Carbon Footprinting, International Protocols & Soil Carbon

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Nature’s Bounty: Capital & Interest

Natural Capital:

Our stocks of natural materials & energy

Ecosystem Services:

The beneficial flows of goods between natural capital stocks, or stocks & humans
The Millennium Ecosystem Assessment (2005)
Sunlight: Providing Ecosystem Services for
- Carbon capture
- Transpiration

Carbon Capture

Soil Carbon Supply

\[ C_{\text{new}} = f(R, T, W, N) \]

\[ \begin{align*}
Y_R & \rightarrow C_{\text{root}} \\
Y_L & \rightarrow C_{\text{leaf}} \\
Y_S & \rightarrow C_{\text{shoot}} \\
Y_C & \rightarrow C_{\text{fruit}} \\
C_{\text{litter}} & \end{align*} \]
Carbon Capture

Carbon Supply to Soil
We consider the farming practices of some five hundred millions who have unimpaired inheritance acquired through 4000 years.

We were amazed how these nations are conserving and utilising their natural resources and surprised at the returns they were getting from their fields.

F.H. King 1911
Lumber and herbage for green manure and compost, and the ash of the fuel and lumber finds its way ultimately to the field.

Manure of all kinds, human and animal, is religiously saved and applied to the fields in a manner which secures an efficiency far above our own.

F.H. King 1911

• Supporting, Provisioning & Regulating Services
Boiling water has been adopted to safeguard against deadly disease germs where the wastes of the body are taken back to the field.

The tea industry had its foundation in the need for something to render boiled water palatable for drinking purposes.

F.H. King 1911

- Regulating & Cultural Services
Production Footprints

An emerging life-cycle assessment metric
Footprints & Super-Market Chains - The Gate-Keepers

“...information about how green certain items are compared to others” (TESCO™ Web site, 2008)

A key role is played by NGOs like the Carbon Trust, WWF, Greenpeace, Food Ethics Council, ...

Sir Terry Leahy, ex-CEO of TESCO: “...we will begin the search for a universally accepted and commonly understood measure of the carbon footprint of every product we sell.” (January, 2007)
“Green pedicure ... these metrics bring to light the broad but subtle implications inherent to various activities. Paying for them is another matter.

“Plan A: We’ve now set ourselves the ambitious target of becoming the world’s most sustainable retailer by 2051, so that we lead the way in making a positive contribution to the environment and society.

climate change

- Extend our social and environmental commitments across the 5 Pillars of Plan A
- Help our customers cut their carbon footprint
- Reduce our operational carbon emissions by 35% and make our operations carbon neutral
- Help our suppliers cut their carbon footprint

“You asked us to find ways to make it easy to identify the carbon footprint of your shopping. So in 2008, we joined forces with the Carbon Trust to test a new label on some of our products.”
**Step 1:** Quantify your footprint

**Step 2:** Assess risks & opportunities

- **Risks:** Regulatory, litigation, & reputation
- **Opportunities:** Cost savings, price premiums, efficiencies, technologies

**Step 3:** Adapt your business

**Step 4:** Do it better than your rivals
Carbon Footprint at the Scale of a Product: An Apple

**Farm**
1. Growing
2. Picking

**Packhouse & coolstore**
1. Forced air cooling
2. Coolstored in field bins until packing (1 to 124 days)
3. Separation (floatation & drying)
4. Grading for quality (colour & sizing) & Phyto sanitary Inspection

**Shipping**
1. Napier to Zeebrugge (possibly via other NZ port)
2. Container unloaded to truck
3. UK distribution centre
   - Possible repacking
   - Coolstore
4. Retail unit
5. Household Consumption

**Domestic Apple Market**
1. Fertilisers
2. Pesticides
3. Fungicides
4. Insecticides
5. Seasonal workers
6. Frost protection

**Process (apples for juice)**
1. Natural cooling
2. Packing in 400kg field bins

**NZ Port**
1. Refrigerated container plugged in

**Life Cycle Analysis**

Sources: GHG footprinting of apples project: Hume et al., unpublished, 2009
The Carbon Footprint for New Zealand Braeburn Apples

