DEFINITION, MONITORING AND EVALUATION OF SOIL QUALITY INDEX

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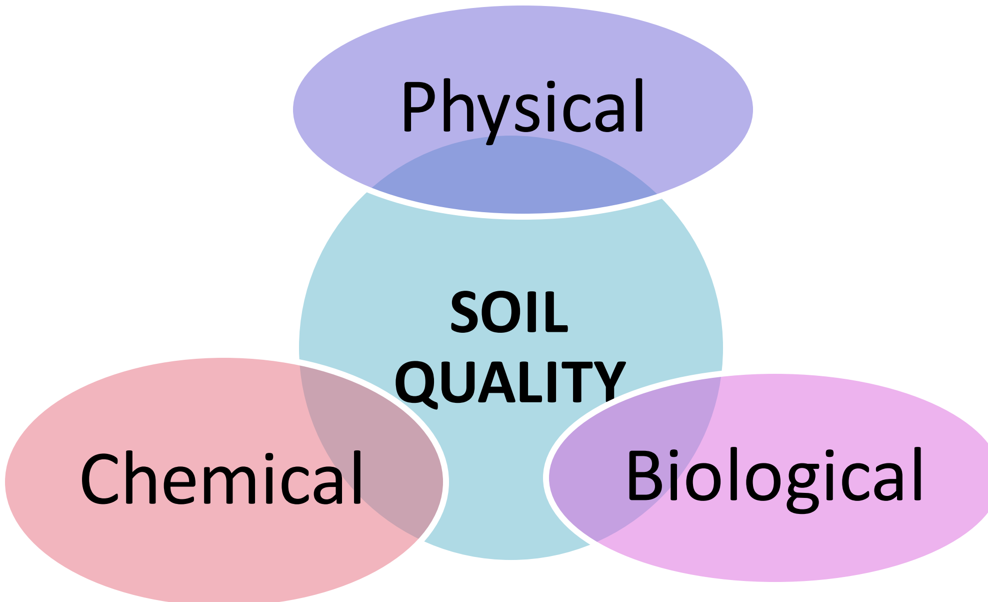
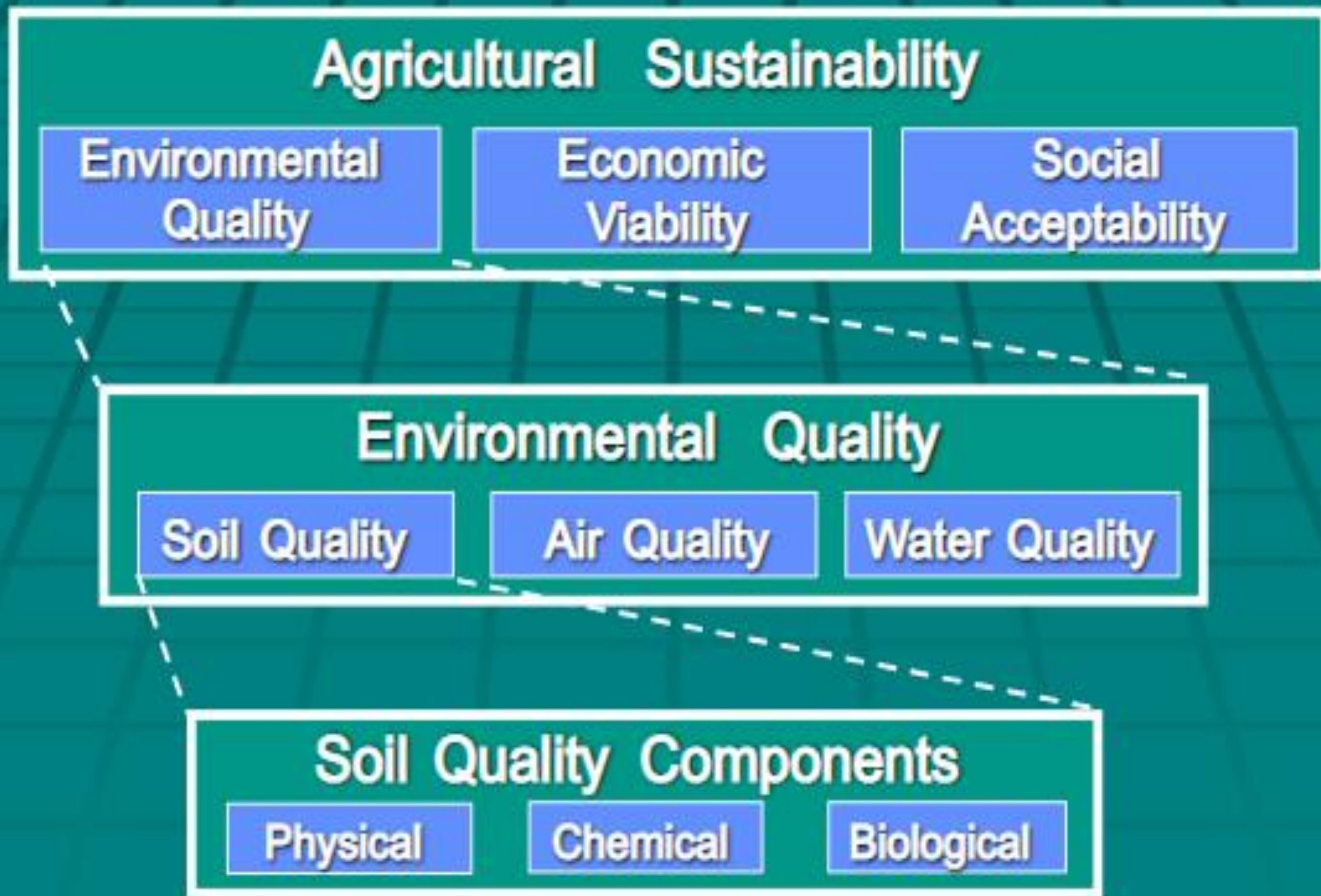
What is soil quality?

Soil quality is a measure of the soil condition to support plant growth, production and is the outcome of interplay of physical, chemical and biological properties.



It is the ability of the soil to the productivity by improving and maintaining the soil health. Soil Quality Assessment Soil quality is an effective tool for monitoring soil function.

Soil Quality and Sustainability



Importance of soil quality

It is generally conceptualized as inherent and dynamic soil quality (Seybold et al., 1999), while the inherent quality shows little change over time, the dynamic soil quality changes with respect to soil management (Larsen and Pierce, 1994).

Maintenance of non-negative trend in productivity while sustaining soil quality is the goal of Sustainable Agriculture. Hence it is very important to assess the soil quality to understand the impact of various management practices, human activities across different ecosystems as it is also involved in providing ecosystem services

In order to evaluate soil quality in every pedo-climatic zone and under different farming systems and agricultural management practices, it is necessary to develop an index that can translate the existing soil quality (or its absence) into quantifiable classes.

Difference between soil quality and health

Soil Health is used as synonym most of the time & had minor variations

Soil Quality	Soil Health
• Includes majorly the inherent quality • Fitness for use & capacity of the soil to function • Use quantitative parameters • Soil conditions to predict the productivity • It also measures soil health • Usefulness over a long run for a particular purpose	• Includes dynamic quality and mostly biology • A soil may have poor inherent quality but still have good health • Mostly qualitative parameters • Helps to predict how soil functions • But good function doesn't have good productivity • State of a soil at a particular time - change in short time

More succinctly, soil quality defines the characteristics and dynamics of soil properties, while soil health defines function in terms of a given soil's capacity to supply a service based on the existing stock or process. (*Wander et al., 2019)*

Difference between soil quality and health

Indicator	Relationship to Soil Health
Soil organic matter (SOM)	Soil fertility, structure, stability, nutrient retention; soil erosion.
PHYSICAL: Soil structure, Depth of soil, Infiltration and bulk density; Water holding capacity	Retention and transport of water and nutrients; habitat for microbes; estimate of crop productivity potential; compaction, plow pan, water movement; porosity; workability.
CHEMICAL: ph; Electrical conductivity; extractable N-P-K	Biological and chemical activity thresholds; Plant and microbial activity thresholds; Plant available nutrients and potential for N and P loss.
BIOLOGICAL: Microbial biomass C and N; Potentially mineralizable N; Soil respiration.	Microbial catalytic potential and repository for C and N; Soil productivity and N supplying potential ;Microbial activity measure

