Assessing the Role of Straw Checkerboard Barriers and Plants in Soil Health and Microbial Activity

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Research Article

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Abstract

[Aims] As a new type of sand barrier, the construction efficiency and service life of brush straw checkerboard barrier are better than traditional artificial straw checkerboard barrier, the aim of this work were to understand the effect of its combination with plants on soil function recovery.

[Methods] This study was conducted in the southeastern edge of the Tengger Desert, Zhongwei, Ningxia. Seven different sand barrier and plant combinations were selected as experimental subjects, with bare sandy land serving as the control group. The investigation included assessments of soil physical and chemical properties and microbial characteristics.

[Results] Results showed the beneficial effect of installing straw checkerboard barriers on enhancing soil moisture levels, with planted variants having lower water content compared to unplanted counterparts. Obviously, *Artemisia desertorum*, *Caragana korshinskii*, *Corethrodendron scoparium*, and *Calligonum mongolicum* showed a pronounced dependence on soil moisture within the 0 ~ 10 cm soil layer. Improvements in soil organic matter, total nitrogen, and electrical conductivity were observed following the implementation of sand control measures, with the combined application of artificial straw checkerboard barriers and *Calligonum mongolicum* providing optimal results. Furthermore, the *Artemisia desertorum* mode promoted increased soil bacterial abundance, while the brush straw checkerboard barrier along with *Corethrodendron scoparium* contributed to increased soil fungal populations.

[Conclusion] Different combinations of straw checkerboard barrier and plant can promote different soil physical and chemical properties and microbial characteristics. These findings can provide relevant scientific evidence and references for selecting sand control measures.

Introduction

Plant-based sand fixation serves as a critical strategy to mitigate the threat of desertification in oases by reducing the intensity of wind-sand interactions while acting on complex biogeochemical cycles. By strategically allocating trees, shrubs, and grasses, sand fixation efforts not only mitigate the risk of desertification in oases, but also improve soil water retention, alleviate heat stress in transition zones, and influence landscape patterns and vegetation succession trends (Deng et al., 2022). Establishing a rational sand-fixing system of trees, shrubs, and grasses represents a critical approach to effectively contain desert encroachment and maintain ecological stability (Zhao et al., 2022). Moreover, the diversification of sand-fixing plant modes can strengthen biodiversity in transition zones, while their organic litter and root exudates enrich soil nutrients, promoting a conducive matrix for microbial growth and metabolism (Xie et al., 2013; Meglioli et al., 2017). Nevertheless, the demanding ecological conditions prevailing in sandy environments result in low vegetation survival rates, which is exacerbated by protracted plant growth cycles, which represents an obstacle to expeditious sand fixation (Jiang et al., 2008).

Sand barriers serve as a primary mechanical strategy to combat desertification and play a dual role in impeding wind-driven sand movements and stabilizing sand surfaces (Wu et al., 2003). In addition, they contribute to reducing evaporation and improving soil moisture content (Wang et al., 2017), thus serving as a fundamental element in vegetative desertification control (Sun et al., 2000). The straw checkerboard barrier is proving to be a ubiquitous feature among sand barrier constructions in ecological environments and is widely used in habitat restoration in arid and semi-arid regions around the world (Xu et al., 2018; Dehkordi et al., 2022). These barriers promote an increase in the fine particle and clay content of the soil, facilitating the transition of soil texture from coarse to fine, thereby promoting a microenvironment conducive to successful vegetation establishment and ecological restoration in arid and semi-arid regions (Wang and Wang, 2019). Nevertheless, harsh environmental conditions prevail in desert regions, characterized by high daytime temperatures, significant temperature fluctuations throughout the day and intense sandstorms. Traditional straw checkerboard barriers typically deteriorate under such conditions and lose their sand-fixing effect within 1 to 2 years (Tang, 2013). Furthermore, in recent years, there has been a shortage of raw materials for traditional straw checkerboards due to the impact of mechanical harvesting practices (Li et al., 2020). In contrast, brush straw checkerboards, a newly developed sand barrier variant, offer numerous advantages over traditional counterparts: they are machine-made, resulting in a 60% increase in operational efficiency compared to manually woven straw checkerboards. The brush net ropes produced by brush straw checkerboard machines are sturdy and durable, extending their service life to 6 years (Qu et al., 2019).

