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Assessment of soil quality indicators under rice ecosystem of Assam, India

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Abstract

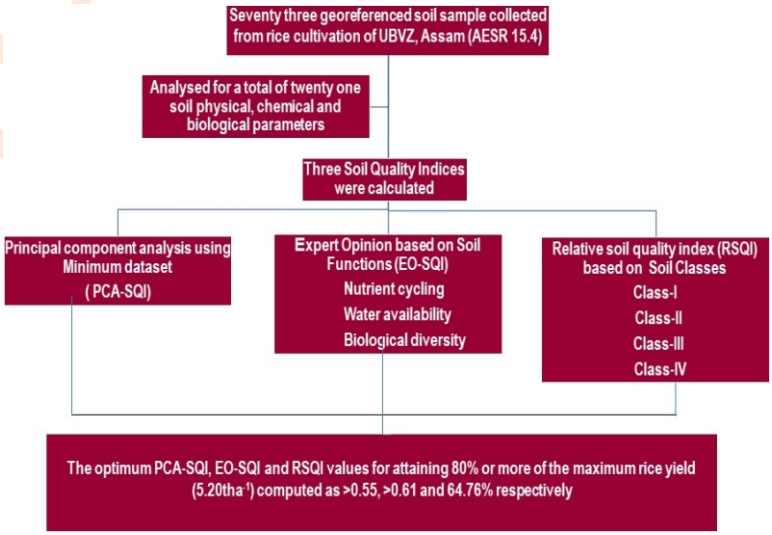
Aim: To assess the soil quality indices and its impact on rice yield in Upper Brahmaputra Valley Zone of Assam.

Methodology: Seventy-three numbers of geo referenced soil samples were collected from the rice ecosystems and analysed for twenty-one soil physical, chemical and biological parameters. The soil quality indices (SQI) were developed using statistical tools like principal component analysis (PCA) techniques and expert opinion (EO). Relative soil quality index (RSQI) was also developed for grouping the soils into categories. Correlation matrices were drawn between different soil quality indices. The optimum values of soil quality indices were computed to sustain 80% or more of the existing *in field* maximum rice yield (5.20 t ha^{-1}).

Results: Multivariate statistics showed that four biological parameters *viz*., fluorescein di-acetate activity, phosphate solubilising bacteria, total bacterial population and collembolan population and three chemical parameters *viz*., cation exchange capacity, electrical conductivity and diethylene tri amine penta acetic acid-Zinc could explain 70.2% of the cumulative variance. RSQI demonstrated that >50% and >30% of soils belonged to medium and good category. The regression of percent relative rice yield obtained from farmers field, illustrated that soil functions based EO-SQI could explain high degree of relationship (R^2=0.289; r=0.537*), followed by RSQI (R^2=0.284;r=0.532*) and PCA-SQI (R^2=0.143; r=0.378*) to explain the variability of soils. The optimum value indicates that the rice soils having PCA-SQI value >0.55 were likely to give 80% or more of the maximum yield of UBVZ of Assam.

Interpretation: Approaches of rating of soil quality based on PCA-SQI may be a useful tool, and there is need of more extensive investigations to validate its usefulness for assessment of soil quality in different cropping sequences of Assam.

Key words: Principal component analysis, Rice ecosystem, Soil quality index, Soil enzymes



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Introduction

The assessment of soil health and soil quality is necessary under intensive land use and management interventions. Different management practices causes variations in biological, chemical and physical properties of soil which in turn, changes the functional quality of soil (Bai *et al*., 2018; Ding *et al*., 2011). A bad choice of land use and management system by farmer's may lead to soil erosion, depletion of organic matter and other nutrients, resulting in soil degradation and losses in productivity (Ramos *et al*., 2011). Therefore, monitoring soil quality and its periodic assessment is necessary for sustenance of agricultural productivity and maintaining environmental parameters. Soil quality can be assessed using a combination of physical, chemical and biological properties (Dengiz, 2020; Constantini *et al*., 2016). It is important to study the changes in soil quality caused by management practices and functions (Nakajima *et al*., 2015).

Rice is an important crop in the South East Asian countries, more particularly in the Indian subcontinent. Assam, a north-east state of India has an area of 2.7 million ha under rice cultivation and about 55% of it as mono crop. Rice is grown in different season in Assam, and Sali rice (winter rice) covers 63.0 % of total area. In Assam, rice is still being cultivated using traditional practices like artificial submergence, ploughing and puddling, straw incorporation after harvest, etc. These practices have resulted in decline in productivity and deterioration of soil health, which has affected crop yield.

