www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; SP-10(11): 1142-1151

www.thepharmajournal.com
Received: 04-09-2021
Accepted: 07-10-2021

V Venkatesh
Research Scholar, Department of Soil Science and Agricultural Chemistry, AC&RI, Coimbatore, Tamil Nadu, India

N Chandra Sekaran
Professor, Department of Soil Science and Agricultural Chemistry, AC&RI, Coimbatore, Tamil Nadu, India

G Sridevi
Assistant Professor, Department of Soil Science and Agricultural Chemistry, AC&RI, Coimbatore, Tamil Nadu, India

S Meena
Professor, Department of Soil Science and Agricultural Chemistry, AC&RI, Coimbatore, Tamil Nadu, India

KT Parthiban
Professor, Department of Agro-forestry, FC&RI, Mettupalayam, Tamil Nadu, India

Corresponding Author
V Venkatesh
Research Scholar, Department of Soil Science and Agricultural Chemistry, AC&RI, Coimbatore, Tamil Nadu, India

Assessment of soil quality under continuous fertilization in garden land ecosystem

V Venkatesh, N Chandra Sekaran, G Sridevi, S Meena and KT Parthiban

Abstract
Soil quality assessment includes physical, chemical and biological properties of the soil, is an important decision support system which aids in checking the efficiency of the adopted management practices in an ecosystem. In recent years, soil quality index assessment in qualitative evaluation is gaining importance. Hence, to assess the impact of constant and continuous application of fertilizers and manures on the soil quality, a study was carried out during 2019-20 in the permanent manurial experiment, which was established during 1909 at the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore. For which, Soil Quality Index (SQI) was developed for the soil receiving different treatments constantly and continuously for a period of 112 years. There were 18 treatments, of which eight treatments were with inorganic fertilizers in different permutation combinations, five treatments with manures of different sources and doses, two treatments with inorganics + organics including one STCR-IPNS recommendation and the remaining three treatments were farmers practice, control and an absolute control (fallow land) . The effect of the treatments on the soil quality was compared by developing the soil quality index at three different soil depths *viz.*, 0-15, 15-30 and 30-45cm's. Totally 27 soil physical, chemical and biological properties along with phosphatase, urease and dehydrogenase enzyme activities were analyzed and Principal Component Analysis (PCP) was used for selecting the indicators to be retained in minimum data set. The PCs with >1 eigen values were selected with a variance of 92.90%. Linear scoring functions were used to convert the indicators into unitless values between 0 and 1. Weighed factor was calculated and soil quality index was developed with the help of weighed factors and scores. Three different methods of soil quality index were analyzed *i.e.*, weighed additive soil quality index, relative soil quality index, additive soil quality index and nemoro soil quality index. In all these methods, the treatments which received inorganics + organics namely100% NPK+FYM and STCR – IPNS had shown their superiority in sustaining the soil health in all the soil depths *viz.*, 0-15, 15-30 and 30-45cm's.

Keywords: Soil quality index, Principal component analysis, minimum data set, linear scoring

Introduction

Soil is an important natural resource, and soil health is the combined effect of management on the majority of soil characteristics that affect crop production and long-term viability (Sharma *et al.*, 2005) [35]. Continuous cultivation with high-yielding cultivars and high-analysis fertilizers is unavoidable in Indian agriculture, which has increased the mining of nutrients from the soil. Large amounts of chemically treated nutrients must be added to the soil, and this may have an effect on the soil's characteristics and productivity over the long run. It's important to watch for changes in the productivity or quality of soil since it is both an important source for both nutrients and water, and a sink for pollution (for toxic chemicals). It has been conventional to focus on the chemical and physical properties of soil since easy analytical methods were available, but soil biology is now widely acknowledged as a sign of healthy soil (Larson and Pierce, 1991) [18]. (Kennedy and Papendick, 1995; Elliott *et al*., 1996; Ruzek *et al*., 2004) [16, 10, 31]. Hence, conducting a long-term experiment on a permanent site with continuous cropping can assist track changes in soil quality and crop production sustainability, as well as guide fertilizer management techniques and reduce environmental damage.

Materials and methods

Study area

The Permanent Manurial Experiment (PME) was established during the year 1909 at the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu Which is located at the prominent central area (11º00978 N latitude, 76°93354 E longitude with an elevation of 426.7 m above mean sea level). The experimental site belongs to hot semi-arid zone with an annual rainfall of 647.2mm. The soil falls under palanthurai series (*Typic Haplustalf*) with sandy loam texture. The initial properties of the soil was given in table.1 with treatment details in table.2.

Table 1: Initial soil properties of Permanent manurial experiment of TNAU, Coimbatore

S. No.	Properties	Value
Soil characteristics (analyzed in 1974)		
1	Clay (%)	18.5
2	Silt (%)	22.4
3	Fine sand (%)	18.8
4	Coarse sand (%)	40.0
5	Soil texture	Sandy loam
6	pH	8.30
7	Electrical conductivity (dS m^{-1})	0.25
8	Soil organic carbon (g kg^{-0})	1.80
9	Available N (kg ha^{-1})	147
10	Available P (kg ha^{-1})	3.58
11	Available K (kg ha^{-1})	381

Table 2: Treatment details of Permanent Manurial Experiment of TNAU, Coimbatore

	Treatments	Sunflower (kg ha^{-1})	Maize (kg ha^{-1})
T_1	Absolute Control	0	0
T_2	N alone	60	250
T_3	NK alone	60:60	250:75
T_4	NP alone	60:90	250:75
T_5	NPK	60:90:60	250:75:75
T_6	PK alone	90:60	75:75
T_7	K alone	60	75
T_8	P alone	90	75
T_9	NPK blanket	60:90:60	250:75:75
T_{10}	100 % NPK + FYM	123:115:123	313:100:138
T_{11}	Farmer's practice	70:58:38	97:58:60
T_{13}	STCR – IPNS (T = 30 & 70 q ha^{-1})	114:52:30	224:88:38
T_{14}	FYM NEB (12 & 50 t ha^{-1})	60:24:60	250:100:250
T_{15}	PM NEB (2.73 & 11.4 t ha^{-1})	60:49:30	250:205:125
T_{16}	Residue mulching	24:7.6:50.3	14:2:45
T_{17}	FYM Every Year (2 crops)	62.5:25:62.5	62.5:25:62.5
T_{18}	FYM Alternate Year (2 crops)	62.5:25:62.5	62.5:25:62.5

N-nitrogen; P- phosphorus; K- potassium; FYM- farm yard manure; STCR- IPNS- soil test crop response- integrated plant nutrient system; NEB- nitrogen equivalent basis; PM- poultry manure

Collection of Soil Samples

Both bulk and core soil samples were collected from all the treatments plot at three different depths *viz.*, 0-15, 15-30 and 30-45cm's by following quadrant method for the assessment of the soil quality index. The samples are processed as per the standard processing procedure.

Analysis

The collected soil samples were analyzed for Soil physical properties ie., bulk density (BD) and percent pore space was analyzed by following cylinder method outlined by Gupta & Dakshinamoorthi (1981). Wet aggregate stability (WAS) and Dry aggregate stability (DAS) was analyzed by Yodger apparatus outlined by Yodger (1936) [42]. Infiltration rate and hydraulic conductivity was analyzed by double ring infiltrometer and constant hydraulic head method proposed by Richards (1954) [30]. Particle size distribution was analyzed by International pipette method by Piper (1906).

