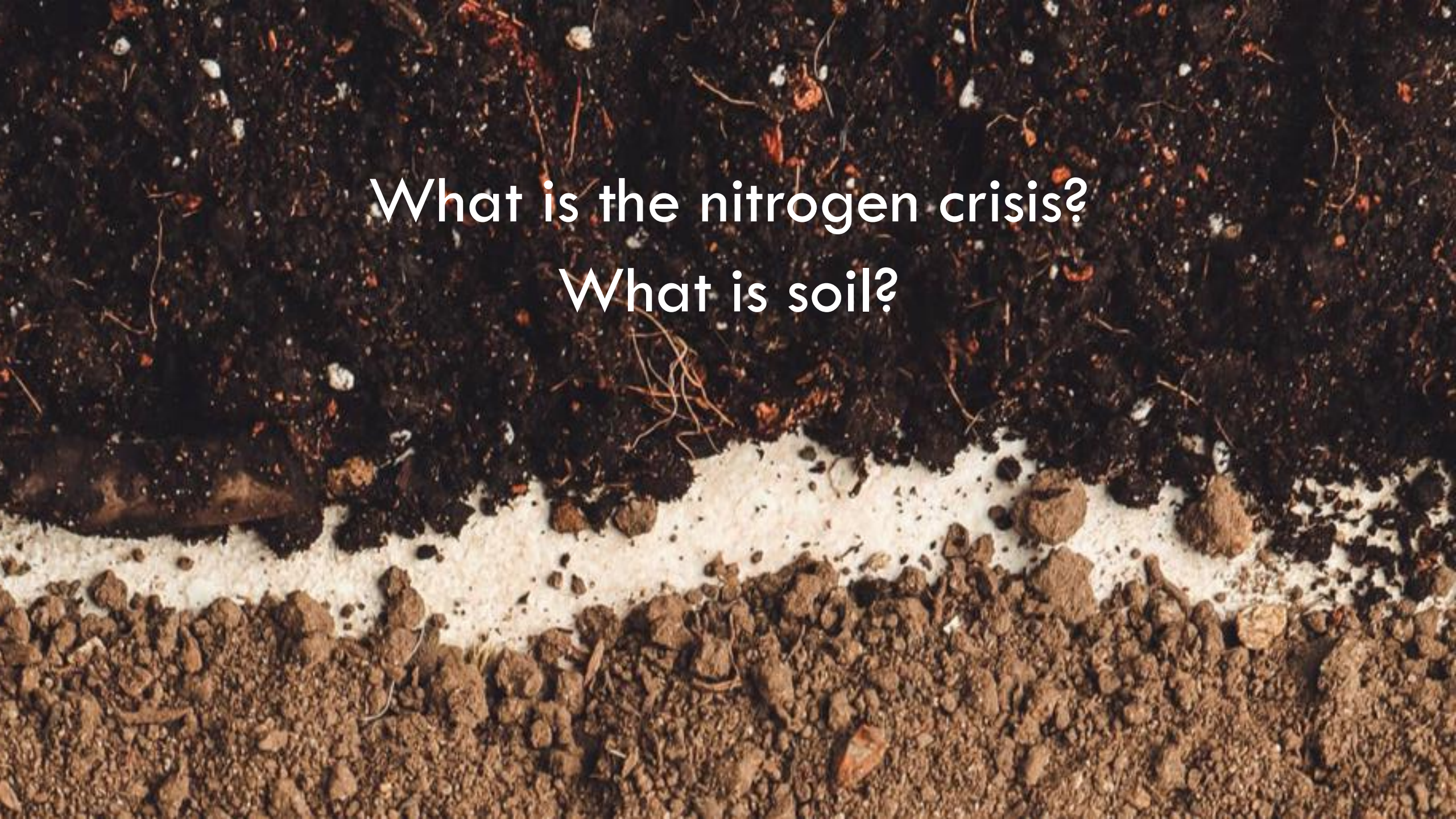


An aerial photograph of a tractor plowing a field, creating a series of curved, wavy furrows in the dark soil. The tractor is visible in the upper center, moving away from the viewer. The overall scene is a deep brown color, emphasizing the texture of the soil.

Can biotech solve the nitrogen crisis? Reengineering soil ecologies and reconceptualizing soil health

Catherine Kendig
Michigan State University

EurSafe 13-09-2024. Ede, Netherlands.

