

Methodologies for Soil Quality Assessment

K.K.Rout

Odisha University of Agriculture and Technology, Bhubaneswar

ABSTRACT

Soil quality or soil health appraisal is needed to identify problem production areas, make realistic estimates of food production, monitor changes in sustainability and environmental quality as related to agricultural management. Soil quality can be assessed in two ways: 1) qualitatively and 2) quantitatively. Early concepts of soil quality dealt mainly with various soil properties that contribute to soil productivity with little definition for soil quality itself. In early 90's Soil quality test kits and farmer based score cards focusing on soil quality were developed. Later in the late 90's various soil quality indexing approaches were pursued. In India work on assessment of soil quality started only recently with the implementation of National Agricultural Technology Project (NATP) during 2000. . For assessment of soil quality the capacity of the soil to function needs to be measured using appropriate indicators. Although several minimum dataset (MDS) of soil attributes have been proposed for use as soil quality indicators at the field scale, none have been evaluated at a regional scale. However, there is lot of scope to standardize the methodology for quantitative soil quality assessment on regional basis and identify problem areas and suggest important remedies for restoration of soil health.

INTRODUCTION

Soil health and soil quality are new concepts having meaning much broader than soil productivity. Maintaining or enhancing soil quality is a key to sustaining the soil resources of the world. High quality soils will produce more food and fibre and provide a better quality of life for the world's growing population. More over, high quality soil will play a major role in stabilizing natural ecosystems and enhancing air and water quality. Soil quality or soil health appraisal is needed to identify problem production areas, make realistic estimates of food production, monitor changes in sustainability and environmental quality as related to agricultural management.

ASSESSMENT OF SOIL QUALITY

In early 90's Soil quality test kits (Liebig *et. al.*, 1996) and farmer based score cards (Romig *et.al.*, 1996) focusing on soil quality were developed. Later in the late 90's various soil quality indexing approaches (Karlen and Stott, 1994, Andrews, 1998, Andrews *et.al.*, 1999; Hussain *et. al.*, 1999 Karlen *et.al.*, 1999b , Wander and Bollero 1999, Dalal and Moloney, 2000, Andrews and Carroll, 2000; Andrews *et. al.*, 2002) were pursued. Soil quality can be assessed in two ways: 1) qualitatively and 2) quantitatively.

Qualitative Assessment

Various qualitative approaches (soil health score card and soil test kit) have been suggested by a number of scientists to measure soil quality. Qualitative measures of soil quality tend to be more subjective in their measurement, but can be assessed more easily, and sometimes be more informative to the land manager. In this approach for assessing scientists and agricultural professionals work with land managers to identify and describe soil quality indicators in their own terms. The indicators they choose can be easily observed and rated qualitatively.

Soil Health Score Card

Based on the farmer's perception of soil quality; a scorecard was developed for assessing soil quality (Harris and Bezdick, 1994; Romig et al. 1997). The scorecard is a farmer-based subjective rating system that placed indicators into three rating scales of healthy (score of 3.0-4.0), impaired (score of 1.5-2.0) and unhealthy (score of 0-1).

The Wisconsin soil health scorecard is a field tool to monitor and improve soil health based on field experience and a working knowledge of a farmer. It has 43 soil health indicator properties (Table 1) that integrate observations made throughout the growing season. The indicators are almost exclusively based on sensory observations (e.g. look, feel and smell). Correctly, the scorecard doesn't recognize the relative importance of indicators, and is only developed for cropping systems in Wisconsin. Modifications of the scorecard to encompass other regions and cropping systems would require structured input from additional farmers (Romig et al., 1997). For indicators either in the impaired and unhealthy categories, careful consideration is necessary to identify that caused the property to be in a less than optimum condition. Unhealthy properties need immediate attention and corrective action.

Limitations and Prospectives of Qualitative Soil Quality Assessment

One shortcoming is that the scorecard represents the unchallenged perception of relatively small group of farmers. A second limitation may be its narrow frame of reference- especially in the light of the expanded definition of soil quality. This approach is also subject to internal bias.

While qualitative approaches are subject to internal bias, they have been found to compare well to quantitative measurements (Liebig and Doran, 1999). Qualitative approaches also have the advantage of making the farmer an active participant in the assessment.

