Agroecology: the key role of beneficial microorganisms in ecosystem services

S. Declerck

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The context
In 1997, a team of researchers from the USA, Argentina and the Netherlands put an approximative price tag of US $33 trillion a year on ecosystem services.
The challenges
(ecosystem services under pressure)
Feeding a growing population

By 2050...

World population will grow to 9.2 billion = \textbf{growth} > 25\%

Urbanization = 70\%

Food production must increase \textbf{by more than} 60\% ...
Climate change

Temperatures rise up to 2.5 °C

New pests and diseases

Water scarcity & desertification

Salinization

Increase in fertilizers and pesticides, irrigation economically impractical and at risk for environment

Burkina Faso – dry soil
(http://earth-observation.org/tag/dry/)
Increasing reliance on few plants

- **300,000** • Known plant species
- **100,000** • Used by humankind
- **30,000** • Edible
- **7,000** • Used as food at local level
- **120** • Important at national scale
- **30** • Provide 90% of plant calories
- **3** • Provide 60%: rice, wheat, maize

(E. Frison, personal communication)
Loss of agricultural biodiversity

A CENTURY AGO
In 1903 commercial seed houses offered hundreds of varieties, as shown in this sampling of ten crops.

80 YEARS LATER
By 1983 few of those varieties were found in the National Seed Storage Laboratory. *

* CHANGED ITS NAME IN 2001 TO THE NATIONAL CENTER FOR GENETIC RESOURCES PRESERVATION

JOHN TOMANIO. NGM STAFF. FOOD ICONS: QUICKHONEY
SOURCE: RURAL ADVANCEMENT FOUNDATION INTERNATIONAL

(E. Frison, personal communication)
How can agriculture reconcile crop production and environmental integrity?

We need to adapt...

Agricultural systems that produce more and better food under harsher conditions while protecting the environment

we need a novel paradigm

develop crop management strategies that optimise soil fertility, biological diversity and crop robustness by creating forms of agroecosystems that respect natural ecological processes and support productivity in the long term (Altieri 1999).

We have trillions of potential partners:

The microbes
Microbes & plants are intimate partners
**Globally, soil contains $4 \text{–} 5 \ 10^{30}$ microbial cells**

<table>
<thead>
<tr>
<th>TAXON</th>
<th>DIVERSITY</th>
<th>ABUNDANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prokaryotes</td>
<td>100–9,000 cm$^{-3}$</td>
<td>4–20 $\times 10^9$ cm$^{-3}$</td>
</tr>
<tr>
<td>Fungi</td>
<td>200–235 g$^{-1}$</td>
<td>100 m g$^{-1}$</td>
</tr>
<tr>
<td>AMF</td>
<td>10–20 m$^{-2}$</td>
<td>81–111 m cm$^{-3}$</td>
</tr>
<tr>
<td>Protists</td>
<td>150–1,200 (0.25 g)$^{-1}$</td>
<td>$10^4$–$10^7$ m$^{-2}$</td>
</tr>
<tr>
<td>Nematodes (genera)</td>
<td>10–100 m$^{-2}$</td>
<td>2–90 $\times 10^5$ m$^{-2}$</td>
</tr>
<tr>
<td>Enchytraeids</td>
<td>1–15 ha$^{-1}$</td>
<td>12,000–311,000 m$^{-2}$</td>
</tr>
<tr>
<td>Tardigrades</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Collembola</td>
<td>20 m$^{-2}$</td>
<td>1–5 $\times 10^4$ m$^{-2}$</td>
</tr>
<tr>
<td>Mites (Oribatida)</td>
<td>100–150 m$^{-2}$</td>
<td>1–10 $\times 10^4$ m$^{-2}$</td>
</tr>
<tr>
<td>Isopoda</td>
<td>10–100 m$^{-2}$</td>
<td>10 m$^{-2}$</td>
</tr>
<tr>
<td>Diplopoda</td>
<td>10–2,500 m$^{-2}$</td>
<td>110 m$^{-2}$</td>
</tr>
<tr>
<td>Earthworms (Oligochaeta)</td>
<td>10–15 ha$^{-1}$</td>
<td>300 m$^{-2}$</td>
</tr>
</tbody>
</table>

*(Bardgett and van der Putten – 2014)*
What kind of services can microbes provide
• **Nutrient cycling and plant nutrition:**
  
  • E.g. Mycorrhizal fungi are responsible for up to 75% of the phosphorus that is acquired by plants annually (van der Heijden et al. 2008).

