Understanding of plant-soil health for sustainable banana production

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Dr. Agustin Molina
Bioversity International
Outline

Concepts

Agriculture
Soil health model
  Indicators
  Soil functions
  Constraints
  Management practices

Examples

Example 1: Soil amendments
Example 2: Disease suppression
Agriculture production characteristics

**Industrial agriculture**
- Ease of management important
- Monocultures
- Crops and cultivars selected for markets
- Intensive inputs

**Subsistence agriculture**
- Management complex
- Diversity of crops
- Crops and cultivars selected for taste and replanting
- Low input
What is constraining banana production?

Potential production

Actual production
Model for soil health

Soil indicators
- Physical
- Chemical
- Biological

Constraints
- Inherent
- Induced

Soil functions
- Structural
- Nutritional
- Hydrological
- Pathological
- Toxicological

Management
- Soil
- Plant

Enviro-impact
- Nutrient loss
- Sediment loss
- Chemical loss

Production
- Yield
- Economics
- Disease

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Model for soil health

Soil indicators
• Physical
• Chemical
• Biological
Physical soil health indicators

**Inherent constraints**

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt</td>
<td>24%</td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>52%</td>
<td></td>
</tr>
</tbody>
</table>

**Induced constraints**

- Common constraints: low water and nutrient holding capacity, acidity, low organic matter, hard setting, compaction.
- Moderate bulk density, giving moderate aeration and root penetration.

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### Chemical soil health indicators

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Unit(s)</th>
<th>{0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0}</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (1:5 Water)</td>
<td></td>
<td>4-9</td>
<td>Slightly acid 1.0-5.5 Slightly alkaline 8.0-9.0</td>
</tr>
<tr>
<td>Electrical Conductivity</td>
<td>dS/m</td>
<td>0-1</td>
<td>Good</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/kg</td>
<td>0-10</td>
<td>Good</td>
</tr>
<tr>
<td>Nitrate Nitrogen</td>
<td>mg/kg</td>
<td>0-70</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Phosphorus (Colwell)</td>
<td>mg/kg</td>
<td>0-80</td>
<td>High</td>
</tr>
<tr>
<td>Phosphorus Buffer Index (PDI-Col)</td>
<td></td>
<td>0-350</td>
<td>High</td>
</tr>
<tr>
<td>Calcium (Amm-acet.)</td>
<td>Meq/100g</td>
<td>0-10</td>
<td>Low</td>
</tr>
<tr>
<td>Potassium (Amm-acet.)</td>
<td>Meq/100g</td>
<td>0-3</td>
<td>High</td>
</tr>
<tr>
<td>Magnesium (Amm-acet)</td>
<td>Meq/100g</td>
<td>0.1-1</td>
<td>Low</td>
</tr>
<tr>
<td>Sodium (Amm-acet.)</td>
<td>Meq/100g</td>
<td>0.01-0.1</td>
<td>Good</td>
</tr>
<tr>
<td>Cation Exchange Cap.</td>
<td>Meq/100g</td>
<td>0-5</td>
<td>Low</td>
</tr>
<tr>
<td>Aluminium Saturation</td>
<td>%</td>
<td>0-20</td>
<td>Good</td>
</tr>
<tr>
<td>Copper (DTPA)</td>
<td>mg/kg</td>
<td>0.1-1</td>
<td>Good</td>
</tr>
<tr>
<td>Iron (DTPA)</td>
<td>mg/kg</td>
<td>0.1-1</td>
<td>Good</td>
</tr>
<tr>
<td>Manganese (DTPA)</td>
<td>mg/kg</td>
<td>1-10</td>
<td>Good</td>
</tr>
<tr>
<td>Zinc (DTPA)</td>
<td>mg/kg</td>
<td>0.1-1</td>
<td>Good</td>
</tr>
<tr>
<td>Sulphate Sulfur (MCP)</td>
<td>mg/kg</td>
<td>0-50</td>
<td>Low</td>
</tr>
</tbody>
</table>
# Biological soil health indicators

