Index Value = (per cent samples in low category x 1 + percent samples in medium category x 2 + per cent samples in high x 3) /100

Sulphur Availability Index (SAI)

Sulphur Availability Index is derived as a key to assess the available S status in soils (Basumatary and Das, 2012).

SAI = (0.4 × $CaCl_2$ extractable SO_4^{-} in mg kg^{-1} soil) + % organic matter

Using statistical software package the statistical analysis and correlation studies were executed for soil samples and Pearson correlation matrix was used to locate the relationship between the two variables. Guildford's thumb rule was taken for the interpretation of the Pearson product moment correlation (Guildford, 1973)

Results and Discussion

Soil fertility status of study area

The data of physico-chemical parameters of soil samples are presented in Table 1.

Soil reaction (Soil pH)

Plant nutrients availability and accordingly soil fertility are affected by pH. Nutrient solubility varies in response to pH, which predominantly affect the accessibility of nutrients by plants (Clark and Baligar, 2000). Analysis of soil pH showed that soil reaction ranged from neutral to alkaline (6.59 – 8.87) across the soil samples. The highest pH value of 8.87 was recorded in the Kaliyapuram village followed by Periapodhu (8.71) and Kariyanchettipalayam (8.60) and 60 percent of samples were falls under the alkaline category. According to Brady and Weil (2005), alkalinity problem in soils arised due to indigenous calcareous parent material with typical low organic matter content. Soils of Somandhurai, Pilchinampalayam and Thensithur villages were identified under neutral category of soil reaction. In soils of Pethanaickanur, Thensangampalayam, Jallipatti, Subbegoundanpudhur, Marappagoundanpudhur, Anaimalai and Athupollachi village pH falls under the range of 7.01 to 7.89. For normal rice growth, pH range should be 5.5-8.0 which facilitates better growth development (Zhoa *et al.,* 2014). Therefore, observed pH in sampled area is favourable for rice cultivation (Table 3).

Among the three major nutrients, N (urea) is being excessively used than P and K. In spite of ammonium based fertilizer (urea), undeniably there might be a chance of fertilizer induced acidification (Mustafa *et al.,* 2018). However urea fertilization seemed to generate more significant change in soil pH in acid paddy soil than in alkaline paddy soil (Hong *et al.,* 2018). The study areas have near neutral to alkaline condition with mean pH values of 6.5 to 8.8. Consequently, a change in pH was observed as urea was applied surplus than the actual plant requirement. Also acid and base forming cations influences the soil pH to a great extent (Reuss, and Johnson, 2012). In this case, added urea possibly results in base forming cations (NH_4^+) which upon hydrolysis increases alkalinity through the discharge of OH- ions into soil solution. As a result, the effects of excess urea application could cause the effects by changing soil pH in acid paddy soil than the alkaline soil along with that base forming cations also responsible factor for maintaining such alkalinity even towards the long time application of excess N. From pearson correlation matrix, pH was identified as negatively correlated with N (-0.099) and Zn (-0.109).

Electrical conductivity (EC)

The electrical conductivity indicates degree of salinity, and its excessive soluble salts in soil solution creates pessimistic impacts on uptake process either by imbalance in ion uptake, antagonistic effect between the nutrients or excessive osmotic potentials of soil solution or a combination of the three effects (Visconti *et al.,* 2010). EC measured in soil samples collected from the Anaimalai block falls within the safer limit. It ranged between 0.15-0.32 dS m^{-1}. Among all the villages the highest EC was observed in Arthanaripalayam village (0.32 dS m^{-1}) and remaining villages were under the nonsaline category. Soil electrical conductivity is a measurement that correlates with soil properties that affect productivity, including cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, and subsoil characteristics (Corwin and Lesch, 2010).

Generally phosphorus fertilizers have the tendency to raise the EC level of soil (Naima *et al.,* 2015). However, the present fertilizer practices followed in the study area did not show any effect on soil EC (Table 4).

Soil organic carbon (OC)

Soil is known as the largest terrestrial carbon pool on earth where soil organic matter (SOM) constitutes the important biologically active form (Bhattacharyya *et al.,* 2013).

Role played by organic carbon is vital for agricultural soils which supplies plant nutrients, improves soil structure, improves water infiltration and retention, feeds soil micro flora and fauna, and augment retention and cycling of applied fertilizer (Johnston *et al.,* 2009).

