



# Soil enzyme profile analysis for indicating decomposer micro-food web

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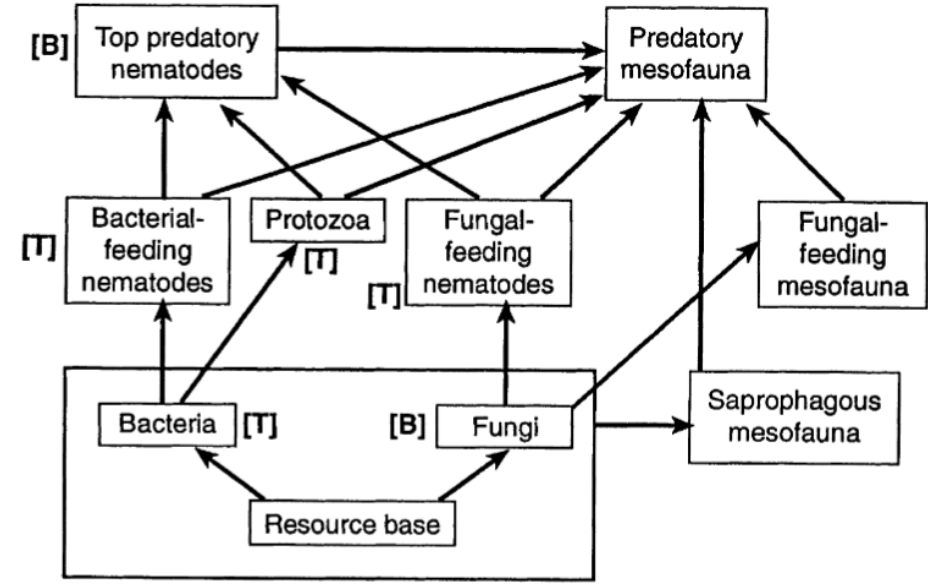
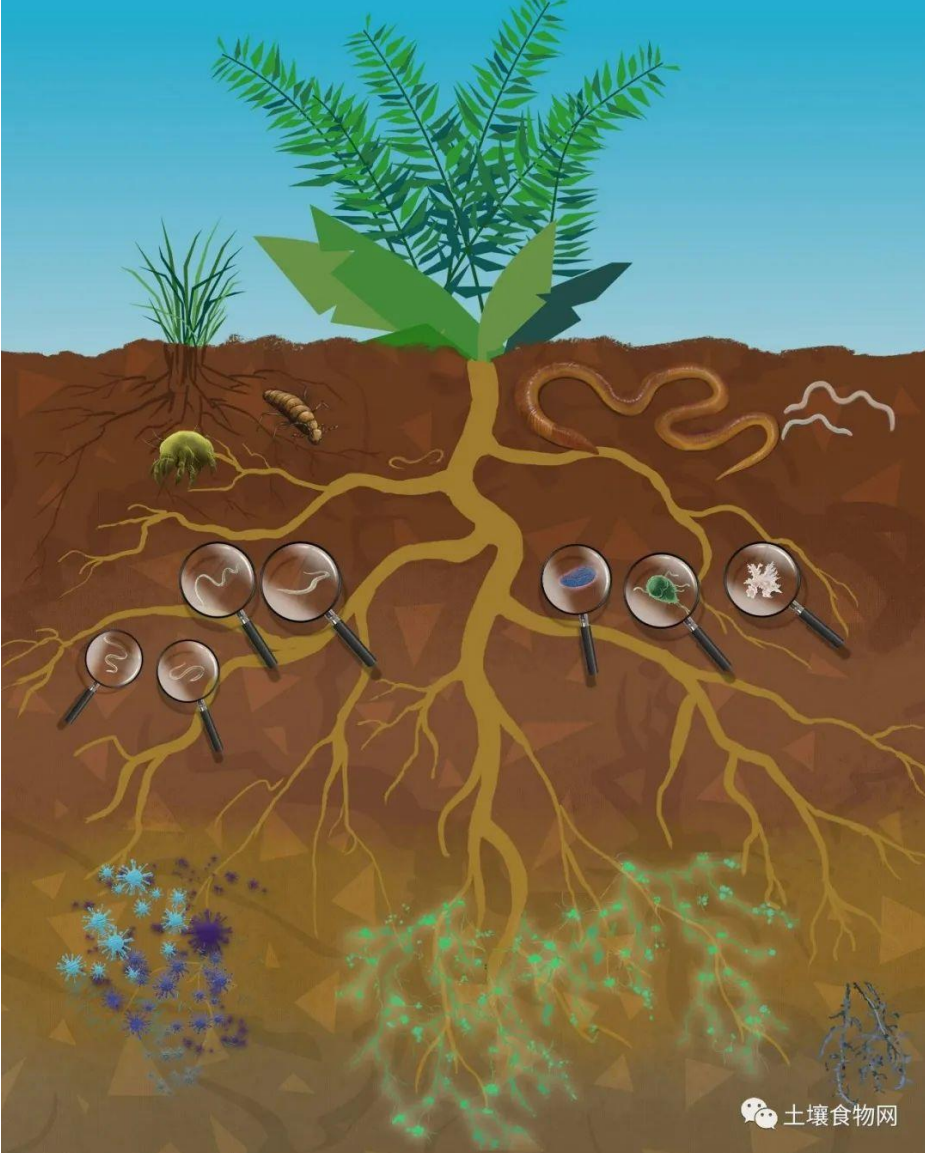
Xing, Wen, Ning Hu, Zhongfang Li, Liangshan Feng, Weidong Zhang, Gerhard Du Preez, Huimin Zhang, et al.  
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# Background