The effectiveness of any single measure to combat desertification remains invariably limited, requiring a multifaceted approach to achieve optimal results. Hu et al. (2017) applied a comprehensive management strategy integrating straw checkerboard barriers with tree, shrub, and grasses, resulting in a gradual increase in natural vegetation height and density over subsequent years, as well as a rapid increase in total phosphorus, total nitrogen, and organic matter of the soil within a compressed time frame. Similarly, Du et al. (2017) introduced a comprehensive management system that included mechanical checkerboard sand barriers associated with trees, shrubs, and grasses, resulting in increased average vegetation size, increased coverage, increased species richness, and increased levels of soil organic carbon, total phosphorus, available phosphorus, and hydrolyzable nitrogen. In contrast, Yan et al. (2013) observed increased concentrations of organic matter, available nitrogen, and available phosphorus in artificial biological crusts shielded by 0.5 m × 0.5 m sand barriers compared to their 1.0 m × 1.0 m ones counterparts. Liu et al. (2016) advocated the inclusion of shrubs in addition to fencing and grass reseeding for medium (coverage of 25–40%) and heavy (coverage of 10 to 25%) sandy areas, with sand barriers essential for extreme sandy areas (coverage less than 10%) .

However, there is still a lack of research results that elucidate the synergistic effects of brush straw checkerboard barriers in interaction with vegetation, especially in different soil habitats. Such studies are of great importance for the selection and application of sand barriers and sand-fixing plant species in initiatives to combat desertification. Further exploration of the evolutionary dynamics of soils and microbial communities following the deployment of brush straw checkerboard barriers is imperative and provides invaluable scientific foundations and theoretical frameworks for optimizing the sand-fixing effectiveness of brush straw checkerboard barriers.

Materials and methods

Study area

The field experiment was conducted in the national nature reserve on the southeastern edge of the Tengger Desert in Zhongwei City, Ningxia Hui Autonomous Region, China (37.43° ~ 37.62°N, 104.82° ~ 105.16°E). The climate in this region is characterized by a temperate continental climate, which has dry conditions with low rainfall, high evaporation, significant diurnal temperature fluctuations, frequent sandstorms, and frequent weather disasters. The annual average temperature is 9.2 ℃, with an annual rainfall of 184.1 mm, mostly concentrated in the months of July to September. Evaporation is between 2300 and 2500 mm per year. The average annual wind speed is 2.9 $m \cdot s^{-1}$, with prevailing winds coming from the northwest. The maximum wind speeds occur in summer while they are minimal in winter (Li et al., 2014).

Experimental design

To eliminate the influence of background conditions, the selected plots had to meet some standards: (1) similar topography, (2) the same soil type and climatic region, (3) identical sampling method and procedures during these plots, and (4) equal plantation care management. In the experiment, two types of straw checkerboard barrier sample areas were selected, a brush straw checkerboard barrier sample area with a sand fixation period of 2 years and an artificial straw checkerboard barrier sample area with a sand fixation period of 2 years, and several main plant types were selected in each sample area. In each sampling area, three 5 m × 5 m squares were created as replicates according to each “sand barrier + plant” mode, and three replicates were randomly selected as blank controls in bare sand. The information about each test mode is listed in Table 1, there are 8 types in total.

Table 1
Basic information of different modes

Plot	Type of sand barrier	Vegetation condition	Coordinate
A	Brush straw checkerboard barrier	*Artemisia desertorum*	N 37°30', E 105°03"
B		*Corethrodendron scoparium*	
C		Unplanted	
D	Artificial straw checkerboard barrier	*Artemisia desertorum*	N 37°30', E 105°02'
E		*Caragana korshinskii*	
F		*Calligonum mongolicum*	
G		Unplanted	
H	No sand barrier	Unplanted	N 37°30', E 105°02'

Soil sampling

The sampling was carried out at the end of April 2023. A total of 48 aluminum boxes, 48 ring knives, and 48 self-sealing bags were collected for determining the physical and chemical properties of soil from eight different mode types on the southeastern edge of the Tengger Desert. In each sampling plot, fresh undisturbed soil samples were collected from each soil layer (0 ~ 10 cm and 10 ~ 20 cm). Aluminum boxes were used to measure soil moisture and ring knives (diameter 5 cm, height 5 cm) were used to determine soil bulk density. In addition, soil samples were collected using a five-point sampling method, mixed thoroughly, and stored in self-sealing bags as replicates for subsequent analyzes of soil organic matter, total nitrogen, pH, and electrical conductivity.

