Joel Williams

Building Natural Capital in Agricultural Soils

what, how, why?

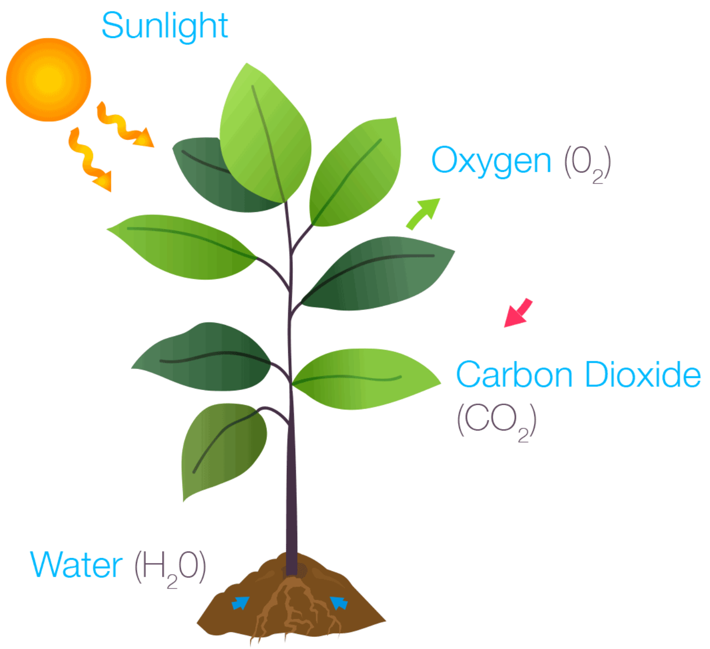
York: 12 March 2020

Integrated Soils

www.integratedsoils.com
@integratedsoils

What is Natural Capital?

- Natural capital can be defined as the world's stocks of natural assets which include geology, soil, air, water and all living things.
- Natural capital consists of stocks of natural assets (e.g. soils, forests, water bodies) that yield a flow of valuable goods or services into the future.
- Natural capital is any stock of natural resources or environmental assets that yields a sustainable flow of ecosystem services.

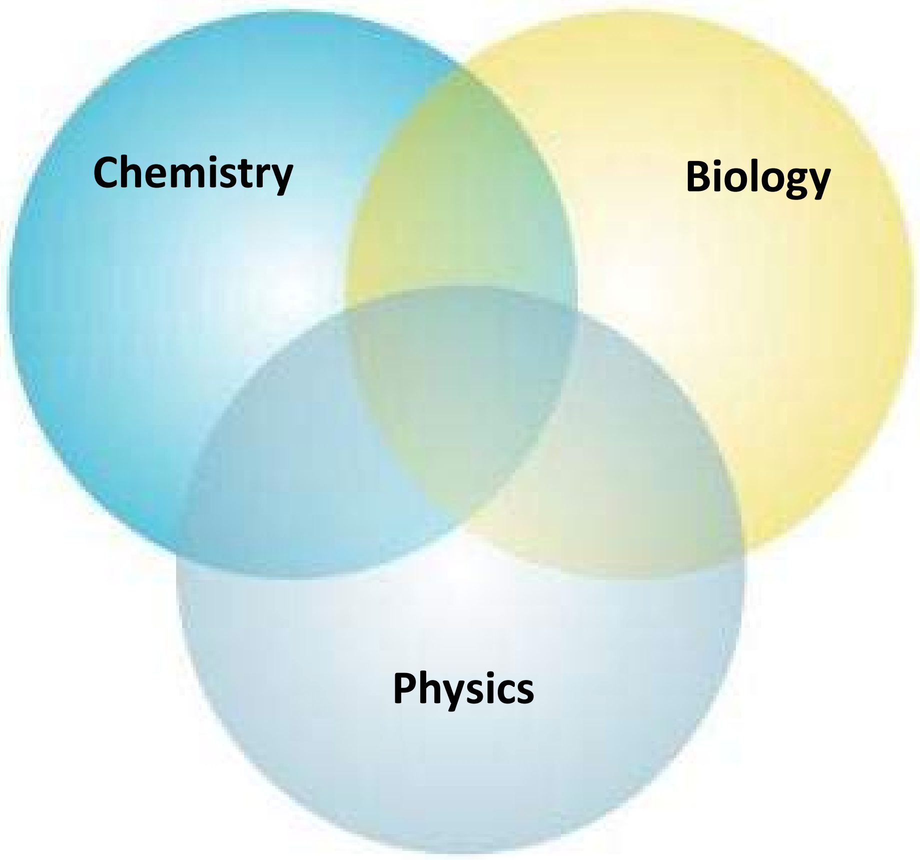


Ecosystem Services

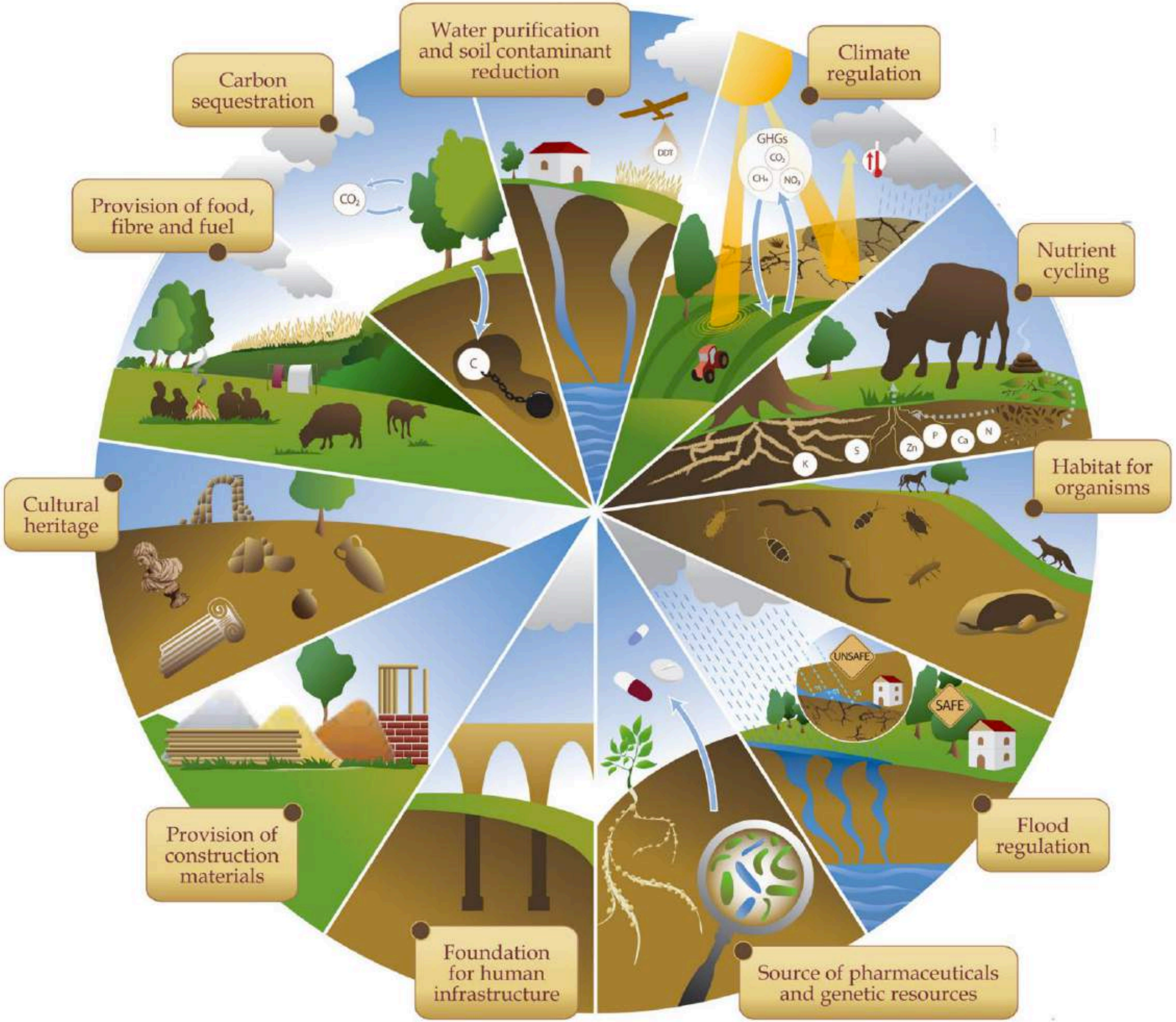
Ecosystem services stem from and are dependent on natural capital

What about Soil Capital?

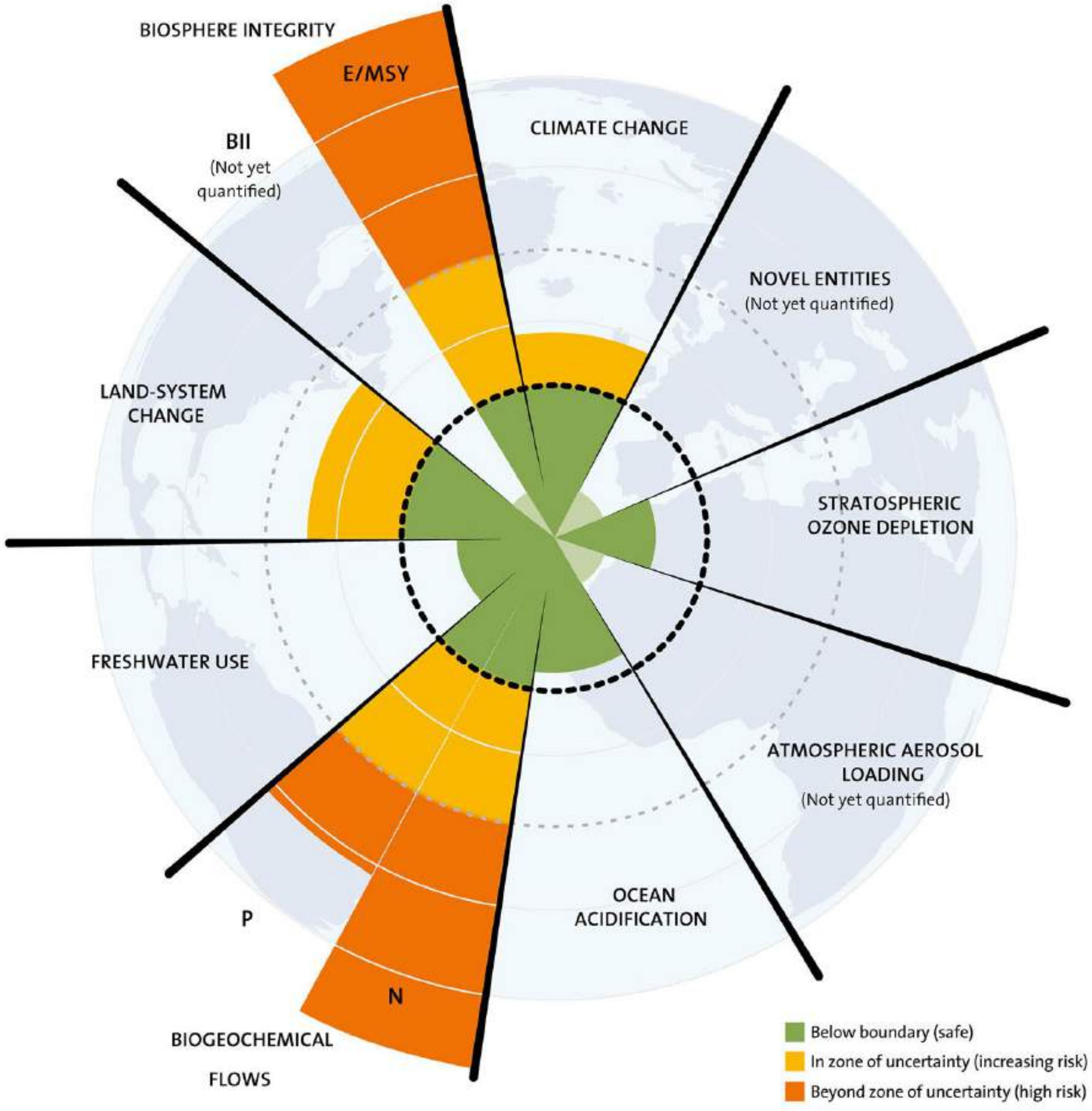
- Perhaps consider the properties of soil as its capital:
  - ***Physical***: texture, aggregation, structure, infiltration, water, gas exchange
  - ***Chemical***: pH, CEC, minerals, OM
  - ***Biological***: microbial biomass and diversity, earthworms, insects
  - Inherent vs Dynamic