## 1) Soil decomposer micro-food web



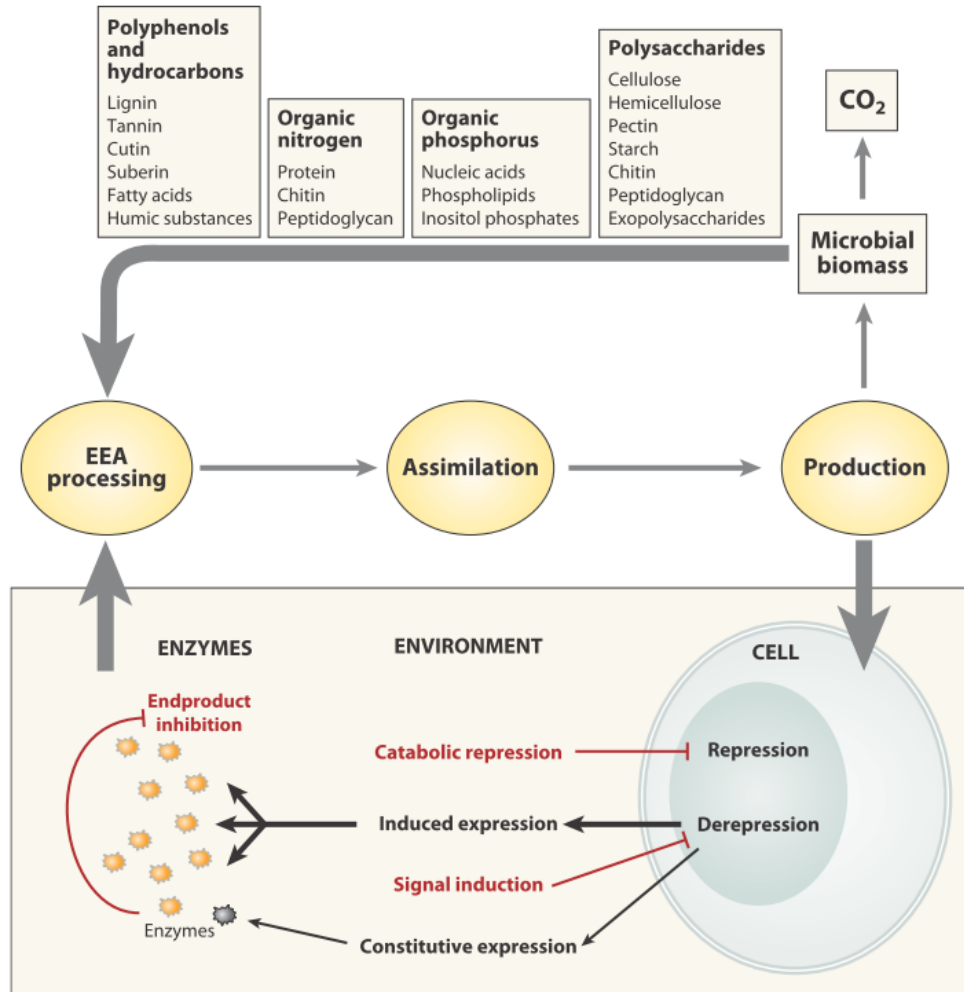
*Wardle et al., 1998*

- The soil decomposer micro-food web consisting of “microorganisms-**protozoa-nematodes**”, plays key roles in underpinning ecosystem functions and in delivering ecosystem services.



# Background

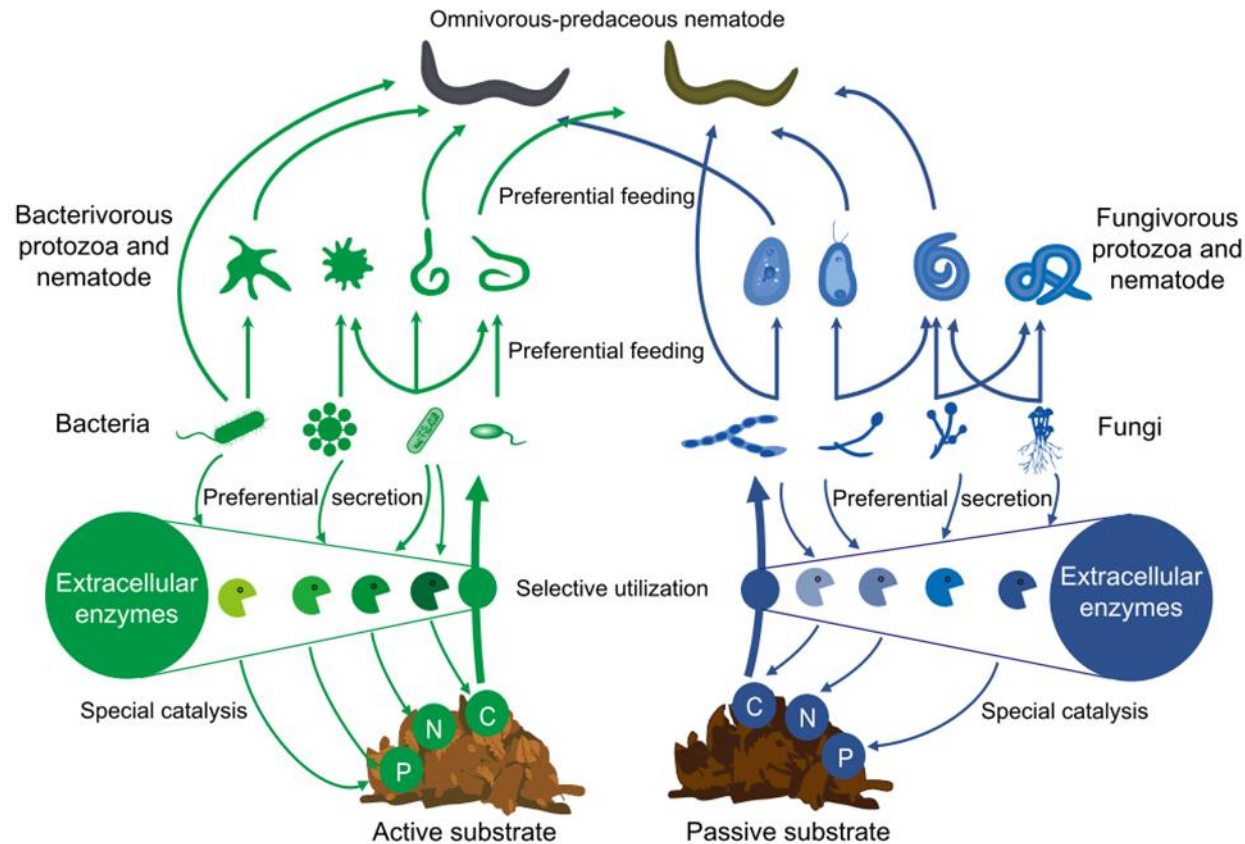
## 2) Relationships between soil exoenzyme and decomposer micro-food web



