How do microbes transform plant residues into soil organic matter and, why does it matter?

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**Soil organic matter**

**Promotes:**
- good soil structure
- aggregate formation and stability

**Regulates:**
- soil moisture availability
- nutrient cycling
- climate (carbon storage and GHG)

**Is a source of:**
- nutrients for plants and microbes
- energy (food) for microorganisms

*Soil organic matter provides resilience to stress*
Soil organic matter supports biota

**Soil biota: ecosystem services**

<table>
<thead>
<tr>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition &amp; cycling of organic matter</td>
</tr>
<tr>
<td>Regulation of nutrient availability</td>
</tr>
<tr>
<td>Suppression of pests and disease</td>
</tr>
<tr>
<td>Maintenance of soil structure &amp; hydrology</td>
</tr>
<tr>
<td>Gas exchange and carbon storage</td>
</tr>
<tr>
<td>Soil Detoxification</td>
</tr>
<tr>
<td>Plant growth control</td>
</tr>
</tbody>
</table>

Where does soil organic matter come from?

In agroecosystems most new C comes from plants (and organic amendments).

Energy held by carbon *fuels* other important processes

(e.g. N, P cycling)

Graphic: J. Lavallee

https://theconversation.com/soil-carbon-is-a-valuable-resource-but-all-soil-carbon-is-not-created-equal-129175
How does plant matter become soil organic matter?

**ODE TO ROT** (J. Updike 1985)

“‘Let there be rot’, and hence bacteria and fungi sprang into existence to dissolve the knot of carbohydrates photosynthesis achieves in plants, in living plants...

...Dead matter else would hold the elements in thrall -- nitrogen, phosphorus…”
Not all soil organic matter is created equally


https://theconversation.com/soil-carbon-is-a-valuable-resource-but-all-soil-carbon-is-not-created-equal-129175

Graphic: J. Lavallee
How is soil organic matter retained?

Particulate organic matter (POM):
- protected within aggregates

Mineral-associated organic matter (MAOM):
- protected by binding with clay minerals

Graphic: J. Lavallee

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Crop residue decomposition - what controls it?

How do soil properties and environmental conditions affect litter decomposition?
Crop residue decomposition

Table 1  Soil classification, texture, organic carbon concentration and pH at the 10 experimental sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil classification (WRB)</th>
<th>Sand (%)</th>
<th>Clay (%)</th>
<th>Organic C (%)</th>
<th>pH</th>
<th>Mean annual air temperature (°C)</th>
<th>Mean annual precipitation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fredericton, NB</td>
<td>Humic Podzol</td>
<td>53</td>
<td>9</td>
<td>1.70</td>
<td>6.2</td>
<td>6.6</td>
<td>1157</td>
</tr>
<tr>
<td>Levis, QC</td>
<td>Mollic, Umbric, Calcic Gleysol</td>
<td>60</td>
<td>15</td>
<td>2.23</td>
<td>5.0</td>
<td>5.6</td>
<td>1231</td>
</tr>
<tr>
<td>Ottawa, ON</td>
<td>Cambisol, Eutric Cambisol</td>
<td>67</td>
<td>12</td>
<td>1.79</td>
<td>6.2</td>
<td>7.4</td>
<td>926</td>
</tr>
<tr>
<td>Delhi, ON</td>
<td>Albic Luvisol, Haplic Luvisol</td>
<td>85</td>
<td>6</td>
<td>0.04</td>
<td>6.5</td>
<td>8.9</td>
<td>970</td>
</tr>
<tr>
<td>Woodslie, ON</td>
<td>Mollic, Umbric, Calcic Gleysol</td>
<td>41</td>
<td>27</td>
<td>2.88</td>
<td>7.1</td>
<td>10.0</td>
<td>875</td>
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<tr>
<td>Morden, MB</td>
<td>Chernozem</td>
<td>32</td>
<td>36</td>
<td>2.86</td>
<td>6.3</td>
<td>4.1</td>
<td>533</td>
</tr>
<tr>
<td>Indian Head, SK</td>
<td>Chernozem</td>
<td>10</td>
<td>48</td>
<td>2.66</td>
<td>7.8</td>
<td>2.5</td>
<td>431</td>
</tr>
<tr>
<td>Swift Current, SK</td>
<td>Kastanozem (Aridic)</td>
<td>33</td>
<td>29</td>
<td>1.17</td>
<td>6.0</td>
<td>4.2</td>
<td>397</td>
</tr>
<tr>
<td>Lethbridge, AB</td>
<td>Kastanozem (Haplic)</td>
<td>53</td>
<td>23</td>
<td>1.52</td>
<td>7.7</td>
<td>6.5</td>
<td>467</td>
</tr>
<tr>
<td>Breton, AB</td>
<td>Albic Luvisol, Gleyed Luvisol</td>
<td>36</td>
<td>22</td>
<td>1.66</td>
<td>5.8</td>
<td>3.5</td>
<td>506</td>
</tr>
</tbody>
</table>
Crop residue decomposition

Barley grown in a chamber with a tracer \((^{13}\text{CO}_2)\)

- Harvested, chopped, mixed with soil
- \(^{12}\text{C}\) residues added annually (no tracer)

10 atom\% \(^{13}\text{C}\)

- Sampled after 6mo, 1, 2, 3, 5 years
Crop residue decomposition: primarily controlled by temperature

Temperature ("thermal time")
- Cumulative growing degree days above zero
What about residue C stabilization?