<table>
<thead>
<tr>
<th>Soil Nematode Community</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Nematode Population</strong></td>
<td>343</td>
</tr>
<tr>
<td><strong>Bacterial Feeding Nematodes</strong></td>
<td>111</td>
</tr>
<tr>
<td><strong>Fungal Feeding Nematodes</strong></td>
<td>57</td>
</tr>
<tr>
<td><strong>Plant Parastic Nematodes</strong></td>
<td>114</td>
</tr>
<tr>
<td><strong>Predator &amp; Omnivore Nematodes</strong></td>
<td>61</td>
</tr>
</tbody>
</table>

**Nematode comments:**

A good balance of nematodes that feed on organic matter decomposers, roots and other soil organisms. Suggests that carbon is entering the soil food web from multiple sources and being recycled.

<table>
<thead>
<tr>
<th>Biochemical</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Labile Carbon</strong></td>
<td>0.30 g/kg</td>
</tr>
<tr>
<td><strong>Microbial Activity (FDA)</strong></td>
<td>25.3 mg/kg/hr</td>
</tr>
<tr>
<td><strong>Cellulose degradation (β-Glucosidase)</strong></td>
<td>17.9 μg pNP/g/hr</td>
</tr>
<tr>
<td><strong>Organic Carbon</strong></td>
<td>1.8 %</td>
</tr>
</tbody>
</table>

| Nematode diversity | High to moderate nematode diversity |
| Structure Index | Good to moderate soil food web structure and activity of predators |
| Enrichment Index | Balanced levels of nutrients available to the soil food web |
| Endoparasitic nematodes | No plant-parasitic nematodes feeding within the roots of bananas |
| Labile Carbon | Low to moderate active soil carbon levels and low to moderate biological activity |
| Microbial Activity (FDA) | Moderate to low biological activity |
| Cellulose degradation (β-Glucosidase) | Moderate to low cellulose degradation by microorganisms |
| Organic Carbon | Moderate carbon levels |
Soil biology

~800 million bacteria
Soil biology

~800,000 fungal forming units = ~42 m of fungal threads (hyphae)
Soil biology

~8 million actinomycetes (bacteria with threads like fungi)
Soil biology

Up to ~1,300 nematodes
~137 mites

Soil biology
Soil biology

~1 ant
Soil biology indicators — “diagnostic”

Soil nematode community structure

- Plant-parasitic nematode
- Fungal-feeding nematode
- Bacterial-feeding nematode
- Predatory nematode

Soil biochemical activity

- KMnO₄ reducable C
- Fluorescein diacetate
- β-glucosidase
Soil biology indicators – “explanatory”

Molecular methods
- e.g. TRFLP,
- 454 pyrosequencing

Physiological profiling
- e.g. Biolog ecoplates

Traditional methods
- e.g. Selective media
Model for soil health

Soil indicators
- Physical
- Chemical
- Biological

Soil functions
- Structural
- Nutritional
- Hydrological
- Pathological
- Toxicological
Soil health functions

Agricultural soil functions = production

- Support plant growth
- Supply nutrients
- Supply water
- Suppress pests & disease
- Soil biodiversity
- Filter toxins

Soil structural stability
- Store & Recycle nutrients
- Store water

Ecosystem soil functions = Enviro-impact

- Remove toxins and heavy metals
- Regulate green house gases

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Linking soil indicators with soil functions

**Soil health indicators**

**Physical**
- ↑ Bulk density

**Chemical**
- ↑ Nitrate-N
- ↓ Organic C

**Biological**
- ↓ Diversity
- ↑ Parasites

**Soil functions**

**Outputs**

- Structure
- Nutrition
- Water
- Pests & disease
- Toxins
- GHG

**Production**

**Enviro-impact**

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Linking soil indicators with soil functions

Soil health indicators
- Physical
  - Bulk density
- Chemical
  - Nitrate-N
- Biological
  - Organic C
  - Diversity
  - Parasites