• **Biological nitrogen fixation**

  • E.g. The total biological nitrogen fixation is estimated to be twice as much as the total nitrogen fixation by non-biological processes.

• **Regulation of pests and diseases**

  • E.g. Biopesticide industry = 2.1 billions/year (2011) = 5 % of chemical pesticides industry (Velivelli et al., 2016).

• **Carbon sequestration**

  • E.g.: Five billion tons of C per year are mobilized by AM plants

• **Soil structure**

  • E.g. glomalin and hyphae
Agricultural practices impacting microbes
**Heavy fertilizer use**: Plants decrease resource allocation to their fungal partners

**Tillage**: Repeated destruction of hyphal network reduces AMF nutrient transport capability

**Fungicides**: Potentially toxic to AMF

**Poor crop rotations/monoculture**: Reduce AMF diversity

AMF need to be properly managed... even in organic farming systems

### Beneficial practices
- Use of low solubility fertilisers
- Exclusion of most biocides
- Ley periods
- Diverse rotations

Low concentration of available nutrients in soil, encourages AMF colonisation
Toxic effects of some biocides on AMF are avoided
Encourages build up of AMF propagule numbers
Encourages a diverse AMF community

### Detrimental practices
- Mechanical tillage for weed control
- Bare fallows
- Non-mycorrhizal crops
- Use of copper based fungicides

Disrupts mycorrhizal hyphal network
Lack of host plants results in decline in propagule numbers
Lack of host plants results in decline in propagule numbers
Directly toxic to AMF

(Gosling et al. – 2006)
Examples of agro-ecological practices favoring ES offered by microbes
Intercropping with push-pull plants for pest control

Fixed talpa net separating banana shoot from of C. spectabilis shoot

Plant of C. spectabilis

Plant of banana

(Anene et al. – 2016)
### Intercropping with push-pull plants

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Juveniles</th>
<th>Females</th>
<th>Males</th>
<th>Total</th>
<th>Multiplication rate</th>
<th>RNI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+M + C + N</td>
<td>10067 ± 02767</td>
<td>15079 ± 05385</td>
<td>596 ± 0252</td>
<td>25741 ± 07864</td>
<td>83,8 ± 28</td>
<td>17,2 ± 5</td>
</tr>
<tr>
<td>+M – C + N</td>
<td>14742 ± 02736</td>
<td>13917 ± 04717</td>
<td>600 ± 0252</td>
<td>29258 ± 04972</td>
<td>106,7 ± 10</td>
<td>19,8 ± 7</td>
</tr>
<tr>
<td>–M + C + N</td>
<td>22625 ± 04887</td>
<td>23325 ± 08350</td>
<td>1325 ± 0761</td>
<td>47275 ± 13172</td>
<td>176,5 ± 70</td>
<td>33,7 ± 5</td>
</tr>
<tr>
<td>–M – C + N</td>
<td>44425 ± 17106</td>
<td>47650 ± 18917</td>
<td>1425 ± 1149</td>
<td>93500 ± 35078</td>
<td>280,3 ± 82</td>
<td>61,7 ± 8</td>
</tr>
</tbody>
</table>

