Measuring Natural Capital on Agricultural Farm

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What is Natural Capital?

– Stock of natural assets that provides natural resource inputs and environmental services for economic production.

– Components of natural capital:
  (a) non-renewable resources – e.g., minerals and fuels
  (b) renewable resources – e.g., water, soil, forest and vegetation
  (c) environmental/ecosystem services – e.g., air and water filtration, pollinations for crops, habitat for fisheries and wildlife
Why natural capital accounting (NCA)?

- Inadequate information on natural capital
- Poor management decision on farm practices
- Unsustainable use of natural capital
- Long-term lower productivity of farm

- Rich information on natural capital
- Improved management decision on farm practices
- Sustainable use of natural capital
- Long-term higher productivity of farm

*Necessity of NAC: if we can’t measure it, we can’t manage it.*
## Stocks and Flows of Benefits of Natural Capital

<table>
<thead>
<tr>
<th>Stocks</th>
<th>Flows of benefits and services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil organic matter/ soil carbon</td>
<td>Soil nutrient, soil fertility</td>
</tr>
<tr>
<td>Subsoils</td>
<td>Minerals and fuels</td>
</tr>
<tr>
<td>Water resources (fresh, ground water and marine)</td>
<td>Water consumption and water use in agricultural production</td>
</tr>
<tr>
<td>Forest and vegetation</td>
<td>Forest timber, fibre resources</td>
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<tr>
<td>Ecosystem assets</td>
<td>Air and water filtration, flood protection, pollinations for crops, habitat for fisheries and wildlife</td>
</tr>
</tbody>
</table>
NCA Model: An example for Beef Cattle Farm
*(Stock and Flow benefits)*

On-farm impacts: Soil erosion, soil quality deterioration, reduction in soil and vegetation cover

Off-farm impacts: Pollution, rising water table, carbon emission, biodiversity loss
Objectives of the Study

• To account for natural capital in the context of agricultural production processes;

• To assess the impact of agricultural production on the natural resource base and surrounding environment, and how it will affect the change in stock and flows of natural capital;

• To estimate the performance of agricultural farming activities in relation to natural resource use to obtain an indication of how efficiently and sustainably natural capital is being used in the agricultural sector.
Table 1. Candidate indicators/variables and attributes for natural capital accounting

<table>
<thead>
<tr>
<th>Candidate indicators</th>
<th>Temporal variability</th>
<th>Spatial variability</th>
<th>Measurability (measurable for management)</th>
<th>Implication for productivity</th>
<th>Management options and (cost)</th>
<th>On/off farm effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil health indicator</td>
<td>Very slow</td>
<td>High</td>
<td>Easy/complex</td>
<td>High</td>
<td>Many (Low)</td>
<td>On farm</td>
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<tr>
<td>Soil EC</td>
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<tr>
<td>Organic carbon</td>
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<tr>
<td>Soil pH</td>
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<tr>
<td>Soil erosion</td>
<td>Slow</td>
<td>Low</td>
<td>Easy</td>
<td>Low</td>
<td>Few (High)</td>
<td>On farm</td>
</tr>
<tr>
<td>Soil /land cover</td>
<td>Slow</td>
<td>Low</td>
<td>Easy</td>
<td>Low</td>
<td>Many (Low)</td>
<td>On farm</td>
</tr>
<tr>
<td>Water use (surface/ground water)</td>
<td>Depends on climate</td>
<td>Low</td>
<td>Easy</td>
<td>High</td>
<td>Many (Low)</td>
<td>On farm</td>
</tr>
<tr>
<td>Water table (flow and scarcity)</td>
<td>Depends on climate</td>
<td>High</td>
<td>Easy</td>
<td>High</td>
<td>Scare (High)</td>
<td>Off farm</td>
</tr>
<tr>
<td>Water quality</td>
<td>Slow and fast</td>
<td>Low and High</td>
<td>Easy</td>
<td>High</td>
<td>Few (High)</td>
<td>On and off farm</td>
</tr>
<tr>
<td>Carbon</td>
<td>Very slow</td>
<td>Low</td>
<td>Complex</td>
<td>Low</td>
<td>Very few (High)</td>
<td>On and off farm</td>
</tr>
<tr>
<td>Vegetation (on farm)</td>
<td>Slow</td>
<td>Low</td>
<td>Easy</td>
<td>Low</td>
<td>Many (Low)</td>
<td>On farm</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Very slow</td>
<td>Low</td>
<td>Complex</td>
<td>Low</td>
<td>Many (Low)</td>
<td>On and off farm</td>
</tr>
<tr>
<td>Energy use (cost/efficiency)</td>
<td>Depends on farm</td>
<td>Depends on farm</td>
<td>Easy</td>
<td>High</td>
<td>Many (Low)</td>
<td>On farm</td>
</tr>
<tr>
<td>Pollution</td>
<td>Slow</td>
<td>Low</td>
<td>Complex</td>
<td>Low</td>
<td>Few (High)</td>
<td>On and off farm</td>
</tr>
</tbody>
</table>
Conceptual framework for Measuring Soil Natural Capital

• Luenberger soil-quality indicator (Hailu and Chambers, 2012)
• Static model: variation across space – can be used when comparing soil quality across farms or regions
• Modify the static model to a time variant, dynamic model
• The dynamic model can be used to measure change in soil quality across time.
Conceptual Framework: Soil Natural Capital Indicator

Assume that $s = \text{vector of } L \text{ soil quality attributes}$
$x = \text{vector of } N \text{ ‘usual’ production inputs}$
$y = \text{vector of } M \text{ outputs}$