Thus, in order to assess the issue of yield sustainability, appraisal of soil quality and its change are required (Masto *et al*., 2007). Khaki *et al*. (2017) reported that assessment of soil productivity using soil quality index may provide useful information to plan advance strategies for sustainable agriculture. As intensive management in rice field results in changes in soil quality that are low, there is an urgent need for appropriate management to improve soil quality (Supriyadi *et al*., 2020).

There are very few studies in which assessment of soil quality indices using multivariate statistics and other techniques have been carried out in Assam (Buragohain *et al*., 2018). Therefore, a study was carried out to assess the impact of soil management practices on physical, chemical and biological properties of soils under rice ecosystem of Upper Brahmaputra Valley Zone of Assam.

Materials and Methods

Study area : The study was conducted in Upper Brahmaputra Valley Zone (UBVZ) of Assam, and it includes five districts *viz*., Sibsagar, Jorhat, Tinsukia, Dibrugarh and Golaghat. These districts account for 20.40% of total geographical area and considered under Agro Economic Sub Region (AESR) 15.4 of Assam. The AESR (15.4) is characterized by warm to hot per humid ecosystem with alluvium derived soils. The length of growing (LGP) period is >300 days with average rainfall of 2500-3000 mm, potential evapo-transpiration of 1400-1600 mm and average temperature of 23-24ºC. The AESR (15.4) has been divided into agro eco unit based on constrains and potentialities for developing long term land use strategies. The agro eco units mainly comprise of humid alluvial flood prone and flood free areas, sub humid medium and high land, Brahmaputra char area, high lands, hilly areas and sub humid alluvial flood free areas. The representative flood free and flood prone villages spread in the agro units under AESR (15.4) were selected for soil sampling which was carried out in consultation with Farm Science Centres, Assam Agricultural University, Jorhat and District Agricultural Offices, Government of Assam, India.

Soil sampling, cropping history of study site: Geo-referenced soil samples (0-15cm) were collected from rice field under AESR (15.4) just after harvest of Sali rice. Each soil sample was split into two groups; one group was air-dried and sieved, and used for further physical and chemical analysis, and the other group (fresh soil) was used to estimate the biological properties of soil**.** The fresh soil was stored at 4ºC until further analysis. In addition to surface soil samples, undisturbed soil samples were also collected from the fields using a tube core sampler for determination of bulk density (Blake and Hartge, 1986)**.** Rectangular soil sampler having a size of 30x11x8 cm was used for collection of soil up to 10 cm depth for the enumeration of collembolan (Singh *et al*., 1978). During collection of soil samples, the cropping history including management practices and rice yield of each field was recorded. A total of 73 representative soil samples were taken for analysis.

Soil analyses: Soil texture was determined following International pipette method (Piper, 1966). Soil pH was estimated in 1:2.5 soil: water suspension using a digital pH meter, and electrical conductivity (EC) with conductivity bridge (Model Elico Solu Bridge type CM-64 at 25ºC). Soil moisture content (SMC) was determined by gravimetric method (Gardner, 1986), soil organic carbon (SOC) by Walkley and Black (1934), available nitrogen by the Kjeldahl method (Subbiah and Asija, 1974), and available phosphorus Bray's I method, available potassium content by neutral normal ammonium acetate method and cation exchange capacity (CEC) determination by extracting the soil with neutral one normal ammonium acetate (Jackson, 1973). Zinc was determined following DTPA (diethylene triamine pentaacetic acid) micronutrient extraction method (Lindsay and Norvell, 1978).

Soil biological analyses: Microbial biomass carbon (MBC) (Vance *et al*., 1987) was measured following the chloroform fumigation-extraction technique. Fluorescein diacetate (FDA) hydrolysis activity was estimated colorimetrically using a Nano Drop 1000 spectrophoto meter (Thermo Fisher Scientific Country,

USA) and following the method of Adam and Duncan (2001). Phosphomonoesterase (PMEase) activity was measured colorimetrically according to the method of Tabatabai and Bremner (1969). Dehydrogenase (DHA) activity was determined by the reduction of triphenyl tetrazolium chloride (TTC) to triphenyl formazan (TPF) (Casida *et al.*, 1964), with modifications in terms of duration of incubation (24 hr instead of 6 hr). Soil aryl sulphatases (ARS) activity was measured using *p*-nitrophenyl sulphate (*p*-NPS) as substrate (Tabatabai and Bremner, 1970), and acetate buffer. The total number of fungi and bacteria were enumerated by the classical serial dilution technique (at a dilution of 1: 1000), using Czapek–Dox agar and Nutrient agar (NA) media respectively. Microbial population was estimated as colony forming unit (cfu g^{-1}) per gram soil on dry weight basis and transformed to Log cfu g^{-1}. Again, the classical serial dilution technique was also used for enumeration of *Azotobacter* (in Burk's media), *Azospirillum (N-free bromothymol blue media)* and PSB (in Pikovskaya's media).Soil collembolan activity was determined using 500 g of soil placed in the containers of Tullgren funnel and exposed to light source supplied by 60 watt bulb for 72 hr. The collembolan population were then observed under Stereoscope and the extracted population was estimated by the standard formula.