Quantitative Assessment

Early concepts of soil quality dealt mainly with various soil properties that contribute to soil productivity with little definition for soil quality itself. However, mere analysis of soil properties alone, no matter how comprehensive or sophisticated, cannot provide a measure of soil quality unless properties evaluated are calibrated related against role function of soil.

To evaluate soil quality the capacity of the soil to function needs to be measured using appropriate indicators. The most desirable attribute of an appropriate indicator include the following:

- 1) It measures one or more soil functions
- 2) It is sensitive enough to measure changes due to disturbance, restoration and land use management
- 3) It provides benchmark, critical and threshold values
- 4) It can be readily interpreted and
- 5) It is cost effective

Many soil attributes including physical, chemical, biochemical and microbiological parameters have been suggested as indicators of soil quality changes, each assessing probably one or more specific functions of soil quality, but none of them alone is comprehensive enough to cover all the components of soil quality. Therefore, it is essential to establish one or more indexing systems with each index covering a number of inter related, directly measurable parameters to better reflect the complex processes affecting soil quality and to compensate for wide variations occurring in individual properties.

The different steps are:

1. Defining goal functions of the soil
2. Identifying the soil properties that influence the functions & selection of a minimum data set that can be used as potential indicators
3. Assigning scores to the observed values of the indicators in the data set
4. Calculation of soil quality index from the score values either integrating with variable weights or simply by summation

1. Defining Goal functions of the Soil

Given the wide scope of functions encompassed in the definition, it would be difficult, if not possible to directly assess the quality of a soil. It is necessary to first identify the functions of interest and then select some set of indicators to observe and measure, thereby inferring the ability of the soil to perform that function. The first step in evaluating soil quality within any ecosystem management

practice is therefore identification of management goals (or soil functions) specific to the objective of the experiment.

2. Selection of Indicators

It would be unrealistic to use all ecosystem or soil attributes as indicators, so a minimum data set (MDS) consisting of a core set of attributes encompassing chemical, physical and biological soil properties are selected for soil quality assessment (Larson and pierce, 1991). To assess soil quality, Larson and Pierce (1994) suggested measuring various soil attributes or indicators that controlled or were influenced by various soil functions. There are different ways how indicators are selected. Broadly there are three ways by which scientists have selected the indicators. Those are:

1. Indicators as suggested by scientists
2. Indicator selection by simple scoring and elimination approach
3. Indicator selection through a statistical framework

Indicator sets as suggested by scientists

Several authors have proposed sets of soil quality indicators(Larsen and pierce, 1991;Doran and Perkin,1994; Sarrantonio et. al,1996 and Karlen et al.,1998). A common feature of the indicator sets is that they all include some combination of physical, chemical and biological soil properties suggesting that for a soil to function effectively all three components must be addressed.

Doran and Parkin(1994) developed a list of basic soil properties or indicators for screening soil quality. They are : (1) Physical indicators: soil texture, depth of soils, top soil or rooting, infiltration, soil bulk density and water holding capacity. (2) Chemical indicators: soil organic matter or organic carbon and nitrogen, soil pH, electrical conductivity and extractable N, P and K (3) Biological indicators: microbial carbon and nitrogen, potential mineralizable N and soil respiration.

Harris and Bezdic(1994) indicated that soil quality indicators might be divided into two major groups; analytical and descriptive descriptions. Hseu et al., (1999) selected some indicators for the evaluation of Taiwan soils. The indicators were; (1) Physical: depth of the A –horizon, soil textural classes, bulk density, available water content and aggregate stability; (2) Chemical: soil pH, EC, organic carbon, extractable N, P, and K and extractable trace elements (3) Biological: potential mineralizable N, microbial C, N and P, soil respiration, the number of earthworms and crop yield. Because organic matter can have a tremendous effect on the capacity of a soil to function, it has been recommended to be a basic component in every minimum data set for assessing soil quality(Gregorich et al.,(1994).

Indicator selection by simple scoring and elimination approach

Cameron et al. (1998), suggested the use of simple scoring approach to help users decide whether to accept or reject a potential soil quality indicators for degraded or polluted soil. They used the equation, $A = f(S+U+M+I+R)$ where ,

A= Acceptance score for indicator

S = Sensitivity of indicators to degradation

U = Ease of understanding of indicators value

M = Ease or cost effectiveness of measurement of soil indicators

I = Predictable influence of properties on soil, plant and animal
Health and productivity

R=Relationship to ecosystem process

Each parameter in the equation is given a score (1-5) based on the user's knowledge and experience of it. The sum of individual scores gives the levels of acceptance(A) score which can be ranked in comparison to other potential indicators, thus aiding the selection of indicators for a site.