Chemical properties i.e., Soil Reaction (pH), Electrical Conductivity (EC) and Cation Exchange Capacity (CEC) were analyzed by the standard procedure given by Jackson (1973) [13]. Organic Carbon (OC) was analyzed by chromic acid wet digestion method by Walkley and Black (1934) [40]. Nitrogen (N) by Alkaline Permanganate Method given by Subbiah and Asijia (1956) [37]. Phosphorus (P) was analyzed with 0.5M $NaHCO_3$ outlined by Olsen *et al.* (1954) [26]. Potassium by following 1N Neutral Ammonium Acetate given by Stanford and English (1949) [36]. Exchangeable calcium and Magnesium was analyzed with EDTA method discovered by Jackson (1973) [13]. Available Micronutrients were analyzed by DTPA extraction given by Lindsay and Norvell (1978) [20].

Soil biological parameters were also analyzed as much of the importance was not given to biological properties in developing soil quality index (SQI). Bacteria, Actinobacteria and Fungi were analyzed in the soil sample by following serial dilution plating technique according to collongs and Lyne (1968) [7], Kenknight and Munice (1939) [15] and Martin (1950) [21] respectively. Phosphatase, Urease and Dehydrogenase were determined by para nitro phenol formation method, 0.05M Tris hydroxymethyl aminomethane method and Triphenyl Tetrazolium Chloride reduction method respectively given by Tabatabai and Bremner, (1969) [39], Tabatabai and Bremner, (1972) [38] and Casida *et al.* (1964) [6].

Soil quality assessment

Three major steps were involved in the development of soil quality includes *viz.*, (1) Selection of minimum data sets using expert opinion, (2) using PCA to transform the data and eliminate the redundant variable and normalized scores assigned for the uncorrelated indicators, (3) Integration of weighed values and scores to develop indices.

Minimum data set selection

In order to avoid the dimensionality, the representative minimum data set were selected using Principal Component Analysis (PCA) (Doran and Parkinson, 1994) [9]. PCA gives number of principal components based on the linear combination of the indicators used which accounts for maximum variance within one set and the same will be followed for all the other PC's. Among all the generated PC's, the ones with eigen value of > 1 was selected for MDS and in that particular PC variables with 10% of the highly weighed variables were retained and the rest were eliminated.

Transformation and normalization of variables

To attain homogeneity in dimensions, each selected indicator was transformed into an unit less score ranging from 0 to 1 based on their contribution to soil function. Linear and nonlinear standard scoring functions were used to score the variables. The indicators for which more is better (eq.1) were considered to be sensitive and was divided by the highest observed value (denominator) and the score was assigned as 1. The indicators for which less is better (eq.2) like BD the lowest observes values (numerator) was divided by those observations and optimum (eq.3) where they received the score 1 as given by Andrews *et al.* (2003) [1]. The equations used for scoring negative and positive variable by standard scoring function is given below,

$$N(x) = \begin{cases} 1 & x \leq l \\ 1 - 0.9\,\frac{x-L}{U-L} & L \leq x \leq U \\ 0.1 & x \geq L \end{cases} \quad (1)$$

$$P(x) = \begin{cases} 0.1 & x \leq l \\ 0.9\,\frac{x-L}{U-L} & L \leq x \leq U \\ 1 & x \geq L \end{cases} \quad (2)$$

$$OR\,(x) = \begin{cases} 0.1 & x \leq L \\ 0.9\,\frac{x-L}{U-L} & L \leq x \leq U \\ 1 & x \geq L \end{cases} \quad (3)$$

*N - Negative; P-Positive; OR -Optimum Range; x-score of indicator (0 to 1); L-Lower and U-Upper threshold value

Computation of soil quality index

After attaining the homogeneity among the variables, various soil quality indices such as weighted SQI (SQI_w) (eq.4), Additive SQI (SQI_a) (eq.5) and Nemoro SQI (SQI_n) (eq.6) were calculated using the below mentioned formulas,

$$SQIw = \sum_{i=0}^{n} W_i\, S_i \quad (4)$$

Where, SQI (Soil Quality Index); W (Assigned Weight of indicators); S (Score the of indicators)

$$SQIa = \frac{\sum_i^n Ni}{n} \quad (5)$$

Where, N_i (Indicator Score); n (Number of indicators)

$$SQIn = \sqrt{\frac{P\,ave^2 + P\,min^2}{2}} \times \frac{n-1}{n} \quad (6)$$

Where, P_{ave} is the average and P_{min} is the minimum of the scores of the indicators selected

Statistical analysis

Soil data were analyzed using three-way analysis of variance (ANOVA) to determine the statistical significance ($p < 0.05$) of the factors and their interaction. The comparison of mean was done by DMRT using OPISTAT. STAR software was used to perform Principal Component Analysis (PCA) and the pearson's correlation was performed using SPSS version 16.

Results and discussion

Effect of long time application of fertilizers and manures on soil physical properties

The impact of constant and continuous application of fertilizers and manures was well expressed on soil physical properties (Table.7,8 &9).

The highest and lowest values were given below by comparing all the depths. Bulk density (BD) of the analyzed soil samples varied from 1.54-1.24 Mg m^{-3} at three different depths and was significantly different in three different depths. Among all the treatments control have the highest BD of 1.56 Mg m^{-3} at 30-45 cm when compared to FYM @ 12.5 t ha^{-1} which was observed to have lowest BD of 1.32 Mg m^{-3} at 0-15 cm depth . The values were noticed to be increased with increase in depth. However, porosity of the soil samples varied along the depth with a decreasing trend and were significantly different. The values ranged from 58.25% (FYM @ 12.5 t ha^{-1}) at 0-15 cm to 34.19% (Control) at 30-45 cm depth which may be due to positive effect of organic manure on soil aggregation at 0-15 cm depth (Meng *et al.* 2005) [22] and negative effect may be due to more bulk density. The similar trend was recorded in field capacity (18.8% in FYM @ 12.5 t ha^{-1} at 0-15 cm to 6.36% in Control at 30-45cm depth). Permanent Wilting Point was seen highest in 100% NP but not in a decreased trend 8.70% (100% NP (0-15 cm)) to 3.01% (Control) at 30-45cm depth. Available Water was observed to follow the same trend of porosity and field capacity (11.48% in FYM @ 12.5 t ha^{-1} at 0-15 cm to 3.35% in Control at 30-45cm depth) which decreased with depth and were significantly different. Hydraulic conductivity ranged from 5.37 cm hr^{-1} (FYM @ 12.5 t ha^{-1}) at 0-15 cm to 1.60 cm hr^{-1} (Control (0-15 cm)), across the depth less conductivity might be due to higher bulk density and lower organic manure (Mishra and Sharma, 1997) [24]. Similarly the Dry aggregate stability and Wet aggregate stability decreased with depth with the values fluctuating between 3.25 mm to 0.19 mm and 1.62 mm to 0.11 mm in the treatments receiving FYM @ 12.5 t ha^{-1} at 0-15 cm to Control at 30-45cm depth respectively may be due to more organic carbon which acts as binding agent (Bendi and Senapati, 2010) and also might be due to high microbial population where fungal hypae may play a significant role (Ladd *et al.* 1994) [17] over the surface depth alone.

