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Soil Resilience: To Mitigate Degraded Soils

K. Sivasabari[1*] and R. Ajaykumar[2]

[1]Dept. of Soil Science and Agricultural Chemistry, J.K.K Munirajah College of Agricultural Science, T.N.palayam, Erode, Tamil Nadu (638 506), India

[2]Dept. of Agronomy, Vanavarayar Institute of Agriculture, Pollachi, Tamil Nadu (642 103), India

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Corresponding Author

K. Sivasabari

e-mail: sabarisiva3@gmail.com

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Abstract

Soil degradative processes, mechanisms that set in motion the degradative trends, include physical, chemical and biological processes. For sustainable use of soil and its protection against degradation soil quality assessment- fitness for use, and its resilience means ability to recover and identification of diagnostic recovery modules are the only options available to address this critical issue. Systematic evaluation through experimentation is needed for establishing quantitative criteria of (i) soil quality in relation to specific functions; (ii) soil degradation in relation to critical limits of key soil properties and processes; and (iii) soil resilience in relation to the ease of restoration through judicious management and discriminate use of essential input. Quantitative assessment of soil degradation can be obtained by evaluating its impact on productivity for different land uses and management systems. There is a need to develop and standardize techniques for measuring soil resilience.

Introduction

Soil degradation is the loss of actual or potential productivity or utility as a result of natural or anthropogenic factors (Lal, 1997). Essentially, it is the decline in soil quality or reduction in its productivity and environmental regulatory capacity. Soil degradative processes, mechanisms that set in motion the degradative trends, include physical, chemical and biological processes. Decline in soil organic matter and its associated nutrients supply in soil is the major factor for yield decline under intensive cropping systems. In addition, stresses due to acidity, salinity, alkalinity and water logging etc., are also there for a considerable land area in different parts of the country.

Soil degradation is a biophysical process driven by socio-economic and political causes. What the population does to itself and to the soil that it depends on determines the extent of soil degradation. People can be a major asset in reversing the degradative trend (Andrew *et al*., 2004). However, subsistence agriculture, poverty and illiteracy are important causes of soil and environmental degradation. People must be healthy and politically and economically motivated to care for the land.

Therefore, for sustainable use of soil and its protection against degradation soil quality assessment - fitness for use, and its resilience - ability to recover and identification of diagnostic recovery modules are the only options available to address this critical issue. Theoretically, soil resilience has been defined as the capacity of soil to recover its function and structural integrity after a disturbance. Agriculture is one of the important stresses and disturbances to the soil environment. Although, there is a conceptual framework for evaluation soil resilience but there is limited field level validation. Soil resilience and resistance are affected by both inherent and dynamic soil characteristics and thus, will vary substantially from one area to the next and will change over time and management practices. Management practices that increase soil organic matter levels will improve most soil functions. Thus, it is necessary to develop a protocol for evaluating soil resilience capacity of degraded soil with field level validation under different management interventions (Figure 1).