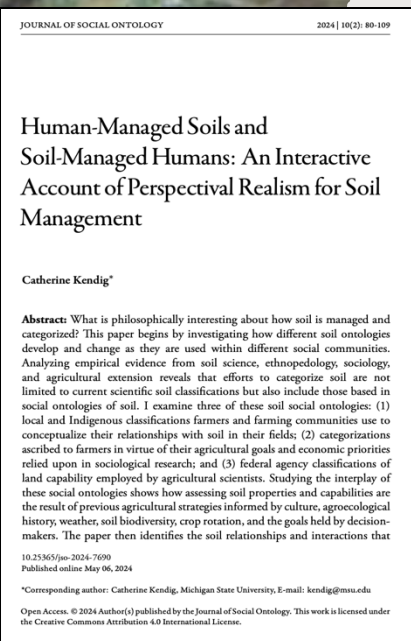
A close-up photograph of a soil profile. The top layer is dark, rich topsoil with visible roots and organic matter. Below this is a distinct, light-colored (white or very light tan) layer, likely representing a specific soil horizon or a layer of material like lime or sand. The bottom layer is a lighter brown, more granular subsoil. The text is overlaid on the dark topsoil layer.

What is the nitrogen crisis?
What is soil?



Making and remaking 'natural kinds' and classification in practice

- “Kinding activities” refers to the different sorts of practices individuals and communities use in making, discovering, delimiting, reconstructing, and sharing the kinds that are of interest to them (Kendig 2015, 1-6). Kinding practices are in use within institutionalized scientific communities and local and indigenous communities (Kendig 2020, 2).
- Soil and evaluations of it are made using an inextricable set of ontological, epistemic, and ethical commitments that shape soil management decisions (Kendig 2024).



The entanglement of soil care & soil ontologies

- Maria Puig de la Bellacasa captures the dynamism of ontology and practice: “modes of soil care and soil ontologies are entangled: what soil is thought to be affects the ways in which we care for it, and vice versa” (Puig de la Bellacasa 2015: 692).



Soil categorizations, origins and impacts

land capability
classifications

Categorizations
of soil health

Ontologies of
soil management
strategies

Conditions of
replicability

Institutional
standardizations

Local agricultural
knowledges

What is (sustainable) soil management?

- “Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern” (FAO 2017: 3).



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EDITORIAL

Contributions of Microbial Biotechnology to Sustainable Development Goals

How can we possibly resolve the planet's nitrogen dilemma?

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Ilje Pikaar⁷ | Korneel Rabaey⁸  | Diederik Rousseau² | Jerald Schnoor⁹ |
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How do you solve the nitrogen problem?



Reduce consumption of meat and dairy products (Godinot et al 2015)



Precision farming (Klages et al 2020)



Replace mineral N fertilizer with biological N, e.g. microbially catalysed protein in the form of sugarcane biomass through the use of filamentous fungi or yeast (Sakarika et al 2020, Areniello et al 2022)