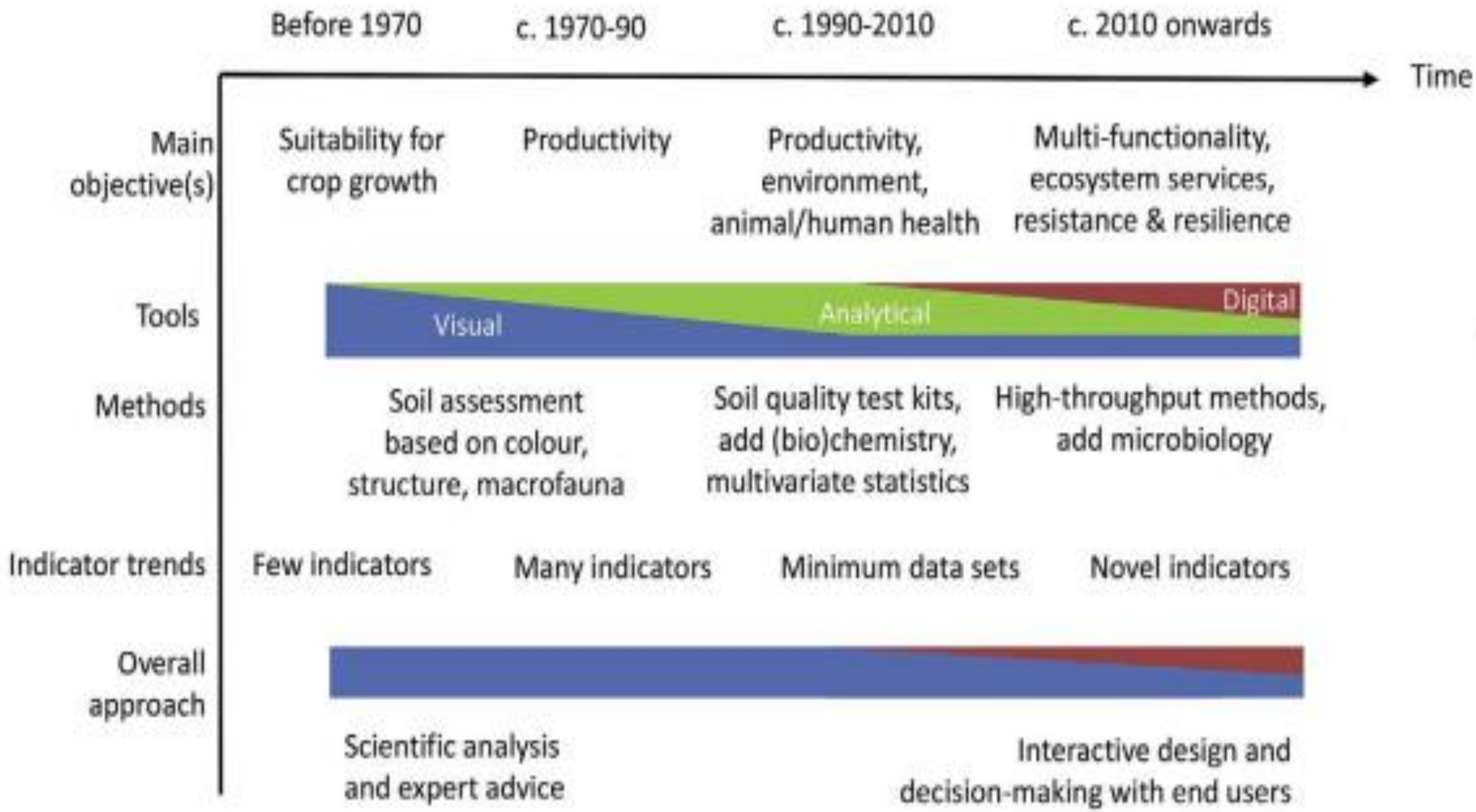
Soil Quality Assessment

The soil quality assessment is carried out by selecting a set of soil properties which are known as soil quality indicators.

The indicators chosen to study the changes in soil should be easy to measure (Dumanski and Pieri, 2000) as they are sensitive to soil functions (Aparicio and Costa, 2007).

Hence, a key aspect of soil quality assessment is identifying suitable and sensitive soil properties that imply a soil's functional capability and serve as quality indicators.

Main objectives, tools and approaches of soil quality assessment through history



Steps in Soil Quality Assessment

1. Defining Objectives
2. Target users
3. Selecting Indicators
4. Sampling Design
5. Sample Collection
6. Laboratory Analysis
7. Data Interpretation
8. Integration and Evaluation
9. Scoring and Ranking
10. Assessment of Ecosystem Services
11. Spatial Analysis (Optional)
12. Interpretation and Reporting
13. Recommendations and Action Plan
14. Monitoring and Feedback

Soil quality assessment is a complex process that requires interdisciplinary expertise and an understanding of local environmental conditions. Tailoring the assessment to the specific goals and context is essential for generating meaningful insights and actionable recommendations.

APPROACHES FOR SOIL QUALITY ASSESSMENT

Qualitative or semi-quantitative visual methodologies

- **Also known as descriptive apporach**
- **Soil and salt crusting, structure, rills, gullies, earthworms etc**

Quantitative methodologies based on analytical indicators

- **soil organic carbon, pH, cation exchange capacity, total porosity, bulk density, total nitrogen, infiltration rate, penetration etc**

Qualitative Approaches

Visual Soil Assessment (VSA)

- Primarily focused on soil structure and sometimes linked to productivity consideration

The Peerlkamp approach

Previously employed in the Netherlands for four decades, has recently been refined through simplified scoring systems and the incorporation of visual keys

Visual Evaluation of Soil Structure (VESS)

Involves taking a sample of undisturbed soil, breaking it up and visually assessing the size and porosity of aggregates, the strength of aggregates, the presence of roots and soil color

Quantitative approaches

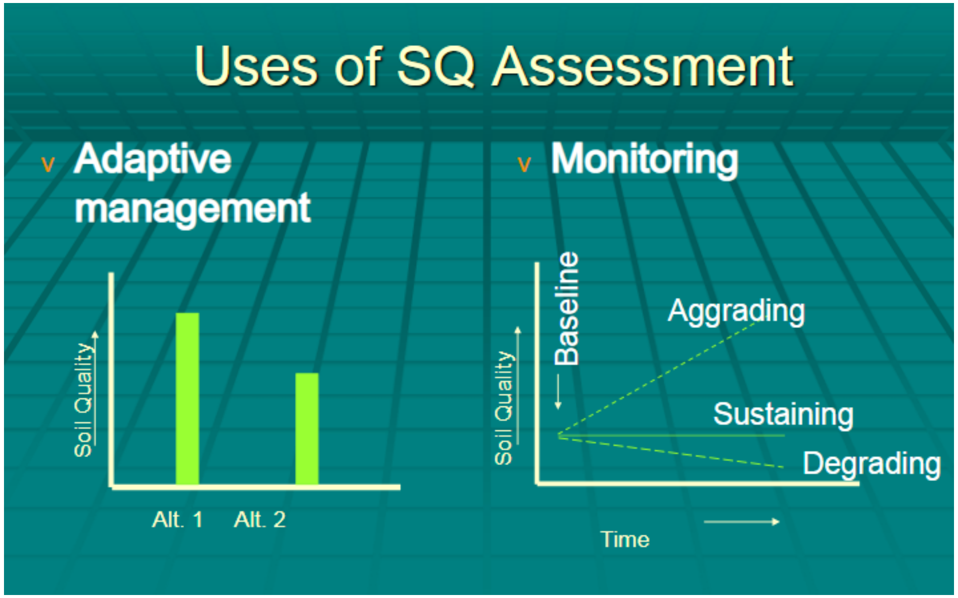
- Quantitative or analytical approaches encompass sophisticated methodologies involving analytical indicators (Harris and Bezdicek, 1994).
- Several analytical indicators have proven valuable for soil quality assessment. These include parameters like total soil organic carbon, pH, cation exchange capacity, total porosity, bulk density, total nitrogen, infiltration rate, penetration resistance, soil respiration, extractable phosphate, magnesium, potassium, and the distribution and stability of aggregate sizes (Lima *et al*., 2013).
- In particular, fractions of organic carbon, such as labile or active carbon, have emerged as highly responsive indicators, often reflecting changes more sensitively than total soil organic matter.

