Food and Agriculture Organization of the United Nations

BLACK SOILS INTERNATIONAL NETWORK

Manure and straw returning benefit for stability of soil microbial ecosystem

Webinar series
SUSTAINABLE MANAGEMENT OF BLACK SOILS

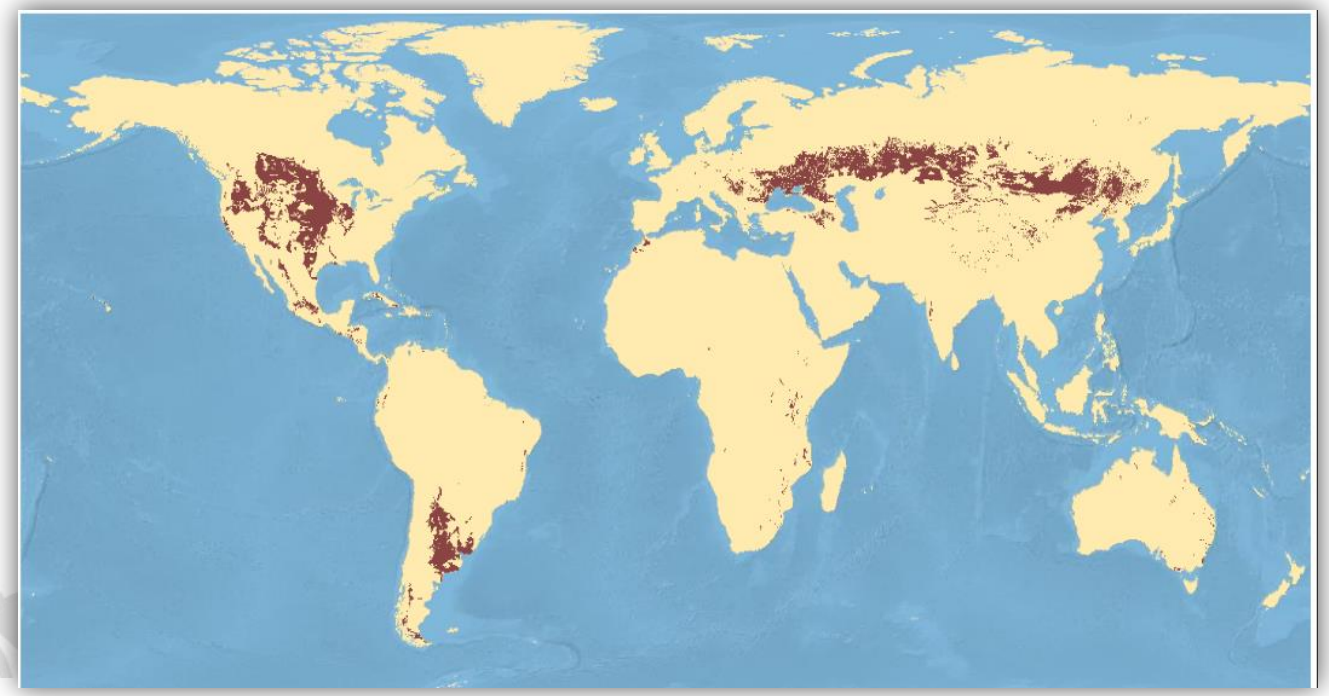
Heilongjiang academy of black soil conservation and utilization, HAAS

Xueli Chen

GLOBAL SOIL PARTNERSHIP

- **Background**
- **Manure with soil microbial diversity**
- **Straw returning with soil microbial diversity**

Global Black Soil Distribution map (GBSmap)



- Soils are the source of 95 percent of our food.
- Black soil represents only 5.6 percent of the global land area.
- While 31 percent of global black soils are cultivated, great portions remain with their natural land cover of forests and grasslands.

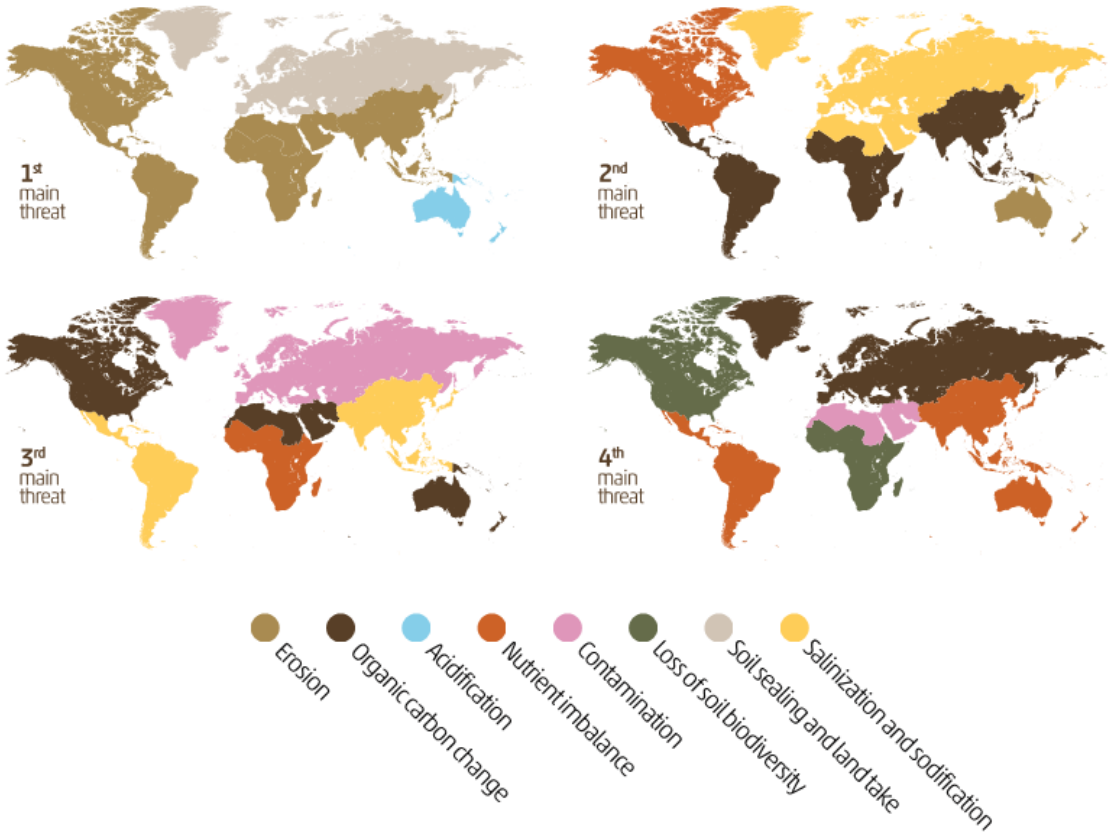
Table 2.2 Land cover and population in black soils

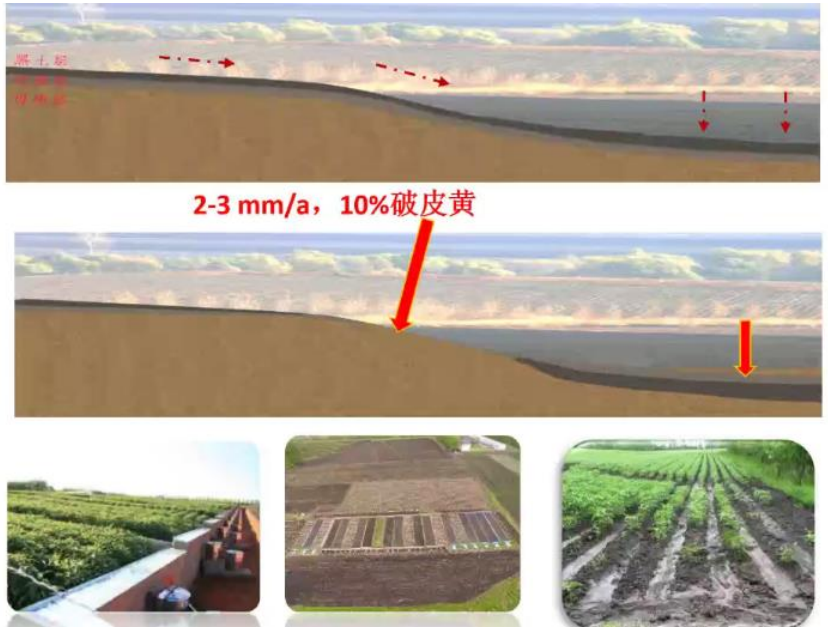
	Black soils	World	Percentage
Area (million hectare)	725	12 995	5.58
Cropland (million hectare)	227	1 308	17.36
Forest (million hectare)	212	4 496	4.72
Grassland (million hectare)	267	3 129	8.52
Population (million people)	223	7 788	2.86

Table 2.1 Top ten countries with the largest black soil areas

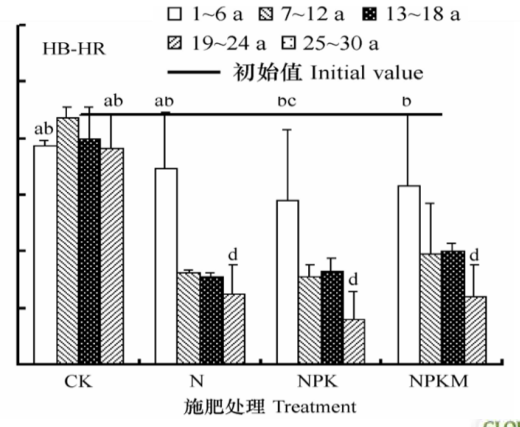
Country	Black soil area (million hectare)	Country area (million hectare)	Black soil proportion (percentage)
Russian Federation	326.8	1700.2	19.22
Kazakhstan	107.7	283.9	37.93
China	50	934.6	5.35
Argentina	39.7	278.1	14.28
Mongolia	38.6	156.5	24.67
Ukraine	34.2	60	57.01
United States of America	31.2	950.1	3.28
Colombia	24.5	113.8	21.54
Canada	13	997.5	1.30
Mexico	11.9	196.4	6.04

World's soil under threat





Zhang *et al*, 2023



Meng et al, Soil a, 2013

- Erosion, soil organic carbon loss, soil acidification and nutrient unbalance.
- 2-3mm/a, 50-60cm to 30cm.
- Soil pH decreased 1.28-1.51 after continuous input of chemical fertilizers for 19 to 24 years.

Soil organic carbon (SOC) contents in China

PNAS

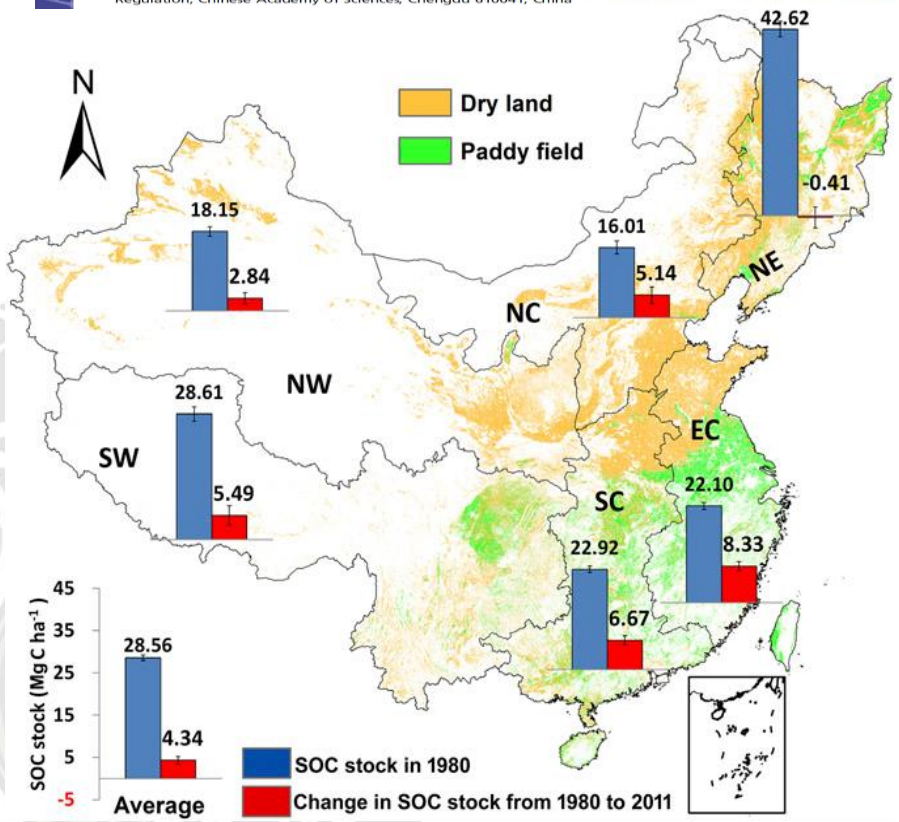
SPECIAL FEATURE

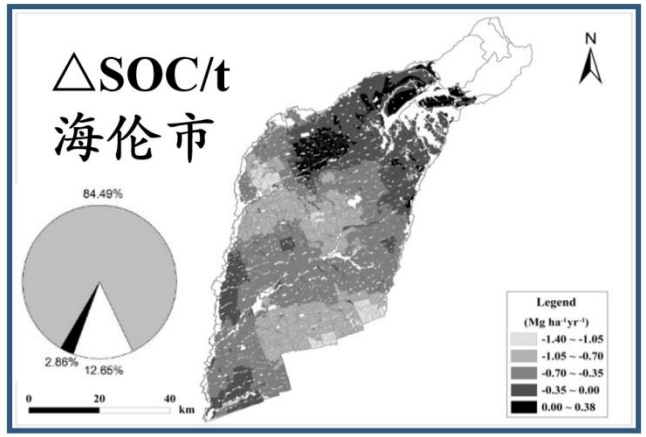
Economics- and policy-driven organic carbon input enhancement dominates soil organic carbon accumulation in Chinese croplands

