Sustainable nutrient cycling through soil biota

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Soil- a black box
Soil life

1g of soil contains: $10^9$ bacteria, 6’000 – 50’000 bacterial species and up to 200m fungal hyphae
Benefits soil organisms can provide

- Organic matter decomposition
- Carbon sequestration
- Soil structure, soil porosity
- Water infiltration
- Pest control
- Nutrient storage
- Nutrient release
- Breaking down toxic compounds

http://landscapeforlife.org/soil/support-the-soil-food-web/
Intensive agriculture

- Monoculture
- Intensive soil tillage
- high fertilization rates
- Pesticides

→ ecosystem simplification, reduced niche diversity

→ reduced biodiversity above-and belowground

Tsiafouli et al. 2015, Global Change Biology
agricultural resource use

Nitrogen (N) and Phosphorus (P) $\rightarrow$ limit plant growth worldwide

Tilman et al. 2002, Nature
globally, about 50% of N fertilizers applied remain unused by crops

Liu et al. 2010, PNAS
THE DISAPPEARING NUTRIENT

Diagram:
- Production (Mt/a of P)
- Year
- Cost per Pound of N ($/lb)

Legend:
- A: Mohr & Evans (2013)
- B: Cordell et al. (2009), Cordell & White (2011)
- C: GPRI (2010), Cordell et al. (2011)
- D: Walan (2013)
- E: Fixen (2009)
- F: Van Kauwenbergh (2010)

Prices of Nitrogen (USDA-ERS, 2013)
Can we manage soils to enhance agricultural sustainability?

Bender et al. 2016, *Trends in Ecology and Evolution*
1. Which role do soil organisms play in nutrient cycling and ecosystem sustainability?
2. How can this knowledge be applied to enhance the sustainability of cropping systems?
Arbuscular mycorrhizal fungi (AMF)

Symbiotic relationships with about 80% of all land plants

Improve plant growth and nutrition

Other services
- Soil structure
- Seedling establishment
- Drought resistance
- Pathogen resistance
- Reduce nutrient leaching

Extend plant-root system
Enhance nutrient uptake from soil

Foto: Giovannetti et al. 2001, New Phytologist
Grafik: Sari Timonen
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Can AMF reduce nutrient losses from soil?

AMF effects vary with soil conditions

Bender et al. 2014, Soil Biology & Biochemistry
Do AMF affect N$_2$O emissions from denitrification?

**Grass experiment:**
Sterilized and re-inoculated sand-soil mix

- With AMF (M)
- Without AMF (NM)

**Tomato experiment:**
Fresh field soil + AMF inoculum

- Mutant (NM) reduced AMF colonization
- Wildtype (M) colonized by AMF
AMF reduce $N_2O$ emissions

Without AMF:
- 42% increase

Without AMF:
- 34% increase

Bender et al. 2014, *ISME Journal*
Tillage practices affect ecosystem services and plant productivity by changing arbuscular mycorrhizal fungal communities.

Do AMF communities from tilled and non-tilled soils have different functional properties?
Tillage practices affect ecosystem services and plant productivity by changing arbuscular mycorrhizal fungal communities.

Luise Olbrecht | © Agroscope Reckenholz-Tänikon Research Station ART, Switzerland
No till communities form more fungal hyphae in soil

Tillage practices affect ecosystem services and plant productivity by changing arbuscular mycorrhizal fungal communities

Köhl et al. 2014, Ecological Applications
No-till communities strongly enhance plant P contents

Köhl et al. 2014, *Ecological Applications*

Tillage practices affect ecosystem services and plant productivity by changing arbuscular mycorrhizal fungal communities
Field inoculation with AMF
+ Pseudomonads + entomopathogenic nematodes

Inoculated AMF can successfully compete with native AMF communities

Schlaeppi et al. 2016, *New Phytologist*

Improved resistance against pathogen attack (frit fly larvae)
Can soil organisms enhance nutrient use efficiency in agricultural systems?

- 7m³ / 9 tons of sterilized soil (sub- and topsoil)
- Sterilized with x-ray irradiation

Bender and Van der Heijden, *Journal of Applied Ecology* 2015
Can soil organisms enhance nutrient use efficiency in agricultural systems?

2 Treatments

**enriched soil life**
organisms <2mm (including AMF)

**reduced soil life**
Control inoculum organisms <11 µm (no AMF)

Crop rotation (2 years):
Corn,
Wheat,
Grass-clover

Leachate collection
Plant biomass
Soil data

8 replicates

Bender and Van der Heijden, *Journal of Applied Ecology* 2015
Can soil organisms enhance nutrient use efficiency in agricultural systems?

ENR: ‘enriched soil-life’
RED: ‘reduced soil-life’

Enhanced corn yield and nutrient contents

Bender and Van der Heijden, *Journal of Applied Ecology* 2015
Can soil organisms enhance nutrient use efficiency in agricultural systems?

ENR: ‘enriched soil-life’
RED: ‘reduced soil-life’

Soil organisms possess great potential to enhance the nutrient use efficiency of cropping systems.
Soil biodiversity and ecosystem multifunctionality

Relative change in soil community characteristic

Inocula size in μm: < 5000 < 250 < 50 < 25 < 10 0 (sterile)

- Mycorrhiza
- Fungi
- Bacteria
- Nematodes
- Soil DNA

Functional Guild Size
Soil biodiversity loss...

reduces nutrient cycling and decomposition

increases nutrient losses

Soil processes
N turnover
Decomposition
C sequestration

Relative Change in Ecosystem Function

Filter size (μm)

decreasing soil biodiversity

N leaching
P leaching
N2O emission

Wagg et al. 2014, PNAS
Soil biodiversity enhances ecosystem multifunctionality

\[ R^2 = 0.56, \quad F(1,73) = 62.9, \quad P < 0.001 \]

Wagg et al. 2014, PNAS
Summary

- AMF can reduce nutrient leaching and enhance plant nutrition depending on environmental conditions
- AMF can reduce $\text{N}_2\text{O}$ emissions from soil
- Soil biota have great potential to enhance the nutrient use efficiency of cropping systems
- Soil biodiversity supports several ecosystem functions simultaneously (multifunctionality)

Reducing management intensity and actively promoting soil biological communities might be a strategy to increase the nutrient use efficiency and sustainability of cropping systems
Outlook

Land-use intensity, soil biodiversity and ecosystem multifunctionality in Northern Californian ecosystems

- Grassland
- Crop rotations
- Fumigated monocultures

Ecosystem functioning? Nutrient cycling processes?
Land-use intensity, soil biodiversity and ecosystem multifunctionality in Northern Californian ecosystems

In the greenhouse

Field soils

Differences in ecosystem functioning?

Field soils, but soil organisms killed

Soil organisms matter for the self-maintaining capabilities of soils
Thanks

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Thank You!

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