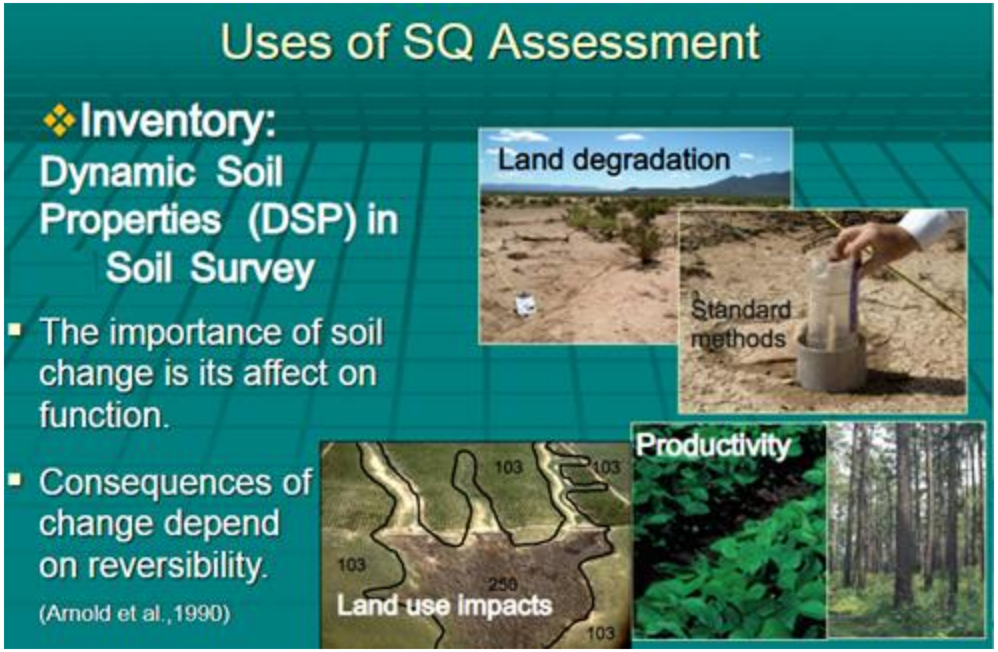
Techniques for the quantification of soil quality (SQ)

These encompass various strategies:

- **Comparative Approach** (Larson and Pierce, 1994): This approach involves comparing soil attributes over time or between different management practices to measure variations in SQ.
- **Computer Models** (Larson and Pierce 1994): Computer models are utilized to simulate soil processes and assess SQ based on various scenarios.
- **Dynamic Approach using Statistical Quality Control Procedures** (Larson and Pierce 1994): This approach employs statistical quality control techniques to monitor and manage SQ changes dynamically.
- **Performance-Based Scale Index** (Doran and Parkin, 1994): The use of a performance-based scale index involves assessing SQ based on predefined criteria and benchmarks.
- **Multi-Scale Approach** (Karlen *et al*., 1997): The multi-scale approach combines various indicators across different spatial and temporal scales comprehensively to evaluate SQ.

Uses of SQ Assessment





Why soil quality Indices ?

- **Synthesize assessment, monitoring or Inventory activities**
- **Organize or prioritize large data sets**
- **Quantitatively evaluate large or complex data sets**

Andrews, (1998) & Kreman, (1996)

What is Soil Quality Index?

- A quantifiable strategy to evaluate the conditions of agricultural soils is through the establishment of a soil quality index (SQI), which depends on specific indicators related to the sampled soils, type of crops, and agricultural management.
- Soil quality indexing (SQI) defines a combination of physical and biochemical indicators by using the scoring equation to arrange measured soil properties into a single index (Doran and Parkin 1994; Qi et al. 2009).
- It is a mathematical or statistical framework was put forward in early 1990s to estimate soil quality. The SQI is an indirect determination calculated using the set of soil physical, chemical and biological properties known as soil quality indicators.

