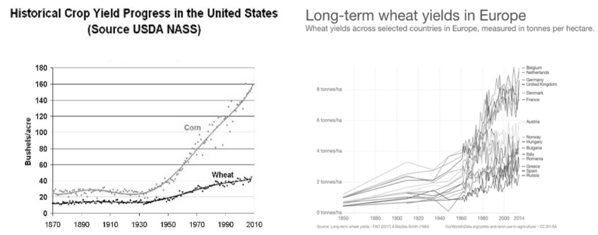
Nitrogen:
Build or Burn SOM?

SSCA: Feb 16 2022

www.**integratedsoils**.com
@integratedsoils

Roots
Microbial biomass/necromass
Root Exudates
Types/Quality of SOM
Nitrogen – build or burn SOM?
Soil Organic Nitrogen
Organic N and plant metabolism
Legumes
Other effects of N
Integrated N Management

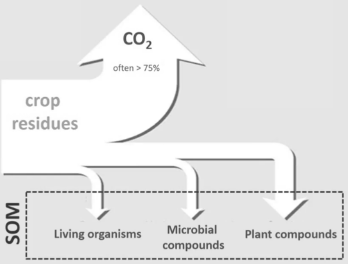


Historical Crop Yield Progress in the United States (Source USDA NASS)

Long-term wheat yields in Europe

Wheat yields across selected countries in Europe, measured in tonnes per hectare.

Source: Long-term wheat yields - FAO (2017) & Bayliss-Smith (1984) OurWorldInData.org/yields-and-land-use-in-agriculture/ • CC BY-SA



CO_2

often > 75%

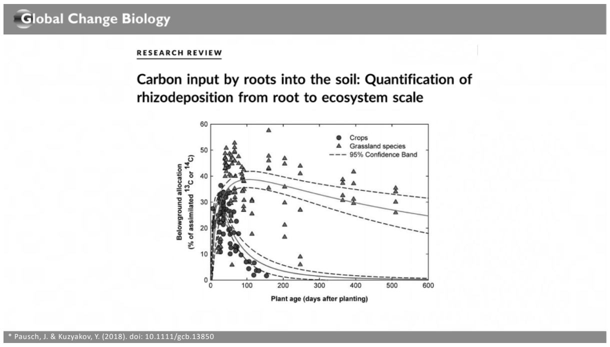
crop residues

SOM

Living organisms

Microbial compounds

Plant compounds

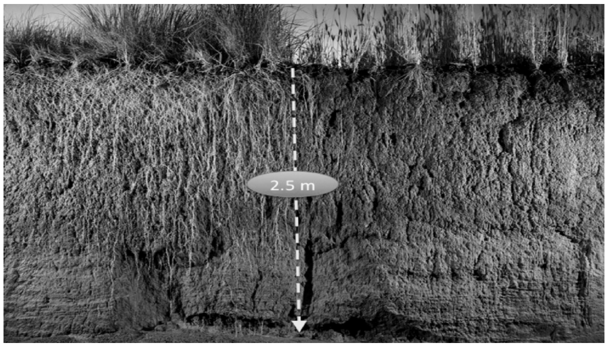


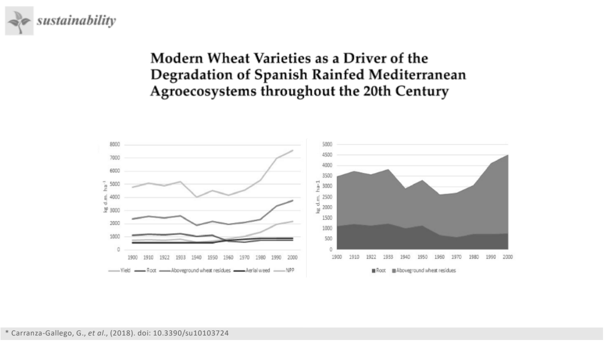
Global Change Biology

RESEARCH REVIEW

Carbon input by roots into the soil: Quantification of rhizodeposition from root to ecosystem scale

* Pausch, J. & Kuzyakov, Y. (2018). doi: 10.1111/gcb.13850





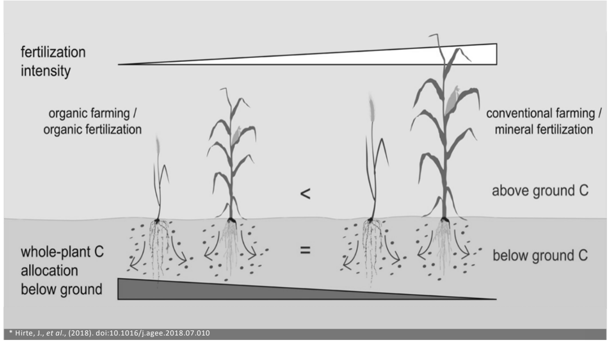
sustainability

Modern Wheat Varieties as a Driver of the Degradation of Spanish Rainfed Mediterranean Agroecosystems throughout the 20th Century

