Soil Quality Index under Organic Farming

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Assessing the quality of soil resources has been stimulated by increasing awareness that it is an important component of the earth's biosphere, functioning not only in the production of food and fiber but also in ecosystems services and the maintenance of local, regional, and global ecological balance (Glanz, 1995). Soil quality primarily describes the combination of chemical, physical, and biological characteristics that enables soils to perform a wide range of ecological functions (Karlen *et al.*, 1997). The functions largely include, sustaining biological activity and diversity; regulating and partitioning water and solute flow; filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic toxic materials; storing and cycling nutrients in soil-plant-atmospheric continuum and providing support of socio-economic treasures. Another way we can tell the quality of a soil is an assessment of how it performs all of its functions now and how those functions are being persuaded in future.

Indiscriminate use of chemical fertilizers and pesticides in intensive agriculture resulted in several harmful effects on soil, water and air quality. This has reduced the productivity of the soil by deteriorating soil fertility and biological activity. However enhancement and maintenance of soil quality is essential for sustainable agriculture. Further, unscientific use of pesticides has led to the entry of harmful compounds into food chain, death of natural enemies and development of resurgence/resistance to pesticides. It is believed that organic farming can solve many of these problems as this system maintain soil productivity and pest control by maintaining natural processes in harmony with environment. Organic farming is defined as a production system which largely excludes or avoids the use of fertilizers, pesticides, growth regulators, etc. and relies mainly on natural organic sources to maintain soil quality, supply plant nutrients and minimize the infestation of insects, weeds and other pests.

Soil Quality

Soil quality has been defined by scientists as the "fitness for use" (Pierce and Larson, 1993), and by others as the as the "capacity of a soil to function" (Doran and Parkin, 1994). "The capacity of a soil to function within boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health", was the definition of soil quality put forth by Doran and Parkin (1994). Lal and Stewart (1995) described soil quality as the inherent attribute of soil and to characteristics and processes that determined the soil's capacity to produce economic goods and services and regulate the environment. The soil quality definition given by Karlen *et al.* (1997) mentioned as, "The capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation". It can be conceptualized as an integration of three major components - sustained biological productivity, environmental quality and plant and animal health.

Importance of Soil Quality and its Assessment

Soil quality is important for two reasons. First, unscientific use of soil can damage itself and the ecosystem; therefore we need to match the management of land to the soil's capability. Second, we need to establish a baseline understanding about soil quality so that we can recognize changes as they occur. Therefore, the ultimate purpose of assessing soil quality is to protect and improve long-term agricultural productivity, water quality, and habitats of all organisms including human being. In recent years, soil quality research has focused on the linkages among the following: management practices and systems; observable soil characteristics; and soil processes and performance of soil functions. Choosing the appropriate soil attributes to include in an index must include consideration of soil function and management goals that are site specific and user-oriented and must focus on sustainability rather than just crop yields. These indices would be useful in ascertaining the fragility of soil and for understanding how improved management might strengthen its resilience (Chaudhury *et al.*, 2005). The testing of soil for routine analysis can only provide a snap shot on soil fertility which is not able to identify the production constraints because of deterioration of other soil properties. Therefore, assessing soil quality is advantageous for its holistic way to judge the management-induced changes. This capacity of the soil to function can be assessed by physical, chemical, and/or biological properties, which is termed as soil quality indicators (Wander and Bollero, 1999). Individual soil properties/processes may not provide an adequate measure of soil quality and integrated soil quality indicators based on a combination of soil properties can better reflect the status of soil quality than individual parameters. Soil quality changes with time can indicate whether the soil condition is sustainable or not (Arshad and Martin, 2002; Doran, 2002). Soil quality cannot be measured directly however; it can be inferred by measuring soil physiochemical and biological properties that serve as quality indicator (Brejda *et al.*, 2000, Diack and Stott, 2001). Therefore an integrated 'soil quality index' based on the weighted contribution of individual soil property to maintain the soil quality may serve better indicator of soil quality for different land uses.

Soil quality indicators

Soils have chemical, biological, and physical properties/ processes that interact in a complex way to give a soil its quality (Karlen *et al.*, 1997). Thus, soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as indicators. Indicators are measurable properties soil. The type of indicator chosen to evaluate soil quality depends on the soil function and the size of the area (i.e. field, farm, watershed, or region etc.) in which the evaluation is made. Considering basic soil functions i.e., provision of sufficient amounts of water, and nutrients, provision of resistance and resilience to physical degradation, and sustaining plant growth under an appropriate utilization, numerous soil analyses might be required to fully characterize the soil/plant system. Thus, broad soil quality indicators could be grouped, *viz*., (i) soil chemical quality and soil fertility indicators, (ii) soil physical quality indicators and (iii) soil biological quality indicators (Table 1).