Simultaneously, within each sampling plot, soil samples were collected from the 0 ~ 10 cm soil layer using a five-point sampling method, mixed thoroughly, and stored as replicates in sterile bags. The soil samples were transported to the laboratory in foam boxes with dry ice. After soil samples were cleaned of debris, they were sieved through a 1 mm mesh sieve and stored in a -80 °C ultra-low freezer for further processing.

Soil measurements

Soil moisture was determined by the oven drying method, soil bulk density was measured by ring knife method, soil organic matter was analyzed according to national standard GB7857-87 combined with heat method, soil total nitrogen was determined by Kjeldahl method, soil pH was determined using the pH shaking distilled water method, and soil electrical conductivity was measured using the distilled water shaking and conductivity meter method. The methods used were based on “Soil Agrochemical Analysis” (Bao et al., 2000).

Soil bacterial and fungal DNA was extracted using the OMEGA Soil DNA Kit (M5635-02) (Omega Bio-Tek, Norcross, GA, USA) according to the manufacturer's instructions and stored at -20°C for further use. The quantity and quality of extracted DNA were assessed using a Nanodrop NC2000 spectrophotometer (Thermo Fisher Scientific, Waltham, MA, USA) and agarose gel electrophoresis, respectively. PCR amplification of the bacterial 16S rRNA gene V3-V4 region was performed using forward primer 338F (5' -ACTCCTACGGGAGGCAGCA- 3') and reverse primer 806R (5' -GGACTACHVGGGTWTCTAAT- 3'). For the fungal ITS rRNA gene V1 region, PCR amplification was performed using the forward primer ITS5 F (5' -GGAAGTAAAAGTCGTAACAAGG- 3') and the reverse primer ITS1R (5' -GCTGCGTTCTTCATCGATGC- 3'). The PCR reaction mixture contained 5× reaction buffer (5 μL), Fast pfu DNA polymerase (5U/μL) (0.25 μL), dNTPs (2.5 mM) (2 μL), forward primer (10 μM) (1 μL), reverse primer (10 μM) (1 μL), DNA template (1 μL), and ultrapure water (ddH2O) (14.75 μL). The thermal cycling conditions consisted of an initial denaturation at 98°C for 5 minutes, followed by 25 cycles of denaturation at 98°C for 30 seconds, annealing at 53°C for 30 seconds, extension at 72°C for 45 seconds, and a final extension at 72°C for 5 minutes. The PCR products were purified using Vazyme VAHTSTM DNA Clean Beads (Vazyme, Nanjing, China) and quantified using the Quant-iT PicoGreen dsDNA Assay Kit (Invitrogen, Carlsbad, CA, USA). After individual quantification, equal amounts of amplicons were pooled and subjected to paired-end sequencing (2 × 250 bp) using the Illumina NovaSeq platform with the NovaSeq 6000 SP Reagent Kit (500 cycles) at Shanghai Personal Biotechnology Co., Ltd (Shanghai, China).*Data analysis*

We performed bioinformatics analysis of the microbial community using QIIME2 2019.4 and followed the official tutorial (https://docs.qiime2.org/2019.4/tutorials/). Briefly, the raw sequence data were demultiplexed using the demux plugin and then trimmed to primer sequences using the cutadapt plugin with minor modifications. The DADA2 plugin was then used for quality filtering, denoising, merging, and chimera removal. Non-singleton amplicon sequence variants (ASVs) were aligned using mafft and a phylogenetic tree was constructed using fasttree2. Alpha diversity indices (Chao1, Shannon, Simpson, Coverage) were estimated using the diversity plugin. ASVs were classified using the naive Bayes classifier plugin “classification-sklearn” with SILVA Release 132 (bacteria) / UNITE Release 8.0 (fungi) databases.

The soil physical and chemical properties data were visualized by radial bar graphs created using R 4.0.3 for comparative analysis. Principal component analysis (PCA) and weight calculation were then performed.

