Pr Philippe Vandenkoornhuyse

Pratiques agricoles et conséquences évolutives sur les microorganismes du sol et les symbioses des plantes cultivées

AG SOERE PRO 2024

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UMR6553 EcoBio,
Rennes, France

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cnrs dépasser les frontières

@symbioticworld

ECOBIO Rennes

Microorganisms can promote evolutionary advantages to its host over generations

A number of examples…

Acremonium coenophialum **associated with** *Festuca arundinacea*

Festuca arundinacea, Kentucky31 (1971 by E. N. Fergus),

Poor soils,
Resistant to pest and drought.

→ *Kentucky 31 = invasive*

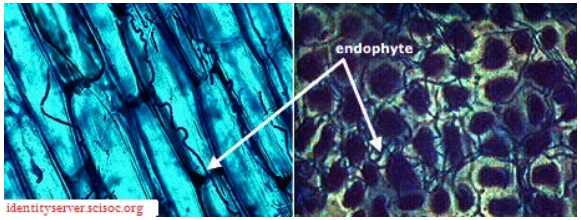
https://www.walmart.com

Festuca arundinacea, Kentucky31 (1971 by E. N. Fergus),

Acremonium coenophialum

Synthesis of Ergovaline + Loline → grazing resistance

alcaloids



+

=

Grazers

-Weight loss

-Abortion

-other negative effects

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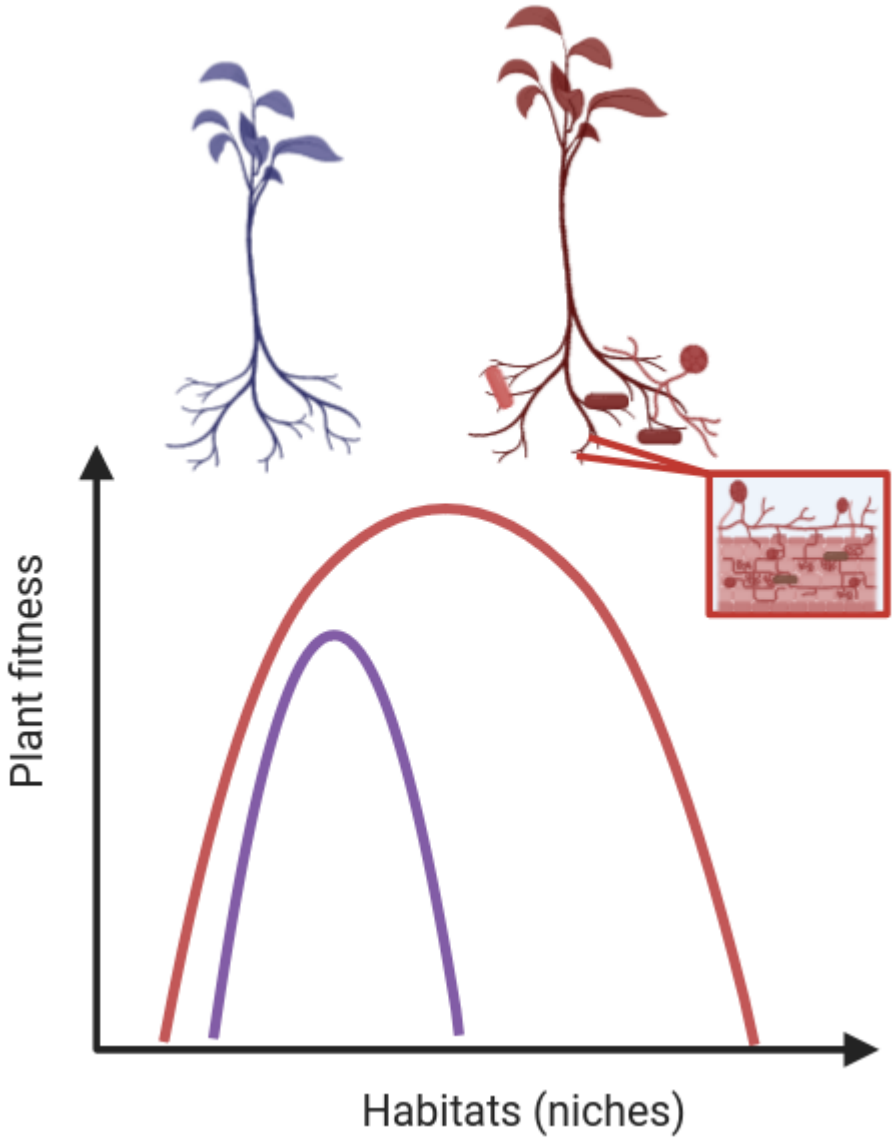

Plant fitness
Habitats (niches)

Plant fitness

Not necessarily a consequence of plant genome itself !

P ≠ G

Microbiota do matter

Plant fitness

Not necessarily a consequence of plant genome itself !

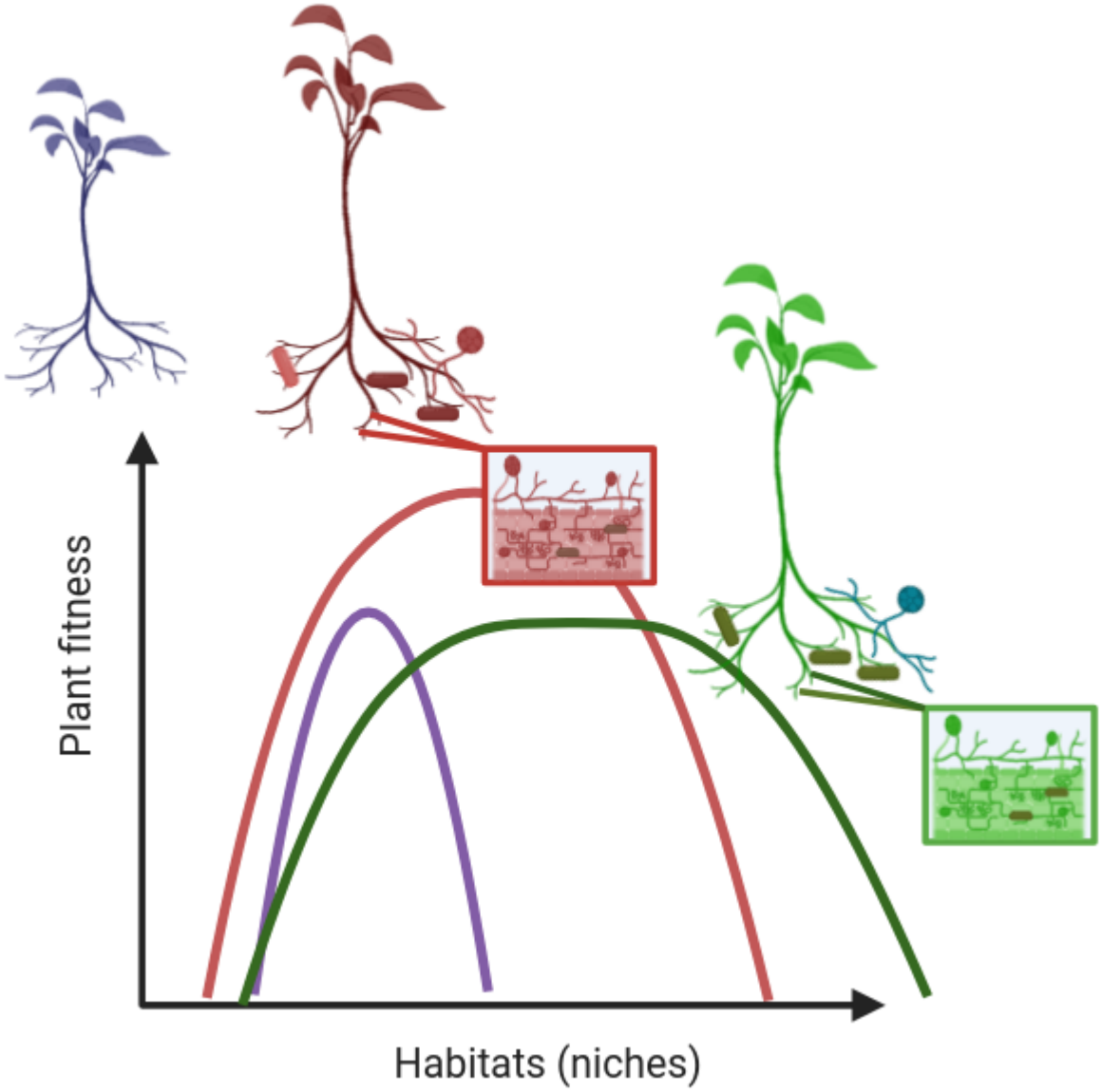
P ≠ G

Microbiota do matter

Trifolium pratense
same growth conditions and duration
3 different mycorrhizal inocula
→ reproducible

