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Physico chemical and biological properties of post flood soils in the south central laterites of southern Kerala

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Abstract

The south central laterites of Kottayam district was one of the worst hit areas during 2018 flood. The post-flood soils of the region required a site specific and detailed analysis of soil fertility parameters to understand the extent of damage. Surface soil samples were analysed for soil texture, particle density, WHC, pH, EC, organic carbon, available primary, secondary nutrients and acid phosphatase. The results showed that sandy clay loam was the predominant soil textural class in the area. Bulk density varied from 1.0 -1.6 Mg m⁻³ and maximum water holding capacity was less than 30 per cent for most of the area. Soils with moderately acidic pH increased compared to pre flood study. Organic carbon and available N were in high and medium range, respectively. The available P was reduced compared to pre flood soils while K was medium. Available Ca and S levels were sufficient. Mg deficiency was observed in 64.71 percentage of the samples in post flood area. A medium range of acid phosphatase activity was noticed in the region.

Keywords: Flood, soil physico-chemical properties, acid phosphatase activity

Introduction

Kerala is bestowed with very high rainfall, receiving an average of 3107 mm of rainfall, two times higher than that of national average (Kumar, S. K., 2013) ^[15]. But during 2018, the state experienced unprecedented rainfall causing much havoc to the entire state, except Kasargod district. From June to August 2018, 2346.6 mm rainfall was received against the normal level of 1649.5 mm which was 41 per cent higher than the expected level (CTCRI, 2018). Heavy rains and flooding have left many farm fields in need of physical repair. Flood water erode exposed soils, leaving deep gullies, drifted crop residues, building materials, as well as other types of debris (Blanco and Lal., 2008) ^[4]. The flood had resulted in landslides, water stagnation and deposition of sand/silt/clay in these areas in different dimensions, which needs urgent attention for restoring and sustaining soil productivity.

Kottayam, Pathanamthitta, Alappuzha, Ernakulam, Idukki, Malappuram and Wayanad districts were the worst hit by the torrential rain and flood (CTCRI, 2018) ^[12]. The flooded condition may remain for a few days or get extended for a longer period depending on soil conditions. Along with the flowing water, it may carry the most fertile top soil, suspended sediments, boulders and other particles and get deposited at faraway places or reach oceans, affecting the natural properties of soil. Flooding may result in shortage of food crops due to loss of entire harvest and the destruction of soil quality. The microorganisms use the available soil O₂ for their survival in the resultant reduced conditions. Free O₂ in the soil is usually depleted within a couple of days after flooding. The longer the soil is flooded, the lower the soil O₂ levels become more reduced. Oxygen deficiency is likely the most important environmental factor that triggers growth inhibition and injury in flooded plants (Visser *et al.*, 2003) ^[26].

In Kottayam district alone, 2014.8 mm RF was received during the three months of June to August, 2018 in 76 rainy days, registering 68 per cent increase over the normal RF of 1197.73 (in an average of 61 days) mm for the last ten years. Agricultural fields under AEU 9 experienced continuous inundation for two to four days mainly due to overflowing of Meenachil river and landslides from adjoining panchayaths. Heavy deposition of sand and silt were noticed on receding of the flood water. The crops were seriously damaged, especially in the low lying areas.

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The post-flood soils of the region require a site specific and detailed analysis of soil fertility parameters to understand the extent of changes. This analysis aids in the revision of nutrient management schedule for various cropping systems in the region. Therefore, the present study was conducted to assess the physicochemical and biological characteristics of post-flood soils.

Materials and Methods

Kottayam district spreads over three agro ecological units (AEU) viz., 4 (Kuttanad), 9 (South Central Laterites) and 12 (Sothorn and Central Foothills). It consists of 11 blocks and 79 panchayaths. AEU 4 and 9 were badly affected by flood while AEU 12 by landslide. The study was carried out in AEU 9 of Kottayam district which covers an area of 80330 ha. About 75% of people in the area are dependent on agriculture. The major crops cultivated in the area are mono cropped rubber and coconut in AEU 9. Sampling sites were selected based on a field survey and was done during the month of April, 2019, before the pre monsoon showers. The worst affected panchayaths in this agro ecological unit were Mutholi, Meenachil, Kuravilangadu, Kadaplamattam, Marangattupally, Madapally and Vakathanam and 51 geo referenced soil samples were collected.