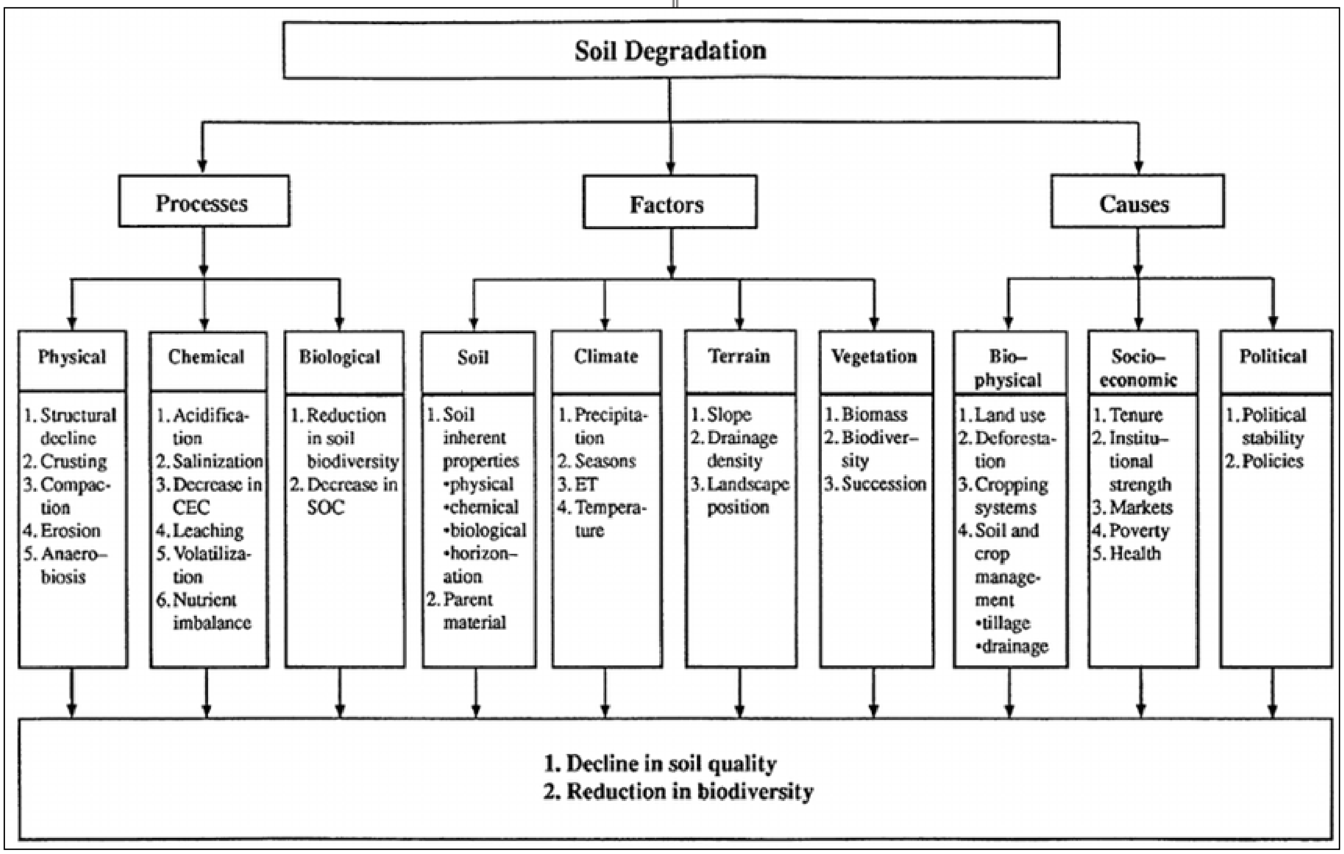

Figure 1: Process, factors and causes of soil degradation

Soil Resilience

Resilience is an ecological concept that involves several attributes that govern responses to disturbance or stress. Several terms used in ecology with relevance to soil resilience are: (i) resilience, the ability to resist change or recover to the initial state; (ii) resistance, the ability to resist displacement from the antecedent state; (iii) elasticity, the rate of recovery; (iv) amplitude, the range of change in a property from which recovery is possible; (v) hysteresis, the divergence in the recovery path or pattern; and (vi) malleability, the difference in the new versus the antecedent state.

Principal Processes Involved in Soil Resilience

a) Control of soil organic matter content;
b) Improvement in soil structure;
c) Increase in soil biodiversity;
d) Reduction in soil degradation and erosion rates below the soil formation rate;
e) Increase in nutrient capital and recycling mechanisms.

Factors Affecting Soil Resilience

These factors are difficult to manage-

- Soil texture
- Soil depth
- Soil horizon sequence

These factors can be managed-

- Disturbance
- Diversity and complexity
- Water, Nutrients and Energy

Methods for Estimation of Soil Resilience

Selection of Sites and Analysis of Soils

GPS based soil sampling is to e done to select farmers' field and soil samples are analysed for different physical (bulk density, clay content, mean weight diameter, aggregate stability water stable aggregate, saturated hydraulic conductivity), chemical (pH of soil, total soil organic carbon, easily oxidizable organic carbon, different fractions of OC, available NPKS, micronutrients) and biological (microbial biomass C and N, enzyme activity viz., dehydrogenase, acid and alkaline phosphatise, Urease) attributes of soil (Figure 2).