Soil Quality Index

Four major tools have been used for soil quality assessment *viz*., Soil Conditioning Index (SCI), Soil Management Assessment Framework (SMAF), the Agroecosystem Performance Assessment Tool (AEPAT) and the New Cornell "Soil Health Assessment". Out of these, SMAF was developed as malleable tools for assessing soil response to management and is most widely used for the assessment of soil quality. The SMAF is an additive, non-linear indexing tool for assessing soil function (Andrews *et al.* 2004). The SMAF is intended for use by land managers and their advisors for use in assessing ongoing management practices. In determination of soil quality index (SQI) using SMAF, four main steps are followed (Fig. 1): (i) formulation of appropriate goals for desired outcomes of soil functions, (ii) selection of a minimum data set (MDS) of indicators that best represent soil function, (iii) scoring the MDS indicators based on their performance of soil function and (iv) integration of the indicator scores into a comparative SQI (Nayak *et al.*, 2016).

Table 1. Soil quality indicators at different levels of soil management and planning

Physical indicators	Chemical indicators	Biological indicators
Field, Farm or Watershed indicators		
Passage of air	Base saturation percentage	Soil Organic carbon
Structural stability	Cation exchange capacity	Microbial biomass carbon
Bulk density	Contaminant availability	C and N/Oxidizable carbon
Clay mineralogy	Contaminant concentration	Total biomass
Colour	Contaminant mobility	Bacterial
Consistence (dry, moist, wet)	Contaminant presence	Fungal
Depth of root limiting layer	Electrical conductivity	Potentially mineralizable N
Hydraulic conductivity	Exchangeable sodium percentage	Soil respiration
Oxygen diffusion rate	Nutrient cycling rates	Enzymes
Particle size distribution	pH	Dehydrogenase
Penetration resistance	Plant nutrient availability	Phosphatase
Pore conductivity	Plant nutrient content	Arlysulfatase
Pore size distribution	Sodium adsorption ratio	Biomass C/total organic Respiration / biomass carbon/
Soil strength		Microbial community fingerprinting
Soil tilth		Substrate utilization
Structure type		Fatty acid analysis
Temperature		Nucleic acid analysis
Total porosity		
Water holding capacity		
Regional or National level		
Desertification	Organic matter trends	Productivity (yield stability)
Vegetative cover	Acidification	Taxonomic diversity at the group level
Water erosion	Salinisation	Species richness diversity
Wind erosion	Changes in water quality	Keystone species and ecosystem engineers
Siltation of rivers and lakes	Changes in air quality	Biomass, density and abundance
Sediment load in rivers		

Source: Singer and Ewing (2000); Nayak *et al.* (2016)

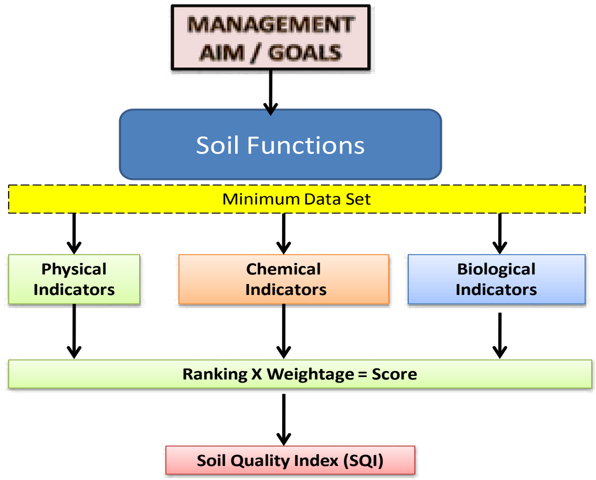


Figure 1. A generalized framework for developing soil quality indices

(i) Formulation of appropriate goals for desired outco*mes of soil functions*

Soil quality indices and indicators should be selected according to the soil functions of interest and the defined management goals for the system. Management goals are often individualistic, primarily focused on on-farm effects, but can also be societal, including the broader environmental effects of farm management decisions such as soil erosion, agrochemical contamination of soil and water, or subsidy imbalance (from over-use of fossil fuels or agrochemicals). Management goals may also differ by the interests and visions of different sections of people concerned with agriculture.