Surface soil samples at 0-15 cm depth were taken. Core samples were also taken from each sampling point. The samples were immediately stored in plastic covers and transported to laboratory for further analysis. Soil samples were dried and sieved using 2 mm sieve before analysis in the laboratory. The samples were analysed for soil texture, bulk density, maximum water holding capacity, pH, EC, organic carbon, available N, P, K, Ca, Mg, S and acid phosphatase in the laboratory using AR grade reagents following standard analytical procedures. Soil textural analysis was done using bouyous hydrometer method (Jackson, 1973) [13]. Bulk density (Black *et al.*, 1965) [3] and maximum water holding capacity (Gupta and Dakshinamurthy, 1980) [10] were analysed using core samples. Soil pH was measured in 1:2.5 soil water suspensions using a pH meter. EC was measured using an EC meter in the supernatant of 1:2.5 soil water suspensions (Jackson, 1973) [13]. Organic carbon was estimated using Walkley and Black (1934) [27] rapid titration method. Available nitrogen was determined by alkaline permanganate method (Subbiah and Asija, 1956) [21]. Available phosphorus was extracted using Bray No. 1 solution and estimated using spectrophotometer (Bray and

Kurtz, 1975) [6]. Available potassium was estimated using flame photometer after extraction with neutral normal ammonium acetate (Jackson, 1973) [13]. Versenate titration method (Hesse, 1971) was followed to determine available calcium and magnesium. Available sulphur was extracted using calcium chloride and estimated using spectrophotometer (Massoumi and Cornfield, 1963) [17]. Acid phosphatase was determined by colorimetric estimation of p-nitrophenol released by soil is incubated with buffered (pH 6.5) sodium p-nitrophenyl phosphate solution and toluene at 37^o C for 1 hr. (Tabatabai and Bremner, 1969) [22]. The frequency distribution of soil pH, organic carbon and available P, K, Ca, Mg and S were compared with the pre flood data of KSPB (2013) [14].

Results and Discussion

Physical parameters

Soil texture, bulk density and water holding capacity

Soil texture refers to the relative proportion of sand, silt and clay particles, which determines the major physical properties (Phogat *et al.*, 2015) [19]. Majority of soils in this area belong to sandy clay loam texture). The mean value of percentage of sand, silt and clay was 52%, 18.5% and 30.2%. 43.14 per cent (Table 1). soils are of sandy clay loam texture; 15.69 per cent each of sandy clay and clay loam; 13.73 per cent sandy loam and 5.88 per cent each of clay and loam texture (Fig. 1).

The bulk density is a dynamic soil property which is influenced by the soil structure, texture, organic matter, constituent minerals and porosity. The mean particle density was 1.26 Mg m⁻³ (Table 2) and 15.69 per cent of the selected samples recorded bulk density 1.4 to 1.6, 52.94 per cent, 1.2-1.4 and 31.37 per cent, below 1.2 Mg m⁻³ (Fig. 2). In areas with high organic matter content and clay deposition, bulk density was comparatively less (Chaudhari *et al.*, 2013) [7]. And is also inversely related with soil porosity (Eluozo and Oba, 2018) [8].

Water holding capacity is a measure of the ability of soils to hold water against gravitational force and is dependent on soil texture and organic matter content. Soils with high content of clay and silt can hold more water because of higher moisture retention capacity. The organic matter stabilizes soil aggregates and improves pore orientation resulting in increased water holding capacity (Munkholm and Kay, 2002) [18]. 85 per cent of soils had WHC less than 30 and 15 per cent, in 30 to 50 range (Fig. 2). The mean value of WHC was 23.13 (%) (Table. 2).

