Leveraging soil biology for nutrient cycling

SSCA: Feb 16 2022

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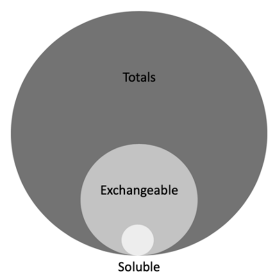
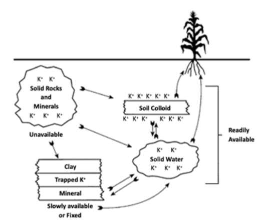
Session Outline

Introduction
Using Plants
Feed Biology - Biostimulants
Inoculate Biology - Biofertilizer

Introduction



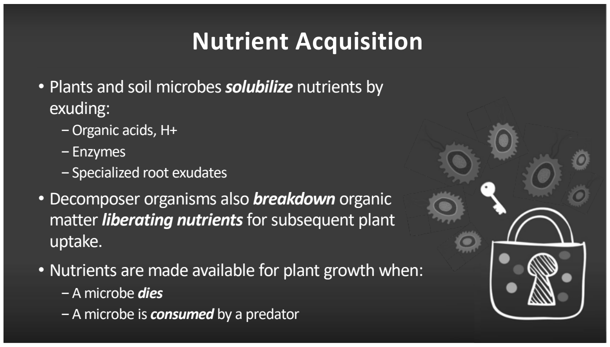


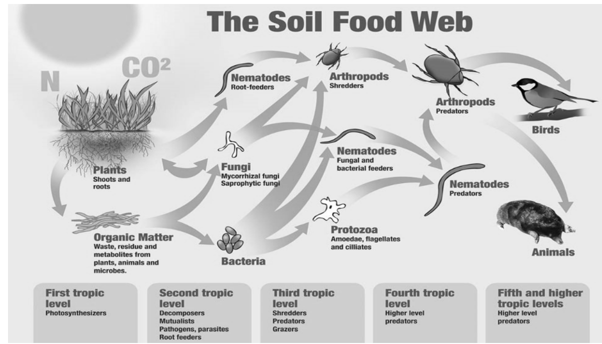
Available vs Total Nutrients

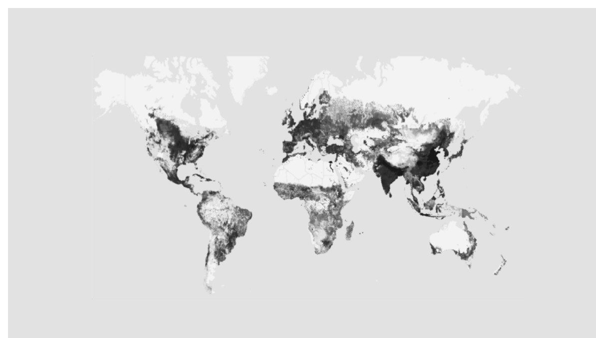
	mg/kg	Field 1	Field 2	Field 3
Ca	Available	5045	6983	7505
	Total	38,804	43,317	47,383
Mg	Available	428	458	985
	Total	14,404	10,453	17,071
K	Available	184	239	347
	Total	1,341	1,657	2,164
S	Available	7.7	10	6.8
	Total	206	213	188
P	Available	23	33	11
	Total	434	524	540

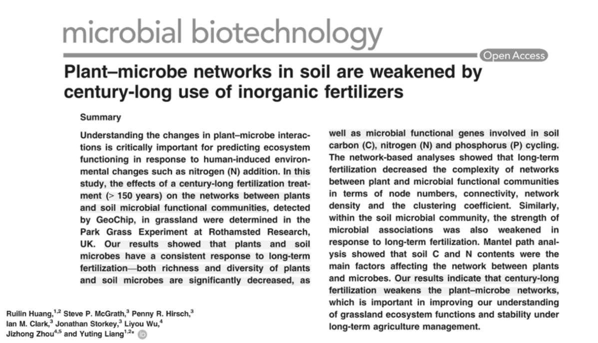
Available vs Total Nutrients

	mg/kg	Field 1	Field 2	Field 3
Zn	Available	0.5	0.5	0.4
	Total	39.9	41.5	63.4
Mn	Available	32	45	29
	Total	432	413	484
Fe	Available	19	14	20
	Total	14,515	13,444	18,044
Cu	Available	1.6	1.8	2.8
	Total	13.3	14.1	20.6
B	Available	0.39	0.43	0.58
	Total	8.5	9.7	13.5








microbial biotechnology
Open Access

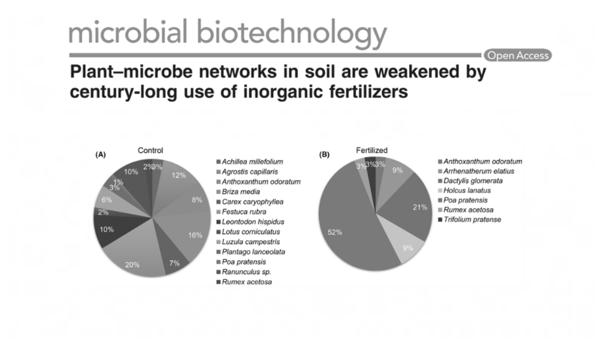
Plant–microbe networks in soil are weakened by century-long use of inorganic fertilizers

Summary

Understanding the changes in plant–microbe interactions is critically important for predicting ecosystem functioning in response to human-induced environmental changes such as nitrogen (N) addition. In this study, the effects of a century-long fertilization treatment (> 150 years) on the networks between plants and soil microbial functional communities, detected by GeoChip, in grassland were determined in the Park Grass Experiment at Rothamsted Research, UK. Our results showed that plants and soil microbes have a consistent response to long-term fertilization—both richness and diversity of plants and soil microbes are significantly decreased, as well as microbial functional genes involved in soil carbon (C), nitrogen (N) and phosphorus (P) cycling. The network-based analyses showed that long-term fertilization decreased the complexity of networks between plant and microbial functional communities in terms of node numbers, connectivity, network density and the clustering coefficient. Similarly, within the soil microbial community, the strength of microbial associations was also weakened in response to long-term fertilization. Mantel path analysis showed that soil C and N contents were the main factors affecting the network between plants and microbes. Our results indicate that century-long fertilization weakens the plant–microbe networks, which is important in improving our understanding of grassland ecosystem functions and stability under long-term agriculture management.