To conclude, the soil physical properties were sustained in the treatments which received organics application irrespective of source and doses, however improvement in the soil physical properties were recorded when organics applied along with inorganic sources including STCR- IPNS treatment. Further leaving the land fallow also registered sustainability of soil physical properties compared to control treatment. Similar trend was registered in all the three depths, but with decreasing proportion.

Effect of long time application of fertilizers and manures on soil chemical properties

The impact of constant and continuous application of fertilizers and manures was well expressed on soil chemical properties (Table.7,8 &9).

Soil reaction (pH) varied from Alkaline to neutral in depth where the highest pH was observed in Control (8.24) at 0-15 cm depth and the lowest in the treatment 100% NPK + FYM (7.51) at 30-45 cm depth. Correspondingly Electrical Conductivity (EC) ranged from 0.32 dS m^{-1} (100% NPK + FYM) at 0-15 cm to 0.10 dS m^{-1} (Control) at 30-45 cm depth. Both were decreased with increase in depth. Cation Exchange Capacity (CEC) was noticed to be decreased with depth with a range of 22.30 Cmol (p^+) kg^{-1} in 100% NPK + FYM treatment at 0-15 cm to 12.44 Cmol (p^+) kg^{-1} in Control at 30-45 cm depth. Both colloidal nature of organic and mineral surface contributed to CEC of the soil might attribute the highest CEC under integrated treatment (Jat and Singh, 2017). Organic Carbon was significantly different in between the treatments and ranged from 9.45 g kg^{-1} (100% NPK + FYM) at 0-15 cm depth to 1.17 g kg^{-1} (Control) at 30-45 cm depth with a decreasing trend. All the available nutrients were noticed to be decreased with depth with, Nitrogen (N) ranging from 270 kg ha^{-1} to 103 Kg ha^{-1}, Phosphorus (P) from 35.7 kg ha^{-1} to 4.75 kg ha^{-1}, Potassium from 731 kg ha^{-1} to 256 kg ha^{-1}, Calcium (Ca) from 3.60 meq 100 g^{-1} to 0.80 meq 100 g^{-1}, Magnesium (Mg) ranged from 2.40 meq 100^{-1} to 0.28 meq 100^{-1} in 100% NPK + FYM(0-15 cm) and Control (30-45 cm), respectively. This might be due to integrated application of inorganics and organics higher microbial population and high organic carbon, organic form of nutrients are converted to inorganic (Dhaliwal *et al.*, 2019) [8]. In the case of micronutrients the trend followed in available nutrients was seen and were significantly different the values are as follows Iron (Fe) ranged from 2.96 mg kg^{-1} to 0.41 mg kg^{-1}; Zinc (Zn) from 2.13 mg kg^{-1} to 0.11 mg kg^{-1}; Copper (Cu) from 1.57 mg kg^{-1} to 0.24 mg kg^{-1} and Manganese (Mn) from 6.96 mg kg^{-1} to 0.24m mg kg^{-1}. The highest amount of micronutrients in the treatment 100% NPK + FYM (0-15 cm depth) might be due to the FYM and more organic carbon which forms moderately stable chelates with the organic ligands (Ylivainio, 2010; Shambhavi *et al.*, 2018; Miner *et al.* 2018; Bhatt *et al.*, 2018) [41, 33, 23, 5] and lowest in control at 30-45 cm depth.

To summarize, significantly higher soil chemical properties were observed in fertilizers applied along with organics including STCR- IPNS treatment followed by application of organics irrespective of source and doses. Fertility buildup was found in land fallow when compared to control. Similar trend was registered in all the three depths, but with decreasing proportion.

Effect of long time application of fertilizers and manures on soil biological properties

The impact of constant and continuous application of fertilizers and manures was well expressed on soil physical properties (Table.7,8 &9).

Soil enzymes analyzed were significantly different with the influenced of different treatments and decreased with the depth. Dehydrogenase (DHA) activity of the soil was noticed to vary from 47.75 µg TPF g^{-1} day^{-1} to 5.91 µg TPF g^{-1} day^{-1}; Phosphatase activity varied from 60.58 µg PNP g^{-1} h^{-1} to 8.25 µg PNP g^{-1} h^{-1} and Urease activity of the soil ranged from 65.56 µg of NH_4 released g^{-1} h^{-1} to 3.70 µg of NH_4 released g^{-1} h^{-1} along the depth in 100% NPK + FYM (0-15 cm depth) and Control (30-45 cm), respectively. In case of Bacteria population the highest was 69.0x10^6 cfu g^{-1} and the lowest was 11.0 x10^6 cfu g^{-1} through the depth. Fungi population ranged from 41.0 x10^4 cfu g^{-1} to 9.67 x10^4 cfu g^{-1} whereas Actinobacteria population ranged from 31.67x10^3 cfu g^{-1} to 9.0 x10^3 cfu g^{-1} across the depth, where the highest was in 100% NPK + FYM (0-15 cm depth) and lowest in Control (30-45 cm), respectively. Application of FYM alone or in conjoint use with inorganic fertilizers showed significant increase in both enzyme activity as well as microbial population when compared to imbalanced inorganic fertilizers (Rai and Yadav 2011 and Nath *et al*. 2012) [29, 25].

To conclude, the soil biological properties were sustained in the treatments which received organics applied along with inorganic sources including STCR- IPNS treatment. Additionally, sustainability of soil biological properties compared to control treatment was registered in the land left fallow. All the three depths were observed to follow the same trend, but with minimal proportions.

Soil Quality Indices (SQI)

The results obtained from the Principal Component Analysis (PCA) for the Permanent Manurial Experiment of Coimbatore is presented in the table.4. Out of 27 parameters 22 were selected for the estimation of the Soil Quality Index (SQI). The PCs with the eigen value >1(fig.1) were selected from the PCA where only two PCs were considered with a variance of 92.90 % within the data set (table.4). The highly weighted variables were selected from each PC. The correlation matrix (table.5) was run for the variables which were selected in the PC1 and the one with the lowest correlation sum was eliminated where remaining all the variables were retained for minimum data set (MDS) based on their function in soil quality. In PC1 phosphorus is been dropped from the PCA. In PC2 Soil reaction (pH) was the highly weighted variable and retained for the MDS. Hence the final MDS consists of field capacity (FC),permanent wilting point(PWP), Available water content (AWC), dry Aggregate stability (DAS), wet aggregate stability (WAS), electrical conductivity (EC), cation exchange capacity (CEC), organic carbon (OC), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), dehydrogenase (DHA), phosphotase (Ptase), urease, bacteria, fungi and actinobacteria and Soil reaction (pH) as the soil quality indicators for the soil of permanent manurial experiment of Coimbatore.

To transform the MDS into an unit less the scoring functions were used and the values were brought down between 0 to 1. Three different functions were used where "More is better" function was used for the indicators which directly influcences the soil quality. "Optimum in better" function was used which are required in optimum quantity and " Less is better" function in usually used for the indicators which are needed in less amounts to improve the soil quality like bulk density(BD) and electrical Conductivity (EC) based on the ratings. The weighted factor was analyzed from the variance percentage of the PCs with eigen value >1 by dividing with the total variance percentage (Sharma *et al., 2019*) [34].