(ii) Selection of a minimum data set (MDS) of indicators

Once the system's management goals are identified, the next step for soil quality indexing is to choosing appropriate indicators for a minimum data set (MDS). It would be unrealistic to use all ecosystems or soil attributes as indicators, so a minimum data set (MDS) consisting of attributes encompassing chemical, physical and biological soil properties are selected for soil quality assessment. Nearly all of the physical, chemical, and biological attributes that comprise a minimum data set have established meanings and published procedures that predate the soil quality concept. A minimum dataset for assessing soil quality should have the characteristics (Doran and Parkin, 1994) like, easy to measure, detect changes in soil function, integrate soil physical, chemical, and biological properties and processes, accessible to many users and applicable to field conditions, sensitive to variations in management and climate, encompass ecosystem processes and relate to process-oriented modeling and where possible, be components of existing soil data bases.

Minimum data set components can be selected based on expert opinion (Karlen *et al.*, 1996) and/or by using statistical methods. The physiological rhizosphere studies of Bachmann and Kinzel (1992) used principle component analysis (PCA), multiple correlation, factor analysis, cluster analysis and star plots to select characteristics for their diagnostic index. Bentham *et al.* (1992) used principal component analysis and other statistical clustering techniques to choose variables best representing the progress of soil restoration efforts. The principal component analysis generally relies less on any individual scientist making selections of goals, functions, and indicators. It uses a statistical technique to identify the indicators that best represent variability in a large existing data set. This technique affords less opportunity for disciplinary bias but does require a robust data set. Mechanistically, the data set must have a sufficient number of observations and variables. Functionally, whatever is measured must have potential value as an indicator (i.e., some relationship to the critical soil functions). After the data are analyzed and mean comparisons are made, only those indicators showing statistically significant differences are included in the PCA. The data are then analyzed using PCA to prioritize and reduce the number of indicators or variables that need to be measured in subsequent samplings. PCs receiving high eigenvalues best represent variation in the systems (Shahid *et al.*, 2013). Therefore, only the PCs with eigenvalues ≥ 1 (Kaiser, 1960) are taken into consideration. Additionally, PCs that explain $\geq 5\%$ of the variability in the soils data (Wander and Bollero, 1999) could be included when fewer than three PCs had eigenvalues ≥ 1. Under a particular PC, each variable is given a weight or factor loading that represents the contribution of that variable to the composition of the PC. Only the highly weighted variables were retained from each PC for the MDS (Table 2). Highly weighted factor loadings were defined as having absolute values within 10% of the highest factor loading or ≥ 0.70 (absolute value, Shahid *et al.*, 2013). When more than one factor was retained under a single PC, multivariate correlation coefficients were employed to determine if the variables could be considered redundant and, therefore, eliminated from the MDS (Andrews *et al.*, 2002). Highly correlated variables were considered redundant and only one was considered for the MDS. If the highly weighted factors were not correlated (assumed to be a correlation coefficient <0.60) then each was considered important, and thus, retained in the MDS. Among well correlated variables, the variable with the highest factor loading (absolute value) was chosen for the MDS. The PCA loading value of the selected variables under the respective

PCs is used to provide "weighting factors" for the indicators included in the soil quality indices (Andrews *et al.*, 2002). To check how well the MDS represented the management systems or goals, multiple regressions of both the EO selected and PCA-MDSs are performed using the indicators retained as independent variables and the end point measures (goals) as dependent variables. If any variable within the MDS did not contribute to the coefficient of determination from the multiple regressions, it was also ignored. After the MDS indicators were determined, results may be transformed using a linear or non-linear scoring method.

(iii) Scoring the MDS indicators based on their performance of soil function

After determining the variables for the MDS, every observation of each MDS indicator was transformed for inclusion in the SQI methods examined. Knowledge on the variations in soil quality indicators in similar type of soils under various distinct management systems is necessary to convert the raw data on soil parameters/soil quality indicators into unit less numerical scores. This will help us to set the limits or thresholds for the soil quality indicators (Table 2). Based on the range of each soil quality indicators and its measures and reported critical values, the limits/thresholds were fixed. As reported by Masto *et al.* (2007), the success and usefulness of a soil quality index mainly depends on setting the appropriate critical limits for individual soil properties. The optimum/critical values of soil quality could be obtained from the soils of undisturbed ecosystems (Warkentin 1996; Arshad and Martin 2002), where soil functioning is at its maximum potential to or in best managed systems or on critical values available in the literature. After finalizing the thresholds or limits the numerical score of each MDS variable is transformed using linear scoring or non-linear scoring functions.

(iv) Integration of the indicator scores into a comparative SQI

The last and final step will be integration of indicator scores into a comparative index of soil quality. Soil quality indicator values were normalized on a scale from 0 to 1. Two soil quality indexing methods are mostly used i.e. (i). Conceptual framework for analyzing soil quality and (ii). Principal component analysis based soil quality index.

