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Soil Quality Assessment under Different Land Uses in Pokkali Lands of Kerala

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Pokkali lands represent waterlogged coastal saline areas of Ernakulam, Thrissur and Alappuzha district of Kerala characterized by a unique farming system named after the renowned saline tolerant rice cultivar "_Pokkali_". Rice cultivation followed by prawn farming is the predominant eco-friendly land use system practiced here traditionally by the farmers. The unsustainable monoculture of prawn has gained momentum recently and resulted in severe soil quality deterioration and ecological imbalance. Hence this study was undertaken to evaluate the soil quality of acid saline _Pokkali_ soils under different land uses. Initial survey was conducted in _Pokkali_ area and five panchayats were selected from Ernakulam district, Kerala in which all the land use systems under the study were covered. The land use systems were, i) rice alone ii) rice – prawn iii) prawn alone iv) fallow and v) mangroves. Surface soil samples were collected from the selected panchayaths representing five land use patterns and were characterized for physical, chemical and biological attributes. From these data, minimum data set which highly influenced the quality of the soil was selected. The highest soil quality index (4.92) was observed in rice- prawn land use system in Nayarambalam panchayat and least value (2.07) was observed in prawn alone land use pattern in Kottuvally panchayat. The observed soil quality index value was in the order, rice- prawn> rice alone> fallow> mangrove> prawn alone. Based on the relative soil quality index value, all land uses were categorized into three groups, _i.e._ poor, medium and good. Rice- prawn land use system in Nayarambalam panchayat was the only one land use system coming under the 'good' category.

(**_Key words:_** _Fallow, Land use, Mangrove, Pokkali, Prawn, Rice, Soil quality_)

Acid saline soils in Kerala, locally known as *Pokkali* occur in the water-logged coastal regions of Ernakulam, Alappuzha and Thrissur districts of Kerala (Fig. 1). The Pokkali rice is famed for its peculiar taste and high protein content and has several medicinal properties and it has received a geographical indication tag also. In this farming system, a single crop of rice is taken in the low saline phase of production cycle (June to mid October) on mounds, followed by prawn farming during the high saline phase *i.e*., November to April. Rice cultivation followed by prawn farming is the predominant eco-friendly land use system practiced here traditionally by farmers. Other land use systems seen in *Pokkali* tracts include rice alone, rice-prawn, prawn alone, fallow and mangrove ecosystem.

The unsustainable monoculture of prawn is catching up in the *Pokkali* lands and has gained momentum in the last decade. Though this provides higher net returns over the traditional rice-prawn culture in the short run, it is found to be unsustainable in the long run, both in the ecological and the social context. Improper land use has caused severe quality degradation. During the past decades the area under *Pokkali* cultivation was about 25000 ha, but it get alarmingly reduced to an area of 5707 ha, showing that the indigenous cultivar is under threat. The factors like urbanization, soil quality deterioration, etc., are the major reasons behind this. Human population pressure upon land resources has increased the need to assess the impacts of land use changes on soil quality. The monitoring of extent of soil quality deterioration in different land use systems is essential for the development of sustainable land management practices in the *Pokkali* area.

MATERIALS AND METHODS

The *Pokkali* area comes under the agro-ecological unit 5, with an area of 26011 ha in Ernakulam, 11704 ha in Thrissur and 2049 ha in Alappuzha district. The land use systems seen in the *Pokkali* area, such as, i) rice alone ii) rice-prawn iii) prawn alone iv) fallow and v) mangrove were used for the present study. Initial