The three different SQI of the permanent manurial experiement of garden land ecosystem of Coimbatore which was influenced by different treatments and different depths was presented in table.6. The SQI_w varied from 7.16 to 4.87 in 0-15 cm depth, 5.64 to 3.37 in 15-30 cm depth and 4.14 to 2.83 at 30-45 cm depth. The SQI_a values varied from 0.84 to 0.53 in 0-15 cm depth; 0.65 to 0.37 in 15-30 cm depth and 0.47 to 0.29 at 30-45 cm depth. The SQI_n values varied from 0.56 to 0.35 in 0-15 cm depth; 0.44 to 0.25 in 15-30 cm depth and 0.32 to 0.20 at 30-45 cm depth. In all the methods the high SQI was observed in the treatment receiving 100% NPK + FYM where the lowest in Control. It was also observed that SQI decreased with increase in depth (fig.2).

Table 4: Principal Component Analysis of the soil quality indicators with different treatments and different depths

Cropping Systems	Maize-Sunflower	
	PC1	PC2
Standard deviation	4.6656	1.821
Proportion Variance	0.8062	0.1228
Cumulative Proportion	0.8062	0.929
EigenValues	21.7674	3.3162
Soil parameters[d]		
BD	-0.188	0.232
Porosity	0.150	-0.369

FC	0.208	0.013
PWP	0.206	0.045
AWC	0.202	-0.021
HC	0.070	-0.483
DAS	0.200	0.030
WAS	0.200	0.075
pH	0.022	0.488[a]
EC	0.203	0.154
CEC	0.196	-0.132
OC	0.206	-0.030
N	0.207	-0.047
P	0.193	-0.117
K	0.211[ab]	-0.017
Ca	0.176	-0.288
Mg	0.209	0.036
Fe	0.210	-0.027
Zn	0.192	0.094
Cu	0.207	0.099
Mn	0.205	0.149
DHA	0.192	0.229
Ptase	0.208	0.007
Urease	0.204	-0.138
Bacteria	0.196	0.195
Fungi	0.198	0.131
Actinomycetes	0.206	0.139

[a] factor loadings are considered as highest weighted in each PC
[b] Highest pearson's correlation sum
[c] Lowest pearson's correlation sum
[d] BD- Bulk density; FC- field capacity; PWP- Permanent Wilting Point; AWC- Available Water Content; HC- Hydraulic Conductivity; DAS- Dry Aggregate Stability; WAS- Wet Aggregate Stability; EC- Electrical Conductivity; CEC- Cation Exchange Capacity; OC- Organic Carbon; N- Nitrogen; P- phosphorus; K- Potassium; Ca- Calcium; Mg- Magnesium; Fe- Iron; Zn- Znic; Cu-Copper; Mn- Manganese; DHA- dehydrogenase; ptase- Phosphotase.

Table 5: pearson correlation matrix for the high weighted variables

	FC	**PWP**	**AWC**	**DAS**	**WAS**	**EC**	**CEC**	**OC**	**N**	**P**	**K**	**Mg**	**Fe**	**Zn**	**Cu**	**Mn**	**DHA**	**Ptase**	**Urease**	**Bacteria**	**Fungi**	**Actinobacteria**
FC	1	0.978	0.976	0.941	0.920	0.915	0.847	0.922	0.917	0.839	0.939	0.956	0.940	0.844	0.946	0.940	0.876	0.914	0.895	0.883	0.895	0.940
PWP	0.978	1	0.909	0.919	0.956	0.903	0.793	0.896	0.886	0.802	0.913	0.964	0.930	0.867	0.966	0.937	0.882	0.888	0.888	0.884	0.919	0.933
AWC	0.976	0.909	1	0.919	0.839	0.884	0.864	0.906	0.906	0.838	0.922	0.902	0.906	0.780	0.880	0.898	0.828	0.899	0.860	0.840	0.827	0.903
DAS	0.941	0.919	0.919	1	0.844	0.901	0.852	0.859	0.864	0.731	0.916	0.955	0.938	0.752	0.914	0.920	0.863	0.873	0.880	0.905	0.793	0.904
WAS	0.920	0.956	0.839	0.844	1	0.898	0.761	0.877	0.869	0.801	0.886	0.931	0.896	0.899	0.957	0.922	0.885	0.896	0.863	0.880	0.957	0.919
EC	0.915	0.903	0.884	0.901	0.898	1	0.834	0.909	0.906	0.813	0.941	0.931	0.916	0.891	0.957	0.990	0.974	0.946	0.832	0.979	0.931	0.985
CEC	0.847	0.793	0.864	0.852	0.761	0.834	1	0.883	0.936	0.884	0.935	0.861	0.928	0.723	0.805	0.818	0.738	0.945	0.937	0.788	0.763	0.817
OC	0.922	0.896	0.906	0.859	0.877	0.909	0.883	1	0.935	0.950	0.960	0.906	0.918	0.929	0.921	0.909	0.842	0.940	0.929	0.850	0.875	0.915
N	0.917	0.886	0.906	0.864	0.869	0.906	0.936	0.935	1	0.924	0.976	0.914	0.955	0.855	0.901	0.897	0.835	0.967	0.932	0.842	0.897	0.922
P	0.839	0.802	0.838	0.731	0.801	0.813	0.884	0.950	0.924	1	0.910	0.806	0.865	0.873	0.821	0.803	0.717	0.910	0.902	0.734	0.827	0.821
K	0.939	0.913	0.922	0.916	0.886	0.941	0.935	0.960	0.976	0.910	1	0.954	0.975	0.874	0.939	0.936	0.878	0.974	0.949	0.894	0.892	0.948
Mg	0.956	0.964	0.902	0.955	0.931	0.931	0.861	0.906	0.914	0.806	0.954	1	0.976	0.848	0.969	0.949	0.909	0.921	0.927	0.916	0.898	0.946
Fe	0.940	0.930	0.906	0.938	0.896	0.916	0.928	0.918	0.955	0.865	0.975	0.976	1	0.830	0.943	0.928	0.863	0.952	0.958	0.896	0.882	0.928
Zn	0.844	0.867	0.780	0.752	0.899	0.891	0.723	0.929	0.855	0.873	0.874	0.848	0.830	1	0.917	0.895	0.860	0.870	0.821	0.846	0.918	0.904
Cu	0.946	0.966	0.880	0.914	0.957	0.957	0.805	0.921	0.901	0.821	0.939	0.969	0.943	0.917	1	0.977	0.933	0.918	0.889	0.944	0.945	0.970
Mn	0.940	0.937	0.898	0.920	0.922	0.990	0.818	0.909	0.897	0.803	0.936	0.949	0.928	0.895	0.977	1	0.970	0.936	0.843	0.983	0.938	0.987
DHA	0.876	0.882	0.828	0.863	0.885	0.974	0.738	0.842	0.835	0.717	0.878	0.909	0.863	0.860	0.933	0.970	1	0.888	0.754	0.964	0.921	0.969
Ptase	0.914	0.888	0.899	0.873	0.896	0.946	0.945	0.940	0.967	0.910	0.974	0.921	0.952	0.870	0.918	0.936	0.888	1	0.922	0.906	0.918	0.938
Urease	0.895	0.888	0.860	0.880	0.863	0.832	0.937	0.929	0.932	0.902	0.949	0.927	0.958	0.821	0.889	0.843	0.754	0.922	1	0.790	0.817	0.843
Bacteria	0.883	0.884	0.840	0.905	0.880	0.979	0.788	0.850	0.842	0.734	0.894	0.916	0.896	0.846	0.944	0.983	0.964	0.906	0.790	1	0.900	0.959
Fungi	0.895	0.919	0.827	0.793	0.957	0.931	0.763	0.875	0.897	0.827	0.892	0.898	0.882	0.918	0.945	0.938	0.921	0.918	0.817	0.900	1	0.954
Actino-bacteria	0.940	0.933	0.903	0.904	0.919	0.985	0.817	0.915	0.922	0.821	0.948	0.946	0.928	0.904	0.970	0.987	0.969	0.938	0.843	0.959	0.954	1
Correlation Sum	20.22	20.02	19.49	19.44	19.66	20.24	18.71	20.03	20.04	18.57	20.51	20.34	20.32	19.00	20.41	20.38	19.35	20.32	19.43	19.58	19.67	20.40