- **Exoenzymes** catalyze the rate limiting steps of decomposition and mediate energy flow in soil micro-food webs.



# Background



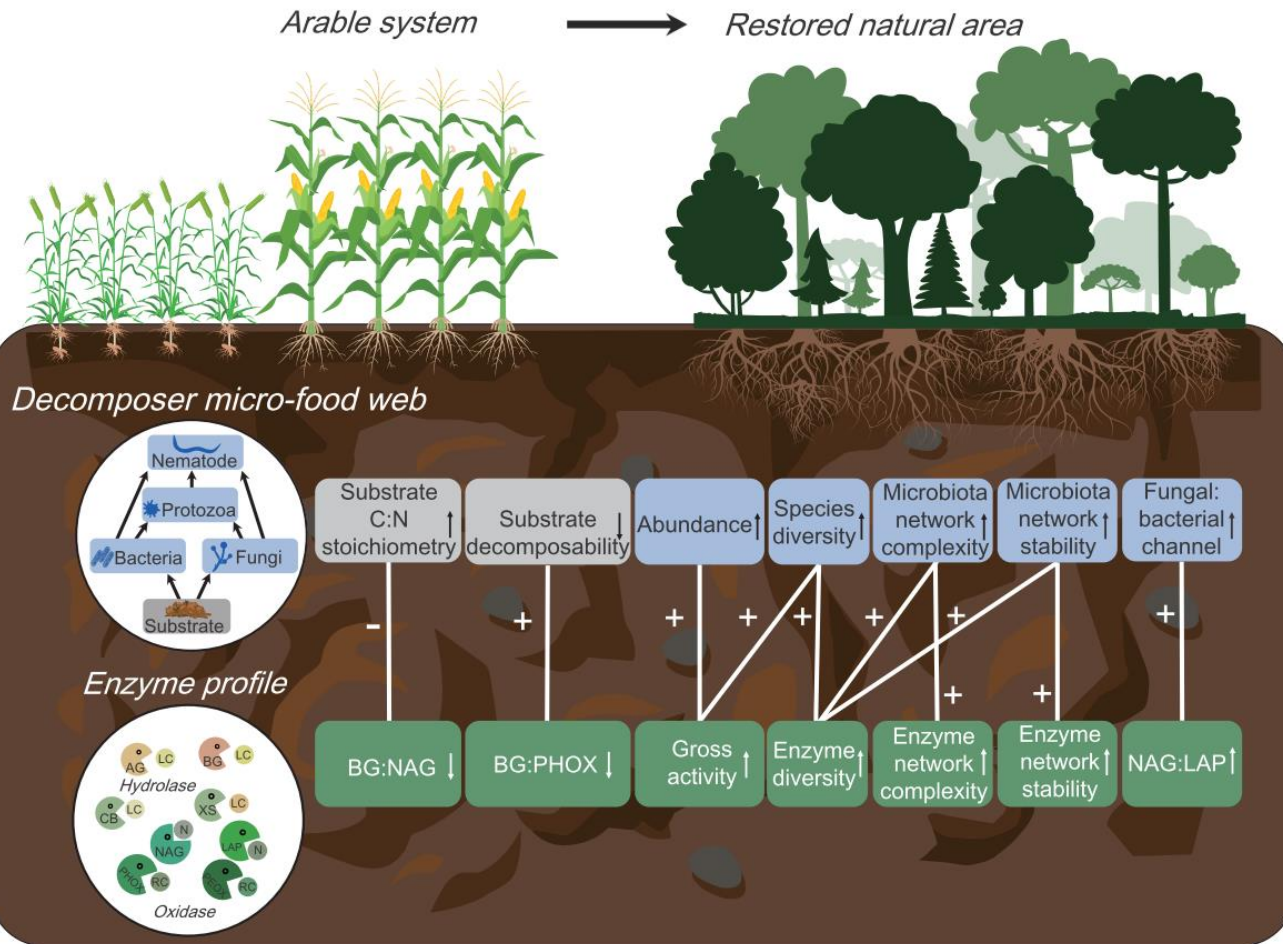
- Catalytic reactions of exoenzymes are **substrate-specific**.
- The exoenzyme production of **microorganisms** is identity-specific.
- Further, the exoenzyme production pattern may be modified by the species composition of **microfauna**.

**Classic structure of soil decomposer micro-food web  
and its conceptual links to exoenzyme profile**



# Background

## 3) The aim of our study



- However, ecological indices that provide comprehensive information on decomposer micro-food web are lacking.
- In this study, we assessed the application of **soil exoenzyme profile analysis** by using a case study based on the conversion of an arable system to a natural area.
- This methodology is expected to be **an integrated measure of decomposer micro-food web features**.