Ricono et al, unpublished

1-Macro-organisms



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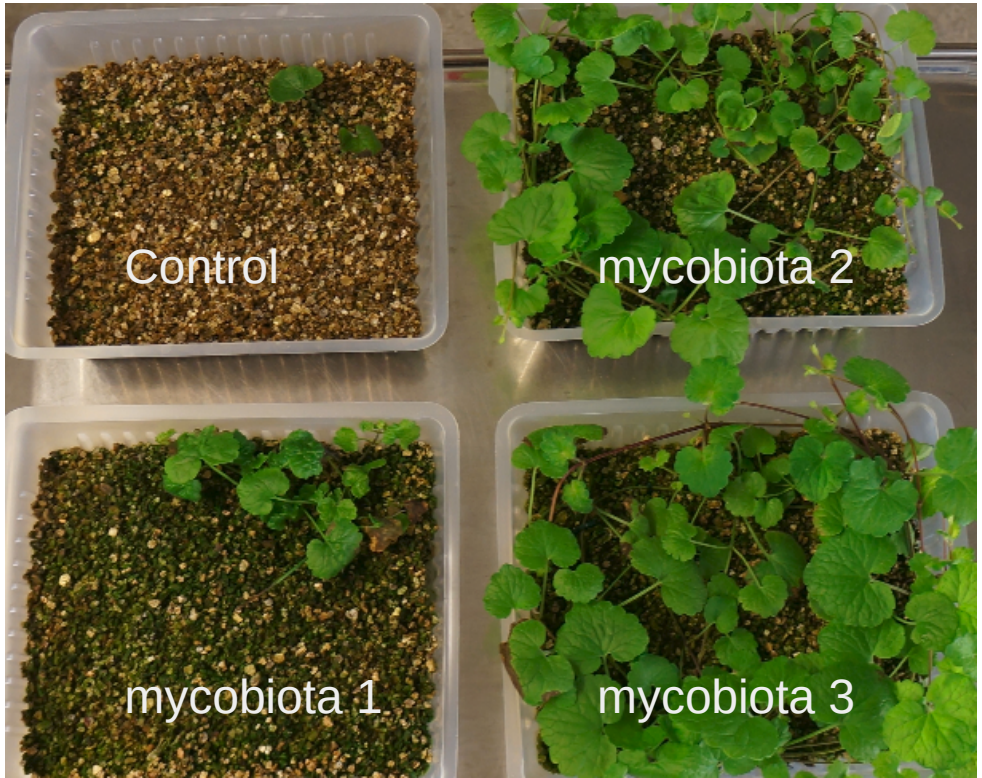
Plant fitness

Not necessarily a consequence of plant genome itself !

Microbiota do matter

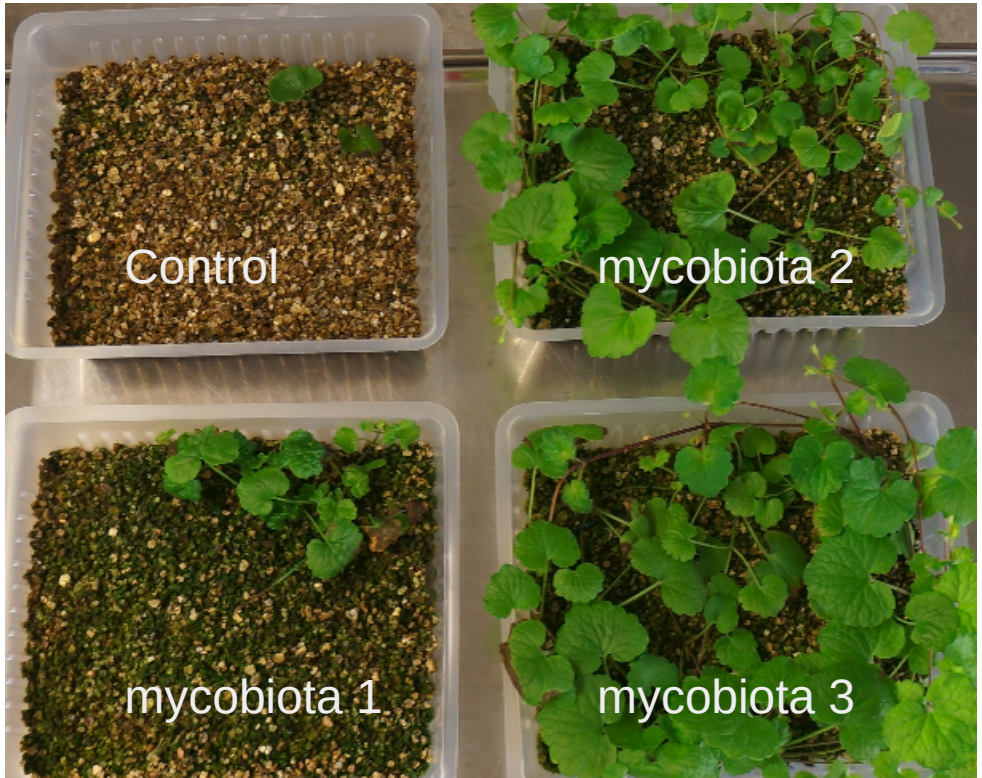
Single genotype of the clonal *Glechoma hederacea*
same growth conditions and duration
3 different mycobiota inocula
→ reproducible