Table 2. Soil quality indicators and scoring functions

Indicator	Scoring curve	Lower threshold	Upper threshold	Lower baseline	Upper baseline	Optimum	Source of limits
Clay (%)	More is better	0	40	20	-	-	
Bulk density (Mg/m3)	Less is better	1	2	1.5	-	-	Glover *et al.*, 2000;
Hydraulic conductivity (cm/h)	Optimum	0.2	2	0.6	1.5	1.6	Lal (1994)
Clay dispersion index	Less is better	0	36	18	-	-	
pH	Optimum	4.5	9	5.5	7.5	6.5	
Electrical conductivity (dS/m)	Less is better	2	12	6	-	-	
Organic carbon (g/kg)	More is better	0	12	6	-	-	Rao (1995)
Microbial biomass carbon (mg/kg)	More is better	0	400	200	-	-	Haynes (2005)
Carbon mineralization (mg/kg)	More is better	0	1200	600	-	-	Haynes (2005)
Total nitrogen (mg/kg)	More is better	0	1200	600	-	-	
Available nitrogen (kg/ha)	More is better	0	400	200	-	-	
Microbial biomass nitrogen (mg/kg)	More is better	0	60	30	-	-	Haynes (2005)
Nitrogen mineralization (mg/kg)	More is better	0	60	30	-	-	Haynes (2005)
Bray's phosphorus (kg/ha)	More is better	0	50	25	-	-	
Available potassium (kg/ha)	More is better	0	400	200	-	-	
DTPA Zinc (mg/kg)	More is better	0	1.5	0.75	-	-	
DTPA Copper (mg/kg)	More is better	0	5	2.5	-	-	
DTPA Iron (mg/kg)	More is better	0	50	25	-	-	
DTPA Manganese (mg/kg)	More is better	0	20	10	-	-	
Urease (µg NH_4^+ /g/h)	More is better	0	200	100	-	-	
Dehydrogenase (µg TPF /g/h)	More is better	0	100	50	-	-	
Acid Phosphatase (µg PNP /g/h)	More is better	0	600	300	-	-	
Alkaline Phosphatase (µg PNP /g/h)	More is better	0	400	200	-	-	

Source: Shahid *et al.* (2013)

Conceptual framework

The Conceptual Framework model has been used to determine soil quality as described by Karlen *et al.* (1992) as follows:

Soil quality index (SQI) P = qnc(wt) + qpss(wt) + qwr (wt) + qrr (wt) (for productivity goal)

Soil quality index (SQI) EP = qnc(wt) + qpss(wt) + qwr (wt) + qrr (wt) + qfb (wt) + qbdh (wt)

(For Production (P), environmental protection (EP) goal)

Where, qnc is the rating for the soil's ability to nutrient cycling, qpss to facilitate physical stability and support, qwr to water relations, qrr to resistance and resilience, qfb to filtering and buffering, qbdh to sustain biodiversity and habitat and (wt) is a numerical weighting for each soil function. Weights for all soil functions sum to 1.00. An ideal soil would fulfill all the functions considered important and under the proposed framework will receive a SQI of 1.00. As a soil fails to meet the ideal criteria, the SQI would fall, with zero being the lowest rating. Associated with each soil function are soil quality indicators that influence, to varying degrees, that particular function. As with soil functions, numerical weights assigned to selected soil quality indicators must sum 1.00 at each level.

Principal component analysis

Principal component analysis (PCA) is the method for reducing correlated measurement variables to a smaller set of statistically independent linear combinations having certain unique properties with regard to characterizing individual differences. Principal components (PCs) for a data set are defined as linear combinations of the variables that account for maximum variance within the set by describing vectors of closets fit to the n-observations in p-dimensional space, subject to being orthogonal to one another (Dunteman, 1989). Each PC explained a certain amount of variation (%) in the total data set, this percentage provided the weight for variables chosen under a given PC. The final PCA based soil quality equation is as follows:

$$SQI = \sum_{i=1}^{n} Wi \ x \ Si$$

(for both productivity and environmental protection goal)