Yongcun Zhao[a], Meiyan Wang[a], Shuijin Hu[b,c], Xudong Zhang[d], Zhu Ouyang[e], Ganlin Zhang[a], Biao Huang[f], Shiwei Zhao[g], Jinshui Wu[h], Deti Xie[i], Bo Zhu[j], Dongsheng Yu[a], Xianzhang Pan[a], Shengxiang Xu[a], and Xuezheng Shi[a,1]

[a]State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China; [b]College of Resources and Environmental Sciences, Nanjing Agricultural University, Nanjing 210095, China; [c]Department of Entomology and Plant Pathology, North Carolina State University, Raleigh, NC 27695; [d]Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China; [e]Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; [f]Key Laboratory of Soil Environment and Pollution Remediation, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China; [g]State Key Laboratory of Soil Erosion and Dryland Farming on Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences, Yangling 712100, China; [h]Key Laboratory of Agro-Ecological Processes in Subtropical Regions, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha 410125, China; [i]College of Resources and Environment, Southwest University, Chongqing 400715, China; and [j]Key Laboratory of Mountain Surface Process and Ecological Regulation, Chinese Academy of Sciences, Chengdu 610041, China

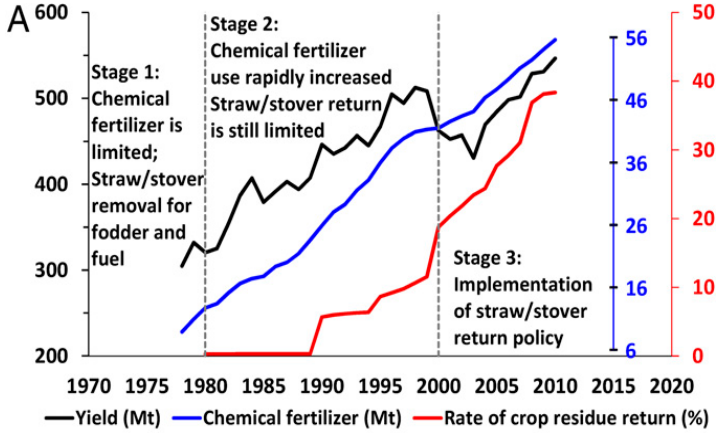
- In past 30 years, Mollisoil was the only area of soil organic matter content decreased in China.
- The stock of soil organic matter decreased 19%.
- Chemical fertilizer input and intensive planting.

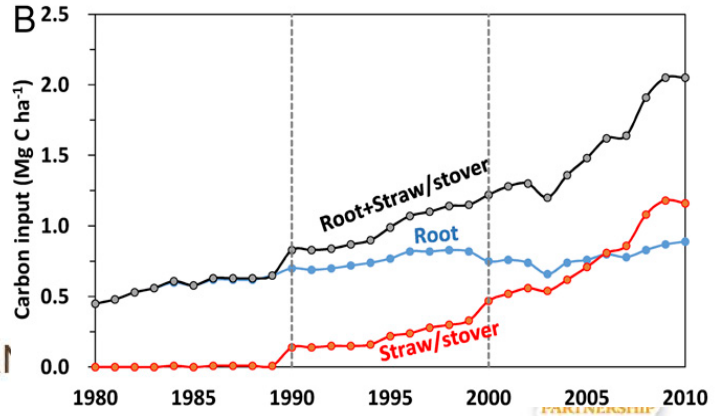




Soil organic matter loss

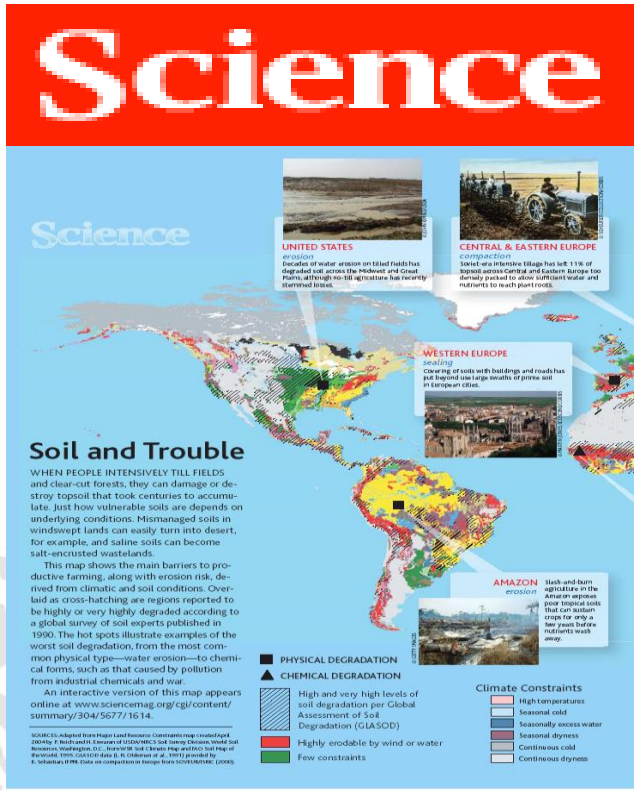
- ✓ Area: 84.5%
- ✓ Stock: -19.1%
- ✓ Rates: -0.5 t C ha^{-1} yr^{-1}

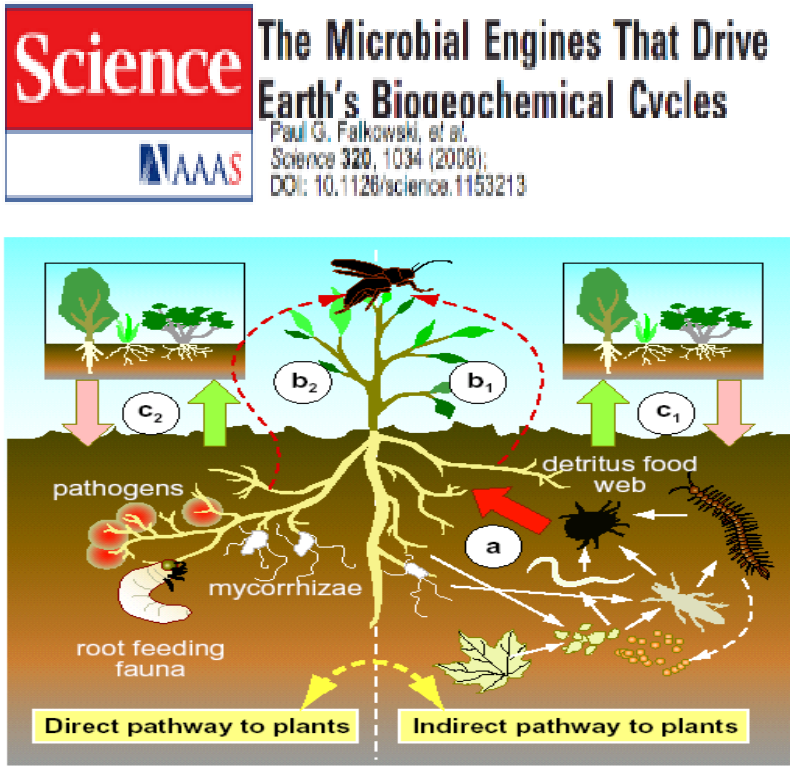


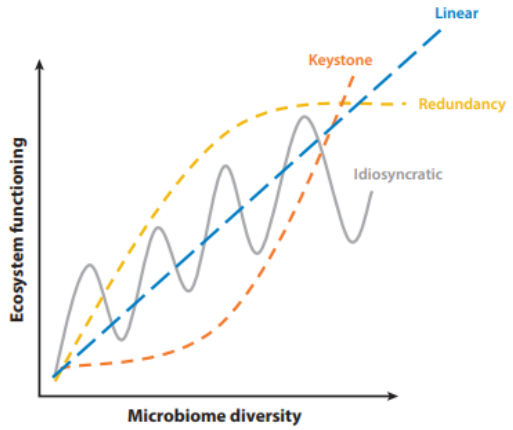


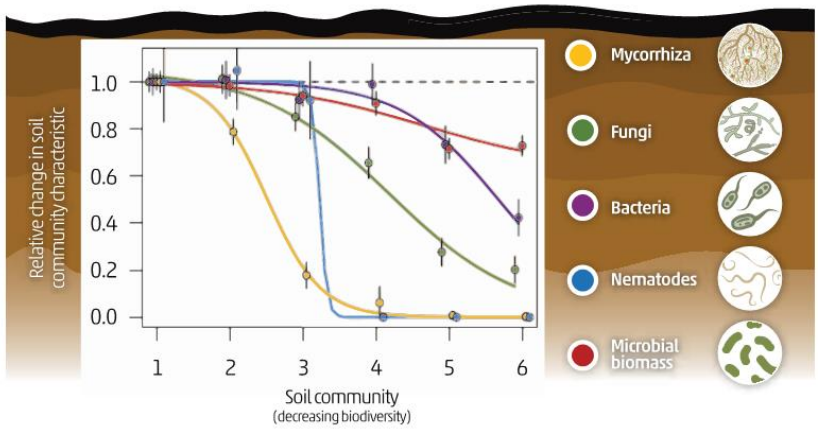
Zhao YC et al., PNAS, 2017

Soil Microbial feed humans









Biodiversity determined the stability of ecosystem

Dolfing *et al*. Sciences, 2004

The Microbial Engines That Drive Earth's Biogeochemical Cycles

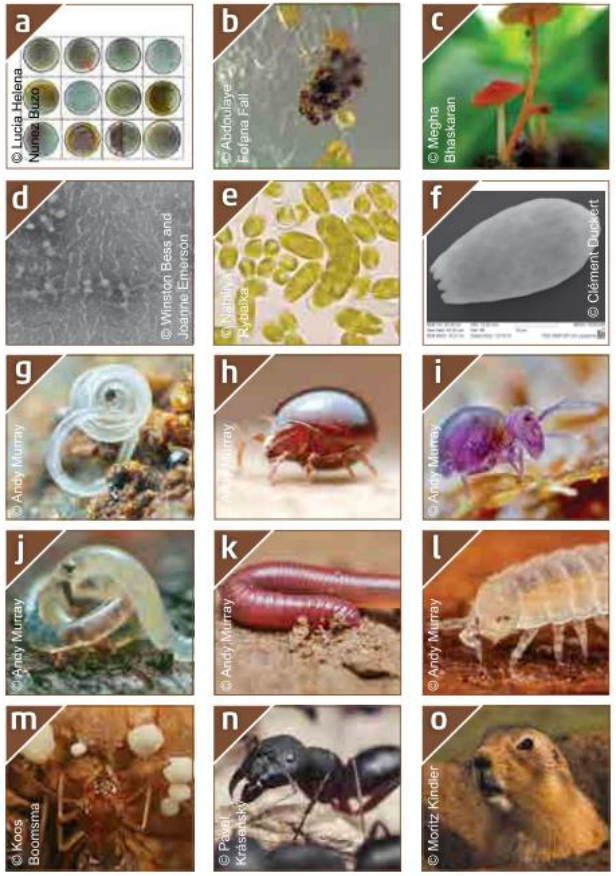
Falkowski *et al.*, Sciences, 2008

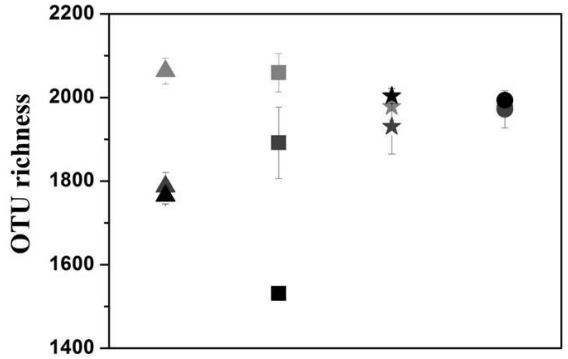
Soil biodiversity and soil community composition determined ecosystem multifunctionality