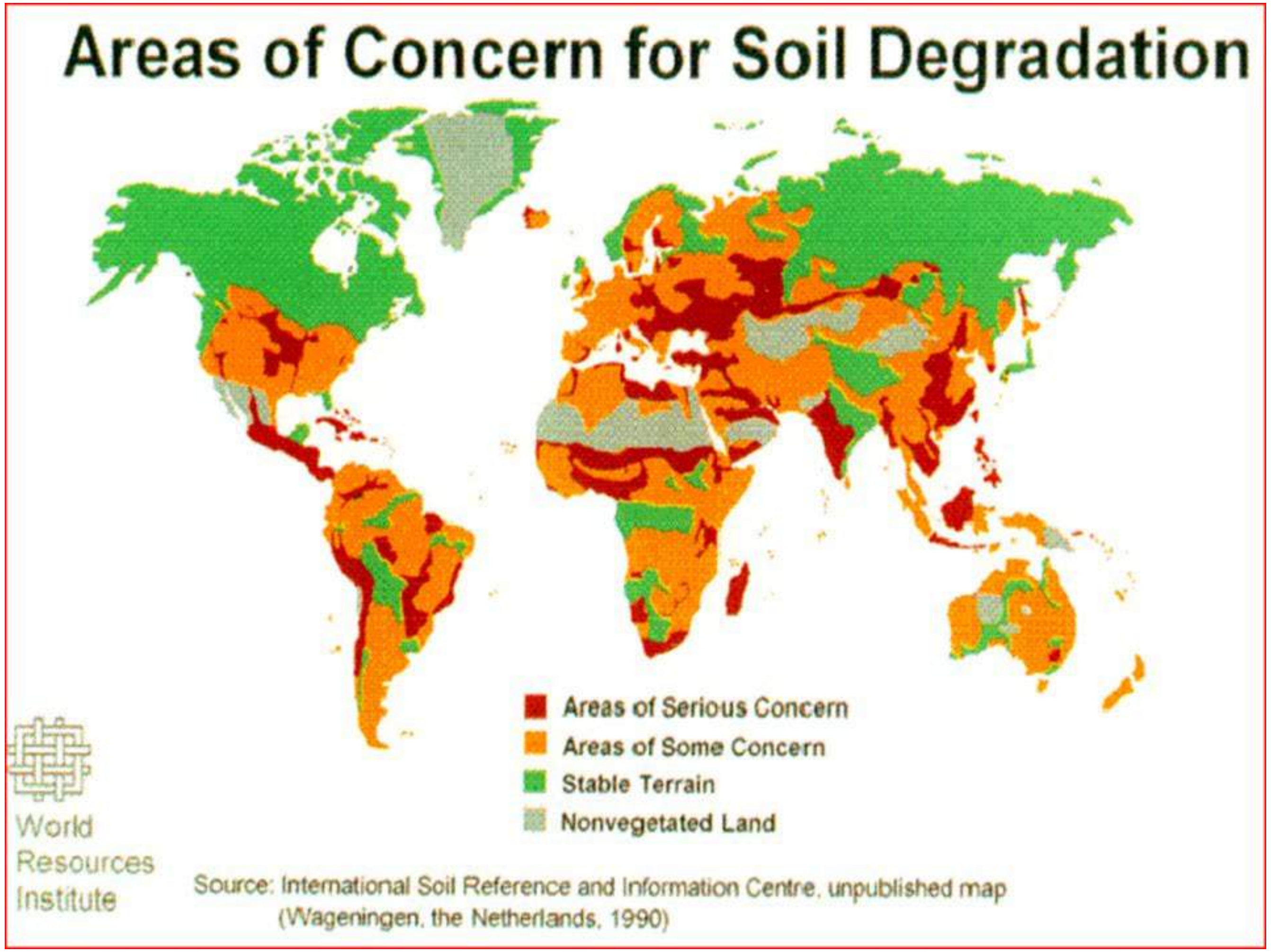


Why Natural Capital?



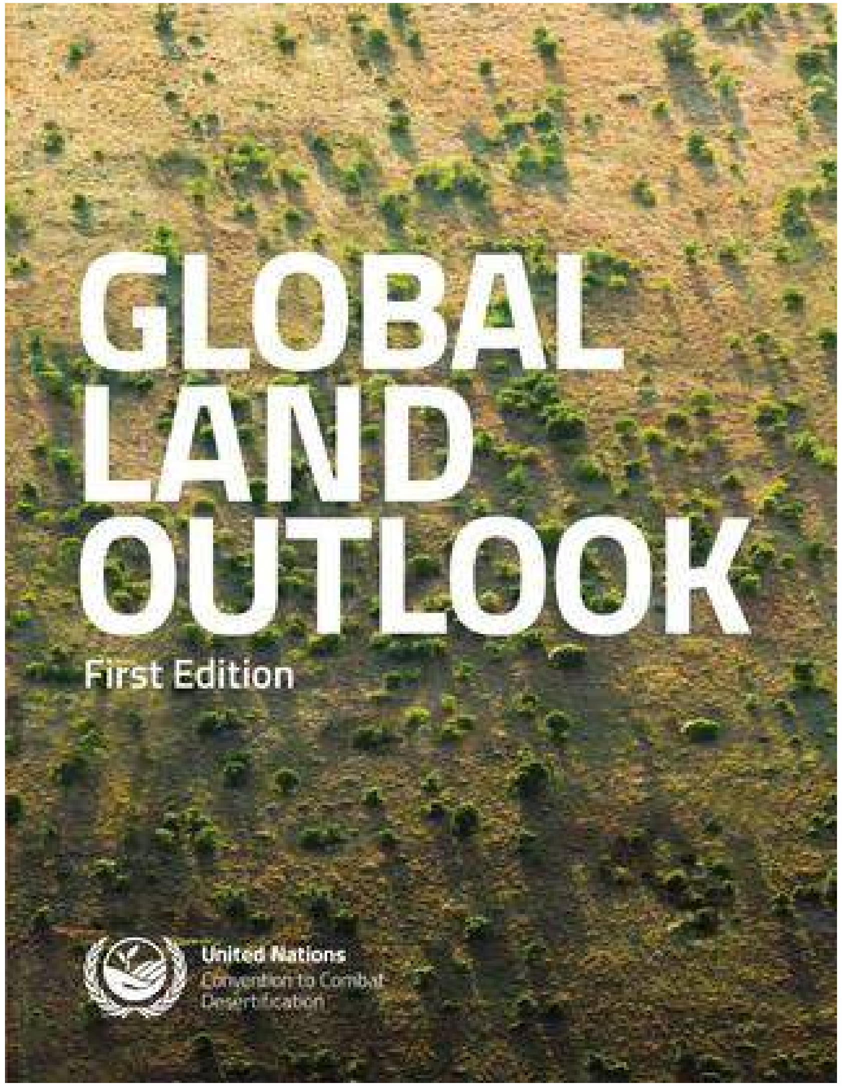
* Bayeye, P.C., *et al.*, (2016). doi: 10.3389/fenvs.2016.00041


BIOSPHERE INTEGRITY
E/MSY
BII
(Not yet quantified)
CLIMATE CHANGE
NOVEL ENTITIES
(Not yet quantified)
STRATOSPHERIC OZONE DEPLETION
ATMOSPHERIC AEROSOL LOADING
(Not yet quantified)
OCEAN ACIDIFICATION
N
P
BIOGEOCHEMICAL FLOWS
FRESHWATER USE
LAND-SYSTEM CHANGE
Below boundary (safe)
In zone of uncertainty (increasing risk)
Beyond zone of uncertainty (high risk)


Areas of Concern for Soil Degradation
Areas of Serious Concern
Areas of Some Concern
Stable Terrain
Nonvegetated Land
World Resources Institute
Source: International Soil Reference and Information Centre, unpublished map (Wageningen, the Netherlands, 1990)

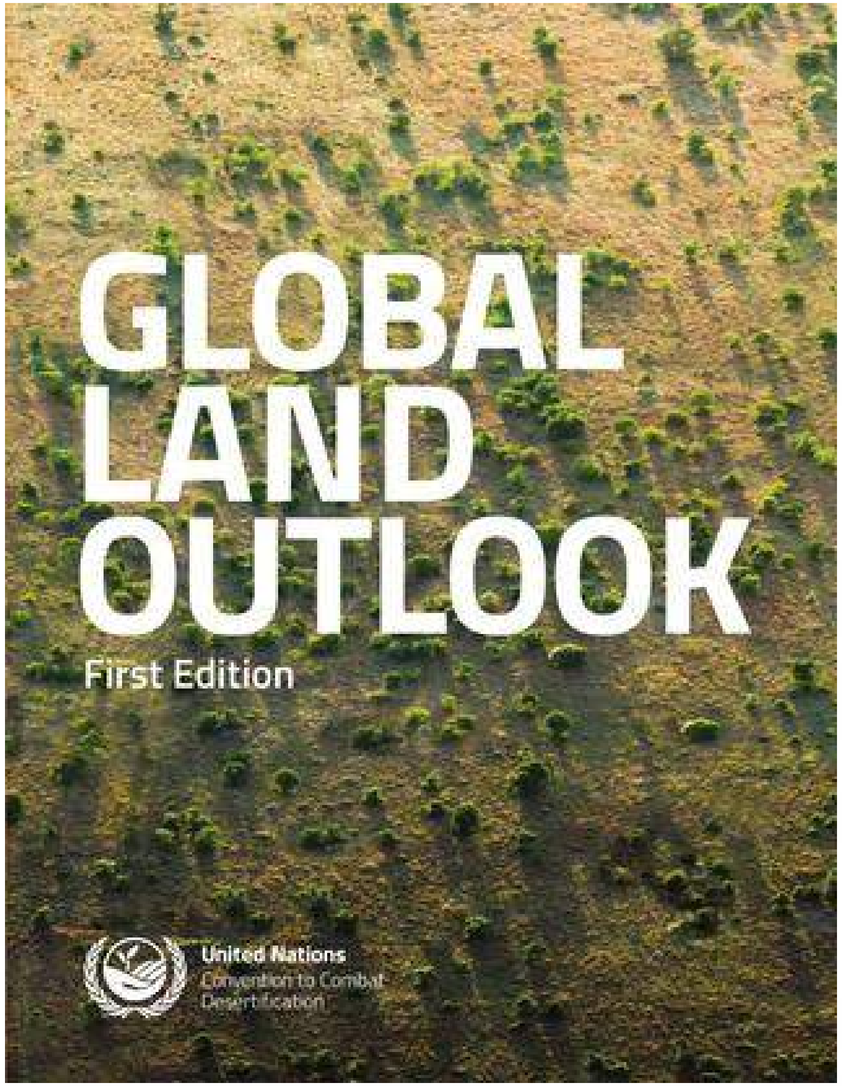
"One third of the worlds soils are degraded"

"24 billion tonnes of soil lost each year"

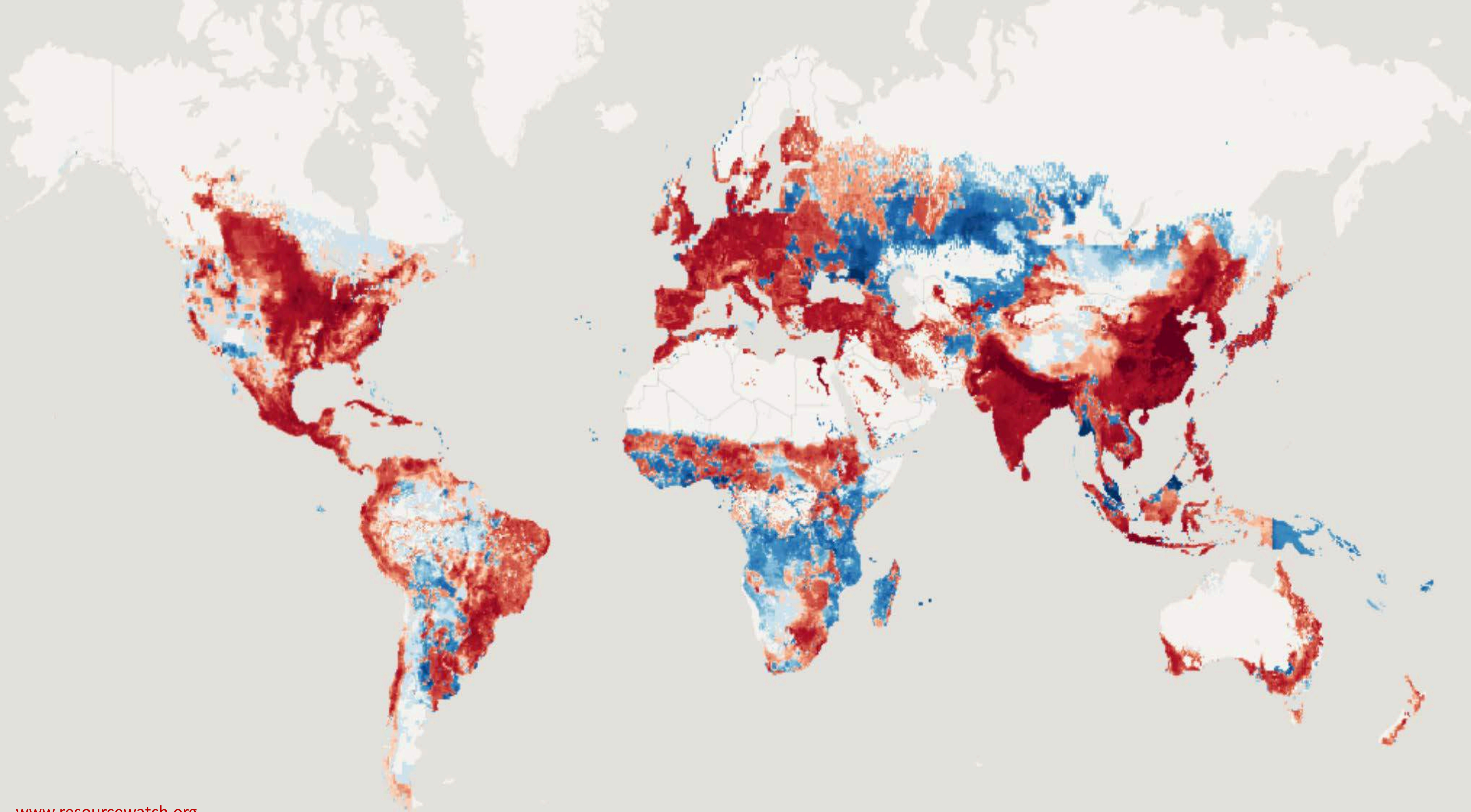


United Nations
Convention to Combat
Desertification

- ***Water erosion*** (includes sheet, rill and gully erosion)
- ***Wind erosion***
- ***Salinity*** (includes dryland, irrigation and urban salinity)
- ***Loss of organic matter***
- ***Fertility decline***
- ***Soil acidity or alkalinity***
- ***Structure decline*** (includes soil compaction and surface sealing)
- ***Soil contamination*** (including effects of toxic chemicals and pollutants).