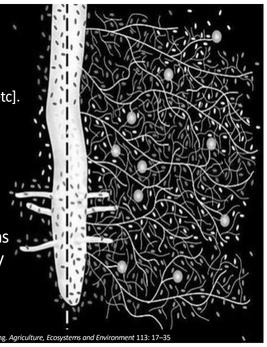
Ruilin Huang,[1,2] Steve P. McGrath,[3] Penny R. Hirsch,[3] Ian M. Clark,[3] Jonathan Storkey,[3] Liyou Wu,[4] Jizhong Zhou[4,5] and Yuting Liang[1,2*]

* Huang, R., *et al* (2019). doi:10.1111/1751-7915.13487

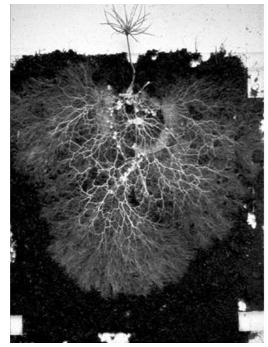


Starter P: Gain a Little or Lose a Lot?

- AMF are not solely about nutrient access [P etc].
- Secondary benefits of AMF include:
  - Drought resistance
  - Tolerance to salinity
  - Disease resistance
  - Tolerance to heavy metals
- Oversupply of P shuts down AMF associations thereby additionally limiting these secondary benefits.

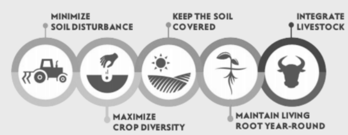


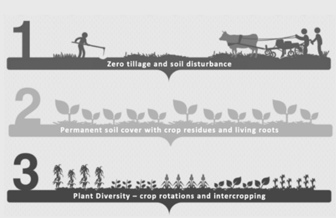
* Gosling, P., Hodge, A., Goodlass, G., and Bending G.D. (2006). Arbuscular mycorrhizal fungi and organic farming. *Agriculture, Ecosystems and Environment* 113: 17–35



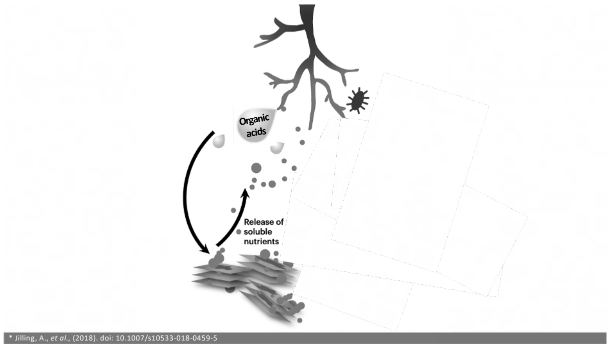
Improving NUE

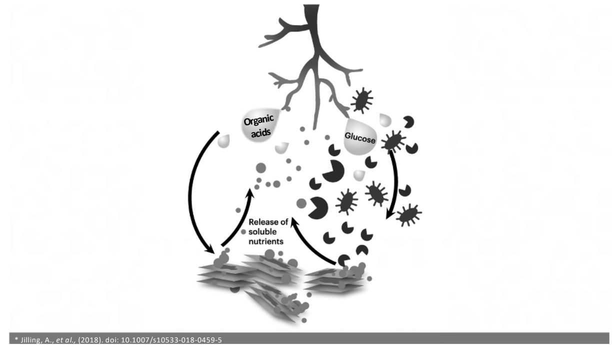
- Options to improve nutrient use efficiencies:
  - Integrated Nutrient Management
  - 4 R's
  - Organic amendments
  - Carbon based inputs
  - Seed treatments
  - Foliar sprays
  - Plants
  - Biostimulants
  - Biofertilizers