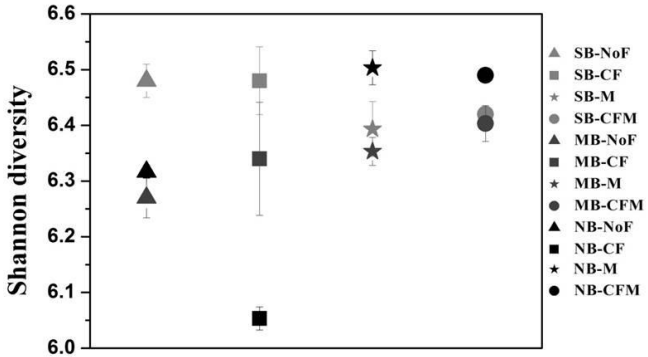
Wang, *et al.*, PNAS, 2014

GLOBAL SOIL PARTNERSHIP

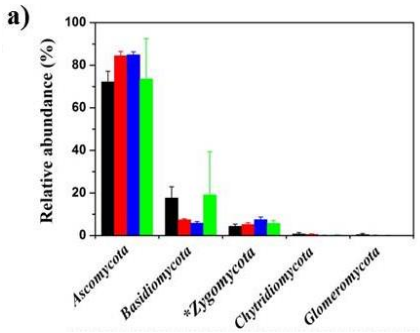
Biodiversity decreased by human activities

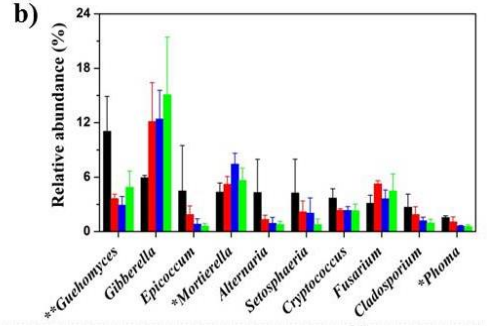




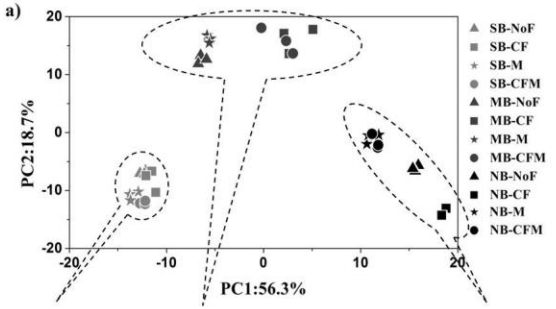


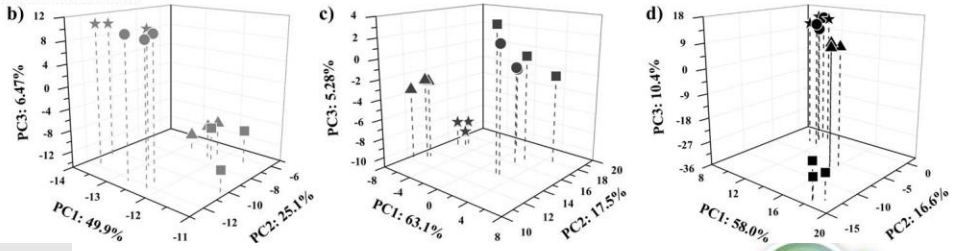
- Diversity and richness of bacterial community
- Community composition.
- 25 years of fertilization on black soil in Northeast of China





Relative abundance of fungi community





- Long term chemical fertilizer input decreased the diversity of soil bacterial community;
- Changed the composition of bacterial community.
- Organic material benefit to the stability of soil microbial community

ABLE MANAGEMENT OF BLACK SOILS

Xiaojing Hu, *et al.* Agriculture, Ecosystems and Environment, 2017

Xiaojing Hu, *et al.* Pedosphere, 2018

Organic materials are considered as remediation measures of degraded soil

- **Main husbandry production areas.**
- **Abundant organic materials, straw and manure.**
- **Reduce environment pollution and GHG emission.**

How organic materials affect the diversity of soil microbial community in black soil?

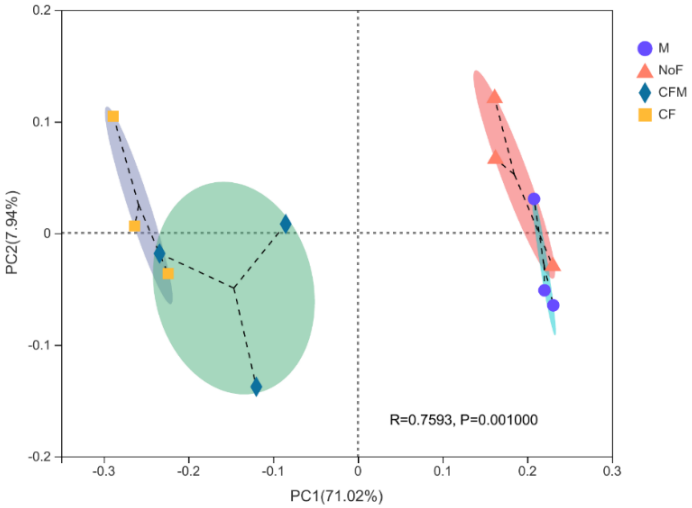
How organic materials affect the ecological functions of soil microbial community in black soil?

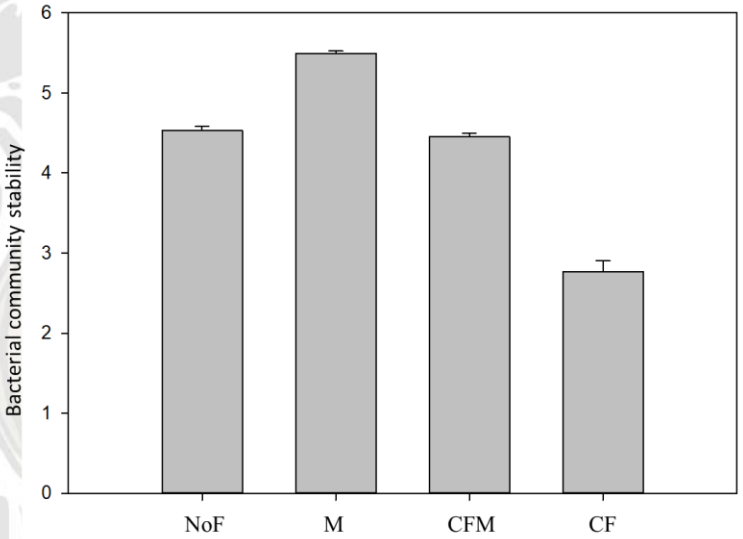
1. Effect of organic fertilization on soil microbial community

Diversity and composition

- Organic manure increased the abundance of soil bacterial community and diversity.
- Organic manure application benefit for stability of bacterial community.

1979, Harbin, soil type is black soil



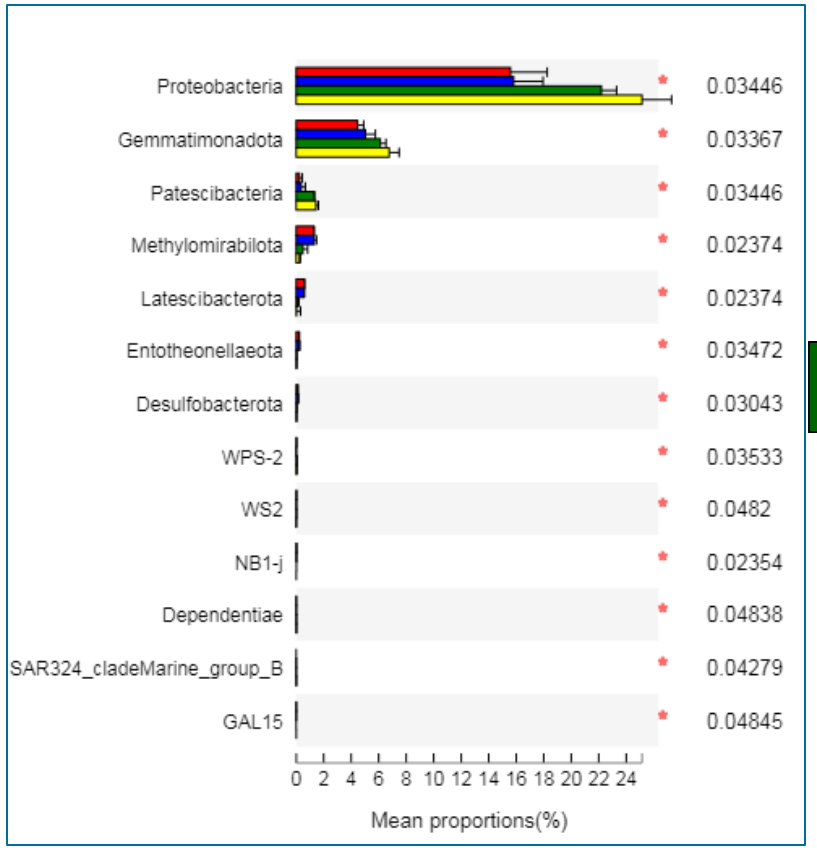


	Ace	Chao	Coverage	Shannon	Simpson
NoF	2538.24±130.92ab	2516.57±144.28ab	0.9850±0.001	6.19±0.07a	0.0057±0.0008b
M	2607.90±16.42ab	2609.76±29.10ab	0.9847±0.0008	6.25±0.06a	0.0045±0.0003b
CFM	2720.91±95.70a	2722.38±66.74a	0.9875±0.0066	6.18±0.04a	0.0059±0.0005b
CF	2386.63±126.4b	2388.23±136.56b	0.9858±0.00145	5.92±0.12b	0.0085±0.0012a

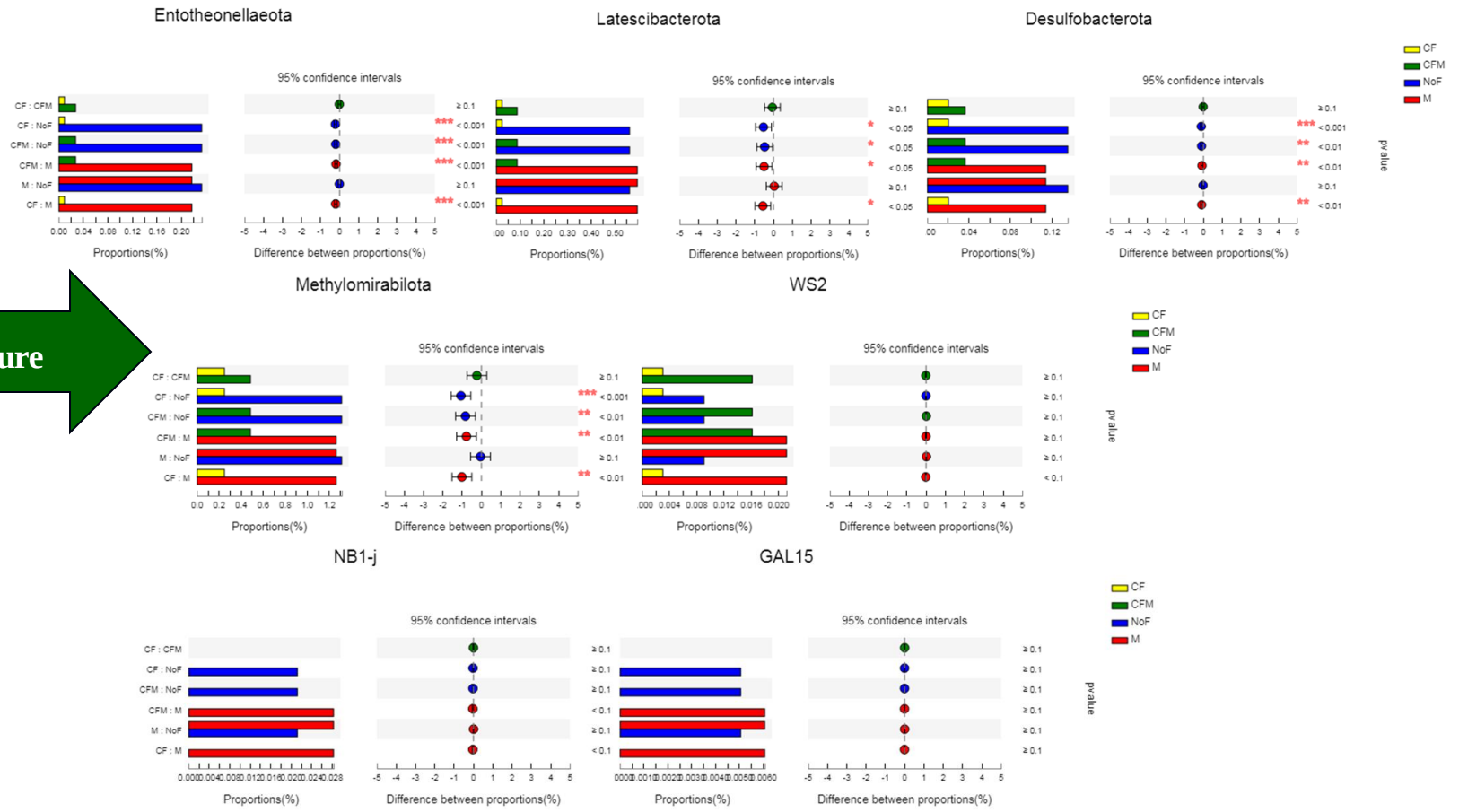
1. Effect of organic fertilization on soil microbial community