* Carranza-Gallego, G., *et al.*, (2018). doi: 10.3390/su10103724

Edward Dickin
@naked_barley

#einkorn #wheat #roots v modern durum sown same day, soil and conditions



fertilization intensity

organic farming / organic fertilization

conventional farming / mineral fertilization

<

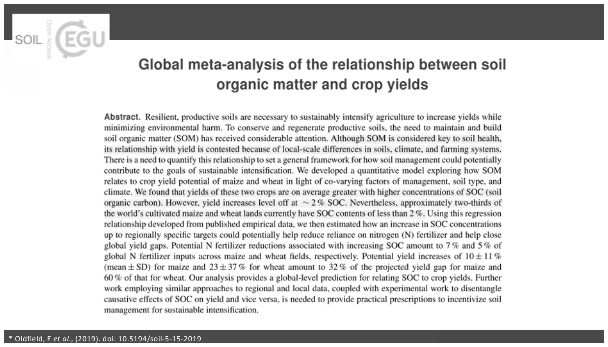
above ground C

=

below ground C

whole-plant C allocation below ground

* Hirte, J., *et al.*, (2018). doi:10.1016/j.agee.2018.07.010

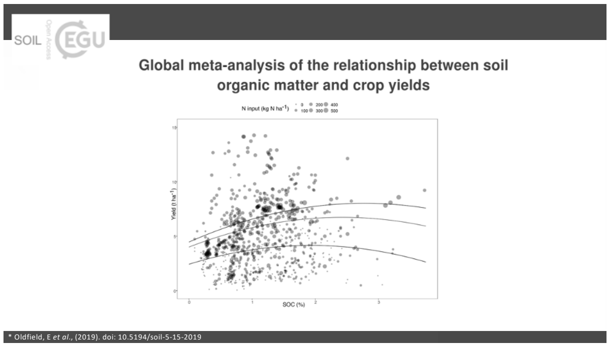


SOIL Open Access EGU

Global meta-analysis of the relationship between soil organic matter and crop yields

Abstract. Resilient, productive soils are necessary to sustainably intensify agriculture to increase yields while minimizing environmental harm. To conserve and regenerate productive soils, the need to maintain and build soil organic matter (SOM) has received considerable attention. Although SOM is considered key to soil health, its relationship with yield is contested because of local-scale differences in soils, climate, and farming systems. There is a need to quantify this relationship to set a general framework for how soil management could potentially contribute to the goals of sustainable intensification. We developed a quantitative model exploring how SOM relates to crop yield potential of maize and wheat in light of co-varying factors of management, soil type, and climate. We found that yields of these two crops are on average greater with higher concentrations of SOC (soil organic carbon). However, yield increases level off at ∼2 % SOC. Nevertheless, approximately two-thirds of the world's cultivated maize and wheat lands currently have SOC contents of less than 2 %. Using this regression relationship developed from published empirical data, we then estimated how an increase in SOC concentrations up to regionally specific targets could potentially help reduce reliance on nitrogen (N) fertilizer and help close global yield gaps. Potential N fertilizer reductions associated with increasing SOC amount to 7 % and 5 % of global N fertilizer inputs across maize and wheat fields, respectively. Potential yield increases of 10 ± 11 % (mean ± SD) for maize and 23 ± 37 % for wheat amount to 32 % of the projected yield gap for maize and 60 % of that for wheat. Our analysis provides a global-level prediction for relating SOC to crop yields. Further work employing similar approaches to regional and local data, coupled with experimental work to disentangle causative effects of SOC on yield and vice versa, is needed to provide practical prescriptions to incentivize soil management for sustainable intensification.

* Oldfield, E *et al.*, (2019). doi: 10.5194/soil-5-15-2019



SOIL Open Access EGU

Global meta-analysis of the relationship between soil organic matter and crop yields

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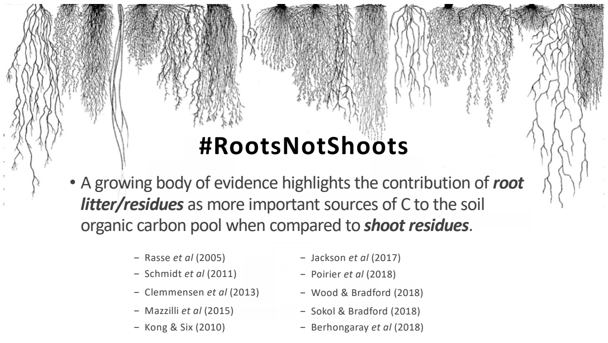
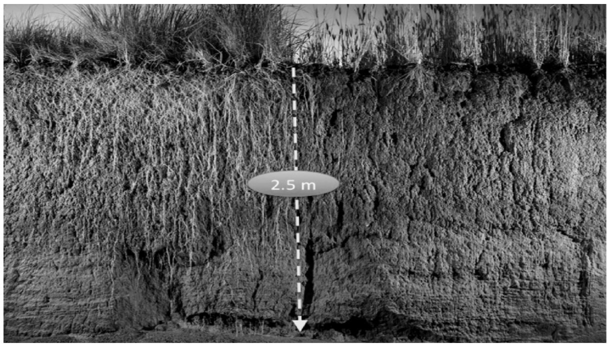
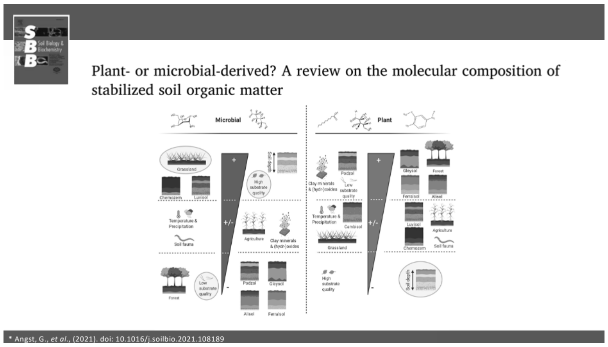


#RootsNotShoots

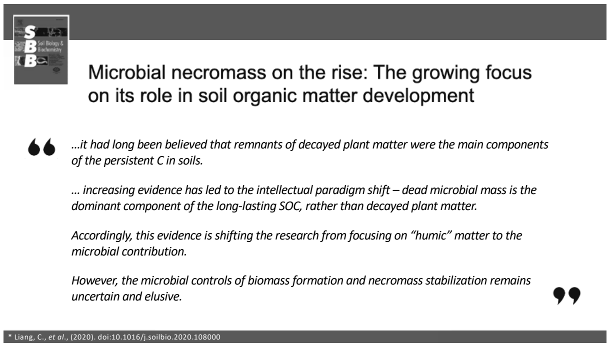
- A growing body of evidence highlights the contribution of ***root litter/residues*** as more important sources of C to the soil organic carbon pool when compared to ***shoot residues***.
  - Rasse *et al* (2005)
  - Schmidt *et al* (2011)
  - Clemmensen *et al* (2013)
  - Mazzilli *et al* (2015)
  - Kong & Six (2010)
  - Jackson *et al* (2017)
  - Poirier *et al* (2018)
  - Wood & Bradford (2018)
  - Sokol & Bradford (2018)
  - Berhongaray *et al* (2018)