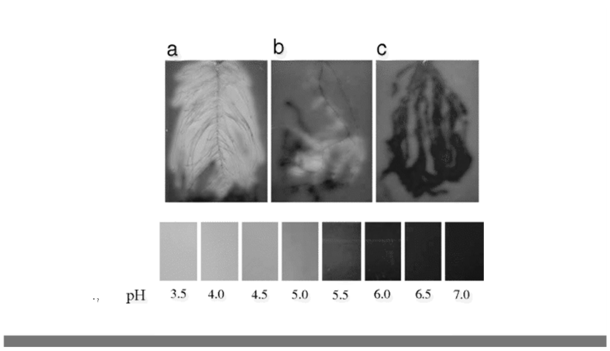


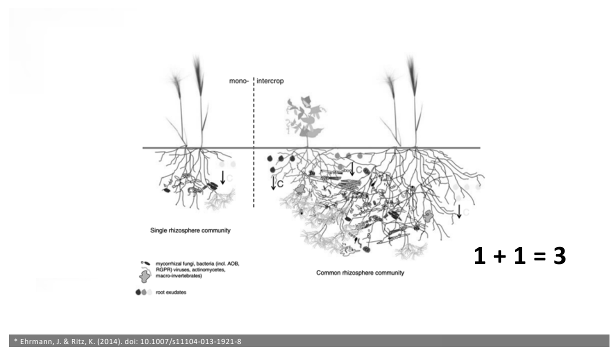


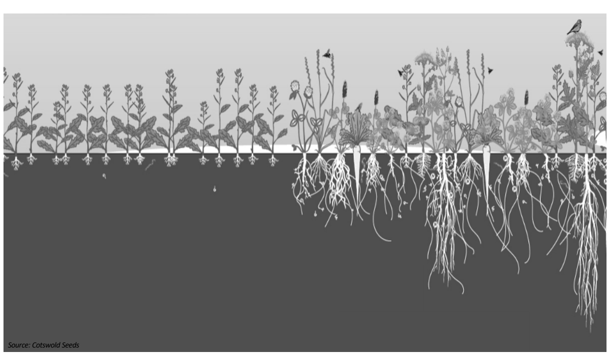
Plants

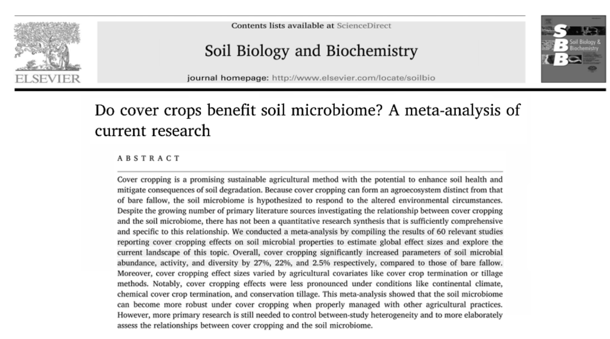











Contents lists available at ScienceDirect

Soil Biology and Biochemistry

journal homepage: http://www.elsevier.com/locate/soilbio

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Do cover crops benefit soil microbiome? A meta-analysis of current research

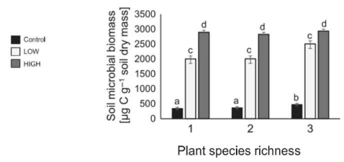
ABSTRACT

Cover cropping is a promising sustainable agricultural method with the potential to enhance soil health and mitigate consequences of soil degradation. Because cover cropping can form an agroecosystem distinct from that of bare fallow, the soil microbiome is hypothesized to respond to the altered environmental circumstances. Despite the growing number of primary literature sources investigating the relationship between cover cropping and the soil microbiome, there has not been a quantitative research synthesis that is sufficiently comprehensive and specific to this relationship. We conducted a meta-analysis by compiling the results of 60 relevant studies reporting cover cropping effects on soil microbial properties to estimate global effect sizes and explore the current landscape of this topic. Overall, cover cropping significantly increased parameters of soil microbial abundance, activity, and diversity by 27%, 22%, and 2.5% respectively, compared to those of bare fallow. Moreover, cover cropping effect sizes varied by agricultural covariates like cover crop termination or tillage methods. Notably, cover cropping effects were less pronounced under conditions like continental climate, chemical cover crop termination, and conservation tillage. This meta-analysis showed that the soil microbiome can become more robust under cover cropping when properly managed with other agricultural practices. However, more primary research is still needed to control between-study heterogeneity and to more elaborately assess the relationships between cover cropping and the soil microbiome.

* Kim, N., et al., (2020). doi: 10.1016/j.soilbio.2019.107701

Ecology and Evolution

Root exudate cocktails: the link between plant diversity and soil microorganisms?



* Steinauer, K., *et al.*, (2016). doi: 10.1002/ece3.2454

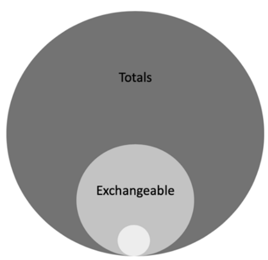
Root Exudate Cocktails

The ***quality*** and ***quantity*** of root exudates is determined by:

- ***Biotic Factors***
  - Plant species
  - Plant age/stage
  - Plant nutrition/photosynthesis
  - Neighbouring plants
  - Interacting organisms
  - Herbivores
- ***Abiotic Factors***
  - Environmental factors
  - Light
  - Temperature
  - Soil pH
  - Moisture
  - Soil nutrient supply

* Steinauer, K., et al., (2016). doi: 10.1002/ece3.2454 * Dietz, S., et al., (2020). doi:10.1038/s41598-019-54309-5

Image : Glyn Bengough



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Soil Biology and Biochemistry

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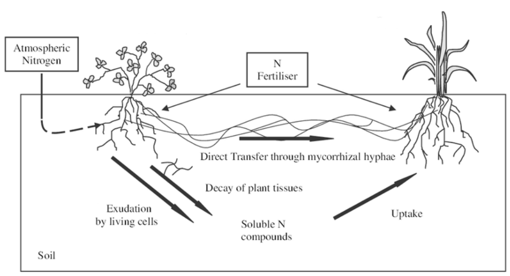
A meta-analysis of global cropland soil carbon changes due to cover cropping

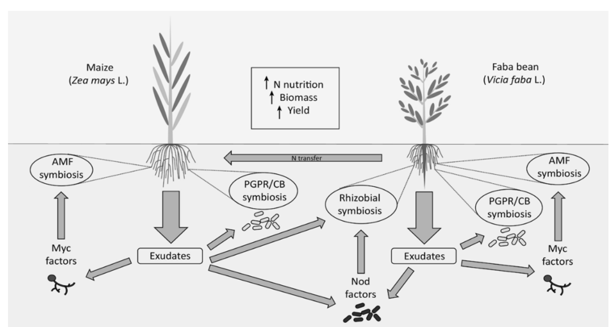
Cover Crops:

- SOC increase of 15%
- Clay soils more responsive that sandy
- More potential in temperate vs tropical
- Mixtures > Monocultures
- Surface soils more responsive (30cm)