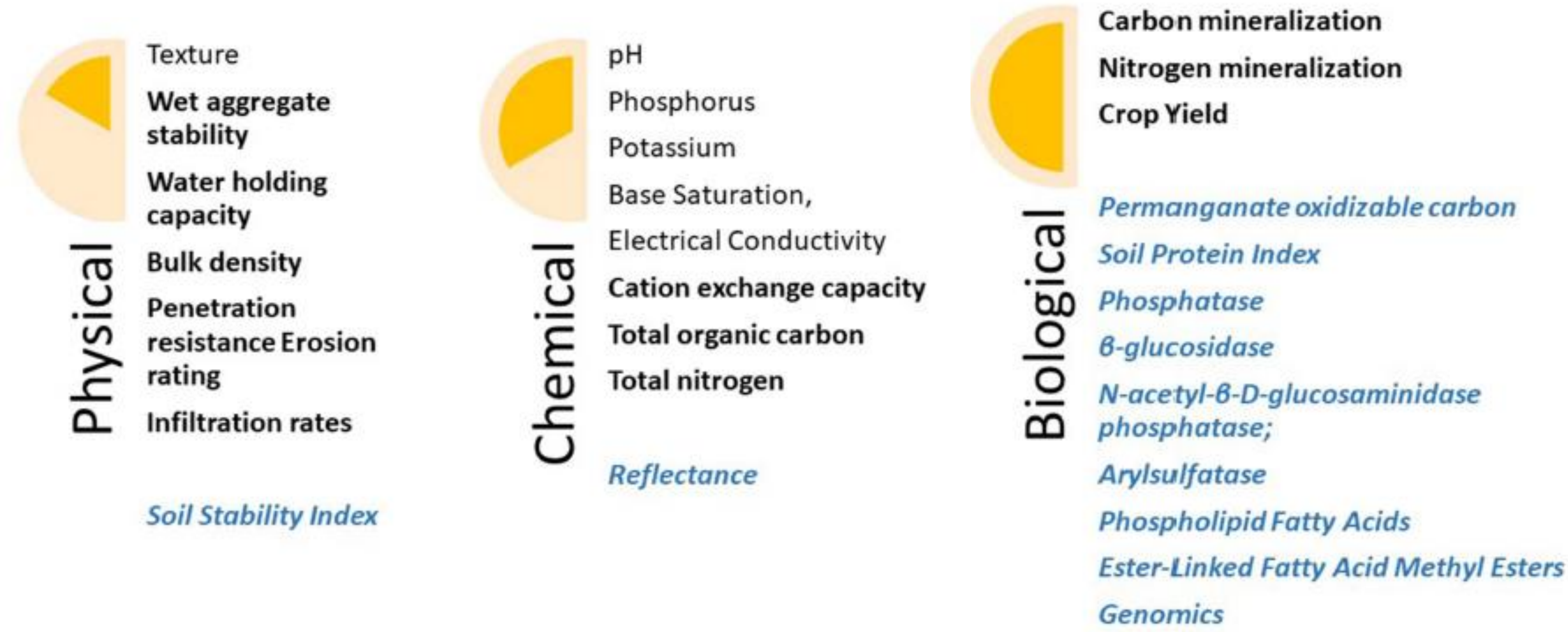
Soil Quality Indicators

Broadly the soil quality indicators could be grouped, viz.,

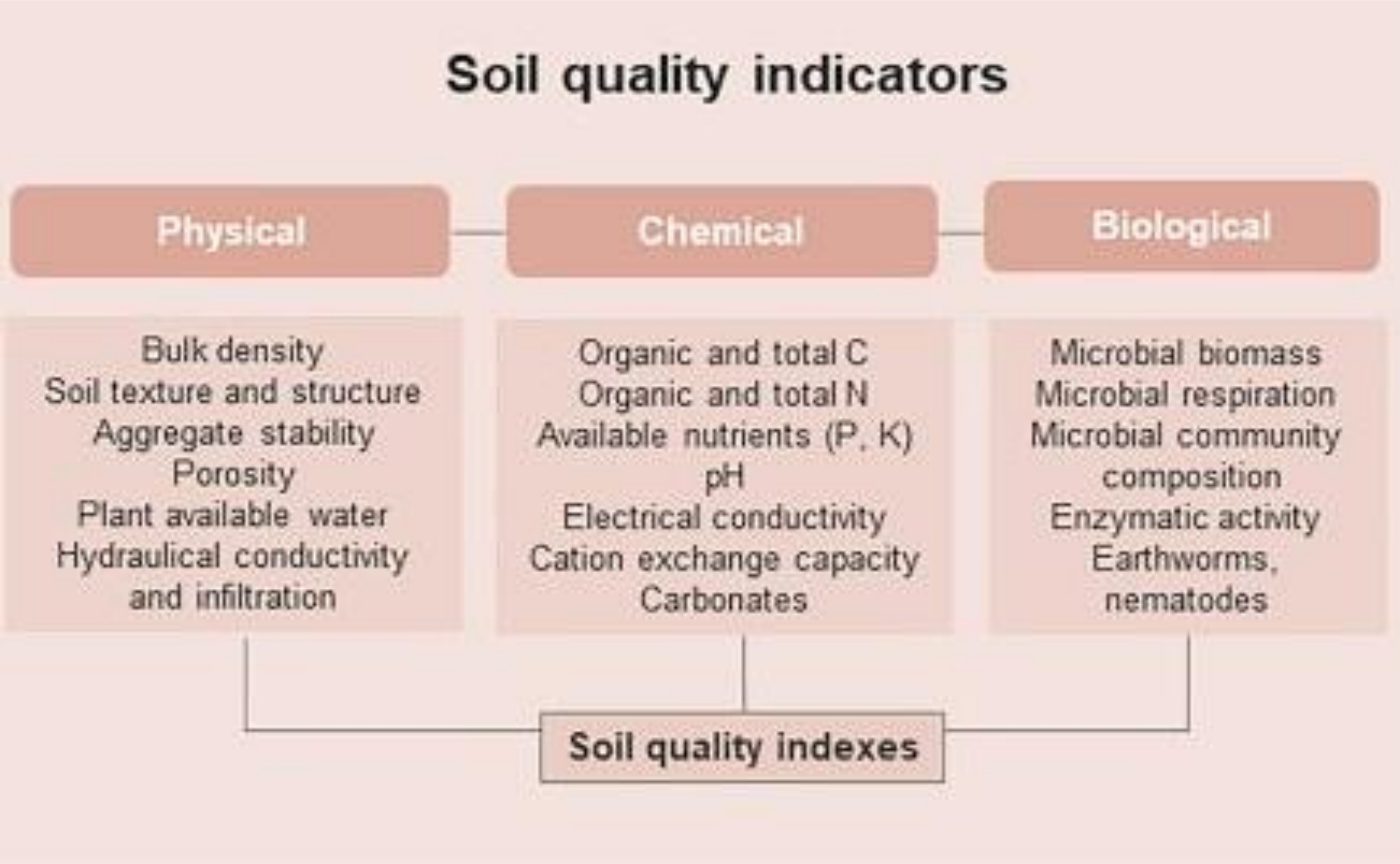
(i) soil chemical quality and soil fertility indicators,

(ii) soil physical quality indicators and

(iii) soil biological quality indicators



Soil Quality Indicators



Evaluation of soil quality for developing SQI

- SQI helps to assess the soil quality of a given site or ecosystem and enables comparisons between conditions at plot, field or watershed level under different land uses and management practices (Gelaw et al. 2015; Rivera et al., 2020).

Four major tools have been used for soil quality assessment viz.,

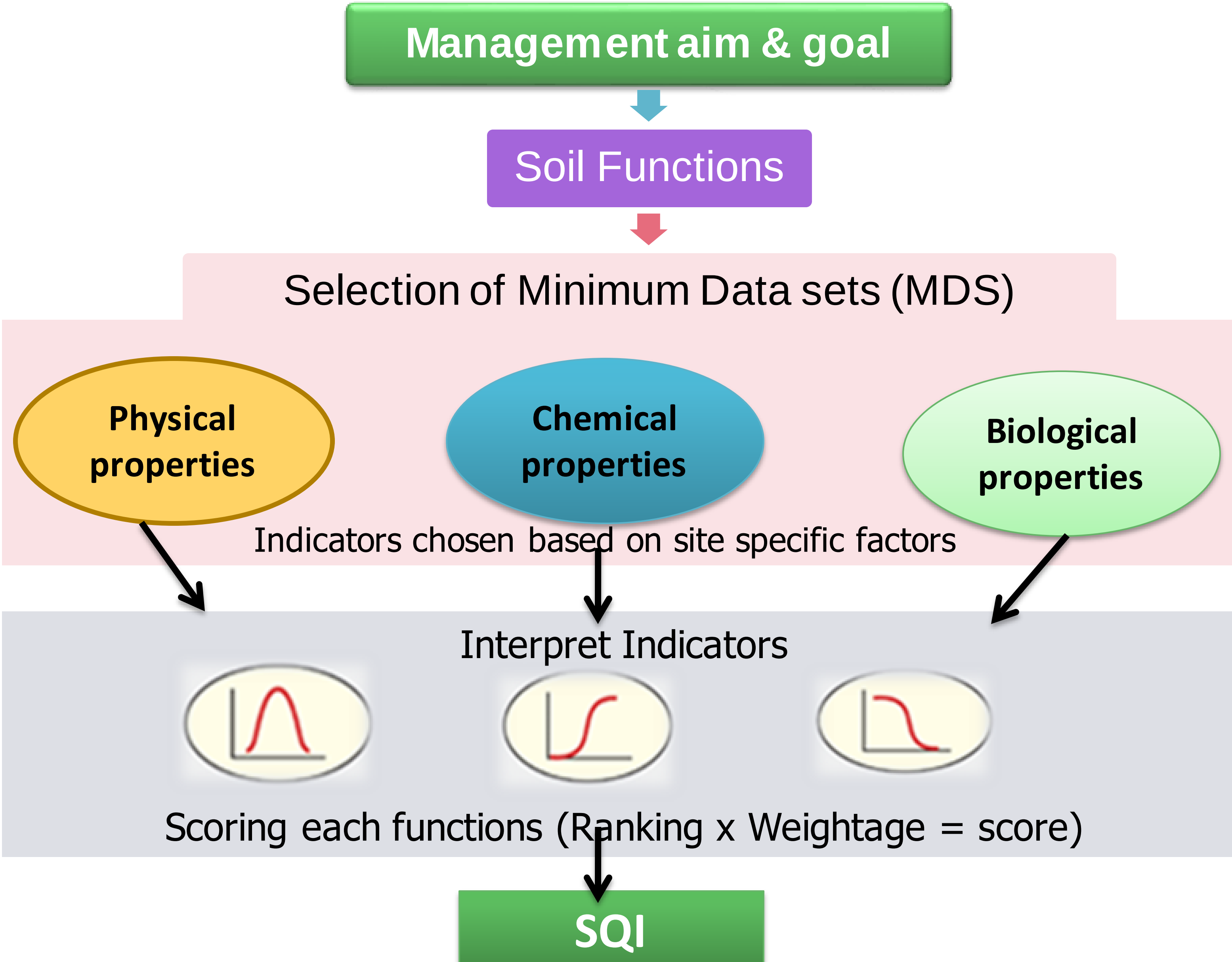
i. Soil Conditioning Index (SCI),
ii. Soil Management Assessment Framework (SMAF),
iii. Agro ecosystem Performance Assessment Tool (AEPAT) and
iv. New Cornell Soil Health Assessment.