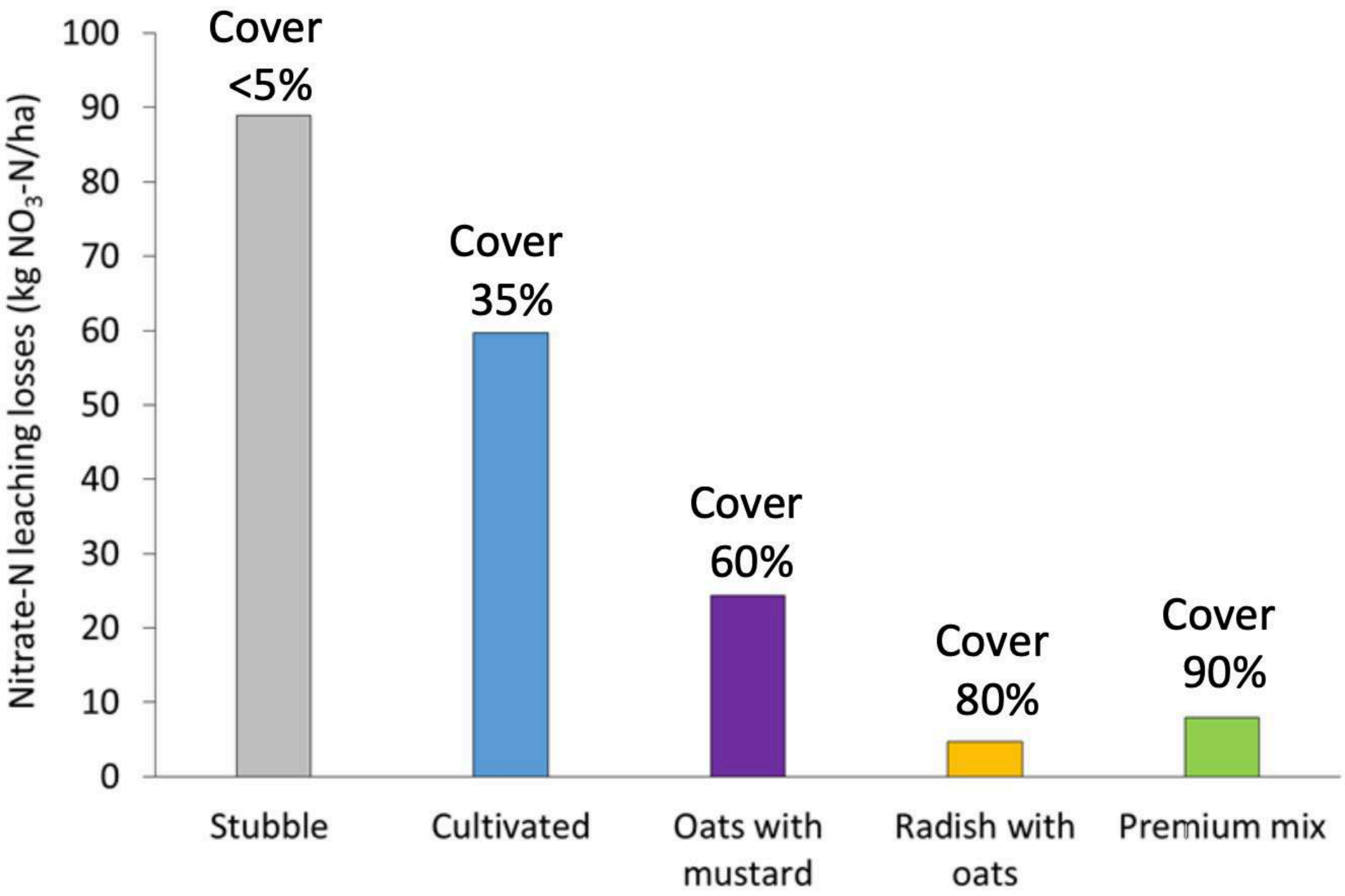



Precious
Pollutant



www.resourcewatch.org

Reduce Nutrient Losses



* *https://www.soilassociation.org/media/19754/fab-farmers-presentation-on-cover-crops-for-farmers.pdf*