* Jian, J., *et al.*, (2020). doi:10.1016/j.soilbio.2020.107735

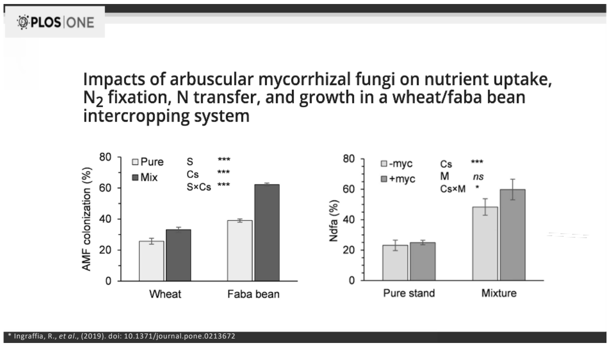


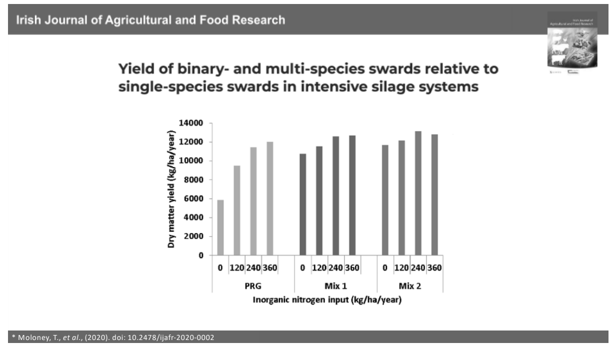
* Paynel, F., et al (2008). doi: 10.1051/agro:2007061

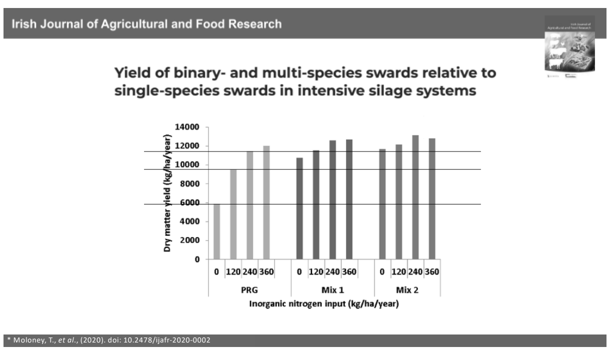


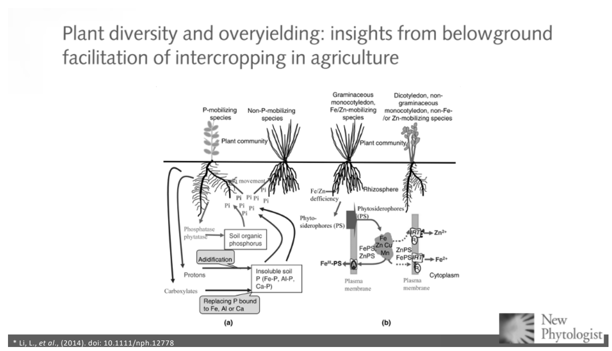
* https://doi.org/10.1016/j.tplants.2017.05.004

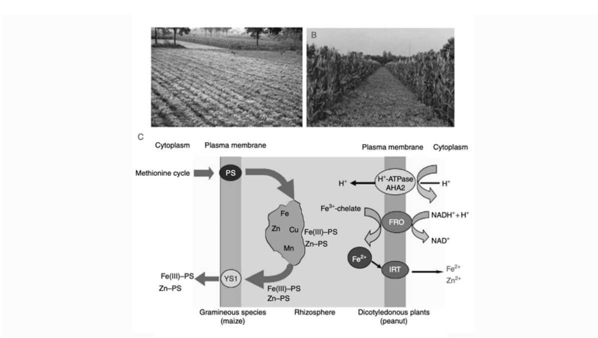
Trends in Plant Science











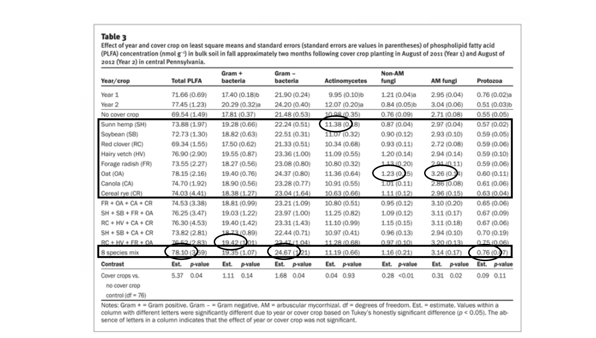


Table 3
Effect of year and cover crop on least square means and standard errors (standard errors are values in parentheses) of phospholipid fatty acid (PLFA) concentration (nmol g^{-1}) in bulk soil in fall approximately two months following cover crop planting in August of 2011 (Year 1) and August of 2012 (Year 2) in central Pennsylvania.