Soil functions
- Structure
- Nutrition
- Water
- Pests & disease
- Toxins
- GHG
- Production
- Enviro-impact

Outputs
- Good
- Caution
- Constrained
<table>
<thead>
<tr>
<th>Cause</th>
<th>Compaction</th>
<th>Tillage</th>
<th>Nutrient overuse</th>
<th>Low biodiversity</th>
<th>Pesticide use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Erosion</td>
<td>Low organic C</td>
<td>Erosion</td>
<td>Acidification</td>
<td>Economic</td>
</tr>
<tr>
<td>Enviro-impact</td>
<td>Erosion</td>
<td>N leaching</td>
<td>Acidification</td>
<td>Poor disease suppression</td>
<td>Poor nutrient recycling</td>
</tr>
<tr>
<td>Economic</td>
<td>Low organic C</td>
<td>P loss</td>
<td>Acidification</td>
<td>Poor disease suppression</td>
<td>Poor nutrient recycling</td>
</tr>
<tr>
<td>Economic</td>
<td>Acidification</td>
<td>Economic</td>
<td>Pests &amp; pathogens</td>
<td>Economic</td>
<td>Economic</td>
</tr>
</tbody>
</table>
Model for soil health

- Soil indicators
  - Physical
  - Chemical
  - Biological

- Constraints
  - Inherent
  - Induced

- Soil functions
  - Structural
  - Nutritional
  - Hydrological
  - Pathological
  - Toxicological

- Enviro-impact
  - Nutrient loss
  - Sediment loss
  - Chemical loss

- Production
  - Yield
  - Economics
  - Disease

- Management
  - Soil
  - Plant

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# Linking management with soil functions

<table>
<thead>
<tr>
<th>Practice</th>
<th>Soil Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>Structure</td>
</tr>
<tr>
<td>Pre-plant</td>
<td>Tillage</td>
</tr>
<tr>
<td></td>
<td>Fallow crop</td>
</tr>
<tr>
<td></td>
<td>Organic amendment</td>
</tr>
<tr>
<td>Post-plant</td>
<td>Fertiliser</td>
</tr>
<tr>
<td></td>
<td>Insecticide</td>
</tr>
<tr>
<td></td>
<td>Herbicide</td>
</tr>
<tr>
<td></td>
<td>Biofertiliser</td>
</tr>
<tr>
<td></td>
<td>Organic amendment</td>
</tr>
<tr>
<td></td>
<td>Cover crop</td>
</tr>
</tbody>
</table>

**Legend:**
- **Positive**
- **Caution**
- **Unsure or no effect**
Example 1: Soil amendments in bananas

• **Constraints:**
  – **Inherent:** dermosol (28% sand, 42% silt, 30% clay)
  – **Induced:** compaction, poor drainage, weak aggregate stability, low organic C, low soil biological diversity.

• **Practices:**
  – Amendments:
    • Mill ash
    • Mill mud
    • Compost
    • Organic matter
    • Untreated / bare

• **Indicators**
  – **Agronomic:** Bunch size
  – **Physical:** bulk density, infiltration, aggregate stability
  – **Chemical:** pH, EC, Labile C
  – **Biological:** Nematode community
Example 1: Soil amendments in bananas

- Grass Hay
- Mill Mud
- Bare soil
- Banana Trash
- Mill Ash
- Bedminster Compost

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Example 1: Soil amendments in bananas

Agronomic measurements: Banana bunch size

Diagram showing the effect of different soil amendments on finger number per bunch. The amendments include Mill ash, Compost, Hay + trash, Mill mud, and Untreated. The graph compares the finger number per bunch between the plant crop and the 1st and 2nd ratoon.
Example 1: Soil amendments in bananas

- Mill ash and organic matter had significantly lower bulk density relative to untreated soil.
- Mill ash had significantly increased water infiltration relative to untreated soil.
Example 1: Soil amendments in bananas

Labile C content in soils

- All treatments significantly increased labile C by the end of the experiment.
Example 1: Soil amendments in bananas

Proportion of nematodes belonging to trophic groups at the termination of the experiment.