(1.2 kg CO$_2$-e kg$^{-1}$ apple consumed in the UK)
Within-Orchard Carbon Footprint

(Total: 0.043 kg CO$_2$-e kg$^{-1}$ apple leaving orchard)
Orchard Operations: Two Groups of Reduction Options

- Reduce the environmental footprint
- Increase productivity

'Eco-efficiency' is the combination of both:

kg apples ha\(^{-1}\) / GHG ha\(^{-1}\)
Orchard Operations: A Hot-spot - Harvesting

- New Hydraladder designs: Four people & solar cells
- Use of dwarfing rootstocks & canopy management

Some 16-50 Hydraladder hours ha$^{-1}$
Orchard Operations: Hot-spot - Diesel Usage

- Application of fertilizers & pesticides
- Mowing
- Collecting & spreading mulch, compost & prunings
- Irrigation & frost protection

↓

Use black-spot resistant cultivars

Multi-task with orchard operations

Improve tractor-use efficiency (idling, speed, tyre pressure, PTO matching ...)

Fuel-efficient tractors
Substitute with 80/20 diesel/biodiesel
Orchard Operations: Increase Productivity

- Improve management – “Learn from the Best”
- Cultivars with a higher harvest index & high packout
- Change in canopy management & dwarfing varieties
- Reduce picking-related storage losses: Robots, trained labour…
Packhouse & Coolstore: Hot-spot - Electricity & Refrigerants

**Short term:**
- Refrigerants with smaller 'Global Warming Potential' (GWP)
  
  \[ \text{R404A (GWP=3300)} \rightarrow \text{R417A (GWP=1610)} \]

- Reduce refrigerant leakage from 10% to 5%
- Increase energy efficiency by 10%

**Medium term:**
- Change to refrigerants (NH\(_3\)) with 0 GWP
- Increase energy efficiency by 10% more
Shipping: Hot-Spot - Diesel

*Short-term:* Some 20% less diesel

- Use of kite-sails & new hull designs
- Route optimisation
- Increase of energy-use efficiency
- Use of 80/20 diesel/biodiesel mixture

*Medium term:*

- Export mainly to Pacific-rim markets
- Grow offshore for offshore markets
Reduction Suggestions

Reducing the Carbon Footprint

• Enhance the 'clean-green' image for eco-premiums
• Reduce input costs

Orchard phase

• Eight reduction options (5 for fuel and 3 for electricity use)
• Little capital investment to reduce the carbon footprint by ~12%
• Operating expenses reduced by ~1% (~NZ$350 ha⁻¹)

Packhouse/coolstore phase

• Two reduction options for electricity use with 'little' capital investment
• Reduce the carbon footprint by ~15%
• Reduce the electricity costs by ~NZ$1-10 per pallet-week of storage
Life Cycle Management of Production & the PAS 2050

5.6 Treatment of soil carbon change: Changes in the carbon content of the soils shall be excluded

Note 2: While it is recognized that soils play an important part in the carbon cycle there is considerable uncertainty regarding agricultural systems.

Inclusion of carbon storage in soils will be considered in future revisions.
The Dutch Horticulture Carbon Footprint Protocol

5.6 Soil carbon change in agricultural soils

PAS2050
No greenhouse gas emissions due to changes in organic matter in agricultural soils are included. In future revisions of the PAS2050, this may be added.

Recommended best practice
Equation 5.3 calculates the greenhouse gas emission due to loss of soil organic matter. Table 5.3 contains the symbols that the equations include and their units and descriptions.

\[
EM_{CO2e,SOM} = EF_{SOM}/M_{yield}
\]  

(5.3)

Table 5.3 Symbols in the Equation 5.3 for calculating greenhouse gas emission due to loss of soil organic matter

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF_{SOM}</td>
<td>Emission factor for loss of soil organic matter</td>
<td>kg CO₂e/m²</td>
</tr>
<tr>
<td>EM_{CO2e,SOM}</td>
<td>Greenhouse gas emission due to loss of soil organic matter</td>
<td>kg CO₂e/kg</td>
</tr>
<tr>
<td>M_{yield}</td>
<td>Yield mass (dry matter content of end product)</td>
<td>kg/m²</td>
</tr>
</tbody>
</table>