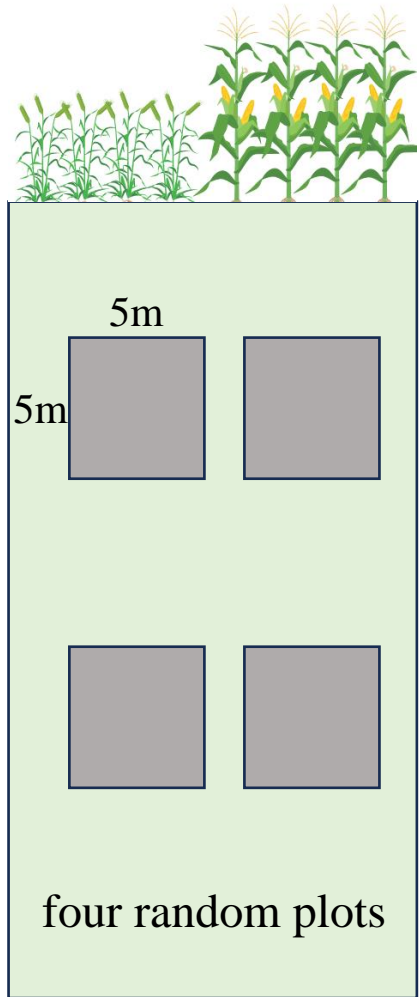
# Background

## The proposed soil exoenzyme profile indices for indicating the decomposer micro-food web features

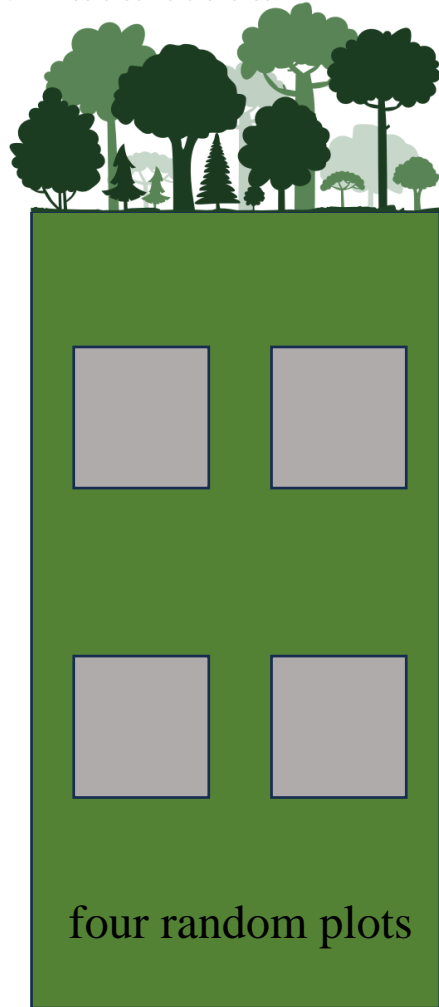
Exoenzyme profile index	Calculation	Implications for decomposer micro-food web features
Stoichiometry index	Ratios of activities of exoenzymes acquiring elements	Linked to substrate stoichiometry and element constraint
Carbon decomposability index	The ratio of carbon hydrolase activity to oxidase activity	Indicating carbon bioavailability of substrate
Channel index	The ratio of fungal- to bacterial-derived exoenzyme activities	Reflecting the dominance of fungal- versus bacterial-based decomposition channel
Exoenzyme composition	The first principal coordination score (PCo1) calculated by the Bray–Curtis dissimilarity matrix	Associated with the taxa composition of microbiota in micro-food web
Gross activity	The average of standardized exoenzyme activity	Greater gross exoenzyme activity indicates greater substrate quantity, community size, diversity, and network complexity
Diversity	Alpha diversity, incorporating species richness and evenness (Shannon Index and Pielou Evenness Index) for a specifically selected exoenzyme profile	Higher diversity of exoenzyme profile indicates more diverse microbiota community
Network complexity	Complexity parameters (such as average degree, average clustering coefficient etc.) derived from co-occurring network analysis	The exoenzyme profile with a greater network complexity corresponds to the more complex microbiota network
Network stability	Stability parameters (such as robustness and vulnerability) derived from co-occurring network analysis	The exoenzyme profile with a higher network stability corresponds to the more stable microbiota network



# Methods



Arable system



Restored natural area

**Study site:** the National Soil Quality Observation Experimental Station at Qiyang (26° 45' N, 119° 52' E) in Hunan Province, China

**Soil sampling time:** June and September 2021

**Soil sampling depth:** 0-15cm

## ➤ Treatment

- **Arable system**
- **Restored natural area**



# Methods

- **Measurement**

- 1) Soil substrate: soil total organic carbon (TOC), total nitrogen (TN),  $\text{KMnO}_4$ -oxidized C ( $\text{C}_{\text{KMnO}_4}$ ), dissolved organic carbon (DOC), and dissolved nitrogen (DN) contents
- 2) Bacterial and fungal community analysis
- 3) Protozoan community analysis
- 4) Nematode community analysis
- 5) Exoenzyme activity

- **Exoenzyme profile indices**

- 1) Stoichiometry index
- 2) Carbon decomposability index
- 3) Channel index
- 4) Exoenzyme composition
- 5) Gross activity
- 6) Diversity
- 7) Network complexity
- 8) Network stability

- **Decomposer micro-food web features**

- 1) Stoichiometry and decomposability of substrates
- 2) Abundance, species diversity, composition, network complexity, and network stability of soil microbiota community
- 3) Decomposition channel ratio