Where did the $^{13}$C from the barley end up
- after 6 months?
- after 5 years?

Graphic: J. Lavallee

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What about residue C stabilization?

At 6 months, a lot of residue was POM; by 5 years residue C remained as MAOM.
Organic matter supports soil biota

After 5 years, $^{13}$C oPOM and MAOM best predicted by:

- degree days above $0^\circ$C
- soil organic C (%) at time 0

Haddix et al. 2020 Geoderma
How does crop diversity affect SOM?

Tiemann et al. 2015 Ecology Letters
How does crop diversity affect SOM?
Long-term cereal monoculture vs. diverse rotations

AAFC New Rotation Experiment (Swift Current est. 1987)
continuous wheat vs. wheat-canola-wheat-pea (n=3)

AAFC Totten Rotation Experiment (Harrow est. 2001)
continuous corn vs. corn-soybean-winter wheat (n=4)
How does crop diversity affect microbial communities?

<table>
<thead>
<tr>
<th>Location</th>
<th>Stage</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harrow, ON</td>
<td>Early Vegetative (EV)</td>
<td>June 21</td>
</tr>
<tr>
<td></td>
<td>Anthesis (AN)</td>
<td>August 3</td>
</tr>
<tr>
<td></td>
<td>Post-harvest (PH)</td>
<td>December 5</td>
</tr>
<tr>
<td>Swift Current, SK</td>
<td>Early Vegetative</td>
<td>June 6</td>
</tr>
<tr>
<td></td>
<td>Anthesis</td>
<td>July 20</td>
</tr>
<tr>
<td></td>
<td>Post-harvest</td>
<td>September 12</td>
</tr>
</tbody>
</table>

**Organic Matter Characterization**
- Lignin (lignin phenols)
- Amino sugars
- Available C (CO₂ respiration; 38d)

**Biogeochemistry**
- PO₄, NO₃, total N, total and organic C
- Microbial enzyme activities

**Microbial community characterization**
- DNA sequencing
- Phospholipid fatty acids
Crop rotation affected SOM quality
Diverse crop rotations resulted in different soil *functioning*.

Yield boost:  
Corn: +36%  
Wheat: +20%
Diverse crop rotations in both systems resulted in different soil function

Aboveground diversity

interact to improve fertility and soil organic matter

Belowground diversity function

Plant matter quality is important for fertility
Diverse crop rotations improve system resilience to adverse conditions

Bowles et al. 2020 doi.org/10.1016/j.oneear.2020.02.007

347 site years from 11 corn experiment.

Rotation diversity increased yields by an average of 28.1%.

Positive effects were most notable under unfavorable conditions (e.g. drought).
Organic matter quality: what is the big deal with roots?

Roots can contribute up to 80% as much C as aboveground biomass (Fan et al. 2019).
What is the big deal with roots?

Rhizodeposition can account for 1-10% of net photosynthate C stored

Figure 2 | The rhizosphere. The rhizosphere is a narrow zone of soil (a few millimetres wide) that surrounds and is influenced by plant roots. The schematic shows magnified pictures of the rhizosphere, containing saprophytic and symbiotic bacteria and fungi, including arbuscular mycorrhizal fungi (AMF). AMF inset modified, with permission, from REF: 158 © (2008) Macmillan Publishers Ltd. All rights reserved.

What is the big deal with roots?

Emerging evidence that root C is preferentially stabilized.


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Acknowledgements

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Saskatoon: Reynald Lemke

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Ryan LaBossiere, Veronica Wang, Kyle LeBlanc
Soil Microbial Ecology Program

- Soil carbon stabilization/destabilization
- Nutrient cycling and prevention of losses (improved efficiency)
- Plant-microbe interactions

Thank you

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How is soil organic matter retained?

3 destabilizing factors:
1) Release from aggregates
   • Tillage, freeze-thaw, wet-dry cycles, bioturbation
2) Desorption from minerals
   • Soil pH, increased moisture
3) Increased biotic metabolism
   • Quality of litter, quality of soil organic matter, microbial carbon use efficiency

Inputs
• Plant C
• Soil amendments

Microbial decomposition
soil organic matter

Outputs
• Respiration (CO₂ & CH₄)
• Physical transport (erosion, leaching) *relocation
Crop residue decomposition: most plant C turns over quickly

Less residue remained:
• in sandy soil
• in warmer, wetter climates

How do we predict decomposition?
Crop residue decomposition: what if our soils get warmer?

Time to 50% decomposition (labile carbon):
• 1-4 months less

Time to 90% decomposition (stable carbon):
• 1 year faster @ cool sites
• 2 years faster @ warm sites