Plant- or microbial-derived? A review on the molecular composition of stabilized soil organic matter

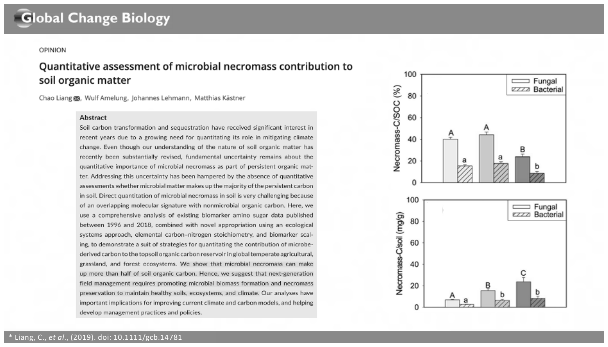
* Angst, G., *et al.*, (2021). doi: 10.1016/j.soilbio.2021.108189



Microbial necromass on the rise: The growing focus on its role in soil organic matter development

> *…it had long been believed that remnants of decayed plant matter were the main components of the persistent C in soils.*
>
> *… increasing evidence has led to the intellectual paradigm shift – dead microbial mass is the dominant component of the long-lasting SOC, rather than decayed plant matter.*
>
> *Accordingly, this evidence is shifting the research from focusing on "humic" matter to the microbial contribution.*
>
> *However, the microbial controls of biomass formation and necromass stabilization remains uncertain and elusive.*

* Liang, C., *et al.*, (2020). doi:10.1016/j.soilbio.2020.108000


Global Change Biology

OPINION

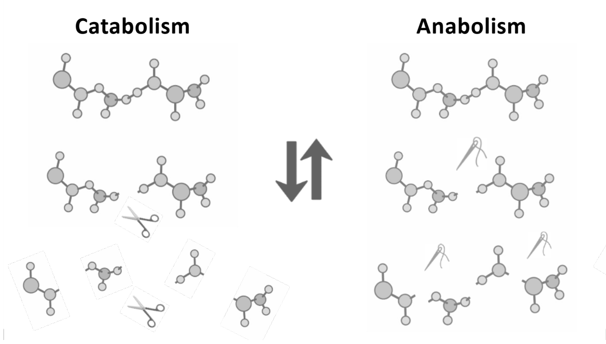
Quantitative assessment of microbial necromass contribution to soil organic matter

Chao Liang, Wulf Amelung, Johannes Lehmann, Matthias Kästner

Abstract

Soil carbon transformation and sequestration have received significant interest in recent years due to a growing need for quantitating its role in mitigating climate change. Even though our understanding of the nature of soil organic matter has recently been substantially revised, fundamental uncertainty remains about the quantitative importance of microbial necromass as part of persistent organic matter. Addressing this uncertainty has been hampered by the absence of quantitative assessments whether microbial matter makes up the majority of the persistent carbon in soil. Direct quantitation of microbial necromass in soil is very challenging because of an overlapping molecular signature with nonmicrobial organic carbon. Here, we use a comprehensive analysis of existing biomarker amino sugar data published between 1996 and 2018, combined with novel appropriation using an ecological systems approach, elemental carbon–nitrogen stoichiometry, and biomarker scaling, to demonstrate a suit of strategies for quantitating the contribution of microbe-derived carbon to the topsoil organic carbon reservoir in global temperate agricultural, grassland, and forest ecosystems. We show that microbial necromass can make up more than half of soil organic carbon. Hence, we suggest that next-generation field management requires promoting microbial biomass formation and necromass preservation to maintain healthy soils, ecosystems, and climate. Our analyses have important implications for improving current climate and carbon models, and helping develop management practices and policies.

* Liang, C., *et al.*, (2019). doi: 10.1111/gcb.14781



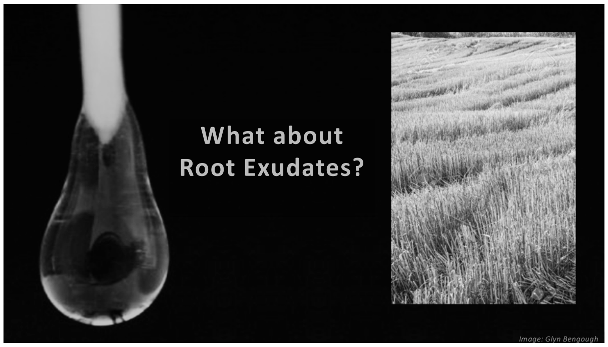
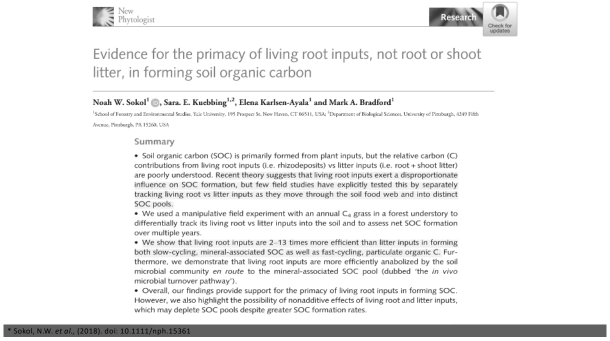

What about Root Exudates?