Where,

S = score for the subscripted variable

W = weighing factor derived from PCA

Soil Quality and Soil Health

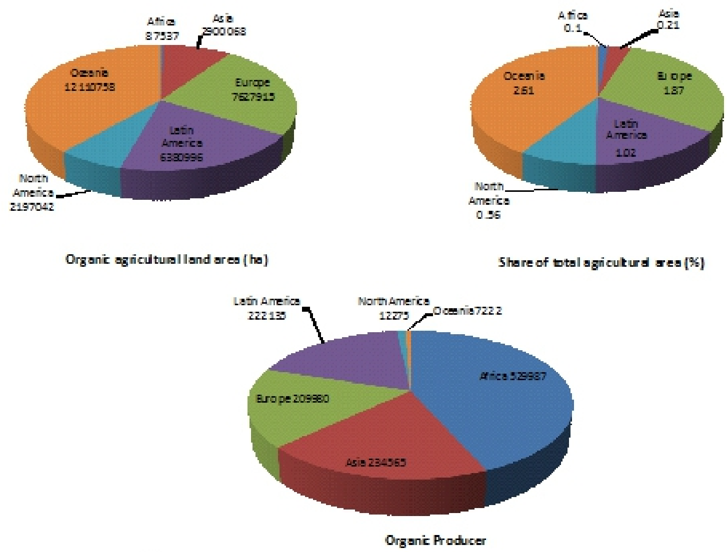
Soil quality and soil health are referred many times as same concept. However, there are differences. Few points are listed here. Soil health refers to the biological, chemical, and physical features of soil that are essential to long-term, sustainable agricultural productivity with minimal environmental impact. Thus, like soil quality, soil health also provides an overall picture of soil functionality. Similarly, it cannot be measured directly, soil health can be inferred by measuring specific soil properties (e.g. organic matter content) and by observing soil status (e.g. fertility). In general, healthy soils maintain a diverse community of soil organisms that help to: (i) control plant diseases as well as insect and weed pests; (ii) form beneficial symbiotic associations with plant roots (e.g. nitrogen-fixing bacteria and mycorrhizal fungi); (iii) recycle plant nutrients; (iv) improve soil structure with positive repercussions for its water- and nutrient-holding capacity; (v) improve crop production. Like soil quality, one of the most important objectives in assessing the health of a soil is the establishment of indicators for evaluating its current status.

Doran *et al.* (1996) presented a list of properties affecting soil ecological functions and quality, for example soil bulk density, water infiltration and holding capacity, total organic C and N, electrical conductivity, pH, plant-available nutrients, and measures of microbial biomass and activity. Although these properties may be useful as indicators for soil quality, they are not necessarily associated with soil health and the maintenance of essential soil ecological functions. The general approach to measure as many variables as possible and relate them to different uses (natural versus agricultural soil) or soil management practices (such as conventional versus alternative practices in terms of tillage, plant nutrition, or pest control) has not resulted in indicators that are consistently correlated with soil health (Pankhurst *et al.*, 1995; Staben *et al.*, 1997). One of the reasons for the inconsistencies may be the sensitivity of many of these measurements to the time of sampling in relation to significant management or environmental events (tillage, irrigation, residue incorporation, fertilization, rainfall, etc.).

Soil Quality and Organic Farming

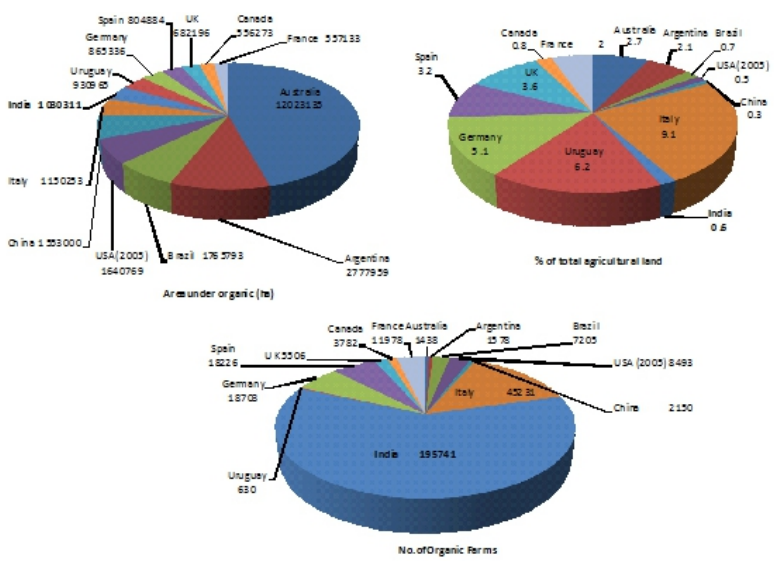
Organic farming is one of the several approaches found to meet the objectives of maintaining soil quality and sustainable agriculture. Many techniques used in organic farming like inter-cropping, mulching and integration of crops and livestock are not alien to various agriculture systems including the traditional agriculture practiced in old countries like India. However, organic farming is based on various laws and certification programmers, which prohibit the use of almost all synthetic inputs, and health of the soil is recognized as the central theme of the method.