The organic carbon content of the soils in the study area varied from 0.24 to 0.54 per cent (Table 5). The highest mean organic carbon value was recorded in Periapodhu (0.54%) and Pethanaickanur (0.52 %) and lowest content in Pilchinampalayam (0.24 %) and Kambalapatty (0.27 %). The study revealed that more than 70% of soil samples were found in the medium (0.5 to 0.75%) category and remaining villages were under the lowest category (<0.50%). The maintenance of SOM is desirable for long-term land use because of the manifold beneficial effects of organic matter on nutrient status, water holding capacity and physical structure (Alekhya *et al.,* 2015; Shukla *et al.,* 2004). Thus majority of rice grown areas are medium in organic carbon. According to Kavitha and Sujatha (2015), high levels of organic matter not only provides part of the N requirement of crop plants, but also enhance nutrient and water retention capacity of soils and create favourable physical, chemical and biological environment. It minimizes negative environmental impacts, and thus improves soil quality (Farquharson *et al.,* 2003).

Paddy soils has the tendency to accumulate SOM (Pan *et al.,* 2004) and represent an important carbon pool due to their high capacity for carbon sequestration under inundated soil conditions. Investigation on SOM accumulation in paddy soils revealed that organic carbon (OC) contents in paddy soils was significantly raised compared to non-inundated agricultural soils (Kalbitz *et al.,* 2013; Wissing *et al.,* 2013), which was ascribed to the OC buildup by the paddy silt- and clay-sized fractions (Wissing *et al.,* 2011). Additionally, it has been suggested that these higher OC contents in paddy soils are attributable to a plant residue or stubbles (Lehndorff *et al.,* 2014) in combination with the slower rates of OM decomposition that occur under inundated anaerobic soil conditions (Lal, 2002; Sahrawat, 2004; Zhang and He, 2004).

It has similarly been suggested that continuous wetland rice cultivation would enhance the accumulation of lignin residues in topsoils (Olk *et al.,* 2002) because they are highly resistant to degradation under anaerobic conditions (Colberg, 1988). Thus rice is cultivated continuously for more than decades in the study area, which might have added considerable quantity of plant residues and stubbles after every harvest of crop and thus on decomposition of the same would have contributed and maintained medium status OC in the soil.

Available nitrogen (N)

N was considerably the nutrient with larger flow in the agro ecosystem topsoil. The available nitrogen content ranged from 140 to 300 kg / ha. More than 90 percent of the soils were deficient (<280 kg ha^{-1}) in available nitrogen. According to the fertility ratings, 93 per cent of soil samples which belongs to the villages *viz.*, Divansipudhur, Subbegoundanpudhur and Pilchinampalayam were under the low category (< 0.5 %) and the remaining 7 percent was medium in status (0.5 - 0.75 %). Even though N was applied in excess, the build of N in soil was unseen. Medium status of N were noticed in Somandhurai, Angalakurichi and Pethanaickanur villages as 300, 254 and 235 Kg / ha respectively. Such variation in available N content may be attributed to soil management, application of FYM and fertilizer to previous crop.

Most of the farms had given excess N than recommended level, and its interaction may have antagonistic effect over the other nutrients. As this region receives high rainfall (1348 mm) every year, available N might have leached out and resulting in low available N in the study area. Denitrification can be major loss mechanism of NO_3^--N when the soil is under saturation. Buresh and Datta (1990) reported that denitrification has long been considered a major loss mechanism for N fertilizer applied to lowland rice (*Oryza sativa* L.) Also continuous and intensive cultivation leads to high crop removal together with insufficient replenishment might be the reason for the high degree of nitrogen deficiency in soils Amara *et al.*, (2017).

The medium status OC content of the soil may be attributed to low level of N in the soil which is also evidenced on the positive correlation obtained between OC and available nitrogen (0.132).

Available phosphorus (P)

Compared to N, phosphorus had only negligible nutrient flow in cropping system. P is a unique ion essential for root development, energy storage and transfer of nutrients, get entered into soil solution all the way through mineral fertilizers or mineralization of organophosphates. Plants can take up P ion by and large in the form of $H_2PO_4^-$ which was available at pH 7.2. The level of phosphorous in study area varied from 15 to 22 kg ha^{-1}.