![Graph showing nematode feeding groups (%) for different treatments including Mill ash, Compost, Hay + trash, Mill mud, and Untreated. The graph uses colors and labels to indicate the proportion of different trophic groups.](image)

- **Mill ash**
  - Plant-parasites: a
  - Bacterivores: ns
  - Fungivores: ns
  - Predatory & Omnivores: a

- **Compost**
  - Plant-parasites: a
  - Bacterivores: ns
  - Fungivores: ns
  - Predatory & Omnivores: ab

- **Hay + trash**
  - Plant-parasites: b
  - Bacterivores: ns
  - Fungivores: ns
  - Predatory & Omnivores: a

- **Mill mud**
  - Plant-parasites: a
  - Bacterivores: ns
  - Fungivores: ns
  - Predatory & Omnivores: b

- **Untreated**
  - Plant-parasites: a
  - Bacterivores: ns
  - Fungivores: ns
  - Predatory & Omnivores: b
Example 1: Soil amendments in bananas

- 1\textsuperscript{st} banana crop production was stimulate by “fast” acting amendments.
- 2\textsuperscript{nd} banana crop production constraints were masked by high fertiliser applications.
- 3\textsuperscript{rd} banana crop production was greatest by overcoming physical soil constraints.
- Overcoming physical constraints also increased the antagonistic potential of the soil and reduced plant-parasitic nematodes.
Example 2: Disease suppression

- **Constraints:**
  - **Inherent:** Ferrosol (49% sand, 26% silt, 25% clay)
  - **Induced:** compaction, low CEC, acidity, low soil biological diversity, *Fusarium* wilt.

- **Practices:**
  - Reduction in inoculum
  - Increased plant tolerance / reduced plant stress
  - Increased antagonistic organisms

- **Indicators**
  - **Agronomic:** Bunch weight, bunches harvested
  - **Physical:** bulk density, infiltration, aggregate stability
  - **Chemical:** pH, EC, Labile C, available nutrients
  - **Biological:** Nematode community, soil enzyme activity
Example 2: Disease suppression

**Disease suppression**

In spite of the presence of a pathogen and susceptible host, disease does not occur.

**Specific suppression**

Depends on a single organism with the ability to antagonise a specific pathogen

e.g. Trichoderma sp.

**General suppression**

The capacity of the total microbial biomass to suppress growth or activity of pathogens

e.g. disease suppressive compost in some crops.
Soil ecology facts

• 1-10% of soil bacteria are cultivable. “the great plate anomaly”, (Amann et al 1995)

• The zone with one of the highest concentrations of bacteria in the soil is around the roots. *The rhizosphere*. (Doornbos et al 1995)

• 30-40% of the carbon fixed by plants for the atmosphere through photosynthesis leaks through the roots. (Bais et al 2006).

• Up to 35% of the soil organisms showed antagonistic capacity to inhibit growth of pathogens in vitro (Berg et al 2002, 2006)
Example 2: Disease suppression

- Suppression = $f$ (Environment + Management (soil + crop))
Example 2: Disease suppression

Management options and practices

Broad focus on general suppression

Research Focus

Specific suppression

Time & investment of research

- Indicators of disease suppression
- Diagnostic soil health indicators
- Explanatory soil health indicators
- Identification of suppressive mechanism

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Example 2: Disease suppression

<table>
<thead>
<tr>
<th>Hygiene</th>
<th>Practice</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>aspirational</strong></td>
</tr>
<tr>
<td></td>
<td>Removal of crop residue</td>
<td>X</td>
</tr>
<tr>
<td>Plant management</td>
<td>Plant defence activation chemical</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Plant growth regulator</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>De-suckering (monthly)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Potassium silica</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Foliar fertilising (May-August)</td>
<td>X</td>
</tr>
<tr>
<td>Soil management</td>
<td>Interplant ground cover</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Bare interplant space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Additional N as chicken manure</td>
<td></td>
</tr>
</tbody>
</table>
Example 2: Disease suppression
Example 2: Disease suppression