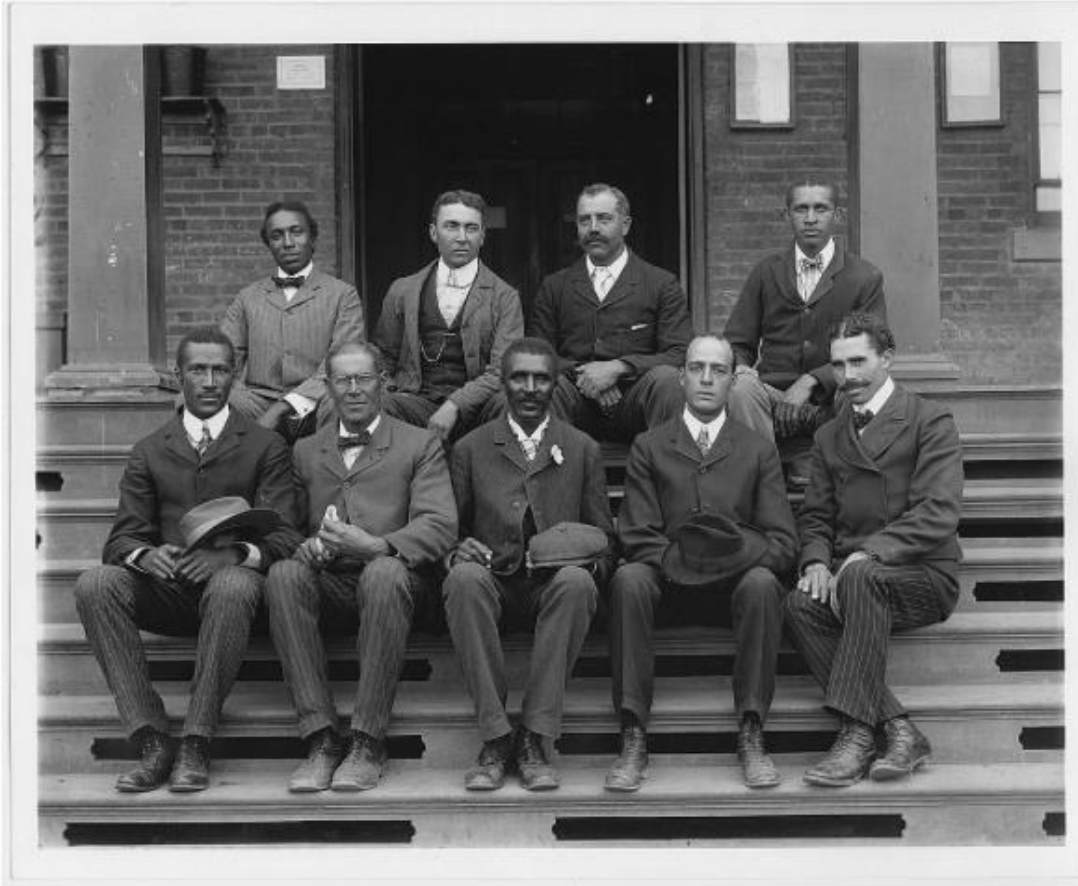


Create a circular N economy, e.g. reuse N from food waste or potato or dairy wastewater; strip ammonia from faecal matter for faecal N like BioFloc tech (Schryver & Verstraete 2009); "Power to Protein" (Gavala et al 2021)

Haber-Bosch process

- Fritz Haber and Carl Bosch recognized that the increase in food production yield from agricultural crops was tied to the availability of nitrogen that was required to produce the necessary amino acids that make food life sustaining.
- While nitrogen is plentiful in the air, in the air it is not available to plants.
- They discovered that N gas could be fixed under high pressure to produce ammonia
- In 1913, H-B developed a reactive fertilizer N that was available to nitrifying bacteria in the soil that could then convert the ammonium ions into nitrates. These nitrates were then available for plants to use in the production of proteins.
- Food harvested from agriculture crops fed 1.6 billion in 1900 and in part due to the H-B process can now feed over 8 billion in 2024 (U.S. Census Bureau, U.S. and World Population Clock, 8-1-2024)

George Washington Carver and the Tuskegee Agricultural Experiment Station (1896-1942)



George Washington Carver, full-length portrait, seated on steps, facing front, with staff, *circa* 1902
Johnston, Frances Benjamin, Photographer. Library of Congress Prints and Photographs Division



Field Work, Tuskegee (between ca. 1910 and ca. 1915).
Bain News Service, Publisher.
Library of Congress, Prints and Photographs Division.

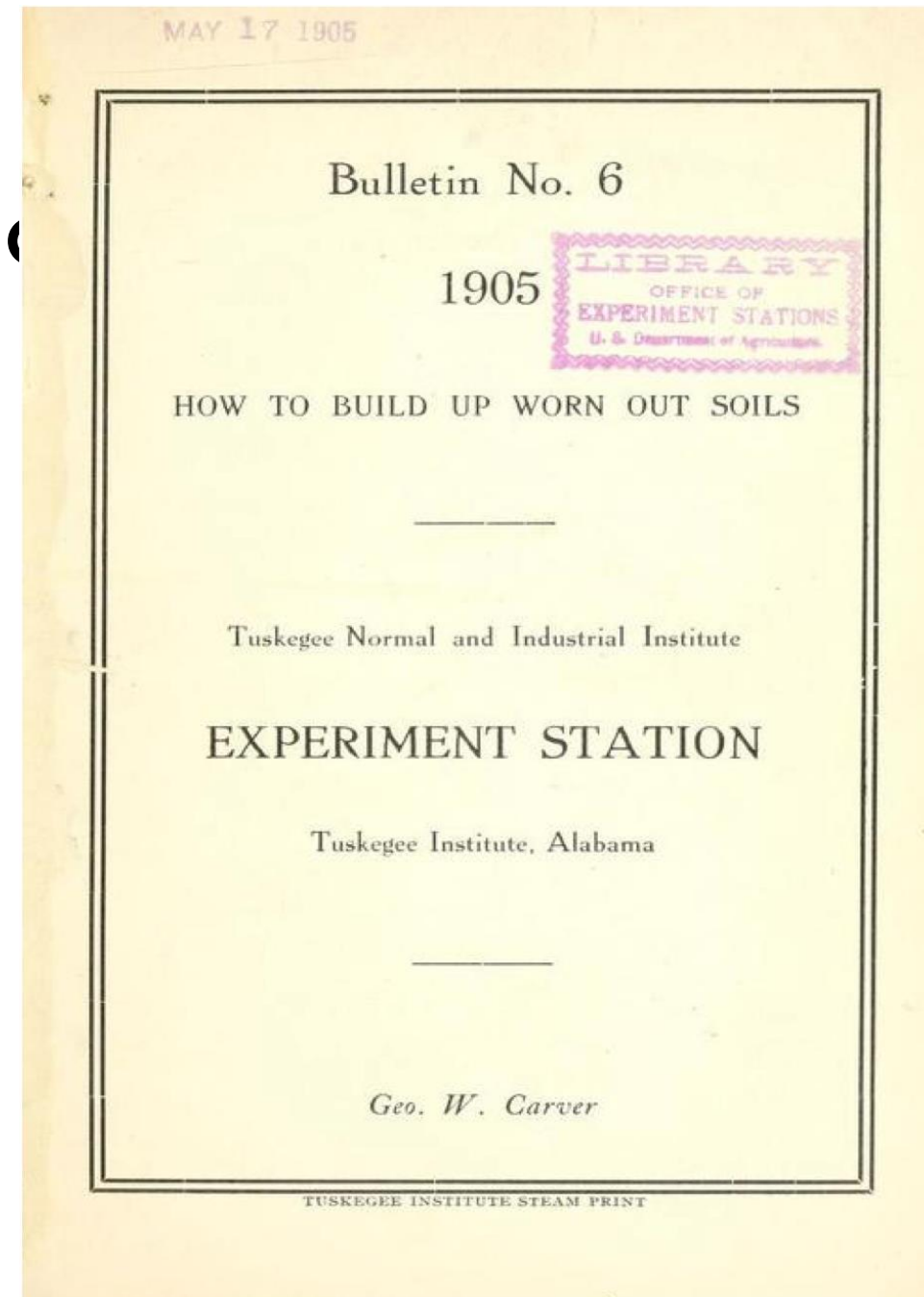
George Washington Carver's 1905 bulletin no. 6 "How to build up worn out soils"