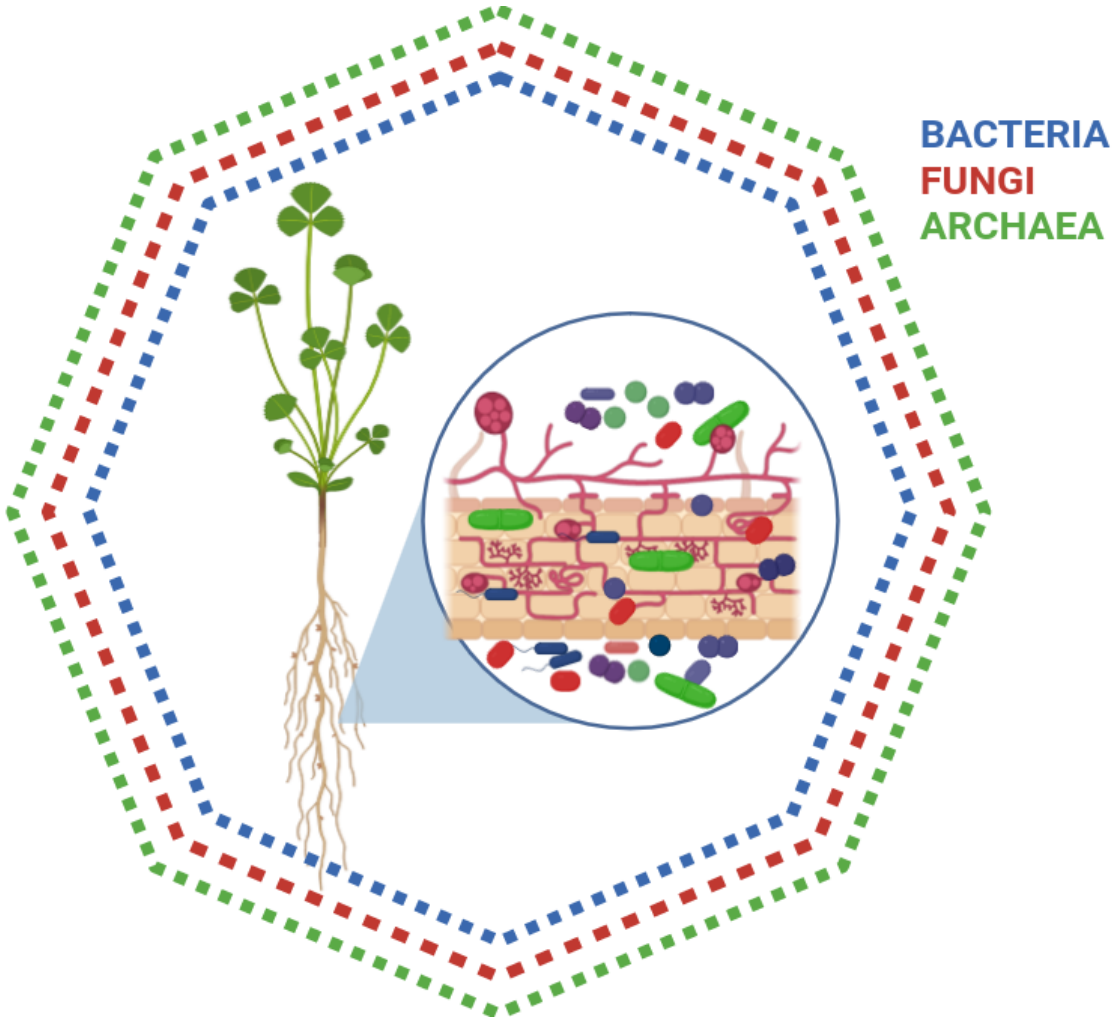
Wang et al, unpublished

Plant fitness

P ≠ G P ≠ GxE but P ~ M



Wang et al, unpublished



The microorganisms functions (microbiota) extend the plant adaptive abilities = add-on genetic components

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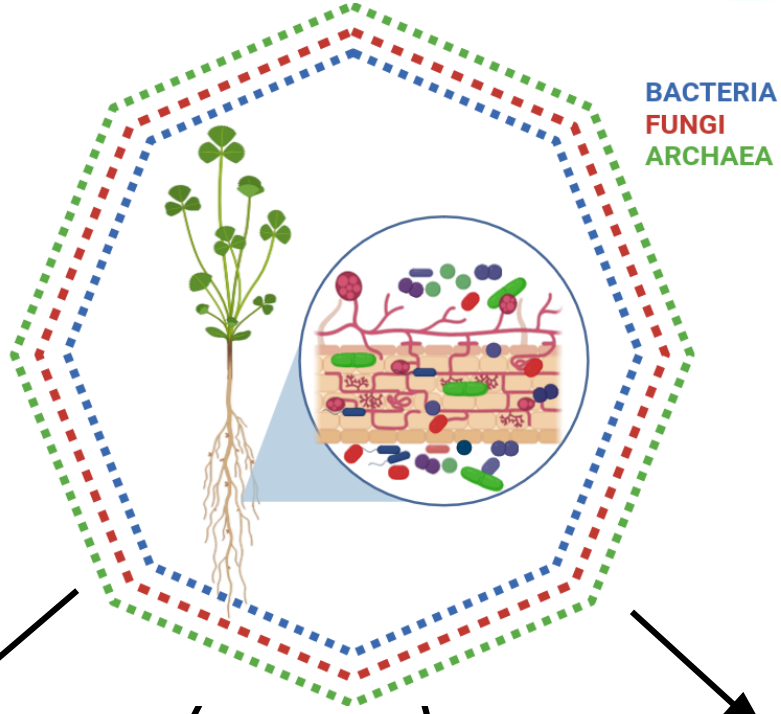
e.g. Vandenkoornhuyse et al., 2015 ; Vannier *et al., Frontiers in Microb* 2015

Microorganisms transmission between generations



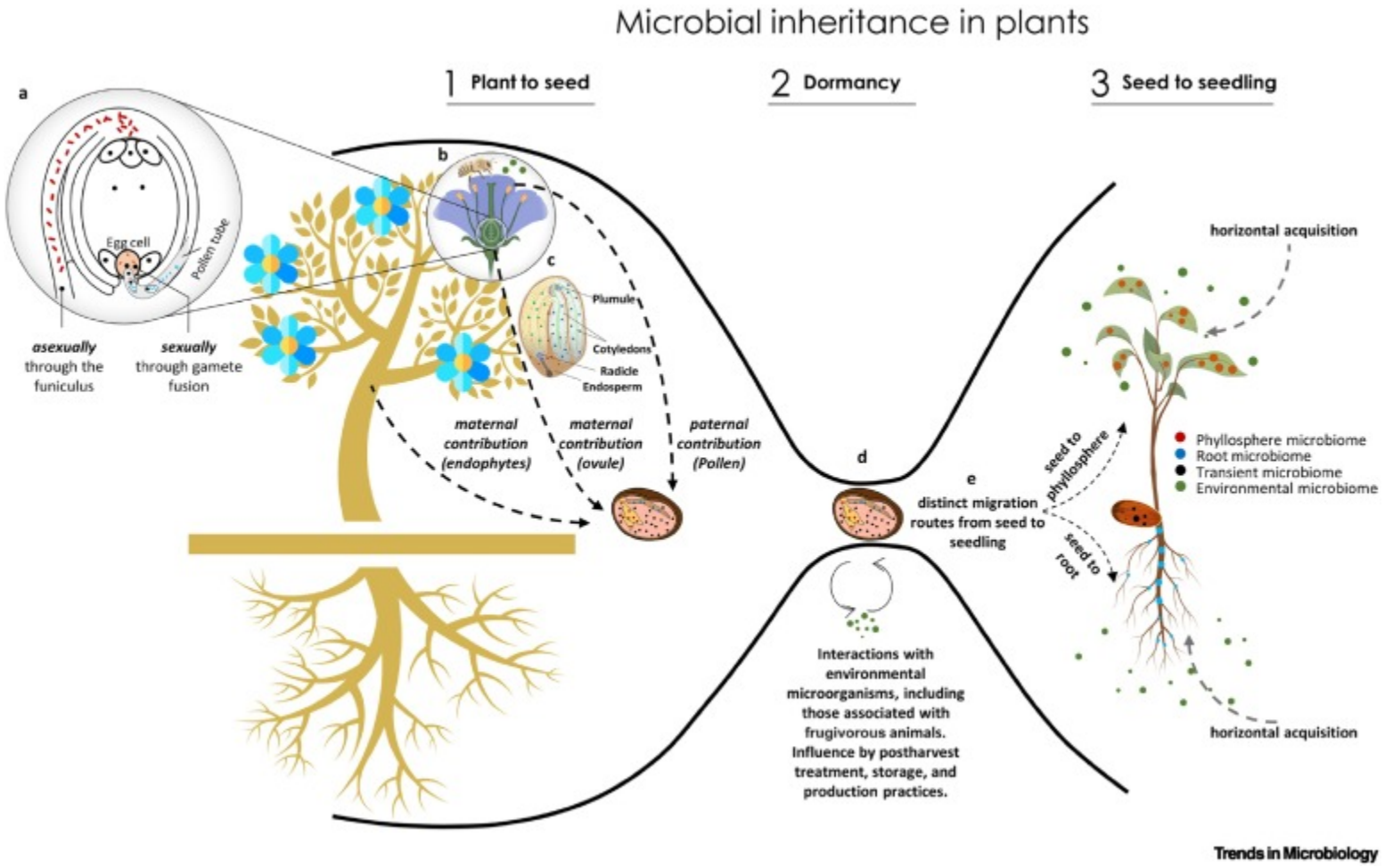
Avoids the cost of searching for symbionts