Management options and practices

- Broad focus on general suppression

Research Focus

- Specific suppression

Time & investment of research

- Indicators of disease suppression
- Diagnostic indicators
- Explanatory indicators
- Identification of antagonists

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# Example 2: Disease suppression

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plant showing no symptoms or yellowing</td>
</tr>
<tr>
<td>2</td>
<td>Plant showing slight streaking and /or yellowing of lower leaves</td>
</tr>
<tr>
<td>3</td>
<td>Plant showing streaking and/or yellowing of majority of lower leaves and/or some symptoms on younger leaves</td>
</tr>
<tr>
<td>4</td>
<td>Plant showing extensive streaking and/or yellowing of most or all of the leaves.</td>
</tr>
<tr>
<td>5</td>
<td>Mother plant dead sucker alive</td>
</tr>
<tr>
<td>6</td>
<td>Mother plant and sucker dead</td>
</tr>
</tbody>
</table>
Example 2: External symptoms

**Rating 1-6**

Foc symptoms (1-6)

Plants showing symptoms (%)

**Plants showing symptoms (%)**

Date:

Nov-10  Feb-11  Jun-11  Sep-11  Dec-11  Apr-12  Jul-12

Legend:

A  B  C  D

Departm
### Example 2: Internal symptoms

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>o vascular discoloration in pseudostem</td>
</tr>
<tr>
<td>2</td>
<td>solated points of discoloration in vascular tissue of the pseudostem</td>
</tr>
<tr>
<td>3</td>
<td>Discoloration of up to one third of vascular tissue of the pseudostem</td>
</tr>
<tr>
<td>4</td>
<td>Discoloration of between one third and two thirds of the vascular tissue of the pseudostem</td>
</tr>
<tr>
<td>5</td>
<td>Discoloration of greater than two thirds and of vascular tissue of the pseudostem</td>
</tr>
<tr>
<td>6</td>
<td>otal discoloration of vascular tissue of the pseudostem</td>
</tr>
</tbody>
</table>
Example 2: Internal symptoms
Example 2: Banana production

Bunches produced (%)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunches produced (%)</td>
<td>a</td>
<td>b</td>
<td>b</td>
<td>b</td>
</tr>
</tbody>
</table>

Bunch weight (kg)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest date</td>
<td>2011-11-03</td>
<td>2011-12-23</td>
<td>2012-02-01</td>
<td>2012-04-01</td>
</tr>
<tr>
<td>Bunch weight (kg)</td>
<td>a</td>
<td>b</td>
<td>b</td>
<td>b</td>
</tr>
</tbody>
</table>

Cumulative bunch harvest (kg)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative bunch weights (kg)</td>
<td>0.0</td>
<td>100.0</td>
<td>200.0</td>
<td>300.0</td>
</tr>
</tbody>
</table>
Example 2: Disease suppression

Management options and practices

- Broad focus on general suppression
- Specific suppression

- Research Focus

- Time & investment of research
  - Indicators of disease suppression
  - Diagnostic indicators
  - Explanatory indicators
  - Identification of antagonists
Example 2: Disease suppression

Microbial activity

Cellulose degradation

Bacterial - fungal ratio
Example 2: Disease suppression

Management options and practices

- Broad focus on general suppression
- Specific suppression

Time & investment of research

- Indicators of disease suppression
- Diagnostic indicators
- Explanatory indicators
- Identification of antagonists

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Example 2: Disease suppression –
Biolog Physiological Microbial Community Profiling
Example 2: Disease suppression — Biolog Physiological Microbial Community Profiling