Steps of SQI

Four main steps (Nayak et al., 2016) are followed in the determination of soil quality index (SQI) using SMAF

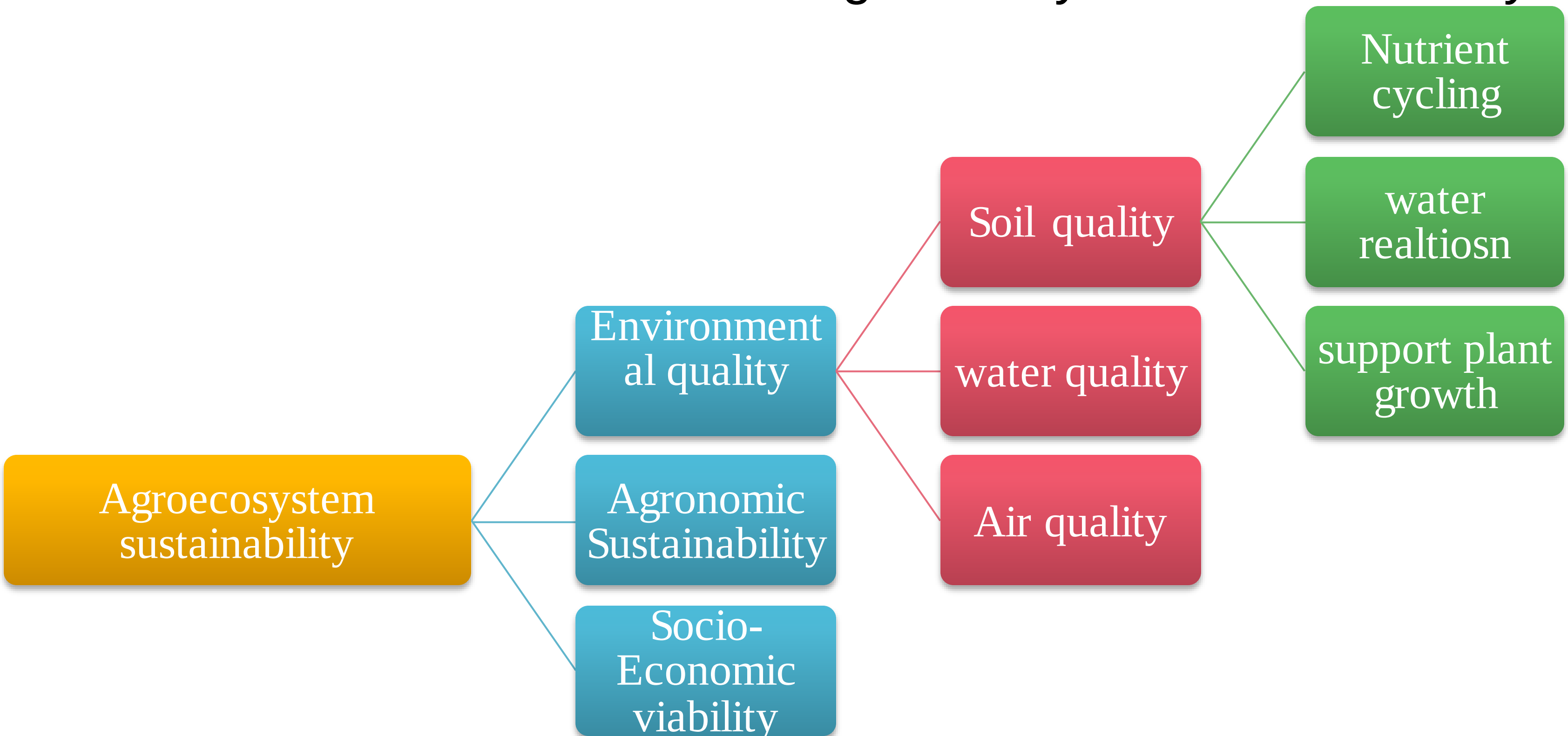
- Formulation of appropriate goals for desired outcomes of soil functions,
- Selection of a minimum data set (MDS) of indicators that best represent soil function,
- Scoring the MDS indicators based on their performance of soil function and
- Integration of the indicator scores into a comparative SQI

Steps in SQ evaluation and developing SQI



(i). Formulation of appropriate goals for desired outcomes of soil functions

- An appropriate SQI may have three component goals: environmental quality, agronomic sustainability, and socio-economic viability
- If the objective is to attain sustainability in agro-ecosystem management, a soil quality index will serve as a constituent within a hierarchical structure of agro-ecosystem sustainability



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

- Selection of MDS from wide range of physico, chemical and biological properties depends on the purpose, soil type, management practices followed etc.
- More accurate assessment of soil quality is achieved by combining these indicators into a single index (Bucher, 2002).

How to select soil quality Indicators?

- Representative of soil function
- Sensitive to management practices
- Easy to measure and reproducible
- Reliable
- Accessible to users
- Applicable to field conditions
- Integrate soil physical, chemical, and biological properties and processes

Doran and Parkin, 1994 & 1996; Gregorich et al., 1994

Key soil quality indicators within soil health frameworks

Soil Indicator	Associated soil function & processes
Physical	
Bulk Density	Soil compaction, Plant root penetration, porosity, adjust analysis to volumetric basis, Enzymatic activity
Texture	Crusting, Gaseous diffusion; Retention and transport of water and chemicals, modeling use
Aggregation	Potential erosivity, Infiltration, Soil structure, crop emergence an early indicator of soil management effect
Water holding capacity	Microbial diversity, Mineralization of nutrients
Depth	Productivity potential, Estimate rooting volume for crop production and erosion
Hydraulic conductivity	Water availability to crops and distribution of soil moisture

Key soil quality indicators within soil health frameworks

Soil Indicator	Associated soil function & processes
Chemical	
Organic matter	Carbon sequestration, Soil fertility and resilience, Defines soil fertility and soil structure, pesticide and water retention, and use in process models
pH	Microbial growth and activities, Nutrient availability to plants, Nutrient availability, pesticide absorption and mobility, process models
Electrical conductivity	Optimum Plant growth, Microbial activity threshold, soil structure, water infiltration; presently lacking in most process models
Cation exchange capacity	Ion exchange, Nutrients leaching
Extractable nutrients	Nutrient cycling, Microbial activity, Plant growth and crop yield; Capacity to support plant growth, environmental quality indicator
Forms of soil N	Availability to crops, leaching potential, mineralization/ immobilization rates, process modeling
Suspected pollutants	Plant quality, and human and animal health
Exchangeable cations, CEC, SAR, ESP, Clay, $CaCO_3$	Assessing the pedogenesis and crop productivity

Key soil quality indicators within soil health frameworks

Soil Indicator	Associated soil function & processes
Biological	
Humic fraction	Organo-mineral complexes, Formation of soil structures
Microbial biomass carbon	Source and sink of soil nutrients,
Enzymatic activity	Organic matter decomposition
Soil respiration	Microbial activity, Gaseous fluxes, process modeling; estimate of biomass activity, early warning of management effect on organic matter
Microbial count	Nutrients transformation

MDS selection methods

The selection of minimum soil data set (MDS) is based on methods and statistical tools like

- Regression analysis
- Principal component analysis (PCA) (Andrews and Carroll, 2001),
- Expert opinion (EO) (Andrews et al., 2002) and
- Factor analysis (Shukla et al., 2006) etc.

Principal component analysis (PCA)

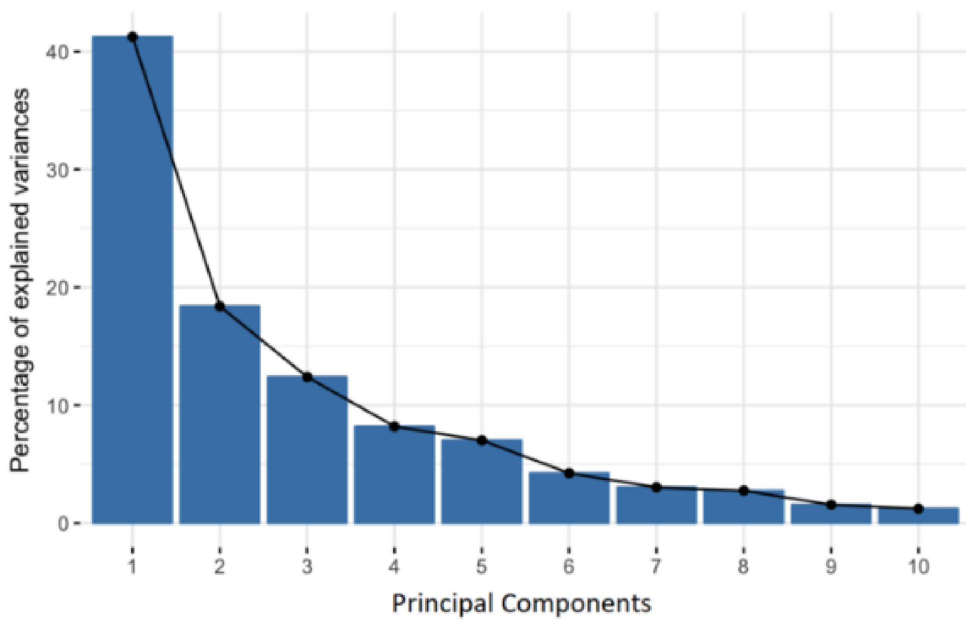
- It is a dimensionality reduction method -used to reduce the dimensionality of large data sets, by transforming a large set of variables into a smaller one that still contains most of the information in the large set.
- Simply, **"reduce the number of variables of a data set, while preserving as much information as possible"**

Requirements for PCA

- 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

PC Construction

- As there are as many principal components as there are variables in the data, PC are constructed in such a manner that the first PC accounts for the **largest possible variance** in the data set.
- The second principal component is calculated in the same way, with the condition that it is uncorrelated with (i.e., perpendicular to) the first PC and that it accounts for the next highest variance.
- This continues until a total of principal components have been calculated, equal to the original number of variables.