Table 1: Sand, silt and clay (%) in the post-flood area of AEU 9 in Kottayam district

Panchayath	Sand		Silt		Clay	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Mutholi	45.5 ± 13.8	27.0 - 72.0	19.3 ± 7.76	5.00 - 30.0	35.1 ± 7.77	23.0 - 43.0
Meenachil	47.1 ± 18.3	22.0 - 67.0	25.7 ± 14.8	5.00 - 45.0	26.5 ± 4.46	23.0 - 33.0
Kuravilangadu	62.0 ± 7.64	47.0 - 72.0	13.5 ± 11.8	5.00 - 35.0	24.4 ± 6.90	18.0 - 33.0
Kadaplamattam	54.2 ± 10.6	42.0 - 67.0	12.8 ± 5.67	5.00 - 20.0	32.8 ± 6.34	23.0 - 38.0
Marangattupally	55.3 ± 12.6	42.0 - 77.0	12.5 ± 9.26	1.00 - 20.0	37.1 ± 8.20	18.0 - 43.0
Madapally	55.7 ± 19.7	17.0 - 72.0	15.5 ± 8.89	5.00 - 30.0	28.7 ± 12.3	18.0 - 53.0
Vakathanam	44.1 ± 13.1	32.0 - 62.0	30.7 ± 9.32	20.0 - 45.0	25.1 ± 6.99	18.0 - 33.0
AEU 9	52.0 ± 14.6	17.0 - 77.0	18.5 ± 11.4	1.00 - 45.0	30.2 ± 8.85	18.0 - 53.0

Fig 1: Frequency distribution of soil textural classes in post-flood soils of AEU 9 in Kottayam district

Table 2: Bulk density and water holding capacity in the post-flood areas of AEU 9 in Kottayam district

Panchayath	Bulk density (Mg m ⁻³)		Water holding capacity (%)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Mutholi	1.22 $\pm$ 0.11	1.05 - 1.35	26.0 $\pm$ 6.14	11.8 - 30.4
Meenachil	1.23 $\pm$ 0.08	1.12 - 1.32	24.3 $\pm$ 2.15	20.4 - 26.1
Kuravilangadu	1.23 $\pm$ 0.11	1.04 - 1.41	24.7 $\pm$ 4.58	17.0 - 28.6
Kadaplamattam	1.23 $\pm$ 0.08	1.12 - 1.34	25.1 $\pm$ 8.22	5.9 - 29.2
Marangattupally	1.32 $\pm$ 0.21	1.04 - 1.60	30.6 $\pm$ 2.82	26.7 - 35.6
Madapally	1.30 $\pm$ 0.15	1.10 - 1.50	27.5 $\pm$ 6.69	18.0 - 35.7
Vakathanam	1.33 $\pm$ 0.16	1.00 - 1.45	28.5 $\pm$ 7.69	13.9 - 35.4
AEU 9	1.26 $\pm$ 0.14	1.00 - 1.60	23.13 $\pm$ 7.71	5.90 - 35.7

Fig 2: Frequency distribution of bulk density and WHC (%) in post-flood soils of Kottayam district

Chemical attributes

Soil reaction, Electrical conductivity and Organic carbon

Soil reaction gives an indirect estimate of the soil biological activity and thus decides the availability of nutrients to plants. It varied from 4.42 and 6.25 as shown in table 3. 45.1 per cent of the soils were strongly acidic (5.01-5.50), 29.41 per cent moderately acidic (5.51-6.0), 17.65 per cent very strongly acidic (4.51-5.0) and 3.92 per cent slightly acidic (6.01-6.50). Only 3.92 per cent of samples (Fig. 3) were extremely acidic (3.51-4.50). It shows a slight decrease in the percentage of samples under extremely acidic and very strongly acidic ranges and an increase in moderately and slightly acidic ranges on comparing with the pre flood data (Geetha *et al.*, 2013). There was a net moderate enhancement in the soil pH in this AEU with flooding due to the deposition of basic cations. This increased pH would create a condition

favourable for microbial activity and result in more N mineralization (Alexander, 1977; Ono, 1991)

Electrical conductivity is a measure of total soluble salts in soil and indicates the availability of nutrients. 100 per cent of the soils were of EC < 1 dS m⁻¹ (Fig. 4). The mean value of electrical conductivity was 0.18 dS m⁻¹ (Table 3).