Ensures habitat quality

Constitutes a continuity of partnership

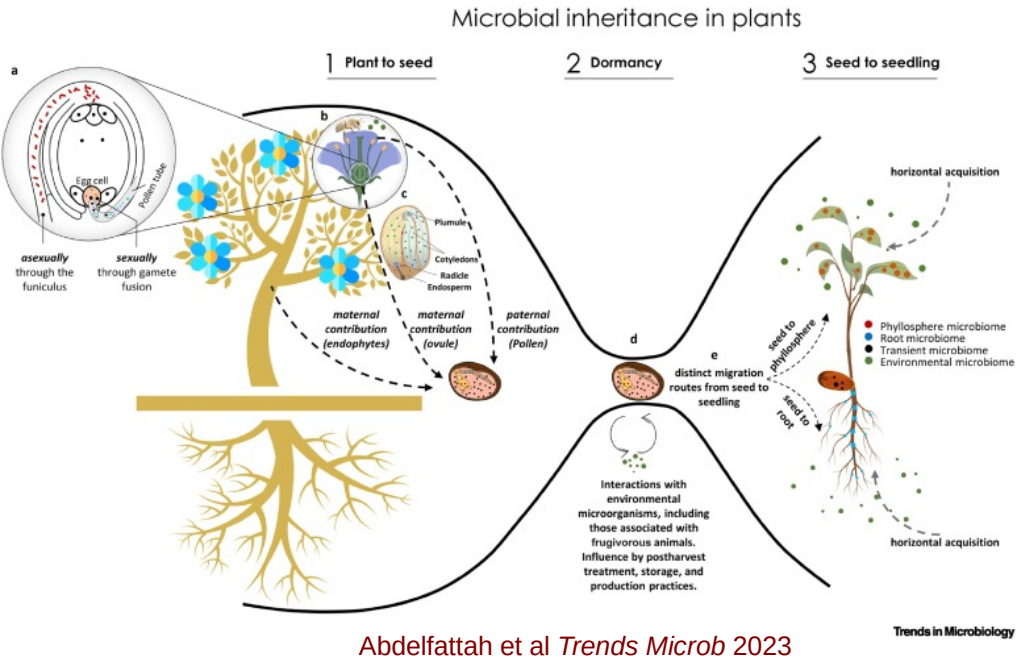
Fitness

Seed-borne microorganisms (i.e. vertical transmission):



e.g. Guo et al., *New Phytol* 2022 ; Abdelfattah et al *Trends in Microb* 2023 ;

Seed-borne microorganisms (i.e. vertical transmission):



Abdelfattah et al *Trends Microb* 2023

Bacillus subtilis *Pseudomonas putida*	phytoprotection
Azoarcus sp *Gluconacetobacter diazotrophicus* *Burkholderia phytofirmans* *Pseudomonas fluorescens*	*growth*
Herbaspirillum seropedicae	*rooting*
Acremonium coenophialum	drought, grazers

And also pathogens often reported …

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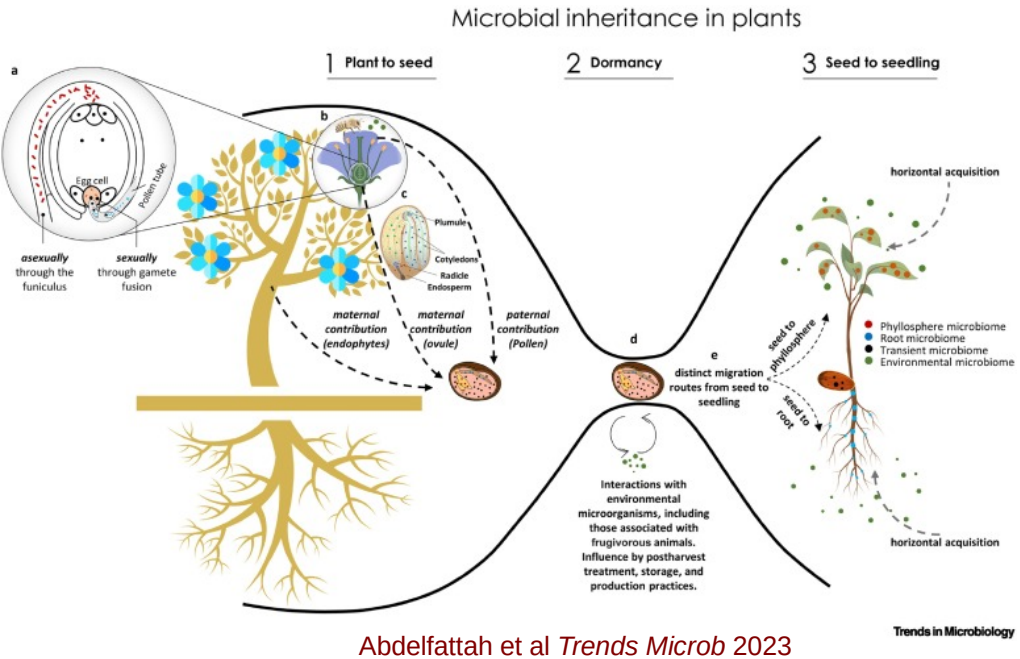
e.g. Kandel et al., *Microorganisms* 2017 ; Chesneau et al., *MBio* 2022 ; Guo et al., *New Phytol* 2022 ; Abdelfattah et al *Trends Microb* 2023 ;

Seed-borne microorganisms (i.e. vertical transmission):



Abdelfattah et al *Trends Microb* 2023

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And also pathogens often reported …

Beside these vertically transmitted microorganisms, a large proportion of the microbiota is recruited from the soil microbial reservoir

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New Phytologist

Research

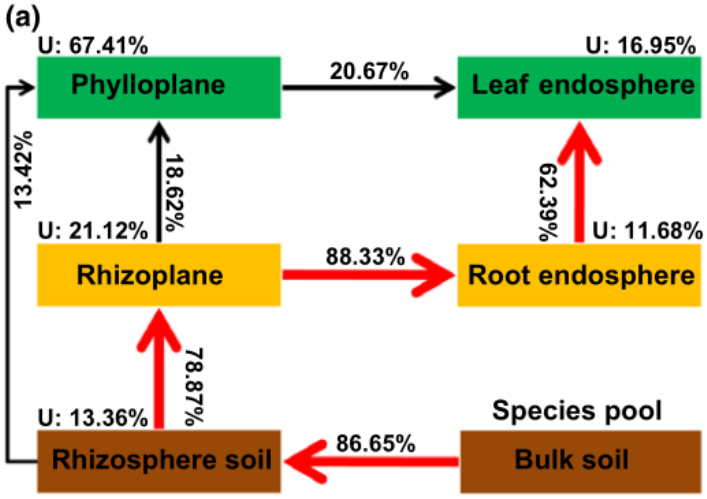
Host selection shapes crop microbiome assembly and network complexity

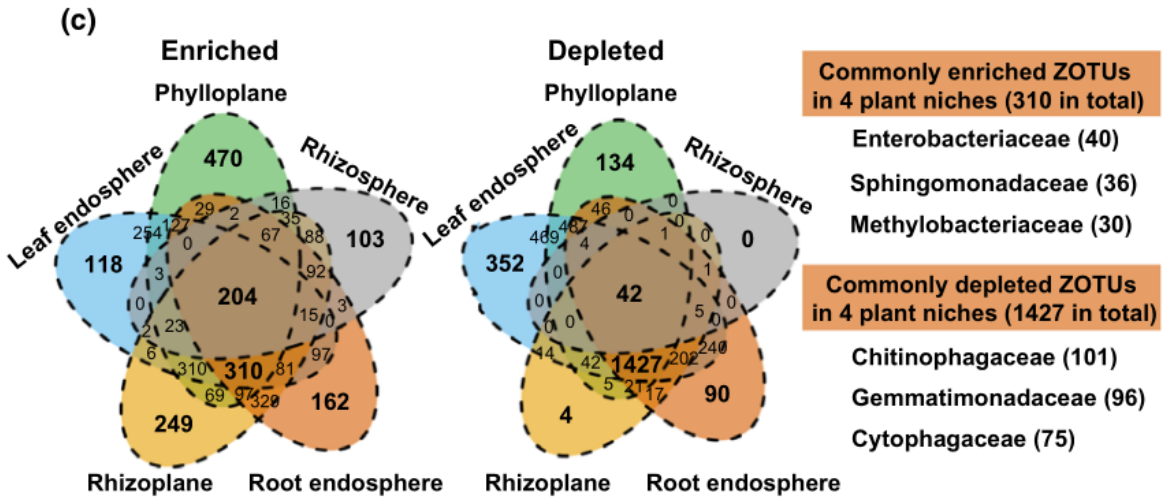
Chao Xiong[1,2], Yong-Guan Zhu[1,3], Jun-Tao Wang[1], Brajesh Singh[4,5], Li-Li Han[1,2], Ju-Pei Shen[1,2], Pei-Pei Li[6], Gui-Bao Wang[7], Chuan-Fa Wu[1,6], An-Hui Ge[1,2], Li-Mei Zhang[1,2] and Ji-Zheng He[1,2]