Microbial diversity index (Shannon diversity index (H') was determined by the following equation (Lupwayi *et al*., 2001).

$$H' = \Sigma\ p_i \times l_n p_i$$

Where, l_n is the natural logarithm and p_i the proportion of individual microbial colony found in the $_i$ soil sites.

Statistical analyses

Computation of Soil Quality Index: Descriptive statistics of physical, chemical and biological properties of soils was calculated. In order to determine the minimum data set for computing soil quality index (SQI) based on soil properties, Principal component analysis (PCA), and Expert Opinion (EO) were used. Relative soil quality index (RSQI) was worked out to group the soils from different regions into categories.

Principal component analysis (PCA): The minimum data set (MDS) was identified following the principal component analysis (PCA) using the principal components (PCs) having eigen values ≥ 1 (Brejda *et al*., 2000). Finally, SQI was calculated following standard methodologies (Andrews *et al*., 2002; Romanuik *et al*., 2011).

$$SQI = \sum_{i=1}^{n} (Wi \times Si)$$

Where, S_i is the score for variable *i* and W_i is the weighting factor derived from PCA.

Expert opinion: For comparison with PCA based SQI, another methodology EO was used to derive the MDS of indicators which best represent soil function, and involves consensus from the experts, concerns of participating farmers, agricultural extension workers and scientists involved during research work recommendations (Rao *et al*., 2012). Soil functions considered in this conceptual framework were nutrient cycling, water availability and biological diversity (Table 1), focussed on sustainable management of rice cultivation. These soil functions cover most of the physical, chemical and biological parameters which are primarily involved in transformation and availability of nutrients in soil. A total of 20 indicators were considered for EO and under the proposed framework.

Relative soil quality index: In order to compare soils of different sites, the RSQI was developed using 20 important and known physical, chemical and biological indicators with uniform weightage and scoring value (Table 2). Each indicator was divided into four classes namely, Class - I, Class - II, Class - III and Class - IV with an assigned mark of 4, 3, 2 and 1, respectively. The SQI in this case was calculated by the following equation:

$$SQI = \Sigma\ W_i \times M_i$$

where, W_i is the weight of indicator and M_i is the mark of indicator classes. Thus, summing up of all the 20 indicators provided, the SQI value for a particular soil of the farmer's field. The maximum value of SQI was 400 (best quality) and minimum value was 100 (poor quality soil) (Wang and Gong, 1998). In order to judge the SQI value of any site against the theoretical maximum value of SQI (*i.e*., 400), the concept of RSQI was used (Karlen and Stott, 1994).

$$RSQI = \frac{\text{Observed SQI of the given site}}{\text{Maximum value of SQI (}i.e.\text{, 400)}} \times 100$$

Mean percent relative yield computation: The mean percent relative yield of rice in farmer's field was computed by the following equation:

$$\text{Mean \% relative yield} = \frac{\text{Observed rice yield of a given site}}{\text{Maximum yield among the sites}} \times 100$$

Correlation coefficient and simple linear regression analysis: Correlation coefficients were calculated between SQIs and mean % relative yield. The optimum values for SQIs were also computed for sustaining existing rice yield of farmer's field. All the statistical analyses was carried out using SPSS software (version, 16.0).

Table 1 : Conceptual framework of soil functions and their allotted weight along with related indicators