Soil organic carbon is one of the most dominant factor that influences soil physical, chemical and biological properties in maintaining soil health. 78.43 per cent of the soil samples had high OC (>1.50%) content and 21.57 per cent, medium status (0.5-1.5%) were given in Fig. 4. Compared to pre flood data, the organic carbon content increased from 37 to 78.43 per cent. The mineral materials brought by landslide may enhance the decomposition of organic matter and conversion to stabilized forms (Blonska *et al.*, 2017) [5].

Table 3: pH, EC and organic carbon in the post-flood areas of AEU 9 in Kottayam district

Panchayath	pH		EC (dS m ⁻¹)		OC (%)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Mutholi	5.18 $\pm$ 0.33	4.43 - 5.50	0.16 $\pm$ 0.07	0.10 - 0.30	1.52 $\pm$ 0.43	0.64 - 2.07
Meenachil	5.58 $\pm$ 0.40	5.09 - 6.25	0.16 $\pm$ 0.08	0.10 - 0.30	1.79 $\pm$ 0.60	1.03 - 2.83
Kuravilangadu	5.14 $\pm$ 0.41	4.42 - 5.62	0.17 $\pm$ 0.11	0.10 - 0.40	1.52 $\pm$ 0.42	0.84 - 2.04
Kadaplamattam	5.38 $\pm$ 0.19	5.17 - 5.67	0.14 $\pm$ 0.08	0.08 - 0.30	1.76 $\pm$ 0.34	1.26 - 2.21
Marangattupally	5.24 $\pm$ 0.47	4.58 - 5.71	0.15 $\pm$ 0.11	0.10 - 0.40	1.90 $\pm$ 0.33	1.15 - 2.17
Madapally	5.27 $\pm$ 0.53	4.58 - 6.19	0.23 $\pm$ 0.10	0.10 - 0.40	1.71 $\pm$ 0.34	1.13 - 2.25
Vakathanam	5.29 $\pm$ 0.46	4.68 - 5.81	0.26 $\pm$ 0.11	0.10 - 0.40	2.14 $\pm$ 0.36	1.51 - 2.58
AEU 9	5.29 $\pm$ 0.41	4.42 - 6.25	0.18 $\pm$ 0.10	0.08 - 0.40	1.76 $\pm$ 0.44	0.64 - 2.83

Fig 3: Frequency distribution of pH of post-flood affected soils of AEU 9 in Kottayam district **Fig 4:** Frequency distribution of EC (dSm⁻¹) and OC (%) in post-flood soils of Kottayam district

Available primary nutrients

Flooding may cause significant alterations in the availability of nutrients due to intense soil erosion and varied microbial activity and soil nutrient content varies with the depth and duration of flooding (Tsheboeng *et al.*, 2014) [23]. 58.82 per cent of samples were in medium and 41.18 per cent in low range of available N (Fig 5). The mean value of available nitrogen was 286 kg ha⁻¹ given in Table 4. The availability of N in flood affected soils may decline either due to increase in denitrification and nitrate reductase or altered residue decomposition (Baldwin and Mitchell, 2000) [2]. Available N decreases with flooding and consequential increase in NH₄-N and decrease in NO₃-N was noticed. Alternate anaerobic and

aerobic conditions result in more loss of N compared to completely flooded condition for a few days (Reddy and Patrick, 1975) [20]. Reduced conditions affect the production of phenolic compounds that can bind with proteins and render them unavailable to plants (Unger *et al.*, 2009) [24].

A wide variation in the soil available phosphorus content in the selected panchayaths. The mean value of available phosphorus in the study area came under high category (Table 4). The 41.18, 7.84 and 50.98 per cent of samples were in low, medium and high available P range, respectively (Fig 5). An increase in available P content under flooded condition was reported by Liang, 1996 [16] and later on declined by 2.8 times on receding of water. Phosphatase plays a big role in the

process of alteration of P components. It catalyzes the hydrolysis of phosphate or phosphoric anhydride, and its activity directly affects the decomposition and transformation of soil organic P and its bioavailability. Continuous decrease in P was observed during the flooding period due to lower phosphatase activity (Allison *et al.*, 2007) ^[1].