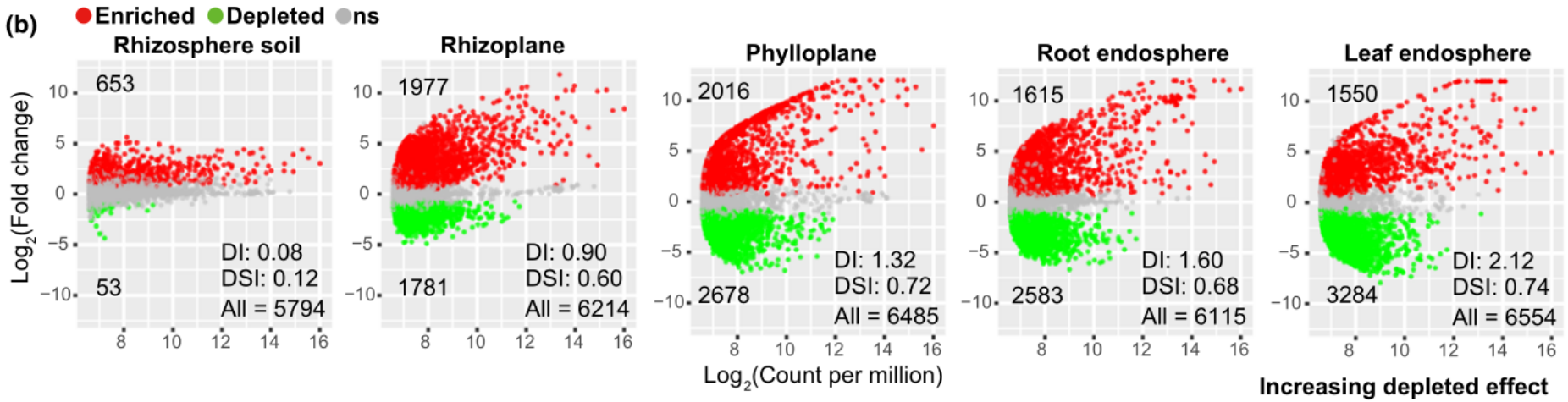
[1]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China; [2]University of Chinese Academy of Sciences, Beijing 100049, China; [3]Key Laboratory of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China; [4]Global Centre for Land-Based Innovation, Western Sydney University, Penrith, NSW 2751, Australia; [5]Hawkesbury Institute for the Environment, Western Sydney University, Penrith, NSW 2751, Australia; [6]College of Resource and Environmental Sciences, Henan Agricultural University, Zhengzhou 450002, China; [7]Soil and Fertilizer Station of Qilin District, Qujing, Yunnan Province 655000, China

e.g. Xiong et al., *New Phytol* 2022

2-Plant microbiota and fitness







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e.g. Xiong et al., *New Phytol* 2022

Testing the validity of the hologenome concept

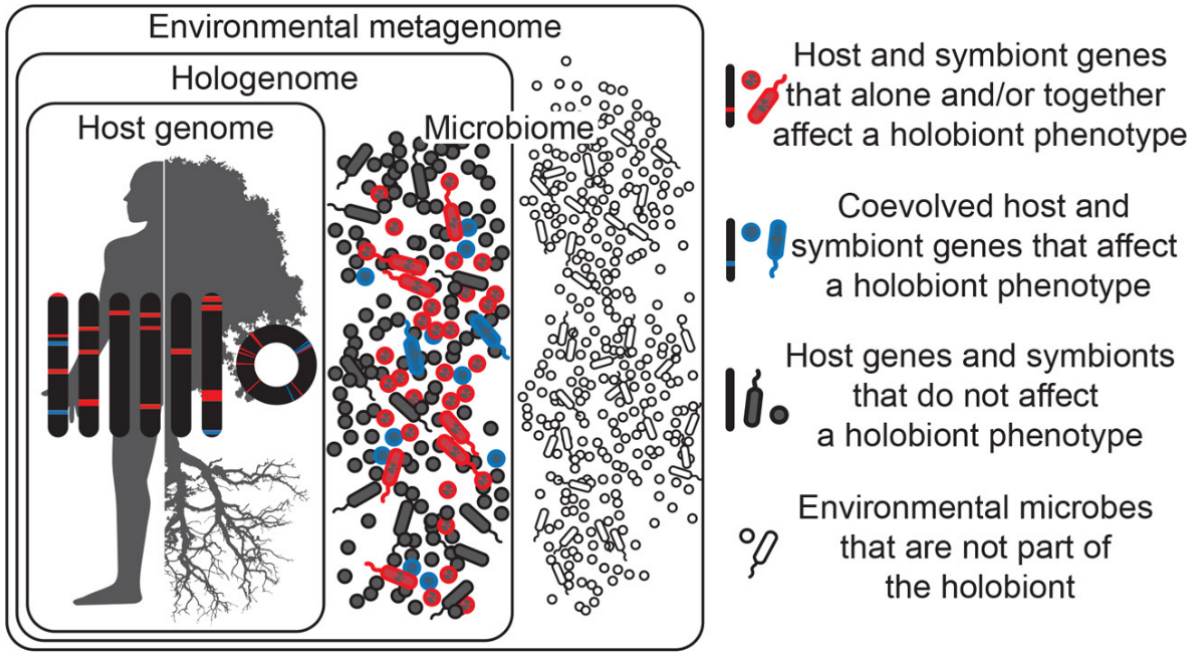


FIG 1 Holobionts are entities comprised of the host and all of its symbiotic microbes, including those which affect the holobiont's phenotype and have coevolved with the host (blue), those which affect the holobiont's phenotype but have not coevolved with the host (red), and those which do not affect the holobiont's phenotype at all (gray). Microbes may be transmitted vertically or horizontally, may be acquired from the environment, and can be constant or inconstant in the host. Therefore, holobiont phenotypes can change in time and space as microbes come into and out of the holobiont.

e.g. Theis et al., *mSystems* 2016

Testing the validity of the hologenome concept

iScience

CellPress
OPEN ACCESS

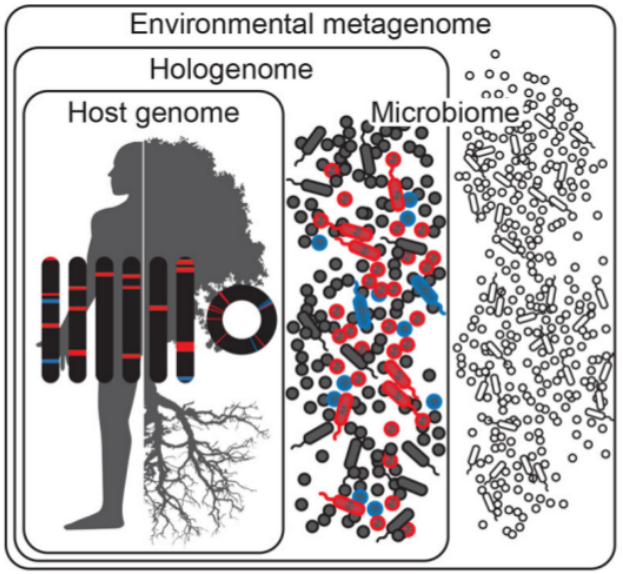
Article

Evaluating the hologenome concept by analyzing the root-endosphere microbiota of chimeric plants

Marine Biget,[1,5,6] Tingting Wang,[1,2,6] Cendrine Mony,[1] Qicheng Xu,[2] Lucie Lecoq,[1] Véronique Chable,[3] Kevin R. Theis,[4] Ning Ling,[2,*] and Philippe Vandenkoornhuyse[1,7,*]

Testing the validity of the hologenome concept

1- Hypothesis H0 : if hologenome is just an intellectual concept, pattern of recruitment are expected only passive, **stochastic** differences in the microbiota community among plants are expected.