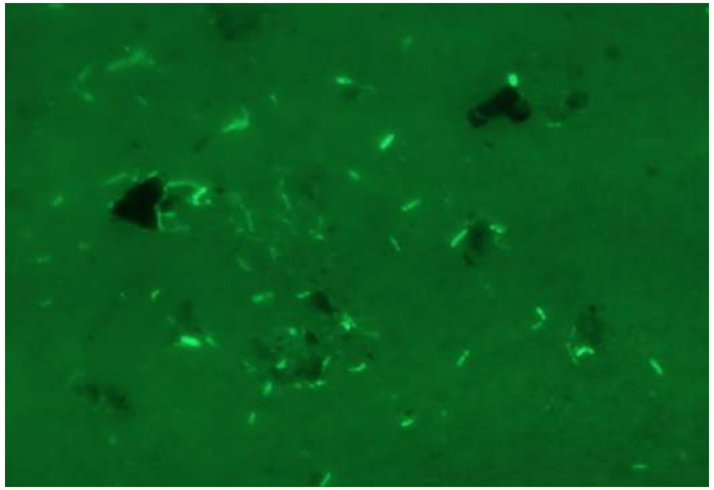
Soil Protection

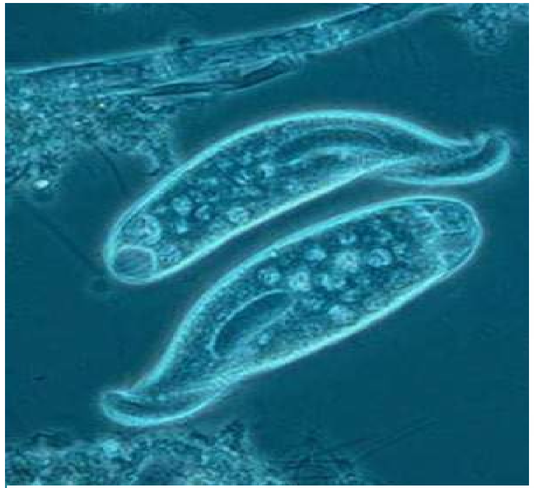
MGA
@maizegrowers

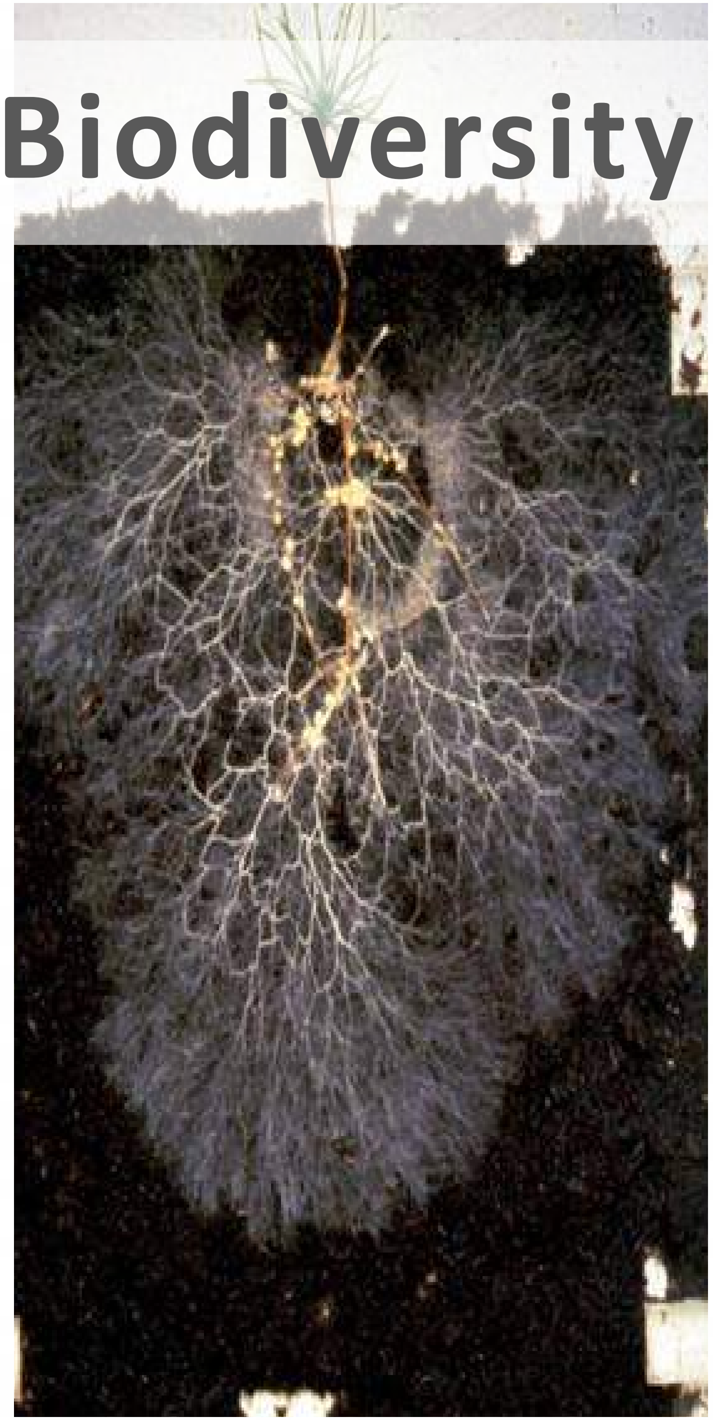
Water Quality

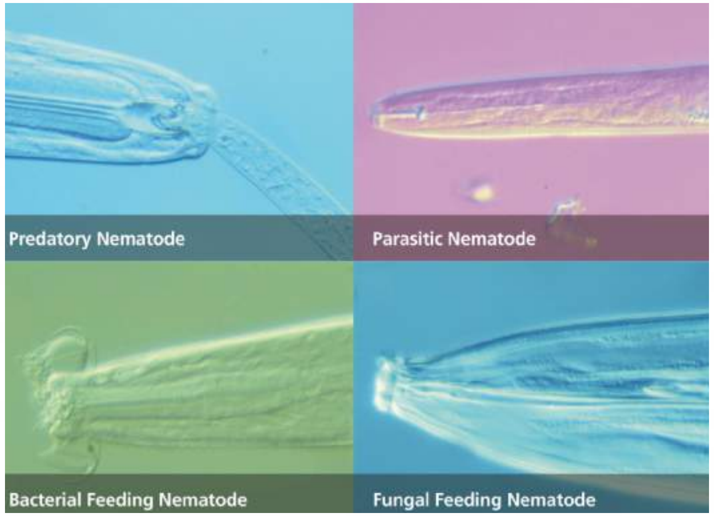
Ecosystem Habitat

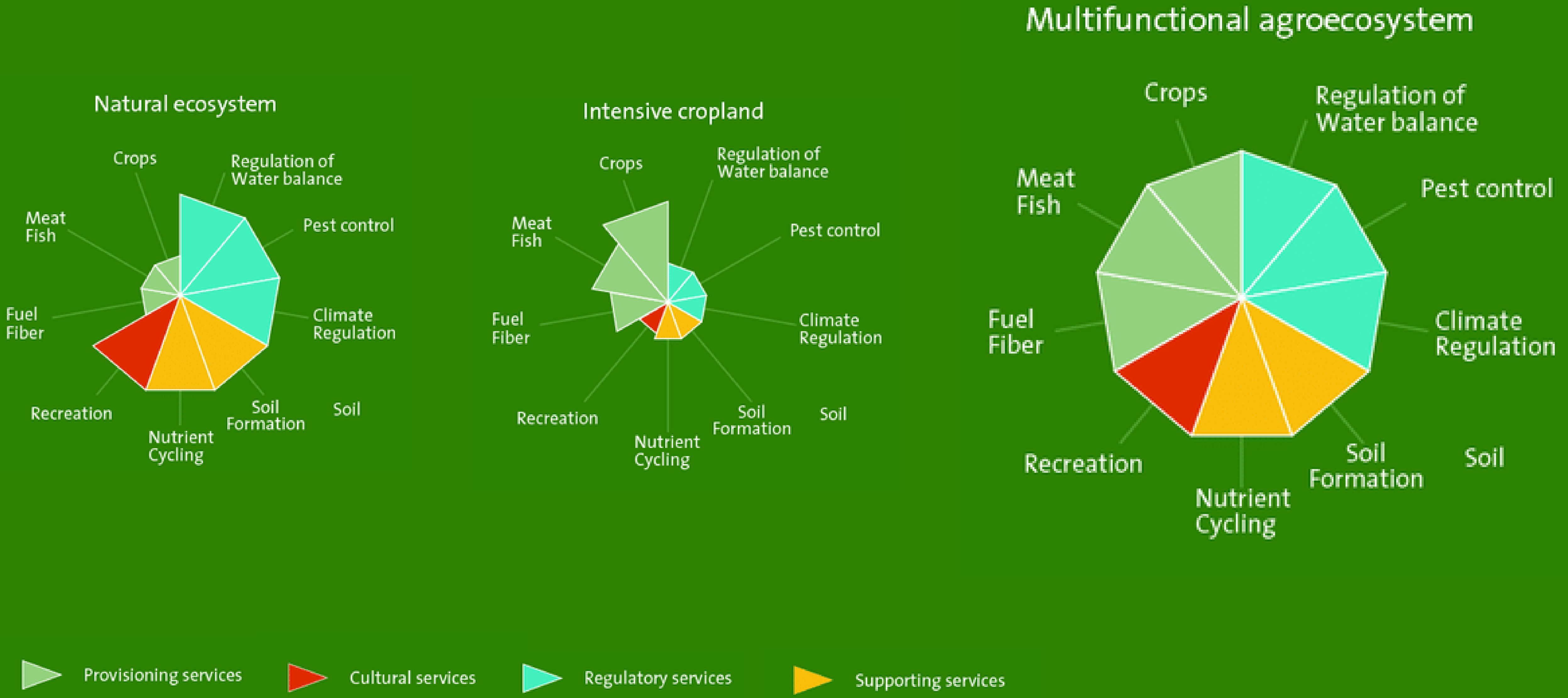
Soil Biodiversity





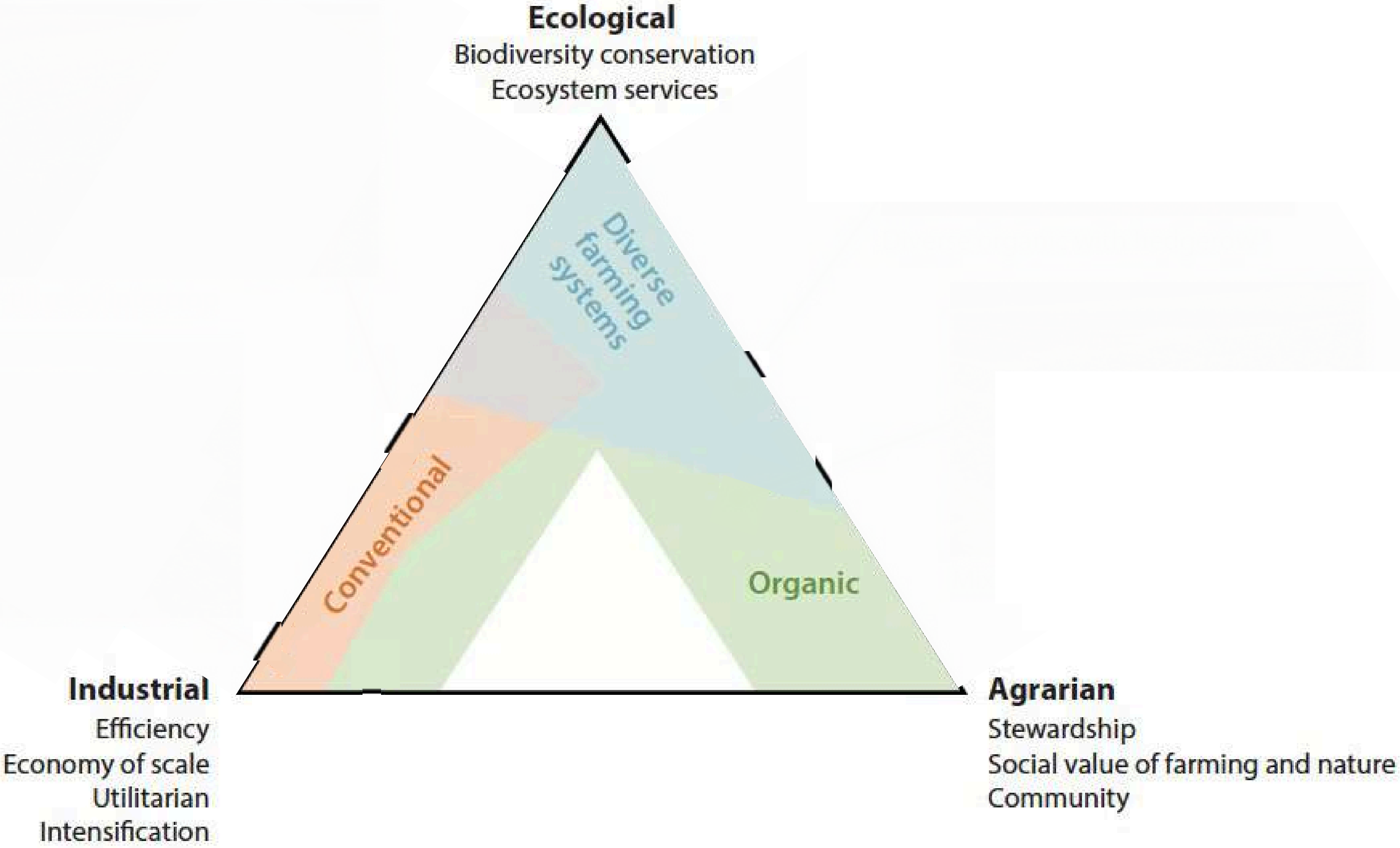






Natural ecosystem
Crops
Regulation of
Water balance
Meat
Fish
Pest control
Fuel
Fiber
Climate
Regulation
Recreation
Nutrient
Cycling
Soil
Formation
Soil
Intensive cropland
Crops
Regulation of
Water balance
Meat
Fish
Pest control
Fuel
Fiber
Climate
Regulation
Recreation
Nutrient
Cycling
Soil
Formation
Soil
Multifunctional agroecosystem
Crops
Regulation of
Water balance
Meat
Fish
Pest control
Fuel
Fiber
Climate
Regulation
Recreation
Nutrient
Cycling
Soil
Formation
Soil
Provisioning services
Cultural services
Regulatory services
Supporting services


a
b



* Shennan (2017), doi: 10.1146/annurev-environ-110615-085750

Increasing Diversity

Novel cash crops
Wider rotations
Annuals/Perennials
Summer/Winter
Cover crops
Companion crops
Intercropping
Biodiversity Strips
Field Margins
Agroforestry
Livestock Integration
Silvopastures

Soil biodiversity is the natural capital of farming.

Soil organic carbon is the currency of this capital, as it determines the amount of soil life and consequently soil fertility and yields.

Monoculture vs Mixtures?

Source: Cotswold Seeds

nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-019-09258-y OPEN

Meta-analysis shows positive effects of plant diversity on microbial biomass and respiration

Chen Chen[1], Han Y.H. Chen[1,2], Xinli Chen[1] & Zhiqun Huang[2,3]

Soil microorganisms are key to biological diversity and many ecosystem processes in terrestrial ecosystems. Despite the current alarming loss of plant diversity, it is unclear how plant species diversity affects soil microorganisms. By conducting a global meta-analysis with paired observations of plant mixtures and monocultures from 106 studies, we show that microbial biomass, bacterial biomass, fungal biomass, fungi:bacteria ratio, and microbial respiration increase, while Gram-positive to Gram-negative bacteria ratio decrease in response to plant mixtures. The increases in microbial biomass and respiration are more pronounced in older and more diverse mixtures. The effects of plant mixtures on all microbial attributes are consistent across ecosystem types including natural forests, planted forests, planted grasslands, croplands, and planted containers. Our study underlines strong relationships between plant diversity and soil microorganisms across global terrestrial ecosystems and suggests the importance of plant diversity in maintaining belowground ecosystem functioning.

Ecology, 84(8), 2003, pp. 2042–2050

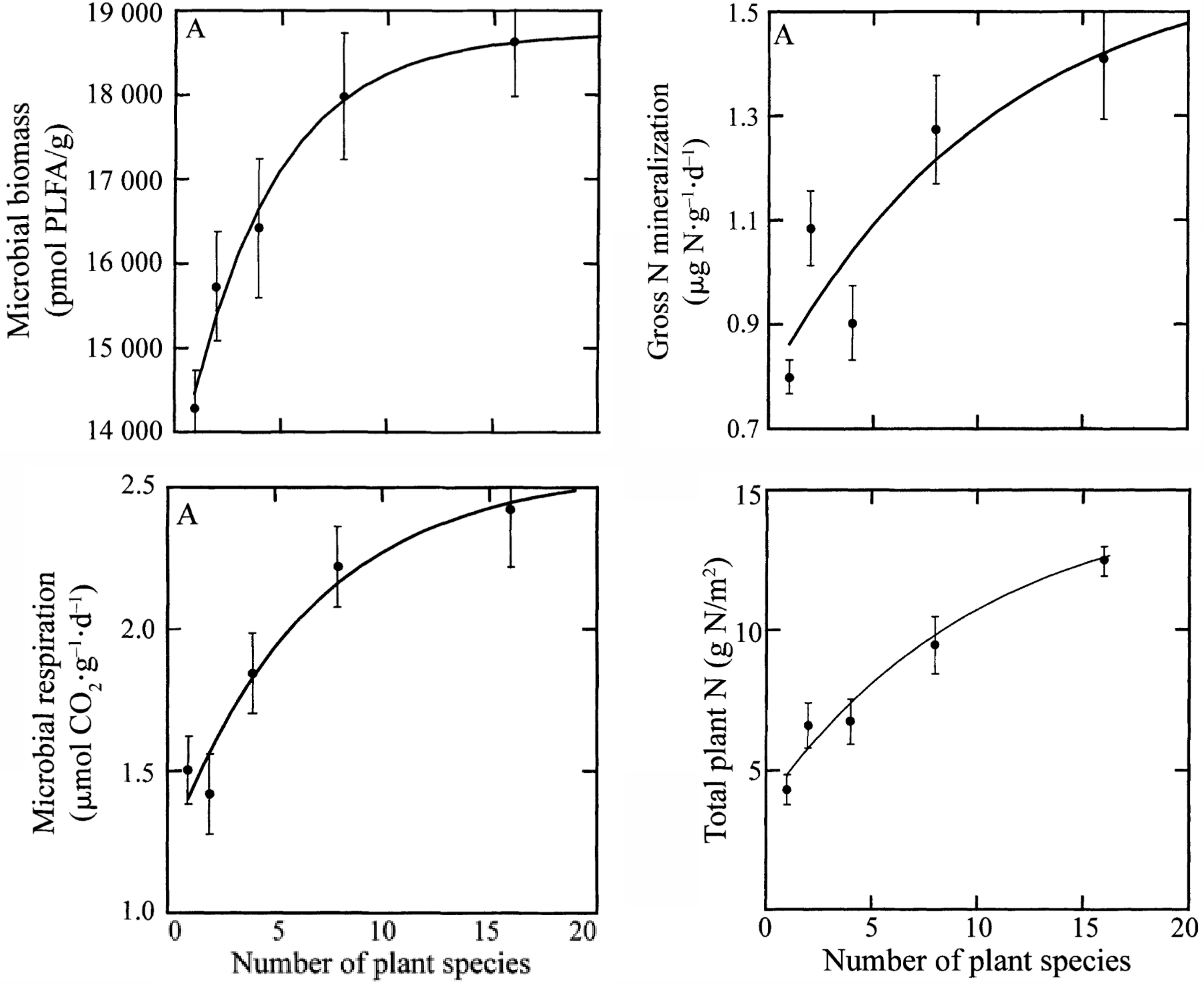
PLANT DIVERSITY, SOIL MICROBIAL COMMUNITIES, AND ECOSYSTEM FUNCTION: ARE THERE ANY LINKS?

DONALD R. ZAK,[1,4] WILLIAM E. HOLMES,[1] DAVID C. WHITE,[2] AARON D. PEACOCK,[2] AND DAVID TILMAN[3]

[1]*School of Natural Resources and Environment, University of Michigan, Ann Arbor, Michigan 48109-1115 USA*
[2]*Center for Biomarker Analysis, University of Tennessee, Knoxville, Tennessee 37932 USA*
[3]*Department of Ecology, Evolution and Behavior, University of Minnesota, St. Paul, Minnesota 55108 USA*

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

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]

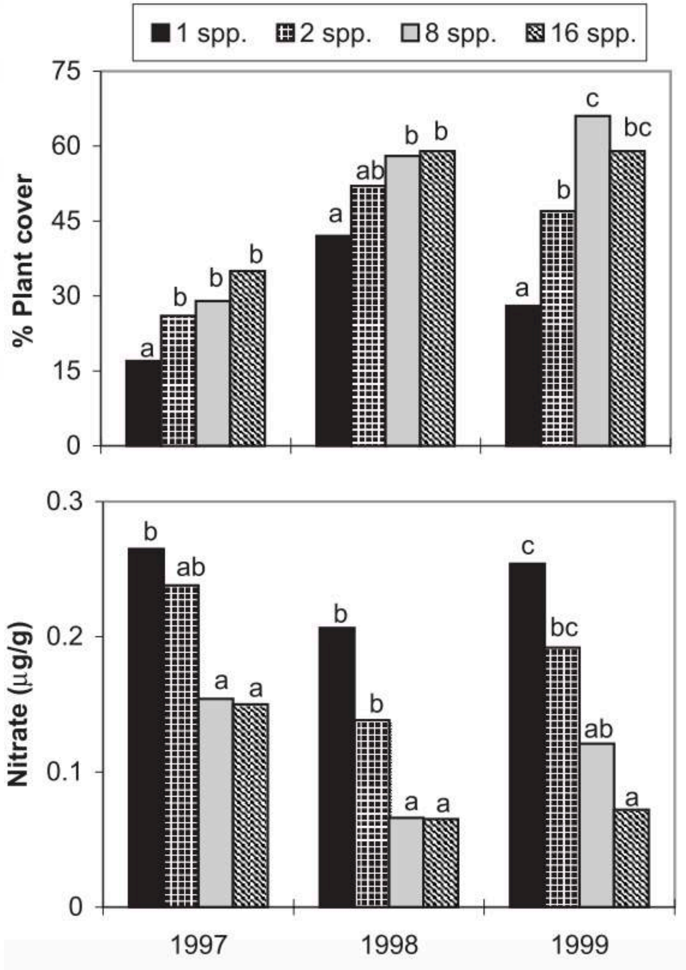
Plant diversity has been shown to determine the composition and functioning of soil biota. Although root-derived organic inputs are discussed as the main drivers of soil communities, experimental evidence is scarce. While there is some evidence that higher root biomass at high plant diversity increases 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.

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.



Contents lists available at ScienceDirect

Soil Biology and Biochemistry

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

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

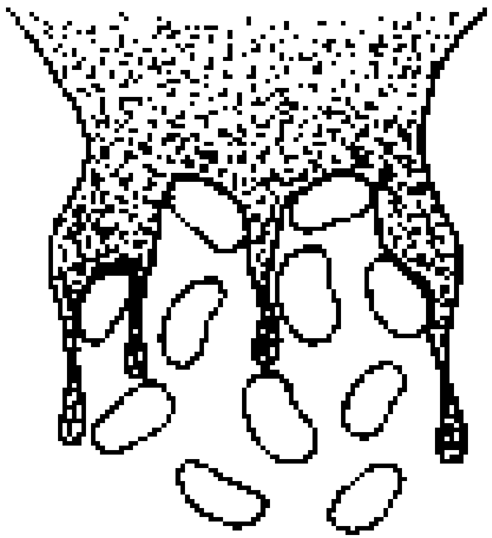
A B S T R A C T

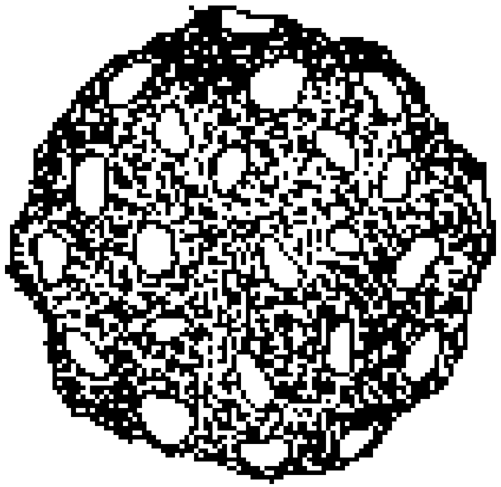
Cover cropping is a promising sustainable agricultural method with the potential to enhance soil health and mitigate consequences of soil degradation. Because cover cropping can form an agroecosystem distinct from that of bare fallow, the soil microbiome is hypothesized to respond to the altered environmental 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

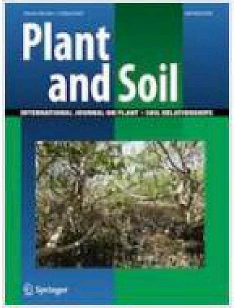
BACTERIAL AND FUNGAL BY-PRODUCTS GLUE SOIL PARTICLES TOGETHER

SOIL IN DISPERSED STATE





SOIL IN AGGREGATED STATE



Plant and Soil
March 2019, Volume 436, Issue 1–2, pp 173–192 | Cite as

Crop diversity facilitates soil aggregation in relation to soil microbial community composition driven by intercropping

Abstract

Background and Aims Studies verify that intercropping increases soil macro-aggregates but the mechanism underlying the increase is poorly understood.

