Joel Williams

Integrated Soils

Soil Health and Nitrogen Management

Part 1: Fundamentals of Soil Health

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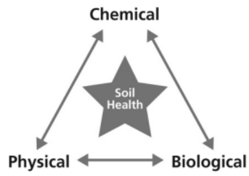
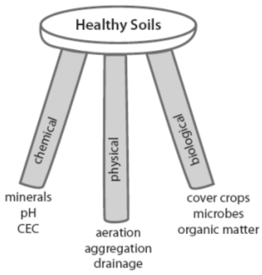
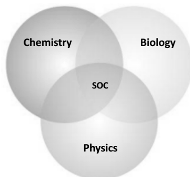
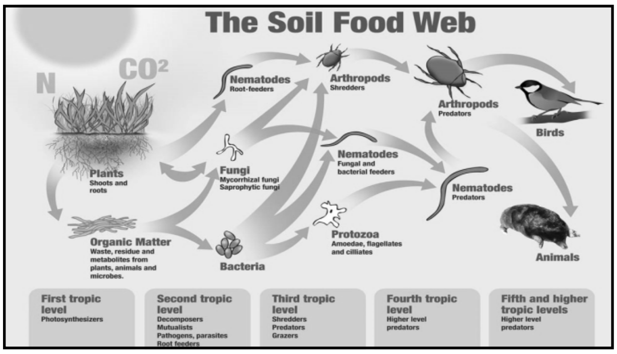
What is a healthy soil?





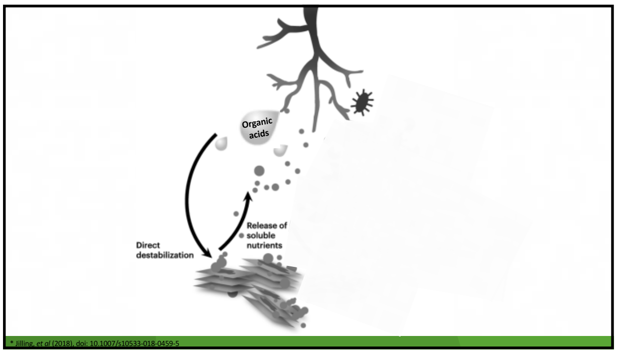
What drives a healthy soil?

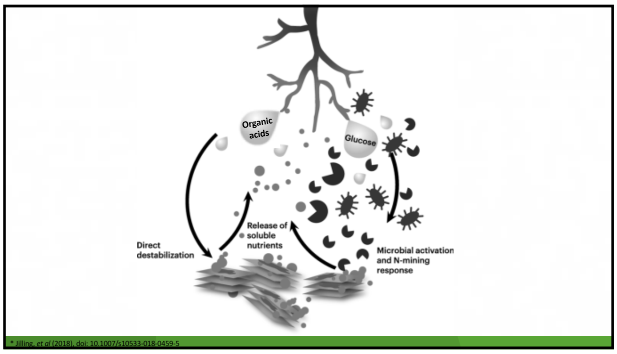


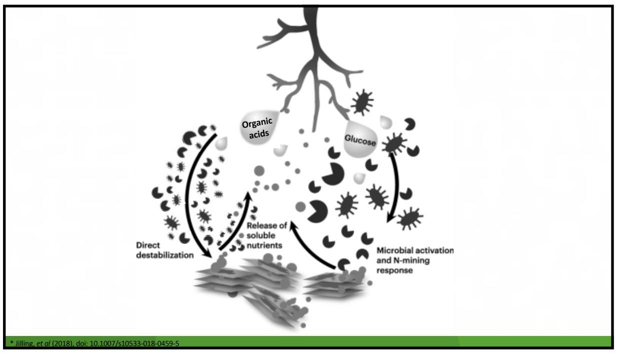


Nutrient Acquisition

- Soils contain significant reserves of nutrients but they locked up and unavailable to the plant.
- Biology is the key to unlocking these soil nutrient reserves.
- Yes plants can do it themselves, but microbes can do it much better.
- Microbes release acids and enzymes to cycle nutrients – diversity of microbiology yields more diverse acquisition of nutrition.


Organic acids
Direct destabilization
Release of soluble nutrients
* Jilling, et al (2018), doi: 10.1007/s10533-018-0459-5


Organic acids
Glucose
Direct destabilization
Release of soluble nutrients
Microbial activation and N-mining response
* Jilling, et al (2018), doi: 10.1007/s10533-018-0459-5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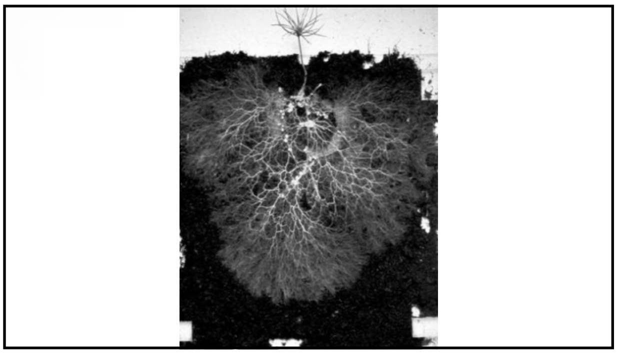
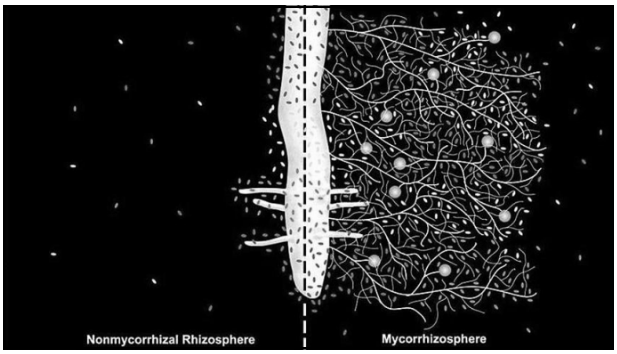
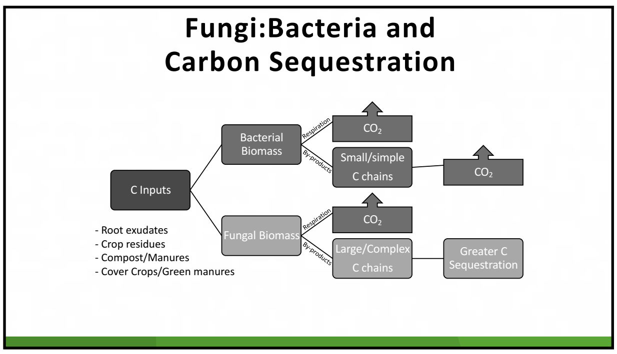
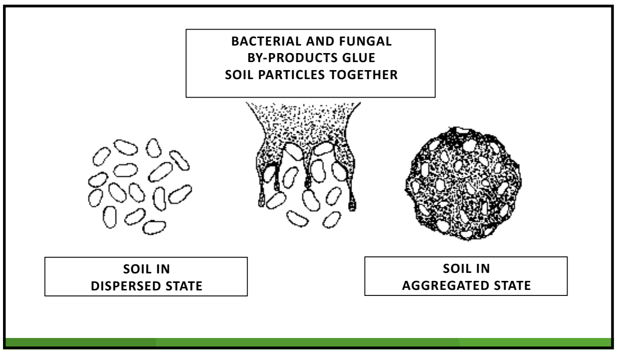
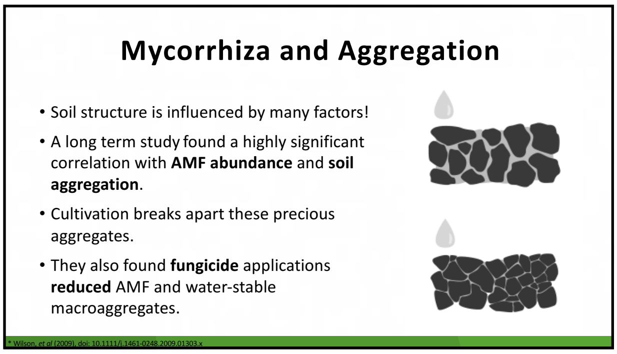
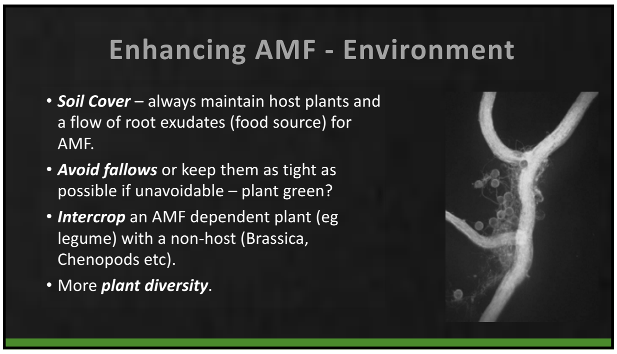