Its mean content was significantly high in soils of Anaimalai, Subbegoundanpudhur and Athupollachi villages which covers 18 percent of the total collected samples and low in Thensamgampalayam and Angalakurichi villages (15 kg ha^{-1}). A high proportion of soil samples (80%) were medium in available phosphorus (15-22 kg/ha), which may be due to the sufficient contribution of phosphate fertilizers over a period of time (Denis *et al.*, 2017). Based on survey, P was sufficiently provided, even though its interaction was negatively correlated with Fe, Cu and Mn (Table 6). Positive correlation between P and OC was noted. Nye and Bertheux (1957) reported that mineralization of organic P is a concomitant reaction with the oxidation of organic matter which contribute 12 kg per ha of available P to the surface layers and also declining reserves of organic matter during subsequent cropping periods however, could not restore concentration of inorganic P at levels high enough to maintain adequate yields. Application of recommended dose of P coupled with P addition through the process of decomposition of organic manure may be attributed to high level of P in the rice soil.

Available potassium (K)

Large number of enzymes participated in physiological process gets activated by K ion only. From the study, accumulation of K in soil obtained by fertilizer K input is not enough to cope with the plant need. Almost all the farmers apply muriate of potash as source of K. Input application of K was not in accordance with recommended level for rice. Most of the rice farms were applied with lesser quantity of K (33 per cent lesser than RDF). Totally ninety per cent of the soil samples were medium in available K. Its mean content was significantly high in soils of Divansipudhur (228 kg ha^{-1}) and low in soils of Angalakurichi (108 kg ha^{-1}). The leaching condition brought in by rainfall does not permit retention of potassium on the soil exchangeable complex which might be the probable reason for the low potassium status (<280 kg ha^{-1}) of these soils (Pulakeshi *et al.*, 2012). The low available N recorded in this present study may be attributed to have lesser exchange with potassium on the soil exchange complex and thus potassium was maintained in medium status (Nguyen, 2003). K is in positive correlation with other nutrients except manganese.

Table.1 List of villages with GPS coordinates

S. No	Name of the villages	GPS Readings
1.	Pethanaickanur	10.5766° N, 76.9744° E
2.	Ramanamudhalipudhur	10.3339° N, 76.5828° E
3.	Thensamgampalayam	10.5474° N, 76.9672° E
4.	Somandhurai	10.5701° N, 76.9845° E
5.	Angalakurichi	10.5334° N, 76.9945° E
6.	Kariyanchettipalayam	10.3410° N, 77.0049° E
7.	Kambalapatty	10.5523° N, 77.0370° E
8.	Arthanaripalayam	10.5367° N, 77.0572° E
9.	Divansipudhur	10.6294° N, 76.8714° E
10.	Jallipatti	10.5367° N, 75.0572° E
11.	Pilchinampalayam	10.3536° N, 77.0573° E
12.	Subbegoundanpudhur	10.6286° N, 76.9326° E
13.	Periapodu	10.6099° N, 76.8807° E
14.	Marappagoudanpudhur	12.6863° N, 81.7209° E
15.	Anaimalai	10.5826° N, 76.9528° E
16.	Kaliyapuram	10.5400° N, 76.9211° E
17.	Thensithur	10.5646° N, 76.9845° E
18.	Athupollachi	10.6487° N, 76.9197° E

Table.2 Ratings followed for calculating the nutrient index

Soil Properties	Unit	Range		
Soil pH	pH	<6.5 (Acidic)	6.5-7.5 (Neutral)	>7.5 (Alkaline)
EC	dS m^{-1}	Upto1(Non saline)	1.1-3.0 (Slightly saline)	>3 (Saline)
Organic Carbon	%	<0.5 (Low)	0.5-0.75 (Medium)	>0.75 (High)
$KMnO_4$-N	Kg ha^{-1}	<280 (Low)	280-450 (Medium)	>450 (High)
Olsen –P	Kg ha^{-1}	< 11 (Low)	11-22 (Medium)	>22 (High)
NH_4OAc – K	Kg ha^{-1}	< 118 (Low)	118-280 (Medium)	>280 (High)
DTPA-Fe	mg kg^{-1}	<3.7 (Deficient)	3.7-8.0 (Moderate)	>8.0 (Sufficient)
DTPA-Mn	mg kg^{-1}	<2.0 (Deficient)	2.0-4.0 (Moderate)	>4.0 (Sufficient)
DTPA-Zn	mg kg^{-1}	<1.2 (Deficient)	1.2-1.8 (Moderate)	>1.8 (Sufficient)
DTPA-Cu	mg kg^{-1}	<1.2 (Deficient)	1.2-1.8 (Moderate)	>1.8 (Sufficient)

Table.3 Based on SAI value, the soils were grouped into three categories

Value	Interpretation (Sulphur availability)
<6.0	Low
6.0 to 9.0	Medium
>9.0	High

Table.4 Chemical properties of soil samples collected from eighteen villages in Anaimalai Block