FC- field capacity; PWP- Permanent Wilting Point; DAS- Dry Aggregate Stability; WAS- Wet Aggregate Stability; EC- Electrical Conductivity; CEC- Cation Exchange Capacity; OC- Organic Carbon; N- Nitrogen; P- phosphorus; K- Potassium; Mg- Magnesium; Fe- Iron; Zn- Znic; Cu-Copper; Mn- Manganese, DHA-dehydrogenas

Table 6: Soil quality indices (SQI_w), Additive Soil Quality Index (SQI_a) and Nemoro Soil Quality Index (SQI_n) values of PME Coimbatore

	SQI_w			SQI_a			SQI_n		
	Depth (cm)			Depth (cm)			Depth (cm)		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
Control	5.38	5.07	10.46	0.56	0.53	1.06	0.41	0.36	0.72
100% N	6.85	5.05	6.40	0.71	0.53	0.66	0.50	0.37	0.45
100% NK	7.03	5.22	5.37	0.72	0.55	0.56	0.51	0.38	0.38
100% NP	7.41	5.49	5.09	0.76	0.57	0.53	0.54	0.40	0.37
100% NPK	7.97	6.03	5.23	0.82	0.63	0.55	0.57	0.45	0.38
100% PK	7.32	5.43	5.36	0.75	0.57	0.56	0.53	0.40	0.38
100% K	6.36	4.83	7.77	0.66	0.51	0.80	0.48	0.35	0.54
100% P	6.67	4.96	7.41	0.69	0.52	0.76	0.49	0.36	0.52
NPK blanket	7.76	5.77	5.25	0.80	0.60	0.55	0.56	0.42	0.38
100% NPK + FYM	9.02	6.77	5.64	0.92	0.70	0.59	0.63	0.49	0.43
farmers practice	7.65	5.63	5.28	0.78	0.59	0.55	0.55	0.41	0.38
No Manure No Crop	6.15	4.57	9.65	0.64	0.48	0.98	0.47	0.34	0.66
STCR – IPNS	8.81	6.63	5.59	0.90	0.69	0.59	0.61	0.48	0.42
FYM NEB	8.14	6.13	5.37	0.83	0.64	0.56	0.58	0.46	0.39
PM NEB	8.32	6.32	5.43	0.85	0.65	0.57	0.58	0.47	0.40
residue mulching	7.89	5.93	5.23	0.81	0.62	0.55	0.56	0.44	0.38
FYM @ 12.5 t ha-1	8.67	6.58	5.59	0.88	0.68	0.58	0.61	0.48	0.42
FYM alternate years	8.46	6.35	5.53	0.86	0.66	0.58	0.59	0.47	0.40

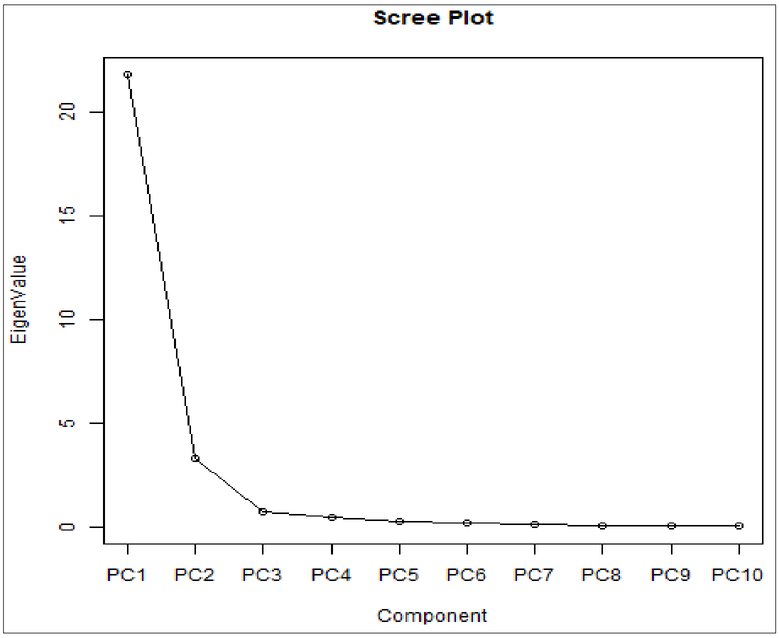
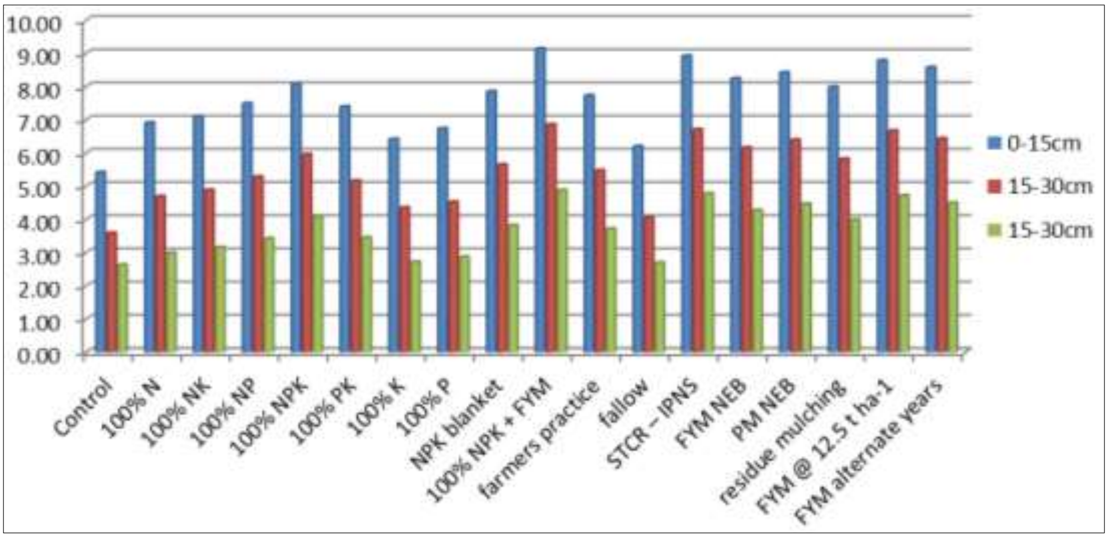
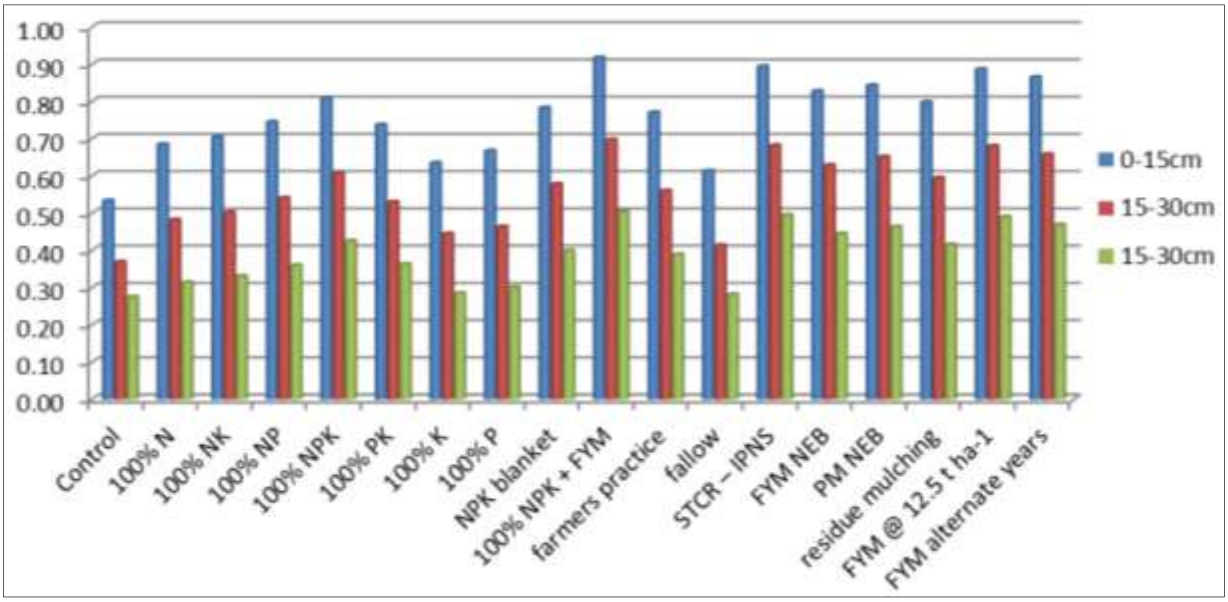