Diversity and composition

- The relative abundance of *Acidobacteria*, *Entotheonellaeota* increased by manure application

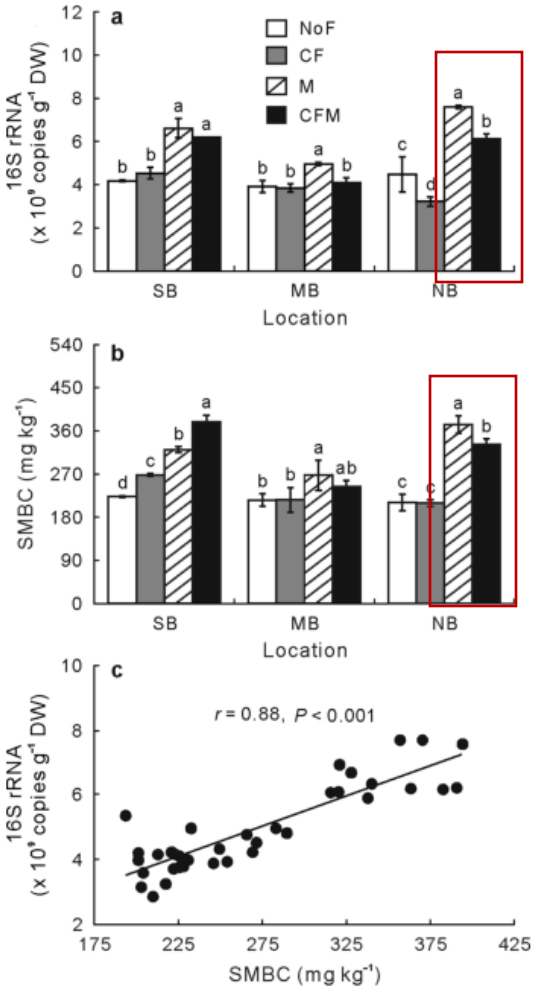


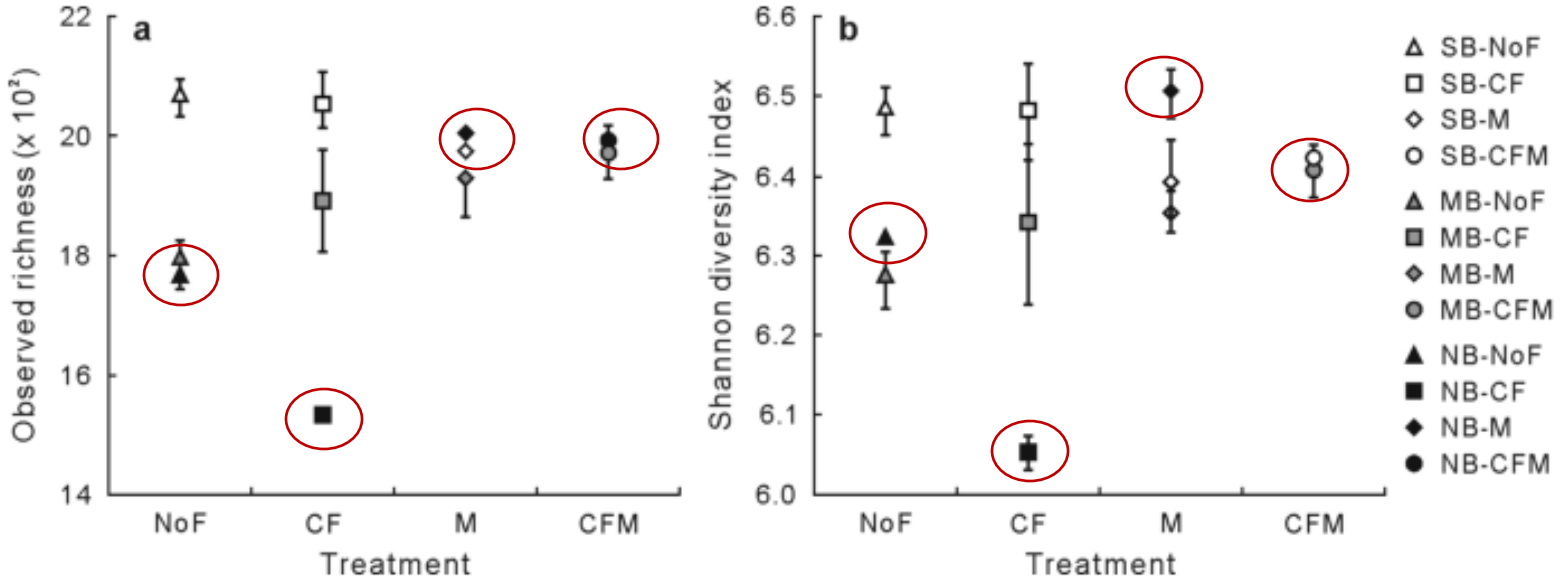
Manure



1. Effect of organic fertilization on soil microbial community

Diversity and composition



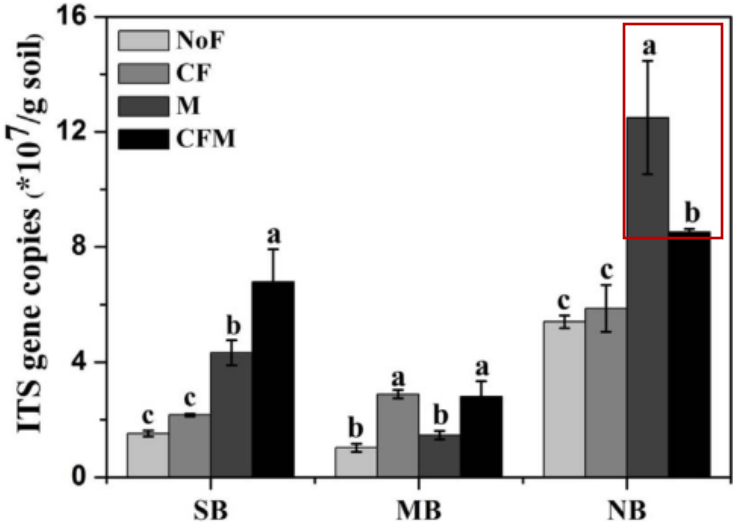


- Long-term inputs of manure contributed to increases in soil nutrient levels and SMBC in comparison to no fertilization, and also had positive effects on copiotrophic taxa.
- With respect to increasing root exudates and root biomass due to crop growth, readily metabolic C in manure .
- Higher diversity index were found in M and CFM

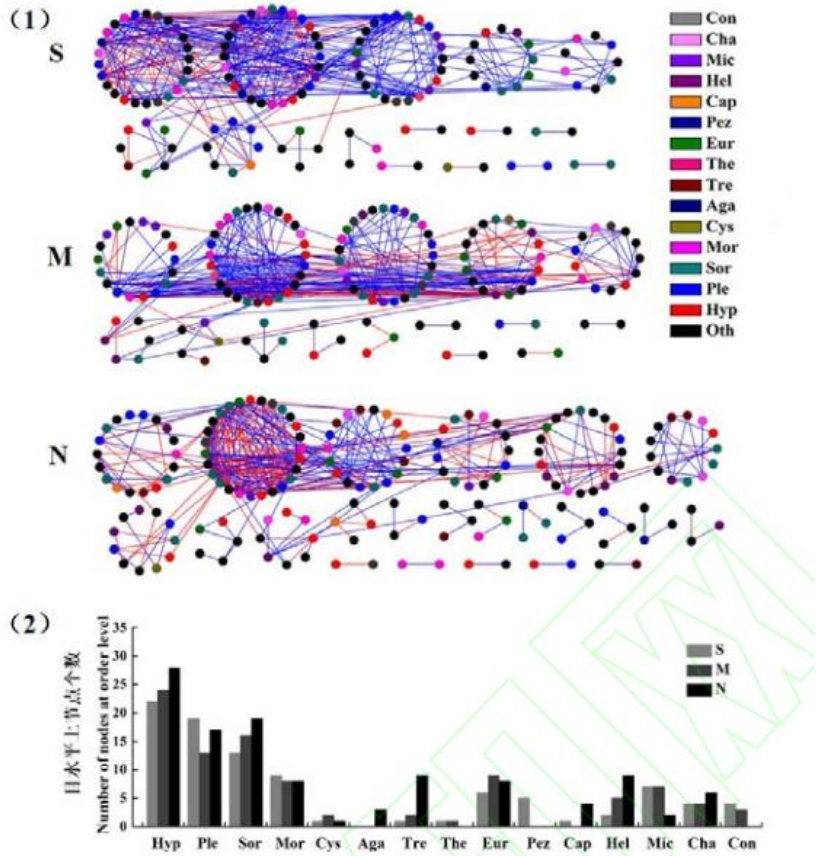
Hu *et al.*, Pedosphere, 2018
Shen *et al*, Applied Soil Ecology, 2010

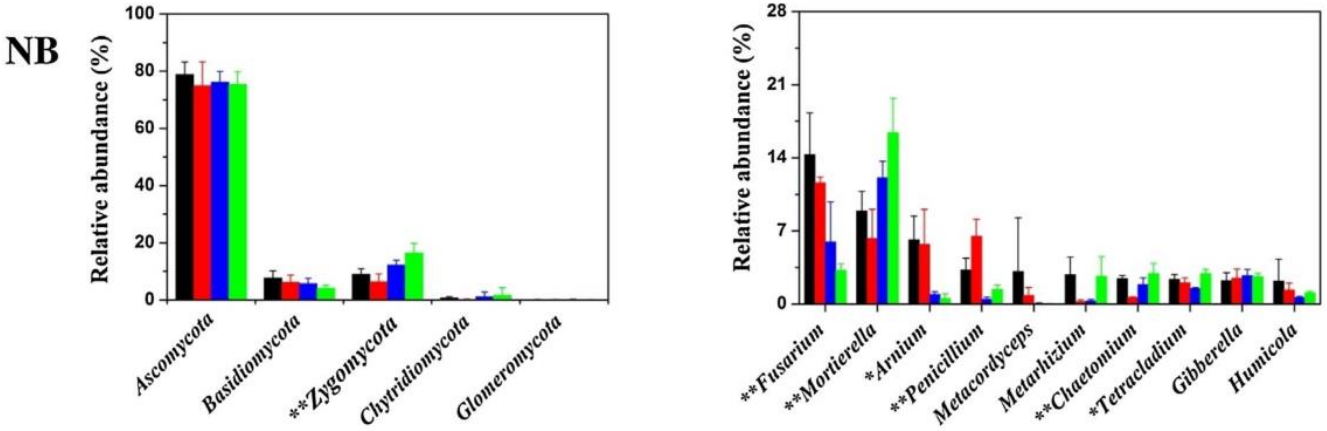
1. Effect of organic fertilization on soil microbial community

Diversity and composition



- Organic fertilization significantly increased the diversity and abundance of fungi community.
- High total carbon content led to high fungi biomass and gene abundance.
- The key species was *Penicillium coralligerum*.
- Complex fungal network.