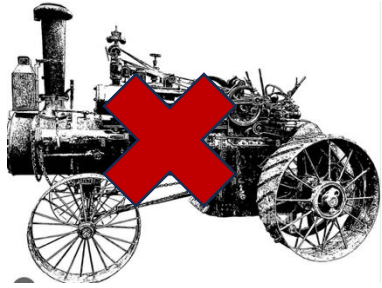
"[soil is] a magazine of inorganic matters, which are prepared by the plant to suit the purposes for which they are destined in its nutrition" (Liebig 1843: 29–30).

"the only known ultimate cause of vital force... is a chemical process" (Liebig 1846: 99).

"our present methods of chemical analysis, do not accurately determine the crop yielding capacity of a soil, but that such analysis should be followed up by carefully conducted crop experiments" (Carver 1905:5).

"the soil was too poor to produce even a small crop of cow-peas" was "variable in character, underlaid with yellow, red and mottled clays, which cropped out here and there" (Carver 1905:4).





“the chief aim was to keep every operation within reach of the poorest tenant farmer occupying the poorest possible soil—worthy of consideration from an agricultural point of view –and to further illustrate that the productive power of all such soils can be increased from year to year until the maximum of fertility is reached” (Carver 1905:5-6).

- The cotton sharecropper's unit is one mule and the land he can cultivate with a one-horse plow. Greene County, Georgia. Lange, Dorothea, photographer, 1937 July.