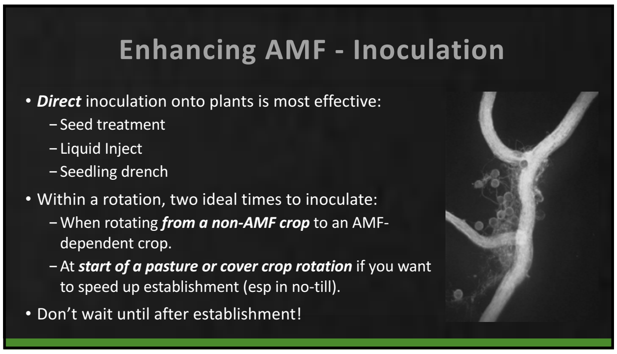

Nonmycorrhizal Rhizosphere
Mycorrhizosphere

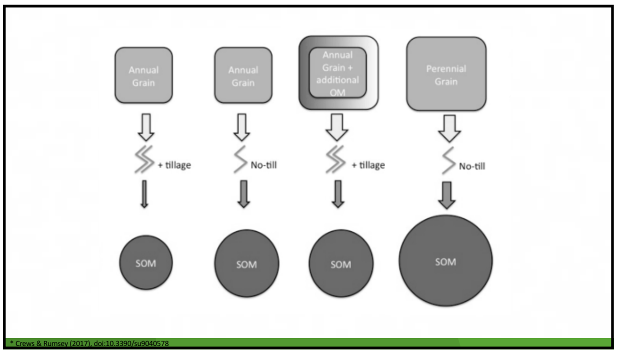

Fungi:Bacteria and Carbon Sequestration
C Inputs
- Root exudates
- Crop residues
- Compost/Manures
- Cover Crops/Green manures
Bacterial Biomass
Fungal Biomass
Respiration
By-products
CO2
Small/simple C chains
Large/Complex C chains
Greater C Sequestration


BACTERIAL AND FUNGAL
BY-PRODUCTS GLUE
SOIL PARTICLES TOGETHER
SOIL IN
DISPERSED STATE
SOIL IN
AGGREGATED STATE

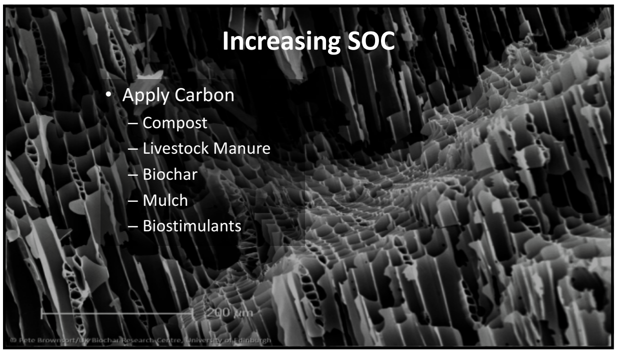

Mycorrhiza and Aggregation
• Soil structure is influenced by many factors!
• A long term study found a highly significant correlation with **AMF abundance** and **soil aggregation**.
• Cultivation breaks apart these precious aggregates.
• They also found **fungicide** applications **reduced** AMF and water-stable macroaggregates.
* Wilson, *et al* (2009), doi: 10.1111/j.1461-0248.2009.01303.x

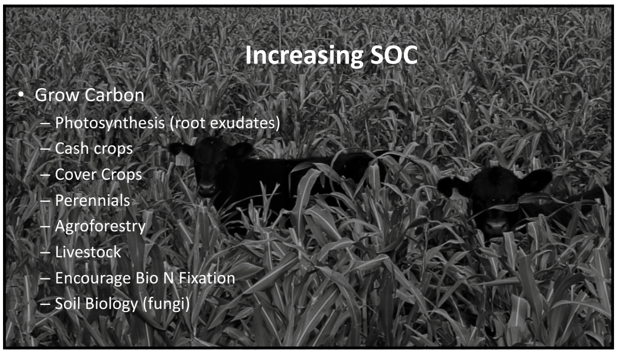

Enhancing AMF - Environment
• ***Soil Cover*** – always maintain host plants and a flow of root exudates (food source) for AMF.
• ***Avoid fallows*** or keep them as tight as possible if unavoidable – plant green?
• ***Intercrop*** an AMF dependent plant (eg legume) with a non-host (Brassica, Chenopods etc).
• More ***plant diversity***.


Enhancing AMF - Inoculation
• ***Direct*** inoculation onto plants is most effective:
– Seed treatment
– Liquid Inject
– Seedling drench
• Within a rotation, two ideal times to inoculate:
– When rotating ***from a non-AMF crop*** to an AMF-dependent crop.
– At ***start of a pasture or cover crop rotation*** if you want to speed up establishment (esp in no-till).
• Don't wait until after establishment!

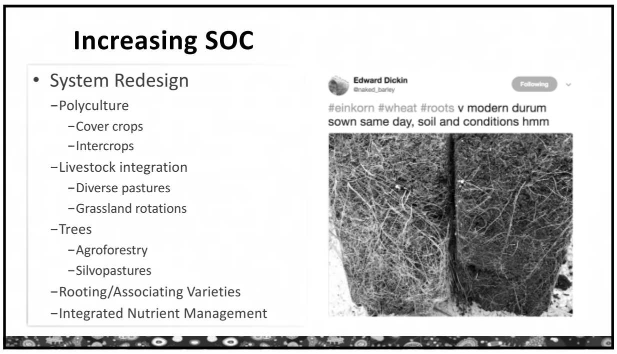

Annual Grain
Annual Grain
Annual Grain + additional OM
Perennial Grain
+ tillage
No-till
+ tillage
No-till
SOM
SOM
SOM
SOM
* Crews & Rumsey (2017), doi:10.3390/su9040578

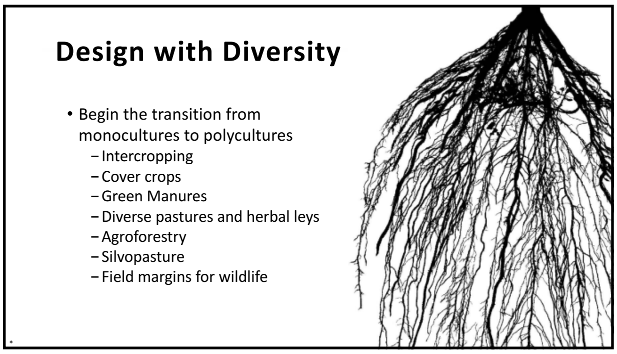

Increasing Soil Organic Carbon?
• Apply
• Grow
• Protect
• System Re-Design

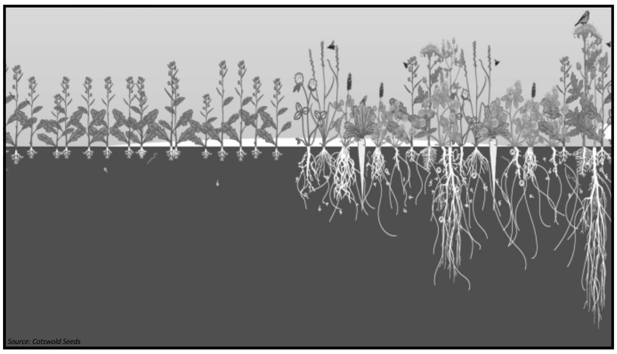

Increasing SOC
• Apply Carbon
– Compost
– Livestock Manure
– Biochar
– Mulch
– Biostimulants
200 µm

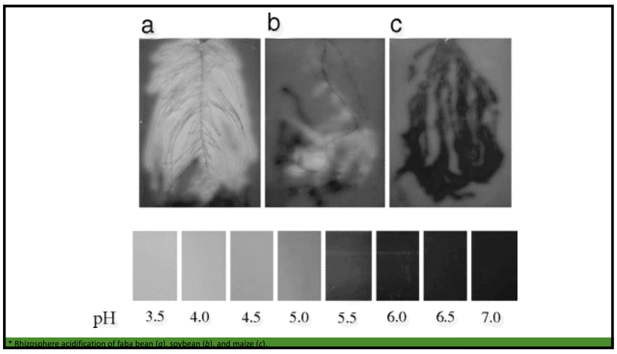

Increasing SOC
• Grow Carbon
– Photosynthesis (root exudates)
– Cash crops
– Cover Crops
– Perennials
– Agroforestry
– Livestock
– Encourage Bio N Fixation
– Soil Biology (fungi)


Increasing SOC
• Protect Carbon
– No bare soil
– Minimise tillage
– Improve aggregation, structure
– Intelligent disturbance


Increasing SOC
• System Redesign
–Polyculture
–Cover crops
–Intercrops
–Livestock integration
–Diverse pastures
–Grassland rotations
–Trees
–Agroforestry
–Silvopastures
–Rooting/Associating Varieties
–Integrated Nutrient Management
Edward Dickin
Following
#einkorn #wheat #roots v modern durum sown same day, soil and conditions hmm


Design with Diversity
• Begin the transition from monocultures to polycultures
–Intercropping
–Cover crops
–Green Manures
–Diverse pastures and herbal leys
–Agroforestry
–Silvopasture
–Field margins for wildlife


Source: Cotswold Seeds


a
b
c
pH
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
* Rhizosphere acidification of faba bean (*a*), soybean (*b*), and maize (*c*).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@RTKfarmer