Image: Glyn Bengough



New Phytologist

Research

Check for updates

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

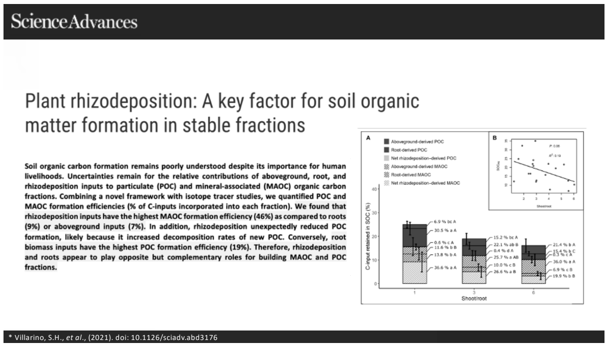
Noah W. Sokol[1], Sara. E. Kuebbing[1,2], Elena Karlsen-Ayala[1] and Mark A. Bradford[1]

[1]School of Forestry and Environmental Studies, Yale University, 195 Prospect St, New Haven, CT 06511, USA; [2]Department of Biological Sciences, University of Pittsburgh, 4249 Fifth Avenue, Pittsburgh, PA 15260, USA

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

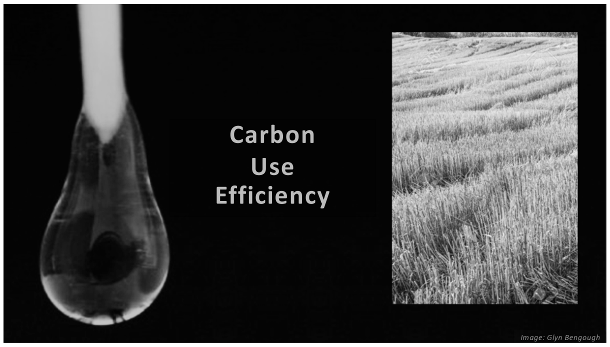


ScienceAdvances

Plant rhizodeposition: A key factor for soil organic matter formation in stable fractions

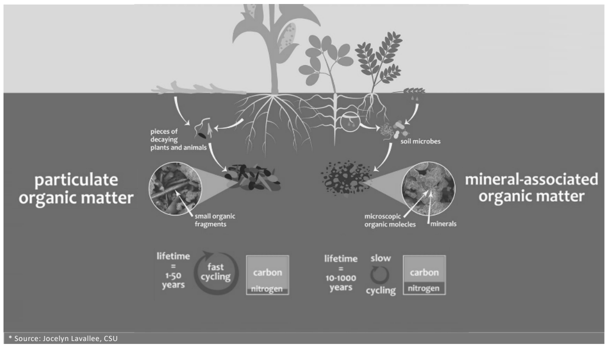
Soil organic carbon formation remains poorly understood despite its importance for human livelihoods. Uncertainties remain for the relative contributions of aboveground, root, and rhizodeposition inputs to particulate (POC) and mineral-associated (MAOC) organic carbon fractions. Combining a novel framework with isotope tracer studies, we quantified POC and MAOC formation efficiencies (% of C-inputs incorporated into each fraction). We found that rhizodeposition inputs have the highest MAOC formation efficiency (46%) as compared to roots (9%) or aboveground inputs (7%). In addition, rhizodeposition unexpectedly reduced POC formation, likely because it increased decomposition rates of new POC. Conversely, root biomass inputs have the highest POC formation efficiency (19%). Therefore, rhizodeposition and roots appear to play opposite but complementary roles for building MAOC and POC fractions.

* Villarino, S.H., *et al*., (2021). doi: 10.1126/sciadv.abd3176

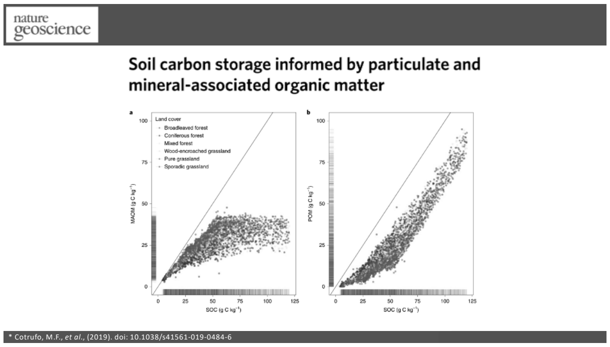


Carbon
Use
Efficiency

Image: Glyn Bengough



* Source: Jocelyn Lavallee, CSU



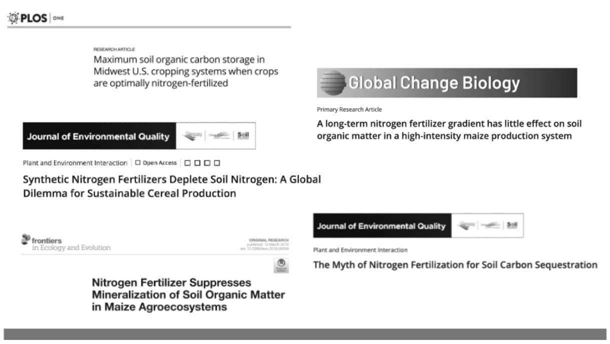
nature geoscience

Soil carbon storage informed by particulate and mineral-associated organic matter

* Cotrufo, M.F., *et al*., (2019). doi: 10.1038/s41561-019-0484-6

N inputs and SOM – Burn or Build?

- Both!
- Mixture of studies show N inputs can:
  - Increase SOM: greater residue input into the soil
  - Decrease SOM: increased mineralisation (N mining)
  - No effect
- The impact of N on SOM depends.



PLOS | ONE

RESEARCH ARTICLE

Maximum soil organic carbon storage in Midwest U.S. cropping systems when crops are optimally nitrogen-fertilized

Global Change Biology

Primary Research Article

A long-term nitrogen fertilizer gradient has little effect on soil organic matter in a high-intensity maize production system

Journal of Environmental Quality

Plant and Environment Interaction | ☐ Open Access | ☐ ☐ ☐ ☐

Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production

frontiers in Ecology and Evolution

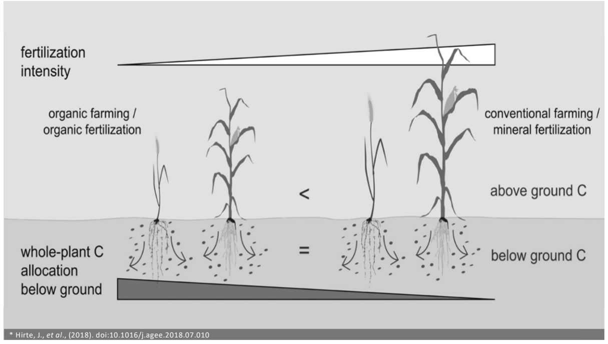
ORIGINAL RESEARCH

Nitrogen Fertilizer Suppresses Mineralization of Soil Organic Matter in Maize Agroecosystems