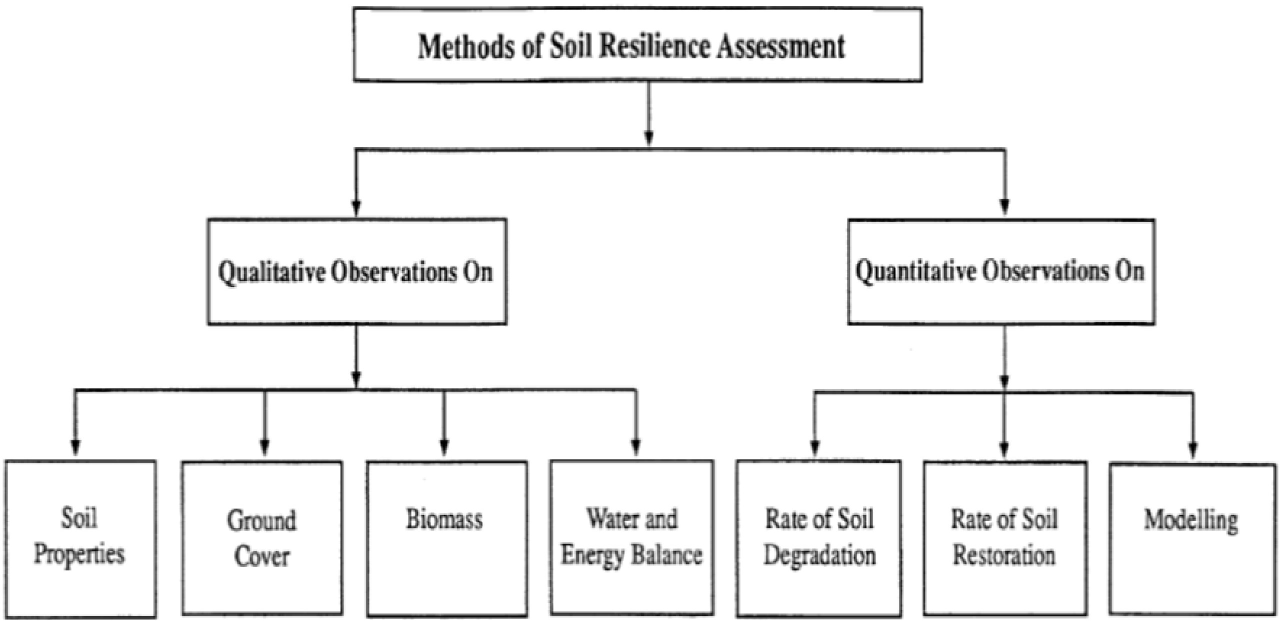

Figure 2: Methods of soil resilience Assessment

Assessment of the Rate of Soil Degradative Process

The rate of soil degradation under a specific ecological stress can be used to evaluate relative soil resilience. These stresses include the rate of soil erosion, SOC decline, changes in soil chemical and nutritional properties, clay and colloid content, and change in porosity.

Soil resilience can be computed from the rate of change of soil quality, as shown in equation (1). The positive value of the right-hand side of equation,

$C{:}N=4.60+2.02\ T-0.15\ T^2, R^2=0.6$

refers to the rate of soil degradation.

$S_r = -dS_q/dt$ (1)

Where, S_q is soil quality and *t* is time. The choice of temporal scale is extremely important and depends on several factors.

Assessment of the Rate of Soil Restoration

In contrast to degradation, the rate of soil restoration can be used to assess soil resilience. Because of the strong hysteresis, there may be differences in degradative and restorative pathways. The rate of soil restoration can also be related to changes in soil quality, as shown in equation (2). The negative value on the right-hand side of equation,

$SOC_{NT}=10.2+t^{0.54}, R^2=0.97$ (Where NT is No-till and *t* is time)

refers to the rate of soil degradation.

$S_r = dS_q/dt$ (2)

Empirical development of time-dependent pedo-transfer functions is useful in assessing positive (resilience) or negative (degradation) changes in soil quality.