S. No	Name of the villages	pH	EC (dSm^{-1})	OC (%)	$KMnO_4$ N (Kg ha^{-1})	Olsen P (Kg ha^{-1})	NH_4 OAc K (Kg ha^{-1})	Sulphur (Kg ha^{-1})	Calcium (Kg ha^{-1})	DTPA-Zn (mg kg^{-1})	DTPA-Fe (mg kg^{-1})	DTPA-Cu (mg kg^{-1})	DTPA-Mn (mg kg^{-1})	Boron (mg kg^{-1})
1.	Pethanaickanur	7.39	0.20	0.52	235.00	18.25	159.25	21.4	25.8	1.24	7.40	2.42	1.98	1.08
2.	Ramanamudhalipudhur	8.46	0.17	0.40	186.50	22.50	166.25	14.6	26.5	0.57	7.18	2.72	1.98	2.70
3.	Thensamgampalayam	7.01	0.19	0.45	228.25	15.25	152.00	20.4	24.3	1.23	4.48	3.48	2.29	2.53
4.	Somandhurai	6.59	0.16	0.52	300.25	17.75	156.50	19.9	22.3	1.57	7.46	2.88	2.41	1.96
5.	Angalakurichi	8.05	0.17	0.43	254.00	15.00	108.75	14.3	26.1	0.75	6.72	2.41	2.46	2.02
6.	Kariyanchettipalayam	8.60	0.16	0.31	257.25	21.00	170.50	21.3	23.1	1.13	7.26	3.14	2.45	2.15
7.	Kambalapatty	8.49	0.32	0.27	245.75	20.25	190.50	18.7	21.0	0.85	5.33	4.95	1.50	1.63
8.	Arthanaripalayam	8.28	0.15	0.40	209.50	19.00	200.50	23.1	26.2	1.29	6.80	4.25	2.34	1.03
9.	Divansipudhur	8.21	0.19	0.48	209.50	19.75	228.25	24.1	25.4	2.35	8.68	4.29	2.39	1.25
10.	Jallipatti	7.39	0.16	0.34	198.50	20.50	185.00	19.4	26.1	1.43	5.75	3.01	2.43	3.76
11.	Pilchinampalayam	6.72	0.27	0.24	174.00	19.50	169.75	20.3	26.0	0.60	4.82	1.95	1.64	2.35
12.	Subbegoundanpudhur	7.53	0.16	0.30	141.75	21.00	142.50	15.7	25.8	1.33	4.29	2.00	1.81	1.48
13.	Periapodu	8.71	0.23	0.54	181.75	16.75	179.50	18.3	25.6	1.13	5.97	2.01	2.31	1.11
14.	Marappagoudanpudhur	7.89	0.22	0.46	195.50	21.75	154.75	16.8	22.0	0.80	6.06	2.02	2.29	1.52
15.	Anaimalai	7.60	0.26	0.47	209.50	22.00	202.75	17.4	25.6	1.83	5.81	3.37	2.14	3.62
16.	Kaliyapuram	8.87	0.23	0.40	159.25	18.50	172.75	22.0	24.5	0.93	7.09	2.63	2.13	3.91
17.	Thensithur	6.96	0.24	0.53	154.25	19.50	174.00	21.5	24.2	0.94	6.47	2.90	1.96	2.40
18.	Athupollachi	7.79	0.18	0.43	187.25	22.00	201.25	23.1	24.3	1.33	5.38	1.57	1.87	1.83

Table.5 Nutrient rating for macro and micro nutrients of surface soil samples from rice growing area of Anaimalai Block of Coimbatore

Nutrients	No of Sample	Rating					
		L	M	H	D	M	S
Organic carbon	72	50(69.5)	22(30.5)	-	-	-	-
$KMnO_4$ N	72	67(93)	5(7)	-	-	-	-
Olsen P	72	1(1.3)	58(80.5)	13(18)	-	-	-
NH_4 OAc K	72	6(8)	66(91.7)	-	-	-	-
DTPA-Zn	72	-	-	-	37(51.4)	28(38.9)	7(9.7)
DTPA-Fe	72	-	-	-	1(1.3)	63(87.5)	8(11.2)
DTPA-Mn	72	-	-	-	51(70.8)	21(29.2)	-
DTPA-Cu	72	-	-	-	-	17(23.6)	55(76.3)
Sulphur	72	-	-	-	-	8(11.1)	64(88.8)
Boron	72	-	-	-	-	-	72(100)