Year/crop	Total PLFA	Gram + bacteria	Gram – bacteria	Actinomycetes	Non-AM fungi	AM fungi	Protozoa
Year 1	71.66 (0.69)	17.40 (0.18)b	21.90 (0.24)	9.95 (0.10)b	1.21 (0.04)a	2.95 (0.04)	0.76 (0.02)a
Year 2	77.45 (1.23)	20.29 (0.32)a	24.20 (0.40)	12.07 (0.20)a	0.84 (0.05)b	3.04 (0.06)	0.51 (0.03)b
No cover crop	69.54 (1.49)	17.81 (0.37)	21.48 (0.53)	10.98 (0.35)	0.76 (0.09)	2.71 (0.08)	0.55 (0.05)
Sunn hemp (SH)	73.88 (1.97)	19.28 (0.66)	22.24 (0.51)	11.38 (0.18)	0.87 (0.04)	2.97 (0.04)	0.57 (0.02)
Soybean (SB)	72.73 (1.30)	18.82 (0.63)	22.51 (0.31)	11.07 (0.32)	0.90 (0.12)	2.93 (0.10)	0.59 (0.05)
Red clover (RC)	69.34 (1.55)	17.50 (0.62)	21.33 (0.51)	10.34 (0.68)	0.93 (0.11)	2.72 (0.08)	0.59 (0.06)
Hairy vetch (HV)	76.90 (2.90)	19.55 (0.87)	23.36 (1.00)	11.09 (0.55)	1.20 (0.14)	2.94 (0.14)	0.59 (0.10)
Forage radish (FR)	73.55 (2.27)	18.27 (0.56)	23.08 (0.80)	10.80 (0.32)	1.13 (0.20)	2.91 (0.11)	0.59 (0.06)
Oat (OA)	78.15 (2.16)	19.40 (0.76)	24.37 (0.80)	11.36 (0.64)	1.23 (0.25)	3.26 (0.14)	0.60 (0.11)
Canola (CA)	74.70 (1.92)	18.90 (0.56)	23.28 (0.77)	10.91 (0.55)	1.01 (0.11)	2.86 (0.08)	0.61 (0.06)
Cereal rye (CR)	74.03 (4.41)	18.38 (1.27)	23.04 (1.64)	10.63 (0.66)	1.11 (0.12)	2.96 (0.15)	0.63 (0.04)
FR + OA + CA + CR	74.53 (3.38)	18.81 (0.99)	23.21 (1.09)	10.80 (0.51)	0.95 (0.12)	3.10 (0.20)	0.65 (0.06)
SH + SB + FR + OA	76.25 (3.47)	19.03 (1.22)	23.97 (1.00)	11.25 (0.82)	1.09 (0.12)	3.11 (0.17)	0.67 (0.09)
RC + HV + CA + CR	76.30 (4.53)	19.40 (1.42)	23.31 (1.43)	11.10 (0.99)	1.15 (0.15)	3.11 (0.18)	0.67 (0.06)
SH + SB + CA + CR	73.82 (2.81)	18.73 (0.89)	22.44 (0.71)	10.97 (0.41)	0.96 (0.13)	2.94 (0.10)	0.70 (0.19)
RC + HV + FR + OA	76.52 (2.83)	19.42 (1.01)	23.47 (1.04)	11.28 (0.68)	0.97 (0.10)	3.20 (0.13)	0.75 (0.06)
8 species mix	78.10 (3.59)	19.35 (1.07)	24.67 (1.21)	11.19 (0.66)	1.16 (0.21)	3.14 (0.17)	0.76 (0.07)

Contrast	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value
Cover crops vs. no cover crop control (df = 76)	5.37	0.04	1.11	0.14	1.68	0.04	0.04	0.93	0.28	<0.01	0.31	0.02	0.09	0.11

Notes: Gram + = Gram positive. Gram – = Gram negative. AM = arbuscular mycorrhizal. df = degrees of freedom. Est. = estimate. Values within a column with different letters were significantly different due to year or cover crop based on Tukey's honestly significant difference ($p < 0.05$). The absence of letters in a column indicates that the effect of year or cover crop was not significant.

* Finney, D.M., *et al.*, (2017). doi:10.2489/jswc.72.4.361

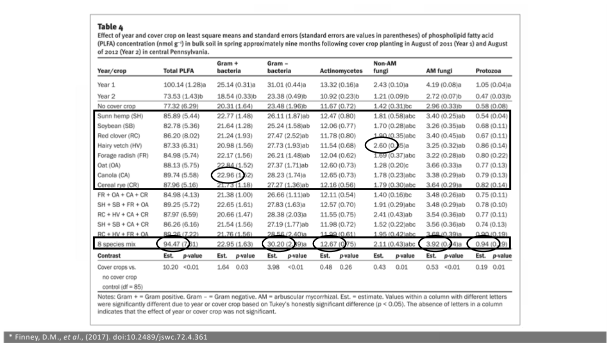


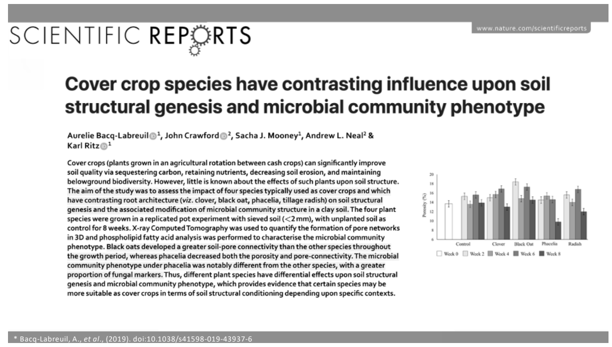
Table 4
Effect of year and cover crop on least square means and standard errors (standard errors are values in parentheses) of phospholipid fatty acid (PLFA) concentration (nmol g⁻¹) in bulk soil in spring approximately nine months following cover crop planting in August of 2011 (Year 1) and August of 2012 (Year 2) in central Pennsylvania.