Soil Resilience Index

Based on this quantitative value of the key indicators, SQI values are calculated for all the experimental sites. On the basis of soil quality assessment data management interventions are selected. The resilience index (RI) of the soils of each of the selected sites after receiving management intervention is calculated using the following expression,

$RI = SQI\ (T) - SQI\ (d) / SQI\ (p) - SQI\ (d) \times 100$

Where, SQI (T): The soil value of soil after management interventions (T); SQI (d): The SQI value of soil before the management intervention (I); SQI (p): The computed SQI value of pristine soil near the corresponding site.

The numerator in the above expression indicates the recovery of SQI value due to management intervention where as the denominator indicates the loss of SQI value due to soil degradation processes (Figure 3).

Soil Resilience and Soil Quality

Resilience is one of the most important critical issues to be addressed when assessing soil quality, yet it is also the most difficult to predict. Soil resilience, soil's ability to restore its quality following a perturbation, depends

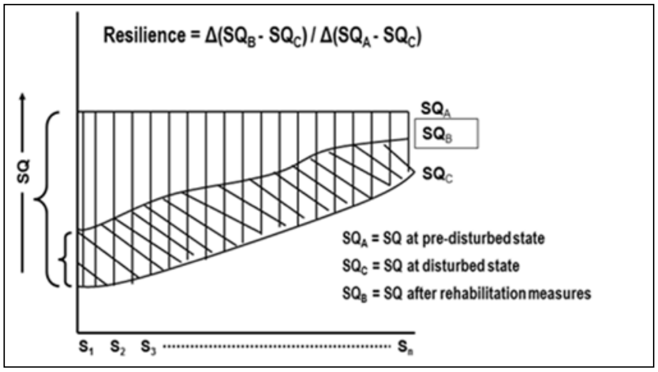

Figure 3: Schematic model for soil resilience measurement

on inherent soil properties and the net balance between soil formative and degradative processes, as per equation,

$S_r = S_a + f(S_n - S_d \pm I_m)dt$

Where, is the soil resilience; is the antecedent soil condition; is the rate of new soil formation; is the rate of degradation/ depletion; is the management inputs and is the time.

The magnitude and sign of the term (S_n-S_d ± I_m) are critical in determining soil resilience. The above equation can be applied to specific soil properties e.g., rooting, depth, top soil thickness, soil organic matter, available nutrients and water etc. as long as the time-dependent relationship of that property is known. Soil resilience affects soil quality by mitigating the adverse effects on predominant degradative processes. Soil resilience has profound influence on soil quality in terms of the degree of change in soil functions as a result of disturbance. At the time disturbance, soil quality becomes the function of soil resilience, and soil resilience is the component of soil quality after disturbance. Thus sustainability depends on soil resilience and resistance of the system. The improper management and misuse of soil over the time can result in reduction of soil quality as result of the degradation or loss of soil resistance/ resilience.

Soil quality as the function 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. Soil health (condition) is the ability of soil to perform according to its potential. Soil quality is a measure of the condition of soil relative to the requirement of one or more species and/or to any human need or purpose. Appropriate use of indicators will depend to a large extent on how well the relevance indicators are interpreted with respect to consideration of ecosystem as given below:

• **Physical:** Texure, depth of soil, topsoil, rooting, infiltration and soil bulk density (SBD) and water holding capacity (water retention characteristics).

• **Chemical:** Soil organic matter (OM), pH, electrical conductivity and extractable N, P and K.

• **Biological:** Microbial biomass C and N, potentially mineralizable N (anaerobic incubation), soil respiration, water content and temperature.

Arshad and Coen (1992) recommended that qualitative information should be an essential part of the soil quality monitoring programme and can be estimated by calibrating qualitative observations against measured value.

Conclusion

Soil quality is assessed integrating physical, chemical and biological attributes of soils. These attributes might be changed under the influence of various management practices and cropping systems and as such aggraded or degrade soil quality. The conceptual framework for evaluating soil resilience has been designed with field level validation. The method described here for measuring soil resilience can successfully be used to measure the resilience power of degraded soils in response to management interventions.

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