Selection of PC and MDS

- 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 ≥5% of the variability in the soils data (Wander and Bollero, 1999) could be included when fewer than three PCs had eigenvalues ≥1.
- 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
- 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
- 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.

Soil function based approach or Expert opinion (EO) method

- In this approach, primary soil functions were defined based on expert opinion with regard to their established role in the soil production function.
- An expert can generate a list of appropriate SQ indicators on the basis of ecosystem processes and functions and other decision rules such as management goals for a site associated with soil functions as well as other site-specific factors, like region or crop sensitivity as selection criteria (Tesfahunegn, 2014).
- Moreover, it is important that the selected indicator(s) should truly represent the complexity and function of the soil (Moncada et al., 2014).
- Vasu et al (2016) also reported that it is necessary to consider the study area characteristics such as climate, rainfall and associated pedogenic processes modifying the soil properties which determine the crop productivity before choosing variable(s) as indicators.

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

- Every observation of each MDS indicator has to be 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
- 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

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)

Scoring functions

Linear scoring

$$\text{Score} = \frac{\text{Parameter value}}{\text{Maxima (highest value) of the dataset}}$$

("For more is better" indicators)

$$\text{Score} = \frac{\text{Minima (Lowest value) of the dataset}}{\text{Parameter value}}$$

("For less is better" indicators)

Non-linear scoring

An advanced way to assess soil quality indicators is to set up standard non-linear scoring functions, which typically represents shapes

i) more is better, ii). less is better, iii) optimum range, or iv) undesirable range,

The shape of such curves is set up based on a combination of expert opinion and literature values (Andrews et al., 2004).

While scoring curves should be formulated on regional data, then scores are comparable to measured values in the particular region (Moebius-Clune et al. 2016).

Every indicator measurement is converted to a value between 0 and 100 (or 0 and 1) by using an algorithmic scoring (Karlen and Stott, 1994), a score of 0 being the lower threshold, and a score of 1 or 100 the upper threshold

(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.

(A). Conceptual framework for analyzing soil quality and

(B). Principal component analysis based soil quality index.

A. Conceptual framework for analyzing soil quality

The Conceptual Framework model has been used to determine soil quality as described by Karlen and stott (1994) 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, to sustain biodiversity and habitat and (wt) is a numerical weightage for each soil function. Weights for all soil functions sum to 1.00.

Principal component analysis based soil quality index

- SQI is arrived using the transformed scoring of each MDS and the weighting factor obtained with PCA analysis.
- The assigning weights to each indicator parameter selected under the MDS are the next step in SQI calculation. This is carried out by two techniques as given below.
- Additive Indexing
- Weightage Indexing

Additive index

- The additive index is calculated by adding the transformed scores for both PCA and EO selected indicators (Vasu et al., 2016).
- The weighted mean is calculated to arrive at a single index value for each soil.
- The mean SQI for each soil is then calculated from weighted mean SQI of soil.
- An additive index produces a number between 1 and 10 in the soil management evaluation framework (Andrews et al., 2004).

Example of Soil functions, their indicators, and assigned weights

Function	Weight	Function indicators	Weight	Scoring function
Maintaining soil structure and water storage	0.35	Soil organic carbon	0.20	More is better
		Available water capacity	0.10	More is better
		Bulk density	0.05	Less is better
Nutrient supply function	0.25	$KMnO_4$ oxidizable C	0.05	More is better
		Available N	0.05	More is better
		Available P	0.05	More is better
		Available K	0.05	More is better
		Available S	0.05	More is better
Soil biological activity	0.20	Soil respiration	0.10	More is better
		Dehydrogenase	0.05	More is better
		Fluorescein diacetate	0.05	More is better
Soil basic properties, potential to limit production	0.20	pH	0.10	Optimum is better
		EC	0.10	Less is better

Weighted Index

- The transformed indicator data is given weightage based on the results of PCA.
- Each PC explained a certain amount (%) of the variation in the total dataset.
- The weight factor for the indicator(s) selected under a particular PC can be determined by dividing the percentage of variance explained by that indicator PC by the cumulative percentage of variance explained by all PCs (Ray et al., 2014).
- The derived weightage factor can be used with selected variables (indicators) from respective PCs.
- The weighted variables will be then summed up to derive index value.

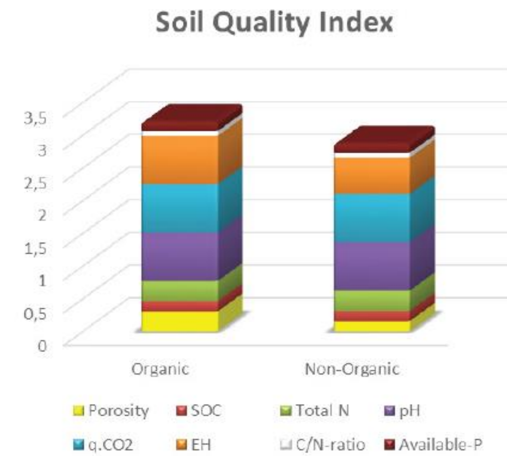
$$\text{Weighted index} = \frac{\text{\% variance of each PC from which MDS chosen}}{\text{\% cumulative variance by all PCs Chosen for MDS}}$$

MODEL SQI (Haryuni et al. (2020)
Soil quality index in organic and non-organic paddy fields

Results of MDS by PCA

Eigenvalue	4.5128	2.5865	2.0182	1.0271	0.6410	0.5913
Proportion	0.376	0.216	0.168	0.086	0.053	0.049
Cumulative	0.376	0.592	0.760	0.845	0.899	0.948

Variable	PC1	PC2	PC3	PC4
Porosity	0.391*	-0.238	0.082*	-0.266
Permeability	0.160	-0.362	-0.442	-0.202
pH	0.066	0.195*	-0.634	0.156*
Soil Organic Matter	0.425*	-0.063	0.022*	-0.039
Total-N	0.270*	-0.395	-0.246	-0.078
C/Nratio	-0.392	-0.278	-0.028	0.201*
Available-P	-0.316	-0.334	-0.226	0.339*
Available-K	-0.221	0.282	-0.140	-0.325
BS	-0.212	0.044	-0.398	-0.482
EC	-0.326	0.175	-0.038	-0.322
qCO_2	0.187	0.352*	-0.317	0.502*
EH	0.274	0.436*	-0.048	-0.087



Soil quality value of organic paddy field and non-organic paddy fields

No.	MDS	Wi	Organic	Non-organic
			Si	
1	Porosity	0.155251	2	1
2	SOC	0.155251	1	1
3	Total N	0.155251	2	2
4	pH	0.184932	4	4
5	qCO_2	0.184932	4	4
6	EH	0.184932	4	3
7	C/Nratio	0.07363	1	1
8	Available-P	0.07363	2	2
	SQI		3.216	0.147
	Score		4	5
	Class		Low	Very Low

Note: MDS – minimum data set; Si – soil index;Wi – weight index

SQI Calculation

- The final PCA based soil quality equation is obtained after adding the score index and weight index: The indicators were assigned weights so that the sum of weights of all factors is unity. The weighted MDS indicator scores for each observation were summed up using the following function:

$$SQI = \sum_{i=0}^{n} w_i \times s_i$$

- Where, n= number of indicators, Wi = weight index assigned to each selected indicator and Si = score index of each indicator (Haryuni et al. 2020)

Soil quality indexing class by Cantú et al. (2007)