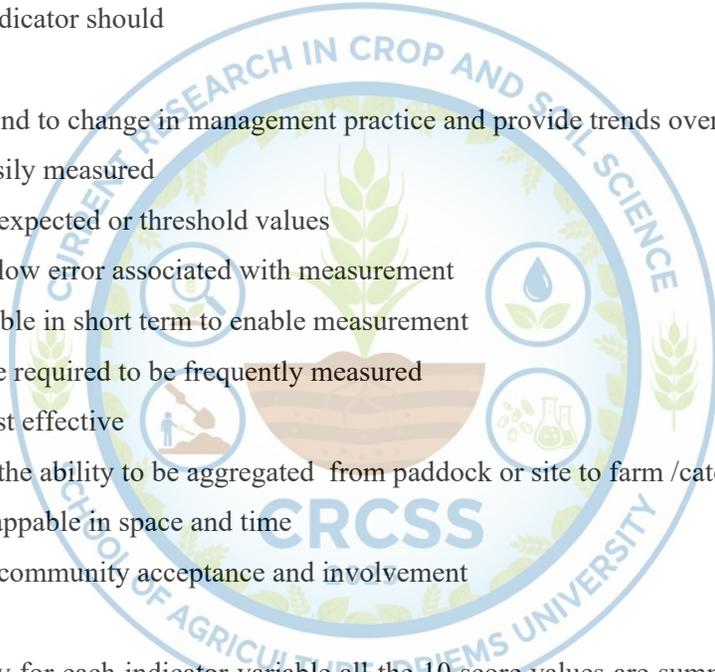
Statistical Techniques for Indicator Selection

Few statistical techniques have been suggested for a minimum dataset selection. Hatcher and Stefanskii (1996) suggested for a two step analysis . Multivariate analysis of variance (MANOVA) was the first step used to determine whether there were significant inherent (regional) or management (tillage) effects on at least one of the physical, chemical and biological variables assessed. After this criteria was met, analysis of variance (ANOVA) of individual parameters was run all the parameters. Those variables for which the F-statistic was significant at $p < 0.06$ and that had CVs < 40 were retained for further analysis. All retained physical, chemical and biological variables were then used in principal component analysis(PCA) for further screening. The number of components were determined by eigen values.. PCs that explained more than 5% of the total variance were considered to be significant.

For comparing the alternate and conventional treatment means for 6 different farms, Andrews et. al (2002) used non parametric Wilcoxin rank sum (C_2) test on JMP v.3 software for Window(SAS Institute, Cary, NC). This non parametric test finds differences less often than its parametric counterpart the t-test (Ott,1988). However, for farm they used one way analysis of variance(ANOVA) and student's t for comparison of means at $\alpha = 0.05$. To select a representative MDS they first performed standardized PCA of all untransformed data that showed statistically differences between management system using ANOVA or Student's t. They examined the PCs with Eigen values $>$ or $=$

1.(Brejda et al 2000b). and retained only the highest weighted variables from each PC of MDS.. Highest weighted variables remained within 10% of the highest factor loading (using absolute values). Under each PC they eliminated the redundant variables. Among well correlated variables within a PC the variable with the highest sum of correlation coefficient (absolute values) are chosen for the MDS (Andrews and Carroll, 2001; Karlen et al., 1999). If the highest weighted variables were not correlated (assumed to be a correlation coefficient of >0.60), then each was considered important and was retained in the MDS.

Dalal and Moloney(2000) suggested a scoring approach to select indicators by assigning scores (0 to 10) depending on the extent of fulfillment of these 10 criteria by any indicator. These criteria are: Indicator should

- 
- 1) Respond to change in management practice and provide trends over time
 - 2) Be easily measured
 - 3) Have expected or threshold values
 - 4) Have low error associated with measurement
 - 5) Be stable in short term to enable measurement
 - 6) Not be required to be frequently measured
 - 7) Be cost effective
 - 8) Have the ability to be aggregated from paddock or site to farm /catchment region
 - 9) Be mappable in space and time
 - 10) Have community acceptance and involvement

Finally for each indicator variable all the 10 score values are summed to get a total score and on the basis of the total score, indicators are either selected or deleted. Benchmarking the positive and undisturbed environments for soil quality and biodiversity using the sustainability indicators and then determining the extent of deviation from the bench values in a given landscape or environment may provide a suite of values. These values then could be integrated over space, attribute and time.