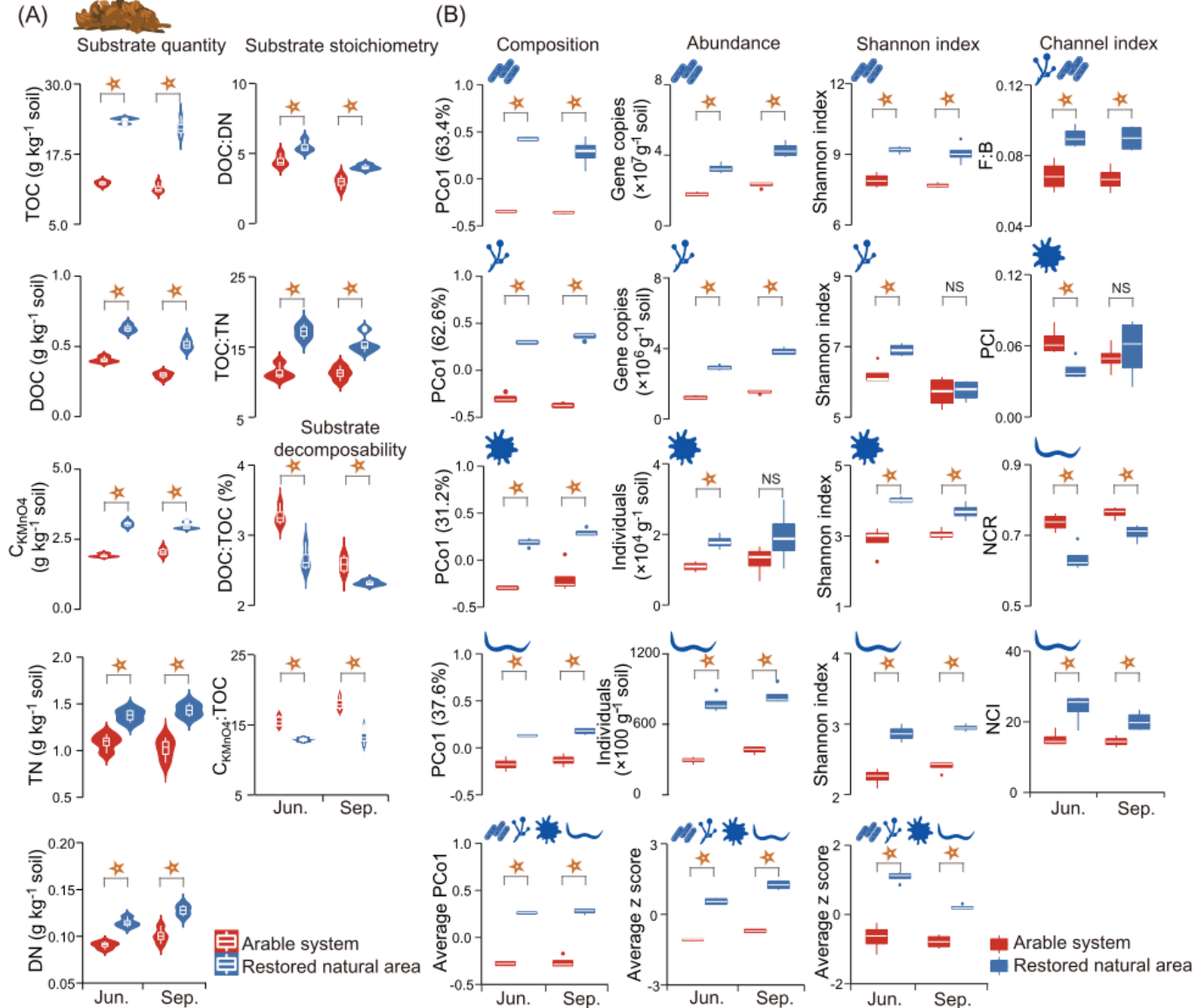


# Methods

## Substrate

## Microbiota

### 1) Decomposer micro-food web features



→ The **substrate** quantity, stoichiometry and decomposability, the composition, abundance, diversity of **microbiota** community, and the **decomposition channel ratio** showed significant changes after the arable system converted to a natural system.

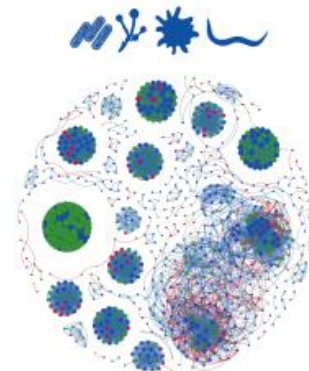
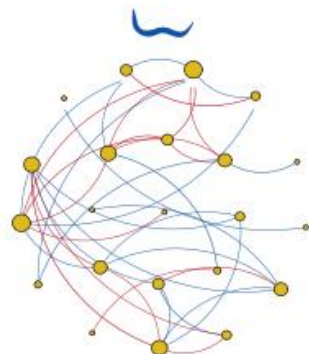
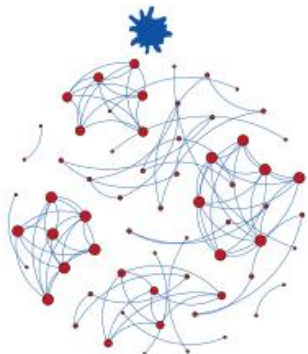
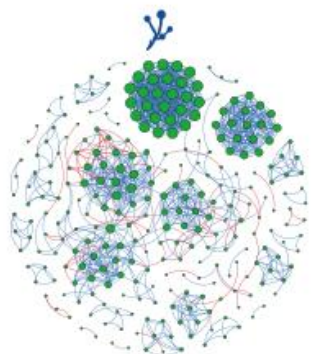
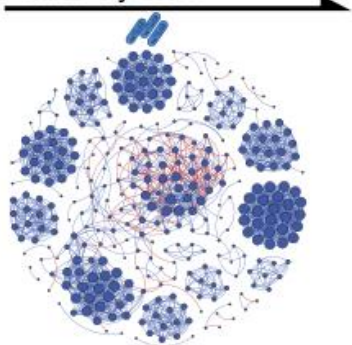