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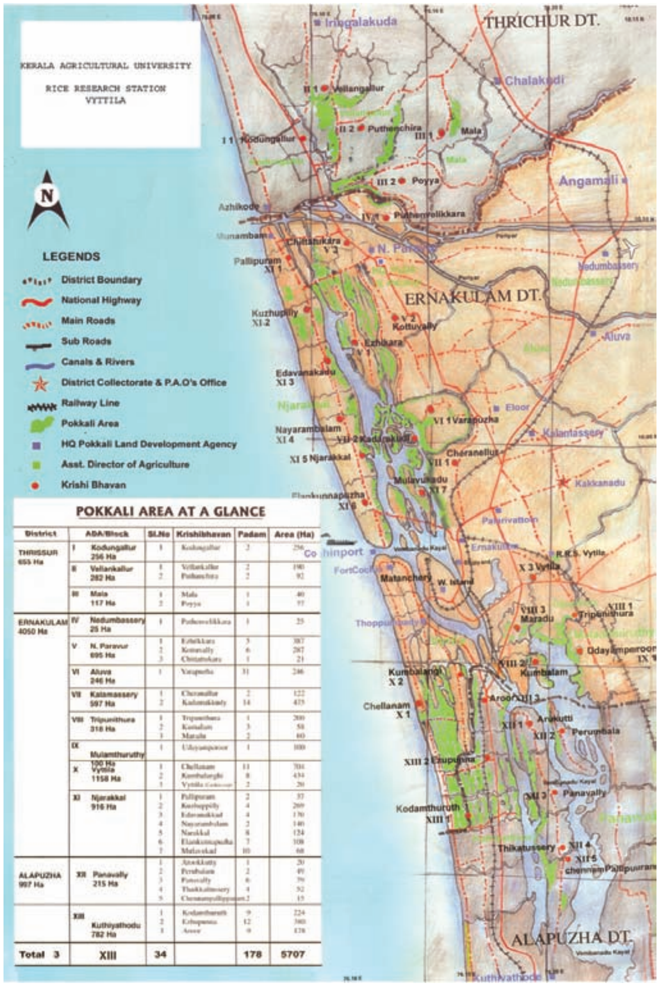

Fig. 1. Map of *Pokkali* area

survey was conducted on *Pokkali* tracts in these districts to identify the panchayats where all these land use systems were practiced. The panchayats were selected based on the criteria that, all the five land use systems existed only in these locations. They were, Kuzhippilly, Nayarambalam, Elamkunnappuzha, Edavanakkad and Kottuvally. Surface soil samples (0-15 cm depth) were collected in the low saline phase (June to November) in June 2013 just before the transplanting of rice from the selected five panchayats under five land uses. Three soil samples were collected from each land use system in each panchayat. A total of seventy five samples (3 samples x 5 land use systems x 5 panchayats) were collected for the study. Soils samples were analyzed for physical, chemical, and biological attributes.

Soil quality evaluation was done by the method described by Andrews *et al*., (2002). Three main steps of this technique includes, i) selection of minimum data set (MDS), ii) scoring of the MDS indicators based on their performance of soil functions, and iii) integration of the indicator scores into a comparative index of soil quality. The selection of representative MDS (Doran and Parkin, 1994) was done by the principle component analysis (PCA) based on the assumption that principle components (PCs) receiving higher values best represent the system attributes. Only the principle components, with Eigen values greater than one was then examined. Among each PC the one with the highest sum of correlation coefficients was chosen for the MDS.

The scores were then combined into an overall weighted additive soil quality index (SQI) using the formula,

$$SQI = \sum_{i=0}^{n} Wi \times Si$$

where, Wi and Si are respectively the weighing factor and score of the indicator. The weighing factors were derived from the PCA outcomes.

The change of soil quality was measured by computing relative soil quality index (RSQI) using the equation proposed by Karlen and Stott (1994).

$$RSQI = \frac{SQI}{SQIm} \times 100$$

RESULTS AND DISCUSSIONS

Soil quality was assessed by analyzing the physical, chemical and biological attributes of the soil. From these, selected attributes were used for working out the soil quality index. The minimum data set (MDS) was constructed using principle component analysis (PCA) for the vector of soil characteristics (28 attributes) namely per cent clay, per cent silt, per cent coarse sand, per cent fine sand, mean weight diameter (MWD), soil moisture at 0.30 bar, soil moisture at 15 bar, available water, bulk density, organic carbon (OC), dehydrogenase activity (DHA), microbial biomass carbon (MBC), pH, EC, available N, P, K, Ca, Mg, Fe, Cu, Mn, Zn, S, B, Na, cation exchange capacity (CEC) and base saturation (BS) (Table 1).