The analyzed samples of available potassium have 29.41 per cent were in the high available potassium (>275 kg ha⁻¹) range, which showed a decline from the pre flood data of 45.71 per cent (Fig.5). Those under medium range (115-275 kg ha⁻¹) increased from 38.28 to 56.86 per cent. The exchange reaction increases K in soil solution under flooded conditions (Valizadeh *et al.*, 2012) ^[25].

Table 4: Soil available major nutrients in the post-flood areas of AEU 9 in Kottayam district

Panchayath	Nitrogen (kg ha ⁻¹)		Phosphorus (kg ha ⁻¹)		Potassium (kg ha ⁻¹)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Mutholi	286 ± 21.5	225 -390	15.9 ± 5.82	10.1 -16.2	197 ± 31.5	145 -234
Meenachil	290 ± 22.2	256 -326	19.2 ± 11.5	8.56 -37.5	129 ± 85.3	95.2 – 317
Kuravilangadu	282 ± 27.3	246 -325	42.3 ± 18.3	15.7 - 58.4	175 ± 39.7	121 – 235
Kadaplamattam	288 ± 19.7	256 -323	33.0 ± 14.3	21.7 - 60.9	253. ± 97.1	112 – 324
Marangattupally	285 ± 25.8	250 – 323	34.6 ± 17.1	14.1 - 57.1	176 ± 59.3	91.4 – 254
Madapally	282 ± 14.0	265 – 303	21.5 ± 8.76	11.4 - 34.1	289 ± 49.5	201 – 336
Vakathanam	290 ± 60.2	246 – 315	16.1 ± 5.47	9.40 - 23.1	263 ± 79.2	112 – 369
AEU 9	286 ± 29.8	225 – 390	26.1 ± 15.3	8.66 - 60.9	223 ± 75.1	91.4 – 369

Fig 4: Frequency distribution of available N and P in post-flood soils of AEU 9 IN Kottayam district

Fig 5: Frequency distribution of available K in post-flood soils of AEU 9 in Kottayam district

Available secondary nutrients

In general, there was a slight increase in the sufficiency level of available Ca and Mg in most of the area. 90.2 per cent of the samples were in sufficiency Ca range. (Fig 6). Regarding Mg availability, 35.29 per cent of samples were found to be in sufficiency level. (Fig 7). The mean value of available calcium and magnesium was 347 and 117 mg kg⁻¹ respectively (Table 5).

Regarding S availability, 66.67 per cent of the samples were in sufficiency range, registering a decline from 85 per cent in the pre flood data. Flooding has resulted in a reduction in the fraction of soils with sufficient level of available sulphur content. Flooding of soils may increase or decrease sulphate sorption (Haque and Walmsley, 1974) ^[11].

Table 5: Soil available secondary nutrients in the post-flood areas of AEU 9 in Kottayam district

Panchayath	Calcium (mg kg ⁻¹)		Magnesium (mg kg ⁻¹)		Sulphur (mg kg ⁻¹)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Mutholi	359 $\pm$ 44.6	304 – 425	143 $\pm$ 67.4	72.0 – 250	20.0 $\pm$ 10.2	7.10 - 32.0
Meenachil	360 $\pm$ 40.7	311 – 420	181 $\pm$ 41.5	122 – 252	17.4 $\pm$ 2.82	12.5 - 21.0
Kuravilangadu	332 $\pm$ 47.4	260 – 410	70.2 $\pm$ 27.2	36.0 – 120	3.36 $\pm$ 1.14	1.00 - 4.50
Kadaplamattam	367 $\pm$ 43.9	308 – 431	83.0 $\pm$ 24.8	60.0 – 125	3.66 $\pm$ 3.17	1.00 - 10.2
Marangattupally	370 $\pm$ 53.9	305 – 432	97.5 $\pm$ 35.3	36.0 – 144	17.3 $\pm$ 4.05	11.0 - 23.0
Madapally	336 $\pm$ 41.2	275 – 386	115 $\pm$ 50.4	72.0 – 224	7.06 $\pm$ 4.72	2.50 - 15.4
Vakathanam	304 $\pm$ 57.7	220 – 372	130 $\pm$ 30.3	108 – 192	24.7 $\pm$ 13.3	7.50 - 44.0
AEU 9	347 $\pm$ 49.8	220 – 432	117 $\pm$ 53.3	36.0 – 252	13.5 $\pm$ 10.3	1.00 - 44.0

