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Soil quality index as affected by temporal long term tea cultivation in Jorhat District of Assam

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Abstract

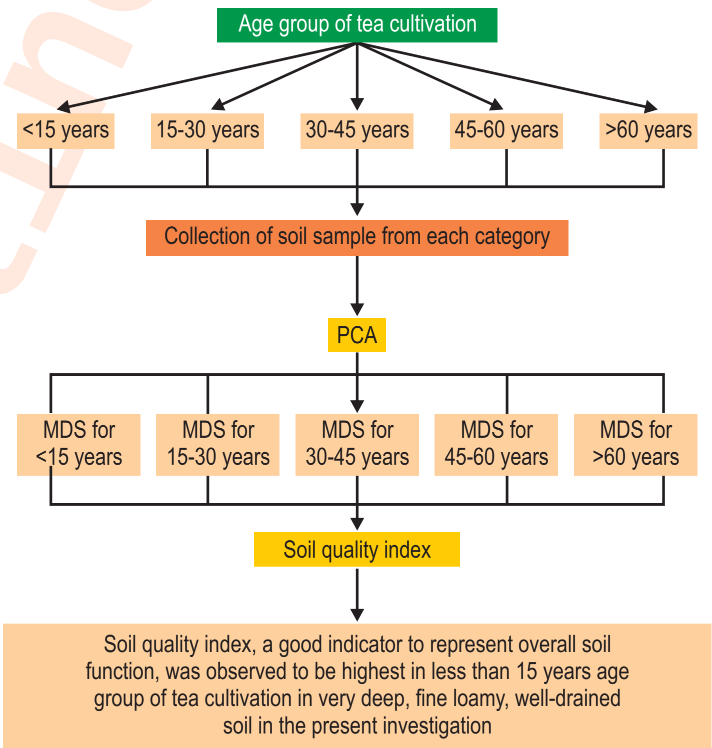
Aim: The investigation was undertaken to identify the Minimum Data Set (MDS) for Soil Quality Index (SQI) assessment in continuouslong-term tea cultivation systems.

Methodology: In the study under very deep, fine loamy, well-drained soil, five age groups of tea plantations *viz.* less than 15 years, 15-30 years, 30-45 years, 45-60 years and more than 60 years were selected and identified minimum data set and soil quality index.

Results: In very deep, fine loamy, well-drained soil under continuous tea cultivation, SQI, 14.74 was obtained for less than 15 years, 14.06 for 15-30 years, 11.12 for 30-45 years, 12.94 for 45-60 years and 11.37 for more than 60 years of plantation, respectively.

Interpretation: The most sensitive soil quality indicators identified in very deep, fine loamy, well-drained soil were pH for less than 15 years, total nitrogen for 15-30 years, available nitrogen for 30-45 years, organic carbon for 45-60 years and exchangeable aluminium for more than 60 years of continuous tea cultivation.

Key words: Minimum data set, Organic carbon, Soil quality index, Tea plantation



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Introduction

Tea (*Camellia sinensis*) is one of the most valuable perennial cash crops of Assam, grown in a varied scale of climate variables at 8°12' to 32°13' N latitude. In India, tea is used for household consumption and for export too. India is the leading producer and consumer of tea in the globe, which accounts for 28 per cent of the world's production and 13 per cent trade in the world. The foremost impetus after the country's tea sector development is the potential of eastern India's tea industry, especially of Assam which not only produces around 53 per cent of the nation's overall production but also generates employment opportunities (Dutta, 2013). Assam occupies approximately 3,22,214 ha of land under tea crop. Most of the state's tea-estates are established in the Upper Brahmaputra Valley Zone (UBVZ) of Assam, while it accounts for 13% of the tea gardens in Jorhat district. In reaction to population pressure and greater market access, the tea production system is experiencing major changes like that of many other upland crops. As a result, there has been an increase in both land-use intensity and soil degradation (Nath, 2015).Studies on soil properties of long-term tea farming system helps in observing the alterations in soil processes over the time and these studies are vital for generating data on the enduring sustainability of agricultural systems to articulate future policies for preserving soil health. There is mounting anxiety amongst the tea planters that long-standing monoculture of tea may not sustainably be owing to their adverse effects on soil quality and health.

Soil health is the continued ability of soil to serve as an important living system that encompasses biological elements which function within specific land-use boundaries (Karlen*et al*., 2001). Protection of soil quality under rigorous land use and rapid economic growth is a major challenge for sustainable resource use in the developing world (Doran *et al.,* 1996b). The basic appraisal of soil health and soil quality is essential to evaluate the degradation status and changing inclinations following various land use and smallholder management interventions (Lal and Stewart, 1995).Information on the evaluation of quality of soil and water particularly in tea growing areas is restricted which has become paramount necessity to increase crop yield and its sustainability in the present-day agricultural system. Tea planters are gradually concerned that long-term tea monoculture may not be sustainable due to their adverse effect on soil health.

Methods and Materials

The study area, Jorhat district of Assam is in the Upper Brahmaputra Valley Zone of Assam. It has a geographical area of 2851sq.km. The mean annual rainfall is 1865 mm and average temperature is 26°C. The maximum temperature rises up to 36°C whereas minimum temperature falls to 10°C.The soil very deep, fine loamy, well-drained were selected and five age groups of tea plantation, viz., less than 15 years, 15-30 years, 30-45 years, 45-60 years and more than 60 years were selected. Ten samples were collected from each age group of tea plantations. Analyses of physical, chemical and biological properties for identification of key soil indicators was estimated by following the standard procedures (Jackson,1973). Multivariate statistical analysis of soil properties was conducted using factor analysis for grouping 23 soil properties into statistical factors (or principal components) to reduce the entire data set also known as Minimum Data Set (MDS) for subsequent matrix analysis. Principal component analysis (PCA) was used as the method of factor extraction.

Soil Quality Index : Determination of Soil Quality Index (SQI) mainly involved with the assimilation of representative highly performing Minimum Data Set (MDS) that best signifies soil function in terms of a particular purpose (Chaudhury *et al.,*2005).The principal components obtaining high eigen values and variables with high factor loading were believed to be variables that best represented the system attributes. Consequently, only PCs with eigenvalues e"1 (Brejda *et al.,*2000) and those that described at least 5% of variation in the data sets (Wander and Bollero, 1999) were considered for identifying the MDS. Within each PC, simple highly weighted factors were kept for MDS. After establishing the MDS indicators, each observation of each MDS indicator was transformed utilizing a linear scoring technique (Andrews *et al.,* 2002b).SQI was revealed after the summation of weighted MDS variables scores for each observation applying the following equation:

$$SQI = \Sigma_{i=1}^{n} WiSi$$

Where, Si is the score for the subscripted variable and Wi is the weighing factor derived from PCA. Here, the hypothesis is that higher index scores means improved soil quality or enhanced performance of soil function (Chaudhury,2005).