Discriminant analysis

Vectors:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D_Glucosaminic_Acid</td>
<td>1.103</td>
<td>0.081</td>
<td>0.013</td>
</tr>
<tr>
<td>Pyruvic_Acid_Methyl_Ester</td>
<td>-2.598</td>
<td>1.320</td>
<td>1.232</td>
</tr>
<tr>
<td>L_Arginine</td>
<td>3.470</td>
<td>-0.930</td>
<td>0.560</td>
</tr>
<tr>
<td>Cyclodextrin</td>
<td>4.124</td>
<td>2.714</td>
<td>1.653</td>
</tr>
<tr>
<td>N_Acetyl_D_Glucosamine</td>
<td>-1.028</td>
<td>-1.225</td>
<td>0.611</td>
</tr>
<tr>
<td>D_Glucosaminic_acis</td>
<td>-0.026</td>
<td>-0.831</td>
<td>-0.980</td>
</tr>
<tr>
<td>Glycogen</td>
<td>1.968</td>
<td>1.400</td>
<td>0.624</td>
</tr>
<tr>
<td>D_Galactonic_Acid_Lactone</td>
<td>0.504</td>
<td>0.008</td>
<td>0.063</td>
</tr>
</tbody>
</table>

True Group

<table>
<thead>
<tr>
<th>Decision</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100.00</td>
<td>0.00</td>
<td>16.67</td>
<td>0.00</td>
</tr>
<tr>
<td>B</td>
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</table>

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Example 2: Disease suppression - L-arginine

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Example 2: Disease suppression - Correlation L-arginine v external symptoms

![Graph showing the correlation between L-arginine (abs) and external symptoms (1-6). The graph includes a regression line with an $R^2$ value of 0.49.]
Model for soil health

Constraints
- Inherent
- Induced

Soil indicators
- Physical
- Chemical
- Biological

Soil functions
- Structural
- Nutritional
- Hydrological
- Pathological
- Toxicological

Management
- Soil
- Plant

Enviro-impact
- Nutrient loss
- Sediment loss
- Chemical loss

Production
- Yield
- Economics
- Disease
Conclusion

• Soil health can be used to improve banana productivity and reduce the enviro-impact by using a model that links soil indicators, soil functions, constraints and management practices.

• Identifying soil constraints means that management practices can be targeted to overcome the limiting factors and indicators used to ensure desirable changes are occurring.

• Suppression of soil borne disease, such as *Fusarium* wilt, can be achieved by overcoming soil constraints and shifting the soil biology to increase indigenous antagonistic organisms.
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  • Conference organisers
  • Bioversity International
  • Taiwan Banana Research Institute
Soil health interactions

Physical soil properties
- Soil structure
- Water supply

Solid soil particles
- Air spaces

Physical soil functions

Chemical soil properties
- Nutrient availability

Chemical soil functions

Organic matter

Biological soil properties

Biological soil functions
- Pests & disease suppression
- Toxin degradation

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Normalising indicators

Constraining production

"Less is better" e.g. Na

"More is better" e.g. K

"Optimum" e.g. Soil pH

Constraining production

Constraint score

Constraint score

Constraint score

Na (meq/100)

K (meq/100)

pH

No constraints on production

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Agricultural production characteristics

- Bananas
- Wheat
- Citrus
Physical constraints

- Induced and inherent soil constraints.
Linking soil indicators with soil functions

Soil health indicators
- Physical
- Chemical
- Biological

Soil functions
- Structure
- Nutrition
- Water
- Pests & disease
- Toxins
- GHG

Production

Enviro-impact
Constraints to healthy banana soils

Banana production in Australia is an intensive, mechanised industry.
Agricultural soil ecology

Photosynthesis

\[ \text{CO}_2 + \text{Sunlight} \rightarrow \text{Organic matter} \]

Parasitism

Mutualism

Undecomposed organic matter
Linking soil indicators, functions & practices

Soil health indicators
- Physical
- Chemical
- Biological

Soil functions
- Structure
- Nutrition
- Water
- Pests & disease
- Toxins
- GHG

Management practices
- Soil
  Amendments, tillage, vegetation cover, fertiliser, pesticides
- Plant