Based on the global survey on organic farming carried out in 2009 by the Research Institute of Organic Agriculture (FiBL), the International Federation of Organic Agriculture Movements (IFOAM) and Foundation Ecology & Agriculture (SOEL), the organic agriculture is developing rapidly and is now practiced in more than 141 countries of the world. Its share of agricultural land and farms continues to grow in many countries. According to the latest survey on global organic farming, about 32.2 million hectares of agricultural land is managed organically as of 2007. Oceania has the largest share of organic agricultural land (37%), followed by Europe (24%) and Latin America (20%). The proportion of organically compared to conventionally managed land, however, is highest in Oceania and in Europe. In the European Union, 4% of the land is under organic management. Most producers are in Latin America (Figure 2 and 3). The total organic area in Asia is 2.9 m.ha. This constitutes 9% of the world's organic agricultural land. The leading countries are China (1.6 m ha) and India (1 m ha). The country with the largest organic area is Australia (12 million hectares)



Source : FiBL and IFOAM 2009

Figure 2. Organic agricultural land and farms by continent



Source: FiBL and IFOAM 2009

Figure 3. Land area of major countries under organic agriculture

SQI in Organic, Inorganic and Integrated Organic + Inorganic Farming: Few Case Studies

A study was carried out by Obriot *et al.* (2016) with the objective to develop a multi-criteria tool to compare fertilizing practices either based on mineral fertilizer (CONT + N) or repeated applications of exogenous organic matter (EOM) and considering the positive but also the negative impacts of these practices. Three urban composts (a municipal solid waste or MSW, a co-compost of sewage sludge and green waste (GWS), and bio-waste (BIO)) and farmyard manure (FYM) have been applied biennially over 14 years. Soils and crops were sampled repeatedly and >100 parameters measured. The development of different quality indices (QI) was used to provide a quantitative tool for assessing the overall effects of recycling different types of EOM. A minimum data set was determined and 7 indices of soil and crop quality were calculated using linear scoring functions: soil fertility, soil biodiversity, soil biological activities, soil physical properties, soil contamination ("available" and "total") and crop productivity. All QI varied between 0 and 1, 1 being the best score. They found that EOM amendments significantly increased soil biodiversity, biological activities and physical properties with intensity generally depending on their characteristics. FYM was the most efficient EOM to improve soil biological properties. EOM application lead to similar yields as mineral fertilizers but grain quality was slightly decreased. Thus, mineral fertilizers remained more efficient at improving crop productivity index (QI = 0.88) than EOM although BIO was not significantly different than CONT + N. All EOM improved soil fertility but only BIO was significantly higher (QI = 0.86). EOM added a range of nutrients but an excess of phosphorus negatively impacted the soil fertility index. Overall, they concluded the positive impact of repeated EOM applications on soil and crop quality in a loamy soil.

In an integrated organic + inorganic farming in eastern India under long-term experiment, Shahid *et al.* (2013) assessed the soil quality index (SQI). The treatments comprised chemical fertilizers and farmyard manure (FYM) either alone or in combination viz. control, N, NP, NK, NPK, FYM, N+FYM, NP+FYM, NK+FYM and NPK+FYM. Soil samples were collected after (40 years) the wet season rice harvest and were analysed for physical, chemical and biological indicators of soil quality. A SQI using principal component analysis (PCA) and nonlinear scoring functions were calculated. Selection of a soil quality indicator three PCs had Eigen values >1 that explained 86.8% of variation in the data. Among all the treatments, the SQI had wide variation (0.10– 0.74) for CDI and least (0.07–0.15) for Avail-K. The value of the dimensionless SQI varied from 1.46 in the control plot to 3.78 in NPK+FYM plot.

Similarly another experiment was conducted by Masto *et al.* (2007) with the objective to quantify the effects of 10 fertilizer and farm yard manure (FYM) treatments applied for 31 years to a rotation that included maize (*Zea mays*), pearl millet (*Pennisetum americanum*), wheat (*Triticum aestivum*) and cowpea (*Vigna unguiculata*) on an Inceptisol. A soil quality index (SQI) based on six soil functions (i.e. the soil's ability to: accommodate water entry, facilitate water movement and storage, resist surface degradation, resist biochemical degradation, supply plant nutrients and sustain crop productivity) was derived for each treatment using bulk density, water retention, pH, electrical conductivity (EC), plant available nutrients, soil organic matter (SOM), microbial biomass, soil enzymes and crop yield. Soil quality index (SQI) ratings ranged from 0.552 (unfertilized control) to 0.838 for the combined NPK fertilizer plus manure treatment.