Supporting soil function	Weight allotted to each soil function	Contributing indicators	Fraction of weight of soil function allotted to each indicator	Total weight of each indicator
Nutrient cycling	0.50	Available N	0.2	0.5X0.2=0.10
		Available P	0.1	0.5X0.1=0.05
		Available K	0.1	0.5X0.1=0.05
		DTPA Zn	0.05	0.5X0.05=0.025
		CEC	0.1	0.5X0.1=0.05
		Organic C	0.1	0.5X0.1=0.05
		pH	0.1	0.5X0.1=0.05
		Microbial biomass carbon	0.05	0.5X0.05=0.025
		Dehydrogenase activity	0.05	0.5X0.05=0.025
		Fluorescein diacetate activity	0.05	0.5X0.05=0.025
		Arylsulphatase activity	0.05	0.5X0.05=0.025
		Phosphomonoesterases	0.05	0.5X0.05=0.025
Water availability	0.30	Bulk density	0.5	0.3X0.5=0.15
		Organic carbon	0.5	0.3X0.5=0.15
Biological diversity	0.20	Azospirillum	0.2	0.2X0.2=0.04
		Azotobacter	0.1	0.2X0.1=0.02
		PSB	0.2	0.2X0.2=0.04
		Bacteria	0.2	0.2X0.2=0.04
		Fungi	0.2	0.2X0.2=0.04
		Collembolan	0.1	0.2X0.1=0.02
All functions	1.0			1.0

Table 2 : Soil quality indicators and their weights and classes for the evaluation of relative soil quality index

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV With score 1
Physical indicators					
Soil moisture content (%)	15	>15	12-15	9-12	<9
Texture	5	Loam	LS/CL/SL/SiCL/SiL	C/S/SCL	Grit
Bulk density(Mg m^{-3})	5	1.3-1.4	1.2-1.3/1.4-1.5	1.1-1.2/1.5-1.6	<1.1/>1.6
Biological indicators					
MBC (µg g^{-1})	10	>400	300-400	200-300	<200
Dehydrogenase (µg TPFg^{-1} 24 hr^{-1})	2	>200	200-150	150-100	<100
Flouresceindiacetate(µg fluorescein g^{-1} hr^{-1})	2	>30	30-20	20-10	<10
Phosphomonoesterase(µg p-nitro phenol g^{-1} hr^{-1})	2	>200	200-150	150-100	<100
Arylsulphatase(µg p-nitro phenol g^{-1} hr^{-1})	1	>50	50-40	40-30	<30
Bacteria (Log10 cfu g^{-1})	1	>5	5-4	4-3	<3
Fungi (Log10 cfu g^{-1})	1	>5	5-4	4-3	<3
Azotobacter (Log10 cfu g^{-1})	1	>5	5-4	4-3	<3
Azospirillum (Log10 cfu g^{-1})	1	>5	5-4	4-3	<3
Phosphate solubilizing bacteria (Log10 cfu g^{-1})	1	>5	5-4	4-3	<3
Chemical indicators					
Organic carbon (%)	15	>1	1-0.75	0.75-0.5	<0.5
Soil pH (1:2.5)	5	6.5-7.5	6-6.5/7.5-8.0	5.5-6.0/8.0-8.5	<5.5/>8.5
CEC [c mol (p+) kg^{-1}]	5	>18	18- 15	15-10	<10
Avail N (kg ha^{-1})	10	>545	545-445	445-272	<272
Avail P (kg ha^{-1})	10	>56	56-40	40-22.50	<22.50
Avail K (kg ha^{-1})	5	>337	337-237	237-136	<136
DTPA Zn (mg kg^{-1})	3	>1.2	1.2-0.6	0.6-0.4	<0.4
	100				

Results and Discussion

Descriptive statistics was carried out for twenty soil parameters (physical, chemical and biological) considered under the study. The mean BD of rice soils was 1.33 mg m^{-3}, with 57.53% soils showing a higher BD (>1.3 Mg m^{-3}) which might be due to continuous use of farm machinery like power tiller and tractor and lesser incorporation of organic inputs. Singh *et al.* (2009) reported that excessive tillage and puddling under rice–wheat cropping system in general, results in gradual compaction of soils, thus increasing BD.A higher SMC (>15) was found in 97.26 % soils, and the mean soil moisture content was found to be 29.35%, which might be due to poor soil drainage (Table 3).

Soil chemical properties are considered as the most affected by land management, while they have a great impact on crop productivity (Takoutsing *et al*., 2016). The mean available N content of rice soil was found to be 319.57 kg ha^{-1} and 79.45% soils showed a medium range of available N (272-544.00 kg ha^{-1}). The study sites, being in the subtropical region and coupled with preponderance of tillage practices and low external inputs, were rarely sufficient in nitrogen (Sanyal, 2014). The available P content of the soil showed a mean value of 31.97 kg ha^{-1}, and 78.08% soils showed available P in the medium range. Available K widely differed across the sampled sites with a range of 100.93 - 376.32 kg ha^{-1} (mean of 210.07 kg ha^{-1}), with 87.67% of the sampled soils showing a medium range (136.00-337.50 kg ha^{-1}). Mean OC was 0.89%, with 67.12% soils in the high range (>0.75%). SOC play a crucial role in long-term productivity of agro-ecosystems because it influences most of the soil properties and affects crop productivity (Tian *et al*., 2013). The CEC of soil was found to be low (<10.00c mol (p+) kg^{-1}) for 72.60% of the samples with a mean value of 7.68 c mol (p+) kg^{-1}. Soil acidity is an important agricultural problem leading to severe toxicity of Fe, Al and Mn in many crops, coupled with deficiency of P and low microbial activity that led to poor yield of crops in NER of India (Patiram, 2007). The mean pH value of rice soil was 4.72 in the ASER 15.4. The mean values of EC was 0.17 dSm^{-1}. DTPA-Zn content differed across the sites with a mean of 0.69 mg kg^{-1} and 57.53% soils were found to be in medium range (0.60-1.20 mg kg^{-1})