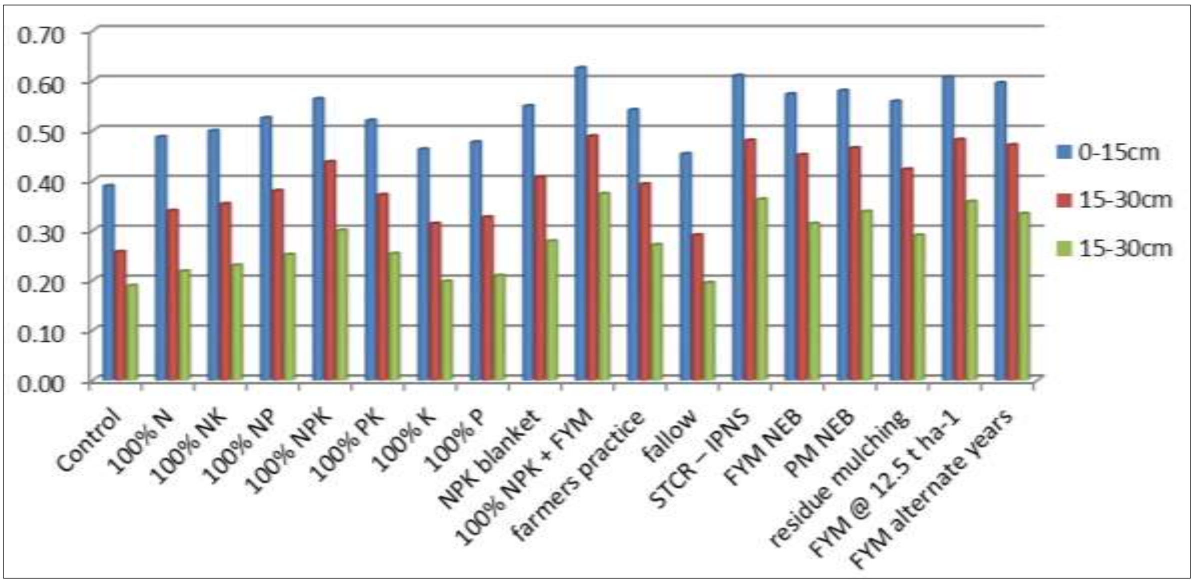
Fig 1: screen plot explaining the eigen values of each PCs



a. Weighed Additive Soil Quality Index (SQI_w)



b. Additive Soil Quality Index (SQI_a)



c. Nemoro Soil Quality Index(SQI_n)

Fig 2: Soil quality indices of PME with different depth of Coimbatore

Table 7: soil physical, chemical and biological properties of PME, Coimbatore at 0-15 cm depth soil.

Soil parameters	Maximum	Minimum	Mean	CD	SE(d)
Bulk Density (Mg m^{-3})	1.45	1.24	1.34	0.082	0.040
Porosity (%)	58.25	37.50	48.64	3.010	1.481
Field Capacity (%)	18.80	13.16	14.82	1.560	0.768
Permanent Wilting Point (%)	8.70	6.23	7.65	1.146	0.564
Available Water Content (%)	11.48	5.11	7.17	1.109	0.546
Hydraulic Conductivity (cm hr^{-1})	5.37	1.60	3.56	0.554	0.273
Dry Aggregate Stability (mm)	3.25	2.08	2.77	0.416	0.205
Wet Aggregate Stability (mm)	1.62	0.90	1.32	0.200	0.098
pH	8.24	7.66	8.08	0.273	0.134
Electrical Conductivity (dS m^{-1})	0.32	0.19	0.26	0.039	0.019
Cation Exchange Capacity [Cmol (p^+) kg^{-1}]	22.30	11.20	18.52	2.206	1.086
Organic Carbon (g kg^{-1})	9.45	3.61	5.94	0.913	0.449
Nitrogen (kg ha^{-1})	270	129	206	9.533	4.691
Phosphorus (kg ha^{-1})	35.75	6.56	18.45	3.013	1.483
Potassium (kg ha^{-1})	731	363	570	19.511	9.601
Calcium (meq 100 gm^{-1})	3.60	1.50	2.71	0.413	0.203
Magnesium (meq 100 gm^{-1})	2.40	1.11	2.06	0.311	0.153

Iron (mg kg^{-1})	2.96	1.18	2.38	0.363	0.179
Zinc (mg kg^{-1})	2.13	0.81	1.09	0.171	0.084
Copper (mg kg^{-1})	1.57	1.22	1.37	0.206	0.101
Manganese (mg kg^{-1})	6.96	4.32	5.77	0.868	0.427
Dehydrogenase (µg TPF g^{-1} day^{-1})	47.75	20.34	42.86	3.211	1.580
Phosphatase (µg PNP g^{-1} h^{-1})	60.58	13.10	43.49	3.364	1.655
Urease (µg of NH_4 released g^{-1} h^{-1})	65.56	14.18	43.83	4.751	2.338
Bacteria (x10^6 cfu g^{-1})	69.00	53.67	63.76	4.737	2.331
Fungi (x10^4 cfu g^{-1})	41.00	24.33	34.26	2.571	1.265
Actinobacteria (x10^3 cfu g^{-1})	31.67	20.67	26.59	1.984	0.976

Table 8: soil physical, chemical and biological properties of PME, Coimbatore at15-30 cm depth soil.