Methods Three long-term field experiments were conducted starting in 2009 at three sites in an oasis in northwest China. The first was a split-plot design: *Rhizobium* (with or without inoculation) and three cropping systems (faba bean/maize intercropping and corresponding monocultures). The second and third experiments were both single-factorial randomized block designs with nine cropping systems (maize intercropped with faba bean, chickpea, soybean, or oilseed rape, and the corresponding monocultures). Soil aggregates were determined by the wet sieving method. Microbial biomass and community composition in 2015 and 2016 were determined by phospholipid fatty acid (PLFA) and high throughput sequencing analysis of 16S *rRNA*.

Results Soil macro-aggregates (> 2 mm) in intercropping systems increased by 15.5–58.6% across three sites and two years, an effect derived partly from increased relative abundance of soil *Sordariales*, from enhanced arbuscular mycorrhizal fungi biomass, or from reduced relative abundance of *Nitrospirae*, depending on soil type.

Conclusions Intercropping alters soil microbial community composition and further facilitates soil aggregation. These findings provide insights into the mechanisms underlying the maintenance of biodiversity in ecosystem functioning.

* Xiu-li, T., (2019). doi:10.1007/s11104-018-03924-8

BIOLOGICAL REVIEWS

Cambridge Philosophical Society

Original Article

Effects of plant diversity on soil carbon in diverse ecosystems: a global meta-analysis

ABSTRACT

Soil organic carbon (SOC) is a valuable resource for mediating global climate change and securing food production. Despite an alarming rate of global plant diversity loss, uncertainties concerning the effects of plant diversity on SOC remain, because plant diversity not only stimulates litter inputs *via* increased productivity, thus enhancing SOC, but also stimulates microbial respiration, thus reducing SOC. By analysing 1001 paired observations of plant mixtures and corresponding monocultures from 121 publications, we show that both SOC content and stock are on average 5 and 8% higher in species mixtures than in monocultures. These positive mixture effects increase over time and are more pronounced in deeper soils. Microbial biomass carbon, an indicator of SOC release and formation, also increases, but the proportion of microbial biomass carbon in SOC is lower in mixtures. Moreover, these species-mixture effects are consistent across forest, grassland, and cropland systems and are independent of background climates. Our results indicate that converting 50% of global forests from mixtures to monocultures would release an average of 2.70 Pg C from soil annually over a period of 20 years: about 30% of global annual fossil-fuel emissions. Our study highlights the importance of plant diversity preservation for the maintenance of soil carbon sequestration in discussions of global climate change policy.

* Chen, X., *et al.*, (2019). doi: 10.1111/brv.12554

nature COMMUNICATIONS

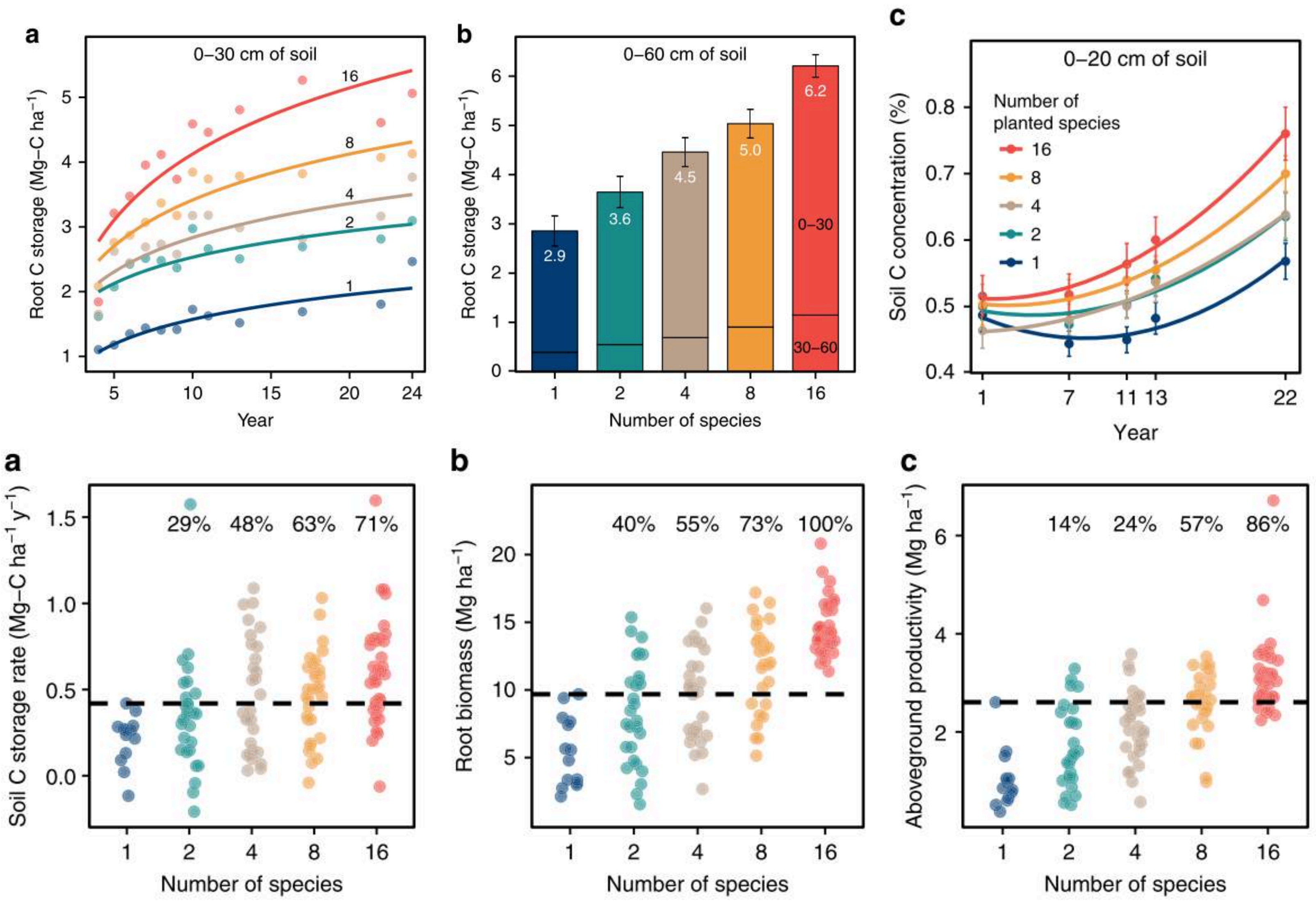
ARTICLE

https://doi.org/10.1038/s41467-019-08636-w OPEN

Soil carbon sequestration accelerated by restoration of grassland biodiversity

Yi Yang[1], David Tilman[1,2], George Furey[1] & Clarence Lehman[1]

Agriculturally degraded and abandoned lands can remove atmospheric CO_2 and sequester it as soil organic matter during natural succession. However, this process may be slow, requiring a century or longer to re-attain pre-agricultural soil carbon levels. Here, we find that restoration of late-successional grassland plant diversity leads to accelerating annual carbon storage rates that, by the second period (years 13–22), are 200% greater in our highest diversity treatment than during succession at this site, and 70% greater than in monocultures. The higher soil carbon storage rates of the second period (years 13–22) are associated with the greater aboveground production and root biomass of this period, and with the presence of multiple species, especially C4 grasses and legumes. Our results suggest that restoration of high plant diversity may greatly increase carbon capture and storage rates on degraded and abandoned agricultural lands.



* Yang, Y. *et al.*, (2019). doi: 10.1038/s41467-019-08636-w

PRIMARY RESEARCH ARTICLE

WILEY Global Change Biology

Grazing enhances belowground carbon allocation, microbial biomass, and soil carbon in a subtropical grassland

Chris H. Wilson[1] | Michael S. Strickland[2] | Jack A. Hutchings[3] | Thomas S. Bianchi[3] | S. Luke Flory[4]

[1]School of Natural Resources and Environment, University of Florida, Gainesville, FL, USA

[2]Department of Biological Sciences, Virginia Tech University, Blacksburg, VA, USA

[3]Department of Geological Sciences, University of Florida, Gainesville, FL, USA

[4]Agronomy Department, University of Florida, Gainesville, FL, USA

Correspondence
Chris H. Wilson, School of Natural Resources and Environment, University of Florida, Gainesville, FL, USA.
Email: chwilson@ufl.edu

Funding information
Division of Environmental Biology, Grant/Award Number: 1501686; NSF DDIG, Grant/Award Number: 1501686

Grazing *exclusion* was associated with:

- less belowground C allocation
- less root biomass
- less root exudation
- less microbial biomass
- lower soil organic carbon

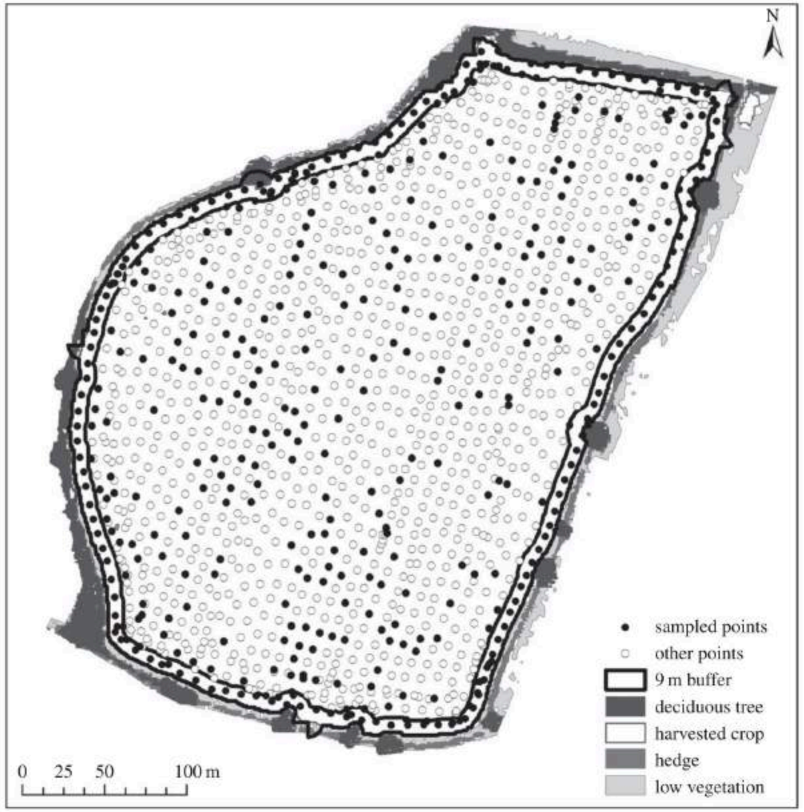
* Wilson, C.H., *et al* (2018). doi: 10.1111/gcb.14070

Wildlife-friendly farming increases crop yield: evidence for ecological intensification

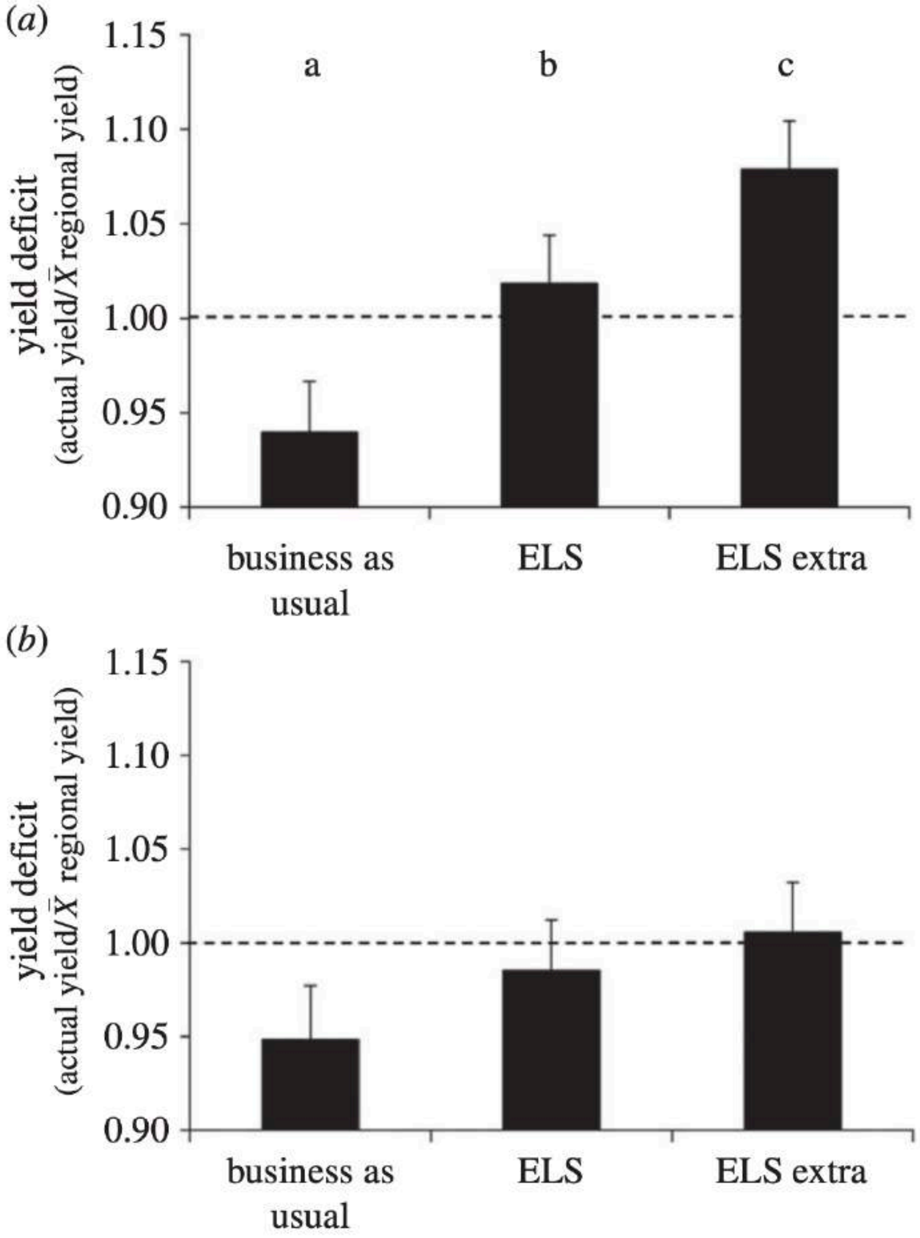
Richard F. Pywell[1], Matthew S. Heard[1], Ben A. Woodcock[1], Shelley Hinsley[1], Lucy Ridding[1], Marek Nowakowski[2] and James M. Bullock[1]