Table 3 : Descriptive statistics, percent distribution of soils properties, Shannon diversity index of microbial population and rice yield under UBVZ of Assam

Parameters	Descriptive Statistics			Percent (%) of rice soils		
	Maximum	Minimum	Mean	Low	Medium	High
Bulk density (mg m^{-3})	1.78	1.08	1.33	1.27	41.10	57.53
Soil moisture content (%)	39.66	13.35	29.35	-	2.73	97.26
Available N (kg ha^{-1})	463.42	137.98	319.57	20.55	79.45	-
Available P (kg ha^{-1})	73.45	15.64	31.97	19.18	78.08	2.74
Available K(kg ha^{-1})	376.32	103.93	210.07	9.59	87.67	2.74
Organic carbon (%)	1.77	0.42	0.89	2.73	30.14	67.12
DTPA-Zn (mg kg^{-1})	1.52	0.21	0.69	35.62	57.53	6.85
pH*(1:2.5)	6.45	4.13	4.72	43.84	52.05	4.11
CEC[c mol(p+) kg^{-1}]	14.98	2.93	7.68	72.60	27.40	-
Bacteria (log10 cfu g^{-1})	6.07	4.87	5.51	-	1.37	98.63
Fungi (log10 cfu g^{-1})	4.61	3.00	3.74	86.30	13.70	-
Azotobacter (log10 cfu g^{-1})	4.78	3.36	4.17	35.60	64.38	-
Azospirillum (log10 cfu g^{-1})	4.78	3.45	4.15	39.73	60.27	-
Phosphate solubilizing bacteria (log10 cfu g^{-1})	4.65	3.21	3.90	61.64	38.36	-
Microbial biomass carbon (µg g^{-1})	898.88	117.76	511.35	5.48	26.03	68.49
Dehydrogenase activity (µg TPFg^{-1} 24 hr^{-1})	332.07	23.32	77.78	69.86	30.14	-
Phosphomonoesterase activity (µg p-nitro phenol g^{-1} hr^{-1})	512.79	9.51	168.48	23.29	49.32	27.40
Fluorescein di-acetate hydrolysis (µg fluorescein g^{-1} hr^{-1})	31.56	4.49	15.60	17.81	80.82	1.37
Arylsulphatase activity (µg p-nitro phenol g^{-1} hr^{-1})	185.37	14.50	76.99	10.96	8.22	80.82
EC (dSm^{-1})	0.77	0.03	0.17	100.00	-	-
Collembolan (nos. m^{-2})	709.81	313.67	515.25	5.75	20.00	74.25
Shannon Index	1.60	1.59	1.58	-	-	-
Rice yield (t ha^{-1})	5.20	2.10	4.26	-	-	-

Ratings for fertility status as per ICAR guidelines for soil physical and chemical properties and for biological properties, the authors referred to Rao *et al.* (2012), Kundu *et al.* (2012) and Siddiky *et al.* (2012)

Understanding the response of soil micro-organisms towards different synthetic fertilizers and organic matter inputs is helpful in assessment of soil quality (Sharma *et al*., 2010). Across the sites, 98.63% rice soils showed higher bacterial population (> 5.0 log_{10}cfu g^{-1}), with a mean of 5.51 Log_{10} cfug^{-1} soil, which may be attributed to profuse root exudation in rice crop favouring the rhizosphere dwelling bacteria, and also high soil moisture conditions during rice cultivation (Canarini *et al*., 2019). Likewise, the mean fungal population was 3.74 Log_{10}cfu g^{-1} soil, and low fungal population in 86.30% soils (<4.0 log_{10}cfu g^{-1}) may be attributed to damaged fungal hyphae owing to tillage practices and intercultural operations. In addition to this, fungi prefer low water content for its growth (Lopes *et al*., 2011).