Mark Lea
@GreenAcres_Farm


Andrew Howard
@FarmerAndyH

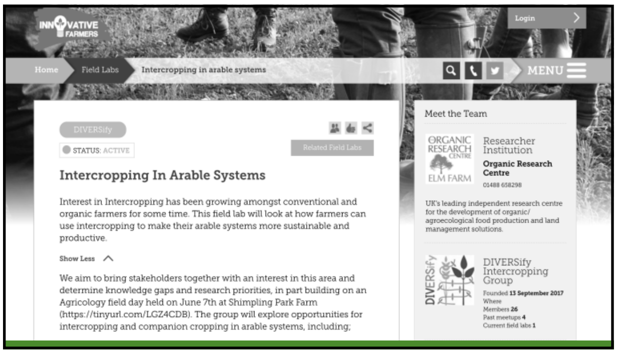

David White
@RTKfarmer


wil armitage
Following
Spring Oat Barley Peas Beans & vetch
enjoying a drink#diversity# biologicalfarming


James Foley @coolydoody · Sep 24
Complex 12species grass /clover /plantain mixture on left. 18species herbal ley on right. Both direct drilled with Moore unidrill during very dry conditions. Flying now. @CotswoldSeeds


James Foley
@coolydoody


Diversity by Design
MONOCULTURE
POLYCULTURE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STATUS: ACTIVE
Related Field Labs
Intercropping In Arable Systems
Interest in Intercropping has been growing amongst conventional and organic farmers for some time. This field lab will look at how farmers can use intercropping to make their arable systems more sustainable and productive.
Show Less
We aim to bring stakeholders together with an interest in this area and determine knowledge gaps and research priorities, in part building on an Agricology field day held on June 7th at Shimpling Park Farm (https://tinyurl.com/LGZ4CDB). The group will explore opportunities for intercropping and companion cropping in arable systems, including;
Meet the Team
Researcher Institution
Organic Research Centre
01488 658298
UK's leading independent research centre for the development of organic/ agroecological food production and land management solutions.
DIVERSify Intercropping Group
Founded 13 September 2017
Where
Members 26
Past meetups 4
Current field labs 1


DIVERSify: Designing InnoVative plant teams for Ecosystem Resilience and agricultural Sustainability
home
why?
how?
who?
activities
links & resources
" Clean air and water, a diversity of animal and plant species, soil and mineral resources, and predictable weather are annuities that will pay dividends for as long as the human race survives - and may even extend our stay on Earth. "
- Alex Steffen
Meet the team in our new videos

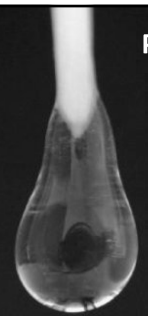
Photosynthesis

$6CO_2 + 6H_2O$ ---------------> $C_6H_{12}O_6$ *(sugar)* + $6O_2$
minerals/enzymes

$C_6H_{12}O_6$ *(sugar)* -----------------> *minerals/enzymes*

- ***Complex sugars***
- ***Carbohydrates***
- ***Amino Acids, Proteins***
- ***Fats & Oils***
- ***Hormones***
- ***Vitamins***
- ***Phyto-nutrients***
- ***Protective Compounds***

Partitioning Photosynthates



- Photosynthates are excreted as root exudates:
  - Cereals: 20-30%
  - Pastures: 30-50%
- Understanding the function and fate of these root exudates is currently a hot spot of scientific endeavour.

* Kumar, R. *et al* (2006). Plant roots and carbon sequestration. *Current Science*, 91: 7

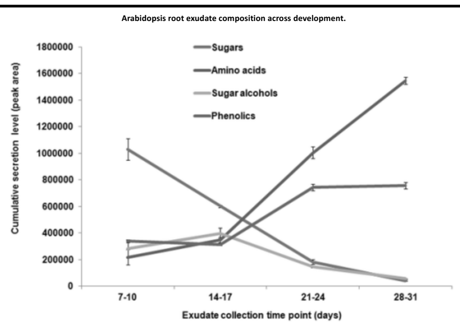
Source: Glyn Bengough

Hundreds of root exudates…

Table 1. Classes of compounds released in plant root exudates

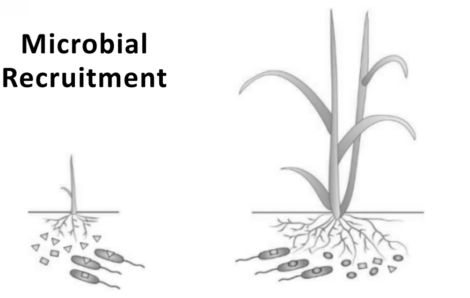
Class of compounds	Single components[a]
Carbohydrates	Arabinose, glucose, galactose, fructose, sucrose, pentose, rhamnose, raffinose, ribose, xylose and mannitol
Amino acids	All 20 proteinogenic amino acids, L-hydroxyproline, homoserine, mugineic acid, aminobutyric acid
Organic acids	Acetic acid, succinic acid, L-aspartic acid, malic acid, L-glutamic acid, salicylic acid, shikimic acid, isocitric acid, chorismic acid, sinapic acid, caffeic acid, *p*-hydroxybenzoic acid, gallic acid, tartaric acid, ferulic acid, protocatacheuic acid, *p*-coumaric acid, mugineic acid, oxalic acid, citric acid, piscidic acid
Flavonols	Naringenin, kaempferol, quercitin, myricetin, naringin, rutin, genistein, strigolactone and their substitutes with sugars
Lignins	Catechol, benzoic acid, nicotinic acid, phloroglucinol, cinnamic acid, gallic acid, ferulic acid, syringic acid, sinapoyl aldehyde, chlorogenic acid, coumaric acid, vanillin, sinapyl alcohol, quinic acid, pyroglutamic acid
Coumarins	Umbelliferone
Aurones	Benzyl aurones synapates, sinapoyl choline
Glucosinolates	Cyclobrassinone, desuphoguconapin, desulphoprogoitrin, desulphonapoleiferin, desulphoglucoalyssin
Anthocyanins	Cyanidin, delphinidin, pelargonidin and their substitutes with sugar molecules
Indole compounds	Indole-3-acetic acid, brassitin, sinalexin, brassilexin, methyl indole carboxylate, camalexin glucoside
Fatty acids	Linoleic acid, oleic acid, palmitic acid, stearic acid
Sterols	Campestrol, sitosterol, stigmasterol
Allomones	Jugulone, sorgoleone, 5,7,4′-trihydroxy-3′, 5′-dimethoxyflavone, DIMBOA, DIBOA
Proteins and enzymes	PR proteins, lectins, proteases, acid phosphatases, peroxidases, hydrolases, lipase

*Badri & Vivanco (2009). doi: 10.1111/j.1365-3040.2009.01926.x

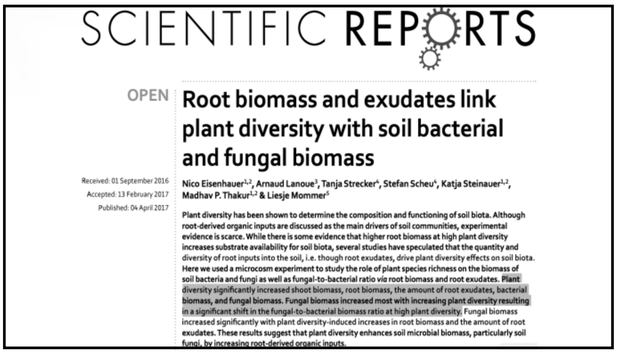


* Chaparro, JM *et al.* (2013) https://doi.org/10.1371/journal.pone.0055731

Microbial Recruitment



* Zhalnina *et al* (2018). doi: 10.1038/s41564-018-0129-3



SCIENTIFIC REPORTS

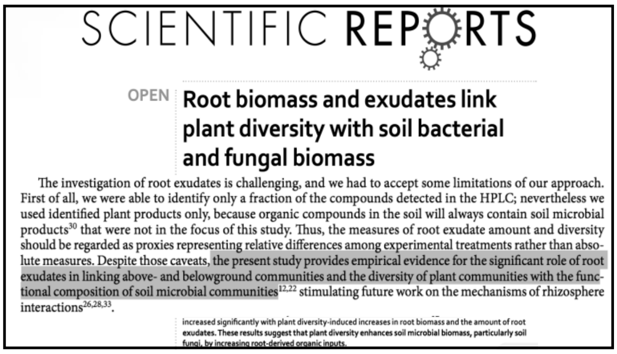
OPEN

Root biomass and exudates link plant diversity with soil bacterial and fungal biomass

Received: 01 September 2016
Accepted: 13 February 2017
Published: 04 April 2017

Nico Eisenhauer[1,2], Arnaud Lanoue[3], Tanja Strecker[4], Stefan Scheu[4], Katja Steinauer[1,2], Madhav P. Thakur[1,2] & Liesje Mommer[5]

Plant diversity has been shown to determine the composition and functioning of soil biota. Although root-derived organic inputs are discussed as the main drivers of soil communities, experimental evidence is scarce. While there is some evidence that higher root biomass at high plant diversity increases substrate availability for soil biota, several studies have speculated that the quantity and diversity of root inputs into the soil, i.e. though root exudates, drive plant diversity effects on soil biota. Here we used a microcosm experiment to study the role of plant species richness on the biomass of soil bacteria and fungi as well as fungal-to-bacterial ratio *via* root biomass and root exudates. Plant diversity significantly increased shoot biomass, root biomass, the amount of root exudates, bacterial biomass, and fungal biomass. Fungal biomass increased most with increasing plant diversity resulting in a significant shift in the fungal-to-bacterial biomass ratio at high plant diversity. Fungal biomass increased significantly with plant diversity-induced increases in root biomass and the amount of root exudates. These results suggest that plant diversity enhances soil microbial biomass, particularly soil fungi, by increasing root-derived organic inputs.