Fig 6: Frequency distribution of available Ca and Mg in post-flood soils of Kottayam district **Fig 7:** Frequency distribution of available S in post-flood soils of Kottayam district

Biological properties

Acid phosphatase activity

All the biochemical transformations in soil are dependent on enzyme activities and hence, an assay of enzyme activities will help to assess the soil fertility. 41.48 per cent of the soils had activity within the range 10-25 $\mu\text{g p-nitro phenol released g}^{-1}\text{ soil h}^{-1}$, 56.86 per cent between 25 and 50 and 1.96 per cent $>50\text{ }\mu\text{g p-nitro phenol released g}^{-1}\text{ soil h}^{-1}$ (Fig.8). The mean value of acid phosphatase was $27.4\text{ }\mu\text{g p-nitro phenol released g}^{-1}\text{ soil h}^{-1}$ (Table 6). It gives an indication of P cycling in soil. It is sensitive to oxygen stress and the activity decreases significantly with water logging, resulting in reduced P availability (Gu *et al.*, 2019) [9].

Table 6: Acid phosphatase activities in the post-flood areas of AEU 9 in Kottayam district

Panchayath	Acid phosphatase ($\mu\text{g p-nitro phenol g}^{-1}\text{ soil h}^{-1}$)	
	Mean $\pm$ SD	Range
Mutholi	33.0 $\pm$ 10.4	12.9 - 47.2
Meenachil	30.6 $\pm$ 18.1	14.2 - 71.3
Kuravilangadu	23.1 $\pm$ 8.78	22.1 - 48.8
Kadaplamattam	23.1 $\pm$ 7.81	10.6 - 63.0
Marangattupally	27.2 $\pm$ 9.55	14.0 - 38.7
Madapally	26.4 $\pm$ 12.79	11.2 - 47.5
Vakathanam	26.1 $\pm$ 7.39	19.4 - 39.6
AEU 9	27.4 $\pm$ 10.9	10.6 - 71.3

Fig 8: Frequency distribution of acid phosphatase activity in the post-flood soils of Kottayam district

Conclusion

Sandy clay loam was the predominant soil textural class in the post-flood soils of AEU 9 of Kottayam district of Kerala. On comparison of results with the pre flood data of KSPB (2013) [14], an increase in percentage of samples under moderately acidic range was observed in most of the area which, indicates leaching of basic cations. Organic carbon was high for about half of the areas. Available N was medium and available S were adequate for most of the area. There was a decrease in available P, adequate level of available Ca and Mg was increased. Comparison with pre flood data showed variations in soil reaction, organic carbon and available nutrient statuses indicating a need for revision in soil management strategies.

References

- Allison VJ, Condron LM, Peltzer DA, Richardso SJ, Turner BL. Changes in enzyme activities and soil microbial community composition along carbon and nutrient gradients at the Franz Josef chronosequence, New Zealand. *Soil Biol. Biochem.* 2007; 39(7):1770-1781.
- Baldwin DS, Mitchell AM. The effects of drying and re-flooding on the sediment and soil nutrient dynamics of lowland river-floodplain systems: a synthesis. *Int. J River Res. Manage.* 2000; 16(5):457-467.
- Black CA, Evans DD, Ensminger LE, White JL, Clark FE. *Methods of Soil Analysis*. American Society of Agronomy, Madison, USA, 1965, 1569.
- Blanco H, Lal R. *Principles of soil conservation and management* New York: Springer. 2008, 167-169.
- Błońska E, Lasota J, Piaszczyk W, Wiecheć M, Klamerus-Iwan A. The effect of landslide on soil organic carbon stock and biochemical properties of soil. *J Soils Sediments*. 2017, 1-11.
- Bray RH, Kurtz LT. Determination of total organic and available forms of phosphorous in soils. *Soil Sci.* 1945; 59:39-45.
- Chaudhari PR, Ahire DV, Ahire VD, Chkravarty M, Maity S. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *Int. J Sci. Res. Publ.* 2013; 3(2):1-8.
- Eluozo SN, Oba AL. Establishing porosity and bulk density analysis effect on foundation and flexible pavement in heterogeneous sand and silty formation. *Material Sci. Engg. Intl. J.* 2018; 2(1):8-13.
- Gu C, Zhang S, Han P, Hu X, Xie L, Li Y *et al.* Soil enzyme activity in soils subjected to flooding and the

