Introduction to Soil quality

• Definition of soil quality
• How to evaluate soil quality
  – Indicators
  – Soil resistance and resilience
  – Scoring algorithms
What is soil quality?

- Soil quality is the capacity of the soil to function within the ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Soil Sci. Soc. Am, 1997).

![Diagram showing the relationship between soil quality, biological productivity, the environment, and human health](image-url)
What is soil quality (cont’d)?

• Soil quality involves the ability of the soil to maintain an appropriate productivity, while simultaneously reducing the effect on the environment and contributing to human health (Schjønning et al. 2004).

• Soil quality or soil health is concerned with some measures of a property or function of soil (good/bad, low/high, etc.)
What is soil quality (cont’d)?

• Soil quality may be regarded as a ‘vessel’ for various attributes of the soil. For example, soil quality in the context of highway constructions in concerned with the bearing capacity of the soil medium but does not consider soil functions for plant growth.
Why do we need soil quality concept?

• To address the problems of nonagricultural uses of soil (e.g., mineland restoration, urban uses and disposal of urban wastes, soil contamination and pollution by industrial activities)

• To develop appropriate indicators of soil quality in relation to specific soil function (e.g., agricultural, urban, industrial, recreational, athletic, environmental, and waste disposal)
How do we evaluate soil quality?

<table>
<thead>
<tr>
<th>Indicator category</th>
<th>Related soil function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>Nutrient cycling, Buffering, Water relations</td>
</tr>
<tr>
<td>Physical</td>
<td>Physical stability and support, Water relations, Habitat</td>
</tr>
<tr>
<td>Biological</td>
<td>Biodiversity, Nutrient cycling, Filtering</td>
</tr>
</tbody>
</table>
Criteria for indicators of soil quality
(Dorans, 2000)

• Their utility in defining ecosystem processes
• Their ability to integrate physical, chemical, and biological properties
• Their sensitivity to management and climatic variations
Is soil organic matter a desirable component?

- Its capacity to perform productivity, environmental, health functions
- It alone is not an adequate indicator
- Relationship between plant, animal, and human health should be considered together (e.g. nitrate vs groundwater pollution)
Indicators of soil quality for New Zealand

• Soil fertility indicator
  – Olsen P
  – Soil pH

• Organic resources
  – Anaerobic nitrogen mineralization
  – Total (organic) C
  – Total (organic) N

• Soil physical quality
  – Bulk density
  – Macroporosity ($Ma = 0.693 - 0.465 \times \text{Bulk density} + 0.212 \times \text{Sand content}$) (Stolf et al. 2011)
Thresholds used for soil quality studies

- Indicator thresholds (universal)
- Management thresholds considering knowledge of soil/management interaction (probably non-universal)
- Management procedures that are sustainable consider productivity, environment, and health
Linkage between soil quality and plant, animal, and human health

• Both essential and nonessential elements should be present in adequate amounts.
• Nonessential plant elements may be essential to animal nutrition (e.g. I, Cr, Se, and Ni).
• Three avenues where soil interact with and affect the health of animals
  – Direct poisoning of plants and/or animals by chemicals in soil
  – Ability of soil to filter contaminants from water
  – Deficient, adequate, or excessive quantities of essential and/or nonessential nutrients to plants
Soil resistance

- The capacity of a soil to resist change when confronted with any kind of force or disturbance
- Resistance to soil erosion, compaction, acidification, and nutrient depletion
- Buffering
  - Resistance to various types of chemical changes (e.g. potassium replenished from nonexchangeable and exchangeable forms in clay soils faster than in sandy soils)
Soil resilience

• The capacity of a soil to rebound from changes simulated by disturbances or external forces

• The degree to which recovery takes place and its speed (e.g. a land is cleared for cultivation and thus its organic matter content declines, but the land is tuned back to nature if appropriate soil management practices are utilized)
How soil resistance and resilience relate to soil quality