SCIENTIFIC REPORTS

OPEN

Root biomass and exudates link plant diversity with soil bacterial and fungal biomass

The investigation of root exudates is challenging, and we had to accept some limitations of our approach. First of all, we were able to identify only a fraction of the compounds detected in the HPLC; nevertheless we used identified plant products only, because organic compounds in the soil will always contain soil microbial products[30] that were not in the focus of this study. Thus, the measures of root exudate amount and diversity should be regarded as proxies representing relative differences among experimental treatments rather than absolute measures. Despite those caveats, the present study provides empirical evidence for the significant role of root exudates in linking above- and belowground communities and the diversity of plant communities with the functional composition of soil microbial communities[12,22] stimulating future work on the mechanisms of rhizosphere interactions[26,28,33].

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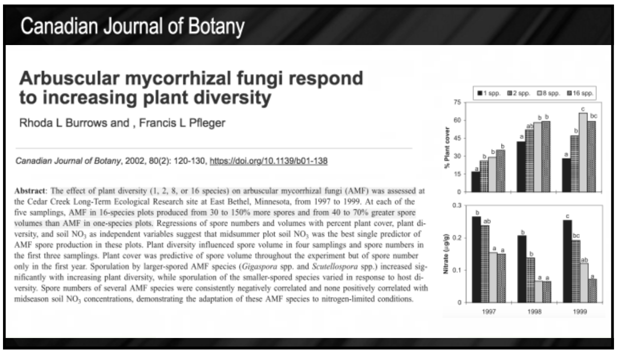


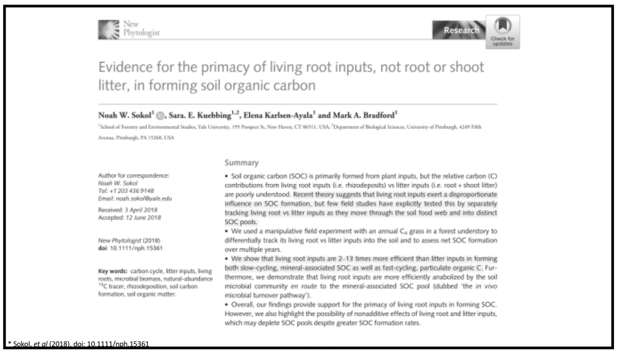
Canadian Journal of Botany

Arbuscular mycorrhizal fungi respond to increasing plant diversity

Rhoda L Burrows and , Francis L Pfleger

Canadian Journal of Botany, 2002, 80(2): 120-130, https://doi.org/10.1139/b01-138

Abstract: The effect of plant diversity (1, 2, 8, or 16 species) on arbuscular mycorrhizal fungi (AMF) was assessed at the Cedar Creek Long-Term Ecological Research site at East Bethel, Minnesota, from 1997 to 1999. At each of the five samplings, AMF in 16-species plots produced from 30 to 150% more spores and from 40 to 70% greater spore volumes than AMF in one-species plots. Regressions of spore numbers and volumes with percent plant cover, plant diversity, and soil NO_3 as independent variables suggest that midsummer plot soil NO_3 was the best single predictor of AMF spore production in these plots. Plant diversity influenced spore volume in four samplings and spore numbers in the first three samplings. Plant cover was predictive of spore volume throughout the experiment but of spore number only in the first year. Sporulation by larger-spored AMF species (*Gigaspora* spp. and *Scutellospora* spp.) increased significantly with increasing plant diversity, while sporulation of the smaller-spored species varied in response to host diversity. Spore numbers of several AMF species were consistently negatively correlated and none positively correlated with midseason soil NO_3 concentrations, demonstrating the adaptation of these AMF species to nitrogen-limited conditions.



New Phytologist

Research

Check for updates

Evidence for the primacy of living root inputs, not root or shoot litter, in forming soil organic carbon

Noah W. Sokol[1], Sara. E. Kuebbing[1,2], Elena Karlsen-Ayala[1] and Mark A. Bradford[1]

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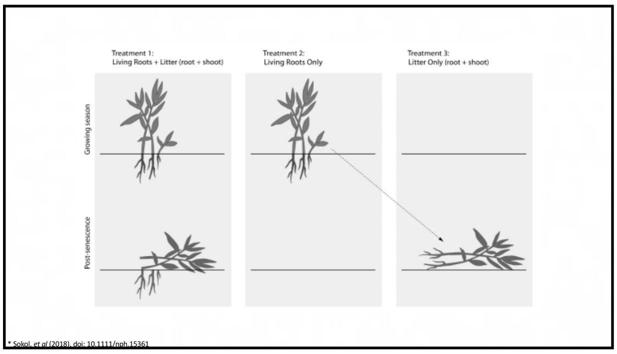
New Phytologist (2018)
doi: 10.1111/nph.15361

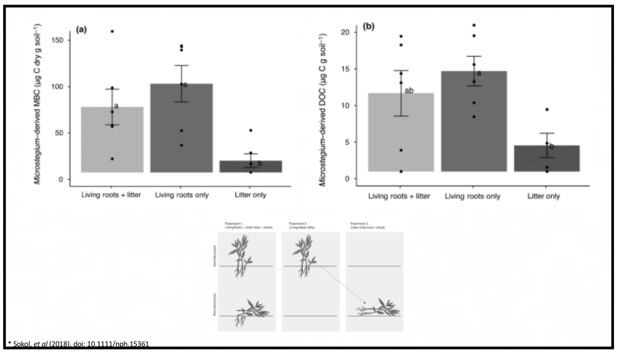
Key words: carbon cycle, litter inputs, living roots, microbial biomass, natural-abundance ^{13}C tracer, rhizodeposition, soil carbon formation, soil organic matter.

Summary

- Soil organic carbon (SOC) is primarily formed from plant inputs, but the relative carbon (C) contributions from living root inputs (i.e. rhizodeposits) vs litter inputs (i.e. root + shoot litter) are poorly understood. Recent theory suggests that living root inputs exert a disproportionate influence on SOC formation, but few field studies have explicitly tested this by separately tracking living root vs litter inputs as they move through the soil food web and into distinct SOC pools.
- We used a manipulative field experiment with an annual C_4 grass in a forest understory to differentially track its living root vs litter inputs into the soil and to assess net SOC formation over multiple years.
- We show that living root inputs are 2–13 times more efficient than litter inputs in forming both slow-cycling, mineral-associated SOC as well as fast-cycling, particulate organic C. Furthermore, we demonstrate that living root inputs are more efficiently anabolized by the soil microbial community *en route* to the mineral-associated SOC pool (dubbed 'the *in vivo* microbial turnover pathway').
- Overall, our findings provide support for the primacy of living root inputs in forming SOC. However, we also highlight the possibility of nonadditive effects of living root and litter inputs, which may deplete SOC pools despite greater SOC formation rates.

* Sokol, *et al* (2018), doi: 10.1111/nph.15361





ANNUAL REVIEWS
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The Ecology of Soil Carbon: Pools, Vulnerabilities, and Biotic and Abiotic Controls

Annual Review of Ecology, Evolution, and Systematics
Vol. 48:419-445 (Volume publication date November 2017)
First published online as a Review in Advance on September 6, 2017
https://doi.org/10.1146/annurev-ecolsys-112414-054234

ANNUAL REVIEWS

The Ecology of Soil Carbon: Pools, Vulnerabilities, and Biotic and Abiotic Controls

Abstract

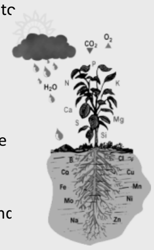
Soil organic matter (SOM) anchors global terrestrial productivity and food and fiber supply. SOM retains water and soil nutrients and stores more global carbon than do plants and the atmosphere combined. SOM is also decomposed by microbes, returning CO_2, a greenhouse gas, to the atmosphere. Unfortunately, soil carbon stocks have been widely lost or degraded through land use changes and unsustainable forest and agricultural practices. To understand its structure and function and to maintain and restore SOM, we need a better appreciation of soil organic carbon (SOC) saturation capacity and the retention of above- and belowground inputs in SOM. Our analysis suggests root inputs are approximately five times more likely than an equivalent mass of aboveground litter to be stabilized as SOM. Microbes, particularly fungi and bacteria, and soil faunal food webs strongly influence SOM decomposition at shallower depths, whereas mineral associations drive stabilization at depths greater than ~30 cm. Global uncertainties in the amounts and locations of SOM include the extent of wetland, peatland, and permafrost systems and factors that constrain soil depths, such as shallow bedrock. In consideration of these uncertainties, we estimate global SOC stocks at depths of 2 and 3 m to be between 2,270 and 2,770 Pg, respectively, but could be as much as 700 Pg smaller. Sedimentary deposits deeper than 3 m likely contain >500 Pg of additional SOC. Soils hold the largest biogeochemically active terrestrial carbon pool on Earth and are critical for stabilizing atmospheric CO_2 concentrations. Nonetheless, global pressures on soils continue from changes in land management, including the need for increasing bioenergy and food production.