Results and Discussion

Under less than 15 years of age group, the correlation matrix amongst the studied variables was analyzed to test the consistency of correlation values with the hypothesized factor structure. The Cattelscree test was performed to plot components as the X-axis and the corresponding eigenvalues as the Y-axis (Fig.1). It indicated that as one moved to the right, towards later components, the eigenvalues decreased. When the drop ceased and the curve made an elbow towards less steep decline, the screen test was said to drop all further components after the one starting the elbow. The first five principal components had eigenvalues >1 and accounted for 88.46 per cent of the total variance (Table.1) in the complete data set and,hence, were taken for interpretation. Finally, seven variables *viz.,* pH, Av P_2O_5, exchangeable calcium(Ex Ca), Water Holding Capacity (WHC), available potassium (Av K_2O), organic carbon (OC) and cation exchange capacity (CEC) were identified for MDS (Fig.2). The MDS variables were transformed by employing scoring functions. The selected indicators can be transformed following a linear or a non-linear scoring rule. For 'more is better' indicators, each

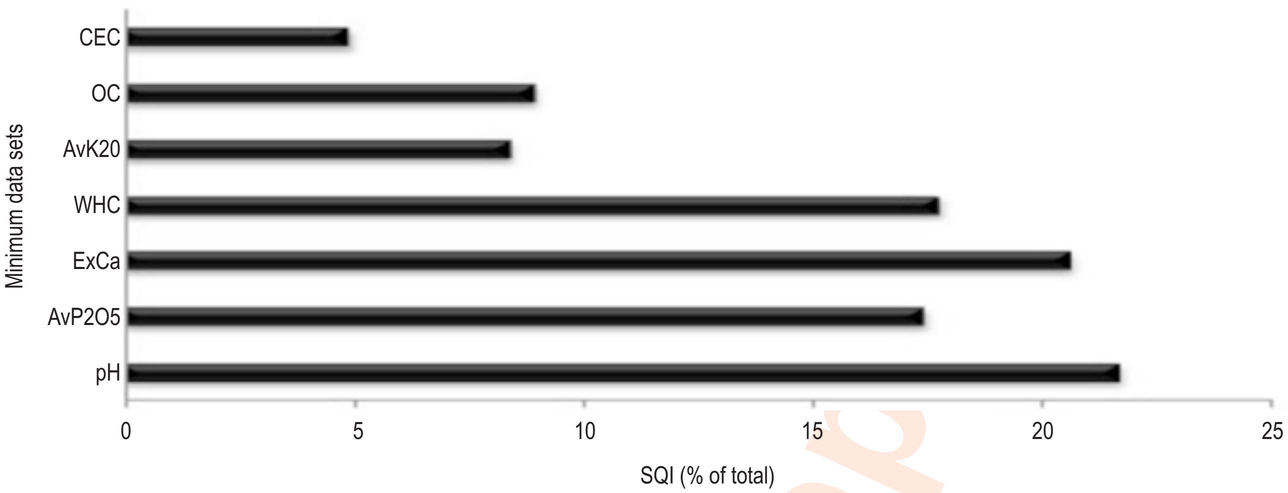

Fig. 1 : SQI less than 15 years of continuous tea cultivation in very deep, fine loamy, well-drained soil.

Table 1: Rotated component loadings and communalities of soil properties in very deep, fine loamy, well-drained soil under less than 15 years of continuous tea cultivation of Jorhat district, Assam

Soil properties	Component					Communalities
	PC1	PC2	PC3	PC4	PC5	
% clay	-0.043	*0.820*	0.450	-0.297	0.033	0.966
BD	-0.202	*-0.756*	-0.518	0.222	0.123	0.945
PD	-0.502	0.717	0.076	-0.329	-0.230	0.933
MWD	0.469	-0.290	0.672	-0.143	0.048	0.778
WHC	0.359	*0.814*	0.219	-0.245	0.144	0.920
AWC	0.426	*0.815*	0.139	-0.056	0.310	0.964
pH	*0.931*	0.106	0.185	0.136	0.194	0.968
EC	-0.032	0.039	*0.855*	-0.204	-0.074	0.781
OC	0.428	0.596	-0.147	*0.657*	-0.052	0.995
CEC	0.388	0.321	-0.140	0.113	*0.729*	0.818
TN	0.325	0.719	-0.232	0.508	-0.018	0.935
Av N	0.355	0.556	0.152	*0.724*	-0.018	0.983
Av P_2O_5	*0.921*	0.032	0.312	0.122	0.112	0.974
Av K_2O	0.065	0.215	*0.814*	-0.293	0.234	0.853
Av Fe	0.754	-0.055	-0.154	-0.518	-0.206	0.906
Ex Al	*0.868*	0.035	-0.206	-0.109	-0.317	0.909
Ex Ca	*0.906*	0.002	0.077	0.180	0.193	0.897
Av Zn	-0.615	0.350	-0.459	-0.184	0.180	0.778
Av B	0.547	-0.567	-0.067	0.434	-0.136	0.833
F	0.375	-0.502	0.082	-0.094	0.639	0.817
As	-0.309	0.365	-0.606	-0.541	-0.132	0.906
MBC	-0.661	-0.140	-0.013	0.331	-0.254	0.630
DHG	0.270	*0.777*	0.260	-0.244	0.236	0.860
						Total
Eigenvalue	6.675	5.971	3.367	2.722	1.611	
% variance	29.02	25.96	14.64	11.85	7.00	88.46

observation was divided by the greatest observed value such that the maximum observed value received a score of 1. For 'less is better' indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value obtained a score of 1 (Leibig *et al.*, 2001). The MDS variables for each observation were weighted by using the PCA results. Every PC described a specific amount (%) of difference in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eigenvectors greater than 0.5, provided the weighted factor for

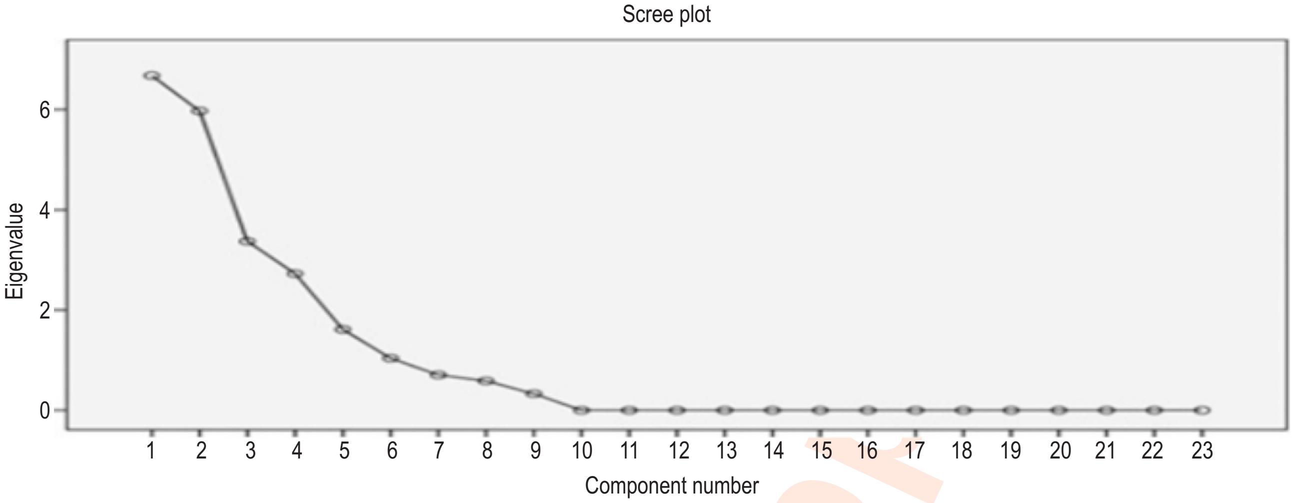

Fig. 2 : SCREE plot for selecting principal components less than 15 years of continuous tea cultivation in very deep, fine loamy, well-drained soil.