# Results and discussion

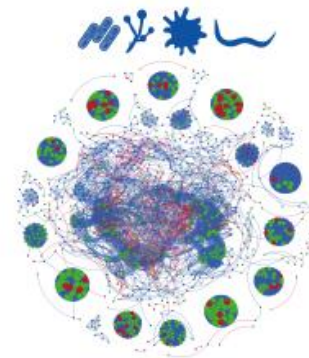
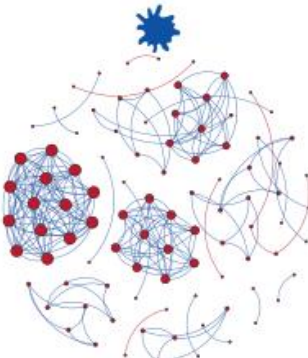
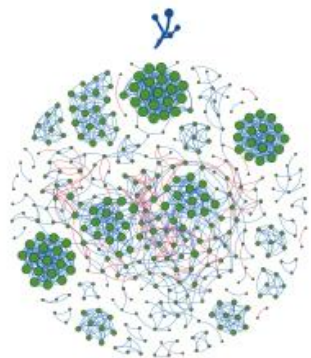
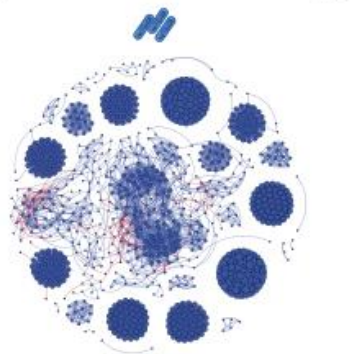
## The network of microbiota

(C)

Arable system →



Restored natural area →



Bacteria

Fungi

Protozoa

Nematode



# Results and discussion

## Network complexity and stability of microbiota

Network indices	Bacteria		Fungi		Protozoa		Nematode		Whole microbiota community	
	Arable system	Restored natural area	Arable system	Restored natural area	Arable system	Restored natural area	Arable system	Restored natural area	Arable system	Restored natural area
<i>Complexity indices</i>										
avgK	<b>6.85(3.34)</b>	<b>20.09(12.20)</b>	4.80(3.26)	5.08(2.23)	2.58(1.17)	3.41(2.68)	<b>1.80(0.61)</b>	<b>2.39(0.31)</b>	<b>11.93(7.22)</b>	<b>20.47(7.09)</b>
avgCC	<b>0.70(0.10)</b>	<b>0.89(0.10)</b>	0.65(0.16)	0.70(0.11)	1(0)	1(0)	0.28(0.31)	0.33(0.09)	0.86(0.08)	0.92(0.06)
GD	3.84(0.88)	4.66(2.42)	<b>3.88(0.66)</b>	<b>5.14(0.48)</b>	1(0)	1(0)	<b>2.05(0.59)</b>	<b>2.74(0.60)</b>	<b>3.76(0.24)</b>	<b>5.60(1.32)</b>
Con	0.05(0.01)	0.08(0.08)	0.03(0.01)	0.03(0.01)	0.29(0.29)	0.11(0.07)	0.12(0.03)	0.11(0.01)	0.03(0.01)	0.03(0.01)
<i>Stability indices</i>										
Robustness	0.28(0.01)	0.44(0.01)	<b>0.28(0.05)</b>	<b>0.30(0.01)</b>	<b>0.33(0.14)</b>	<b>0.35(0.04)</b>	<b>0.13(0.05)</b>	<b>0.19(0.02)</b>	0.31(0.03)	0.37(0.03)
Vulnerability	0.06(0.05)	0.02(0.01)	<b>0.06(0.03)</b>	<b>0.07(0.04)</b>	<b>0.08(0.07)</b>	<b>0.07(0.04)</b>	Na	Na	0.03(0.01)	0.01(0.01)