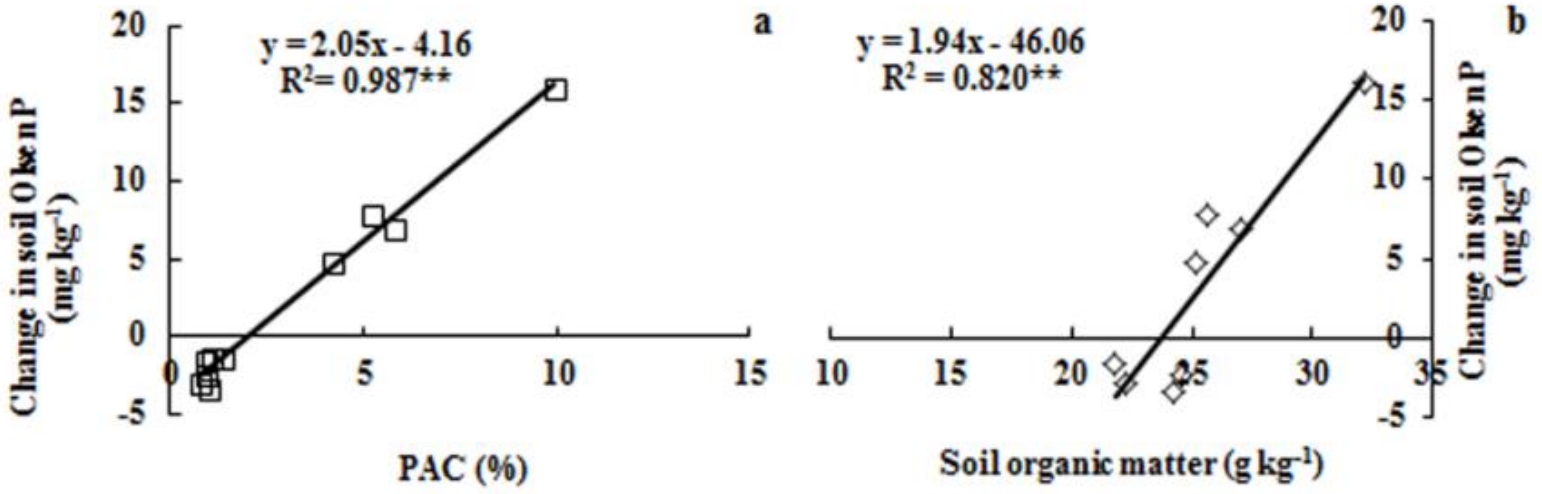




Hu *et al*, Agriculture, Ecosystems and Environment, 2017
Hu *et al*, Chinese Journal of Applied Ecology, 2018
Ding *et al*, Applied Soil Ecology, 2017

1. Effect of organic fertilization on soil microbial community

Organic fertilization with soil P



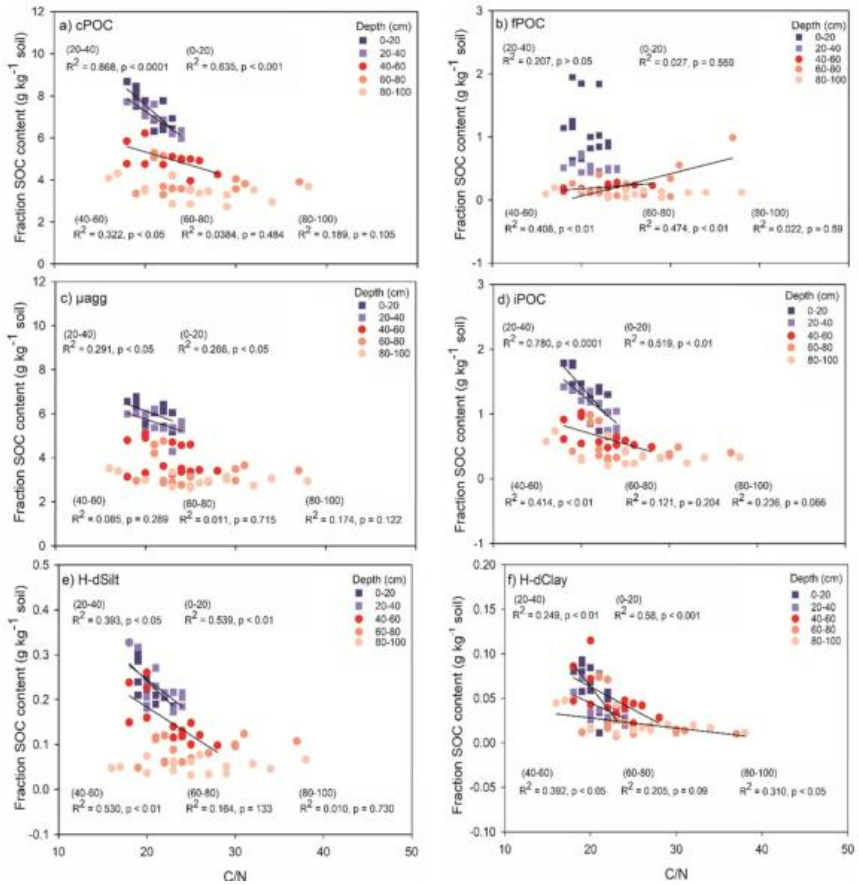
Soil organic matter and pH have important effects on the change in soil Olsen P by 1 kg ha $^{-1}$ of P balance

P activation coefficient (PAC)

Zhan et al., Plos One, 2015

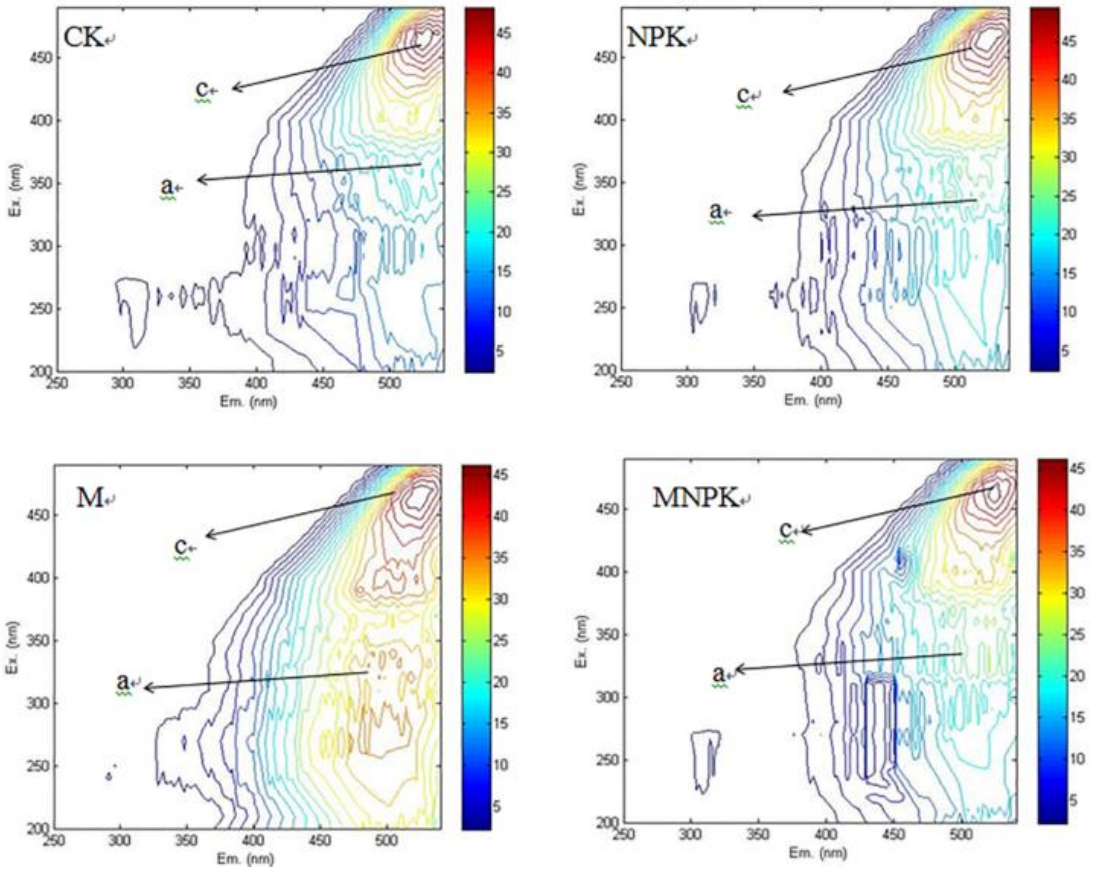
1. Effect of organic fertilization on soil microbial community

Organic fertilization with soil carbon



Long-term manure applications improved the C sequestration not only in the topsoil but also in the deep layers;

Abra et al., Journal of Soils and Sediments, 2020

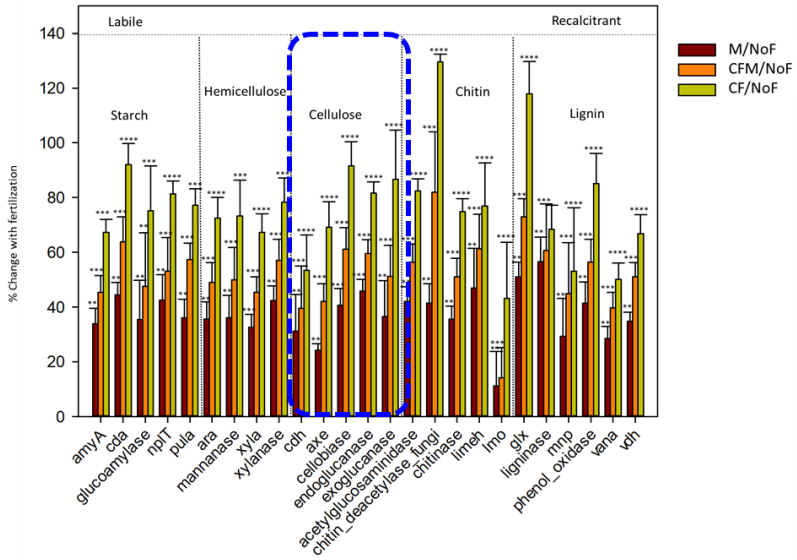


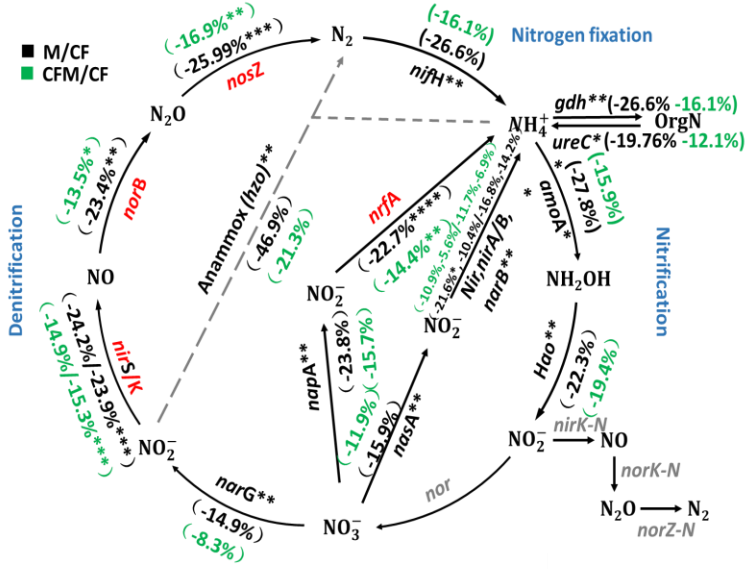
The molecular structure of HA in Black Soil tends to be aliphatic, simpler, and younger after the application of manure

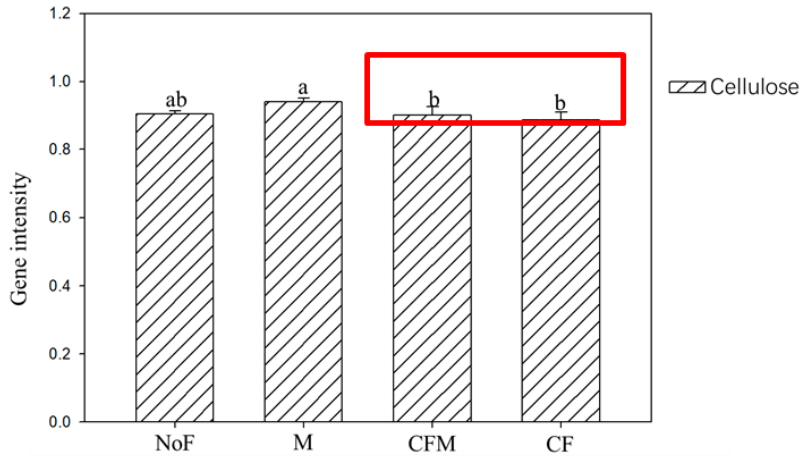
Zhang *et al*., Plos One, 2017

1. Effect of organic fertilization input on soil microbial community

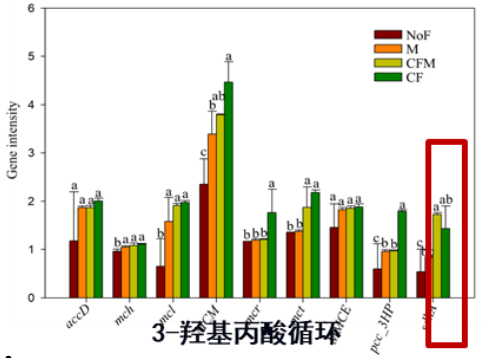
Ecosystem functions

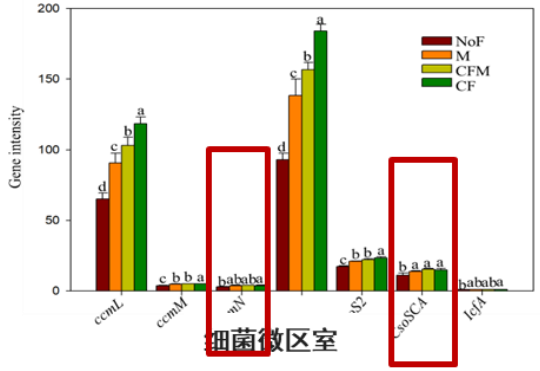






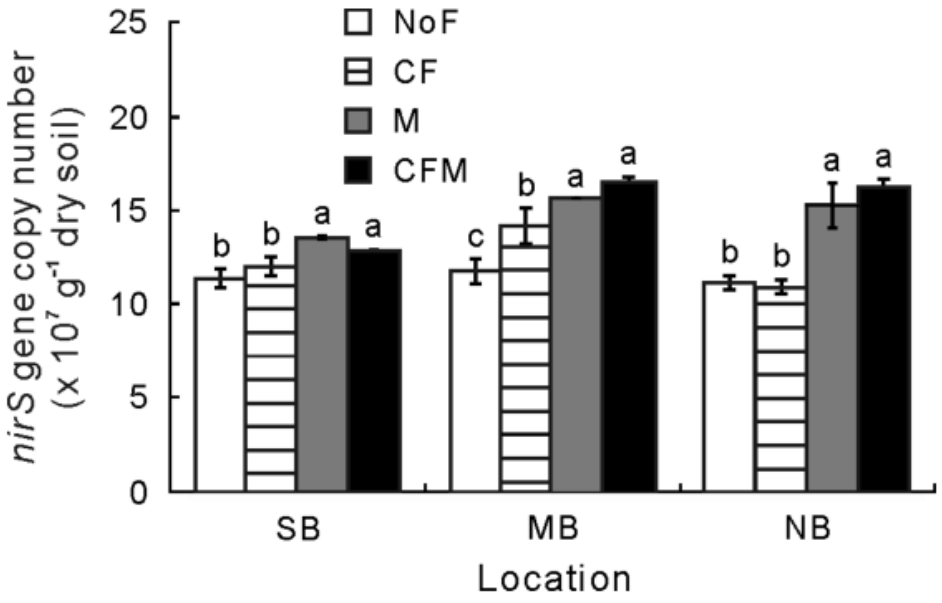
- Fertilization significantly increased the capability of C, N and P transformation.
- Organic fertilization increased the relative abundance of functional genes involved in Cellulose, C degradation stage and C fixation.
- Manure application increased the course of soil denitrification.