Hypothesis REJECTED
Pattern of recruitment is not stochastic
and hologenome is most likely not just an intellectual concept

Determinism in microbial recruitment & homeostasis
Variations mostly related to heterogenity in the soil microbial reservoir

Biget, Wang et al. *iScience* 2023

Hologenome concept opens opportunities to see life in a different way

Hologenome / holobiont :
a new level of biological organization

=A breakup paradigm in the understanding of the world around us, that transforms scientific methods and philosophical ideas

A Copernican revolution (E Kant)

A shift in the ideas for future agriculture :
Rethinking what is key

(taking into account the need of a sustainable and productive agriculture
→ microorganisms within agriculture)

Holobionts : the right way to consider plant individuals

Toward an agriculture of holobionts ? → Key concern One

A needed soil microorganisms reservoir for plant microbiota recruitment

Detrimental effects of current conventional agriculture on soil microbial reservoir ?

A needed soil microorganisms reservoir for plant microbiota recruitment

AMERICAN SOCIETY FOR MICROBIOLOGY | mSystems®

July/August 2020 Volume 5 Issue 4 e00337-20

RESEARCH ARTICLE
Applied and Environmental Science

Check for updates

Long-Term Chemical-Only Fertilization Induces a Diversity Decline and Deep Selection on the Soil Bacteria

Qicheng Xu,[a,b] Ning Ling,[a,b] Huan Chen,[c] Yinghua Duan,[d] Shuang Wang,[e] Qirong Shen,[a] Philippe Vandenkoornhuyse[b]

A needed soil microorganisms reservoir for plant microbiota recruitment

Detrimental effects of current conventional agriculture on soil microbial reservoir

A needed soil microorganisms reservoir for plant microbiota recruitment

Detrimental effects of current conventional agriculture on soil microbial reservoir

→ Evolutionary effects of agriculture ?

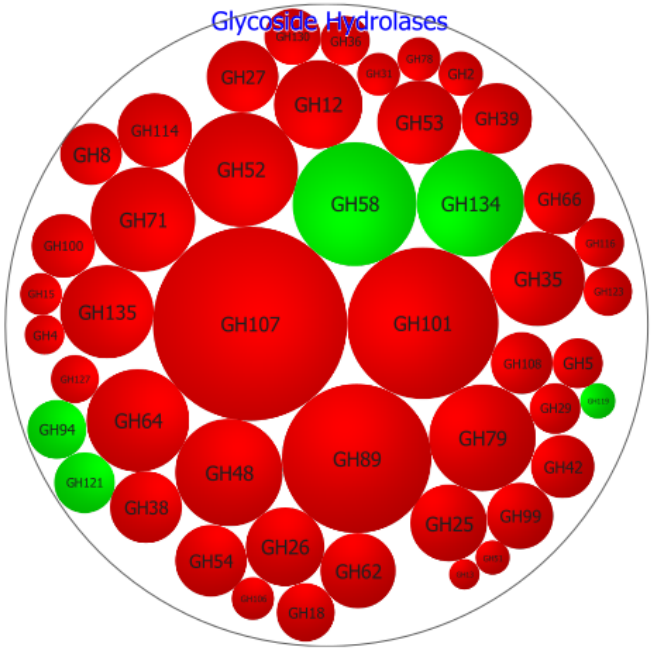
PNAS RESEARCH ARTICLE | AGRICULTURAL SCIENCES OPEN ACCESS

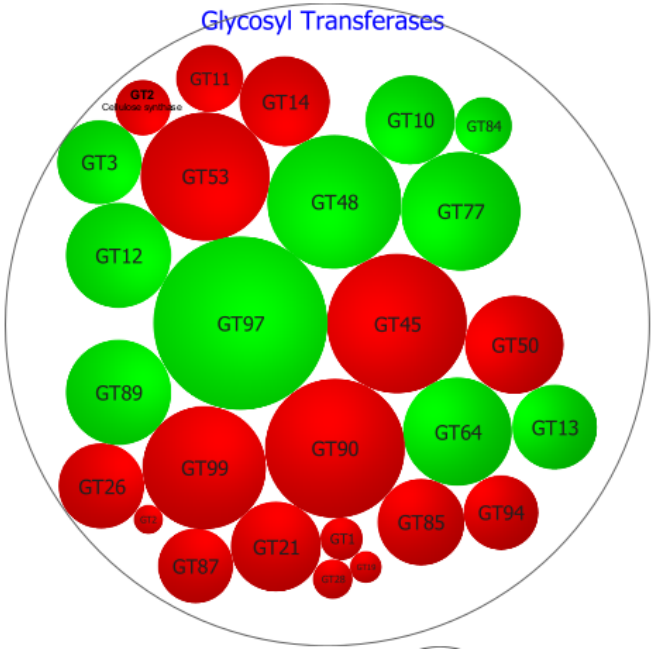
Carbon starvation raises capacities in bacterial antibiotic resistance and viral auxiliary carbon metabolism in soils

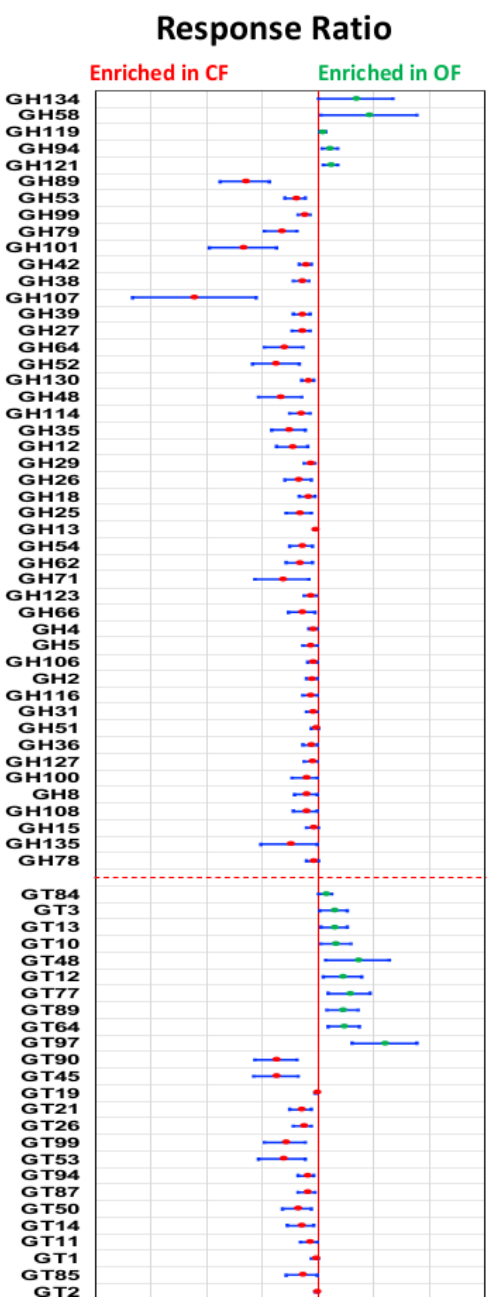
Qicheng Xu[a,b,1], He Zhang[a,c,1], Philippe Vandenkoornhuyse[b], Shiwei Guo[a], Yakov Kuzyakov[d,e], Qirong Shen[a,2], and Ning Ling[c,2]