3. Assigning scores to observed values of Indicators

After the MDS selection process, each MDS variable observed value was transformed into a value between 0 and 1 using scoring functions. These scoring functions are widely used in economics as utility functions(Norgaard,1994), in multi objective decision and management sciences as

preference functions (Miller ,1970; and Raiffa,1976) and in systems engineering approach(Wymore, 1993).

Wang and Gong(1998) used an information system approach to develop and indexing system for assessing acid soil quality. This approach was applied to evaluate quality changes of acid soils after 11 years of reclamation at the Qian-Yan-Zhou experimental Station, located in sub tropical China. The Qian-Yan-Zhou soil quality information system(QYZSQIS) was developed using ARC/INFO Qian-Yan-Zhou O and FOXBASE software. A relative soil quality index(RSQI) defined as fractions of soil quality indicators in the tested soils against a reference soil and its difference(Δ RSQI) before and after 11years reclamation was established for comparing land use effects on soil quality indicators. The equation for calculating RSQI value is : $RSQI(\%) = (SQI / SQIm) \times 100$, where SQI is soil quality index and SQIm is the maximum value of SQI. The SQI is calculated from the equation:

$SQI = \sum W_i \times S_i$ where, W_i is the weight assigned to each individual indicator and S_i is the score assigned to each indicator class. An optimal soil in a specific region has a normalised RSQI of 100 but real soils have lower values which indicate directly their distance from the optimal level. The RSQI and the Δ RSQI provide a standard for evaluating spatial or temporal changes in soil quality.

Another approach for developing an acid soil quality indexing system is to define a reference soil against which the quality change of soils can be compared or quantified. A native soil supporting climax vegetation that has undergone minimal anthropogenic disturbance is used as a high quality reference soil(Leiros et al.,2000). Trasar-Cepeda et al.,(1998) examined three such native acid soils of Garcia(NW Spain) and found that the native soils of Garcia exhibit a biochemical equilibrium such that total N can be defined as a function of five biochemical and microbiological parameters: $Total\ N(X10^{-3}) = 0.38\ MBC + 1.40N\ mineralization\ capacity + 13.6\ phospho\ mono\ esterase + 8.9\ \beta\ glucosidase + 1.6\ urease$. the ratio of thecalculated total N(N_c) to the total N measured by the Kjeldahl method (N_k) was proposed as an index of soil quality(Leiros et al., 1999). For these climax soils ,the N_c/N_k ratio is 1.00 and for disturbed soils soil degradation is reflected by the ratio of less than one. For the samples polluted by tannin effluent intense contamination is indicated by decreased N_c/N_k ratios ranging from 0.15 to 0.28(Trasar-Cepada et al., 2000a).these results together with some previous reports by the same research group (Leiros et al.,1999) indicate that this kind of indexing system is simple, but has the advantage of providing common criteria for comparing the degree of soil degradation at different sites. And caused by different factors(pollution, land use and management) because all the examined soils can be ranked by a single index.

Andrews and Carroll (2000) used non linear scoring functions with Y axis ranging from 0 to 1 and the X axis representing a range of site dependent scores for that variable. The actual shape of the

decision function either a sigmoid curve with an upper asymptote, a sigmoid curve with a lower asymptote or some variation on a bell shaped curve was indicator dependent. Accordingly they assumed an upper asymptote to total N and extractable Ca, lower asymptote to bulk density and mid point optimum for pH, nitrate N , extractable Zn and WHC (Karlen et al., 1994). This assignment of scoring functions both curve shape and X axis range assumed value judgements on the part of the user (Andrews and Carroll, 2000).