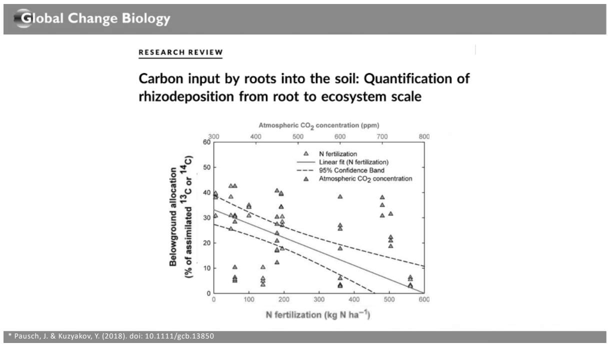
Journal of Environmental Quality

Plant and Environment Interaction

The Myth of Nitrogen Fertilization for Soil Carbon Sequestration



* Hirte, J., *et al.*, (2018). doi:10.1016/j.agee.2018.07.010

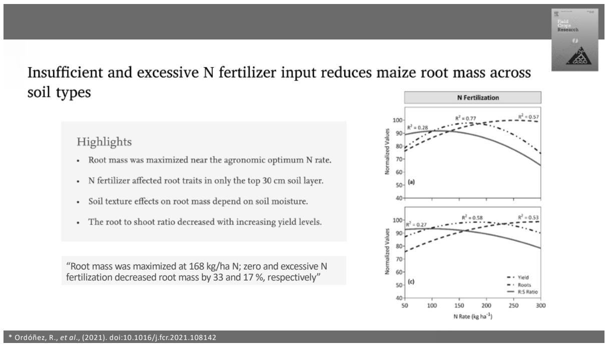


Global Change Biology

RESEARCH REVIEW

Carbon input by roots into the soil: Quantification of rhizodeposition from root to ecosystem scale

* Pausch, J. & Kuzyakov, Y. (2018). doi: 10.1111/gcb.13850



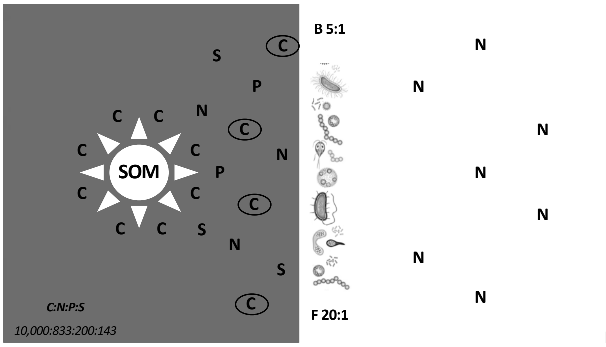
Insufficient and excessive N fertilizer input reduces maize root mass across soil types

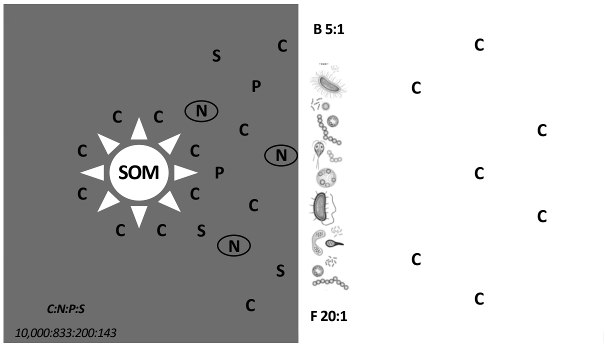
Highlights

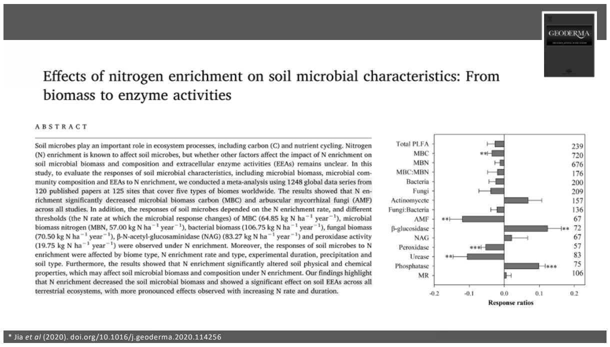
- Root mass was maximized near the agronomic optimum N rate.
- N fertilizer affected root traits in only the top 30 cm soil layer.
- Soil texture effects on root mass depend on soil moisture.
- The root to shoot ratio decreased with increasing yield levels.

"Root mass was maximized at 168 kg/ha N; zero and excessive N fertilization decreased root mass by 33 and 17 %, respectively"

* Ordóñez, R., *et al.*, (2021). doi:10.1016/j.fcr.2021.108142





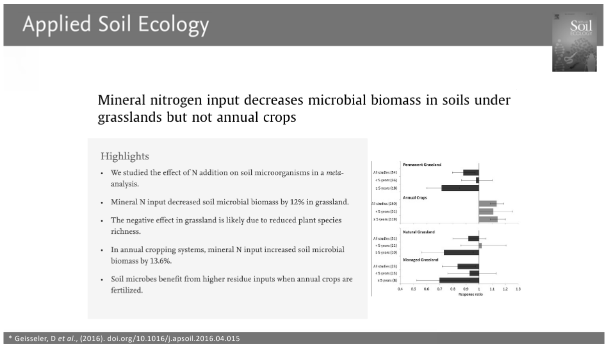


Effects of nitrogen enrichment on soil microbial characteristics: From biomass to enzyme activities