2024 Vol. 121 No. 16 e2318160121

4-concerns about soil microorganisms







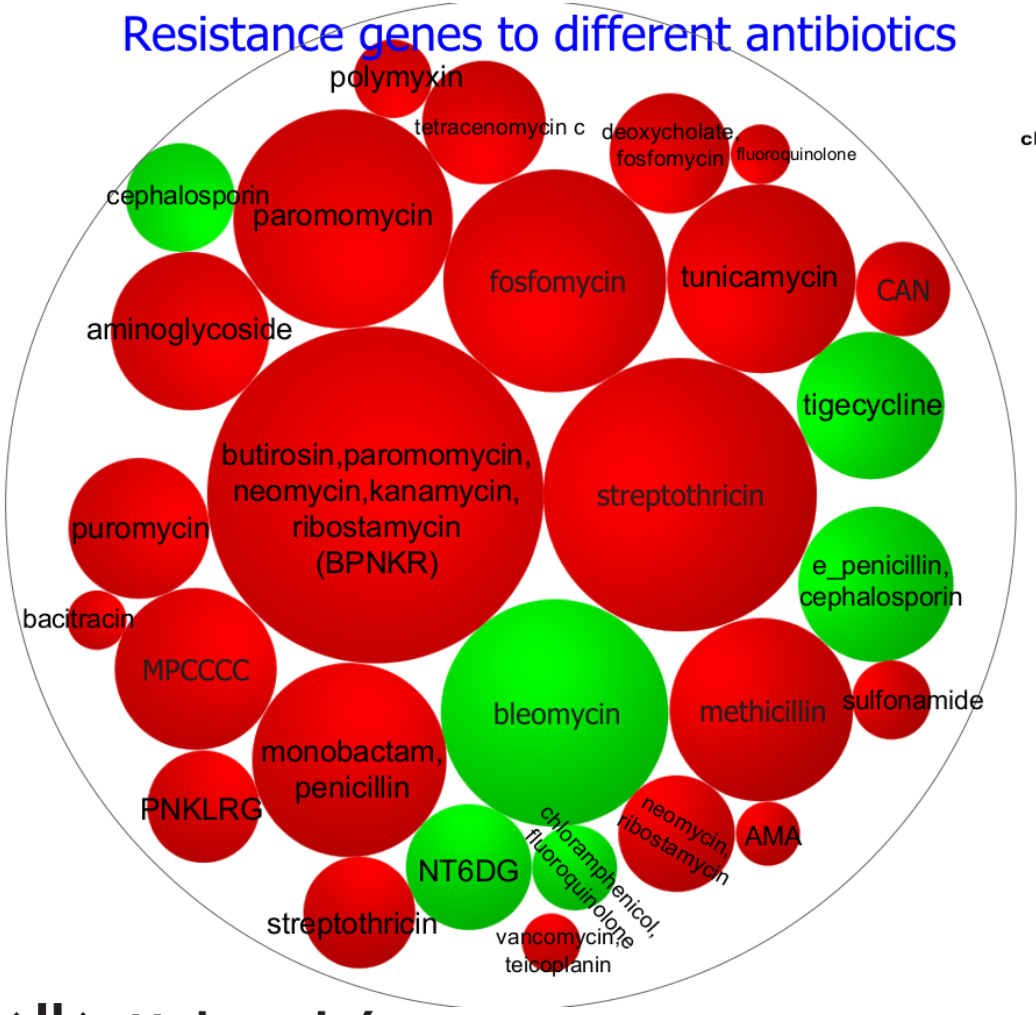
4 long term exp (>30 yrs)
Latitudinal gradient

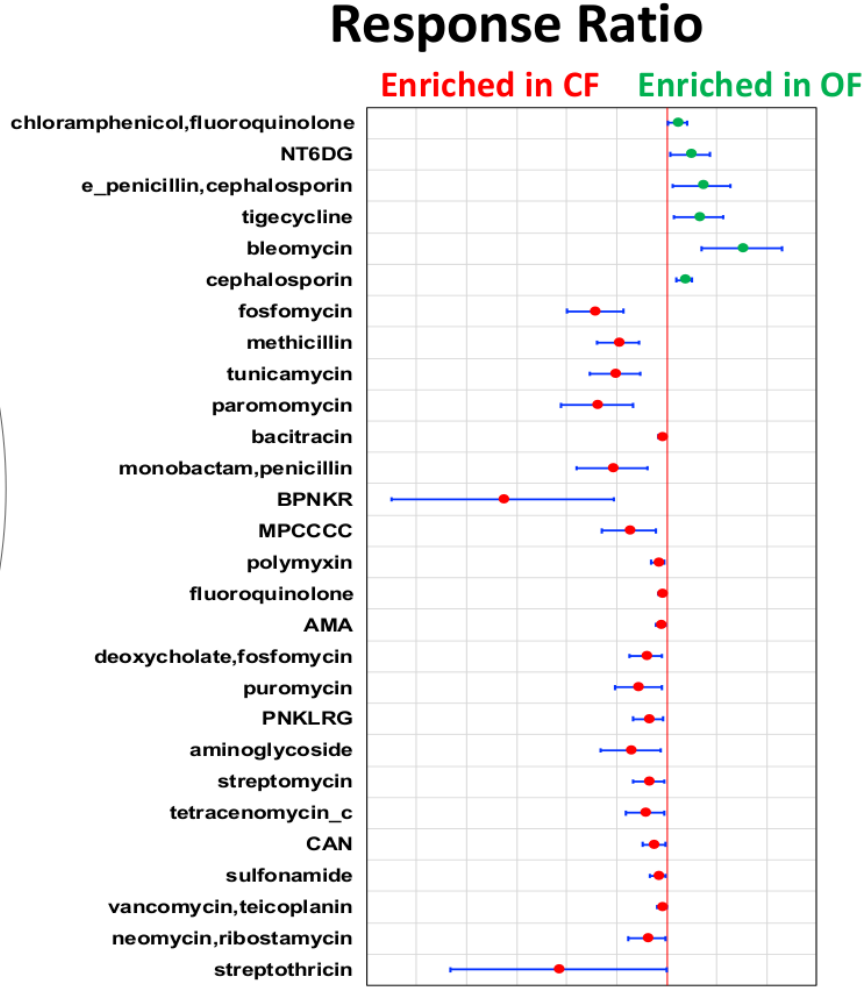
CAZYmes :

→ mobilisation of soil C difficult to breakdown and/or soil-bounded C

Xu et al., *PNAS* 2024

4-concerns about soil microorganisms





Xu et al., *PNAS* 2024

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Toward an agriculture of holobionts ?