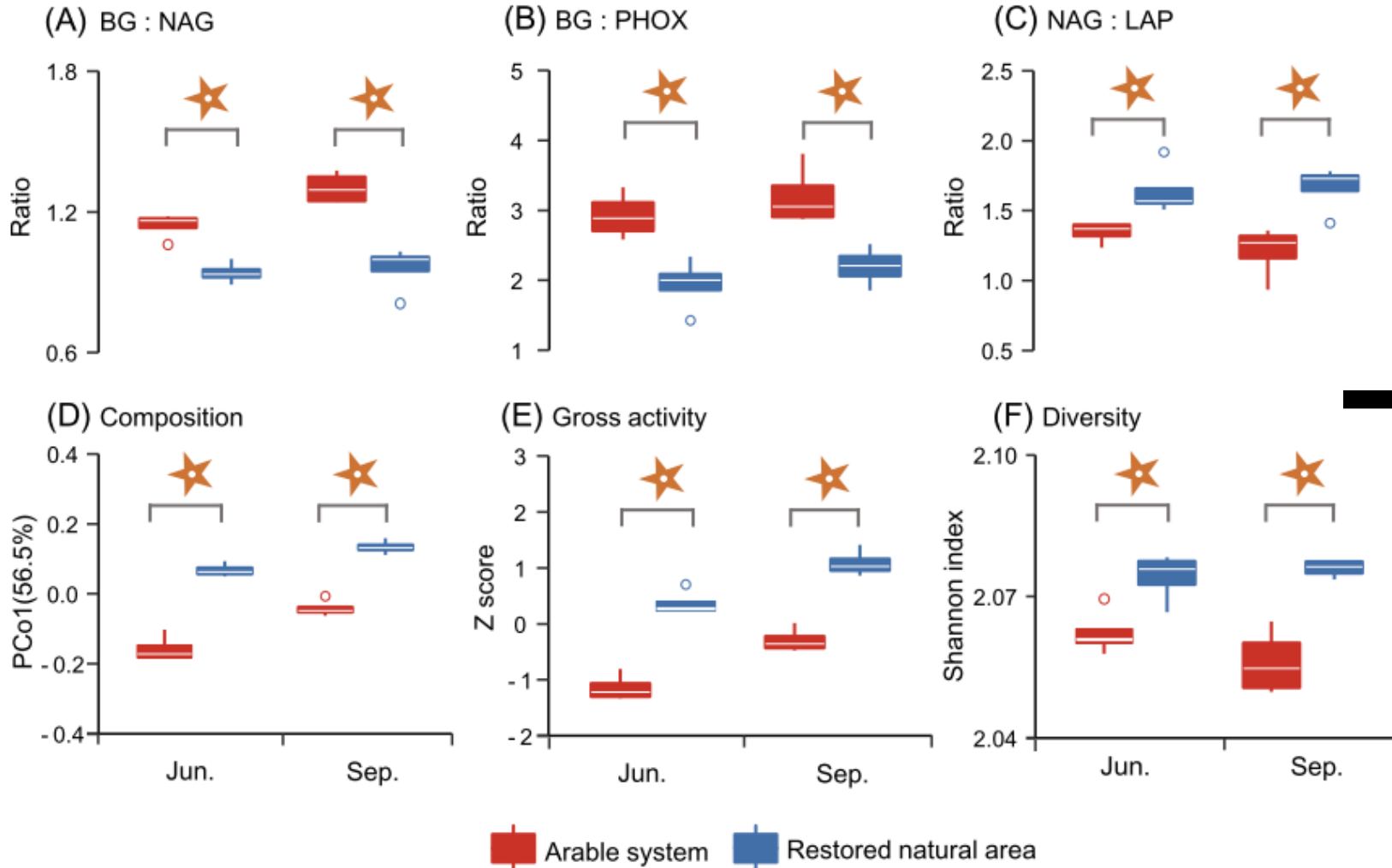
Parameter	Bacteria		Fungi		Protozoa		Nematode		Whole microbiota community	
	Arable system	Restored natural area	Arable system	Restored natural area	Arable system	Restored natural area	Arable system	Restored natural area	Arable system	Restored natural area
Positive link	<b>2673(2096)</b>	<b>9136(3087)</b>	2515(2133)	5458(4085)	<b>2673(2096)</b>	<b>9136(3087)</b>	<b>6.75(4.23)</b>	<b>13.88(1.96)</b>	<b>13362(10299)</b>	<b>34651(18535)</b>
Negative link	1345(815)	1181(411)	<b>916(398)</b>	<b>2114(718)</b>	<b>0(0)</b>	<b>8(4)</b>	<b>7.50(2.07)</b>	<b>13.50(2.67)</b>	<b>5409(2492)</b>	<b>8983(2582)</b>
Keystone taxa	0.63(0.92)	2.88(4.94)	2.75(3.01)	0.88(2.10)	0(0)	0(0)	0(0)	0.38(0.52)	6.75(10.59)	13.88(9.99)
Module	18.75(3.58)	18.50(2.20)	<b>21.88(2.80)</b>	<b>27.13(3.36)</b>	<b>4.88(2.23)</b>	<b>10.50(2.33)</b>	<b>3.38(0.92)</b>	<b>4.38(0.52)</b>	46.13(5.03)	48.88(5.28)

- The network complexity and stability, numbers of both positive and negative links, the numbers of keystone taxa and modules showed significant increase trends after the arable system converted to a natural system.



# Results and discussion

## 2) Exoenzyme profile indices



The exoenzymatic stoichiometry and decomposability indices, decomposition channel index, composition, gross activity, and diversity indices all showed significant changes after the arable system converted to a natural system.



# Results and discussion

## Network complexity and stability of exoenzyme

Network indices	Arable system	Restored natural area
<i>Complexity indices</i>		
avgK	<b>1.57(0.26)</b>	<b>2.53(0.62)</b>
avgCC	<b>0.30(0.19)</b>	<b>0.78(0.09)</b>
GD	1.81(0.17)	1.23(0.09)
Con	<b>0.27(0.05)</b>	<b>0.37(0.07)</b>
Modularity	0.26(0.09)	0.04(0.02)
<i>Stability indices</i>		
Robustness	<b>0.28(0.01)</b>	<b>0.44(0.01)</b>
Vulnerability	Na	Na