1. Effect of organic fertilization on soil microbial community

Functional genes diversity



Treat-ment	SB		MB		NB	
	OTU richness	Shannon diversity	OTU richness	Shannon diversity	OTU richness	Shannon diversity
NoF	257a[b)]	3.01b	162a	3.68a	195b	3.74a
CF	244a	3.32ab	133b	2.97b	138c	3.03b
M	260a	3.61a	125b	3.39a	234a	3.80a
CFM	257a	3.65a	112b	2.63b	206b	3.03b

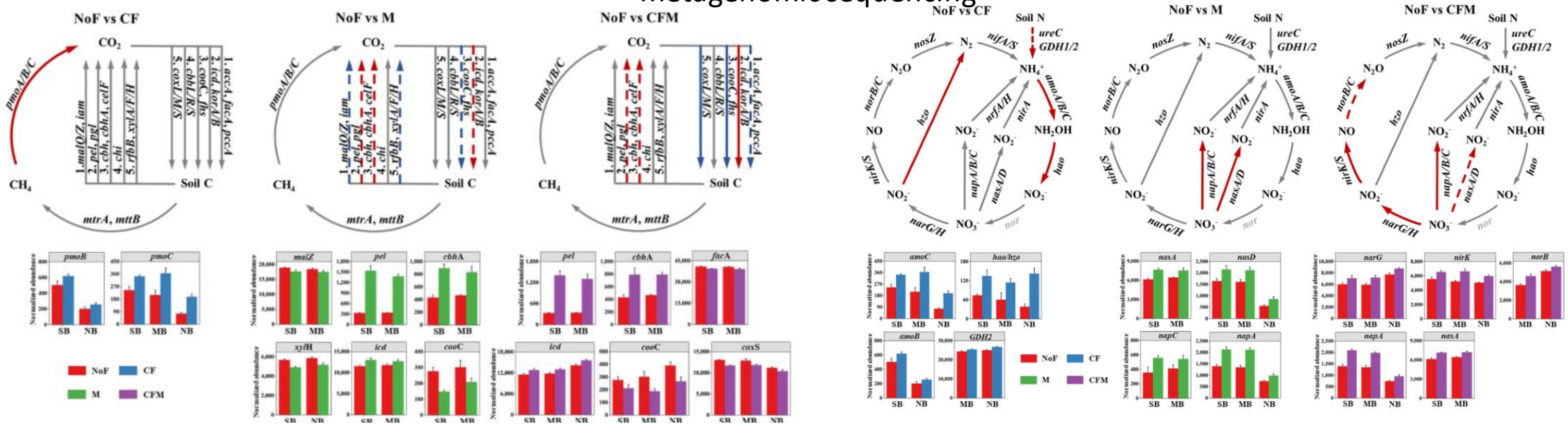
M and CFM regimes significantly increased the abundances and the diversity of *nir*S-type denitrifiers compared with NoF

Hu *et al.*, Pedosphere, 2020

1. Effect of organic fertilization on soil microbial community

Ecosystem functions

metagenomic sequencing

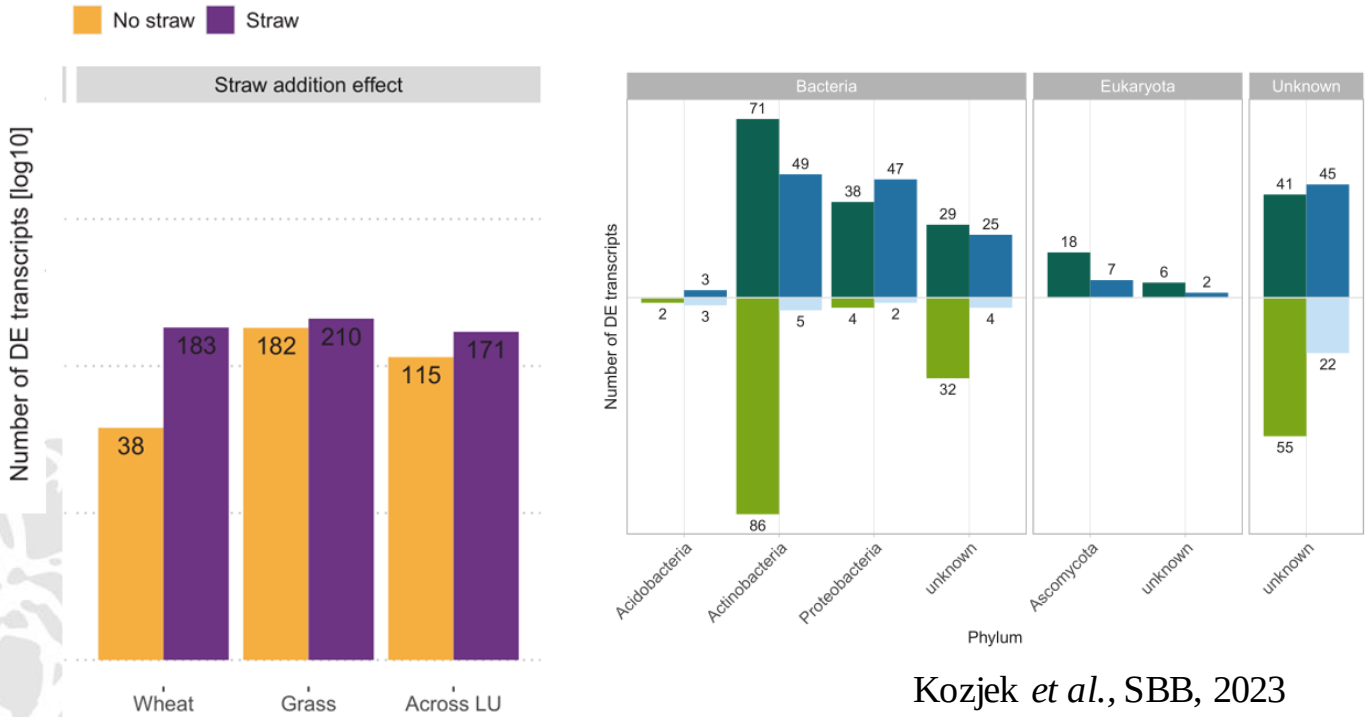


- Organic fertilization enriched the relative abundances of *Proteobacteria* and *Planctomycetes* that carry C and N cycling genes, while inhibited the growth of oligotrophic groups such as Verrucomicrobia.
- Manure fertilization, particularly the combination of chemical and organic fertilizers (CFM), significantly enhanced the abundance of icd (rTCA cycle), which are involved in C fixation.
- The substantial enhancement in soil P contents induced by manure addition predominantly affected the C and N cycling profiles, abundance of functional genes and microbial taxa

Hu *et al*., Geoderma, 2022

2. Effect of crop straw returning on soil microbial community

Diversity and composition

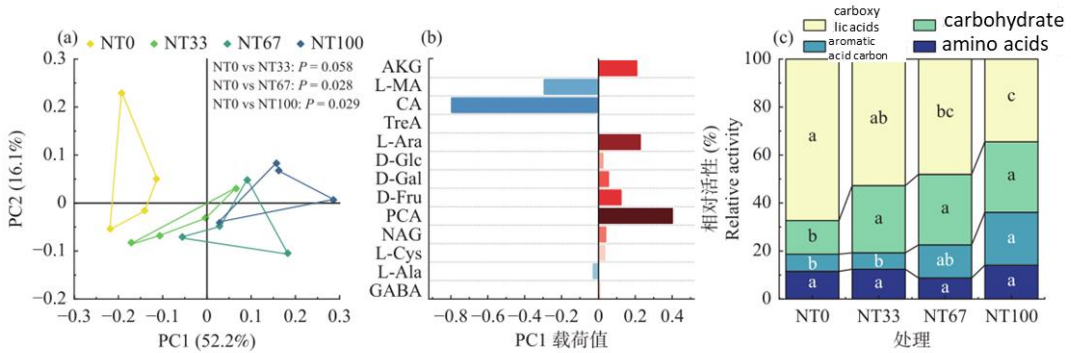


Kozjek *et al.*, SBB, 2023

- Arable soils with a low organic carbon content have a potential to get a higher and more active microbial diversity with amendments
- The majority of the differentially expressed transcripts produced at straw addition belonged to Bacteria.

Alpha diversities of soil microbial metabolic function in different amounts of corn stover mulch treatments

处理 Treatment	Simpson多样性指数 Simpson_1-D	Shannon多样性指数 Shannon_H	Evenness均匀度指数 Evenness_e^H/S
NT0	0.773 ± 0.005 b	1.837 ± 0.048 b	0.485 ± 0.024 b
NT33	0.846 ± 0.025 a	2.161 ± 0.098 a	0.677 ± 0.063 a
NT67	0.855 ± 0.017 a	2.161 ± 0.083 a	0.675 ± 0.054 a
NT100	0.862 ± 0.013 a	2.200 ± 0.066 a	0.698 ± 0.045 a

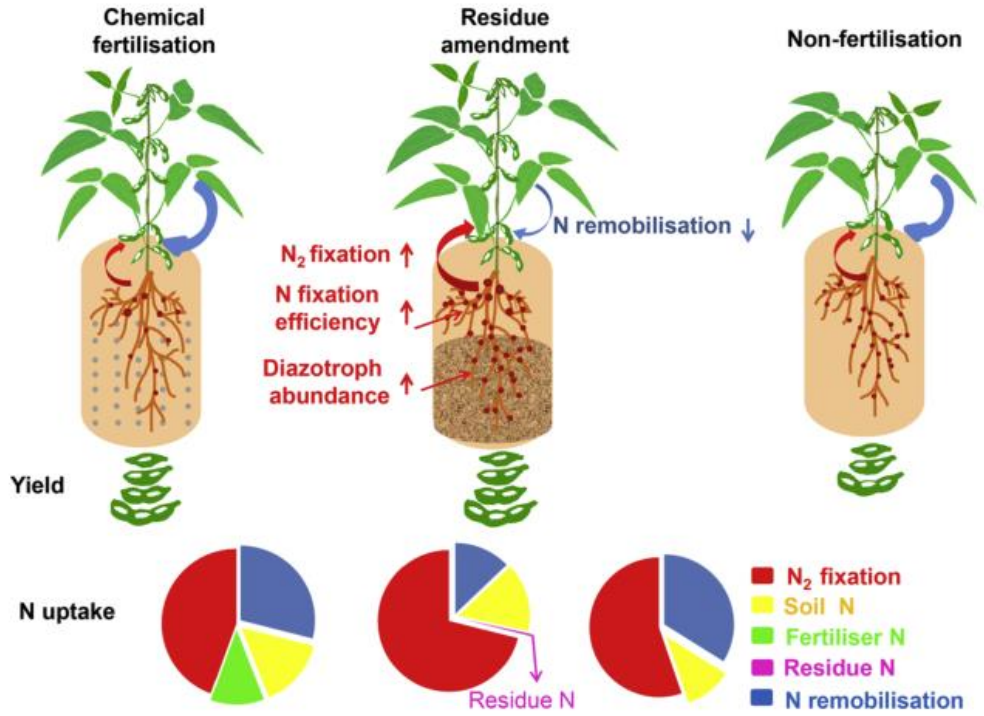


Long-term corn straw cover (14 a) could improve soil microbial carbon metabolic functions by reducing microbial metabolic demand for readily available carbon sources and increasing microbial carbon metabolic diversities.