**Effects (p-values)**

<table>
<thead>
<tr>
<th>Effect</th>
<th>p-value</th>
<th>p-value</th>
<th>p-value</th>
<th>p-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMF</td>
<td>&lt;.0001***</td>
<td>&lt;.0001***</td>
<td>0.0142**</td>
<td>&lt;.0001***</td>
<td>&lt;.0001***</td>
</tr>
<tr>
<td>C. spectabilis</td>
<td>0.0003***</td>
<td>0.0561</td>
<td>0.9992</td>
<td>0.0039**</td>
<td>0.0121**</td>
</tr>
<tr>
<td>AMF X C. spectabilis</td>
<td>0.3459</td>
<td>0.0225*</td>
<td>0.9807</td>
<td>0.0589</td>
<td>0.0934</td>
</tr>
</tbody>
</table>

(Anene et al. – 2016)
Cover cropping
Yield of caliber 2 and 3 with (BCA+) or without (BCA-) biological control agents

BCA+ cover crop + intensif: + 18% Yield
BCA+ cover crop + bio: + 11% Yield

(Buysens et al. – 2016)
Direct seeding (into cover crops) with microbial inoculants

- **Inoculum in vivo**
- **Production of beads**
- **Drying of beads**
- **Maize**
- **Bead application**

Mison et al. – In prep.
Host plant – AM fungi

Cultivar choice

Relative Mycorrhizal Dependency

Biomass AM – Biomass non AM

Biomass AM

Cultivar

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Density root hairs (No. mm(^{-1}))</th>
<th>Length root hairs (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Williams</td>
<td>54(^b)</td>
<td>0.50(^{ab})</td>
</tr>
<tr>
<td>Grande Naine</td>
<td>66(^a)</td>
<td>0.53(^{ab})</td>
</tr>
<tr>
<td>Petite Naine</td>
<td>68(^a)</td>
<td>0.55(^{ab})</td>
</tr>
<tr>
<td>Americanii</td>
<td>57(^{ab})</td>
<td>0.47(^b)</td>
</tr>
<tr>
<td>Poyo</td>
<td>64(^a)</td>
<td>0.59(^a)</td>
</tr>
<tr>
<td>Intokatoke</td>
<td>50(^b)</td>
<td>0.48(^b)</td>
</tr>
<tr>
<td>Gros Michel</td>
<td>48(^b)</td>
<td>0.55(^{ab})</td>
</tr>
</tbody>
</table>

RMD

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>RDW (g)</th>
<th>Density root hairs (No. mm(^{-1}))</th>
<th>Length root hairs (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. mosseae</td>
<td>-0.80**</td>
<td>-0.68*</td>
<td>-0.67*</td>
</tr>
<tr>
<td>G. macrocarpum</td>
<td>-0.83**</td>
<td>-0.73*</td>
<td>-0.81**</td>
</tr>
</tbody>
</table>

(Declerck et al. 1995)
Cultivar choice

Intensity of the mycorrhizal colonization in the root system M%:

- Highest colonization for line 66: 50.7%
- S. pimpinellifolium: 25.38%
- CastleMart: 20.10%
- S. lycopersicum: 15.02%
- Lowest colonization for line 209: 2.2%

(Plouznikoff et al. – In prep.)
Disease management through diversification: potato cultivars mixture in Peru against shoot/root pest and diseases

EU VALORAM project)
Scientific challenges
LOOKING AT THE RHIZOBIOME

- Opportunistic Microbiome
- Dynamic Core Microbiome
- Stable Core Microbiome

Occasional colonization – depending on environment

(Pfeiffer et al. – accepted for publication)
Knowing the players – knowing their functions

(Lebeis – 2014)
Breeding for optimal interaction

Breeding plants to optimize interactions with beneficial microbes has not yet been attempted.

Specific functions
- e.g. N fixation
- P acquisition

Broad characteristics
- e.g. functional redundancy
- Plant health

(Bakker et al. – 2012)
Conclusion
- Microbes are key players in many ES

- Microbes are under pressure due to classical agricultural practices

- A broad diversity of agroecological practices exists that can be combined efficiently with microbes

- For some practices, profound systems change might be necessary (e.g. intercropping, reduced/no tillage, direct seeding…)}
MANY THANKS FOR YOUR ATTENTION