The PCA analysis resulted in six principle components (PCs) (having eigen value more than one) with PCs explaining 40.93 per cent, 11.904 per cent, 9.713 per cent, 7.49 per cent, 5.39 per cent and 4.61 per cent variance respectively. Since the major soil

Table 1. *Result of principle component analysis (PCA)*

Particulars	PC1	PC2	PC3	PC4	PC5	PC6
Eigen value	11.461	3.333	2.720	2.097	1.512	1.277
Variance %	40.933	11.904	9.713	7.491	5.399	4.561
Cumulative %	40.933	52.837	62.55	70.041	75.44	80.001
Eigen vectors						
Per cent clay	0.747	0.216	-0.060	-0.389	0.044	-0.081
Per cent silt	0.436	-0.273	0.193	0.375	-0.634	0.038
Per cent coarse sand	-0.712	0.104	0.434	-0.058	-0.236	0.109
Per cent fine sand	0.098	-0.285	-0.599	0.368	0.470	-0.079
MWD (mm)	0.396	-0.392	-0.008	-0.496	-0.220	0.232
FC	0.948	0.010	-0.124	-0.106	-0.034	-0.071
PWP	0.880	0.081	-0.080	-0.373	-0.027	-0.078
Available water	0.880	0.081	-0.080	-0.373	-0.027	-0.078
BD	-0.899	0.062	0.244	0.150	0.078	0.159
OC	0.814	-0.093	0.163	-0.104	0.156	-0.340
DHA	0.400	0.478	0.389	-0.006	0.423	-0.115
MBC	0.368	0.334	0.554	0.005	-0.080	-0.386
pH	-0.253	0.678	0.204	0.410	0.027	0.094
EC	0.468	0.125	-0.623	-0.027	0.060	-0.028
N	0.817	-0.230	0.196	-0.098	0.028	-0.026
P	0.653	0.274	0.316	0.350	0.148	0.035
K	0.741	0.273	0.059	0.193	-0.253	0.161
Ca	0.740	-0.238	0.170	0.248	0.151	0.313
Mg	0.619	-0.048	0.193	-0.297	-0.083	0.522
Fe	0.790	-0.112	0.296	0.119	0.127	0.018
Cu	0.513	-0.494	0.331	0.440	0.192	-0.154
Mn	-0.080	-0.374	0.310	-0.197	0.583	0.493
Zn	0.562	0.479	0.382	-0.10	0.061	-0.031
S	0.452	-0.684	-0.135	0.232	-0.068	-0.245
B	0.627	-0.367	0.176	0.372	-0.198	0.160
Na	0.623	0.341	-0.444	0.241	-0.035	0.156
CEC	0.811	0.163	-0.276	0.273	-0.005	0.212
BS	0.346	0.702	-0.400	0.169	-0.056	0.213

components were distributed in all six PCs based on the criteria of maximum component loading as suggested by Andrews *et al*., (2002) all these six PCs were taken into consideration for development of MDS. From each PC the highly weighted variable for MDS was only retained. As suggested by Andrews *et al*., (2002), highly weighted variables defined as that within 10 per cent of the highest factor loading (using absolute values).

In the first PC, per cent moisture at field capacity, permanent wilting point, available water, bulk density and organic carbon showed the high values of factor loading. But only available water, bulk density and organic matter were selected from the first PC, since available water content was derived from the difference between the moisture content at permanent wilting point and field capacity. From the second PC available sulphur, pH and base saturation showed the highest factor loading. In the third PC microbial biomass carbon (MBC), EC and per cent fine sand content were retained for MDS. From fourth PC only one variable was selected *i.e.*, aggregate stability which was measured in terms of mean weight diameter (MWD). Per cent silt and available Mn were selected from the fifth PC and available Mg content was retained for MDS from sixth PC. Final data base of MDS turned out to a set of 13 attributes (Table 2).