(Brady and Weil, 2008)
Soil quality assessment

• Selecting management goal(s) (e.g. productivity, waste management)
• Identifying critical soil functions (e.g. nutrient cycling, water infiltration and retention, filtering and buffering) related to each goal
• Selecting appropriate physical (e.g. aggregate stability, bulk density), chemical (e.g. pH, organic carbon, total N, EC, phosphorus) and biological (e.g. soil enzymes, microbial biomass) indicators
Soil quality assessment (cont’d)

- Scoring algorithms help to interpret indicator data.
- Soil- and site-specific threshold and optimal values

(Karlen et al. 2004)
## Specific soil functions that support broad soil management goals

<table>
<thead>
<tr>
<th>Management goal</th>
<th>Supporting function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant productivity</td>
<td>Nutrient cycling, water relations, physical stability and support, resistance and resilience</td>
</tr>
<tr>
<td>Waste recycling</td>
<td>Nutrient cycling, water relations, filtering and buffering, resistance and resilience</td>
</tr>
<tr>
<td>Environmental protection</td>
<td>Nutrient cycling, water relations, physical stability and support, filtering and buffering, resistance and resilience, biodiversity and habitat</td>
</tr>
</tbody>
</table>
Scoring algorithms to calculate a soil quality index

(Brady and Weil, 2008)
Scoring algorithms to calculate a soil quality index (cont’d)

- **Mineralizable N**
  - PMN (mg N kg soil$^{-1}$)

- **Sodium absorption ratio (SAR)**
  - 0.2 to 1.2

- **Available P**
  - Soil P (mg P kg soil$^{-1}$)

- **Organic C**
  - TOC (g C kg soil$^{-1}$)
  - Depends on climate & texture

- **qCO$_2$**
  - qCO$_2$ (mg g$^{-1}$ d$^{-1}$)

- **Active C**
  - Active C (mg/(kg (silt & clay)))

(Brady and Weil, 2008)
Calculate a soil quality index

• Unweighted soil quality index (SQI)
  \[ SQI = \frac{1}{n} \times \sum S_t \times M \]
  where \( n \) = the number of scores,
  \( S = \) scoring scale with a maximum score \( (M) \)

• Weighted soil quality index (SQI\(_w\))
  \[ SQI_w = \frac{1}{n} \times \sum S_{wt} \times M \]
  where \( S_{wt} = \) weighted scores
# Simplified example of calculating soil quality indices

(Brady and Weil, 2008)

<table>
<thead>
<tr>
<th>Management Goal</th>
<th>Supporting ecological function</th>
<th>Indicator property</th>
<th>Measured value</th>
<th>Indicator score (S)</th>
<th>Weighting factor (w)</th>
<th>Weighted indicator score (S \cdot w = S_w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant production</td>
<td>Nutrient cycling</td>
<td>Soil test P</td>
<td>80 mg P kg soil(^{-1})</td>
<td>10</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PMN</td>
<td>20 mg N kg soil(^{-1})</td>
<td>8</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30%</td>
<td>8</td>
<td>1</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Water relations</td>
<td></td>
<td>AGG</td>
<td>20 g H(_2)O g soil(^{-1})</td>
<td>8</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AWC</td>
<td>30%</td>
<td>8</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Physical stability</td>
<td></td>
<td>AGG</td>
<td>30%</td>
<td>8</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Db</td>
<td>1.4 Mg m(^{-3})</td>
<td>6</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Resilience</td>
<td></td>
<td>TOC</td>
<td>25 g C kg soil(^{-1})</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SAR</td>
<td>1.0</td>
<td>9.5</td>
<td>1</td>
<td>9.5</td>
</tr>
</tbody>
</table>

Sum of scores or factors = 61.5 \[n_w = 10\] 79.5

Average of S = 61.5/8 = 7.7

Unweighted Soil quality index (SQL) = 7.7 \times 10 = 77

Average of S\(_w\) = 79.5/10 = 8.0

Weighted Soil quality index (SQL\(_w\)) = 8.0 \times 10 = 80
General soil quality indicators

- Soil texture
- Bulk density
- Soil aggregates
- Soil pH
- Organic matter content
- Electrical conductivity (EC)
- Available nutrients
- Microbial biomass
Soil texture