Using Wymore's Standard scoring functions (SSF) scores were assigned to the observed values of MDS using specific algorithms developed by Wymore (1993). Using algorithm of SSF –3

Score = $1 / (1 + (B-L) / (V-L) \wedge (2 * S * (B + V - 2 * L)))$ where $V = \text{or} < B$

And score = $1 / (1 + B - (2B-U) / V - (2B-U) \wedge (2 * S * (B + V - 2 * (2B-U) / (2B - V))))$ where $V > B$

L= Lower threshold value

U=Upper threshold value

S=Slope of the curve

B= Base value and

V= Observed value

4. Integration of scores into Index Values

After transforming the MDS variable into scores for each observation, Andrews and Carroll (2000) added them to get a cumulative soil quality index (SQI).

$$SQI = \sum_{i=1}^n S_i$$

Higher SQI meant greater soil quality. They compared the SQIs for different management practices by calculating means, standard deviations, student's t at $\alpha = 0.05$ and ANOVA for each treatment SQI score. The SQI values obtained by them indicated that for both the alfisol and ultisol sites the compost management had the best soil quality. Instead of using an additive index where the scores were simply added, Andrews et al (2002) used an integrative Index. Each PC explained a certain amount (%) of the variation in the total data set. This percentage divided by the total percentage of variation explained by all PCs with eigen values > 1 , provided the weighted factor variables chosen under a given PC. They then summed the weighted MDS variable scores for each observation in the following formula:

$$SQI = \sum_{i=1}^n W_i \times S_i$$

where W is the PC weighting factor and S is the indicator score. They compared the calculated SQI treatment means using ANOVA and students t at $\alpha = 0.10$ and assumed that higher index scores meant better soil quality or greater soil performance of soil functions. Using this formula, they demonstrated that soil quality indices for the manure and compost systems were significantly lower than the organic system but significantly higher than the conventional treatments. These results supported the SQI outcomes of Karlen et al., (1999).

As discussed above, soil quality has various components (fertility quality, environmental quality and health quality) corresponding to different functions of the soil. All indicators can be grouped as subsets of data under each component of soil quality and SQI for each component can be developed. If necessary all the component indices from each subsets of data can be integrated and processed using an GIS –data base system to establish one or more comprehensive indexing systems for quantifying and monitoring quality changes of soils as a whole (He et al., 2001).

In a study Hussain et al., (1999) calculated an overall soil quality index from functional components and they could provide a comprehensive assessment of soil quality. These functional components were used to identify soil management problems which were considered important for sustaining or improving the soil resources.

WORKS DONE IN INDIA

In India work on assessment of soil quality started only recently with the implementation of National Agricultural Technology Project (NATP) during 2000. Works started in 8 different centres located in the states of West Bengal (BCKV and CRIJAF), Orissa (OUAT), Assam (AAU), Andhra pradesh (CRIDA & ANGRAU) and Uttar pradesh (BHU) with BCKV in West Bengal as the lead center and others as co-operating centers where the results of long term experiments on dominant cropping systems of the region were used for the study. Standard methods already used by Andrews et al., 2002 were used for selection of MDS and quantification of soil quality. The MDS were selected entirely through a statistical frame work from a large set of variables drawn from physical, chemical and biological domain and both linear and non linear scoring functions were used for assigning scores. The soil quality index values were calculated through integrative approaches. All the centres reported that INM practices involving FYM maintained better soil and crop quality than other management practices. Most of the results have been published in Annual reports and bulletins. In Orissa Rout et. al., (2004) compared 3 different methods of integrative indexing (Andrews et al., 2002), component integrative indexing (Hussain et al., 1999) and integrative indexing (Andrews et al., 2002) through Wymore's algorithm scoring approach (Wymore, 1993). The results clearly demonstrated differences in soil quality of among differently manured treatments which were in the order of $100\%NPK+FYM > 100\%NPK > 100\%NP > 100\%N$.

Singh(2006) in India recently suggested nine indicators such as soil depth, texture, slope, organic matter, available N, available P , available K , CEC, and pH to evaluate soil quality under integrated nutrient management at farm situation. He calculated the soil quality index of each indicator separately by multiplying weight of indicators with marks allotted to the observed value. In his study he suggested weights to the indicators on the basis of existing soil conditions, cropping pattern, agro climatic condition and prevalence of flood so that all weights is normalized to 100%. He also divided all the indicator values into 4 categories and assigned marks of 4,3,2 and 1 to these classes depending on their suitability for crop growth. Through this study he showed improvement in soil quality under both farmers’ practice and INM practice. Soil quality under INM trial was improved by 12-19 units as compared to 7-9 units of farmer’s practice of farming.His results were however more speculative and based on assumptions.