We estimate the emission factor for loss of soil organic matter to be 1.65 kg CO₂e/m² for conventional cropping systems (in the Netherlands), 1.1 kg CO₂e/m² for organic cropping systems, and zero for cultivated grasslands (see Blonk 2009 for further details).
5.2.4 The carbon footprint shall not include offsetting

5.3.4.2 Biogenic carbon sources & sinks shall be included. The life cycle of biomass shall be included.

5.3.4.4 Emissions & removals occurring as a result of direct land-use change shall be assessed.

Indirect land use change will be considered when an agreed procedure exists

5.3.4.5 Emissions & removals as a result of soil carbon change should be assessed

... there is on-going research to develop methodology
Good News?

Measured Carbon Change in 35 Pastoral Soils across NZ

\[ \Delta C = -106 \text{ g-C m}^{-2} \text{ yr}^{-1} \]

Schipper et al., Global Change Biology 2009
An Apple Orchard in Hawke’s Bay & a Vineyard in Marlborough

Integrated Orchard & Vineyard Systems:
No carbon conservation in the rows
Very high harvest indices
Soil Carbon: Insights & Issues

Net soil loss: 8.5 t-C ha⁻¹  
11 t-C ha⁻¹

Standing biomass after 12 years ~ 26 t-DM ha⁻¹

So DM @ 47% C

~ 12 t-C ha⁻¹

No net orchard 'loss' of C

... yet care needed for redevelopment

<table>
<thead>
<tr>
<th>Depth [m]</th>
<th>Organic – row [kg-C/m²]</th>
<th>Organic – alley [kg-C/m²]</th>
<th>Integrated – row [kg-C/m²]</th>
<th>Integrated – alley [kg-C/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.3</td>
<td>7.8±1.9</td>
<td>9.5±1.2</td>
<td>5.9±0.6</td>
<td>8.1±0.7</td>
</tr>
</tbody>
</table>

Comparing row to alley

Estimated change in soil organic stocks over 12 years [kg-C/m² year]

-0.14±0.3 0 -0.18±0.1 0
Soil Carbon Loss: Integrated Systems

Ten years under apples

Fifteen years under grapes

![Graph showing carbon loss with bars labeled a and b.](image)

-0.05 -0.15 -0.25  
Depth [cm]

Carbon [kg m⁻²]

-0.05 -0.15 -0.25  
Depth [cm]

Carbon [kg m⁻²]

-0.05 -0.15 -0.25  
Depth [cm]

Carbon [kg m⁻²]

-0.05 -0.15 -0.25  
Depth [cm]

Carbon [kg m⁻²]

Row Inter-row
Options to Sequester Carbon in Horticultural soils

Apple orchards in Hawke’s Bay

Vineyards in Marlborough
Organic: 3.8 kg-C m$^{-2}$

Integrated: 2.6 kg-C m$^{-2}$

Next-door neighbours

**Carbon Management: Soil Structure & Ecosystem Services**
Organic: 3.8 kg-C m$^2$

Integrated: 2.6 kg-C m$^2$

X-ray Tomography - Checking out Soil Health
Ecosystem Services Reliant on Soil Carbon

- Soil structure & aeration
- Nutrient cycling
- Biodiversity
- Filtering of nutrients & contaminants
- Water storage
- Greenhouse gas storage
Hoard it or Burn it? - The Soil Carbon Dilemma*

- Filtering of nutrients & contaminants
- Water storage
- Greenhouse gas storage

Hoard it!

- Soil structure
- Nutrient cycling
- Biodiversity

Burn it!