Liu *et al.*, Chinese Journal of Soil Sciences, 2023

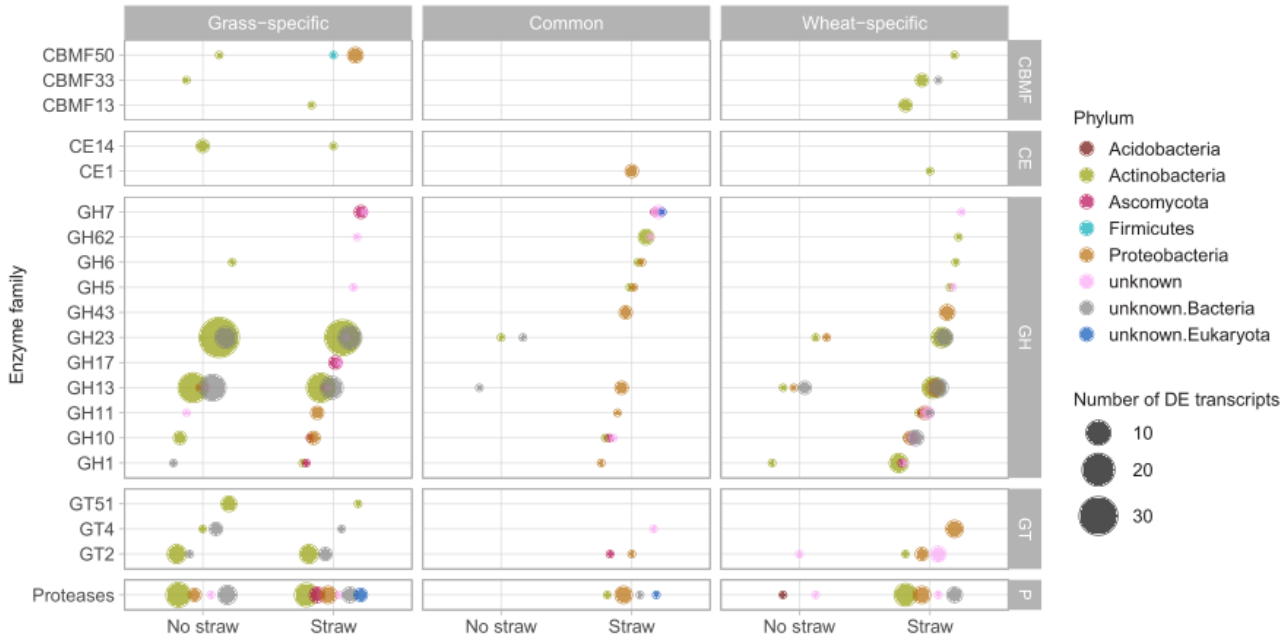
2. Effect of crop straw returning on soil microbial community

Ecosystem functions



Incorporation of maize crop residue maintains soybean yield through the stimulation of nitrogen fixation rather than residue-derived nitrogen in Mollisols

Xie *et al.* Field Crops Research, 2021



The straw addition triggered the upregulation of a set of enzyme families catalysing the organic matter degradation

Kozjek *et al.*, SBB, 2023

2. Effect of crop straw returning on soil microbial community

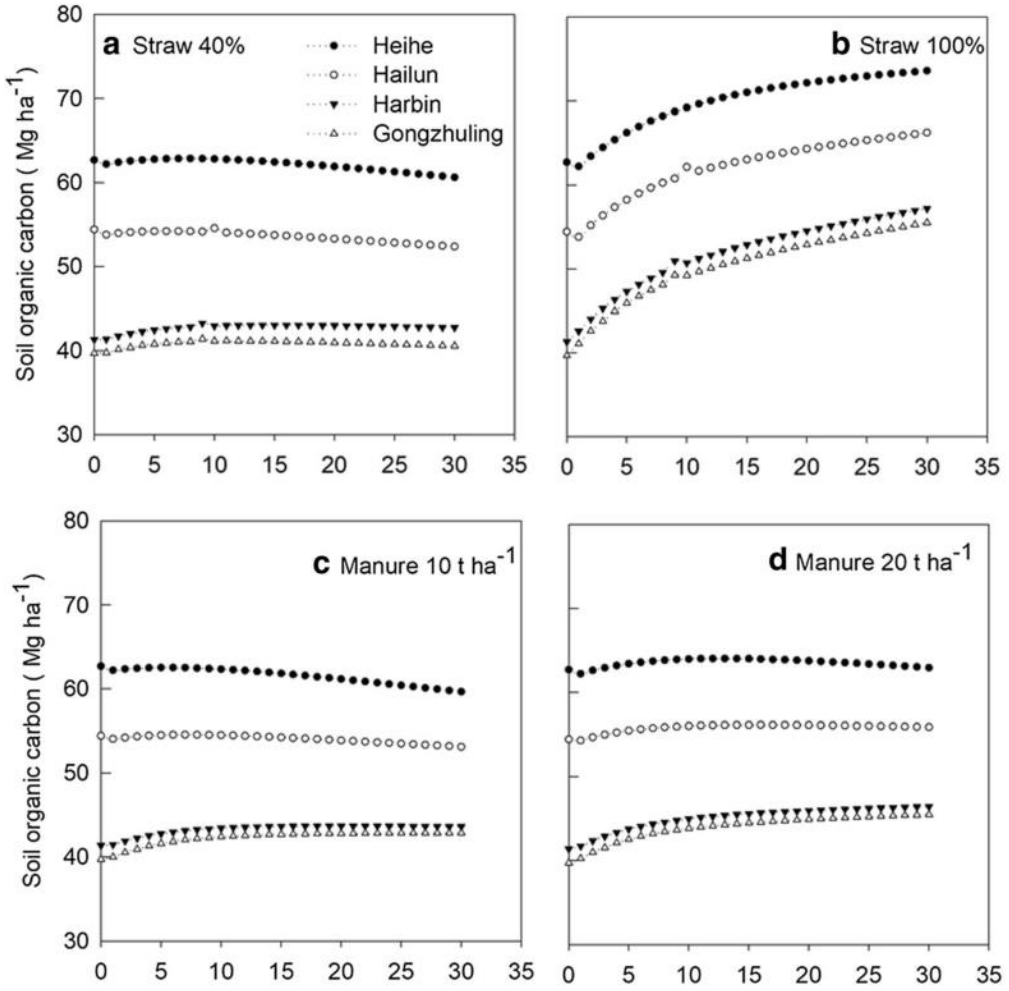
Ecosystem functions

Predicted annual changes in topsoil (0-20 cm) SOC stocks (Mg ha^{-1} yr^{-1}) under four scenarios at each experimental site over a 30 yar period

Scenario	Heihe	Hailun	Harbin	Gongzhuling
Straw 40%	− 0.07	− 0.07	0.05	0.03
Straw 100%	0.36	0.39	0.53	0.53
Manure 100%	− 0.10	− 0.04	0.08	0.10
Manure 200%	0.01	0.05	0.17	0.19

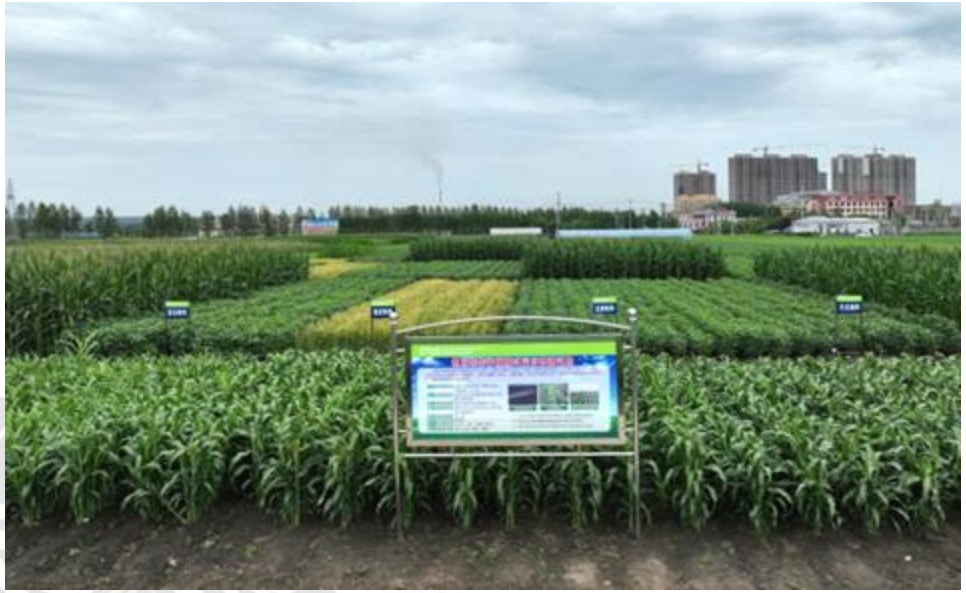
- Increasing inputs of carbon sources such as straw and manure, together with appropriate tillage, could substantially improve SOC sequestration in the black soil region of northeastern China.