In a study Mastro et al.,(2007) normalised soil quality indicator values on a 0 to 1 scale using the following linear and non linear scoring functions.

Linear Scoring Function, $LSF(Y) = (x-s)/(t-s)$(1)

and $Y = 1 - (x-s)/(t-s)$ (2)

where Y is the linear score, x the soil property value, s and t are the lower and upper threshold values. Equation 1 is used for more is better scoring function and equation 2 is used for less is better and a combination of both for optimum scoring function.

Non Linear Scoring Function, $NLSF (Y) = 1 / (1+e^{-b(x-A)})$(3)

Where x is the soil property value, A the base line value where score equals 0.5 and b is the slope. After deciding the shape of the anticipated response(more is better, less is better or optimum) they assigned the limits or threshold values for each indicator and quantified the soil quality index using three processes; 1). Unscreened transformation, 2).based on regression equation and 3). based on Principal Component analysis(PCA).

SQI with unscreened transformation

$SQI = \sum Si / n$ where S denotes linear score of observed indicator and n is the number of indicators.

SQI based on Regression Equation

$SQI = \sum Si. \beta$

Where S denotes linear or non linear score and β is the standardized regression co-efficient of the retained parameters.

The PCA based index remained the same

$SQI = \sum W_i x S_i$

i=1

Based on the results they suggested that regression based index as the most sensitive index and PCA based index related well with the wheat grain yield. Thus either regression equation or PCA with non linear scoring function can be used successfully to evaluate soil quality.

Limitations and Prospectives of Soil Quality Assessment

The progress of soil quality research has been hindered because in most cases scientists have established ranges and benchmark values for only a few of the parameters listed in the MDS. Many biochemical and microbiological parameters which are considered early indicators of soil quality lack benchmark values. This makes it difficult to correctly convert the measured values to scores.

Future studies need to focus on development of relationship between indicator values and scores for all potential parameters. Application of GIS database can be immensely useful for this purpose. Although several MDS of soil attributes have been proposed for use as soil quality indicators at the field scale, none have been evaluated at a regional scale. Accurate, relatively inexpensive, less time consuming and simple methods need to be developed. However, there is lot of scope to standardize the methodology for quantitative soil quality assessment on regional basis and identify problem areas and suggest important remedies for restoration of soil health. Soil quality research data need to be translated into management tools for end users such as farmers, growers, agricultural production agencies, environmental production agencies and decision making organisations.

REFERENCES:

- Andrews, S.S. and Carroll, C.R. (2000) Designing a soil quality assessment tool for sustainable agroecosystem management. *Ecol Applic*, 11(6): 1573-1585.
- .Andrews, S. S. & Carroll, C.R.,2001. Designing a soil quality assessment tool for sustainable agro ecosystem management, *Ecological society of America*,11(6),pp. 605-620.
- Andrews S.S.; Mitchell, J.P.; Mancinelli, R.; Karlen, D.L.; Hartz, J.K.; and Munk, D.S. (2002) On farm assessment of soil quality in California's central valley. *Agron. J.* 94: 12-23.
- Arshad, M.A.; Schnitzer, M.; Anders, D.A. and Ripmeester, J.A. (1990) Effects of till Vs. no-till on the quality of soil organic matter. *Soil Biol. Biochem.* 22, 595-599.
- Arshad, M.A., Coen,G.M.,(1992).Characterization of soil quality;Physical and chemical criteria. *Am.J.Alternative Agric.*7,12-16.
- Brejda, J.J.; Karlen,D.L.; Smith, J.L. and Allan, D.L. (2000a) Identification of regional soil quality factors and indicators II. Northern Mississippi Loess Hills and Palouse Prairie. *Soil Sci. Soc. Of Am. J.* 64: 2125-2135.