In a study in China, Wang *et al.* (2017) assessed of effect of organic farming on soil quality and compared with conventional farming. Soil samples were collected from 14 farms (i. e. 7 organic farms and 7 neighboring conventional farms) for analysis of soil physic-chemical properties, i.e. bulk density, pH, organic matter, total N (TN), total P, readily available P and readily available K, and biological properties as well, i.e. microbial biomass carbon, diversity and dominance of microbial communities, and population, diversity and dominance of nematodes. Statistics of the 13 indices was done for principal components analysis. Out of the 13, 6 (TN, pH, bulk density, microbial biomass carbon, and population and dominance of nematodes) were cited to form a minimum data set (MDS). Soil quality index (SQI_6) based on MDS was in the range of 0.39-0.72 in the soils under organic farming and in the range of 0.18-0.54 in the soils under conventional farming. The concluded that based on the fact that the 6 indices in MDS, particularly dominancy of the nematode community, contributed 12.4%-21.8% to soil quality and that SQI_{13} (SQI derived from the 13 soil property indices) is significantly related to SQI_6 (r=0.89, P<0.05), so it is quite clear that MDS-based soil quality assessment is a workable and effective tool.

CONCLUSION

Soil quality index is a useful tool to assess soil health and well being. Few methods are available to estimate it. Among those PCA based scoring, ranking and weightage method gaining popularity. However, SQI assessment primarily depends on objectives of study or soil functions need to be addressed. Selection of MDS and its ranking play important role for determining SQI. As obvious organic farming has great influence on SQI. And more so inorganic and organic farming affect SQI differently. So they need to be assessed in site specific conditions keeping the goal in mind. In nutshell, SQI is a tool to quantitative measure of "soil condition: both in medium and long term". It has to be interpreted precisely, when comparing organic or inorganic farming keeping in view of spatial and socio-economic variations.

REFERENCES

Andrews, S.S., Karlen, D.L. and Mitchell, J.P. 2002. A comparison of soil quality indexing methods for vegetable systems in Northern California. *Agriculture Ecosystem and Environment.* 90, 25-45.

Andrews, S.S., Karlen, D.L. and Cambardella, C.A. 2004. The soil management assessment framework: A quantitative evaluation using case studies. *Soil Science Society of America Journal.* 68, 1945-1962.

Arshad, M.A. and Martin, S. 2002. Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, Ecosystems and Environment.* 88, 153-160.

Bachmann, G. and Kinzel, H., 1992. Physiological and ecological aspects of the interactions between plant roots and rhizosphere soil. *Soil Biology and Biochemistry,* 24 (6), 543–552.

Bentham, H., Harris, J.A., Birch, P. and Short, K.C. 1992. Habitat classification and soil restoration assessment using analysis of microbiological and physico-chemical characteristics. *Journal of Applied Ecology,* 29, 711–718.

Brejda, J.J., Moorman, T.B., Karlen, D.L. and Dao, T.H. 2000. Identification of regional soil quality factors and indicators. I. Central and Southern High Plains. *Soil Science Society of America Journal.* 64, 2115–2124.

Chaudhury, J., Mandal, U.K., Sharma, K. L., Ghosh, H. and Mandal, B. 2005. Assessing Soil Quality Under Long-Term Rice-Based Cropping System. *Communications in Soil Science and Plant Analysis.* 36, 1141-1161.

Diack, M. and Scott, D.E. 2001. Development of a soil quality index for the Chalmers silty clay loam from the Midwest USA. In: Scott, D.E., Mohtar, R.H., Steinhardt, G.C. (Eds.), The global farm, selected papers from the 10th international soil conservation meeting held on May 24-29 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Doran, J. W. and Parkin. T. B. 1996. Quantitative indicators of soil quality: A minimum data set. In: Methods for Assessing Soil Quality, (J. W. Doran and A. J. Jones, Eds.). *Soil Science Society of America,* Special Publication No. 49, Madison, Wisconsin, USA, pp. 25-37.

Doran, J.W. 2002. Soil health and global sustainability: translating science into practice. *Agriculture, Ecosystems and Environment*. 88, 119-127.

Doran, J.W. and Parkin, T.B. 1994. Defining and assessing soil quality. In: Defining Soil Quality for a Sustainable Environment. Doran, J.W., Coleman, D.C., Bezdicek, D.F. and Stewart, B.A. (eds.), SSSA Special Publication No. 35, ASA and SSSA, Madison, WI. 3–21 pp.