effect on nitrogen and phosphorus uptake by oilseed rape. *Front. Plant Sci.* 2019; 10:368-378.

- Gupta RP, Dakshinamoorthi C. *Procedures for Physical Analysis of Soil and Collection of Agro - Meteorological Dates*. India Meteorological Department, Pune, 1980, 74
- Haque I, Walmsley D. Movement of sulphate in two Caribbean soils. *Plant and Soil.* 1974; 40(1):145-152.
- ICAR- CTCRI, Post-flood loss assessment and rehabilitation of tuber crops in Kerala. (Publ.) Dr. Archana Mukherjee, Director, ICAR-Central Tuber Crops Research Institute (Indian Council of Agricultural Research) Sreekariyam, Thiruvananthapuram. 2018, 103.
- Jackson ML. *Soil Chemical Analysis*. Prentice Hall of India Ltd., New Delhi, 1973, 219-221.
- KSPB [Kerala State Planning Board] *Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala*. Kerala State Planning Board, Thiruvananthapuram, 2013, 514.
- Kumar SK. *Kerala Model of Development-Critical Analysis and a Design for the Future* (Doctoral dissertation, BITS), 2013.
- Liang J. Studies on the composed form and releasing amount of phosphorus in podzoluvial under submerge condition. *Heilongjiang Agric.* 1996; 3:9-11.
- Massoumi A, Cornfield AH. A rapid method for determining sulphate in water extracts of soils. *Analyst.* 1963; 88:321-322.
- Munkholm IJ, Kay BD. Effect of water regime on aggregate- tensile strength, rupture energy and friability. *Soil Sci. Soc. Am. J.* 2002; 66:702-709.
- Phogat VK, Tomar VS, Dahiya R. Soil physical properties. In: *Soil Science: An Introduction*. (Eds.) Rattan, R. K., Katyal, J. C., Dwivedi, B. S., Sarkar, A. K., Tapan, B., Tarafdar J.C., and Kukal S.S. Indian Soc. Soil Sci. 2015, 135-141.
- Reddy KR, Patrick Jr WH. Effect of alternate aerobic and anaerobic conditions on redox potential, organic matter decomposition and nitrogen loss in a flooded soil. *Soil Biol. Biochem.* 1975; 7(2):87-94.
- Subbiah BV, Asija GL. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.* 1956; 25:259-260.
- Tabatabai MA, Bremner JM. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil boil. Biochem.* 1969; 1(4):301-307.
- Tsheboeng G, Bonyongo M, Murray-Hudson M. Flood variation and soil nutrient content in floodplain vegetation communities in the Okavango Delta. *South African J. Sci.* 2014; 110(3, 4):1-5.
- Unger IM, Motavalli PP, Muzika RM. Changes in soil chemical properties with flooding: A field laboratory approach. *Agric. Ecosys. Environ.* 2009; 131(1, 2):105-110.
- Valizadeh FF, Reyhani TA, Najafi N, Oustan S. Effects of combined application of Cd and Zn on the growth characteristics of rice plant and zinc, cadmium, iron and manganese concentration in soil under flooded vs. non flooded conditions. *J Soil Water.* 2012; 43:195-205.
- Visser EJW, Voesenek LACJ, Vartapetian BB, Jackson MB. Flooding and Plant Growth. *Annals of Botany.* 2003; 91(2):107-110.
- Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934; 39:29-38.