A needed soil microorganisms reservoir for plant microbiota recruitment

Detrimental effects of current conventional agriculture on soil microbial reservoir

N inputs to soils and diazotrophy

→ Diazotrophs not competitive
No need for N fixation by diazotrophs
=> mitigation of selection pressure on N fixing genes

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N inputs to soils and diazotrophy

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Fan *et al. Microbiome* (2019) 7:143
https://doi.org/10.1186/s40168-019-0757-8

Microbiome

RESEARCH Open Access

Suppressed N fixation and diazotrophs after four decades of fertilization

Kunkun Fan[1,2], Manuel Delgado-Baquerizo[3,4], Xisheng Guo[5], Daozhong Wang[5], Yanying Wu[6], Mo Zhu[6], Wei Yu[6], Huaiying Yao[7,8], Yong-guan Zhu[7] and Haiyan Chu[1*]

Trends in Ecology & Evolution

CellPress
REVIEWS

Review

Agriculture and the Disruption of Plant–Microbial Symbiosis

Stephanie S. Porter[1] and Joel L. Sachs[2,3,4,*]

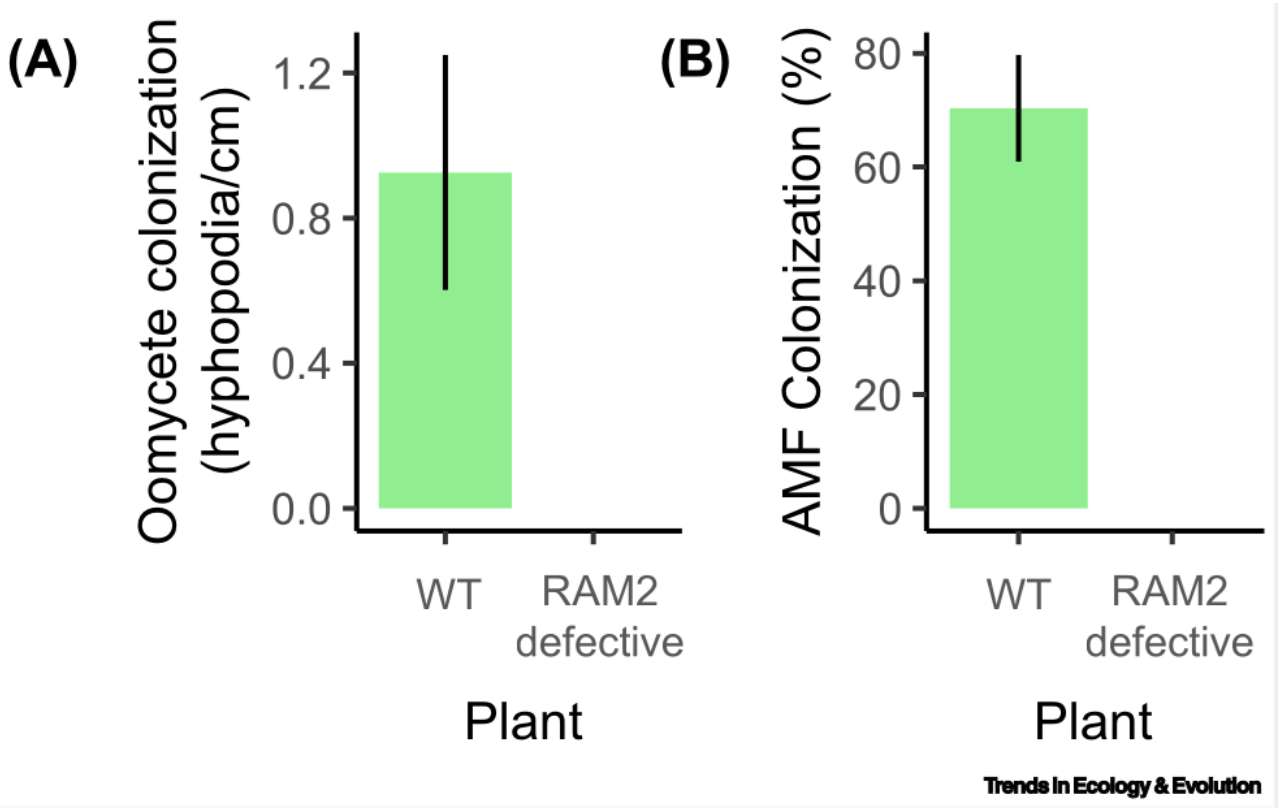

Figure I. Oomycete Resistance due to Loss of *Reduced Arbuscular Mycorrhization 2* (*RAM2*) Results in Loss of Mycorrhization Ability compared with Wild-Type (WT) [109].

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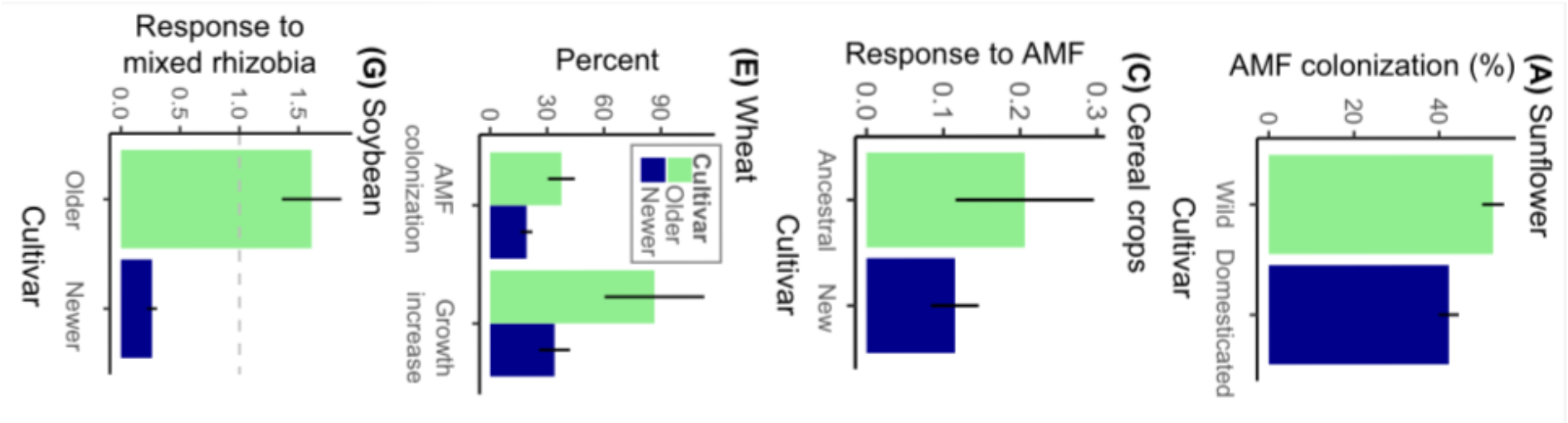
Wang et al., *Current Biol* 2012



Disruption of the plant traits that regulate symbiosis is selectively neutral under agricultural conditions and related artificialization

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Porter & Sachs *Trends Ecol Evol* 2020

PROCEEDINGS OF THE ROYAL SOCIETY B

Proc. R. Soc. B (2007) **274**, 3119–3126
doi:10.1098/rspb.2007.1187
Published online 17 October 2007

Human selection and the relaxation of legume defences against ineffective rhizobia

E. Toby Kiers[1,4,*], Mark G. Hutton[2] and R. Ford Denison[3,4]

‘Modern’ crop more prone to be colonized by cheaters

Research

New Phytologist

Impacts of domestication on the arbuscular mycorrhizal symbiosis of 27 crop species

Nieves Martín-Robles[1], Anika Lehmann[2], Erica Seco[1], Ricardo Aroca[3], Matthias C. Rillig[2] and Rubén Milla[1]

[1]Departamento de Biología y Geología, Área de Biodiversidad y Conservación, Escuela Superior de Ciencias Experimentales y Tecnología, Universidad Rey Juan Carlos, c/Tulipán s/n, Móstoles 28933, Spain; [2]Institut für Biologie, Dahlem Center of Plant Sciences, Freie Universität Berlin, Altensteinstr. 6, 14195 Berlin, Germany; [3]Departamento de Microbiología del Suelo y Sistemas Simbióticos, Estación experimental del Zaidín, CSIC, C/Profesor Albareda 1, 18008 Granada, Spain

Toward an agriculture of holobionts ?

A needed reconsideration of the plant breeding strategy

Today, breeding for the best possible plant cultivar in the context of conventional farming and artificialization → not holobiont breeding

Detrimental effect on the capacity of plant to interact and control interactions with microorganisms

Toward an agriculture of holobionts ?

A needed reconsideration of the plant breeding strategy

→ breeding of holobionts NOT host only !

Trends in Plant Science November 2013, Vol. 18, No. 11

Sustainable agriculture: possible trajectories from mutualistic symbiosis and plant neodomestication

Marie Duhamel[1,2] and Philippe Vandenkoornhuyse[1]

Many thanks

-to the organizers
-to all the peoples that have been involved in this work in the group
-Funding bodies for past and present grants for research