Year/crop	Total PLFA	Gram + bacteria	Gram – bacteria	Actinomycetes	Non-AM fungi	AM fungi	Protozoa
Year 1	100.14 (1.28)a	25.14 (0.31)a	31.01 (0.44)a	13.32 (0.16)a	2.43 (0.10)a	4.19 (0.08)a	1.05 (0.04)a
Year 2	73.53 (1.43)b	18.54 (0.33)b	23.38 (0.49)b	10.92 (0.23)b	1.21 (0.09)b	2.72 (0.07)b	0.47 (0.03)b
No cover crop	77.32 (6.29)	20.31 (1.64)	23.48 (1.96)b	11.67 (0.72)	1.42 (0.31)bc	2.96 (0.33)b	0.58 (0.08)
Sunn hemp (SH)	85.89 (5.44)	22.77 (1.48)	26.11 (1.87)ab	12.47 (0.80)	1.81 (0.58)abc	3.40 (0.25)ab	0.54 (0.04)
Soybean (SB)	82.78 (5.36)	21.64 (1.28)	25.24 (1.58)ab	12.06 (0.77)	1.70 (0.28)abc	3.26 (0.35)ab	0.68 (0.11)
Red clover (RC)	86.20 (8.02)	21.24 (1.93)	27.47 (2.52)ab	11.78 (0.80)	1.90 (0.35)abc	3.40 (0.45)ab	0.67 (0.11)
Hairy vetch (HV)	87.33 (6.31)	20.98 (1.56)	27.73 (1.93)ab	11.54 (0.68)	2.60 (0.[illegible]5)a	3.25 (0.32)ab	0.86 (0.14)
Forage radish (FR)	84.98 (5.74)	22.17 (1.56)	26.21 (1.48)ab	12.04 (0.62)	1.69 (0.37)abc	3.22 (0.28)ab	0.80 (0.22)
Oat (OA)	88.13 (5.75)	22.84 (1.52)	27.37 (1.71)ab	12.60 (0.73)	1.28 (0.20)c	3.66 (0.33)a	0.77 (0.13)
Canola (CA)	89.74 (5.58)	22.96 (1.[illegible]2)	28.23 (1.74)a	12.65 (0.73)	1.78 (0.23)abc	3.38 (0.29)ab	0.79 (0.13)
Cereal rye (CR)	87.96 (5.16)	21.73 (1.18)	27.27 (1.36)ab	12.16 (0.56)	1.79 (0.30)abc	3.64 (0.29)a	0.82 (0.14)
FR + OA + CA + CR	84.98 (4.13)	21.38 (1.00)	26.66 (1.11)ab	12.11 (0.54)	1.40 (0.16)bc	3.48 (0.26)ab	0.75 (0.11)
SH + SB + FR + OA	89.25 (5.72)	22.65 (1.61)	27.83 (1.63)a	12.57 (0.70)	1.91 (0.29)abc	3.48 (0.29)ab	0.78 (0.10)
RC + HV + CA + CR	87.97 (6.59)	20.66 (1.47)	28.38 (2.03)a	11.55 (0.75)	2.41 (0.43)ab	3.54 (0.36)ab	0.77 (0.11)
SH + SB + CA + CR	86.26 (6.16)	21.54 (1.56)	27.19 (1.77)ab	11.98 (0.72)	1.52 (0.22)abc	3.56 (0.36)ab	0.74 (0.13)
RC + HV + FR + OA	89.26 (7.22)	21.76 (1.56)	28.56 (2.40)a	11.99 (0.61)	1.95 (0.42)abc	3.68 (0.39)a	0.90 (0.19)
8 species mix	94.47 (7.[illegible]1)	22.95 (1.63)	30.20 (2.[illegible]9)a	12.67 (0.[illegible]75)	2.11 (0.43)abc	3.92 (0.[illegible]4)a	0.94 (0.[illegible]9)

Contrast	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value
Cover crops vs. no cover crop control (df = 85)	10.20	<0.01	1.64	0.03	3.98	<0.01	0.48	0.26	0.43	0.01	0.53	<0.01	0.19	0.01

Notes: Gram + = Gram positive. Gram – = Gram negative. AM = arbuscular mycorrhizal. Est. = estimate. Values within a column with different letters were significantly different due to year or cover crop based on Tukey's honestly significant difference ($p < 0.05$). The absence of letters in a column indicates that the effect of year or cover crop was not significant.

* Finney, D.M., *et al.*, (2017). doi:10.2489/jswc.72.4.361



SCIENTIFIC REPORTS

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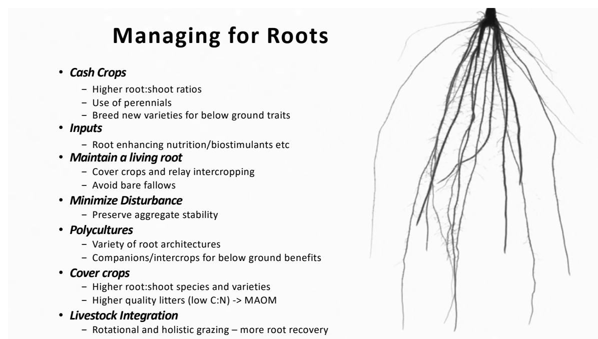
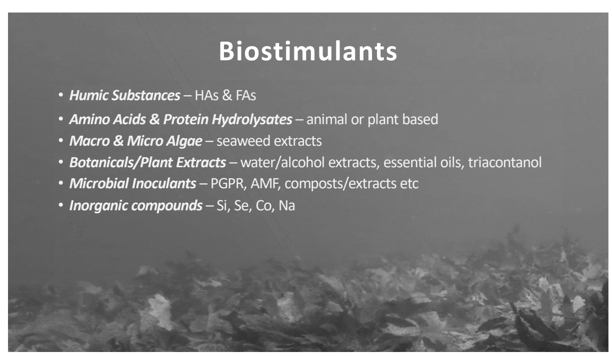
Cover crop species have contrasting influence upon soil structural genesis and microbial community phenotype

Aurelie Bacq-Labreuil[1], John Crawford[2], Sacha J. Mooney[1], Andrew L. Neal[2] & Karl Ritz[1]

Cover crops (plants grown in an agricultural rotation between cash crops) can significantly improve soil quality via sequestering carbon, retaining nutrients, decreasing soil erosion, and maintaining belowground biodiversity. However, little is known about the effects of such plants upon soil structure. The aim of the study was to assess the impact of four species typically used as cover crops and which have contrasting root architecture (*viz.* clover, black oat, phacelia, tillage radish) on soil structural genesis and the associated modification of microbial community structure in a clay soil. The four plant species were grown in a replicated pot experiment with sieved soil (<2 mm), with unplanted soil as control for 8 weeks. X-ray Computed Tomography was used to quantify the formation of pore networks in 3D and phospholipid fatty acid analysis was performed to characterise the microbial community phenotype. Black oats developed a greater soil-pore connectivity than the other species throughout the growth period, whereas phacelia decreased both the porosity and pore-connectivity. The microbial community phenotype under phacelia was notably different from the other species, with a greater proportion of fungal markers. Thus, different plant species have differential effects upon soil structural genesis and microbial community phenotype, which provides evidence that certain species may be more suitable as cover crops in terms of soil structural conditioning depending upon specific contexts.