Table 2 : Rotated component loadings and communalities of soil properties under 15-30 years of continuous tea cultivation of Jorhat district, Assam

Soil properties	Components						Communalities
	PC1	PC2	PC3	PC4	PC5	PC6	
% clay	*0.869*	0.353	-0.149	0.044	-0.019	0.094	0.914
BD	-0.698	-0.294	0.475	0.371	0.013	-0.046	0.940
PD	0.371	-0.509	-0.628	-0.316	-0.164	0.170	0.947
MWD	-0.011	0.229	0.294	0.270	*-0.789*	-0.071	0.839
WHC	0.709	0.519	0.265	-0.081	0.131	0.148	0.888
AWC	0.782	0.148	-0.197	-0.029	-0.336	-0.146	0.807
pH	-0.463	*0.777*	0.263	-0.292	0.105	0.016	0.984
EC	-0.034	-0.178	-0.717	0.402	0.206	-0.425	0.931
OC	*0.843*	0.135	0.107	-0.311	0.308	-0.120	0.945
CEC	-0.602	0.119	-0.043	0.172	*0.834*	0.503	0.849
TN	*0.937*	0.283	0.122	-0.023	-0.032	-0.046	0.976
Av N	0.841	0.237	0.175	-0.230	0.335	-0.052	0.961
Av P_2O_5	0.184	0.380	0.226	0.035	-0.259	*0.706*	0.796
Av K_2O	0.201	-0.423	0.550	-0.008	*0.829*	0.078	0.712
Av Fe	0.303	*-0.794*	-0.010	0.265	-0.045	0.399	0.954
Ex Al	0.490	*-0.795*	0.208	0.176	-0.158	-0.007	0.971
Ex Ca	-0.518	*0.809*	-0.013	-0.172	-0.085	0.099	0.970
Av Zn	-0.475	0.063	-0.757	-0.287	0.294	-0.031	0.973
Av B	0.238	0.613	-0.365	0.511	0.282	0.173	0.936
F	0.064	-0.165	*0.847*	0.352	0.275	0.068	0.952
As	-0.197	0.473	0.573	0.127	-0.050	-0.565	0.928
MBC	0.044	0.521	-0.456	0.647	-0.197	0.184	0.972
DHG	0.420	0.173	-0.162	*0.800*	0.273	-0.184	0.981
							Total
Eigenvalue	6.547	4.790	3.862	2.420	1.871	1.637	
% variance	28.46	20.83	16.79	10.52	8.14	7.12	91.86

variables selected in each PC. SQI was computed by employing weighing factors for each scored MDS variable according to the following formula:

$$SQI = \Sigma(0.328\ pH + 0.328\ Av\ P_2O_5 + 0.328\ Ex\ Ca + 0.293\ WHC + 0.165\ Av\ K_2O + 0.134\ OC + 0.079\ CEC) = 14.74$$

If all seven MDS were considered to be accountable for providing ideal (100%) SQI for less than 15 years of tea cultivation, then it might be concluded that pH was the most important indicator of soil quality in the arena of tea cultivation. A soil with pH ranging in between 4.5 -5.5 is opposite for rising tea crops (Zoysa, 2008) and the ability of soil to provide mineral

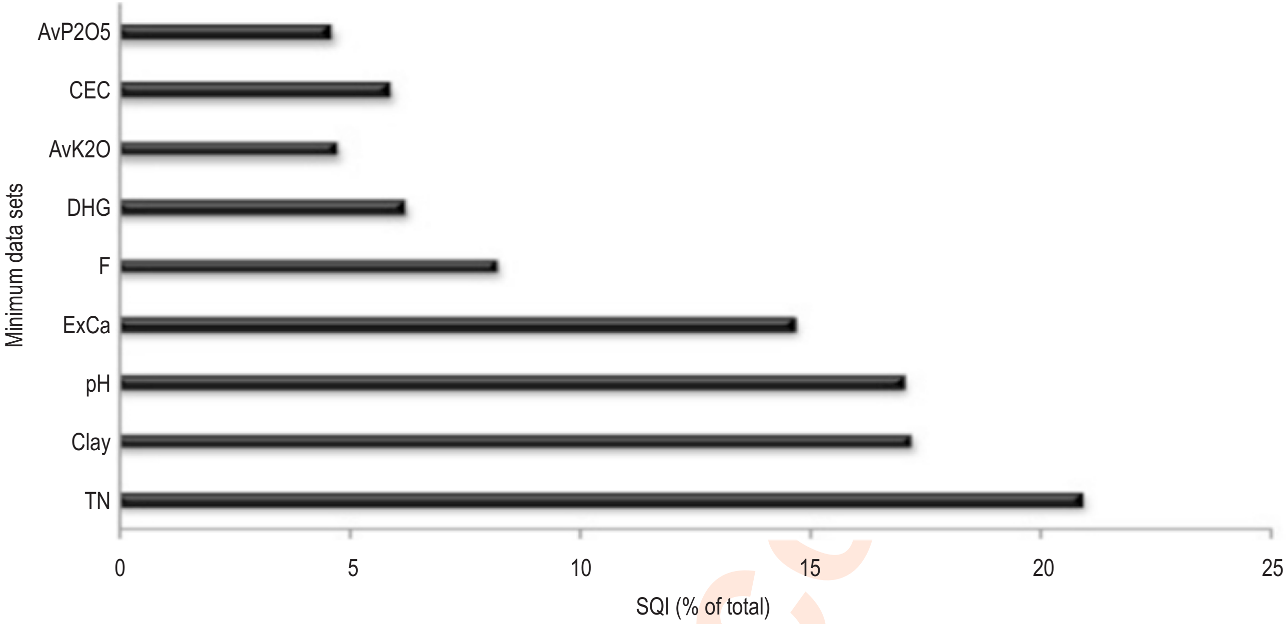

Fig. 3 : SQI under 15-30 years of continuous tea cultivation in very deep, fine loamy, well-drained soil.

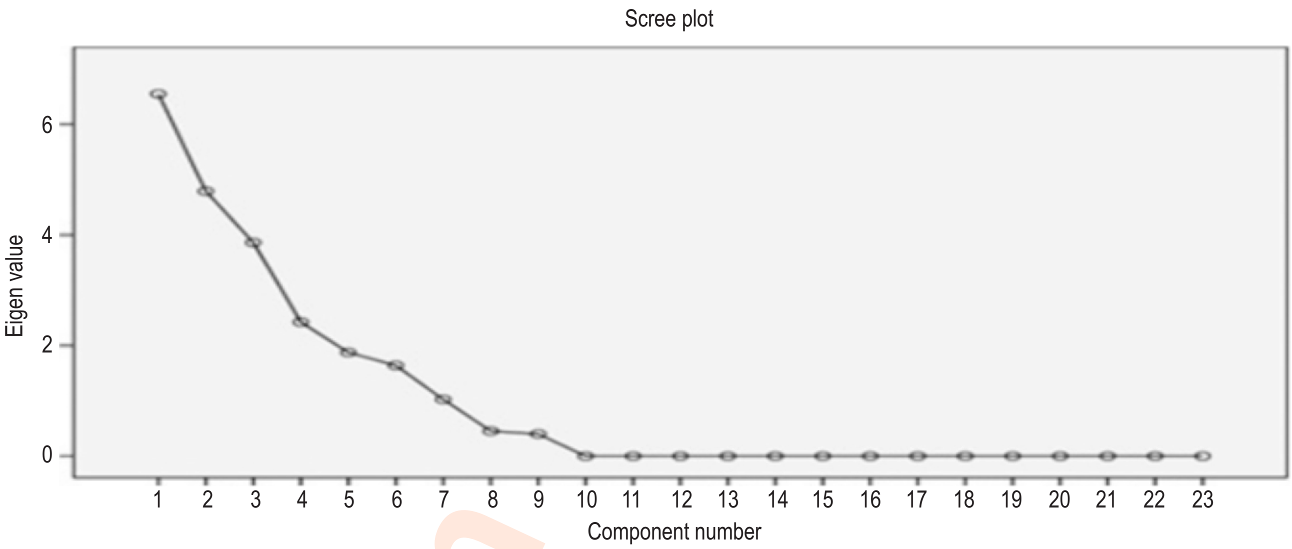

Fig. 4 : SCREE plot for selecting principal components under 15- 30 years of continuous tea cultivation in very deep, fine loamy, well-drained soil.