- Brejda, J.J.; Moorman, T.B.; Karlen, D.L. and Dao, T.H. (2000b). Identification of regional soil quality factors and indicators. I. Central and Southern High plains. *Soil Sci. Soc. Of Am. J.* 64: 2115-2124.
- Cameron, K.; Beare, M.H.; McLaren, R.P. and Di, H. 1998. Selecting physical, chemical and biological indicators of soil quality for degraded on polluted soils. Proceedings of 16th world congress of soil science. Scientific registration No. 2516 Symposium No.37. Aug. 20-26,1998 Montpellier, France.
- Dalal, R.C.& Moloney, D., 1999. Sustainability indicators of soil health and biodiversity, *Aust, J. Exp. Agric.*, 39,pp. 605-620.
- Dallal,R.C. and Moloney, D.(2000).Sustainability indicators of soil health and biodiversity.In: Hale et.al. (eds). Management for Sustainable Ecosystems. Centre for conservation of Biology . Brisbane:101-108.
- Devi, S. (2002). Effect of long term manuring on soil quality of a *vertic Haplaquept* under rainfed rice production system. M. Sc. Thesis, OUAT, Bhubaneswar.
- Doran, J.W. & Parkin, T. B.1994. Defining and assessing soil quality. p.3-21. In J.W. Doran et al. (ed.). Defining soil quality for sustainable environment . SSSA Spec. Publ. 35. SSSA. Madison, WI.
- Doran,J.W.,Coleman,D.C.,Bezdieck,D.F.,Stewart,B.A.(eds.),Defining Soil Quality for a Sustainable Environment,Chapter 3,1st ed,Soil Sci.Soc.Am.,Madison,WI,pp 37-52.
- Dunteman, G.H. (1989). Principal component analysis. Sage, London, UK.
- Gregorich, L.J. & Acton, D.F. 1995. Understanding soil health.pp.5-10 In D.F. Acton & L.J. Gregorich, eds. The health of our soils towards sustainable agriculture in Canada. Center for land and biological resources research, Research Branch, Agriculture and Agri food Canada, Ottawa, ont. Canada.
- Gregorich, E.G.; Carter, M.R.; Angers, D.A.; Monreal, C.M. and Ellert, B.H. (1994). Towards a minimum dataset to assess soil organic matter quality in agricultural soils. *Can J. Soil Sci.* 74: 367-385.
- Harris, R.F. & Bezdicek, D.F. 1994. Descriptive aspects of soil quality/health. P. 23-35. In J.W. Doran ; Coleman, D.C.; Bezdicek, D.F. & Stewart B.A.(eds.). Defining soil quality for a sustainable environment. SSSA. Spec. Publ. No. ASA. CSSA. And SSSA., Madison WI.
- He, Z.L. ;Yang, X.E. , Baligar, V.C. and Calvert, D.C.(2001)Microbiological and biochemical indexing systems for assessing Quality of acid soils.*Adv. Agron.*78:89-138.
- Hseu, Z.Y.; Chen, Z.S. and Tsai, C.C. (1999) Selected indicators and conceptual framework for assessment methods of soil quality in arable soils of Taiwan. *Soil and environ*, 2: 135-139.
- Hendrix, P.F.; Parmelee, R.W.; Crossley, D.A.; Coleman, D.C.; Odum, E.P. and Groffman, P.M. (1986). Ditrutus food webs in conventional and no-tillage agroecosystems. *Bio. Sci.* 36: 374-380.
- Karlen, D.L.; Mausbach, M.J.; Doran, J. W.; Cline, R.G.; Harris, R.F. & Schuman, G.E. 1997. Soil quality : concept, rationale and research needs. *Soil sci. soc. Am. J.* 60: 4-10.

Kaiser, E.A.; Mueller, T.; Joergensen, R.G.; Insam, H. and Heinemeyer, O. (1992) Evaluation of methods to estimate the soil microbial biomass and the relationship with soil texture and organic matter. *Soil Biol. Biochem.* 24: 805-813.

Karlen, D.L.; Wollenhaupt, N.C.; Erbach, D.C.; Berry, E.C.; Swan, J.B.; Eash, N.S. and Jordahl, J.L.(1994a). Crop residue effects on soil quality following 10 years of no till corn. *Soil Tillage Res* 31: 149-167.

Karlen,D.L.; J.C.Gardner and M.J. Rosek.(1997a). A soil quality framework for evaluating the impact of CRP.J.Prod.Agric.(In Press.)

Karlen, D.L. and Stott, D.E. (1994). A frame work for evaluating physical and chemical indicators of soil quality. SSSA, Madison, Wisconsin, USA.