Soil parameters	Maximum	Minimum	Mean	CD	SE(d)
Bulk Density (Mg m^{-3})	1.51	1.29	1.40	0.213	0.105
Porosity (%)	56.71	35.19	46.74	2.898	1.426
Field Capacity (%)	13.26	10.11	11.29	1.203	0.592
Permanent Wilting Point (%)	7.08	4.51	5.70	0.673	0.331
Available Water Content (%)	6.79	4.38	5.59	0.664	0.327
Hydraulic Conductivity (cm hr^{-1})	5.11	3.17	4.34	0.325	0.160
Dry Aggregate Stability (mm)	2.91	1.26	2.21	0.267	0.131
Wet Aggregate Stability (mm)	0.90	0.24	0.54	0.068	0.033
pH	8.19	7.59	8.00	0.270	0.133
Electrical Conductivity (dS m^{-1})	0.23	0.14	0.18	0.021	0.011
Cation Exchange Capacity [Cmol (p$^+$) kg^{-1}]	21.06	13.06	17.14	1.993	0.981
Organic Carbon (g kg^{-1})	6.05	3.07	4.15	0.498	0.245
Nitrogen (kg ha^{-1})	201	122	165	7.487	3.684
Phosphorus (kg ha^{-1})	21.27	4.30	11.15	1.79	0.881
Potassium (kg ha^{-1})	572	317	454	15.47	7.615
Calcium (meq 100 gm^{-1})	3.30	1.10	2.51	0.383	0.189
Magnesium (meq 100 gm^{-1})	1.78	0.72	1.37	0.209	0.103
Iron (mg kg^{-1})	2.26	0.44	1.68	0.261	0.129
Zinc (mg kg^{-1})	0.66	0.21	0.40	0.063	0.031
Copper (mg kg^{-1})	1.24	0.72	1.02	0.153	0.075
Manganese (mg kg^{-1})	4.39	1.15	3.16	0.486	0.239
Dehydrogenase (µg TPF g^{-1} day^{-1})	27.48	19.30	23.54	2.781	1.368
Phosphatase (µg PNP g^{-1} h^{-1})	40.68	11.62	26.72	3.006	1.479
Urease (µg of NH_4 released g^{-1} h^{-1})	50.78	5.94	30.34	3.862	1.900
Bacteria (x10^6 cfu g^{-1})	51.67	19.67	38.85	4.249	2.091
Fungi (x10^4 cfu g^{-1})	21.67	14.00	17.44	2.069	1.018
Actinobacteria (x10^3 cfu g^{-1})	21.33	15.33	19.02	1.415	0.696

Table 9: soil physical, chemical and biological properties of PME, Coimbatore at 30-45 cm depth soil.

Soil parameters	Maximum	Minimum	Mean	CD	SE(d)
Bulk Density (Mg m^{-3})	1.54	1.32	1.42	0.221	0.109
Porosity (%)	55.85	34.19	45.89	2.860	1.407
Field Capacity (%)	11.65	6.36	9.11	0.986	0.485
Permanent Wilting Point (%)	6.62	3.01	4.80	0.525	0.259
Available Water Content (%)	5.45	3.35	4.32	0.514	0.253
Hydraulic Conductivity (cm hr^{-1})	4.74	2.89	4.02	0.302	0.148
Dry Aggregate Stability (mm)	1.93	0.19	1.10	0.183	0.090
Wet Aggregate Stability (mm)	0.81	0.11	0.44	0.052	0.026
pH	7.89	7.51	7.76	0.262	0.129
Electrical Conductivity (dS m^{-1})	0.13	0.10	0.11	0.013	0.006
Cation Exchange Capacity [Cmol (p$^+$) kg^{-1}]	15.27	12.44	13.99	1.039	0.511
Organic Carbon (g kg^{-1})	4.10	1.17	2.83	0.344	0.169
Nitrogen (kg ha^{-1})	160	103	127	5.784	2.846
Phosphorus (kg ha^{-1})	10.41	4.75	7.94	1.214	0.597
Potassium (kg ha^{-1})	447	256	332	11.340	5.580
Calcium (meq 100 gm^{-1})	2.90	0.80	2.16	0.262	0.129
Magnesium (meq 100 gm^{-1})	1.38	0.28	0.85	0.109	0.054
Iron (mg kg^{-1})	1.57	0.41	1.06	0.166	0.082
Zinc (mg kg^{-1})	0.48	0.11	0.25	0.041	0.020
Copper (mg kg^{-1})	1.06	0.64	0.84	0.123	0.061
Manganese (mg kg^{-1})	1.82	0.24	1.07	0.176	0.087
Dehydrogenase (µg TPF g^{-1} day^{-1})	12.39	5.91	8.78	1.340	0.659
Phosphatase (µg PNP g^{-1} h^{-1})	19.18	8.25	13.44	2.048	1.008
Urease (µg of NH_4 released g^{-1} h^{-1})	37.20	3.70	21.27	3.484	1.714

Bacteria (x10^6 cfu g^{-1})	17.33	11.00	15.80	2.383	1.173
Fungi (x10^4 cfu g^{-1})	17.33	9.67	14.09	1.057	0.520
Actinobacteria (x10^3 cfu g^{-1})	16.33	9.00	13.15	1.410	0.694

Conclusion

Assessing soil quality is a useful tool for agriculture managers and policy makers to obtain a better understanding of how different soils influence the potential for agriculture. The soil quality index was the best performing index and when calculated using MDS approach could be applied as an efficient tool to assess soil quality. All the relevant soil indicators were taken into consideration for the evaluation in this study and produced consistent and logical results. The importance of different treatments on soil quality index was clearly indicated in this study. Under the intensive cropping system, the treatment dose of 100% NPK + FYM was found to be having good soil quality followed by STCR – IPNS. It was also observed that the results obtained from three SQI methods constantly reduced with depth. The indicators selected can further be used for assessing soil quality indices for better understanding of soil quality index change with time. Therefore application of inorganic and organic in an integrated manner is essential for the proper nutrient supply and sustaining crop productivity