nutrients also depended largely on the soil pH (Arshad and Coen, 1992). Consequently, altering the soil reaction and adding organic matter are the popular means of decreasing phosphorus deficiencies in tea growing soils (Zhang *et al.,* 1997). Ranganathan and Natesan (1985) stated that the ideal pH for better growth and optimum nutrient consumption was between 4.0 and 5.0.Soil pH is considered as a key of variables that affects the physico-chemical and biological properties of soil required for plant growth and development (Dora Neina,2019)

Under 15-30 years of incessant cultivation of tea, PCA of 23 variables revealed that only six PCs had eigenvalue > 1 (Fig.3) and described 91.86 per cent variance of the whole data set. After running correlation matrix for highly weighted variables under different PCs individually (Table 2),finally nine variables *viz.,* total nitrogen, clay, pH, exchangeable calciuma, Fluoride, dehydrogenase activity, available potassium, cation exchange capacity and available phosphorus were selected as MDS (Fig.4). MDS variables were transformed by using scoring functions. SQI was calculated by using weighing factors for each scored MDS variable by the following formula:

SQI = (0.310 TN + 0.310 OC + 0.310 Clay + 0.227 pH + 0.227 Ex Ca + 0.183 F+0.115 DHG + 0.089 Av K_2O + 0.089 CEC + 0.077Av P_2O_5) = 14.06

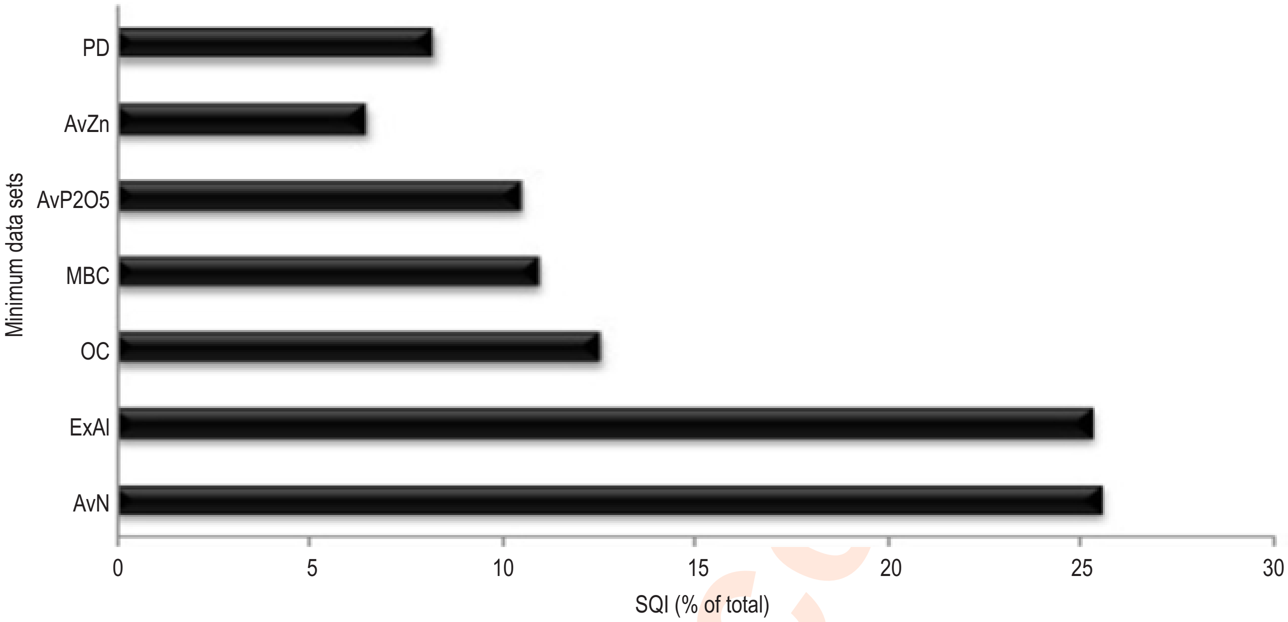

Fig. 5 : SQI under 30-45 years of continuous tea cultivation in very deep, fine loamy, well-drained soil.

Table 3 : Rotated component loadings and communalities of soil properties under 30-45 years of continuous tea cultivation in very deep, fine loamy, well-drained soil in Jorhat district, Assam.

Soil properties	Components					Communalities
	PC1	PC2	PC3	PC4	PC5	
% clay	0.218	*0.893*	-0.313	-0.195	-0.070	0.986
BD	-0.115	-0.801	0.492	0.223	0.190	0.983
PD	0.424	-0.568	-0.028	-0.297	*0.443*	0.788
MWD	*-0.891*	0.033	-0.211	-0.293	-0.073	0.930
WHC	0.412	0.717	-0.324	-0.164	-0.269	0.888
AWC	0.390	0.586	*-0.675*	0.023	0.025	0.952
pH	*0.853*	-0.160	0.183	-0.221	-0.320	0.939
EC	-0.135	-0.450	0.461	*-0.697*	-0.148	0.940
OC	0.003	0.734	*0.634*	-0.109	0.057	0.956
CEC	0.710	-0.042	0.181	-0.348	*0.484*	0.894
TN	0.453	0.641	*0.583*	0.057	0.007	0.959
Av N	-0.811	*-0.795*	0.409	-0.197	0.044	0.890
Av P_2O_5	0.135	0.038	-0.086	*0.662*	*-0.446*	0.883
Av K_2O	-0.532	0.094	0.543	-0.187	-0.415	0.795
Av Fe	*-0.927*	0.140	0.136	0.035	0.084	0.906
Ex Al	0.611	0.804	0.181	0.248	0.157	0.923
Ex Ca	*0.809*	-0.433	0.133	0.024	-0.192	0.898
Av Zn	0.189	0.664	0.279	0.117	*0.476*	0.795
Av B	-0.467	0.423	0.076	*0.666*	0.230	0.898
Av F	0.592	0.061	0.398	0.575	0.244	0.903
As	*0.772*	0.189	-0.214	0.230	0.245	0.791
MBC	0.059	-0.580	0.117	*0.719*	-0.073	0.875
DHG	-0.594	-0.302	-0.489	-0.044	*0.487*	0.923
						Total
Eigen value	6.843	5.934	3.045	2.894	1.979	
% variance	29.75	25.80	13.24	12.58	8.61	89.97