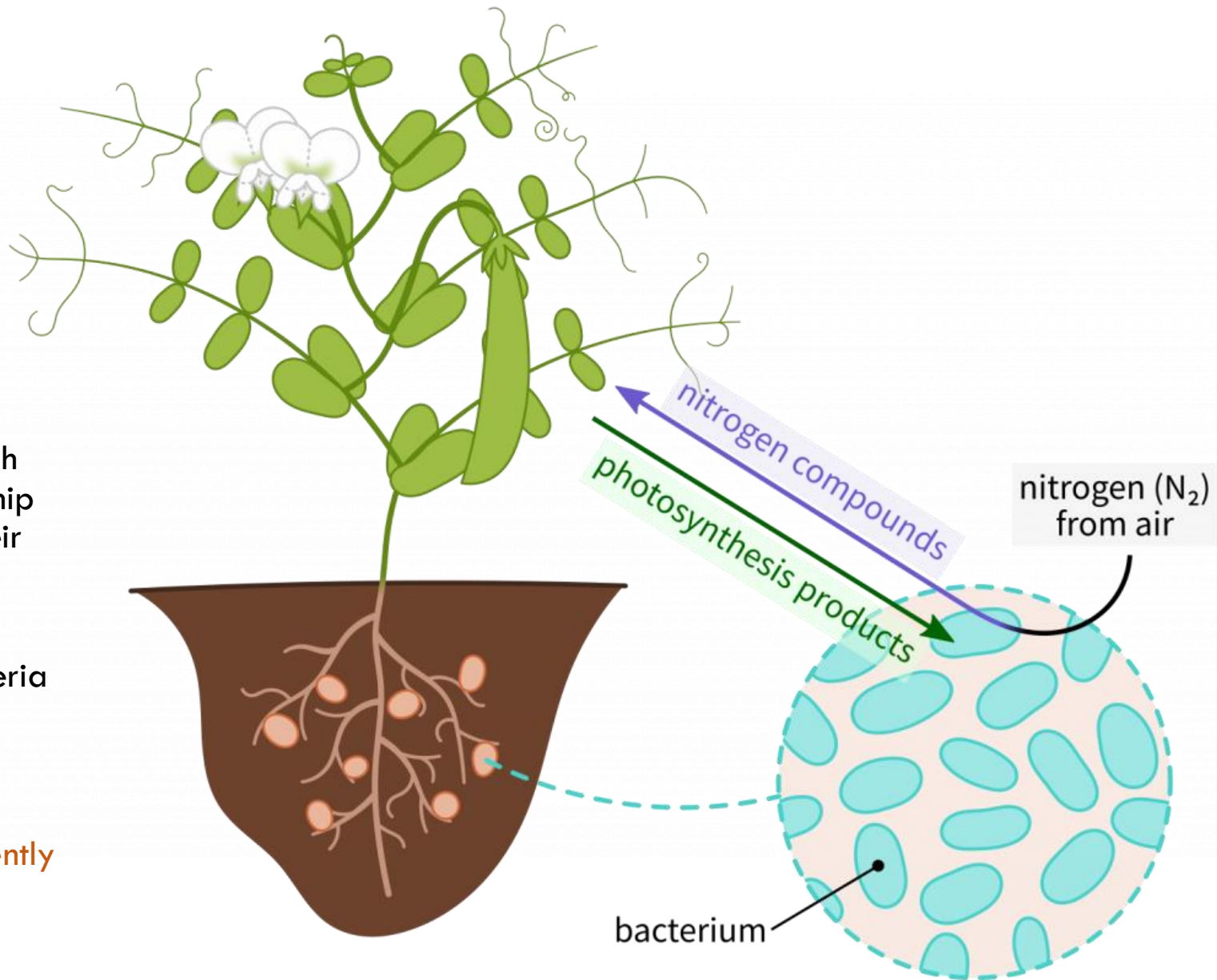
Carver's 8-year experiment

- “All these experiments seem to show:
 - 1) That it pays to make a good seed bed by preparing the soil deep and pulverizing it thoroughly.
 - 2) That swamp muck and leaf mould are valuable as fertilizer and should be used whenever they can be gotten easily.
 - 3) That deep plowing permits the water to go into the soil, thus reducing the terracing to a minimum, which gives more area upon which to grow crops, and also renders cultivation much more easy.
 - 4) That peanuts should be grown by every farmer.
 - 5) That with proper manipulation our poorest soils may be made to produce an abundance of the staple crops” (Carver 1905: 15).