ABSTRACT

Soil microbes play an important role in ecosystem processes, including carbon (C) and nutrient cycling. Nitrogen (N) enrichment is known to affect soil microbes, but whether other factors affect the impact of N enrichment on soil microbial biomass and composition and extracellular enzyme activities (EEAs) remains unclear. In this study, to evaluate the responses of soil microbial characteristics, including microbial biomass, microbial community composition and EEAs to N enrichment, we conducted a meta-analysis using 1248 global data series from 120 published papers at 125 sites that cover five types of biomes worldwide. The results showed that N enrichment significantly decreased microbial biomass carbon (MBC) and arbuscular mycorrhizal fungi (AMF) across all studies. In addition, the responses of soil microbes depended on the N enrichment rate, and different thresholds (the N rate at which the microbial response changes) of MBC (64.85 kg N ha^{-1} $year^{-1}$), microbial biomass nitrogen (MBN, 57.00 kg N ha^{-1} $year^{-1}$), bacterial biomass (106.75 kg N ha^{-1} $year^{-1}$), fungal biomass (70.50 kg N ha^{-1} $year^{-1}$), β-N-acetyl-glucosaminidase (NAG) (83.27 kg N ha^{-1} $year^{-1}$) and peroxidase activity (19.75 kg N ha^{-1} $year^{-1}$) were observed under N enrichment. Moreover, the responses of soil microbes to N enrichment were affected by biome type, N enrichment rate and type, experimental duration, precipitation and soil type. Furthermore, the results showed that N enrichment significantly altered soil physical and chemical properties, which may affect soil microbial biomass and composition under N enrichment. Our findings highlight that N enrichment decreased the soil microbial biomass and showed a significant effect on soil EEAs across all terrestrial ecosystems, with more pronounced effects observed with increasing N rate and duration.

* Jia *et al* (2020). doi.org/10.1016/j.geoderma.2020.114256



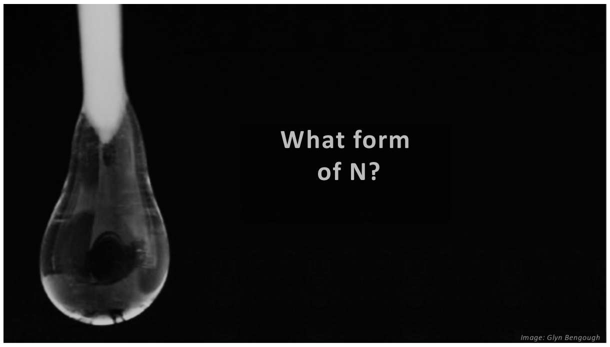
Applied Soil Ecology

Mineral nitrogen input decreases microbial biomass in soils under grasslands but not annual crops

Highlights

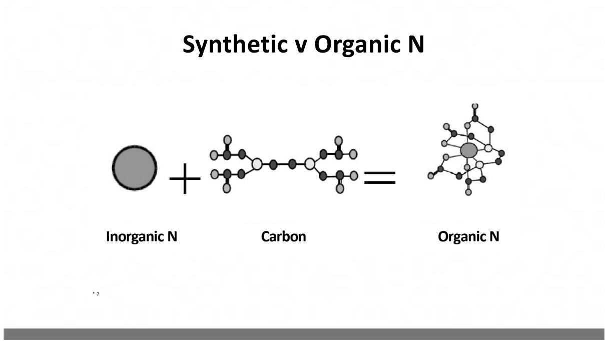
- We studied the effect of N addition on soil microorganisms in a *meta*-analysis.
- Mineral N input decreased soil microbial biomass by 12% in grassland.
- The negative effect in grassland is likely due to reduced plant species richness.
- In annual cropping systems, mineral N input increased soil microbial biomass by 13.6%.
- Soil microbes benefit from higher residue inputs when annual crops are fertilized.

* Geisseler, D *et al.*, (2016). doi.org/10.1016/j.apsoil.2016.04.015



What form of N?

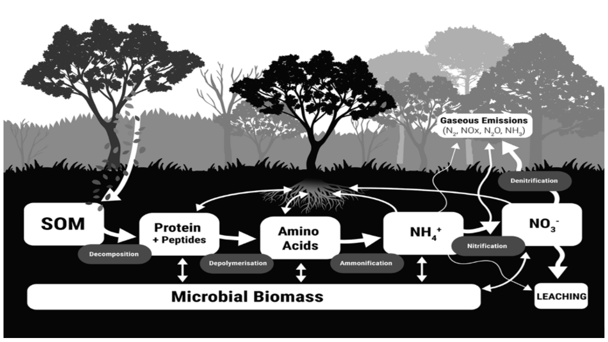
Image: Glyn Bengough



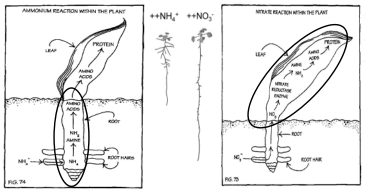
Synthetic v Organic N

Soil Organic N

- Soil organic matter (95% of total soil N)
- Proteins
- Peptides
- Amino acids
- Amino sugars



Ammonium Nitrate



Ammonium, Urea, Org N

- Converted in ***roots***
- Encourages ***below*** ground biomass [BGB]
- More subsequent nutrient & moisture scavenging; enhances AGB later in season

Nitrate

- Converted in ***leaf***
- Encourages ***above*** ground biomass [AGB] at expense of roots

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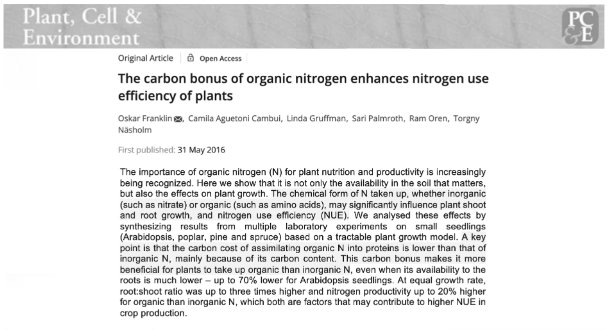