The mean population status of *Azotobacter*, *Azospirillum* and PSB was 4.17Log_{10} cfu g^{-1} soil, 4.15 Log_{10} cfu g^{-1} soil and 3.90 Log_{10} cfu g^{-1} soil, respectively, with 64.38%, 60.27% and 38.36% of the soils samples belonging to medium range of population count of these plant growth promoting micro-organisms.

Microbial biomass and soil enzymes are closely related to biochemical processes such as residue decomposition and nutrient cycling (Wang *et al*., 2013). Soil MBC respond more quickly to soil management than total soil organic matter and most other carbon pools (Blagodatskaya *et al*., 2011; Guillaume *et al*., 2016). In the study, mean microbial biomass carbon (MBC) was recorded to be 511.35 µ g^{-1} soil (Table 3). The higher MBC in 68.49% of the soils may be a result of better crop growth, owing to release of root exudates and also the left over crop residues which subsequently decompose and facilitate availability of carbon and nitrogen to the soil microbial pool (Chen *et al*., 2018; Mandal *et al*., 2007).

Various soil enzyme activities are influenced by agricultural practices like tillage, nutrient management, cropping system, etc. (Srinivasarao *et al*., 2014). The mean value of PMEase and ARS activity was 168.48 µg *p*-nitrophenol g^{-1} hr^{-1} and 76.99 µg *p*-nitrophenol g^{-1} hr^{-1} respectively, while that of DHA and FDA was 77.78 µg TPFg^{-1} and 15.6µg fluorescein g^{-1} hr^{-1} respectively. These enzymes show rapid response to changes in soil management and their better activity in rice soils could be due to higher levels of OC (mean value 0.89%) (Verma *et al*., 2017).

Table 4 : Principal components (PC) of soil quality parameters, eigen values, communalities and rotated component matrix variables under rice cultivation

Parameters	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**Communalities**
Eigen value	**3.967**	**2.097**	**1.925**	**1.673**	**1.431**	**1.128**	**1.112**	**>0.5**
% Variance	**20.879**	**11.035**	**10.131**	**8.807**	**7.532**	**5.934**	**5.851**	
Cumulative %	**20.879**	**31.914**	**42.045**	**50.852**	**58.383**	**64.318**	**70.169**	
Weightage	**0.297**	**0.157**	**0.144**	**0.125**	**0.107**	**0.084**	**0.083**	
Rotated component matrix								
Av.N	0.062	0.730	0.162	0.021	-0.289	0.054	-0.224	**0.700**
Av.P	0.619	-0.174	0.215	-0.221	0.011	0.213	-0.288	**0.637**
OC	0.494	0.437	0.255	-0.180	0.009	0.394	-0.136	**0.706**
DTPA-Zn	-0.035	-0.064	-0.040	-0.113	-0.063	0.877	0.138	**0.813**
CEC	-0.006	0.808	-0.042	-0.029	0.049	-0.111	0.030	**0.672**
pH	-0.436	-0.067	-0.153	-0.503	0.158	0.373	-0.028	**0.636**
EC	-0.116	0.062	-0.116	0.835	0.019	-0.112	0.174	**0.771**
BD	-0.090	-0.123	0.497	0.569	-0.192	-0.134	-0.003	**0.649**
SMC	0.005	0.097	-0.300	0.543	0.213	0.322	-0.403	**0.706**
Bacteria	0.109	-0.052	-0.194	0.095	0.778	0.070	-0.090	**0.680**
Fungi	-0.135	0.013	0.275	-0.175	0.658	-0.136	-0.101	**0.586**
Azotobacter	-0.002	0.274	0.759	0.030	-0.057	0.020	0.115	**0.669**
PSB	0.125	0.060	0.830	-0.106	0.093	-0.029	-0.058	**0.732**
MBC	0.279	0.705	0.289	0.160	0.118	0.012	-0.031	**0.699**
DHA	0.785	0.026	-0.097	-0.111	0.004	-0.133	0.067	**0.661**
PME	0.652	0.215	0.265	0.089	0.247	0.047	0.153	**0.636**
FDA	0.872	0.145	-0.096	0.095	-0.179	-0.022	-0.031	**0.833**
ARS	0.552	0.447	0.024	0.004	0.230	-0.051	0.484	**0.795**
Collembolan	0.001	-0.197	0.029	0.120	-0.211	0.185	0.787	**0.752**