Table 2. *Minimum data set (MDS)*

PC1	PC2	PC3	PC4	PC5	PC6
Available water	pH	Fine sand per cent	Aggregate stability	Silt per cent	Available Mg
Bulk density	Available Sulphur	MBC	-	Available Mn	-
Organic carbon	Base saturation	EC	-	-	-

The MDS variables selected were scored using non linear scoring functions, where the y-axis ranged from 0 to 1 and x-axis represented a site dependent expected range. Three types of scoring functions were used.

More is better function

This function was used for the indicators like available water, organic carbon, available Mg, base saturation, microbial biomass carbon, aggregate stability and silt per cent. The upper asymptotes or more is better function was selected for soil organic matter (SOM) and water stable aggregates (WSA) based on their roles in soil fertility, water partitioning, and structural stability (Tiessen *et al*., 1994)

Less is better function

This function was used for indicators like bulk density (BD), available S, EC and available Mn. A lower asymptote or less is better function was used for BD due to the inhibitory effect of high BD on root growth and soil porosity. Since, the observed available Mn content in the different land uses was in toxic level (>1 mg kg^{-1} soil); the less is better function to mark the scores. The EC values recorded from study area was unfavorable for the crop growth (>1 dS m^{-1}). So less is better curve was selected for the development of scores. The available S content under different land uses came under toxic levels. So less is better curve function was selected for the development of scores for available S content.

Optimum curve

For indicators like pH, and fine sand per cent the optimum curve function was used. Starting from threshold, optimum level scores were allotted to both tales of the values in a decreasing order of importance.

Table 3. *Weight of each PC derived from PCA*

PCs	1	2	3	4	5	6
Weights (Wi)	0.41	0.12	0.09	0.07	0.05	0.04

Weights were determined by the fraction of precent variance of the PC where from the MDs variables were chosen (Table 3).

The calculated soil quality indices (SQI) are given in Table 4. In rice alone land use system the SQI values ranged from 3.88 in Elamkunnappuzha to 4.53 in Nayarambalam. The SQI in Kuzhippally, Edavanakkadu and Kottuvally was 3.94, 3.99 and 4.02, respectively. In rice-prawn land use system, SQI value varied from 3.24 to 4.92 and the lowest SQI value was observed in Edavanakkadu and highest was in Nayarambalam. In prawn alone land use system, SQI ranged from 2.07 in Kottuvally to 4.29 in Elamkunnappuzha, whereas, in fallow it was found to vary from 3.15 in Kottuvally to 4.36 in Elamkunnappuzha. In case of mangrove land use system, the lowest SQI value was observed in Kuzhippilly (2.23) and highest in Kottuvally (4.32).

Table 4. *SQI values in different panchayats under different land uses*

Panchayats	Rice alone	Rice-prawn	Prawn alone	Fallow	Mangrove
Kuzhippilly	3.94	4.71	2.4	3.35	2.23
Nayarambalam	4.53	4.92	3.84	3.35	3.43
Elamkunnappuzha	3.88	3.96	4.29	4.36	4.14
Edavanakkadu	3.99	3.24	2.31	4.04	3.56
Kottuvally	4.02	4.25	2.07	3.15	4.32
Average	4.07	4.22	2.98	3.65	3.54
RRS, Vyttila	4.66				

The mean values of rice alone, rice-prawn, prawn alone, fallow and mangrove systems were 4.07, 4.22, 2.98, 3.65 and 3.54, respectively. The SQI value calculated from Rice Research Station (RRS), Vyttila was 4.66. Among the various land use systems studied, the lowest SQI was observed in prawn alone land use pattern in Kottuvally (2.07) and highest was observed in rice-prawn land use system in Nayarambalam (4.92). Cultivation of rice improved the biological potential of fields since the stubbles left after the harvest decomposed and provided shelter and feed for the growth of microorganisms, which formed ideal food for prawns. In turn, the excreta of the prawn improved the soil quality. The highest soil quality in rice prawn system was attributed to the beneficial role on rice by aeration of the soil and subsequent release of soil nutrients. The improved oxygen exchange on account of the movement of prawn in rice field enhanced the dissolved nutrient mobilization due to mechanical stirring of the impounded water.