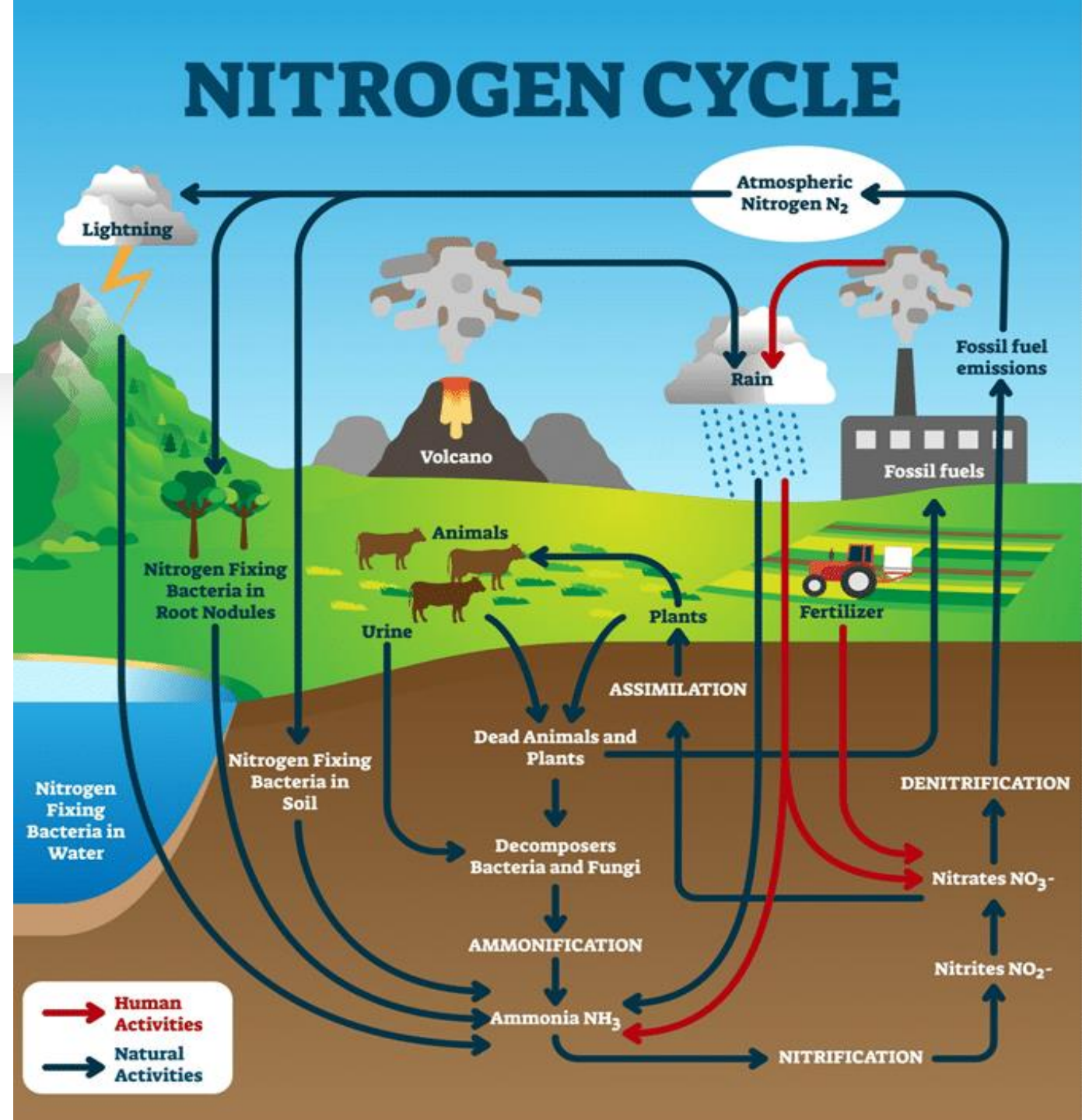
chemical v biological nitrogen

- Nitrogen used in agriculture is the product of many sources—some through the Haber-Bosch process and some via the symbiotic relationship between legumes (including peanuts) and their Rhizobium bacterial partners.
- Legumes such as peanuts form nodules that furnish the soil nitrogen-fixing rhizobial bacteria with a specialized oxygen poor environment where bacteria can better fix nitrogen.
- What about solving the nitrogen crisis by increasing biological nitrogen fixation? (currently only 25% of all nitrogen) (Islam 2017)



Legume + rhizobium symbiosis
= reengineering the nitrogen cycle?

- N_2 gas in the atmosphere is unreactive.
- To make it reactive, the bond between the 2 nitrogen atoms needs to be broken.
- Plants can't use N directly from the atmosphere to make proteins
- Lightening splits N_2 bonds turning it into nitrous oxides, N_2O and NO_2
- N-fixing bacteria in root nodules of leguminous plants (peanuts, clover, peas) take $N_2 \Rightarrow$ nitrates in soil which plants can use





Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in
Biotechnology

Biotechnological solutions to the nitrogen problem

Giles ED Oldroyd and Ray Dixon

**If only
everything
grew like
peanuts...**

- “While the nitrogen-fixing symbiosis is predominantly restricted to legumes, the mycorrhizal association is ubiquitous within the plant kingdom and the signalling pathway defined in legumes has been shown to function during mycorrhizal colonisation in other plant species, including rice. The parallels between mycorrhizal and rhizobial signalling extends also to the structure of the signalling molecules produced by mycorrhizal fungi and rhizobial bacteria, both being lipo-chitoooligosaccharides”

Enabling Biological Nitrogen Fixation for Cereal Crops in Fertilized Fields

Amy Wen, Keira L. Havens,* Sarah E. Bloch, Neal Shah, Douglas A. Higgins, Austin G. Davis-Richardson, Judee Sharon, Farzaneh Rezaei, Mahsa Mohiti-Asli, Allison Johnson, Gabriel Abud, Jean-Michel Ane, Junko Maeda, Valentina Infante, Shayin S. Gottlieb, James G. Lorigan, Lorena Williams, Alana Horton, Megan McKellar, Dominic Soriano, Zoe Caron, Hannah Elzinga, Ashley Graham, Rosemary Clark, San-Ming Mak, Laura Stupin, Alice Robinson, Natalie Hubbard, Richard Broglie, Alvin Tamsir, and Karsten Temme