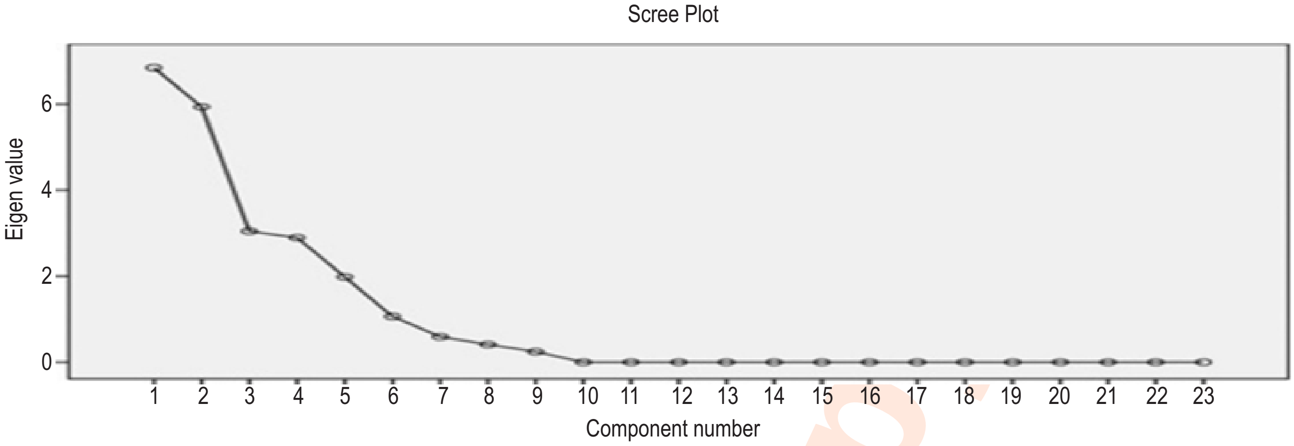

Fig. 6 : SCREE plot for selecting principal components under 30-45 years of continuous tea cultivation in very deep, fine loamy, well-drained soil.

Table 4 : Rotated Component loadings and communalities of soil properties under 45-60 years of continuous tea cultivation in very deep, fine loamy, well-drained soil of Jorhat district, Assam

Soil properties	**Component**					**Communalities**
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	
% clay	0.720	0.632	0.039	-0.064	-0.178	0.955
BD	-0.286	*-0.889*	-0.025	0.197	0.236	0.967
PD	0.056	0.601	-0.150	0.434	0.440	0.768
MWD	-0.376	0.538	0.049	0.395	0.540	0.882
WHC	0.759	0.555	-0.097	0.014	-0.300	0.983
AWC	0.643	0.615	0.245	0.202	-0.131	0.910
pH	0.749	-0.342	0.476	0.156	-0.077	0.934
EC	0.543	-0.059	-0.533	0.390	0.141	0.753
OC	*-0.822*	-.027	.189	.468	-.219	0.980
CEC	0.451	-.407	-.717	-.003	-.003	0.884
TN	-0.589	-.114	.331	*.604*	-.281	0.914
Av N	-0.621	0.144	0.258	*0.631*	-0.350	0.994
Av P_2O_5	0.625	-0.359	-0.023	0.183	0.507	0.810
Av K_2O	-0.249	*-0.807*	0.432	0.040	0.108	0.761
Av Fe	-0.661	0.386	-0.492	0.133	-0.269	0.917
Ex Al	-0.732	-0.014	-0.588	-0.022	0.288	0.966
Ex Ca	*0.863*	-0.202	0.347	0.177	0.109	0.950
Av Zn	-0.208	0.394	0.307	0.377	*0.677*	0.893
Av B	-0.674	0.013	-0.292	-0.409	0.258	0.774
F	0.106	0.259	*0.619*	-0.507	0.434	0.908
As	0.733	-0.240	-0.173	0.395	-0.062	0.784
MBC	-0.449	*0.737*	0.198	-0.327	-0.044	0.893
DHG	-0.495	-0.307	0.488	-0.257	-0.100	0.653
						Total
Eigenvalue	7.862	4.583	3.098	2.568	2.121	
% variance	34.18	19.93	13.47	11.17	9.22	87.96

If all nine MDS were thought to be responsible for contributing ideal (100%) soil quality index for 15-30 years of continuous cultivation of tea, then we could conclude that total nitrogen was the most sensitive indicators of soil quality in 15 to 30 years of continuous tea cultivation system. Total soil nitrogen along with soil organic matter are the key determining factors and indicators of soil quality and fertility (Reeves, 1997). Next to total nitrogen, organic carbon is the crucial MDS indicator that contributes maximum for SQI. According to Adeboye *et al.* (2011), the soil carbon and soil total nitrogen are appropriate indicative markers of the quality of soilin different tea cultivation systems. Grey *et al.* (2003) during their studies observed that the decrease

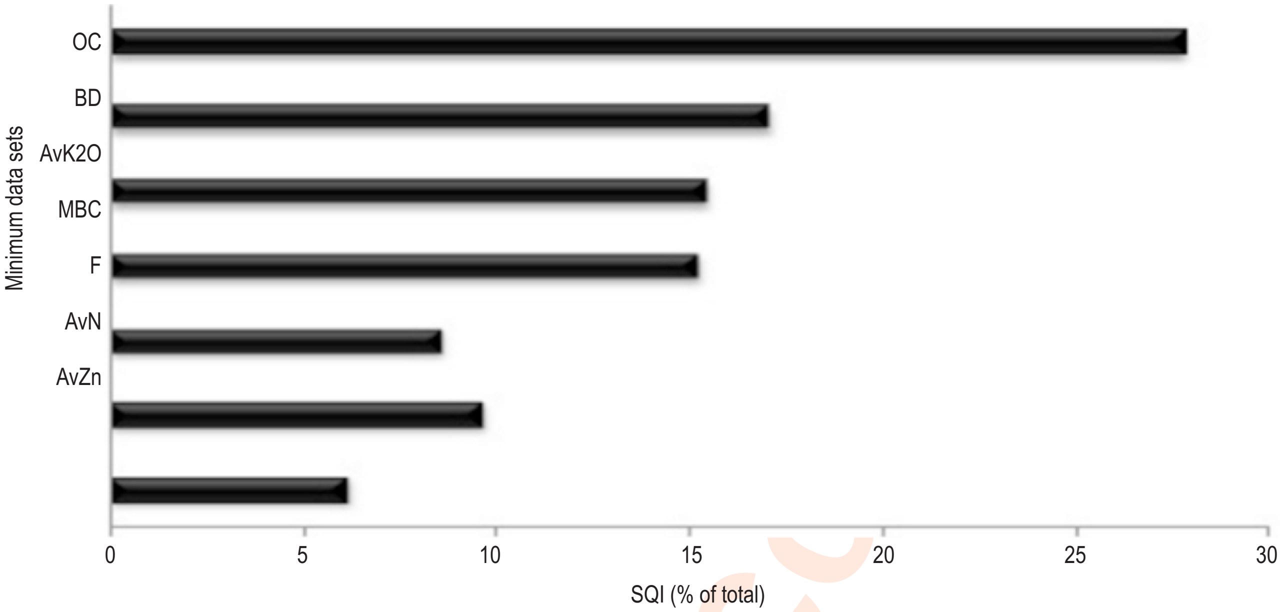

Fig. 7 : SQI under 45-60 years of continuous tea cultivation in very deep, fine loamy, well-drained soil.