The computed SQI followed the order; rice-prawn> rice alone> fallow> mangrove> prawn alone land use systems. The lowest SQI value (2.07) was recorded in prawn alone land use system in Kottuvally panchayat, and rice prawn land use system in Nayarambalam showed the highest value (4.92). The rice-prawn land use system showed highest values for all available nutrients except available Cu and Mn indicating better nutrient recycling in the land use system. Sasidharan (2004) reported that the integrated farming system involving rice fish dual culture during the low saline phase and selective culture of *Tiger* prawn subsequently is capable of increasing the productivity and income from *Pokkali* lands. Many other researchers also reported that rice-prawn farming in *Pokkali* is a sustainable system of production harmoniously blended with natural processes like sea water inundation in the low-lying coastal zones of Kerala (Sasidharan, 2004; Sasidharan *et al*., 2012).

From the computed SQI values, per cent fine sand, EC, available Mn, MBC and MWD variables appeared to drive the SQI results. The rice-prawn integrated system recorded the highest SQI value. The prawn alone land use pattern showed lowest SQI value where toxicity due to available Mn acted as the major limiting factor. In rice alone land use system relative soil quality index (RSQI) value varied from 57.2 per cent in Elamkunnappuzha to 66.7 per cent in Nayarambalam (Table 5). In rice-prawn land use system, RSQI varied from 47.8 per cent to 72.5 per cent. The lowest value was observed in Edavanakkadu and highest was in Nayarambalam. In prawn alone system the lowest RSQI (30.5 per cent) was recorded in Kottuvally and highest value (63.2 per cent) in Elamkunnappuzha. In fallow system, lowest RSQI was recorded in Kottuvally (46.4 per cent) and highest in Elamkunnappuzha (64.2 per cent). In mangrove system, it varied from 32.8 percent in Kuzhippally to 63.7 per cent in Kottuvally. The average RSQI value calculated in various land use patterns were 60.0, 62.2, 43.9, 53.8 and 54.1 per cent, respectively (Table 6). In rice-prawn land use system, the recycling of nutrients in the rice ecosystem was enhanced and the environment was improved. The rice-fish/prawn system in the *Pokkali* lands continuously replenished the nutrients which in turn helped to improve soil quality. Hence, rice-prawn system in *Pokkali* lands is an economically viable, environmentally sound and socially acceptable enterprise.

Table 5. *Relative Soil Quality Index (RSQI) in different panchayats under different land use system*

Panchayats	Rice alone	Rice-prawn	Prawn alone	Fallow	Mangrove
Kuzhippilly	58.1	69.4	35.3	49.4	32.8
Nayarambalam	66.7	72.5	56.7	49.4	50.5
Elamkunnappuzha	57.2	58.4	63.2	64.2	61.1
Edavanakkadu	58.8	47.8	34.1	59.6	52.5
Kottuvally	59.2	62.7	30.5	46.4	63.7
Average	60.0	62.2	43.9	53.8	52.1
RRS, Vyttila	68.7	-	-	-	-

The RSQI calculated was good (72.50 per cent) only in rice-prawn land use system in Nayarambalam. Poor RSQI values were observed in rice-prawn system in Edavanakkadu, prawn alone land use system in Edavanakkadu and Kottuvally, fallow land use system in Kuzhippally, Nayarambalam and Kottuvally and mangrove land use system in Kuzhippally. RSQI value was medium in all panchayats with various land use patterns.

The results of the present study showed that among the land use systems in *Pokkali* lands, rice- prawn system recorded the highest soil quality index indicating the importance of this traditional farmers' practice which is economically viable and environmentally sustainable. The monoculture of prawn recorded lowest soil quality index which showed that this practice will deteriorate the soil quality in long run. Rice prawn farming system in *Pokkali* lands will sustain soil quality, ecological balance and economic viability.

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