Wang *et al.*, Journal of Soils and Sediments, 2019

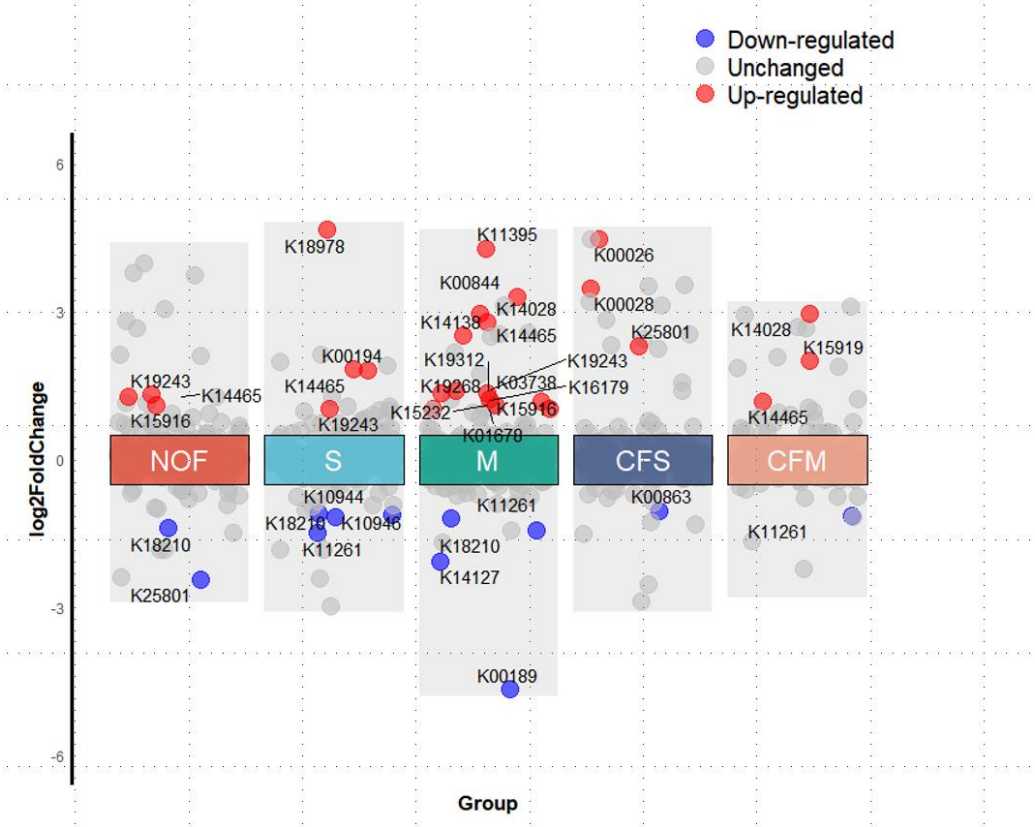


2. Effect of crop straw returning on soil microbial community

Diversity and composition



1979, Heihe, soil type is black soil

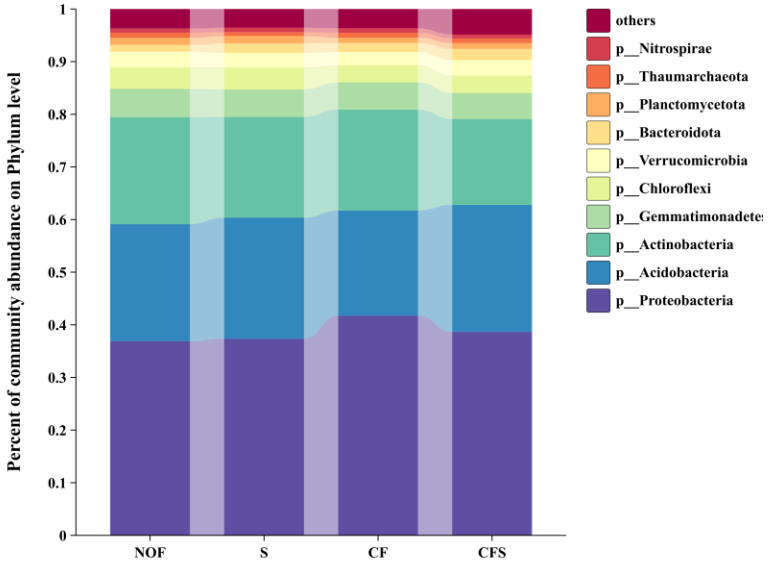


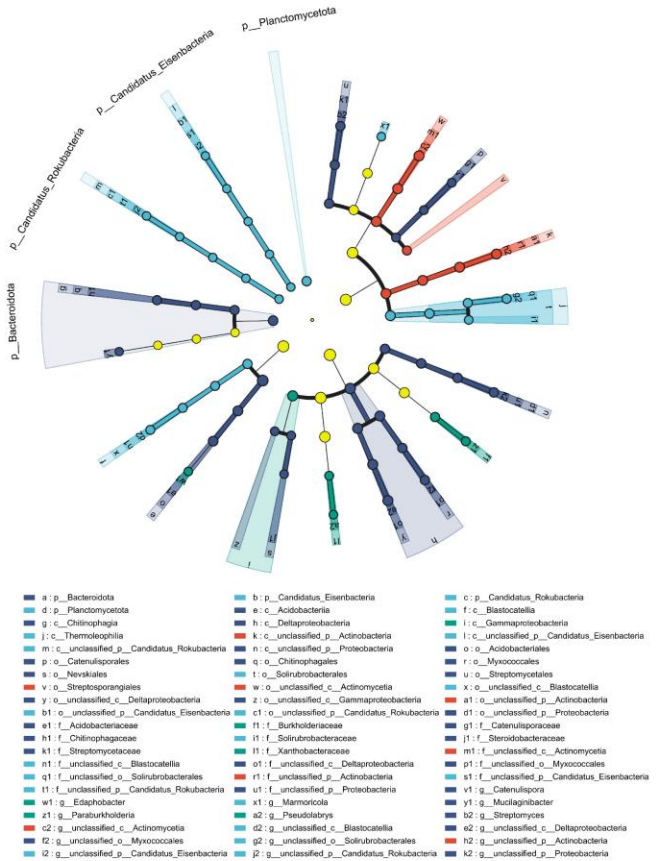
- Compared with CF, straw addition didn't significantly change the composition and diversity of bacterial community.
- Yan et al., 2020 confirmed no significant affect on diversity of soil microbial community.

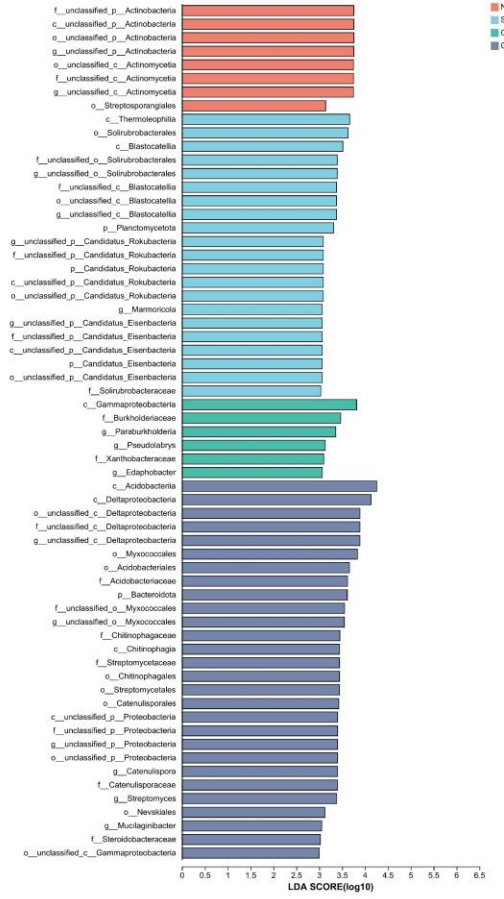
Unpublished data

2. Effect of crop straw returning on soil microbial community

Diversity and composition





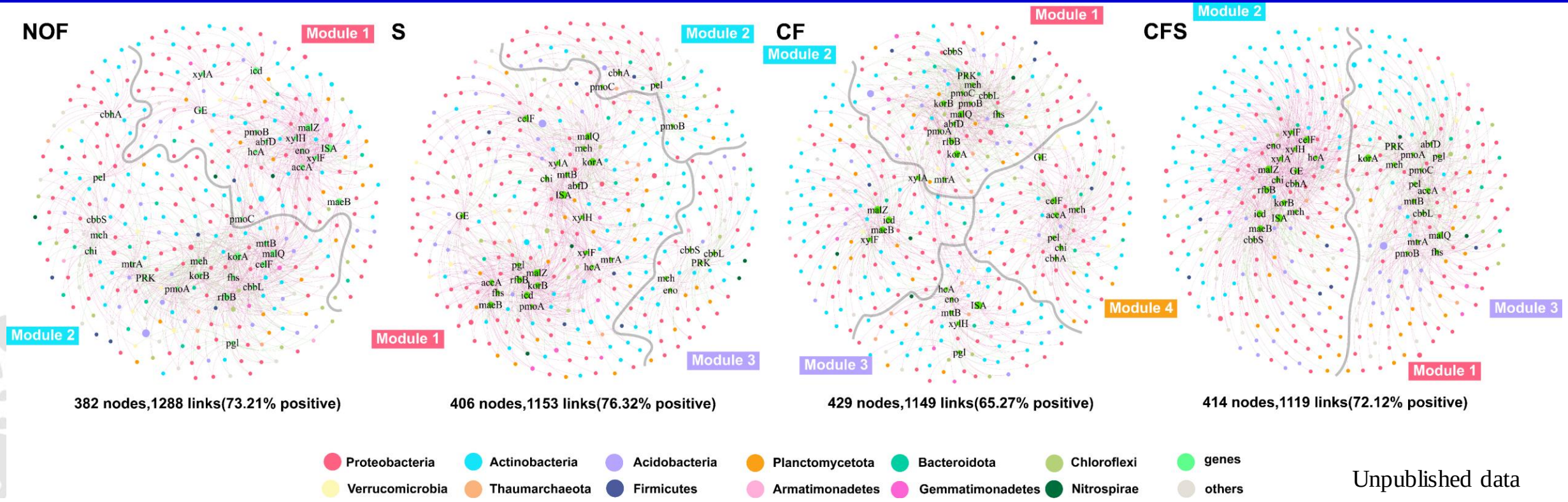


- *Proteobacteria*, *Acidobacteria*, *Actinobacteria*, *Gemmatimonadetes* and *Chloroflexi* are dominant group, accounting for more than 80%.
- The abundance of *Proteobacteria*, *Acidobacteria* increased in S, CF and CFS.
- The most significant difference species of S is Thermoleophilia in Phylum of *Actinobacteria*
- The most significant difference species of CFS is Acidobacteriia in Phylum of *Acidobacteria*.

Unpublished data

2. Effect of crop straw returning on soil microbial community

Ecosystem functions



Unpublished data

By identifying the gene node with the highest degree of network as a key node

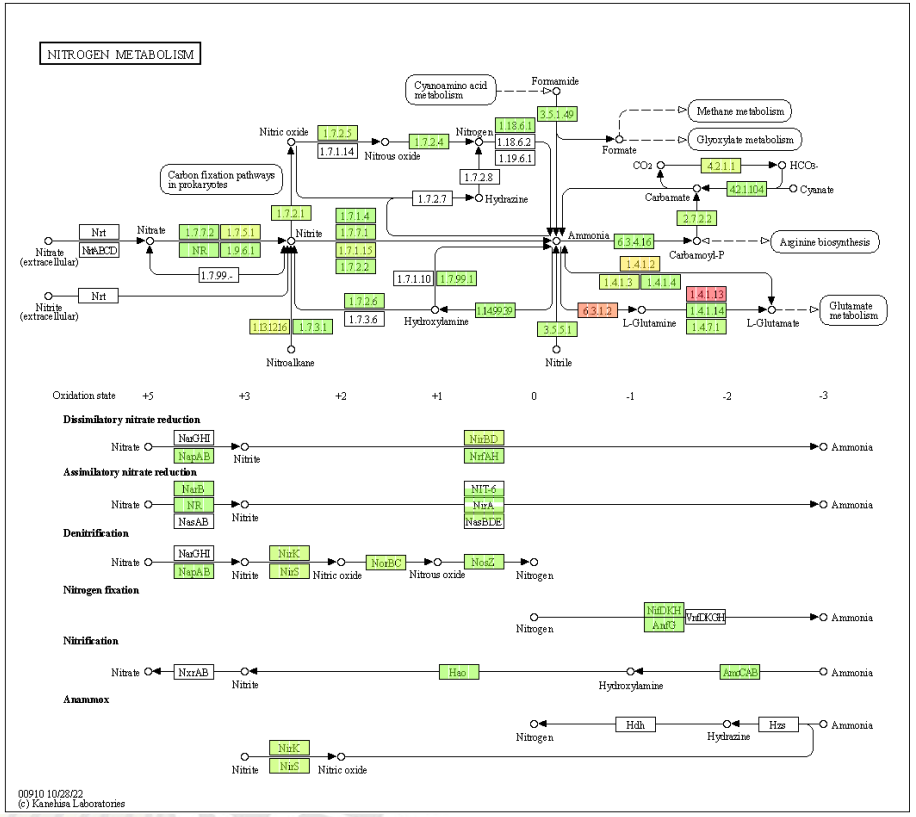
The key node of straw application alone (S) treatment is *celF* gene related to cellulose decomposition, and the two genera with the highest degree of positive correlation are *Actinobacteria* g__ Kutzneria and the g__ Candidatus_ Koribacters of *Acidobacteria*

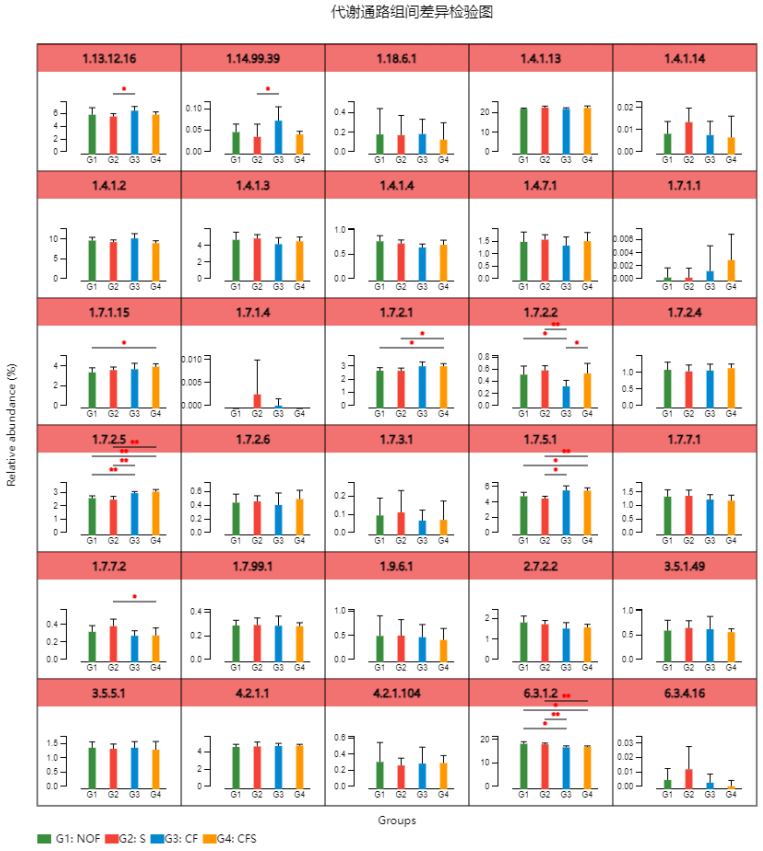
The key node of CF is the malQ gene associated with starch metabolism and glycogen degradation, belonging to the phylum of *Acidobacterium*__ Unclassified_ C__ Acidobacteria

The key node of CFS is the cbbL gene related to carbon sequestration, belonging to the phylum of *Proteobacteria*__ Nitrobacter.

2. Effect of crop straw returning on soil microbial community

Ecosystem functions





Unpublished data

Compared to the application of chemical fertilizers, the addition of straw increased the relative gene abundance of nitrite reductase (EC: 1.7.2.2) and glutamine synthase (EC: 6.3.1.2)

Summary

- Organic fertilization increased the diversity of bacterial community, then straw returning almost no effect on diversity.
- Organic fertilization inhibited the growth of oligotrophic groups, then straw promote the copiotrophic groups.
- Organic fertilization enhanced the metabolic of carbon cycle, then straw retuning enhanced N fixation.
- Manure application decreased the course of soil denitrification

Food and Agriculture Organization of the United Nations

BLACK SOILS INTERNATIONAL NETWORK

Thanks for your attention!

GLOBAL SOIL PARTNERSHIP