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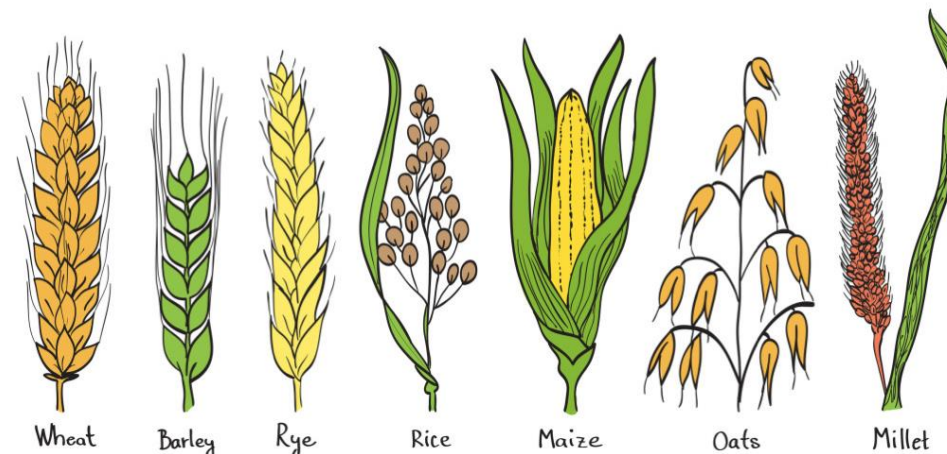
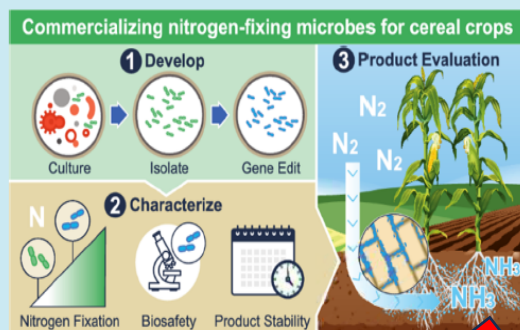
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Metrics & More

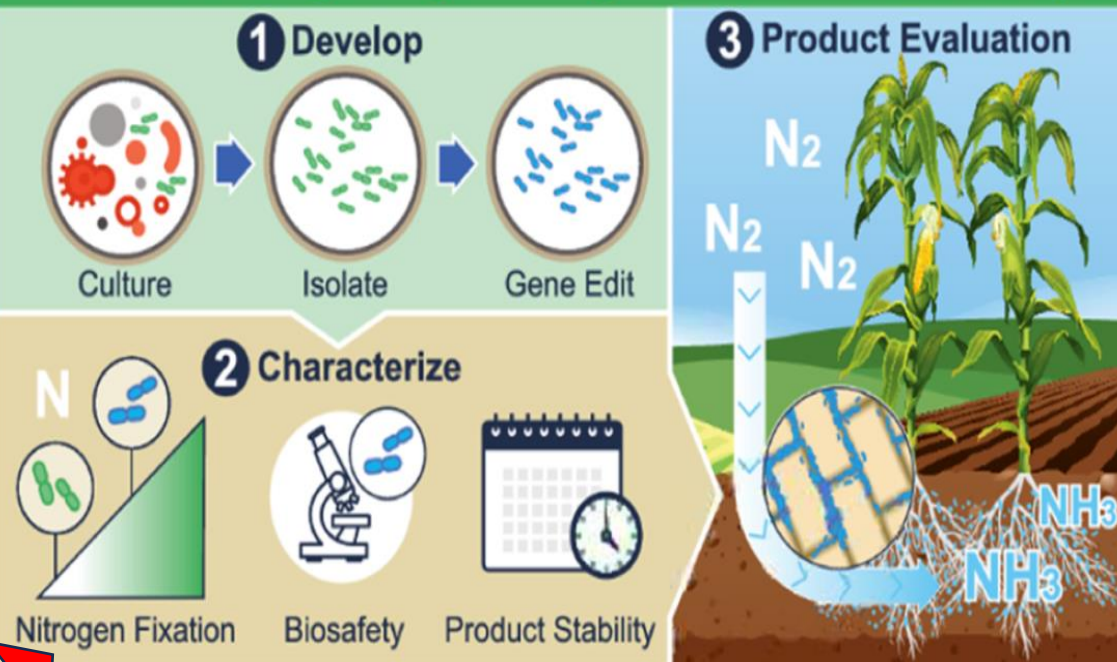
Article Recommendations

Supporting Information

ABSTRACT: Agricultural productivity relies on synthetic nitrogen fertilizers, yet half of that reactive nitrogen is lost to the environment. There is an urgent need for alternative nitrogen solutions to reduce the water pollution, ozone depletion, atmospheric particulate formation, and global greenhouse gas emissions associated with synthetic nitrogen fertilizer use. One such solution is biological nitrogen fixation (BNF), a component of the complex natural nitrogen cycle. BNF application to commercial agriculture is currently limited by fertilizer use and plant type. This paper describes the identification, development, and deployment of the first microbial product optimized using synthetic biology tools to enable BNF for corn (*Zea mays*) in fertilized fields, demonstrating the successful, safe commercializa-