* Bacq-Labreuil, A., *et al.*, (2019). doi:10.1038/s41598-019-43937-6





Multiple compounds

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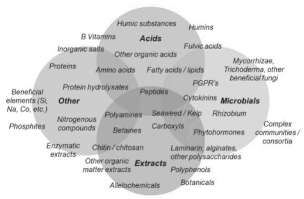
Multiple MoAs



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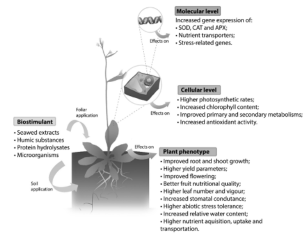
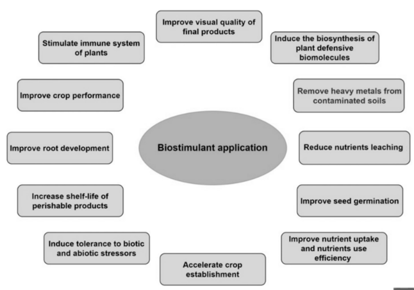
Recent Advances in the Molecular Effects of Biostimulants in Plants: An Overview



* Baltazar *et al* (2021). doi.org/10.3390/BIOM11081096



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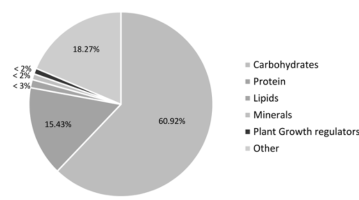
* Shahrajabian *et al* (2021). doi.org/10.3390/biom11050698

plants

Biostimulant Properties of Seaweed Extracts in Plants: Implications towards Sustainable Crop Production



* Ali *et al* (2021). doi.org/10.3390/plants10030531

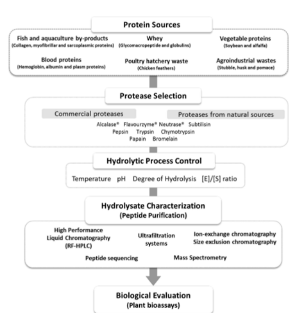
plants

Trends in Seaweed Extract Based Biostimulants: Manufacturing Process and Beneficial Effect on Soil-Plant Systems

Table 1. Effect of seaweed extracts on plant nutrient uptake and translocation.

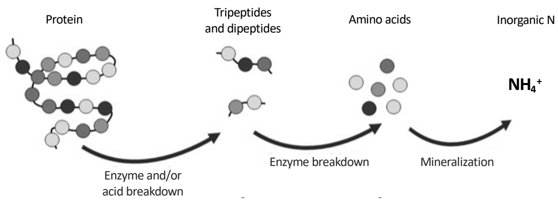
Plant	Seaweed Species	Extraction Technic	Elemental Composition	Experiment Conditions	Mode of Application	Findings	Source
Maize	*Kappaphycus alvarezii (Ka)/Gracilaria edulis (Ge)* (Applied separately)	Liquid filtrate from fresh seaweed	K^+ 33,654; 682.1, P^{3+} 17.45; not detected, Ca^{2+} 321; 352, Mg^{2+} 112; 311 for Ka and Ge respectively.	Field experiment	Foliar spray	Enhanced N, P and K uptake (grain + stover) for both extracts	[78]
Oilseed Rape	*Ecklonia maxima*	Cold cell burst	N 3.6 $g.kg^{-1}$, P 8.2 $g.kg^{-1}$, K 7.2 $g.kg^{-1}$, Ca 0.8 $g.kg^{-1}$, Mg 0.2 $g.kg^{-1}$, Fe 13.6 $mg.kg^{-1}$, Mn 8.4 $mg.kg^{-1}$, B 0.24 $mg.kg^{-1}$, Zn 4.2 $mg.kg^{-1}$, and Cu 0.2 $mg.kg^{-1}$	Pot experiment	Root application	Enhanced Leaf P and K concentration.	[38]
Tomato	*Ecklonia maxima*	Cold cell burst	N 3.6 $g.kg^{-1}$, P 8.2 $g.kg^{-1}$, K 7.2 $g.kg^{-1}$, Ca 0.8 $g.kg^{-1}$, Mg 0.2 $g.kg^{-1}$, Fe 13.6 $mg.kg^{-1}$, Mn 8.4 $mg.kg^{-1}$, B 0.24 $mg.kg^{-1}$, Zn 4.2 $mg.kg^{-1}$, and Cu 0.2 $mg.kg^{-1}$	In soil under greenhouse	Foliar spray	Enhanced Fruit Ca concentration.	[79]
Tomato	*Ascophyllum nodosum*	Not mentioned	Fe 39.9 $\mu g.mL^{-1}$, Mn 20.9 $\mu g.mL^{-1}$, Cu 3.0 $\mu g.mL^{-1}$, Zn 4.1 $\mu g.mL^{-1}$	Pots under growth chamber	Not mentioned	Enhanced concentration of Mn, Cu, and Zn in root and leaf.	[57]
Oilseed Rape	*Ascophyllum nodosum*	Acid extraction	Ca 0.854, Cu 0.009, Fe 0.030, K 6.630, Mg 0.919, N not detected, Na 3.102, P 0.116, S 2.660, Si 0.027, Zn 0.002% of dry weight	Hydroponic under greenhouse	In nutrient solution	Increased relative Mn, Cu, and Mg concentration in whole plant.	[80]
Wheat	*Ascophyllum nodosum*	Acid extraction	K 4442, P 78, S 1782, N 0 (concentration of 67 g DW dissolved in 1 L of water).	Pot experiment	Foliar spray	Enhanced Grain K	[81]
Oilseed Rape	*Ascophyllum nodosum*	Acid extraction	K 4442, P 78, S 1782, N 0 (concentration of 67 g DW dissolved in 1 L of water).	Pots under greenhouse conditions	In nutrient solution	Stimulation of root and shoot N and S.	[76]
Soybean	*Kappaphycus alvarezii*	Liquid filtrate from fresh seaweed	N 0.03%, P 33.99 $mg.L^{-1}$, K 1.97%, S 0.06%, Ca 460.11 $mg.L^{-1}$, Mg 581.2 $mg.L^{-1}$, Na 0.51%, Cu 0.3 $mg.L^{-1}$, Fe 10.59 $mg.L^{-1}$, Mn 2.5 $mg.L^{-1}$, Zn 0.62 $mg.L^{-1}$	Soil, field experiment	Foliar spray	Enhanced N, P, K, S grain uptake and N, P straw uptake.	[82]