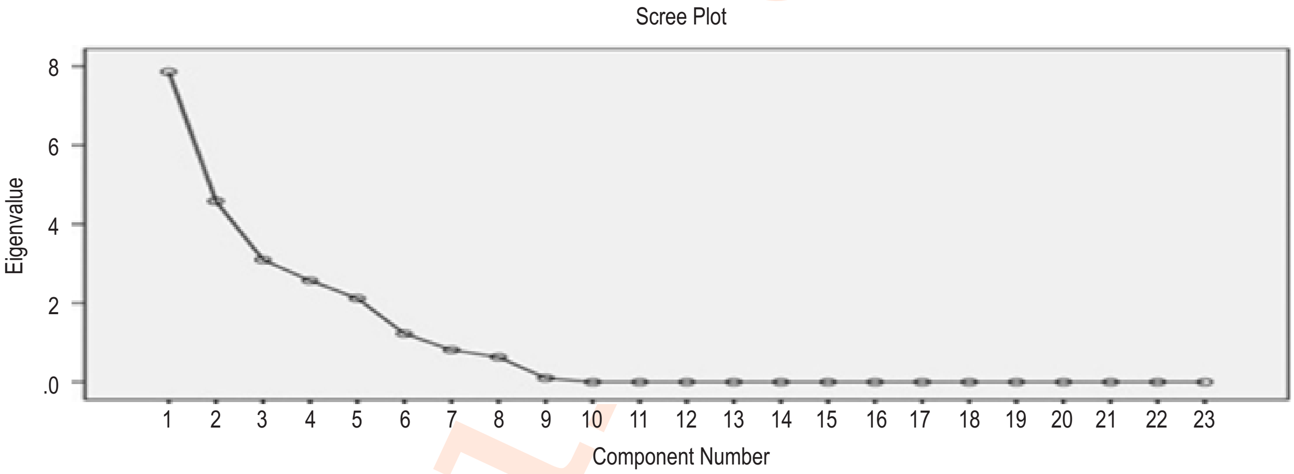

Fig. 8 : SCREE plot for selecting principal components under 45-60 years of tea cultivation in very deep, fine loamy, well-drained soil.

of soil organic carbon and soil total nitrogen reduced soil fertility, soil nutrient supply and porosity.

Under 30-45 years of continuous tea cultivation system,out of the PCA of 23 variables, only five PCs received eigenvalue > 1 (Fig.5) and described 89.97% variance of the entire data set. A correlation matrix for the highly weighted variables in different PCs was run separately (Table 3). In PC1, Exchangeable Aluminum (Ex Al) was retained for MDS. Av N for PC2, Organic Carbon (OC), Microbial Biomass Carbon (MBC), Available Phosphorus (Av P_2O_5) for PC4 andDTPA extractable Available Zinc (Av Zn) and Particle Density (PD) for PC5 were booked in the MDS. Considering all these, ultimately, seven variables *viz.*, Ex Al, Av N OC, MBC, Av P_2O_5, Av Zn and PD were selected as MDS(Fig.6) and the MDS variables were transformed by using scoring functions. SQI was calculated by using weighing factors for each scored MDS variable by the formula:

$$SQI = \Sigma(0.331 \text{ Av N} + 0.287 \text{ Ex Al} + 0.147 \text{ OC} + 0.140 \text{ MBC} + 0.140 \text{ Av } P_2O_5 + 0.096 \text{ Av Zn} + 0.096 \text{ PD}) = 11.12$$

Under this age bracket of continuous tea cultivation, soil quality index was 11.12. If all seven MDS were liable for providing ideal (100%) SQI for 30-45 years of continuous cultivation of tea, then we can conclude that the contribution of Av N towards SQI was significant. In deep, fine loamy, well-drained soil Av N is found as a most vital indicator for SQI (Baruah *et al.,* 2017).Long-term tea cultivation with the application of nitrogenous fertilizers affects the bacterial population dynamics of soil and considerably decreases the soil pH and microbial activities resulting in a dropin

Table 5 : Rotated Component loadings and communalities of soil properties under more than 60 years of continuous tea cultivation in very deep, fine loamy, well-drained soil of Jorhat district, Assam

Soil properties	Component					Communalities
	PC1	PC2	PC3	PC4	PC5	
% clay	0.122	-0.749	0.423	0.117	-0.002	0.769
BD	-0.104	0.761	-0.096	*-0.593*	0.089	0.959
PD	-0.389	0.539	-0.435	0.171	-0.176	0.692
MWD	0.424	0.224	-0.453	*0.564*	-0.357	0.881
WHC	-0.191	*-0.813*	0.430	0.274	-0.145	0.979
AWC	-0.160	-0.541	0.704	-0.252	0.233	0.932
pH	0.855	-0.284	-0.134	0.192	0.345	0.986
EC	0.087	0.098	*0.863*	-0.023	-0.113	0.776
OC	0.867	-0.235	-0.312	0.015	0.073	0.909
CEC	0.094	0.764	0.557	0.026	0.175	0.935
TN	0.827	-0.400	-0.109	-0.159	-0.173	0.911
Av N	0.846	0.233	-0.295	0.033	0.029	0.859
Av P_2O_5	-0.754	-0.157	-0.007	0.471	0.245	0.874
Av K_2O	0.515	0.352	0.449	0.447	0.285	0.873
Av Fe	-0.838	0.204	0.273	0.175	-0.373	0.989
Ex Al	*-0.882*	0.343	0.187	-0.107	-0.188	0.976
Ex Ca	*0.978*	0.039	-0.044	-0.020	0.034	0.961
Av Zn	0.197	0.591	0.332	0.477	*0.457*	0.934
Av B	0.603	0.241	0.362	*-0.517*	0.136	0.838
F	-0.495	0.501	-0.090	0.117	0.381	0.663
As	-0.650	-0.272	-0.468	-0.090	*0.502*	0.976
MBC	0.606	0.310	0.487	0.169	-0.371	0.866
DHG	0.339	*0.883*	0.074	0.002	-0.153	0.923
						Total
Eigen value	8.142	5.297	3.557	1.924	1.542	_
% variance	35.40	23.03	15.47	8.36	6.70	88.96

beneficial bacterial population particularly PGPR activities (Lin *et al.,* 2019). Wienhold *et al*. (2005) reported that soil nitrate-nitrogen might act as an indicator for agronomic goal line of crop yield and as soil nitrate-nitrogen rises, yield per unit area could be boosted sufficiently. Minh Van Dang (2007) also observed that under long-term tea production, soil organic carbon and available nitrogen supply were realized to be extremely sensitive chemical properties for sustainability. The impact of Av N towards SQI was considerable and available soil nitrogen performed a leading role in retaining the leaf yield of the crop (Sharma *et al.,* 2005). According to Ranganathan and Natesan (1985), nitrogen is the most essential nutrient for tea plantation since it is needed in significant quantities, accounting for nearly 4 to 5 per cent of dry weight of the harvested shoots.