Bold Italicized factor loadings are considered highly weighted when within 10% of variation of the absolute value of the highest factor loading in each PC. Boldface variables represent those indicators selected for the SQI after redundancy analysis; Av.N, Available nitrogen; Av.P, Available phosphorus; OC, Organic carbon; DTPA-Zn, Diethylene triamine penta-acetic acid extracted Zn; CEC, Cation exchange capacity; EC, Electrical conductivity; BD, Bulk density; SMC, Soil moisture content; PSB, Phosphate solubilizing bacteria; MBC, Microbial biomass carbon; DHA, Dehydrogenase activity; PME, Phosphomonoesterase activity, FDA, Fluorescein di-acetate hydrolysis; ARS, Arylsulphatase activity

Table 5 : Soil quality index and contribution of individual indicators computed using PCA cultivated rice soils and contribution of individual and cumulative percentage of key indicators towards maximum, minimum and mean SQI

Indicators under PCs	SQI of Individual indicators			Percentage contribution of individual and cumulative indicators towards maximum, minimum and mean values					
	Maximum	Minimum	Mean (±SD)	Maximum SQI		Minimum SQI		Mean SQI	
				Individual	Cumulative	Individual	Cumulative	Individual	Cumulative
FDA (PC1)	0.26	0.10	0.15(±0.05)	34.21	34.21	23.26	23.26	25.86	25.86
CEC (PC2)	0.12	0.04	0.08(±0.03)	15.79	50.00	9.30	32.56	13.79	39.65
Phosphate solubilizing bacteria (PC3)	0.13	0.10	0.12(±0.01)	17.11	67.11	23.26	55.82	20.69	60.34
EC (PC4)	0.04	0.02	0.03(±0.02)	5.26	72.37	4.65	60.47	5.17	65.51
Bacteria (PC5)	0.10	0.09	0.10(±0.01)	13.16	85.53	20.93	81.40	17.24	82.75
DTPA-Zn (PC6)	0.05	0.02	0.04 (±0.02)	6.58	92.11	4.65	86.05	6.90	89.65
Collembollan (PC7)	0.06	0.06	0.06(±0.01)	7.89	100.00	13.95	100.00	10.34	100.00
SQI	0.76	0.43	0.58(±0.07)						

Table 6 : Expert opinion-based soil quality index (EO-SQI) of rice soils

Soil functions	Rice soils		
	Maximum	Minimum	Mean (±SD)
Nutrient cycling	0.36	0.18	0.27(±0.04)
Water availability	0.27	0.13	0.19(±0.02)
Biological diversity	0.18	0.15	0.17(±0.01)
EO-SQI	0.81	0.46	0.63(±0.06)

Table 7 : Grouping of rice soils based on relative soil quality index (RSQI) values

RSQI (%)	Quality rating	% Rice soils (n=73)
<50%	Poor	1(1.37%)
50-70%	Medium	43(58.90%)
>70%	Good	29(39.73%)
Total		73(100)

Soil biological indicators, mainly collembolan, soil mites, and several microorganisms play an incredibly significant role in maintaining soil health. Collembola are abundant in wetlands and affect decomposition process through fragmentation of litter and fecal matter production, and influence bacterial and fungal population (Siddiky *et al.*, 2012). In the present study, the mean of soil collembolan population was 515.25 nos. m^{-2}, which is considered low, and the findings are in tune with the observations of Chang *et al*. (2013), who found that tillage operations significantly decreases the density and species richness of collembolan in rice cultivation.

The mean Shannon's Index value for microbial diversity was 1.59, which indicates the presence of versatile bacterial members in highly heterogeneous habitat of rice soils prevalent in Assam (Table 3). Lopes *et al*. (2011), reported a reported a Shannon's Index of 1.28 and 1.26 for two differently managed rice soils.

Computation of soil quality index using different statistical tools

SQI computation using principal component analysis: PCA resulted in seven principal component (PC) groups, that could best explain variability in the data. These seven PCs with eigen values >1 accounted for 70.2% of the cumulative variance in the data. Communalities of SQ indicators showed that individual indicators accounted for 58.60 to 83.30% of the soils (Table 4). Indicators with high communality got preference over those with low. The variations and derivation of PCs in the data sets for different bioclimatic situations of a particular crop (rice in this study) might be due to the management practices followed (Gui *et al*., 2009).