Plant, Cell & Environment

Original Article | Open Access

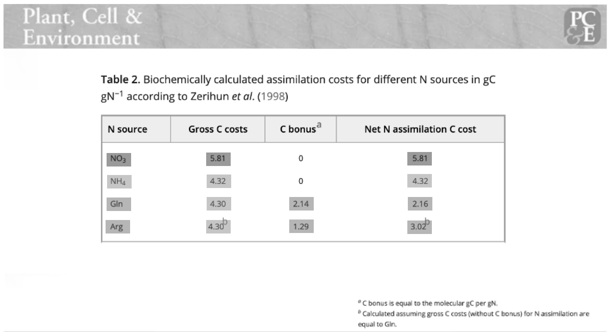
The carbon bonus of organic nitrogen enhances nitrogen use efficiency of plants

Oskar Franklin, Camila Aguetoni Cambui, Linda Gruffman, Sari Palmroth, Ram Oren, Torgny Näsholm

First published: 31 May 2016

The importance of organic nitrogen (N) for plant nutrition and productivity is increasingly being recognized. Here we show that it is not only the availability in the soil that matters, but also the effects on plant growth. The chemical form of N taken up, whether inorganic (such as nitrate) or organic (such as amino acids), may significantly influence plant shoot and root growth, and nitrogen use efficiency (NUE). We analysed these effects by synthesizing results from multiple laboratory experiments on small seedlings (Arabidopsis, poplar, pine and spruce) based on a tractable plant growth model. A key point is that the carbon cost of assimilating organic N into proteins is lower than that of inorganic N, mainly because of its carbon content. This carbon bonus makes it more beneficial for plants to take up organic than inorganic N, even when its availability to the roots is much lower – up to 70% lower for Arabidopsis seedlings. At equal growth rate, root:shoot ratio was up to three times higher and nitrogen productivity up to 20% higher for organic than inorganic N, which both are factors that may contribute to higher NUE in crop production.

* Franklin, O., *et al.*, (2016). doi: 10.1111/pce.12772



Plant, Cell & Environment

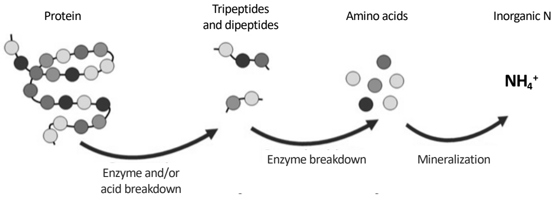
Table 2. Biochemically calculated assimilation costs for different N sources in gC gN^{-1} according to Zerihun *et al.* (1998)

N source	Gross C costs	C bonus[a]	Net N assimilation C cost
NO_3	5.81	0	5.81
NH_4	4.32	0	4.32
Gln	4.30	2.14	2.16
Arg	4.30[b]	1.29	3.02[b]

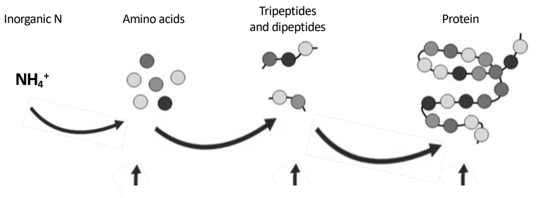
[a] C bonus is equal to the molecular gC per gN.
[b] Calculated assuming gross C costs (without C bonus) for N assimilation are equal to Gln.

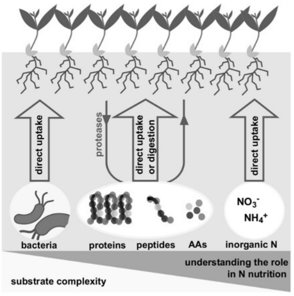
* Franklin, O., *et al.*, (2016). doi: 10.1111/pce.12772

Decomposition



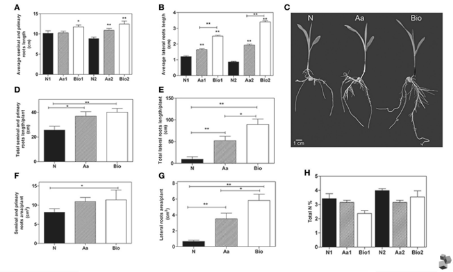
Metabolic Shortcutting





* Adamczyk (2021). doi.org/10.1007/s11104-021-05022-8

Growth Stimulatory Effects and Genome-Wide Transcriptional Changes Produced by Protein Hydrolysates in Maize Seedlings



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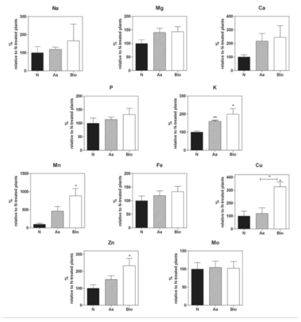
* Santi *et al* (2017). doi.org/10.3389/fpls.2017.00433



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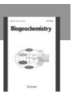
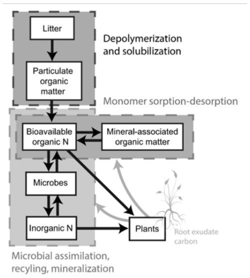
* Santi *et al* (2017). doi.org/10.3389/fpls.2017.00433



A holistic framework integrating plant-microbe-mineral regulation of soil bioavailable nitrogen

> *In agroecosystems, global fertilizer nitrogen use efficiency (NUE) remains stubbornly low at around 40%, and must nearly double by 2050 to meet predicted food and environmental demands.*
>
> *The modest success of technological solutions focused on fertilizer management reveals the short-comings of a narrow focus on managing inorganic N.*
>
> *Our model adds to calls for active management of SON and suggests that future agronomic research should seek to develop ways to enhance N supply from POM and MAOM when plant demand is high, but equally, to rebuild those SON pools during non-growing or fallow seasons.*

* Daly, A.E., *et al*., (2021). doi: 10.1007/s10533-021-00793-9

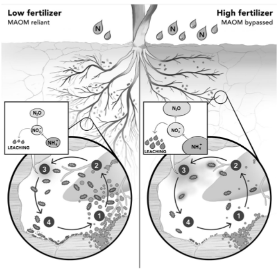


* Daly, A.E., *et al*., (2021). doi: 10.1007/s10533-021-00793-9

Potential fertilizer impacts on bioavailable N supply from MAOM in soils with adequate MAOM-N

Left: Modest, economical fertilizer application (lighter green gradient) incentivizes plants to invest in root production and associations with mycorrhizae (pink). Resulting plant-microbe-mineral interactions in minimally fertilized soils (1) liberate more bioavailable N from MAOM (orange); (2) increase microbial biomass; (3) produce less microbial ammonium waste and contribute less to N losses; and (4) increase necromass inputs that can replenish MAOM-N pools.