Karlen, D.L.; Gradner, J.C. and Rosek, M.J. (1998). A soil quality frame work for evaluating the impact of CRP. *J. Prod. Agric.* 11: 56-60.

Karlen, D.L.; Andrews S.S. and Mitchell, J.P. (1999). A soil quality index for vegetable production. In 1999 Agron. Abstr. ASA, Madison, Wisconsin, USA, 219.

Keeney, R.L. and Raiffa, H. (1976). Decisions with multiple objectives: Preferences and value tradeoffs. John Wiley and Sons, New York, New York, UAS.

Larson,W.E., and Pierce, F. J. (1994). The dynamics of soil quality as a measure of sustainable management. In:

Larson, W.E. and Pierce, F.J. (1991). Conservation and enhancement of soil quality. In: Dumanksi, J. Pushparajan, E., Latham., M. and Mayers, R.J.K. (eds). Evaluation for sustainable land management in the developing world volume 2, Technical Papers, Bangkok, Thailand, International Board for Soil Research and Management, I.B.S.R.A.M.

Leiros, M.C. Trasar-Cepeda, C., Garcia Fernandez, F. and and Gil-Stores, F.(1999).Defining the validity of a biochemical index of soil quality. *Biol. Fert. Swoils* 30.140-146.

Leiros, M.C. Trasar-Cepeda, C., Seoane,S. and Gil-Stores, F.(2000).Biochemical properties of acid soils under climax vegetation in an area of temperate humid zone: General parameters. *Soil Biol. Biochem.*32,733-745.

Masto, R.E., Chhonkar, P.K., Dhyan Singh and A.K. Patra(2007). Alternative soil quality indices for evaluating the effect of intensive cropping, fertilization and manuring for 31 years in the semi arid soils of India. *Enviro. Monit. Assess.*

Norgaard, R. B.(1994). Ecology, politics and economics: finding the common ground for decision making in conservation. Pages 439-465 in G.K. Meffe and C.R. Carroll, editors. Principles of conservation biology. Sinauer Associates, Sunderland, Massachusetts, USA.

Roming, D.E.; Garlynd, N.J. & Harris, R.F. (1997). Farmer based assessment of soil quality : A soil health scorecard in J.W. Doran and A.J. Jones(eds.). Methods for assessing soil quality. SSSA Spec. Publ. SSSA Madison, WI. (In press).

Rout K.K.; Majhi, P.; Rout, B. & Devi, S.(2002). Quantitative assessment of soil quality, Abstract papers, presented at the 26th annual convention, Bhubaneswar, ISSS, on 24th day of sept., 2002 pp. 18-19.

Rout, K.K., Pattanaik, M.R.; Majhi, P. ; Behera, B.B.;Rout, B.;Devi, S. ; Malla, A. and Das, N.(2004). Thirteen years of cropping with fertilization and manuring of arainfed rice based production system in an Inceptisol of Keonjhar district: Effect on soil quality, Crop productivity and sustainability. Research Bulletin, NATP/RRPS-20, OUAT, Bhubaneswar.

Singh ,A.K. (2007) Evaluation of soil quality under integrated nutrient management . J . Indian Soc. Soil Sci. 55(1):58-61.

Smith, T.L. ; Halvorson, J.I. & Papedick, R.I.(1993). Multiple variable indicator kringing: For evaluating soil quality, SSSAJ. 743-749.

Trasar-Cepeda, C., Leiros, M.C., Gil-Stores, F. and Seoane,S.(1998). Towards abiochemical quality index for soils: an expression relating several biological and bio chemical properties.Biol. Fert. Soils 26:100-106.

Trasar-Cepeda, C., Leiros, M.C.,and Gil-Stores, F. (2000a).Biochemical properties of acid soils under climax vegetation in an area of the European temperate –humid zone : Specific parameters. Soil Biol. Biochem.32,747-755.

Wander, M.M. and Bollero, G.A.(1999). Soil quality assessment of tillage impacts in Illinois. SSSAJ 63: 961-971.

Wymore, A.W. (1993). Model based systems engineering : an introduction to the mathematical theory of discrete systems and to the tricotyledon theory of systems design. CRC Press, Boca Raton, Florida, USA.