(L: low; M: medium; H: high; D: deficient; M: moderate; S: sufficient)
(Numbers in the parenthesis denote percentage of samples falling within range)

Table.6 Nutrient index for macro and micronutrients in rice grown areas of Anaimalai block

S. No	Nutrient	Nutrient index	Fertility Rating
1.	Organic carbon	1.305	Low
2.	$KMnO_4$ N	1.07	Low
3.	Olsen P	2.163	Adequate
4.	NH_4 OAc K	1.914	Marginal
5.	Sulphur	2.88	Very high
6.	DTPA-Zn	1.583	Low
7.	DTPA-Fe	2.099	Adequate
8.	DTPA-Mn	1.292	Very low
9.	DTPA-Cu	2.761	Very high
10.	Boron	3	Very high

Sulphur (S)

In soils, S mostly remains in organic combination, constituting more than 95% (Wang *et al.*, 2008) of total sulphur. Sulphur is required by crops in amounts comparable with P and one of the essential secondary macronutrient elements required for optimum growth, metabolism and development of all plants and is rightly called as the fourth major plant nutrient (Tripathi *et al.*, 2018). On the whole S content ranges between 14.3 to 24.1 mg $kg^{-1.}$ In Anaimalai block, availability of sulphur was found to be in surplus (>15 mg kg^{-1}) in all the villages except Ramanamudhalipudhur (14.6 mg kg^{-1}) and Angalakurichi (14.3 mg kg^{-1}). The highest S content (24.1 mg kg^{-1}) was recorded in Divansipudhur followed by Arthanaripalayam (23.1 mg kg^{-1}).

The main source of sulphate in soils is through clay content and organic matter addition from plant and animal sources and inorganic fertilizes (Mess and Stoops, 2018). In the present study, organic carbon content of the soil was medium in status in 70 per cent of soil coupled with the addition of SO_4^- through the phosphatic fertilizer may be contributed to the high S status of soils.

The sulphur availability index (SAI) values varied between 6 and 10. Based on the values of SAI, soils of Ramanamudhalipudhur (6.53), Thensangampalayam (6.46) and Angalakurichi (6.8) were low in S. Divansipudhur traced with high SAI of 10.47. Generally organic matter is a reservoir of S. As 90 per cent of S is present in organic form, the OC of the rice soils are medium in status, which would have contributed enough S and thus recorded high S status and higher SAI values. According to SAI concept, if a soil containing SO_4^-S content just above the critical limit and low in organic matter content(<0.5%), it cannot be considered as sufficient in available sulphur, since there is less organic matter to support to inorganic fraction of S in case of any depletion. In soil sulphur is continuously cycled between inorganic sulphur and organic forms of sulphur (Saha *et al.,* 2018). It is also supported by positive correlation observed between SOC and S.

DTPA exctracted micronutrients (Zn, Cu, Mn and Fe)

With the intensive cropping of high yielding rice varieties, deficiencies of zinc initially and subsequently deficiencies of iron emerged as threats to sustaining high levels of rice productivity (Singh *et al.*, 2018).

The status of micronutrients (Zn, Cu, Mn and Fe) was analyzed and given in Table 2. The available zinc in soils varied from very low to high (0.57–1.83 ppm). In the soils of Ramanamudhalipudhur (0.57 mg kg^{-1}), Angalakurichi (0.75 mg kg^{-1}), Kambalapatty (0.85 mg kg^{-1}), Pilchinampalayam (0.60 mg kg^{-1}) and Marappagoudanpudhur (0.80 mg kg^{-1}) Zn deficiency was observed. Moreover 50 percent of the area surveyed in Anaimalai block was found to be deficient in available zinc. Remaining villages such as Pethanaickanur (1.24 mg kg^{-1}), Thensamgampalayam (1.23 mg kg-1), Kariyanchettipalayam (1.13mg kg^{-1}), Arthanaripalayam (1.29 mg kg^{-1}), and Subbegoundanpudhur (1.33 mg kg^{-1}) were found to have medium Zn content. 39 per cent of soil sample was moderate in Zn. The Zn status in the soils of Anaimalai and Divansipudhur villages was sufficient (>1.8 mg kg^{-1}). Deficiency of Zn might be due to the formation of Zn-phosphates following large applications of P fertilizer (Kavitha and Sujatha, 2015) and also conversion of soluble Zn to other insoluble forms of Zn like zinc hydroxide/zinc carbonate in rice soil (Kavitha and Sujatha, 2015). Hence, their solubility and mobility may decrease resulting in reduced availability.