Soil quality	**Range**	**Class**
Very good	0.80–1	**1**
Good	0.60–0.79	**2**
Middle	0.35–0.59	**3**
Low	0.20–0.34	**4**
Very low	0–0.19	**5**

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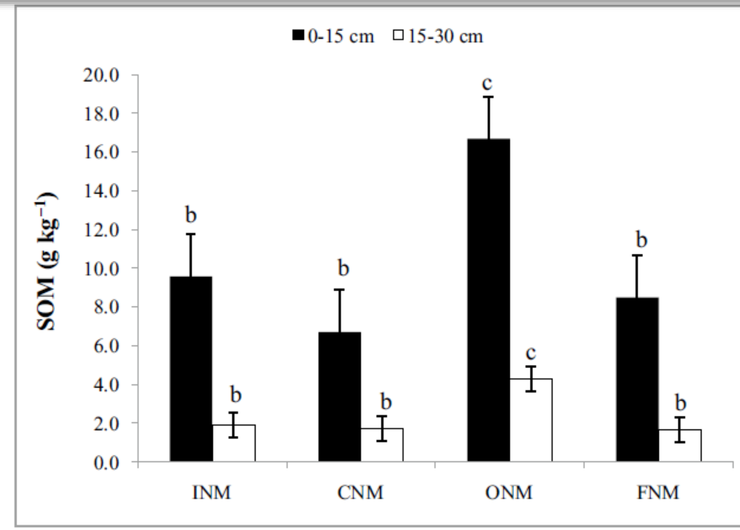
RESEARCH

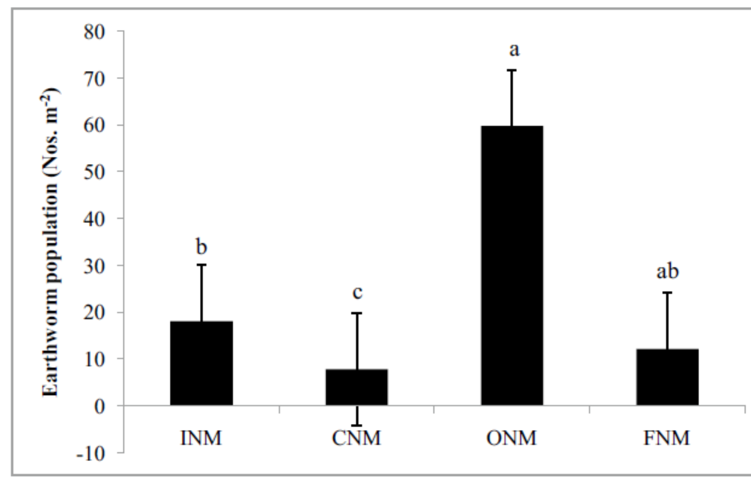
Comparison of biological soil quality indicators under different nutrient management techniques in semi-arid parts of India

D. Udhaya Nandhini · P. Janaki · E. Somasundaram

Field experiment (with tomato) was conducted involving four nutrient management practices, viz., integrated nutrient management (INM), conventional nutriment management (CNM), organic nutrient management (ONM), and farmers practicing nutrient management (FNM) at 2 different soil depths (0–15 and 15–30 cm) in western agro-climatic zone of Tamil Nadu. The data across the nutrient management practices revealed that soil pH and EC were greatest in CNM, whereas higher available N, P, K, SOC, SOM, DOC, MBC, count on microbes and earthworms, microbial indices MBC/SOC ratio, fungal/bacteria ratio, and enzyme activity were higher in ONM.
The study found that SOM, SOC, MBC, and microbial counts are the major drivers for variability among the nutrient practices. The results signify that biological indicators are influenced by different nutrient management practices in the semiarid tropical vertisols through the resilience of SOC.

SOM and Earthworm at two different depths (0–15 cm and 15–30 cm) for the organic and conventional farming systems.





Organic nutrient management (ONM): Multivarietal seed incorporation (25 kg/ha) + enriched compost (1 t/ha) + FYM (6 t/ha) + neem cake (50 kg/ha) + ash (1.0 t/ha) + vermicompost (4.0 t/ha) + fish waste extract foliar spray @ 3% + *Beauveria bassiana @ 2% + mulching with* sugarcane trashes. Seeds were treated with *Azotobacter beijerinckii (200*

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RESEARCH

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Assessing changes in soil quality indicators, turmeric (*Curcuma longa* L.) yield, and monetary returns under different years of organic nutrient management

Dhandayuthapani Udhaya Nandhini · Ponnusamy Janaki · Subramanian Venkatesan · Kandasamy Senthilraja · Eagan Somasundaram · Sadasivam Meena

Changes in physico chemical indicators of turmeric cultivated soils influenced by organic and conventional nutrient management regimes

Soil Properties	ORG 1 (4 yrs)	ORG 2 (5 yrs)	ORG 3 (6 yrs)	ORG 4 (7 yrs)	ORG 5 (12 yrs)	ORG 6 (13 yrs)	ORG 7 (28 yrs)	CON
pH	8.22 ± 0.32^{ab}	7.07 ± 0.52^{c}	7.29 ± 0.11^{bc}	7.56 ± 0.10^{bc}	7.92 ± 0.27^{abc}	8.09 ± 0.01^{ab}	7.81 ± 0.27^{abc}	8.64 ± 0.37^{a}
EC dS m^{-1}	0.47 ± 0.05^{bc}	0.22 ± 0.02^{e}	0.31 ± 0.01^{de}	0.32 ± 0.02^{de}	0.58 ± 0.06^{b}	0.48 ± 0.05^{bc}	0.46 ± 0.03^{cd}	0.92 ± 0.07^{a}
Bulk density (g/cc)	0.42 ± 0.05^{c}	0.17 ± 0.01^{e}	0.19 ± 0.01^{e}	0.21 ± 0.01^{de}	0.32 ± 0.04^{cd}	0.55 ± 0.06^{b}	0.41 ± 0.03^{c}	0.93 ± 0.07^{a}
SOC (g kg^{-1})	12.7 ± 1.40^{cd}	18.25 ± 0.67^{a}	15.5 ± 1.07^{ab}	14.8 ± 0.94^{bc}	12.1 ± 1.25^{cd}	11.1 ± 1.16^{d}	14.2 ± 0.89^{bc}	5.4 ± 0.42^{e}
SOM (g kg^{-1})	31.0 ± 7.37^{b}	36.8 ± 7.07^{ab}	34.1 ± 5.90^{a}	31.1 ± 5.11^{b}	25.6 ± 3.97^{b}	25.6 ± 3.97^{b}	31.7 ± 5.81^{ab}	11.0 ± 2.33^{c}
Mineral N (kg ha^{-1})	284 ± 19.6^{bc}	398 ± 15.4^{a}	361 ± 39.3^{a}	342 ± 21.2^{ab}	256 ± 26.2^{cd}	244 ± 25.4^{cd}	266 ± 16.7^{cd}	210 ± 15.7^{d}
Bray P (kg ha^{-1})	56 ± 5.4^{cd}	97 ± 10.6^{a}	78 ± 2.9^{b}	82 ± 10.1^{ab}	45 ± 2.8^{de}	37 ± 3.8^{e}	69 ± 9.8^{bc}	19.2 ± 1.2^{f}
Exchangeable K (kg ha^{-1})	366 ± 39.8^{bc}	485 ± 18.8^{a}	483 ± 33.3^{a}	443 ± 27.7^{ab}	361 ± 37.0^{bc}	299 ± 18.5^{cd}	382 ± 39.8^{bc}	247 ± 15.5^{d}
Available Fe (mg kg^{-1})	22.6 ± 2.45^{bc}	36.4 ± 1.40^{a}	38.3 ± 2.63^{a}	34.8 ± 2.59^{a}	21.3 ± 2.19^{c}	19.4 ± 2.03^{c}	28.4 ± 1.77^{b}	17.1 ± 1.07^{c}
Available Zn (mg kg^{-1})	6.63 ± 0.06^{c}	9.73 ± 0.31^{a}	7.68 ± 0.12^{b}	7.81 ± 0.13^{b}	6.75 ± 0.04^{c}	6.87 ± 0.10^{c}	6.94 ± 0.06^{c}	3.13 ± 0.04^{d}
Available Cu (mg kg^{-1})	2.81 ± 0.07^{c}	3.21 ± 0.22^{ab}	3.34 ± 0.09^{a}	2.46 ± 0.03^{d}	2.76 ± 0.04^{c}	2.8 ± 0.09^{c}	2.94 ± 0.06^{bc}	1.07 ± 0.02^{e}
Available Mn (mg kg^{-1})	7.53 ± 0.4^{b}	8.12 ± 0.20^{a}	8.27 ± 0.09^{a}	7.36 ± 0.03^{b}	7.47 ± 0.03^{b}	7.48 ± 0.06^{b}	7.51 ± 0.03^{b}	3.44 ± 0.04^{c}