Dunteman, G.H. 1989. Principal Components Analysis. Sage Publications, London, UK.

Glanz, J.T. 1995. Saving Our Soil: Solutions for Sustaining Earth's Vital Resource. Johnson Books, Boulder, CO.

Kaiser, H.F. 1960. The application of electronic computers to factor analysis. *Educ. Psychol. Meas*. 29, 141–151.

Karlen, D.L., Eash, N.S. and Unger, P.W. 1992. Soil and crop management effects on soil quality indicators. *American Journal of Alternate Agriculture.* 7, 48-55.

Karlen, D.L., Mausbach, M.J., Doran, J. W., Cline, R. G., Harres, R. F., and Schuman, G. E. 1997. Soil quality: A concept definition, and framework for evaluation. *Soil Science Society of America Journal.* 61, 4-10.

Karlen, D.L., Parkin T.P. and Eash, N.S. 1996. Use of soil quality indicators to evaluate conservation reserve program sites in Iowa. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. SSSA Special Publication No. 49. SSSA, Madison, WI, pp. 345–355.

Lal, R. and Stewart, B.A. 1995. Need for long-term experiments in sustainable use of soil resources. In: Soil Management: Experimental Basis for Sustainability and Environmental Quality. Lal, R. and Stewart, B.A. (eds.) Lewis Publishers, Boca Raton, FL. 537-545 pp.

Masto, R.E., Chhonkar, P.K., Singh, D. and Patra, A.K. 2007. Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. *Agriculture Ecosystems and Environment.* 118, 130-142.

Nayak, A.K., Bhattacharyya, P., Shahid, M., Tripathi, R., Lal, B., Gautam, P., Mohanty, S., Kumar, A., Chatterjee, D. 2016. Modern Techniques in Soil and Plant Analysis. Kalyani Publishers, New Delhi, 110002; ISBN: 978-93-272-7059-4; pp 272.

Obriota, F., Stauffera, M., Goubarda, Y., Chevironb, N., Peresc, G., Edend, M., Revalliere, A., Vieublé-Gonoda, L. and Houota, S., 2016. Multi-criteria indices to evaluate the effects of repeated organic amendment applications on soil and crop quality. *Agriculture, Ecosystems and Environment*. 232, 165–178.

Pankhurst, C.E., Hawke, B.G., MacDonald, H.J., Kirkby, C.A., Buckerfield, J.C., Michelsen, P., O'Brien, K.A., Gupta, V.V.S.R. and Doube, B.M., 1995. Evaluation of soil biological properties as potential bioindicators of soil health. *Australian Journal of Experimental Agriculture,* 35, 1015–1028.

Pierce, F.J. and Larson, W.E. 1993. Developing criteria to evaluate sustainable land management. In: Kimble, J.M. (ed.) Proceedings of The Eighth Intern. Soil Management Workshop: Utilization of Soil Survey Information For Sustainable Land Use. USDA, Soil Conservation Service, National Soil Survey Center, Washington, D.C. 7-14 pp.

Shahid, M., Nayak, A.K., Shukla, A.K., Tripathi, R., Kumar, A., Mohanty, S., Bhattacharyya, P., Raja, R. and Panda, B.B. 2013. Long-term effects of fertilizer and manure applications on soil quality and yields in a sub-humid tropical rice-rice system. *Soil Use and Management*. doi: 10.1111/sum.12050.

Singer, M.J. and Ewing, S. 2000. Soil quality. In*: Handbook of Soil Science (Sumner, Ed.*), CRC Press, Boca Raton, FL. pp. G-271-G-298.

Staben, M.L., Bezdicek, D.F., Smith, J.L. & Fauci, M.F. 1997. Assessment of soil quality in conservation reserve program and wheat-fallow soils. *Soil Science Society of America Journal.* 61, 124–130.

Wander, M.M. and Bollero, G.A., 1999. Soil quality assessment of tillage impacts in Illinois. *Soil Science Society of America Journal.* 63, 961–971.

Wang Lei, Yang Jing, Xi Yun-guan, Chen Qiu-hui, Yin Kui-yang, Li Gang, Zhang Chi, Tian Wei, Zhang Hong-qi, Li Xu, Zhang Ji-bing and Xiao Xing-ji. 2017. Assessment of Quality of Soils Under Organic Farming in South China. *Journal of Ecology and Rural Environment*. 564-570.

Warkentin, B.P. 1996. Overview of soil quality indicators. In: Proceedings of the Soil Quality Assessment on the Prairies Workshop, Edmonton, 22-24 January, 1996. pp. 1-13.