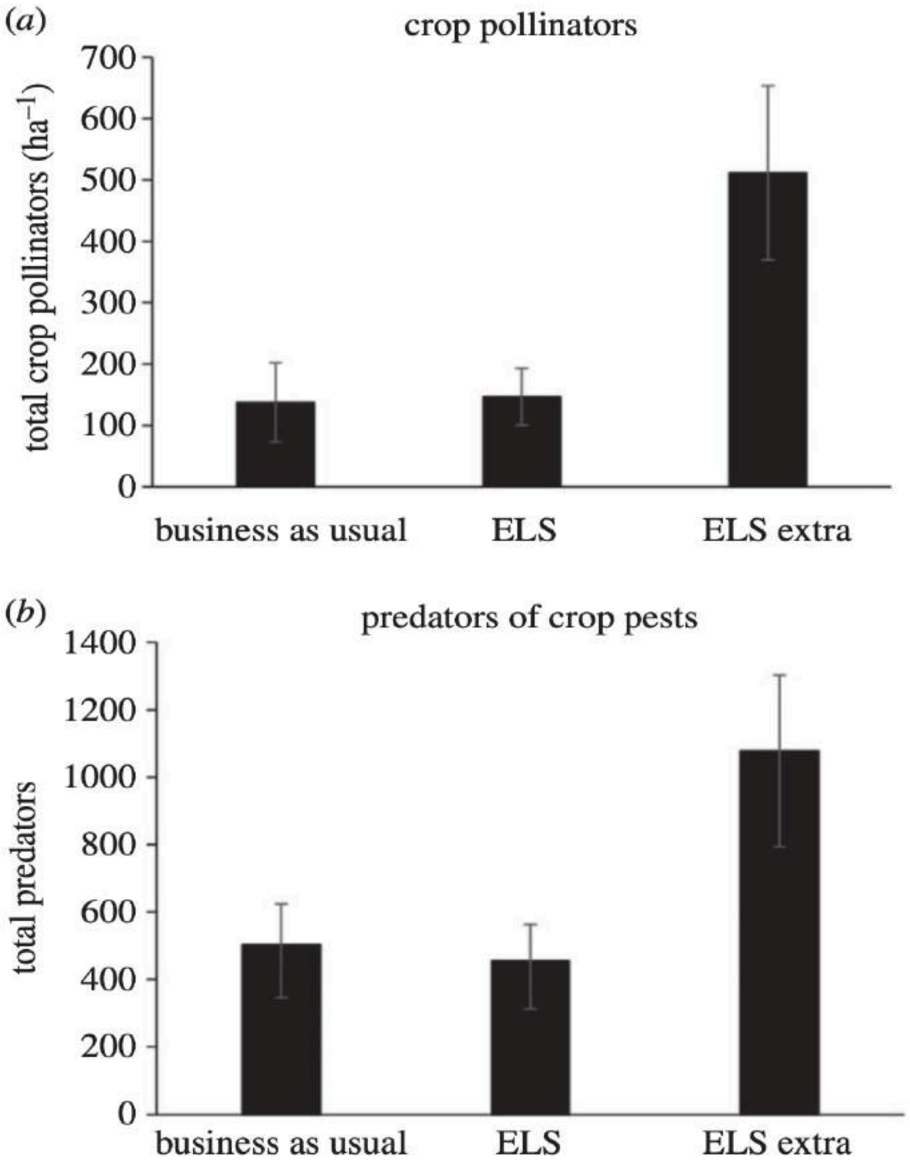
[1]NERC Centre for Ecology and Hydrology, Wallingford OX10 8BB, UK
[2]Wildlife Farming Company, Bicester OX26 1UN, UK

Ecological intensification has been promoted as a means to achieve environmentally sustainable increases in crop yields by enhancing ecosystem functions that regulate and support production. There is, however, little direct evidence of yield benefits from ecological intensification on commercial farms growing globally important foodstuffs (grains, oilseeds and pulses). We replicated two treatments removing 3 or 8% of land at the field edge from production to create wildlife habitat in 50–60 ha patches over a 900 ha commercial arable farm in central England, and compared these to a business as usual control (no land removed). In the control fields, crop yields were reduced by as much as 38% at the field edge. Habitat creation in these lower yielding areas led to increased yield in the cropped areas of the fields, and this positive effect became more pronounced over 6 years. As a consequence, yields at the field scale were maintained—and, indeed, enhanced for some crops—despite the loss of cropland for habitat creation. These results suggested that over a 5-year crop rotation, there would be no adverse impact on overall yield in terms of monetary value or nutritional energy. This study provides a clear demonstration that wildlife-friendly management which supports ecosystem services is compatible with, and can even increase, crop yields.



* Pywell, R.F., et al., (2015). doi: 10.1098/rspb.2015.1740

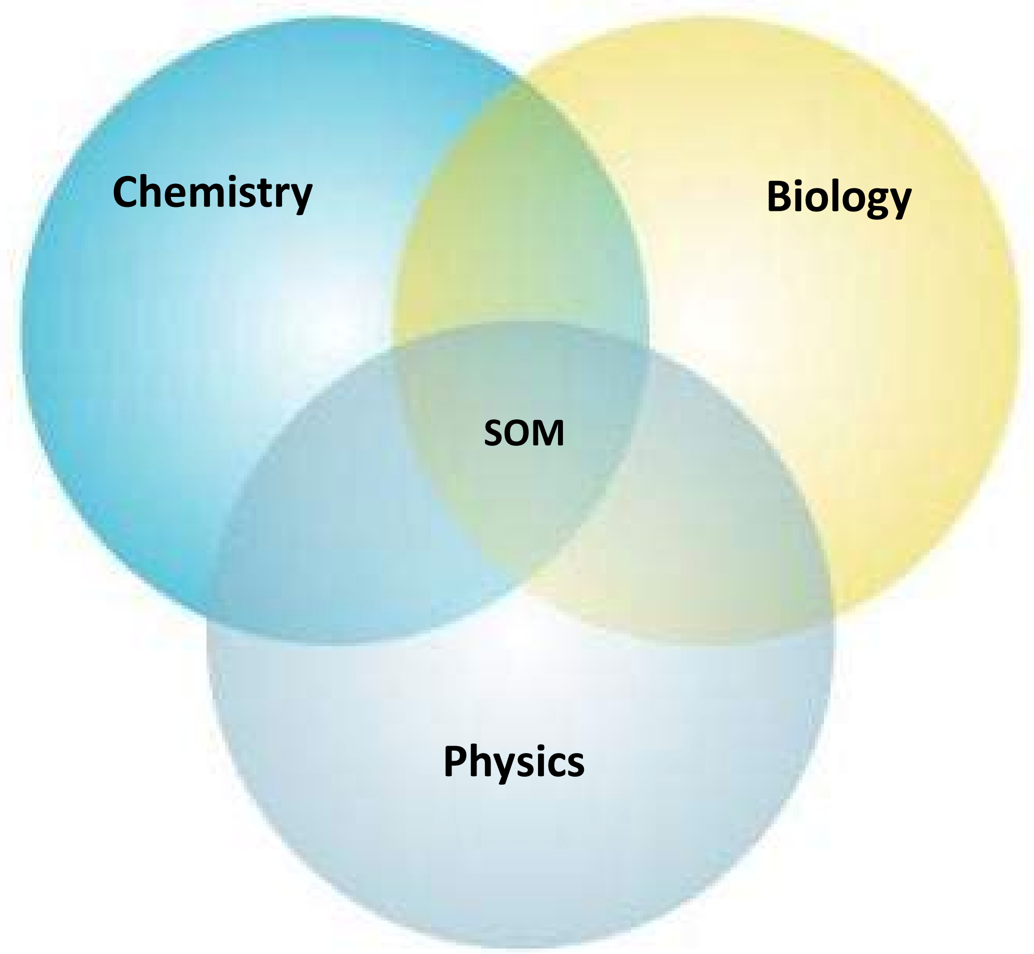




* Pywell, R.F., et al., (2015). doi: 10.1098/rspb.2015.1740

* Source: Matthias Tschumi/Agroscope

Improve SOM




Shoots
Roots
Exudates

#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***.

  - Schmidt *et al* (2011)
  - Clemmensen *et al* (2013)
  - Mazzilli *et al* (2015)
  - Jackson *et al* (2017)
  - Wood & Bradford (2018)
  - Sokol & Bradford (2018)
  - Berhongaray *et al* (2018)

Edward Dickin
@naked_barley

Following

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

Source: David Cunningham, Scotland

Biogeochemistry (2012) 111:41–55
DOI 10.1007/s10533-011-9658-z

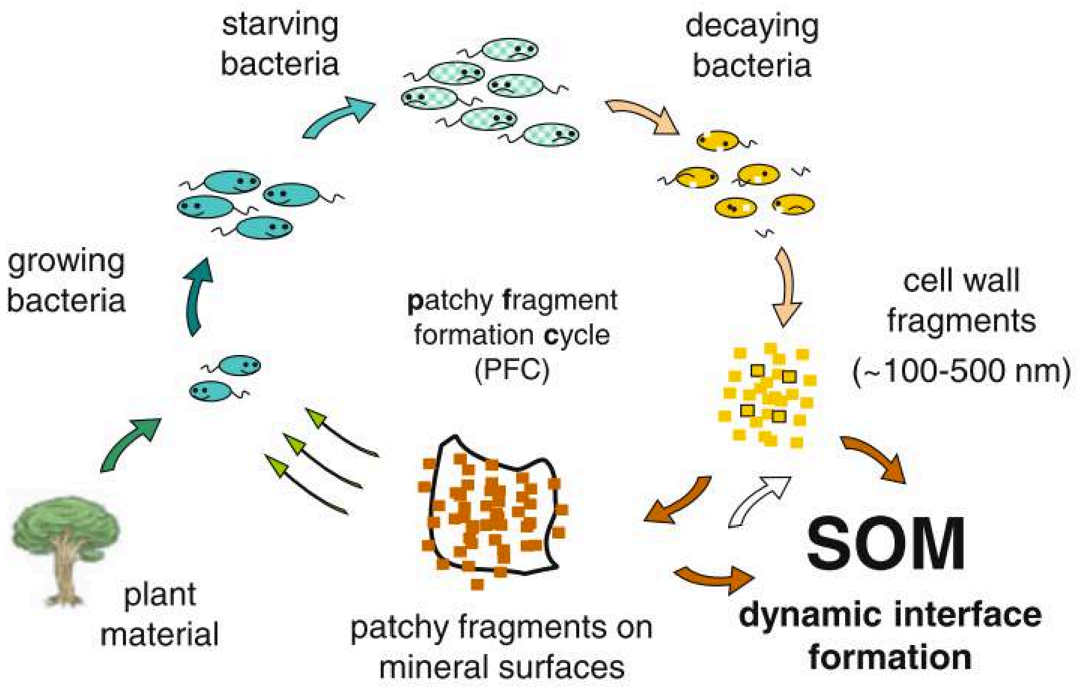
SYNTHESIS AND EMERGING IDEAS

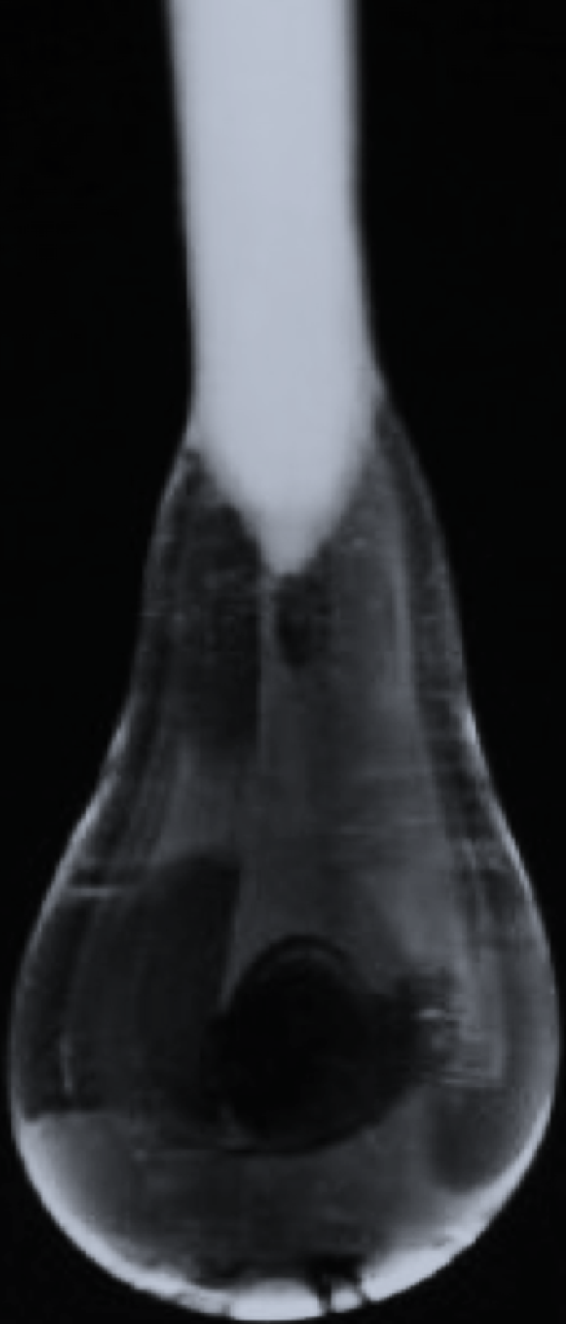
SOM genesis: microbial biomass as a significant source