References

1. Andrews SS, Flora CB, Mitchell JP, Karlen DL. Grower's perceptions and acceptance of soil quality indices. *Geoderma* 2003;114:187-213.
2. Andrews SS, Karlen DL, Mitchell JP. A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agriculture Ecosystems & Environment 2002a;90:25-45.
3. Andrews SS, Mitchell JP, Mancinelli R, Karlen KL, Hartz TK, Horwath WR *et al*. On-farm assessment of soil quality in California's central valley. Agronomy Journal, 2002b;94:12-23.
4. Benbi DK, Senapati N. Soil aggregation and carbon and nitrogen stabilization in relation to residue and manure application in rice–wheat systems in northwest India. Nutrient cycling in agroecosystems 2010;87(2):233-247.
5. Bhatt MK, Raverkar KP, Labanya R, Bhatt CK. Effects of long-term balanced and imbalanced use of inorganic fertilizers and organic manure (FYM) on soil chemical properties and yield of rice under rice-wheat cropping system. J. of Pharmacogn. Phytochem 2018;7(3):703-708.
6. Casida Jr LE, Klein DA, Santoro T. Soil dehydrogenase activity. Soil sci. 1964;98(6):371-376.
7. Collings CH, Lyne MP. Microbiological methods, London: Butter Worth. Reprint 1968, 5.
8. Dhaliwal SS, Naresh RK, Mandal A, Walia MK, Gupta RK, Singh R *et al*. Effect of manures and fertilizers on soil physical properties, build-up of macro and micronutrients and uptake in soil under different cropping systems: a review. Journal of Plant Nutrition 2019;42(20):2873-2900.
9. Doran JW, Parkin TB. Defining and assessing soil quality. SSSA special publication 1994;35:3-3.
10. Elliott ET, Paustian K, Frey SD. Modeling the measurable or measuring the modelable: a hierarchical approach to isolating meaningful soil organic matter fractionations. In: Powlson, D.S., Smith, P., Smith, J.U. (Eds.), Evaluation of Soil Organic Matter Models. Springer-Verlag, NATO ASI Series 1996, 161-179.
11. Flora CB. Food security in the context of energy and resource depletion: sustainable agriculture in developing countries. Renew. Agric. Food Syst 2010;25:118-128.
12. Gupta RP, Dakshinamoorthy C. Procedures for physical analysis of soil and collection of agrometeorological data. New Delhi: Indian Agricultural Research Institute 1980, 293.
13. Jackson ML. Soil chemical analysis. Prentice-Hall of India Pvt. Ltd. New Delhi, India 1973a, 327-350.
14. Jat LK, Singh YV. Short-term effects of organic and inorganic fertilizers on soil properties and enzyme activities in rice production. Int. J. of Curr. Microbiology App. Sci. 2017;6(2):185-194. http://dx.doi.org/10.20546/ijcmas.2017.602.025.
15. Kenknight G, Muncie JH. Isolation of phytopathogenic actinomycetes. Phytopathology 1939;29(11):1000-1001.
16. Kennedy AC, Papendick RI. Microbial characteristics of soil quality. Journal Soil Water Conservation 1995;50:243-248.
17. Ladd JN, Amato M, Zhou LK, Schultz JE. Differential effects of rotation, plant residue and nitrogen fertilizer on microbial biomass and organic matter in an Australian Alfisol. Soil Biology and Biochemistry 1994;26(7):821-831
18. Larson WE, Pierce FJ. Conservation and enhancement of soil quality. In: Dumanski, J., Pushparajah, E., Latham, M., Myers, R., Elliot, C.R. (Eds.), Evaluation for Sustainable and Management in the Developing World, vol. 2. Int. Board for Soil Res. and Management, Bangkok, Thailand, IBSRAM Proc 1991;12(2):175-203.
19. Larson WE, Pierce FJ. The dynamics of soil quality as a measure of sustainable management. Defining Soil Quality for a Sustainable Environment. Soil Science Society of America, SSSA and ASA, Madison, Wisconsin, USA, SSSA Special Publication 1994;35:37-52
20. Lindsay WL, Norvell WA. Development of a DTPA soil test for zinc, iron, manganese and copper. SSSA 1978;42(3):421-428. https://doi.org/10.2136/sssaj1978.03615995004200030009x.
21. Martin JP. Use of acid, rose bengal, and streptomycin in the plate method for estimating soil fungi. *Soil science.* 1950;69(3):215-232.
22. Meng L, Ding W, Cai Z. Long-term application of organic manure and nitrogen fertilizer on N_2O emissions, soil quality and crop production in a sandy loam soil. Soil Biol. and Biochem. 2005;37(11):2037-2045. https://doi.org/10.1016/j.soilbio.2005.03.007.
23. Miner GL, Delgado JA, Ippolito JA, Barbarick KA, Stewart CE, Manter DK *et al*. Influence of long-term nitrogen fertilization on crop and soil micronutrients in a no-till maize cropping system. Field Crops Research 2018;228:170-182. https://doi.org/10.1016/j.fcr.2018.08.017.
24. Mishra YK, Sharma RB. Effect of fertilizers alone and in combination with manure on physical properties and productivity of Entisol under rice-based cropping systems. Journal Indian Society Soil Science

1997;45(1):84-88.
25. Nath DJ, Ozah B, Baruah R, Barooah RC, Borah DK, Gupta M. Soil enzymes and microbial biomass carbon under rice-toria sequence as influenced by nutrient management. Journal Indian Society Soil Science. 2012;60:20-24.
26. Olsen SR. Estimation of available phosphorus in soils by extraction with sodium bicarbonate: US Department of Agriculture 1954.
27. Piper CS. Soil and plant analysis. Hans Publishers: Bombay, India 1966.
28. Qin MZ, Zhao J. Strategies for sustainable use and characteristics of soil quality changes in urban-rural marginal area: a case study of Kaifeng. Acta Geogr. Sin. (In Chinese with English abstract) 2000;55:545-554.
29. Rai TN, Yadav J. Influence of inorganic and organic nutrient sources on soil enzyme activities. Journal of Indian Society Soil Science 2011;59(1):54-59.
30. Richards LA. Diagnosis and Improvement of Saline and Alkali Soils. Handbook 60. Soil Tillage Research 1954;112:167-74.
31. Ruzek L, Vorisek K, Strnadova S, Novakova M, Barabasz W. Microbial characteristics, carbon and nitrogen content in cambisols and luvisols. Plant Soil Environment 2004;50:196-204.
32. Seybold CA, Mausbach MJ, Karlen DL, Rogers HH. Quantification of soil quality, In: Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (Eds.), Soil Processes and the Carbon Cycle, Boca Raton, FL 1997, 387-404.
33. Shambhavi S, Kumar R, Sharma SP, Verma G, Sharma SK, Sharma RP. Effect of 36 years of continuous cropping and fertilization on productivity, micro and secondary nutrient status and uptake by maize-wheat cropping system in western Himalayas. International Journal of Bio-resource and Stress Management 2018;9(2):197-202.
34. Sharma KL, Chary GR, Reddy KS, Lal M, Indoria AK, Srinivas K *et al*. Effect of Conjunctive Use of Inorganic and Organic Sources of Nutrients on Soil Quality Parameters, Key Indicators and Soil Quality Indices (SQIs) under Sorghum+ Cowpea Intercropping System in Rainfed Vertisol Soils of Southern India. Indian Journal of Dryland Agriculture Research and Devvelopment. 2019;34(2):47-59.10.5958/2231-6701.2019.00019.8.
35. Sharma KL, Mandal UK, Srinivas K, Vittal KPR, Mandal B, Kusuma JG *et al*. Long term soil management effects on crop yields and soil quality in a dryland Alfisol. Soil Tillage Research 2005;83:246-259.
36. Stanford G, English L. Use of the flame photometer in rapid soil tests for K and Ca. Agron. J. 1949;41(9):446-447. https://doi.org/10.2134/agronj1949.00021962004100090012x.
37. Subbiah BV, Asija GL. Alkaline method for determination of mineralizable nitrogen. Current Science. 1956;25(2):259-260.
38. Tabatabai MA, Bremner JM. Assay of urease activity in soils. Soil Biology and Biochemistry 1972;4(4):479-487. https://doi.org/10.1016/0038-0717(72)90064-8.
39. Tabatabai MA, Bremner JM. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biology and Biochemistry 1969;1(4):301-307. https://doi.org/10.1016/0038-0717(69)90012-1.
40. 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 science 1934;37(1):29-38.
41. Ylivainio K. Effects of iron (III) chelates on the solubility of heavy metals in calcareous soils. Environmental Pollution 2010;158(10):3194-3200. https://doi.org/10.1016/j.envpol.2010.07.004.
42. Yoder RE. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Agronomy journal 1936;28(5):337-351. https://doi.org/10.2134/agronj1936.00021962002800050001x