Vegetation type or treatment	Belowground carbon inputs retained in SOM (%)	Aboveground carbon inputs retained in SOM (%)	Ratio	Reference
Conventional agriculture	35%	4.8%	7.4	Kong & Six 2010
Low-input agriculture	65%	4.9%	13.2	Kong & Six 2010
Organic agriculture	91%	3.6%	25.6	Kong & Six 2010
Mixed C_3 and C_4 crops	36%	4.0%	9.0	Ghafoor et al. 2017
Mixed C_3 and C_4 fertilized crops	18%	10%	1.8	Ghafoor et al. 2017
Maize	61%	5.0%	12.2	Mazzilli et al. 2015
Soybean	80%	3.0%	26.7	Mazzilli et al. 2015
Rye cover crop, 5 months	26%	5.2%	5.0	Austin et al. 2017
Rye cover crop, 12 months	27%	3.5%	7.7	Austin et al. 2017
Rye cover crop	24%	5.9%	4.1	Austin et al. 2017
Maize	21%	12%	1.7	Bolinder et al. 1999
Maize	38%	11%	3.5	Balesdent & Balabane 1996
Maize	73%	14%	5.1	Clapp et al. 2000
Maize, fertilized	58%	16%	3.6	Clapp et al. 2000
Vetch	49%	13%	3.7	Puget & Drinkwater 2001
Maize	34%	8.0%	4.3	Barber 1979
Mix C_3 and C_4 crops	39%	17%	2.3	Kätterer et al. 2011
Average, median	46%, 39%	8.3%, 6.6%	8.1, 5.0	

* Jackson *et al* (2017), doi: 10.1146/annurev-ecolsys-112414- 054234

In Summary

- We must integrate all 3 – chemistry, physics and biology into our 'soil health' thinking.
- More plant diversity is good for ecosystem benefit.
- More plant diversity (via root exudates) drives microbial processes and hence SOC sequestration (farm resilience).
- Root exudates are emerging as a critical piece of the puzzle which for the most part are overlooked.
- We need to redesign our production systems so ecological processes support plant production, ecosystem services and farm profitability.



Joel Williams

Integrated Soils

Soil Health and Nitrogen Management

Part 2: Integrated Nitrogen Management

www.integratedsoils.com
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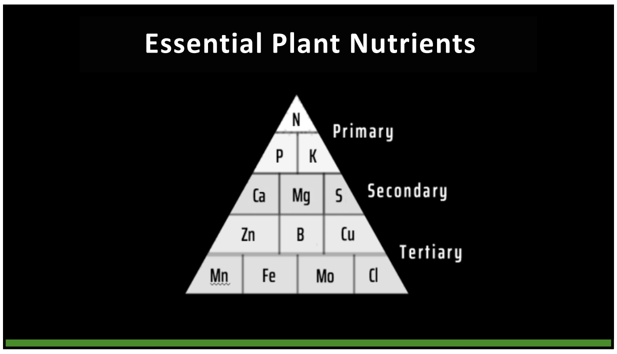
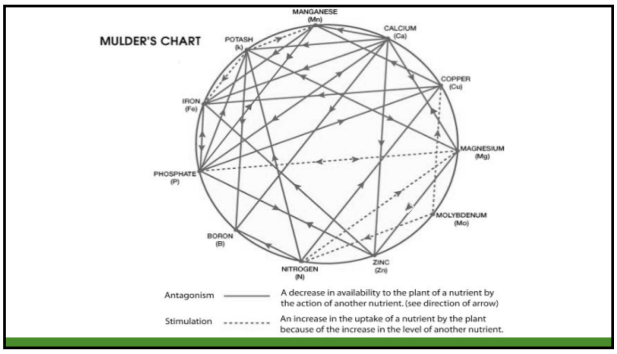
Key Functions of Essential Nutrients

- *N – Chlorophyll, AA, P*
- *P – Energy, root development*
- *K – Enzyme production, sugar movement, N utilisation*
- *Ca – Cell wall strength*
- *Mg – Chlorophyll*
- *S – N utilisation, root development*
- *Si – cell wall strength*
- *B – sugar translocation, reproductive processes*
- *Cu – disease protection*
- *Zn – auxin production, leaf size*
- *Mn – reproductive processes*
- *Fe – chlorophyll production*
- *Mo – N utilisation*
- *Co – N fixation*
- *Ni – urease enzyme*

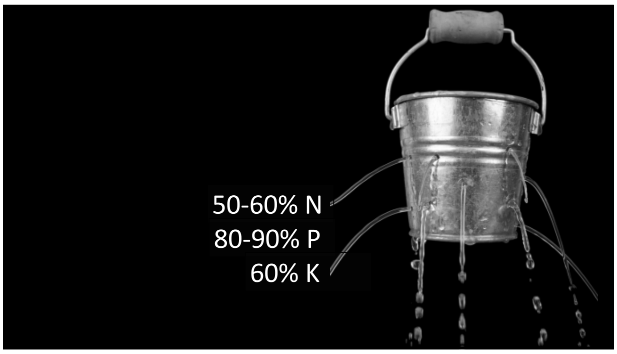


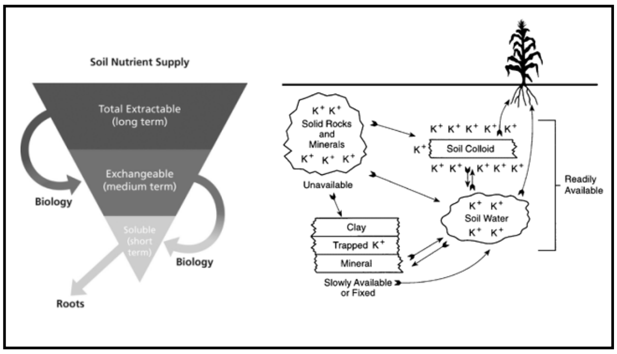


Nutrient Efficiency

- How efficient are we at delivering nutrients to crops?
- How much of our applied nutrients are actually being taken up by plants?
  - N ~ 40-50% of applied N [1,3]
  - P ~ 10-20% of applied P [1,2]
  - K ~ 40% of applied K [1]

[1] Baligar and Bennett, 1986; [2] Richardson, 2000; [3] Chen et al. 2008





Integrated Nutrient Management

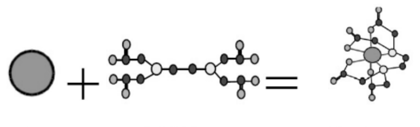
- INM simply ***integrates as many tools as possible*** to manage fertility to reduce dependency on artificial inputs.
- The INM strategy is broadly about combining ***organics with inorganics*** but it also places importance on nutrient recycling via:
  - Crop residues
  - Other biosolids such as manure and compost
  - Increasing biological N fixation (BNF) through leguminous cover crops
  - Using biofertilisers/microbial inoculants
  - Integrating livestock

* Naylor *et al.* (2005).

Nutrients and Carbon

- **Every single time** any nutrients are applied, they should be **combined** with a carbon source (liquid or dry).
- The carbon **binds** to the nutrients **chelating** and **complexing** them, **stabilising** them, **buffering** them and improving **uptake** by plants.

Chelation



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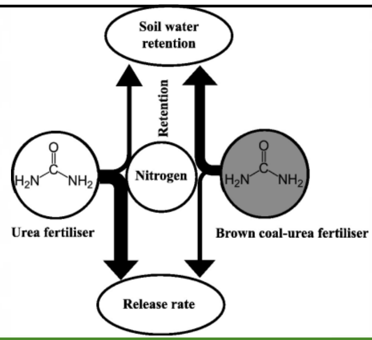


* ?

Integrated Nutrient Management

- INM – carbon protects biology.
- Research findings investigating soil life recovery after:
  - Fumigant application vs
  - Fumigant + composted manure
- Fumigant: **little recovery** of soil function **12** weeks later.
- Fumigant + compost: **normal** biological activity observed within **8-12** weeks.

* * Dungan, et al (2006), doi: 10.1111/j.1574-6941.2003.tb01047.x

INM: Fertilisers – with or without C base?

- 200 kg/ha of nitrogen was added to the soil in the form of:
  - Ammonium nitrate, or
  - Dairy manure
- Soil respiration and enzyme activity were higher in the organically amended soil*.
- Increasing carbon in your fertiliser program will increase microbial health irrespective of nutrient content.

* Marinari, et al (2000), doi: 10.1016/S0960-8524(99)00094-2

Carbon Sources

Liquid Carbon
- Molasses
- Fulvic acid & Humic acid
- Fish Emulsions
- Seaweed/Kelp Extracts
- Plant Teas/Extracts

Dry Carbon
- Compost
- Manures
- Raw Humates
- Humic & Fulvic granules/powder
- Green Manures & Cover Crops

Manure Management

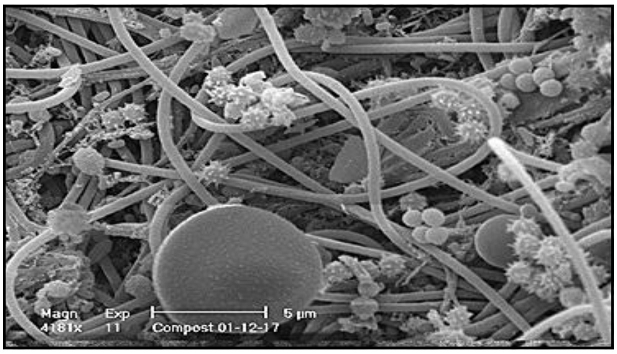
- The benefits of manure to soil health can be greatly enhanced by composting the manure first.
- Composting stabilises the nutrients in manure and improves its biological qualities.
- Manure and Compost are not the same thing.