• Describes size of soil particles
• Relative proportions of various soil separates (sand, silt, and clay)
• Diameters of soil particles: sand (0.05–2 mm), silt (0.002–0.05 mm), clay (< 0.002 mm)
• Soils with coarser textures have less clay and organic matter and therefore lower amounts of exchangeable cations and lower cation exchange capacity (CEC)
• Fineness of texture increases with generally increasing available water storage
General relationship between soil water characteristics and soil texture

(Brady and Weil, 2008)
Bulk density

• Defined as the mass of a unit volume of dry soil
• Fine-textured soils generally have lower bulk densities (high total pore space) than do sandy soils
• A higher bulk density prevents root penetration (e.g. a pan with a bulk density of 1.7 Mg/m³) and water movement
• Affects air-filled pore space and biological activity
Soil aggregates

• Many soil particles held in a single mass or cluster.
• Macroaggregates (0.25–5 mm in diameter) and microaggregates (0.25–5 µm) formed via biological (e.g. fungal hyphae, roots) and physical-chemical (abiotic) processes (e.g. clay and clay-humus domains).

• Soil quality effects
  – Soil structure and erosion resistance
  – Crop emergency
  – Infiltration
Organic matter increases soil aggregates
Soil pH

- Determined by a pH electrode inserted into a soil:water suspension (1:1 or 1:2.5)
- Affects availability of plant nutrients and activity of beneficial soil microbes
- Associated with ion toxicity
- CEC declines with decreasing pH

(Brady and Weil, 2008)
Organic matter content

• Nutrient cycling
• Pesticide and water retention (e.g. the water-holding capacity of sandy soils is improved by adding stable organic amendments)
• Soil structure
• Biological effects
  – Food for soil organisms
  – Influence the type and diversity of soil
Electrical conductivity (EC)

- Measuring salinity (indirect measurement of salt content)
- Expressed in terms of deciSiemens per meter (ds/m = mmho/cm)
- Soil quality effects
  - Crop growth
  - Soil structure
Available nutrients

- Mineralizable nitrogen
- Available phosphorus (e.g. Olsen P, Mehlich 3)
- Available potassium (e.g. Mehlich 3)
- Soil quality effects
  - Capacity to support crop growth
  - Environmental hazard
Microbial biomass

- Biological activity
- Nutrient cycling
- Capacity to degrade pesticides

Microflora and earthworms dominate the life of most soils.

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Number$^a$</th>
<th>Biomass$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per m$^2$</td>
<td>Per gram</td>
</tr>
<tr>
<td>Microflora</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacteria and Archaea</td>
<td>$10^{14}$–$10^{15}$</td>
<td>$10^9$–$10^{10}$</td>
</tr>
<tr>
<td>Actinomycetes</td>
<td>$10^{12}$–$10^{13}$</td>
<td>$10^7$–$10^8$</td>
</tr>
<tr>
<td>Fungi</td>
<td>$10^6$–$10^8$ m</td>
<td>$10$–$10^3$ m</td>
</tr>
<tr>
<td>Algae</td>
<td>$10^9$–$10^{10}$</td>
<td>$10^4$–$10^5$</td>
</tr>
<tr>
<td>Fauna</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protozoa</td>
<td>$10^7$–$10^{11}$</td>
<td>$10^2$–$10^6$</td>
</tr>
<tr>
<td>Nematodes</td>
<td>$10^5$–$10^7$</td>
<td>$1$–$10^2$</td>
</tr>
<tr>
<td>Mites</td>
<td>$10^3$–$10^6$</td>
<td>$1$–$10$</td>
</tr>
<tr>
<td>Collembola</td>
<td>$10^3$–$10^6$</td>
<td>$1$–$10$</td>
</tr>
<tr>
<td>Earthworms</td>
<td>$10$–$10^3$</td>
<td></td>
</tr>
<tr>
<td>Other fauna</td>
<td>$10^2$–$10^4$</td>
<td></td>
</tr>
</tbody>
</table>

(Brady and Weil, 2008)