The results showed that FDA, CEC, PSB, EC, total bacterial population, DTPA-Zn and collembolan population are the final key indicators for assessing the SQ variability for rice soils in AESR 15.4 of Assam. The key indicators may vary for different cropping system under varied agro-ecological situations (Triantafyllidis *et al*., 2018). Rakshit *et al*. (2018) found that electrical conductivity, available phosphorus, soil organic carbon,

porosity, microbial biomass carbon and dehydrogenase activity as the MDS affecting crop yield under long term fertilizer trial with rice-wheat cropping system. Buragohain *et al*. (2018) reported that labile carbon fraction, total P, available K, MBC and PSB explained variations in soil quality under 10 years biofertiliser experiment on rice cultivation in an Inceptisols of Assam.

Weighting factors were developed based on the percent variation explained by the first seven PCs resulting in a final PCA based SQI equation for rice soil:

$$PCA\text{-}SQI = \Sigma (0.279x\ S_{FDA} + 0.157x\ S_{CEC} + 0.144x\ S_{PSB} + 0.125x\ S_{EC} + 0.107x\ S_{Bacteria} + 0.084x\ S_{DTPA\text{-}Zn} + 0.083x\ S_{Collembolan})$$

Where, S is the score for subscripted variable and the coefficients are weighting factors derived from PCA.

Using linear scoring technique, out of the seven selected key indicators, 'more is better' was considered for indicators like FDA, CEC,DTPA-Zn, PSB count and total bacterial population count, while in case of indicator EC, 'less is better' was considered for scoring (Mukherjee and Lal, 2014). Thus, the PCA-SQI obtained for the rice soils ranged between 0.76 and 0.43 with a mean of 0.58 (±0.069). The key indicator, FDA activity contributed highest (34.21%) towards the maximum value of SQI (0.76) (Table 5). The global hydrolytic soil enzyme FDA again contributed the highest share of 25.86% to the mean SQI (0.58). Recognizing the significance of soil enzymes, Pulgisi *et al.* (2006), illustrated the indices of soil alteration, using different enzymatic activities to establish soil degradation index owing to agricultural practices, including crop density and application of organic fertilizers.

SQI computation using expert opinion: The EO-SQI demonstrated a mean value of 0.63 in AESR 15.4. Of the three soil functions, nutrient cycling , water availability and biological diversity accounted for 77.58%, 67.39% and 73.02% towards the maximum (0.81), minimum (0.46) and mean (0.63) EO-SQI in the rice soils (Table 6).

Relative soil quality index : The RSQI based on 20 soil indicators (which were known to exert significant influence on soil health) was computed (Table 7). The results illustrated that only 1.37% of the soils belong to poor category while 58.90% and 39.73% of the soils belonged to medium and good categories respectively. In AESR 10.1, India, majority of cultivated soils (rice-wheat, soybean-wheat and soybean-chickpea) fell under the medium (77.50%) and poor (11.20) categories (Kundu *et al*., 2012).

The correlation coefficients between PCA-SQI and EO-SQI for rice soils was 0.700** and between PCA-SQI and RSQI was illustrated 0.672** indicates the usefulness of impartial choices of MDS such as soil biological diversity function or biological indicators in EO-SQI and RSQI.

Relationship between percent relative yields (%RY) with SQI indices : The regression lines were computed to observe the effectiveness among the SQIs, and the relationship were in the form of y=69.60x + 41.83(R^2=0.143, r=0.378*) and y = 0.954 x + 18.22 (R^2=0.284, r=0.532*) in between % rice yield (RY) of rice and PCA-SQI and RSQI, respectively. Similarly, the regression line was also computed between *% RY* and EO-SQI which yielded a very good relationship in the form of y = 116.2 x + 9.302 (R^2=0.289, r=0.537*). The results illustrated that the EO-SQI could explain better relationship with percent relative yield followed by RSQI and PCA-SQI establishing negligible differences in their abilities to explain the variability of soils under the rice ecosystem of UBVZ of Assam. The regression lines were used to work out optimum values of SQI indices to sustain 80% (4.16 t ha^{-1}) or more of the existing *in field* maximum rice yield (5.20 t ha^{-1}) of UBVZ. The optimum value indicates that the rice soils having PCA-SQI value >0.55 are likely to give 80% or more of the maximum yield of UBVZ (AESR 15.4) of Assam. Accordingly, the optimum RSQI and EO-SQI values for attaining 80% or more of the maximum yield computed 64.76% and 0.61, respectively.

Three SQI indices, *viz*., PCA-SQI, EO-SQI and RSQI were calculated using the data set. In calculation of PCA-SQI, soil enzymes played major role towards the maximum values of SQI for the soils, establishing the importance of biological properties as sensitive indicators along with the physico-chemical properties. The significant correlation of PCA-SQI with EO-SQI and RSQI, illustrated that the EO-SQI and RQSI based on soil functions could adequately provide information required for selection of soil management practices.

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