Compost vs Manure?

- **Aerobic** decomposition of organic materials into humus.
- Original materials are unidentifiable in well humified (humus rich) compost .
- Good quality compost contains all **macro** and **micro nutrients**, all in stabilised, slow release form.
- Compost is also rich in beneficial **humic substances** which condition soil, improve nutrient uptake and feed soil microbes.

Compost

- But most importantly, compost is alive! It is a **living** fertiliser (biofertiliser).
- Quality compost is teeming with beneficial microbes (many of which are same species as found in soils).
- Organic carbon in compost is also a 'house' for microbes, being both a **house** and a **food** source for them.
- Therefore, compost is an ideal way to inoculate soils with beneficial microbes.



Compost

- Compost quality depends on:
  - Food sources (C:N)
  - Moisture
  - Temperature
  - Oxygen
  - Turning
  - Maturation

C:N Ratio

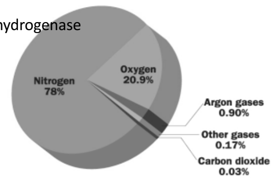
- Balance of ingredients is important:
  - **carbon**-rich woody materials (browns)
  - **nitrogen**-rich green leafy matter or manures (greens)
  - must be balanced = C:N Ratio.
- **Browns** – stubble, straw, dry grass, woodchips/shavings, autumn leaves, newspaper, tree prunings.
- **Greens** – manures, chicken litter, fresh grass, green leaves, vegetable waste, blood and bone, legume hay.

Unfinished Compost?

- **Unfinished** compost will scavenge nutrients from the soil (esp N) to finish its decomposition **before** it releases anything back to the soil.

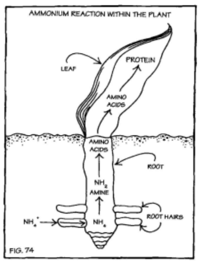
Free Nitrogen

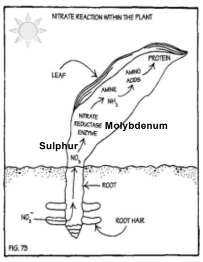
- Mineral constraints to Biological N Fixation?
  - **Mo**: Mo-nitrogenase, nodule function
  - **Fe**: Fe-nitrogenase, Leghemoglobin, Fe-hydrogenase
  - **Ni**: Ni-hydrogenase
  - **Co**: nodule initiation
  - **B**: nodule development & maturation
  - **Ca**: low multiplication of rhizobia



* O'hara, G.W., Boonkerd, N. & Dilworth, M.J. Plant Soil (1988) 108: 93. https://doi.org/10.1007/BF02370104
* Weisany, Weria & Raei, Yaghoub & Haji Allahverdipoor, Kaveh. (2015). Role of Some of Mineral Nutrients in Biological Nitrogen Fixation Bulletin of Environment, Pharmacology and Life Sciences. 2. 77-84.

Ammonium vs Nitrate





PLOS | BIOLOGY
FIFTEENTH ANNIVERSARY

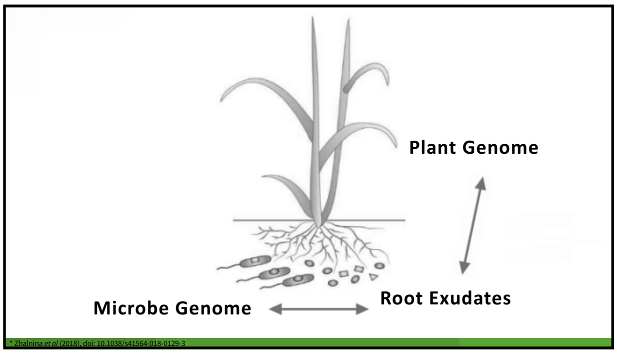
Nitrogen fixation in a landrace of maize is supported by a mucilage-associated diazotrophic microbiota

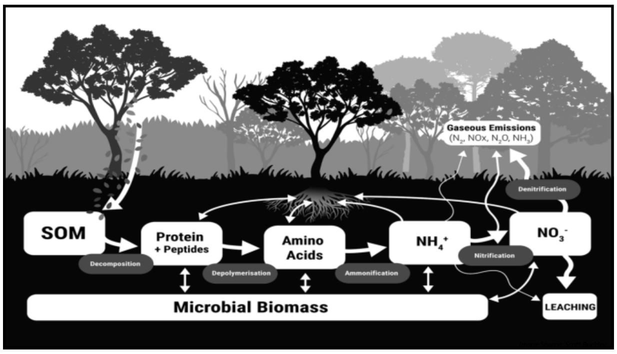
Published: August 7, 2018 • https://doi.org/10.1371/journal.pbio.2006352

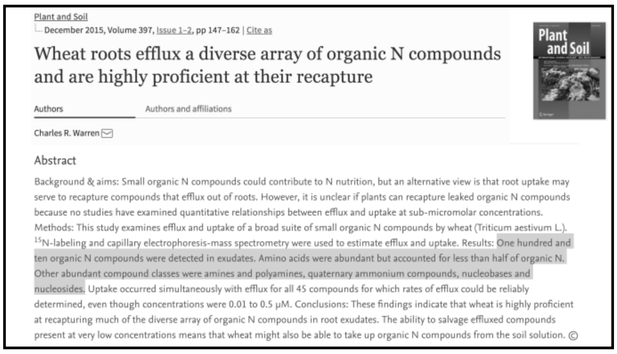
Abstract

Plants are associated with a complex microbiota that contributes to nutrient acquisition, plant growth, and plant defense. Nitrogen-fixing microbial associations are efficient and well characterized in legumes but are limited in cereals, including maize. We studied an indigenous landrace of maize grown in nitrogen-depleted soils in the Sierra Mixe region of Oaxaca, Mexico. This landrace is characterized by the extensive development of aerial roots that secrete a carbohydrate-rich mucilage. Analysis of the mucilage microbiota indicated that it was enriched in taxa for which many known species are diazotrophic, was enriched for homologs of genes encoding nitrogenase subunits, and harbored active nitrogenase activity as assessed by acetylene reduction and $^{15}N_2$ incorporation assays. Field experiments in Sierra Mixe using ^{15}N natural abundance or ^{15}N-enrichment assessments over 5 years indicated that atmospheric nitrogen fixation contributed 29%–82% of the nitrogen nutrition of Sierra Mixe maize.

* Van Deynze *et al* (2018), doi: 10.1371/journal.pbio.2006352






Plant and Soil
December 2015, Volume 397, Issue 1–2, pp 147–162 | Cite as

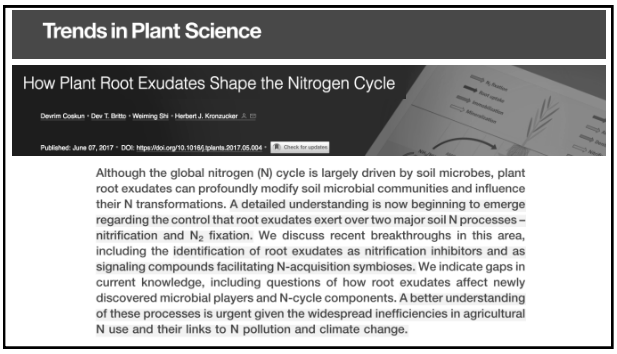
Wheat roots efflux a diverse array of organic N compounds and are highly proficient at their recapture

Authors Authors and affiliations

Charles R. Warren

Abstract

Background & aims: Small organic N compounds could contribute to N nutrition, but an alternative view is that root uptake may serve to recapture compounds that efflux out of roots. However, it is unclear if plants can recapture leaked organic N compounds because no studies have examined quantitative relationships between efflux and uptake at sub-micromolar concentrations. Methods: This study examines efflux and uptake of a broad suite of small organic N compounds by wheat (Triticum aestivum L.). ^{15}N-labeling and capillary electrophoresis-mass spectrometry were used to estimate efflux and uptake. Results: One hundred and ten organic N compounds were detected in exudates. Amino acids were abundant but accounted for less than half of organic N. Other abundant compound classes were amines and polyamines, quaternary ammonium compounds, nucleobases and nucleosides. Uptake occurred simultaneously with efflux for all 45 compounds for which rates of efflux could be reliably determined, even though concentrations were 0.01 to 0.5 μM. Conclusions: These findings indicate that wheat is highly proficient at recapturing much of the diverse array of organic N compounds in root exudates. The ability to salvage effluxed compounds present at very low concentrations means that wheat might also be able to take up organic N compounds from the soil solution. ©