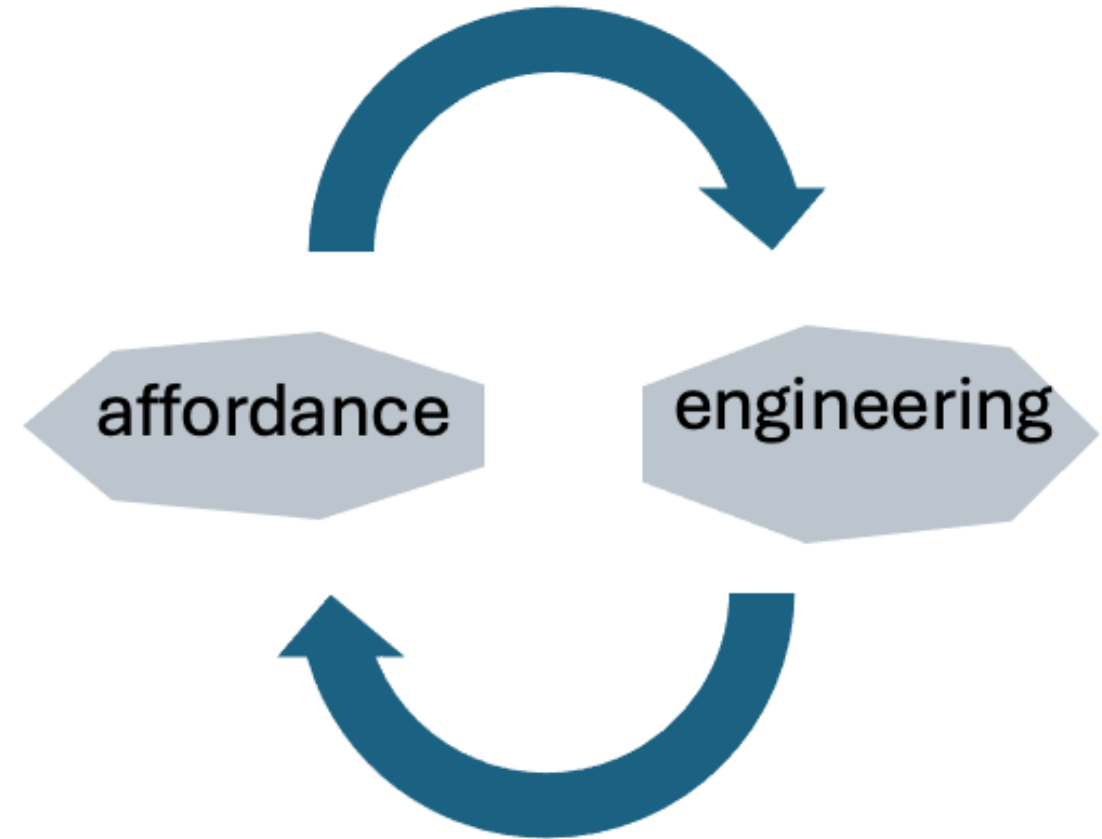


Commercializing nitrogen-fixing microbes for cereal crops



How do biotech interventions affect agroecological systems?

- Biological, chemical and physical amendments to crops and soil resulting from adoption of technological developments and associated guidelines reshape agriculturalized landscapes.
- Adoption of these furnish different agricultural opportunities and/or burdens (affordances) to plants, microbial and macrobial communities?
- These affordances change the engineered agricultural ecologies as well as the concepts used to describe and understand them which in turn shape future research decisions, technological developments, and management decisions
- This is the **affordance-engineering cycle**→



How to build up worn out soils AND solve the nitrogen crisis

- How is the problem defined; what are possible sites of biotech engineering?
- The nitrogen problem is a problem with many proposed solutions often linked to the categorization of the main causes of it.
 - First as, what is soil—for whom? How is it conceptualized?
 - An abiotic system explainable fully via soil physics,
 - A biological substrate for plants, the potting-soil model
 - An active multispecies community of microbial, macrobial, and megaflora and faunal interactions?
 - The rhizosphere and beyond...
- How will biotech create new opportunities/burdens for interspecies communities of organisms (plants, soil, microbial and macrobial, micro and mega flora and fauna inc. humans)
- How might bioengineered N fixing plants contribute to conceptually reengineered notions of soil health, plant health, human health, planet health?



Comments or questions?

Please contact me:

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Thank you for your attention!



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