Production technology function

$T = \{(s, x, y): (s, x) \text{can produce } y\}$

The production function can be characterised by a directional distance function:

$$D(s, x, y: g_s, g_x, g_y) = \sup\{\theta: (\Delta s - \theta \cdot g_s, x - \theta \cdot g_x, y + \theta \cdot g_y) \in T, \theta \in \mathbb{R}_+\}$$

Where, $g_s \in \mathbb{R}_+^L, g_x \in \mathbb{R}_+^N, g_y \in \mathbb{R}_+^M$

To define a soil natural capital indicator, directional vectors for both inputs ($g_x$) and outputs ($g_y$) are set to zero:

$$D(s, x, y: g_s) = \sup\{\beta: (\Delta s - \beta \cdot g_s, x, y) \in T, \beta \in \mathbb{R}_+\}$$
Conceptual Framework: Soil Natural Capital Indicator

Consider two time variant soil quality vectors $s^t$ and $s^{t+1}$, which are vectors of changes of soil quality attributes observed on a farm over two time periods, $t$ and $t+1$.

To compare soil vector $s^{t+1}$ against $s^t$ using isoquant $I_{s0}^t$ as the frontier, the soil quality indicator for a production unit can be constructed as follows:

$$SQ^t (s^t, s^{t+1}, x_0^t, y_0^t; g_s) = D_{s0}^t (s^{t+1}, x_0^t, y_0^t; g_s) - D_{s0}^t (s^t, x_0^t, y_0^t; g_s)$$

This indicator measures the difference between the distances of two soil quality vectors $(s^t, s^{t+1})$ from the production frontier (isoquant) $I_{s0}^t$, where the distances are measured in the direction of $g_s$. 
Conceptual Framework: Soil Natural Capital Indicator

If $D_{s0}^t(s^{t+1}, x_0^t, y_0^t; g_s) < D_{s0}^t(s^t, x_0^t, y_0^t; g_s)$,

Then $s^{t+1}$ can be treated as improvement in soil quality

Farm has improved its soil natural capital (represented by the soil quality vector) while producing a given level of output $y_0^t$ in conjunction with a variable input usage of $x_0^t$.

If we want to compare soil quality vector $s^{t+1}$ against $s^t$ using this new frontier $I_{si}^{t+1}$, then the soil quality indicator can be written as:

$$SQ^{t+1}(s^t, s^{t+1}, x_i^{t+1}, y_i^{t+1}; g_s) = D_{si}^{t+1}(s^{t+1}, x_i^{t+1}, y_i^{t+1}; g_s) - D_{si}^{t+1}(s^t, x_i^{t+1}, y_i^{t+1}; g_s)$$
Graphical Presentation: Soil Natural Capital Indicator

\[ \Delta S_{2}^{t+j} \]

\[ \Delta S_{1}^{t+j} \]
Conceptual Framework: Soil Natural Capital Indicator

The soil natural capital indicator can be derived based on the average value of two soil quality indicators, $SQ^t(s^t, s^{t+1}, x_0^t, y_0^t; g_s)$ and $SQ^{t+1}(s^t, s^{t+1}, x_i^{t+1}, y_i^{t+1}; g_s)$ (Hailu and Chambers, 2012).

In this case both isoquant, $I_{s0}^t$ and $I_{si}^{t+1}$ are to be considered as the production frontier.

The soil natural capital indicator:

$$SNCI \left( s^t, x_0^t, y_0^t, s^{t+1}, x_i^{t+1}, y_i^{t+1}; g_s \right) =$$
$$-\frac{1}{2}[SQ^t(s^t, s^{t+1}, x_0^t, y_0^t; g_s) + SQ^{t+1}(s^t, s^{t+1}, x_i^{t+1}, y_i^{t+1}; g_s)]$$
Conceptual Framework: Soil Natural Capital Indicator

- This dynamic soil quality indicator can signal whether a farm has improved its soil quality between period $t$ and $t+1$.
- If the value of the soil natural capital indicator is zero, there is no change in soil quality between these two periods.
- The positive value of this indicator indicates an improvement in soil quality.
- Soil quality declines if the value of the indicator is less than zero.
<table>
<thead>
<tr>
<th>Input data</th>
<th>Output data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture (area, growth)</td>
<td>Volume of sale (number of cattle)</td>
</tr>
<tr>
<td>Land for fodder crops</td>
<td>Sale price of beef cattle</td>
</tr>
<tr>
<td>Soil quality data (soil pH, EC, organic carbon)</td>
<td></td>
</tr>
<tr>
<td>Fertiliser use</td>
<td>Production per hectare (‘total weight of cattle sold’ divided by ‘total land grazed’)</td>
</tr>
<tr>
<td>Other purchase inputs</td>
<td>Meat income per grazing hectare (‘proceeds from cattle sold’ divided by ‘total hectare grazed’)</td>
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<tr>
<td>On-farm vegetation</td>
<td></td>
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<tr>
<td>Energy and fuel cost</td>
<td></td>
</tr>
<tr>
<td>On and off-farm impacts</td>
<td></td>
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<tr>
<td>Numbers of beef cattle bought and purchase prices</td>
<td></td>
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</tbody>
</table>
Soil Data Collection Using on-the-go Sensors

Sensor can measure:
- pH
- Organic carbon
- Soil electrical conductivity

Supplier in Australia: CormaGeo Instruments
Conclusions

• Measuring NC on agricultural Farms very challenging
• Complex relationship between stock and flow of NC
• More methods/techniques to measure NC is needed – particularly for quantifying some environmental services (i.e., pollination for crops)
• Non-availability of farm level data