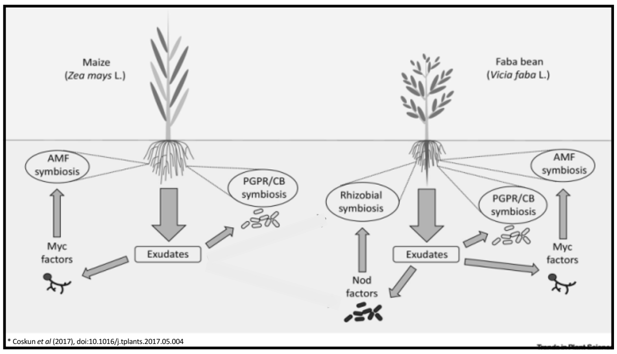

Trends in Plant Science

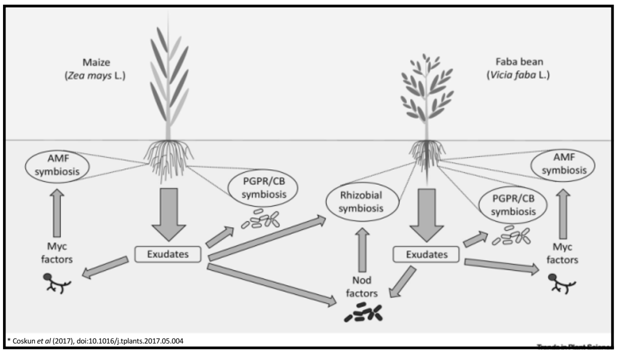
How Plant Root Exudates Shape the Nitrogen Cycle

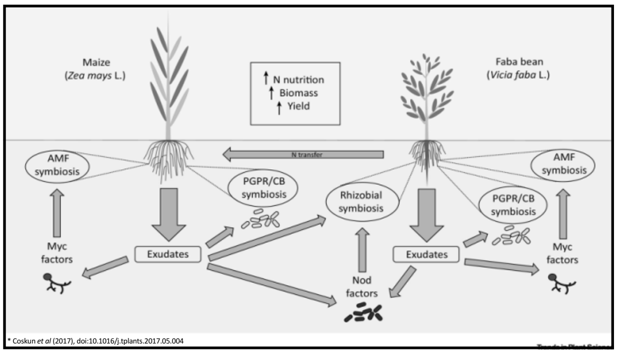
Devrim Coskun • Dev T. Britto • Weiming Shi • Herbert J. Kronzucker

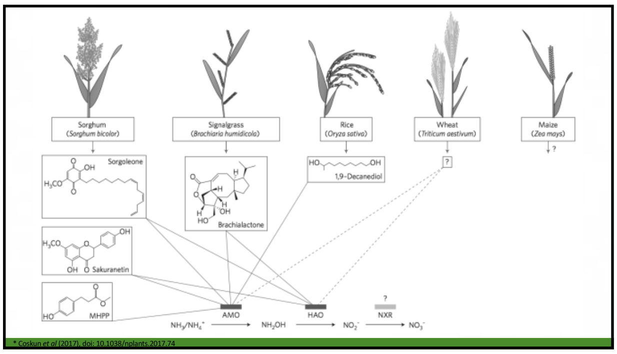
Published: June 07, 2017 • DOI: https://doi.org/10.1016/j.tplants.2017.05.004 • Check for updates

Although the global nitrogen (N) cycle is largely driven by soil microbes, plant root exudates can profoundly modify soil microbial communities and influence their N transformations. A detailed understanding is now beginning to emerge regarding the control that root exudates exert over two major soil N processes – nitrification and N_2 fixation. We discuss recent breakthroughs in this area, including the identification of root exudates as nitrification inhibitors and as signaling compounds facilitating N-acquisition symbioses. We indicate gaps in current knowledge, including questions of how root exudates affect newly discovered microbial players and N-cycle components. A better understanding of these processes is urgent given the widespread inefficiencies in agricultural N use and their links to N pollution and climate change.









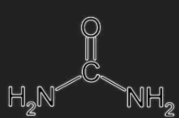
Urea as Foliar

- ***Soil applied urea*** is lost via volatilisation or converted into leachable nitrates.
- Plants contain a specific absorption channel for the urea molecule.
- Urea is ***readily absorbed via foliar*** tissues – urea > ammonium > nitrate.
- Foliar applied urea improves NUE via rapid absorption and efficient utilisation/conversion into amino acids/proteins.

* Witte, C. P. Urea metabolism in plants. Plant Science 180, 431–438 (2011)

Urea as Foliar

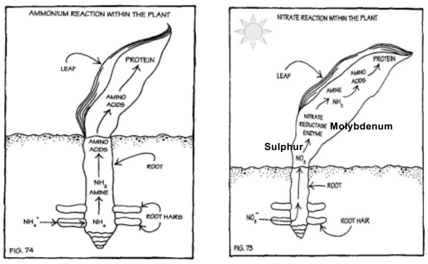
- A range of evidence highlights effective response of foliar urea solutions at:
  - 10, 20 or 80 kg/ha urea
  - 3, 4, 5 and 7% urea solutions
- Timing
  - ***Cereals***: at anthesis + 2 weeks
  - ***OSR***: mid-end of flowering
  - ***Pulses***: 2% solution at pod set
- Spray pH – 6.5 considered optimum



Nickel

- Nickel [Ni] was classified essential for plant growth in 1978.
- Ni is part of the ***urease enzyme*** which splits the urea molecule liberating the N for plant metabolism.
- Without Ni/urease, urea can build up in plant tissues and become toxic.
- Plants specifically fed urea without Ni can be 'functionally N deficient'
- ***Nickel sulphate*** at 0.2% solution in barley – also 50-100 mg/ha on pastures.

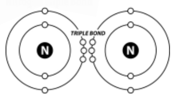
Ammonium vs Nitrate



Nitrogen Synergists

N Utilisation

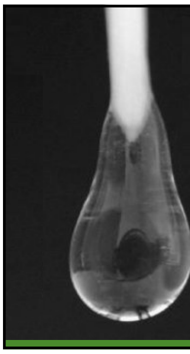
- Sulphur
- Molybdenum
- Magnesium
- Nickel



N Fixation

- Molybdenum
- Iron
- Cobalt
- Boron
- Calcium
- Nickel

- Do we consider **all** of these synergistic minerals **along with** rhizobium or nitrogen inputs in our attempts to optimise N fixation or N utilisation?



Rhizosphere link to Foliars…

- Foliar applying nutrients is actually all about **indirect microbial** stimulation.
- When calculated back, the amount of nutrient applied via foliar applications is very small.
- Effective foliar applied nutrients prime photosynthesis.
- Products of photosynthesis are exuded to **feed soil microbes**.
- Soil microbes in return, solubilise **much more** nutrient **from the soil** and feed the plant.

Photosynthesis

$6CO_2 + 6H_2O$ ----------------> $C_6H_{12}O_6$ (sugar) + $6O_2$

minerals/enzymes

$C_6H_{12}O_6$ (sugar) ------------------>

minerals/enzymes

- ***Complex sugars***
- ***Carbohydrates***
- ***Amino Acids, Proteins***
- ***Fats & Oils***
- ***Hormones***
- ***Vitamins***
- ***Phyto-nutrients***
- ***Protective Compounds***

Plant Response to Foliars?

- Formulation
  - pH, EC, adjuvants, carbon
- Application Considerations
  - Nozzle, pressure,
- Crop Characteristics
  - Crop stage, leaf surface, abiotic & biotic stresses
- Environment
  - Time of day, humidity, temperature, light
- F-A-C-E

Vol. 64, 2018, No. 3: 138–146 *Plant Soil Environ.*

https://doi.org/10.17221/9/2018-PSE

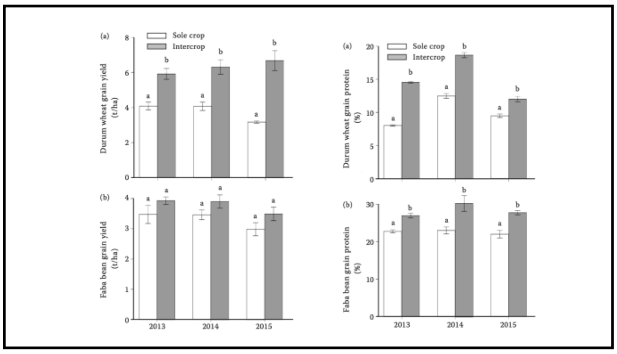
The effect of intercropping on the efficiency of faba bean – rhizobial symbiosis and durum wheat soil-nitrogen acquisition in a Mediterranean agroecosystem

Ghiles KACI[1,*], Didier BLAVET[2], Samia BENLAHRECH[1], Ernest KOUAKOUA[2], Petra COUDERC[3], Philippe DELEPORTE[4], Dominique DESCLAUX[5], Mourad LATATI[1], Marc PANSU[2], Jean-Jacques DREVON[6], Sidi Mohamed OUNANE[1]

ABSTRACT

Kaci G., Blavet D., Benlahrech S., Kouakoua E., Couderc P., Deleporte P., Desclaux D., Latati M., Pansu M., Drevon J.-J., Ounane S.M. (2018): The effect of intercropping on the efficiency of faba bean – rhizobial symbiosis and durum wheat soil-nitrogen acquisition in a Mediterranean agroecosystem. Plant Soil Environ., 64: 138–146.

The aim of this study was to compare the rhizobial symbiosis and carbon (C) and nitrogen (N) accumulations in soil and plants in intercropping *versus* sole cropping in biennial rotation of a cereal – durum wheat (*Triticum durum* Desf.), and a N_2-fixing legume – faba bean (*Vicia faba* L.) over a three-year period at the INRA (National Institue of Agronomic Research) experimental station in the Mauguio district, south-east of Montpellier, France. Plant growth, nodulation and efficiency in the use of rhizobial symbiosis (EURS) for the legume, nitrogen nutrition index (NNI) for the cereal, and N and C accumulation in the soil were evaluated. Shoot dry weight (SDW) and NNI were significantly higher for intercropped than for the sole cropped wheat whereas there was no significant difference on SDW between the intercropped and sole cropped faba beans. EURS was higher in intercropped than in sole cropped faba bean. Furthermore, by comparison with a weeded fallow, there was a significant increase in soil C and N content over the three-year period of intercropping and sole cropping within the biennial rotation. It is concluded that intercropping increases the N nutrition of wheat by increasing the availability of soil-N for wheat. This increase may be due to a lower interspecific competition between legume and wheat than intra-specific competition between wheat plants, thanks to the compensation that the legume can achieve by fixing the atmospheric nitrogen.