**Anja Miltner · Petra Bombach ·
Burkhard Schmidt-Brücken · Matthias Kästner**

Received: 23 November 2010 / Accepted: 14 September 2011 / Published online: 12 October 2011

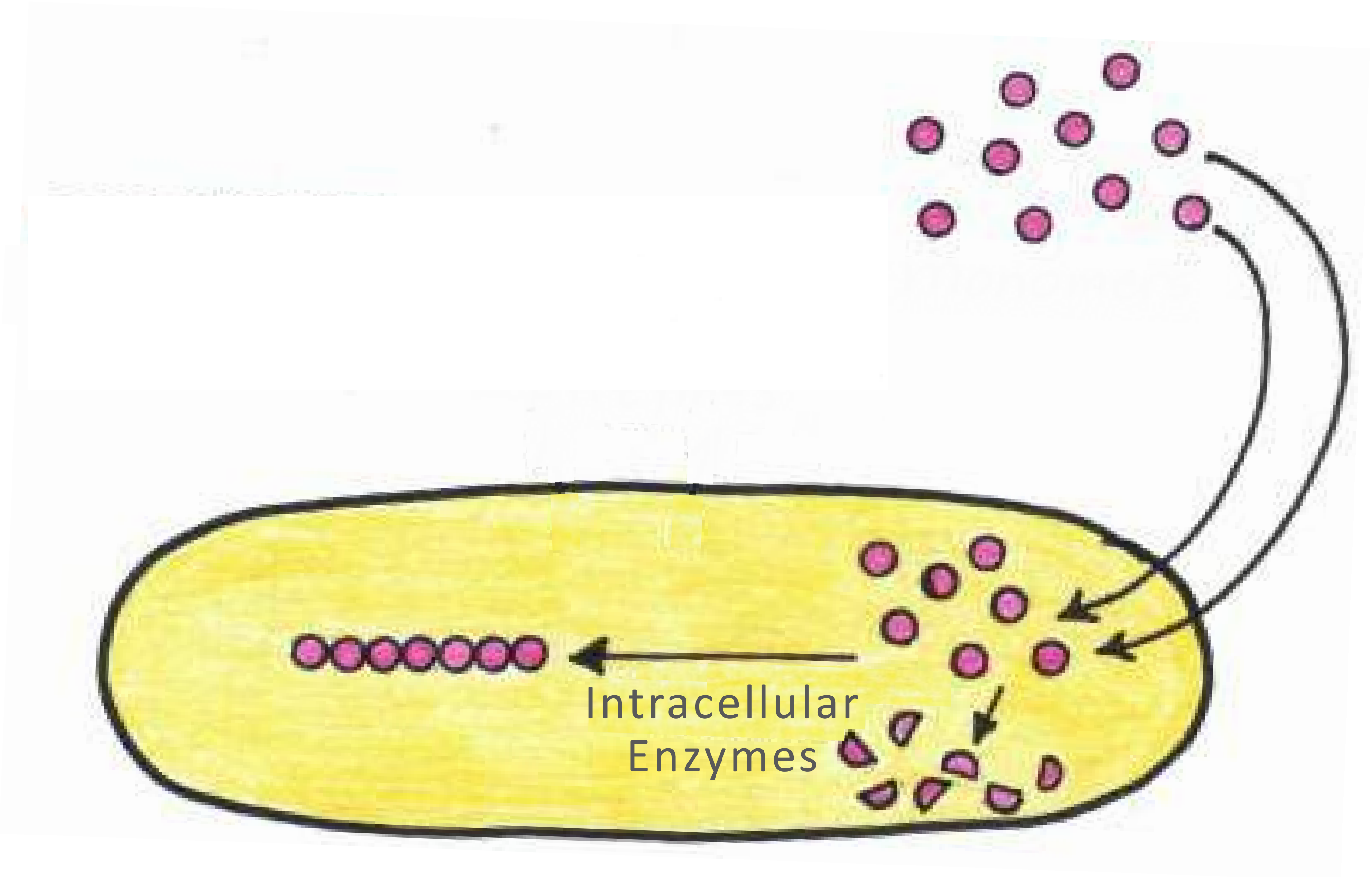
Abstract Proper management of soil organic matter (SOM) is needed for maintaining soil fertility and for mitigation of the global increase in atmospheric CO_2 concentrations and should be informed by knowledge about the sources, spatial organisation and stabilisation processes of SOM. Recently, microbial biomass residues (i.e. necromass) have been identified as a significant source of SOM. Here, we propose that cell wall envelopes of bacteria and fungi are stabilised in soil and contribute significantly to small-particulate SOM formation. This hypothesis is based on the mass balance of a soil incubation experiment with ^{13}C-labelled bacterial cells and on the visualisation of the microbial residues by means of scanning electron microscopy (SEM). At the end of a 224-day incubation, 50% of the biomass-derived C remained in the soil, mainly in the non-living part of SOM (40% of the added biomass C). SEM micrographs only rarely showed intact cells. Instead, organic patchy fragments of 200–500 nm size were abundant and these fragments were associated with all stages of cell envelope decay and fragmenta-

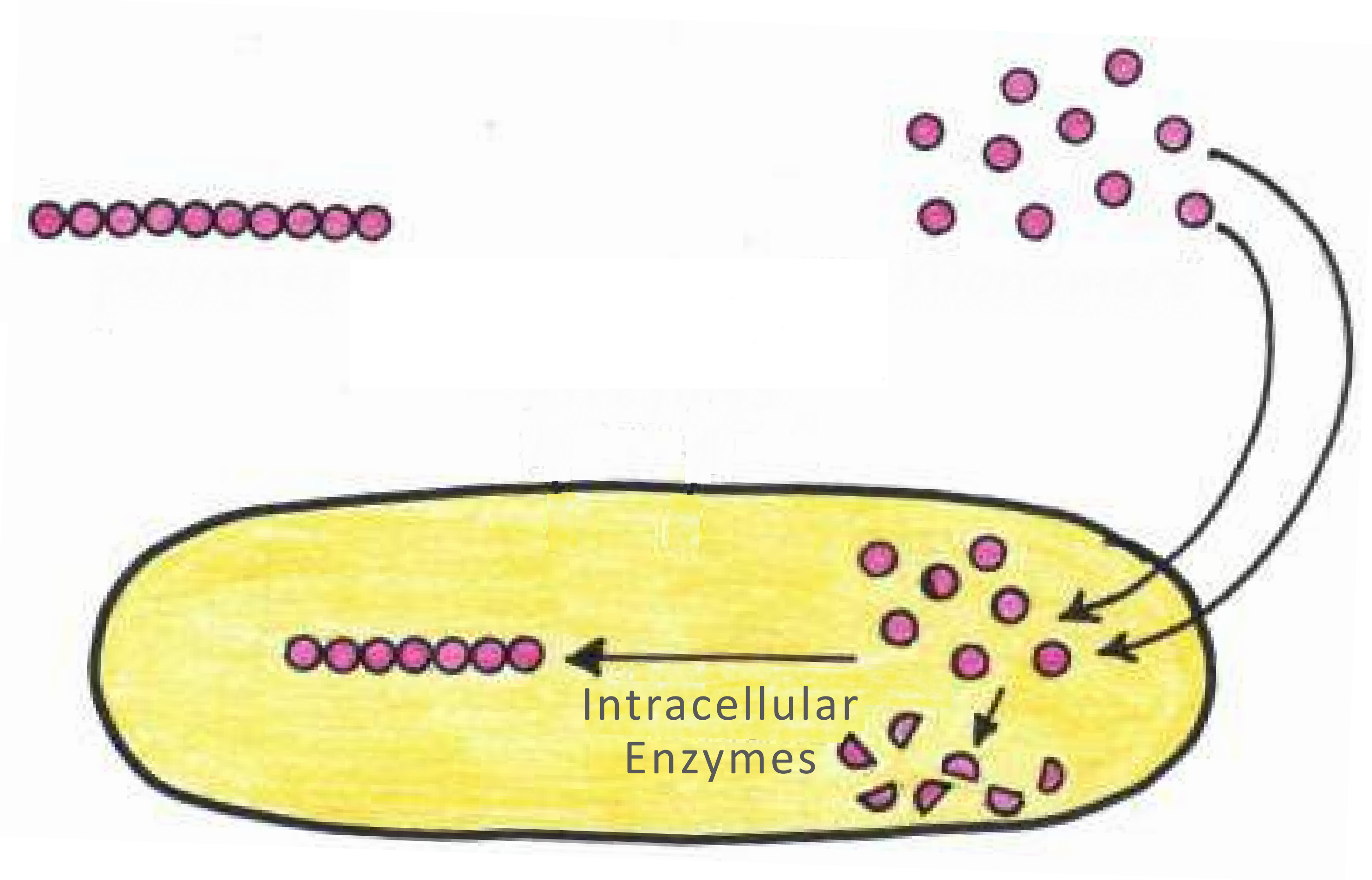




Carbon Use Efficiency?

Image: Glyn Bengough


Intracellular
Enzymes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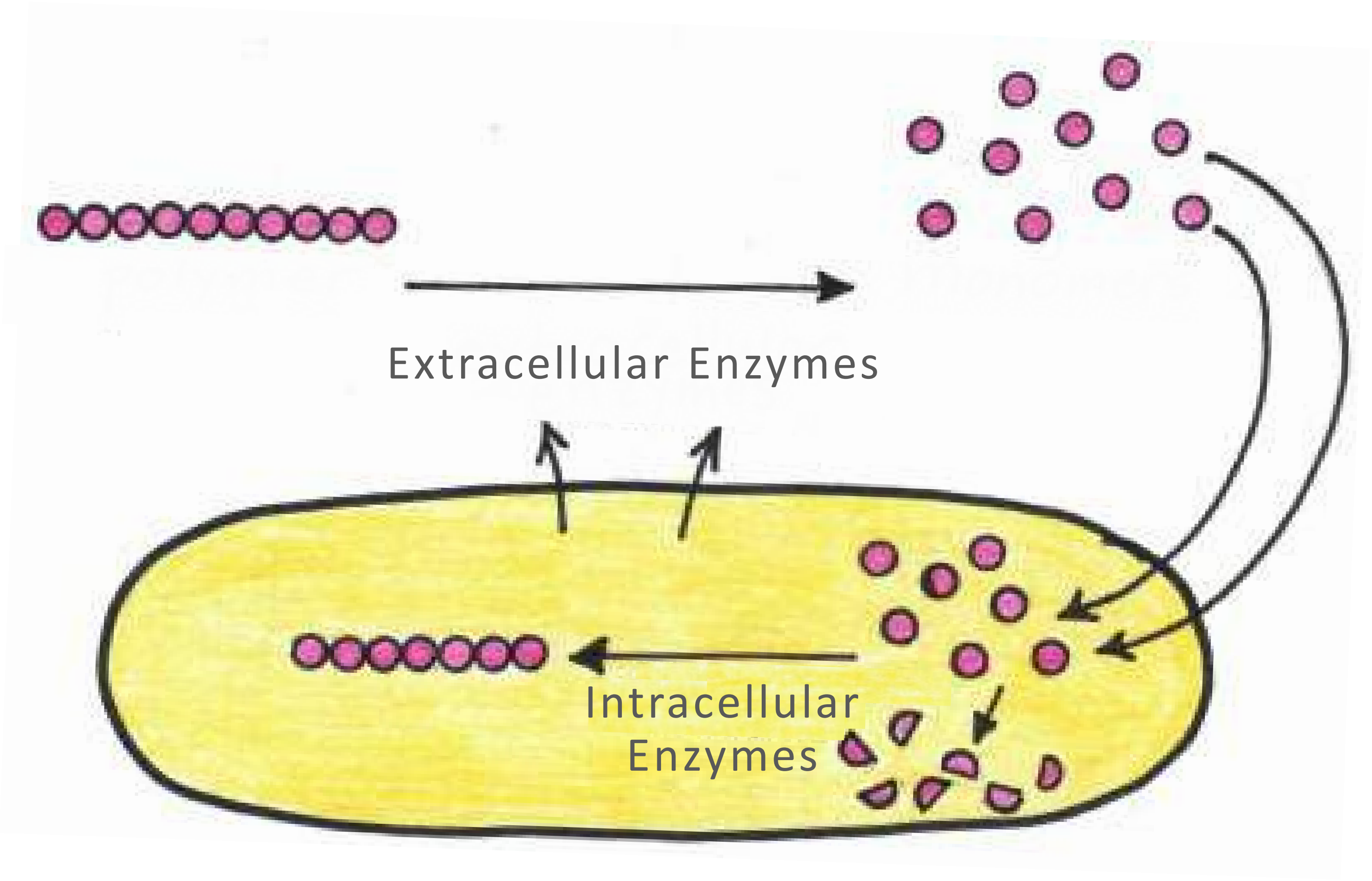