Under 45-60 years of continuous cultivation of tea, only six PCs showed eigenvalue > 1 (Fig.7) and supported 87.97 per cent variance of the complete data set and seven variables *viz*., organic carbon, BD, Av K_2O, MBC, F, Av N, Av Zn were selected as MDS (Fig.7). MDS variables were transformed by using scoring functions. SQI was calculated by using weighing factors for each scored MDS variable according to the formula:

$$SQI = \Sigma(0.389\ OC + 0.227\ BD + 0.227\ Av\ K_2O + 0.227\ MBC + 0.153F + 0.127\ Av\ N + 0.105\ Av\ Zn) = 12.94$$

SQI under this age group was 12.94 and organic carbon was the most sensitive indicator of soil quality in this age group of tea cultivation. Soil organic carbon is the most often stated trait from long-term studies and is considered as the most valuable indicator of soil quality and agronomic sustainability because of its effect on physical, chemical and biological indicators of soil quality. Arshad and Coen (1992) revealed that soil organic matter enhanced the fertility by improving nutrient and water storage capacity, soil buffering and microbial activities in soil. The soil was counted as a sink and supplier of plant-available nutrients (Doran *et al.,* 1996). Bulk density is the second MDS indicator that adds to maximum SQI next to soil organic carbon. Soil organic matter buildup can improve SQI by reducing bulk density, surface sealing and crust development (Mohanty *et al.,* 2007), and by augmenting soil aggregate strength and stability (Somasundaram *et al.,* 2013), cation exchange capacity, nutrient transformation and dynamics and soil biological activities (Karlen and Andrews, 2004)

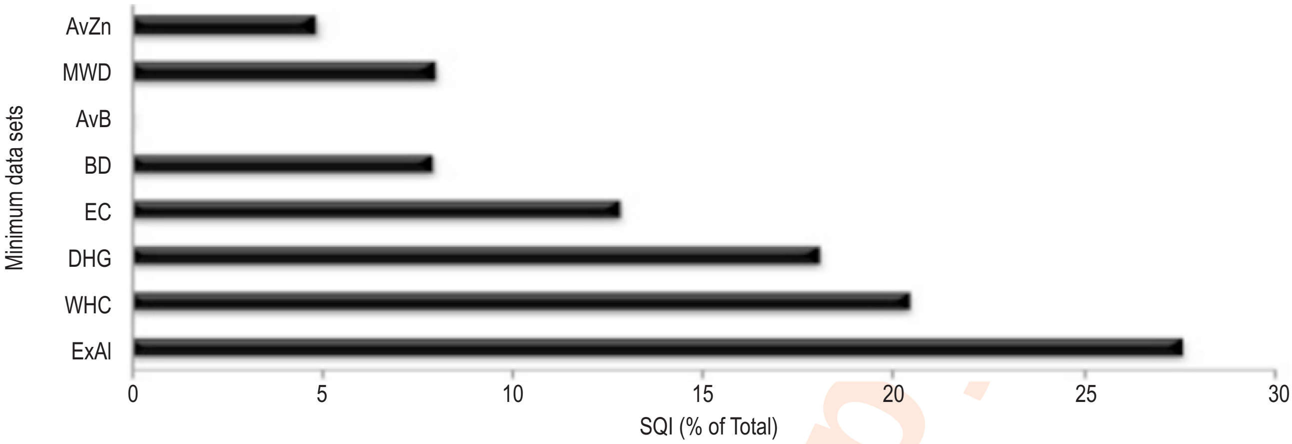

Fig. 9 : SQI more than 60 years of continuous tea cultivation in very deep, fine loamy and well-drained soil.

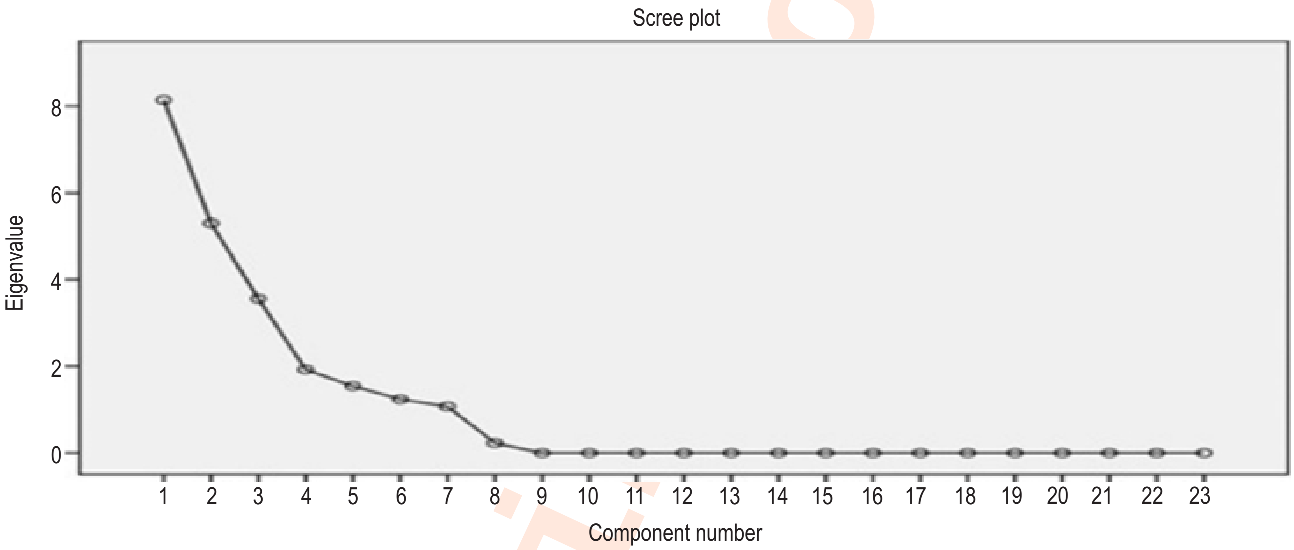

Fig. 10 : SCREE plot for selecting principal components for more than 60 years continuous tea cultivation in very deep,fine loamy,well-drained soil.

In more than 60 years of continuous tea cultivation system, out of PCA of 23 variables, only five PCs had eigenvalue > 1 (Fig.9) and accounted for 88.96 per cent variance of full data set. A correlation matrix for highly weighted variables under different PCs was run separately (Table 5). It was presumed that variables having the highest correlation sum best represented the group. Exchangeable Aluminum in PC1; Water Holding Capacity and Dehydrogenase activity in PC2; Electrical Conductivity in PC3, Bulk Density, Available Boron and Mean Weight Diameter in PC4 and Available Zinc in PC5. Altogether eight variables *viz.,*Exchangeable Al, WHC, DHG, EC, BD, MWD, Av B and Av Zn were selected as MDS (Fig.10). SQI was calculated by using weighing factors for each scored MDS variable by the following formula:

SQI = Σ(0.398 Ex Al+0.259 WHC+0.259 DHG + 0.174 EC + 0.094 BD + 0.094 Av B + 0.094 MWD + 0.075 Av Zn) = 11.37

In this age group of tea plantation system, SQI was found to be 11.37. If all eight MDS were responsible for supporting ideal (100%) SQI for continuous tea cultivation system, then it can be concluded that the contribution of Ex-Al was observed to be highest towards SQI.Foy *et al.* (1988) stated that tea crop demanded ample distribution of exchangeable Al and Fe. At high pH and low content of exchangeable Al, Zn and Fe in soils triggered elevated mortality and impeded the growth of tea plant (Liang *et al.,* 1995).Tea plantations are typified by intensive nutrient recycling from leaf litter fall, decay in soil and biogeochemical recycling of nutrients that returns substantial quantities of Al to the soil because older leaves are extremely rich source of Al (Ruan and Wong,2001). Comparing soils from tea plantations of various ages, Ding and Huang (1991)reported that the exchangeable Al and Al complexes increased in soil with increase in planting duration.