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RESEARCH

Impact of regenerative farming practices on soil quality and yield of cotton-sorghum system in semi arid Indian conditions

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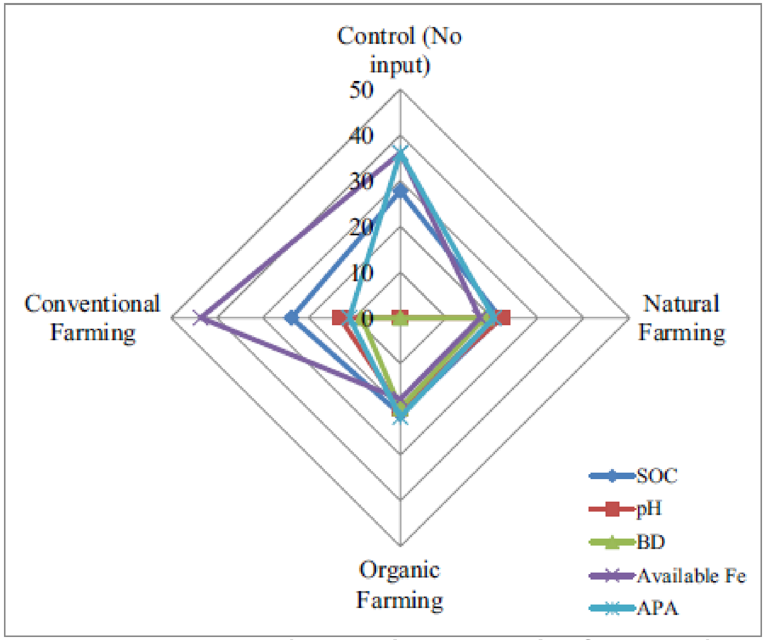
Abstract Regenerative agricultural practices, i.e. organic and natural farming, are rooted in India since ancient times. However, the high cost of production, lack of organic pest control measures and premium price of organic produces in chemical agriculture encourage natural farming. In the present study, the quality improvement of calcareous soils under organic (OGF) and natural (NTF) management was compared with integrated conventional (ICF) and non-invasive (NIF) farming practices with cotton-sorghum crops over three consecutive years. A total of 23 soil attributes were analyzed at the end of the third cropping cycle and subjected to principal component analysis (PCA) to select a minimum data set (MDS) and obtain a soil quality index (SQI). The attributes soil organic carbon (SOC), available Fe, pH, bulk density (BD) and alkaline phosphatase (APA) were selected as indicators based on correlations and expert opinions on the lime content of the experimental soil. The SQI was improved in the order of OGF (0.8 9) > NTF(0.69) > ICF(0.48) > NIF(0.05). The contribution of the indicators to SQI was in the order of available Fe (17–44%) > SOC (21–28%), APA (11–36%) > pH (0–22%), and BD (0–20%) regardless of the farming practices. These indicators contribute equally to soil quality under natural (17–22%) and organic (18–22%) farming. The benefit:cost ratio was calculated to show the advantage of natural farming and was in the order of NTF(1.95–2.29), ICF (1.34–1.47), OGF (1.13–1.20) and NIF (0.84–1.47). In overall, the natural farming significantly sustained the soil quality and cost benefit compared to integrated conventional farming practices.

Keywords Organic · Natural farming · Calcareous soil · Conventional practice · Continuous cropping · Soil quality index

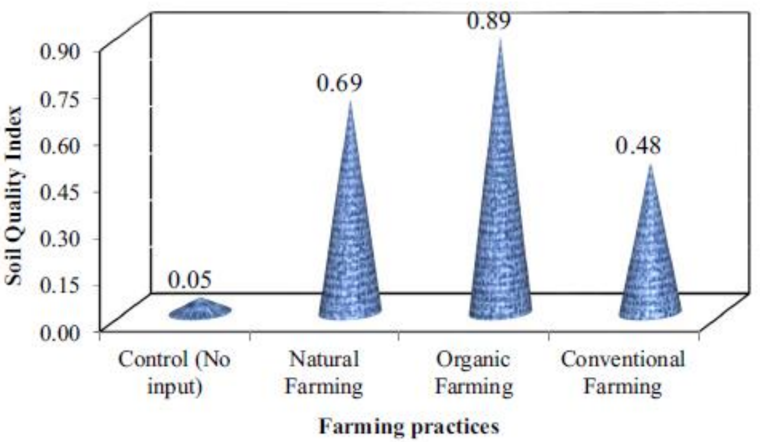
Table 1 Influence of farming practices on soil chemical, biological and physical properties after the third cycle of cotton-sorghum system

Soil properties	NIF	NTF	OGF	ICF
SOC (g 100 g^{-1})	0.63^{c}	0.73^{ab}	0.76^{a}	0.70^{b}
pH	8.53^{a}	8.35^{b}	8.32^{b}	8.46^{a}
EC (dS m^{-1})	0.35^{a}	0.29^{c}	0.28^{c}	0.32^{b}
CEC (c mol (p+) kg^{-1})	9.20^{d}	13.00^{c}	15.70^{b}	17.00^{a}
Avail_N (kg ha^{-1})	186^{d}	234^{c}	289^{b}	311^{a}
Avail_P (kg ha^{-1})	12.16^{c}	18.40^{b}	19.33^{b}	21.97^{a}
Avail_K (kg ha^{-1})	512^{c}	620^{b}	648^{ab}	700^{a}
Avail_Fe (mg kg^{-1})	4.26^{d}	6.77^{c}	7.76^{b}	8.62^{a}
Avail_Mn (mg kg^{-1})	5.64^{d}	7.87^{c}	8.46^{b}	9.35^{a}
Avail_Zn (mg kg^{-1})	0.37^{d}	0.55^{c}	0.69^{b}	0.75^{a}
Avail_Cu (mg kg^{-1})	0.67^{c}	0.88^{b}	0.94^{b}	1.16^{a}
DHA (μg TPF g^{-1} day^{-1})	30.33^{d}	45.83^{b}	50.00^{a}	40.73^{c}
UA (μg NH_4– N g^{-1} h^{-1})	8.67^{c}	16.72^{a}	19.67^{a}	11.16^{b}
APA (μg PNP g^{-1} h^{-1})	12.67^{d}	21.84^{b}	25.33^{a}	16.92^{c}
Bacteria (× 10^{6})	30.72^{d}	43.84^{b}	46.87^{a}	37.78^{c}
Fungi (× 10^{4})	68.64^{d}	86.82^{b}	89.23^{a}	78.56^{c}
Actinomycetes (× 10^{3})	47.81^{d}	60.00^{b}	65.45^{a}	51.00^{c}
Bulk density (Mg m^{-3})	1.33^{a}	1.23^{b}	1.19^{b}	1.30^{a}
Particle density (Mg m^{-3})	2.65^{a}	2.46^{b}	2.37^{b}	2.56^{a}
WHC (%)	46.00^{b}	48.76^{a}	49.38^{a}	47.59^{ab}
Infiltration rate (cm h^{-1})	1.70^{d}	2.17^{b}	2.52^{a}	1.97^{c}
Hydraulic conductivity (cm h^{-1})	0.49^{d}	1.67^{b}	1.74^{a}	0.83^{c}
Porosity (%)	49.00	50.82	51.88	49.60

Values followed by superscript letter indicate the significant difference among the farming practice treatments at 5% level of significance. *NIF* no input farming, *NTF* natural farming, *OGF* organic farming, *ICF* integrated conventional farming



Relative contribution (in percent) of selected indicators to soil quality index from different regenerative farming practices



SQI of soils under different regenerative farming practices after the third cycle of cotton-sorghum system

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Thank you