Extracellular Enzymes
Intracellular
Enzymes

Global Change Biology

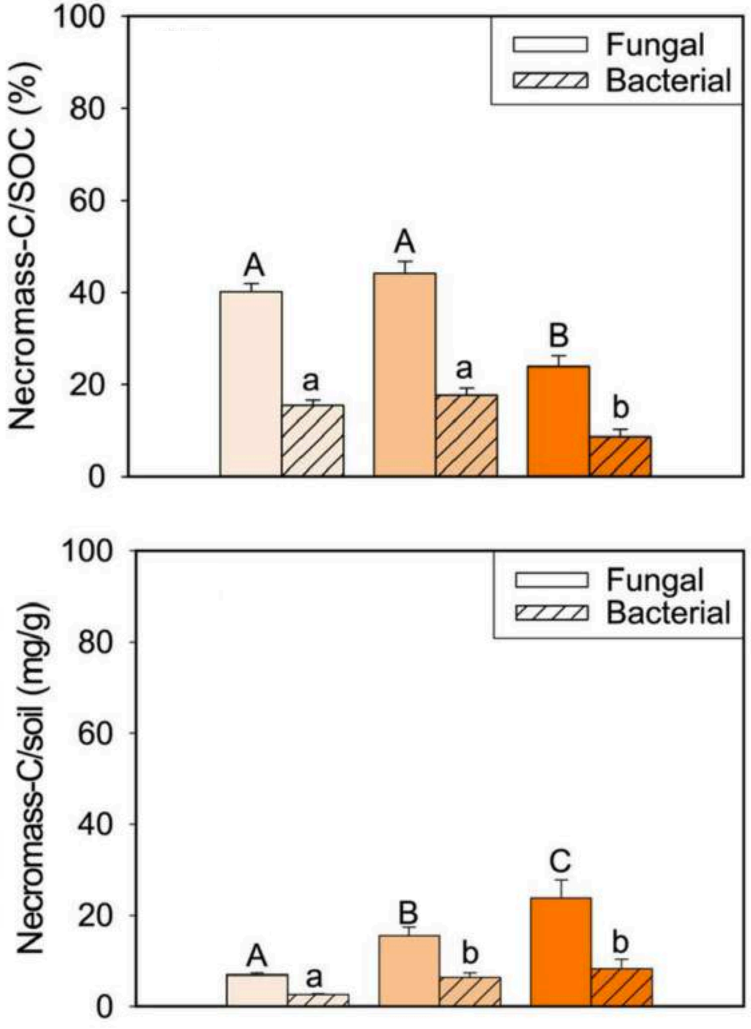
OPINION

Quantitative assessment of microbial necromass contribution to soil organic matter

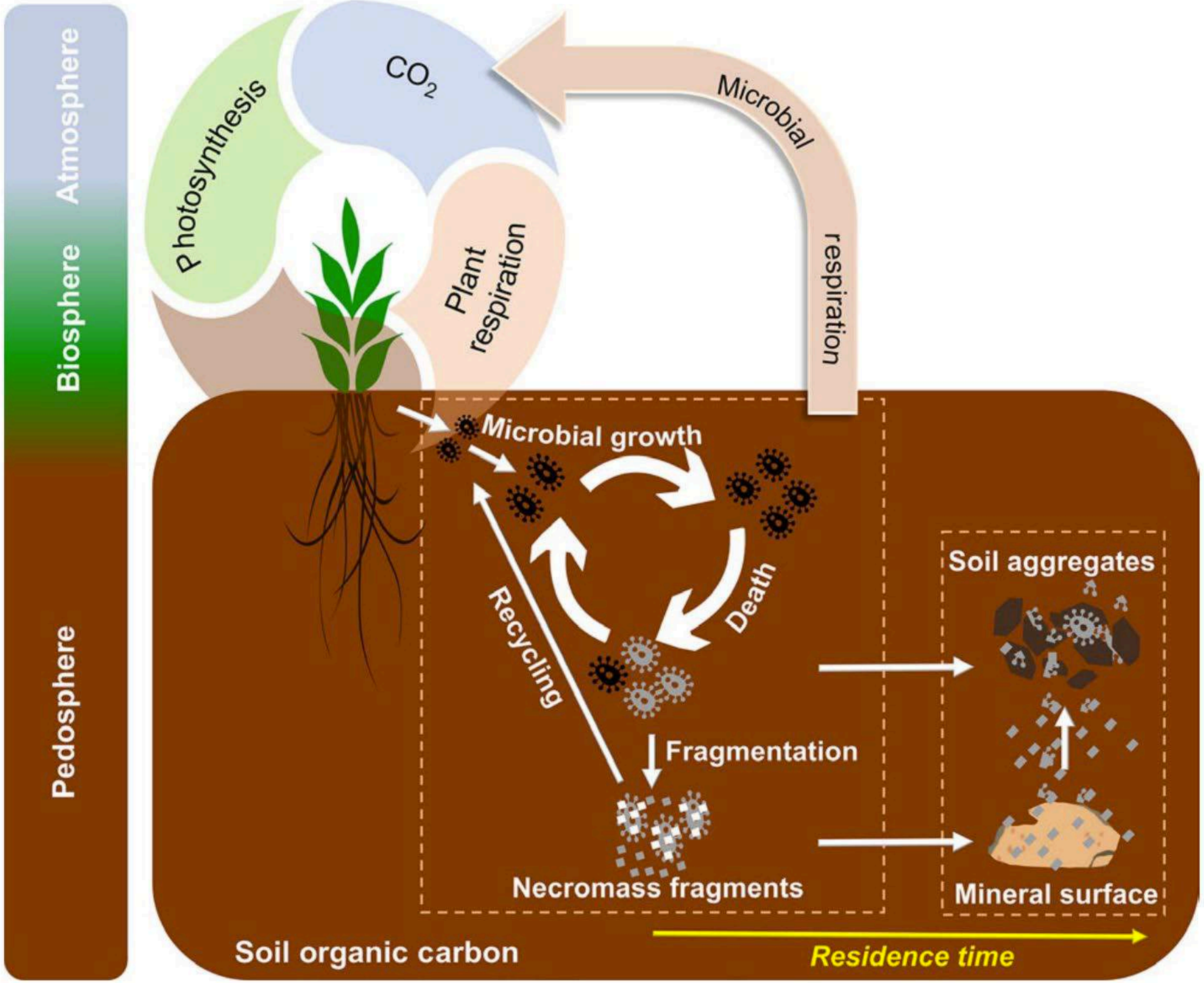
Chao Liang, Wulf Amelung, Johannes Lehmann, Matthias Kästner

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



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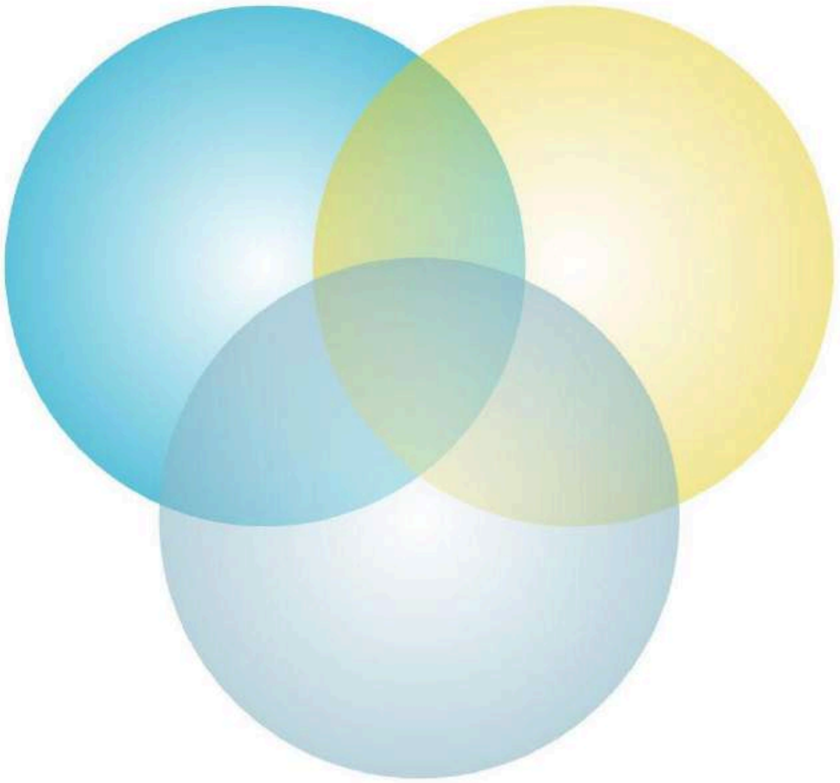
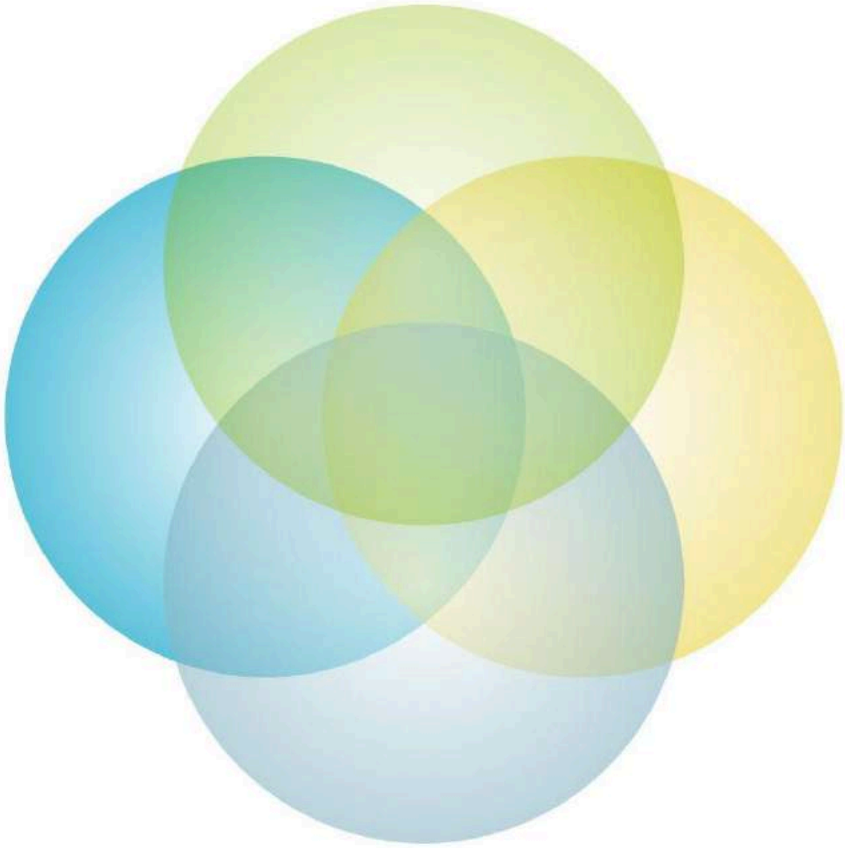
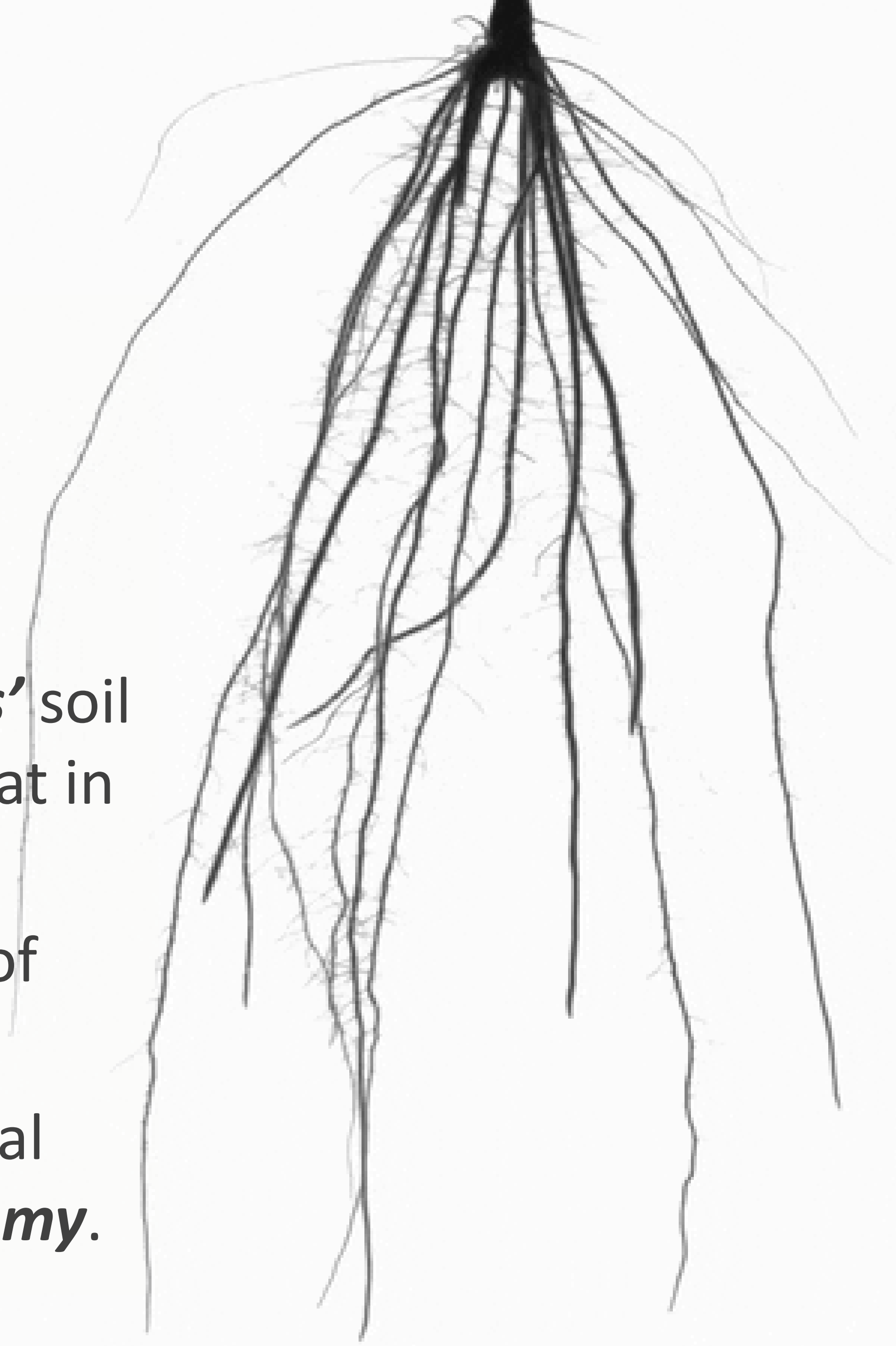




Roots and Natural Capital?

- ***Roots*** and ***exudates*** play a critical role in feeding microbes and building SOM.
- Microbial transformation of these C inputs is key to stabilising as SOM.
- This perhaps suggests that perhaps the ***'living roots'*** soil health principle should be taking more of a front seat in our management strategies.
- ***Polycultures*** additionally support a greater variety of above and belowground interactions.
- More ***plant species diversity*** can build natural capital and soil health – good for both ***ecology*** and ***agronomy***.



Thank you, Questions?

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