Soil Quality Index (SQI), a decent indicator to represent overall soil functions, was observed to be highest in less than 15 years of the age group of tea cultivationin well-drained, fine loamy very deep soils in the present investigation. Here, pH played a key role towards SQI. However, theexchangeable Aluminum had the maximum per cent contribution towards overall SQI at more than 60 years of age group of tea plantation might be due to poor adoptive measures to correct the soil acidity. Therefore, this study may give a direction for sustainable soil quality management of tea soils throughappropriate adoptive measures of management of soil reaction in a systematic approach.

References

Adeboye, M.K.A., E.N.O. Iwuafor and J.O. Agbenin: Assessment of soil quality using soil organic carbon and total nitrogen and microbial properties in tropical agro eco systems. *Agric. Sci.,* **2,** 34-40 (2011).

Arshad, M.A. and G.M. Coen: Characterization of soil quality: Physical and chemical criteria. *Amer. J. Alter. Agric,* **7**, 25-31 (1992).

Baruah, N., B.K. Medhi, N. Borah, A.M. Baruah and G.K. Saikia: Effect of long term tea cultivation in deep, fineloamy, well-drained soils of Jorhat district, Assam. *J. Soil Water Conser.,* **16**, 347-355 (2017).

Brejda, J.J., T.B. Moorman, D.L. Karlen and T.H. Dao: Identification of regional soil quality factors and indicators. I. Central and Southern High Plains. *Soil Sci. Soc. Am. J.,* **64**, 2115–2124 (2000).

Chaudhury, J., U.K. Mandal, K.L. Sharma, H. Ghosh and B. Mandal: Assessing soil quality under long-term rice-based cropping system. *Commun. Soil Sci. Pl. Anal*., **36**, 1141-1161 (2005).

Dang, M.N.: Quantitative and qualitative soil quality assessments of tea enterprises in Northern Vietnam. *African J. Agric. Res.,* **2**, 455-462 (2007).

Ding, R. X. and X. A. Huang: Biogeo chemical cycle of aluminium andûuorine in a tea garden soil system and its relationship to soil acidification. *Acta Pedologica Sinica*, **28**, 229–236 (1991).

Doran, J.W. and A.J. Jones: Methods for assessing soil quality. SSSA Special Publication No. 49. Soil Sci. Soc. Am., Inc. Madison, WI (1996b).

Doran, J.W., M. Sarrantonio and M.A. Leibig: Soil health and sustainability. *Adv. Agron.,* **56**, 1-54 (1996).

Dutta, J.: Fluoride, arsenic and other heavy metals contamination of drinking water in the tea garden belt of Sonitpur district, Assam, India. *Int. J. Chem. Tech. Res.,* **5**, 2614-2622 (2010).

Foy, C.D.: Plant adaptation to acid, aluminium-toxic soils. *Commun. Soil Sci. Pl. Anal*., **19**, 959-987(1988).

Gray, L.C. and P. Morant: Reconciling indigenous knowledge with scientific assessment of soil fertility changes in southwestern Burkina Faso. *Geoderma,* **111**, 425-437(2003).

Karlen, D.L. and S.S. Andrews: Soil quality, fertility, and health historical context, status and perspectives. In: Managing Soil Quality: Challenges in modern agriculture (Eds.: P. Schjønning). CABI Int. Publ., Oxon, UK, 17-33 (2004).

Karlen, D.L., S.S. Andrews and J.W. Doran: Soil quality: Current concepts and applications. *Adv. Agron*., **74**, 1-40 (2001).

Lal, R. and B.A. Stewart: Soil management experimental basis for sustainability and environment quality. *Adv. Soil Sci.* CRC Press, Boca Raton, Florida (1995).

Lin, W., M. Lin, H. Zhou, H. Wu, Z. Li and W. Lin: The effects of chemical and organic fertilizer usage on rhizosphere soil in tea orchards. PLoS ONE, **14**, e0217018 (2019).

Liang, Y., J. Lu, L. Zhang, S. Wu and Y. Wu: Estimation of black tea quality by analysis of chemical composition and colour difference of tea infusions. *Food Chem.,* **80**, 283-290 (2003).

Liebig, M.A., G. Varvel and J. Doran: A simple performance-based index for assessing multiple agro-ecosystemfunctions. *Agron. J.,* **93**, 313–318 (2001).

Miller, R.W. and D.T. Grardiner: Soils in Our Environment. 9th Edn., Prentice-Hall Inc., Englewood Cliffs, New Jersey, p. 671(2001).

Mohanty, M., D.K. Painuli, A.K. Misra and P.K. Ghosh: Soil quality effects of tillage and residue under rice-wheat cropping on a vertisol in India. *Soil Till. Res.***92**, 243-250 (2007).

Nath, T.N.: Physico-chemical properties and its relationship with soil bulk density of roadside tea cultivated soils in Dibrugarh district of Assam, India. *Chem. Sci. Rev. Lett.,* **4**, 746-752 (2015).

Ranganathan, V. and S. Natesam: Nutrition of tea. In: *Proc. Int. Symp. Potassium in Agric.* ASA-CSSA-SSSA, Madison, Wisconsin, USA, 981-1022 (1985).

Reeves, D.W.: The role of soil organic manure in maintaining soil quality in continuous cropping systems. *Soil Till. Res.***43**, 131-167(1997).

Ruan, Jianyun, LifengMa, YuanzhiShi: Aluminium in tea plantations: Mobility in soils and plants, and the influence of nitrogen fertilization. *Environ. Geochem. Hlth.,* **28**, 519-528 (2006).

Ruan, J. and M.H. Wong:Accumulation of ûuoride and aluminium related to different varieties of tea plant. *Environ. Geochem. Hlth.*, **23**, 53–63 (2001).

Sharma, K.L., U.K. Mandala, K. Srinivasa, K.P.R. Vittala, B. Mandal, J.K. Gracea and V. Ramesha: Long-term soil management effects on crop yields and soil quality in a dryland Alfisols. *Soil Till. Res*., **83**, 246-259(2005).

Somasundaram, J., R.K. Singh, S. Ali, B.K. Sethy, D. Singh, B.L. Lakaria, R.S. Chaudhary, R.K. Singh and N.K Sinha: Soil aggregates and other properties as influenced by different long term land uses under table landscape topography of Chambal region, Rajasthan, India. **40**, 212-217(2013).

Wander, M.M. and G.A. Bollero: Soil quality assessment of tillage impacts on Illinois. *Soil Sci. Soc. Am. J.,* **63**, 961–971(1999).

Wienhold, B.J., J.L. Pikul, M.A. Liebig, M.M. Mikha, G.E. Varvel, J.W. Doran and S.S Andrews: Cropping system effects on soil quality in the Great Plains: Synthesis from a regional project. *Renew. Agri. Food Sys.,* **21**, 49–59 (2005).

Zhang, Y.L., S.H. Luo, Y.H. Zeng and P.Y. Pengo: Study nutrient scale of sufficiency or deficiency in tea soils in Hunan province and fertilizing recommendation. *J. Tea Soil,* **17**, 161-170 (1997).

Zoysa, A.K.N., A. Anandacoomaraswamy and M.S.D.L. De Silva: Management of soil fertility in tea lands: In: Handbook on Tea, Tea Res.Insti.Sri Lanka, pp. 27-33 (2008).