* Janzen, H.H., 2006, SB&BC, 38, 419-424
"Burning it"-Nitrogen Mineralization

\[ Y = -0.291 + 0.001X \]

\[ R^2 = 0.495 \]
Hoard it in the Subsoil?
Soil Carbon Sequestration by Kiwifruit

Bay of Plenty

• ZESPRI™ Gold
• ‘Young’ – 10 years
• ‘Old’ – 25 years

• Te Puke sandy loam
• One soil pit per block
Soil-C: Sampling & Analysis

- Four profiles in the row, four profiles in the alley
- Bulk density, soil organic carbon measurement
- Soil organic carbon by loss-on-ignition
Hoardng It: Sequestration

Deep Sequestration Agents:
• Roots
• Worms

- The old orchard has sequestered more C at depth
- Young orchard ~ 139 t-C ha\(^{-1}\); Old ~ 145 t-C ha\(^{-1}\)
- Sequestering ~ 0.4 t-C ha\(^{-1}\) yr\(^{-1}\)
Soil Carbon Research in PIPS

Horticulture Australia Ltd (HAL) and Apple & Pear Australia Ltd (APAL) identify their integrated project “Productivity, Irrigation, Pests & Soils” project (PIPS) as...

'...undoubtedly a significant, high-profile development for the Australian apple and pear industry, and a role model for how projects will be formulated in the future. It is a flagship project for the industry.

• Protocol established for soil-carbon monitoring & tested across a range of land uses (Plant & Food Research)
Sampling Soil Carbon: Down to 1 m
... in duplex soils, in summer!

Shepparton
Two pits

Pink Lady, Shepparton

Granny Smith, Shepparton

Pink Lady, Huon Valley

Huon Valley

Over 100 samples per pit
Soil C, N, ρ & microbial biomass

Soil Carbon Profiles
Soil C Sampling Protocol

- Only weak spatial structure along the row, so random sampling OK

- Surface contouring leads to inter-row differences
  - At Shepparton 60% C in top 0.3m, 80% in the Huon
  - Soil C in top 1m about the same as 0.3m in NZ
Soil C Sampling: How deep?

- To capture >80% of the soil C to 1 m, we suggest sampling to 0.7 m; 10 cm increments to 30cm, & 20cm ones to 70cm
- This is IPCC compatible in the top 30 cm
- Nine locations in an orchard, 3 randomly in the row, 3 in the mid-alley & 3 in the inter-row.
Soil C Sampling: How many?

For 88% confidence in bulk density, $\rho$, & 86% in soil-C:

- At each of the nine locations, $\rho$, by undisturbed cores at 10, 20, 30 & 40 cm.
- At each $\rho$ location, disturbed cores for soil-C at 5 surrounding points 0-10, 10-20, 20-30, 30-50 & 50-70 cm. Same depths bulked & a sub-sample for soil-C.
- Thus 36 $\rho$ samples ($9 \times 4$), and 45 soil-C samples ($9 \times 5$).
- Provides good measures of soil-C stocks
- What of temporal change? We’ll sample again in 4 years’ time!
Enhancing Soil-C & Understanding C Dynamics

- Compost - from prunings & reject fruit
- Biochar - from prunings & cultivar replacement

... & other sources, since “… storages that are not offsets can occur within the system boundaries of the product system (ISO 5.2.4)”

- Disc permeametry to measure the soil’s changed hydraulic character & functioning
- Time Domain Reflectometry to monitor the impact of soil C on soil water storage
Enhancing Soil Carbon & Understanding C & N Dynamics: Fluxmeters

- Monitoring of N mineralisation
- Leaching of N
- Change in soil carbon stocks
- Leaching of dissolved organic carbon
Enhancing Soil Carbon & Understanding C & N Dynamics: Fluxmeters

- Biochar in the top 150 mm
- Real-time monitoring of soil-water content (from our desk in NZ)
- Real-time monitoring of drainage & leachate collection
Carbon Footprints of the Future …

Life Cycle Analysis

Sources: GHG footprinting of apples project: Hume et al., unpublished, 2009
• Carbon – A pollutant from production systems
• Carbon – A vital component for soil ecosystem services
• Regulatory & consumer pressures for carbon footprinting
• Science & technology to reduce carbon footprints
• Understanding carbon dynamics to sustain soil health
• The stakes are high, yet the prospects great

www.plantandfood.com

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E/Prof Ulrich Zimmerman

How do plants take up water in a drying climate?

Date: 15 February 2011
Time: From 5-6pm
Place: Agriculture Lecture Theatre G013, UWA
Parking: (Hackett entrance no 3, car park 8)