Right: Heavy fertilizer application (darker green gradient) disrupts these plant-microbe-mineral interactions.



* Daly, A.E., *et al*., (2021). doi: 10.1007/s10533-021-00793-9

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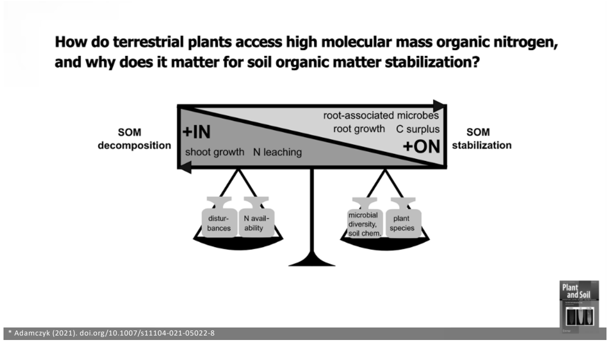
Nitrogen Use Efficiency Definitions of Today and Tomorrow

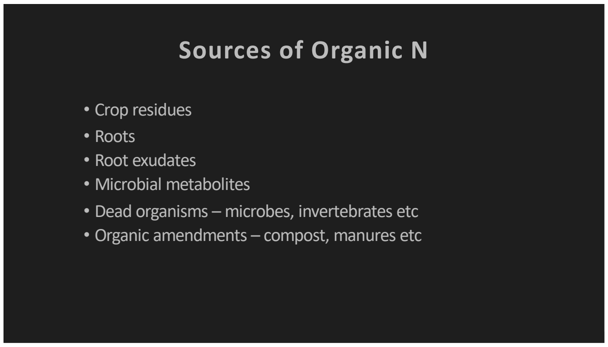
> *For a more complete picture of measuring NUE, the entire plant should be considered—including the roots. Roots comprise roughly 14% of total plant N in common annual crops with 4–71% of total plant N released to soil as rhizodeposits.*
>
> *A conspicuous oversight in how several NUE indices are conceptualized is the neglect to consider forms of N other than inorganic N.*
>
> *To better capture all the forms of N that plants use, the reconceptualizing of NUE must […] include the soil organic N pool that is available to and usable by plants—as this would numerically reduce several traditional estimates of NUE.*

* Congreves, K *et al*., (2021). doi: 10.3389/fpls.2021.637108



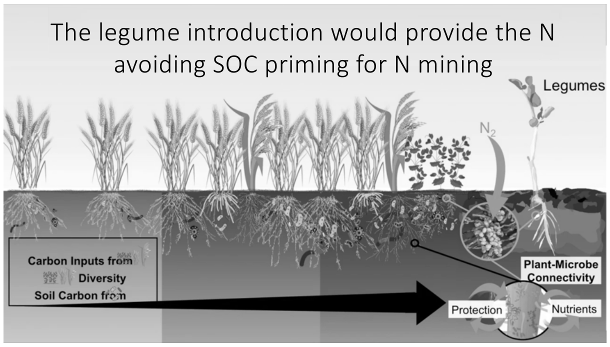
How do terrestrial plants access high molecular mass organic nitrogen, and why does it matter for soil organic matter stabilization?

* Adamczyk (2021). doi.org/10.1007/s11104-021-05022-8



Sources of Organic N

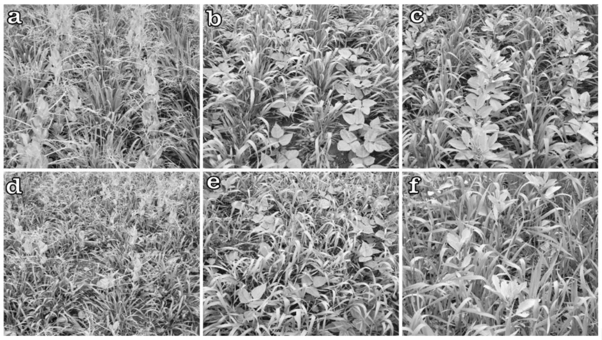
- Crop residues
- Roots
- Root exudates
- Microbial metabolites
- Dead organisms – microbes, invertebrates etc
- Organic amendments – compost, manures etc

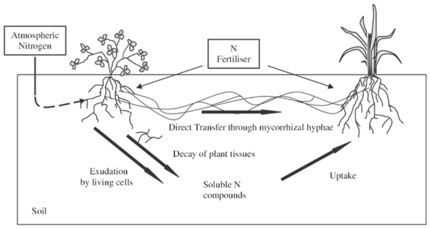


The legume introduction would provide the N avoiding SOC priming for N mining

Robbo Robinson
@AnashkaFarms

Mark Lea
@GreenAcres_Farm





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

Integrated N Management

- Carbon based inputs
- Intercrop with legumes
- Organic amendments
- Livestock Integration
- Foliar N
- Synergistic nutrients
- Biofertilisers – N fixers
- Plant breeding for NUE

In Summary

- Soil organic C & N dynamics are complex – many knowledge gaps
- Emerging paradigm on soil C is challenging existing ideas – watch this space
- N inputs should be optimised as best possible – excess N on roots and SOM?
- C-based additions to artificial N inputs creates 'organic N'
- Use organic amendments where possible
- Intercropping with legumes

Thank you, Questions?

Mailing List, More info:

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