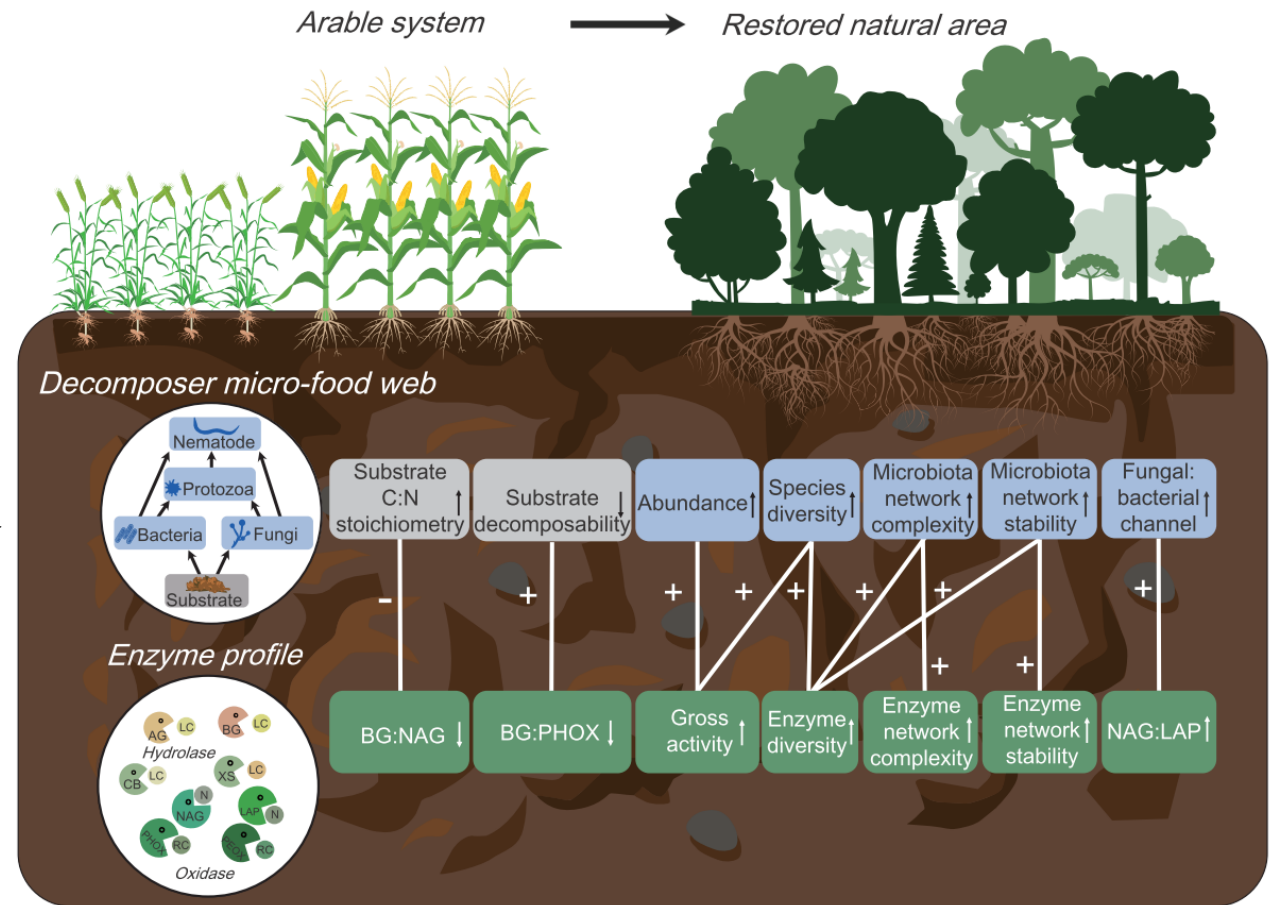
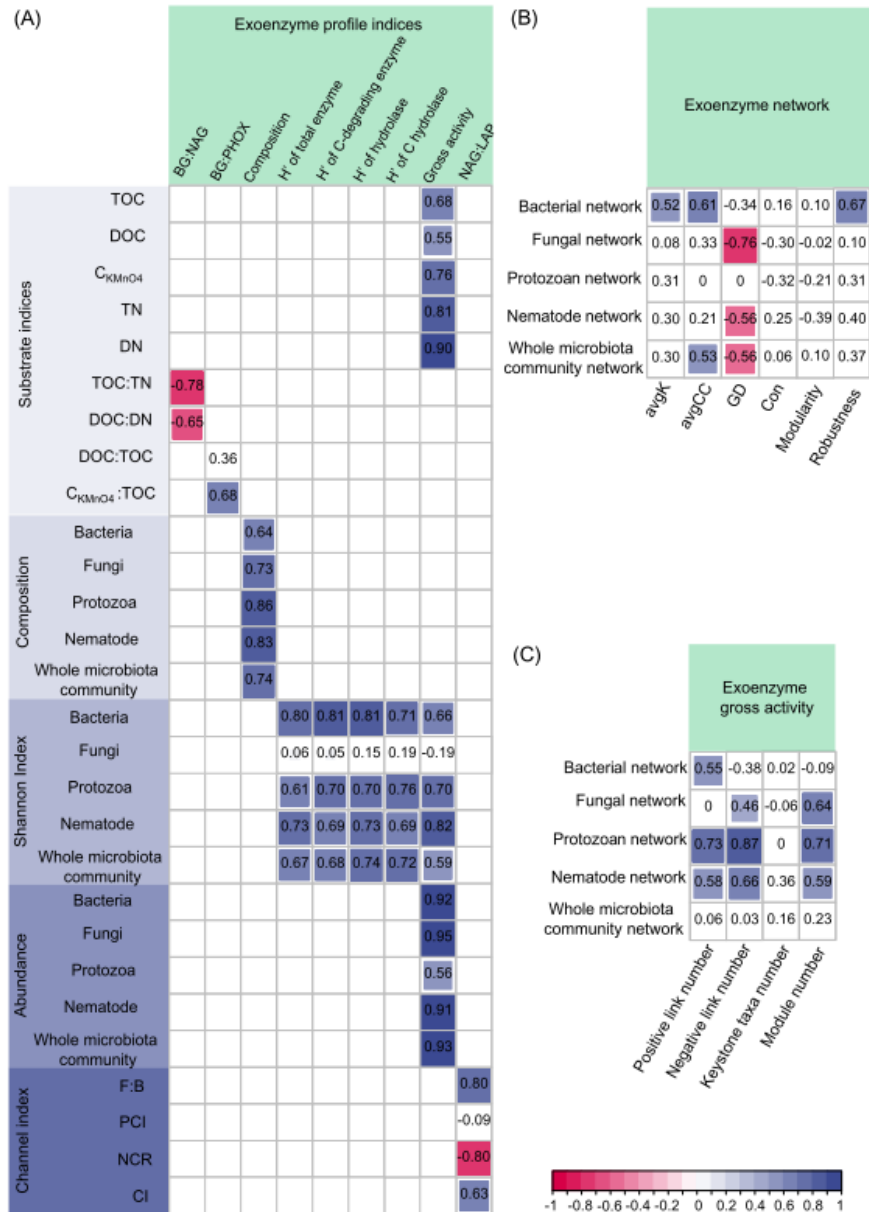


The network complexity and stability of exoenzyme also showed significant increase after the arable system converted to a natural system.



# Results and discussion

## 3) Relationships between exoenzyme profile indices and decomposer micro-food web features



The “soil enzyme profile analysis” can effectively indicate the key features of substrate and multi-trophic levels of microbiota in soil micro-food web.



# Summary

- In this case study on the restored natural area of an arable system, we found close associations between the proposed soil enzyme profile indices and the corresponding parameters of the decomposer micro-food web.
- Our data indicated that “soil enzyme profile analysis” can be a useful tool to comprehensively reflect decomposer micro-food web features.

Xing, Wen, Ning Hu, Zhongfang Li, Liangshan Feng, Weidong Zhang, Gerhard Du Preez, Huimin Zhang, et al. 2023.  
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