OCL 2015, 22(3) D302

DOI: 10.1051/ocl/2015014

OCL
Available online at:
www.ocl-journal.org

RESEARCH ARTICLE – DOSSIER OPEN ∂ ACCESS

Abstract – Mixing plant species in agroecosystems is highlighted as an agroecological solution to reduce pesticides and fertilizers while maintaining profitability. In the French context, intercropping frost-sensitive legume crops with winter oilseed rape is potentially interesting and began to be implemented by farmers. In this study we aimed at measuring the services and disservices of this intercrop with three different legume mixtures, in terms of growth and yield for rapeseed, ground cover of weeds in autumn and damage caused by rape winter stem weevil. The experiment was carried out at four sites from 2011 to 2014. We showed higher total aerial dry weights and total aerial nitrogen contents in the intercrops compared to sole winter oilseed rape in November. The companion plants contributed to the control of weeds and the mitigation of rape winter stem weevil damage, notably through the increase in the total aerial weight. In spring, after destruction of the companion plants, the intercrops had partially compensated a reduction in the N fertilization rate (–30 kg per hectare) in terms of aerial nitrogen content in rapeseed, with no consequences on the yield which was maintained or even increased. There were probably other interactions such as an improvement in rapeseed root exploration. The consequences were an increase in the nitrogen use efficiency in intercrops. The intercrop with faba bean and lentil showed the best results in terms of autumn growth, weed control, reduction in rape winter stem weevil damage, and rapeseed N content in spring and yield. Intercropping frost-sensitive legume crops with winter oilseed rape is thus a promising way to reconcile yield and reduction in pesticides and fertilizer use and perhaps to benefit more widely to the cropping system.

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Can legume companion plants control weeds without decreasing crop yield? A meta-analysis

CrossMark

Valentin Verret*, Antoine Gardarin, Elise Pelzer, Safia Médiène, David Makowski, Muriel Valantin-Morison

UMR Agronomie, INRA, AgroParisTech, Université Paris-Saclay, 78850 Thiverval-Grignon, France

A B S T R A C T

Companion plant intercropping involves growing a cash crop with another plant that is not harvested, to confer a set of benefits on the crop and the environment. Weed control and herbicide use reduction are one of the principal reasons for adopting this approach. Companion plants should compete with weeds for light, nutrients and water, but they may also compete with the crop. The species grown must therefore be carefully chosen and managed so as to outcompete weeds but limit competition with the crop and yield loss. In this meta-analysis, we aimed to quantify the effects of companion plants on weed regulation and cash crop yields, and to analyze their sources of variability. We reviewed different intercropping systems involving an annual cash crop and a legume companion plant from around the world. We report data from 34 scientific articles, corresponding to 476 experimental units (i.e. combinations of site × year × cash crop × legume companion plant species × agricultural practices), and we explore whether intercropping with legume companion plants can control weeds while maintaining crop yield. Yield and weed biomass ratios were analyzed as response variables. We used the type of cash crop (straw cereals, maize or other crops), the methods used to establish the companion plants (living mulch, synchronized sowing or relay intercropping) and the overlap between the growth periods of the companion plants and the cash crop as explanatory variables.

Intercropping with a companion plant resulted in a lower weed biomass and a higher yield (win-win situation) than non-weeded or weeded control treatments, in 52% and 36%, respectively, of the experimental units considered. A higher weed biomass associated with a lower yield (lose-lose) was observed in only 13% and 26% of the experimental units, in comparisons with non-weeded and weeded control treatments, respectively. Considering all the experimental units together, the companion plants had no significant effect on cash crop yield, but significantly decreased weed biomass, by 56% relatively to a non-weeded control treatment, and 42% relative to a weeded control treatment. The greatest benefits from companion plant intercropping were reported for maize, with yields 37% higher than those for non-weeded control treatments. The other explanatory variables tested had no significant effect on yield or weed control. Thus, the use of legume companion plants generally seems to enhance weed control without reducing crop yield, but the conditions giving rise to win-win situations should be explored further, to encourage the spread of this technique among farmers.

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A B S T R A C T

Satisfying the nutritional needs of a growing population whilst limiting environmental repercussions will require sustainable intensification of agriculture. We argue that intercropping, which is the simultaneous production of multiple crops on the same area of land, could play an essential role in this intensification. We carried out the first global meta-analysis on the multifaceted benefits of intercropping. The objective of this study was to determine the benefits of intercropping in terms of energetic, economic and land-sparing potential through the framework of the stress-gradient hypothesis. We expected more intercropping benefits under stressful abiotic conditions. From 126 studies that were retrieved from the scientific literature, 939 intercropping observations were considered. When compared to the same area of land that was managed in monoculture, intercrops produced 38% more gross energy (mean relative land output of 1.38) and 33% more gross incomes (mean relative land output of 1.33) on average, whilst using 23% less land (mean land equivalent ratio of 1.30). Irrigation and the aridity index in non-irrigated intercrops did not affect land equivalent ratio, thereby indicating that intercropping remains beneficial, both under stressful and non-stressful contexts concerning moisture availability. Fertilisation and intercropping patterns (rows and strips *vs.* mixed) did not affect land equivalent ratio. Although intercropping offers a great opportunity for intensification of existing agricultural lands, many challenges need to be tackled by experts from multiple disciplines to ensure its feasible implementation.

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PLANT DIVERSITY, SOIL MICROBIAL COMMUNITIES, AND ECOSYSTEM FUNCTION: ARE THERE ANY LINKS?

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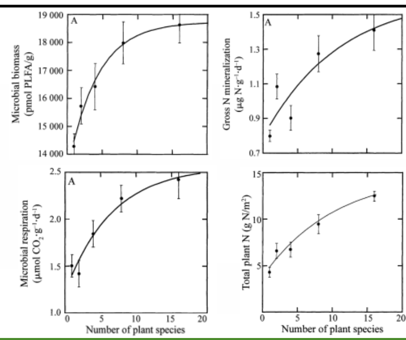
Abstract. A current debate in ecology centers on the extent to which ecosystem function depends on biodiversity. Here, we provide evidence from a long-term field manipulation of plant diversity that soil microbial communities, and the key ecosystem processes that they mediate, are significantly altered by plant species richness. After seven years of plant growth, we determined the composition and function of soil microbial communities beneath experimental plant diversity treatments containing 1–16 species. Microbial community biomass, respiration, and fungal abundance significantly increased with greater plant diversity, as did N mineralization rates. However, changes in microbial community biomass, activity, and composition largely resulted from the higher levels of plant production associated with greater diversity, rather than from plant diversity per se. Nonetheless, greater plant production could not explain more rapid N mineralization, indicating that plant diversity affected this microbial process, which controls rates of ecosystem N cycling. Greater N availability probably contributed to the positive relationship between plant diversity and productivity in the N-limited soils of our experiment, suggesting that plant–microbe interactions in soil are an integral component of plant diversity's influence on ecosystem function.

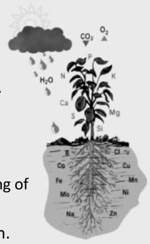
* Zak *et al.*, (2003); doi: 10.1890/02-0433



* Zak *et al.*, (2003); doi: 10.1890/02-0433

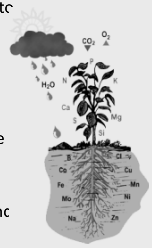
In Summary – Part 2

- Bring all the pieces of the puzzle together in an integrated strategy for nitrogen management.
  - Complete plant nutrition and nutrient synergists.
  - INM (combine with carbon).
  - Composting manures to stabilise N and improve bio quality.
  - Consider nutrition for rhizobia and free living N fixers.
  - Foliar applied nutrients (esp urea) for increased NUE.
  - More plant diversity – pastures and intercrops.
  - More diverse root exudates for overall soil health and cycling of soil mineral reserves.
- Integrate all relevant strategies into your systems approach.

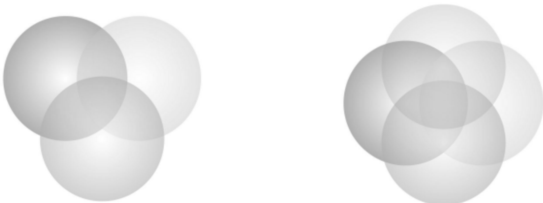


In Summary – Part 1

- We must integrate all 3 – chemistry, physics and biology into our 'soil health' thinking ***and go beyond this with plants***.
- More plant diversity is good for ecosystem benefit.
- More plant diversity (via root exudates) drives microbial processes and hence SOC sequestration (farm resilience).
- Root exudates are emerging as a critical piece of the puzzle which for the most part are overlooked.
- We need to redesign our production systems so ecological processes support plant production, ecosystem services and farm profitability.



Plant Diversity, Plant Nutrition?



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Thank you

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