Iron is an important micro nutrient which involves in activation of more enzymes which plays a vital in physiological process of the plants. The availability ranges of Fe in anaimalai block were 4.29 to 8.68 mg kg^{-1}. The samples collected from Thensamgampalayam (4.48 mg kg^{-1}) and Subbegoundanpudhur (4.29 mg kg^{-1}) villages were moderate in Fe content. Soil samples of Divansipudhur had sufficient Fe (8.68 mg kg^{-1}). Nearly 87 per cent of soil was sufficient in Fe (8.3 -9.4 mg kg^{-1}) status. Under anaerobic conditions ferric (Fe_3^+) is reduced to ferrous (Fe^{2+}) which would have significantly increased its solubility in soils (Zhang *et al.*, 2018).

As the study area maintained >0.5 percent of OC which would have contributed higher Fe^{2+} in the rice soils which was also reported by Hafeez *et al.,* (2018). It's also evident from the study that positive correlation was obtained between Fe and OC.

The DTPA extractable copper (Cu) content in rice soil ranged from 1.50 – 4.95 mg kg^{-1}. As per the fertility ratings (1.2-1.8 ppm), the Cu content was found to be sufficient in all villages of Anaimalai block (Table 1). The sample collected from Thensamgampalayam, Somandhurai, Angalakurichi, Kariyanchettipalayam, Arthanaripalayam, Jallipatti, Anaimalai and Periapodu villages had high Cu content (> 2.0 mg kg^{-1}). Out of total samples, 76 percent of samples were adequate in Cu content. The high Cu content recorded in 70 percent of the soil samples may be attributed to the production of organic complexing agents which might have solubilized and improved the availability (Cao and Hu, 2000).

The Mn content of soil samples ranged from 1.5 to 2.4 mg kg^{-1}. The highest Mn was recorded in Angalakurichi (2.46 mg kg^{-1}) and very low in Kambalapatty village (1.5 mg kg^{-1}). Seventy percent of the soil samples collected from the Anaimalai block was deficient in manganese. Manganese deficiency is, most often occurring in the soil with a pH above 6 and heavily weathered, tropical soils. It is typically worsened by cool and wet conditions (Alloway *et al.,* 2008) and moreover very common in degraded paddy soil high in Fe content, accumulation of H_2S. Since the study area was cultivated with rice for a long time and also the soil with high Fe content leads to such below level of Mn content in soil. Alkaline soils and the soils low in manganese rarely contain >10ppm at any stage of submergence as it is precipitated as manganese content (Das *et al.,* 1992).

Boron

Boron is water-soluble and is mobile in soil-water solutions. Boron is present in soil solution in several forms but, at soil pH of 5.5-7.5, the most dominant form is the soluble undissociated boric acid (H_3BO_3). Plants take up boron from soil in the form of boric acid. It appears that much of the B uptake mainly follows water flow through roots. Critical level of deficiency of B in rice at tillering to panicle initiation is 5 mg kg^{-1} (Dobermann, 2000). The results showed that, the boron content ranged between 1.03 to 3.97 mg kg^{-1}. Soil samples collected from Kaliyapuram (3.91 mg kg^{-1}) and Jallipatti (3.76 mg kg^{-1}) villages was rich in boron amongst other villages and in the remaining villages it was found between 2.0 and 1.0 mg kg^{-1}. It is observed that boron content was found to be adequate in all the villages. Boron associated with humic colloids is the principal B pool for plant growth (Jones, 2012). The strongest evidence that OM affects the availability of soil B is derived from studies that show a positive correlation between levels of SOM and the amount of hotwater-soluble B (Rasheed, 2009). In the present study also B content was positively correlated with organic carbon content.

However, it has been observed that in most plant species the boron requirement for reproductive growth is much higher than for vegetative growth this is especially true for gramineaceous plants, which have the lowest boron requirement to maintain normal vegetative growth, but need as much boron as other species at the reproductive stage (Matoh *et al.,* 1996). Hence the essentiality of boron for rice is vital and supplied in surplus amount as per the soil test values.

The study revealed that analysis of rice growing soils in Anaimalai block was neutral to alkaline and non-saline in nature. Organic carbon content ranged from low to medium across the locations. Majority of soils were medium in phosphorus and potassium and low in nitrogen. Despite N was applied above recommended level, available N was low in status (140- 300 kg ha^{-1}). With respect to micronutrients, except copper other three elements were deficient. From the nutrient index, Cu was above sufficiency range and P, Fe was found adequate and the other elements were deficit in soil.

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