* El Boukhari *et al* (2020). doi.org/10.3390/plants9030359

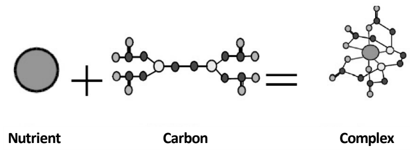


* Moreno-Hernández *et al* (2020). doi.org/10.4067/S0718-58392020000200274

Protein Hyrolysates



Carbon Based Inputs



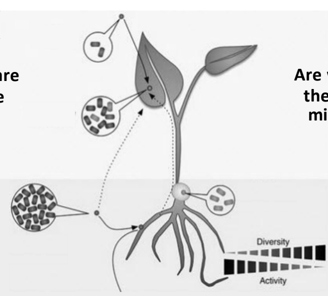
Inoculate Biology: Biofertilizers

Soil Biology: Two schools of thought…

- Stimulate/feed ***native*** organisms
  - Soil health
  - Plant diversity
  - Feed the soil
- Introduce/inoculate ***new*** populations
  - Soil applied
  - Plant applied

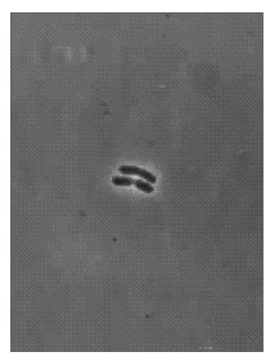
Biofertilizers are a drop in the ocean?

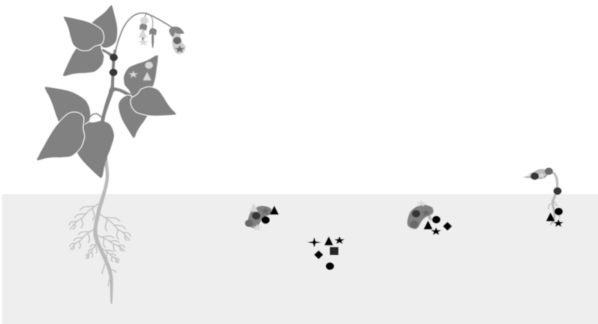
Are we changing the whole soil microbiome?



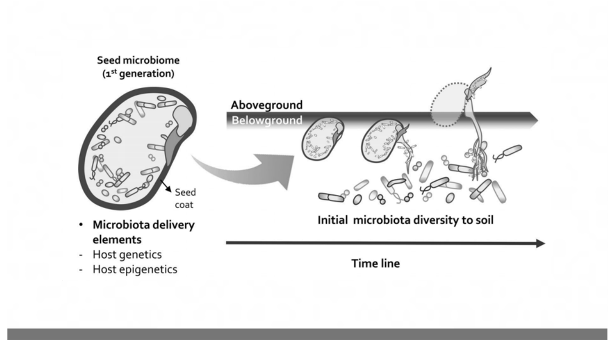
Biofertilisers

- Compost
- Compost Extract, Tea & Slurry
- Anaerobic Ferments / IM
- Manures
- Commercial Products
  - N fixers, PSM, EM
  - AMF, Trichoderma
  - Endophytes
  - Consortiums etc etc

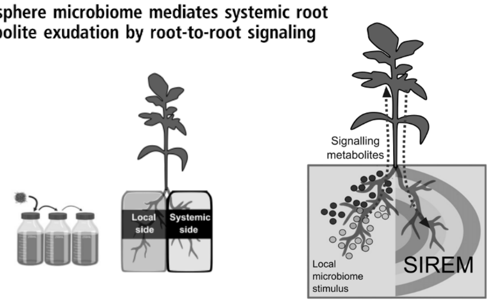




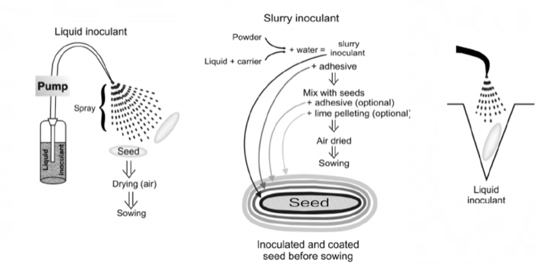
* http://dx.doi.org/10.1016/j.mib.2017.03.010



Rhizosphere microbiome mediates systemic root metabolite exudation by root-to-root signaling

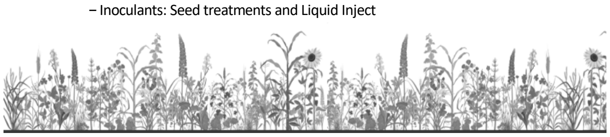


* Korenblum, E., *et al.*, (2020). doi: 10.1073/pnas.1912130117



In Summary

- Soil nutrients are often plentiful
- Fertilizer inputs are often inefficient
- Leveraging fertility with biology:
  - System Design: Take a systems approach, integrate many tools, livestock
  - Plants: The living roots are the key, mono or mixtures
  - Feed: C-based inputs and biostimulants
  - Inoculants: Seed treatments and Liquid Inject



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Questions, Discussion?

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