ASV-level alpha diversity indices were calculated using the ASV table in QIIME2, including Chao1, Shannon, Simpson, and Coverage indices. Venn diagrams were created using the R package “VennDiagram” to visualize common and unique ASVs between different groups based on ASV occurrence regardless of their relative abundance. Taxonomic composition and abundance were visualized using MEGAN and GraPhlAn. Hierarchical clustering heatmaps were visualized using the R package “Pheatmap” based on clustering results for each taxonomic unit.

Results

Effects of different straw checkerboard barriers combined with plants on soil physical and chemical properties

Figure 1 showed the soil physical and chemical properties at depths of 0 ~ 10 cm and 10 ~ 20 cm under different treatments. It was obvious that soil moisture content was highest in the 0 ~ 10 cm layer under the brush straw checkerboard barrier without vegetation treatment (0.37 ± 0.04), while it was highest in the 10 ~ 20 cm layer under the artificial straw checkerboard barrier combined with *Calligonum mongolicum* treatment (2.24 ± 0.40). The moisture content of the soil in the 10 ~ 20 cm layer exceeded that in the 0 ~ 10 cm layer and reaches up to 14.20 times.

In the 0 ~ 10 cm layer, the brush straw checkerboard barrier combined with *Artemisia desertorum* treatment had the highest organic matter content (2.76 ± 0.16), while in the 10 ~ 20 cm layer below the artificial straw checkerboard barrier combined with *Calligonum mongolicum* treatment was highest (2.11 ± 0.24). In the 0 ~ 20 cm layer, the combined treatment of artificial straw checkerboard barrier and *Calligonum mongolicum* had the highest total nitrogen content (0.13 ± 0.02 and 0.12 ± 0.00, respectively).

The electrical conductivity was highest in the 0 ~ 10 cm layer under the combined treatment of artificial straw checkerboard barrier and *Calligonum mongolicum* (42.50 ± 9.68), while in the 10 ~ 20 cm layer under the brush straw checkerboard barrier combined with *Artemisia desertorum* treatment was highest (21.92 ± 3.80). The electrical conductivity of the soil was consistently higher in the 0 ~ 10 cm layer than in the 10 ~ 20 cm layer, with a maximum ratio of 2.35 times higher.

Principal component analysis (PCA) was performed based on the physical and chemical properties of the soil. In the 0 ~ 10 cm soil layer, the cumulative variance explained by two principal components reached 57.66%, and there were differences between vegetated and unvegetated patterns (Fig. 3a). Similarly, in the 10 ~ 20 cm soil layer, the cumulative variance explained by two principal components was 63.64%, and variations existed between different straw checkerboard barrier areas (Fig. 3b).

The weights of soil physical and chemical properties were determined using principal component analysis(Fig. 3c and d). In the 0 ~ 10 cm soil layer, moisture content had the highest weight (20.86%), while organic matter had the lowest weight (11.61%). Conversely, in the 10 ~ 20 cm soil layer, organic matter had the highest weight (17.62%), while electric conductivity had the lowest weights (15.28%).

Effects of different straw checkerboard barriers combined with plants on soil bacterial and fungal diversity

Table 2 showed the indices of soil bacterial diversity under different treatments. The Chao1 index of bacteria index was highest in the combined mode of brush straw checkerboard barrier and *Artemisia desertorum*, while it was lowest in the bare sand treatment, in comparison, an increase of 96.98% was observed. Similarly, the Shannon index of bacteria peaked in the combined mode of artificial straw checkerboard barrier and *Artemisia desertorum*, with the lowest Shannon index observed in the bare sand treatment, in comparison, an increase of 8.44% was observed. The differences in the Simpson index between the different modes were in the a range of 0.7%, and the Coverage index exceed 98% in all treatments.

Table 2
Soil bacterial diversity index of different modes

Mode	Chao1	Shannon	Simpson	Coverage
A	3890.53 ± 289.17	9.58 ± 0.53	0.9881 ± 0.0071	0.9821 ± 0.0010
B	3529.29 ± 266.23	9.79 ± 0.13	0.9947 ± 0.0001	0.9859 ± 0.0009
C	2597.15 ± 292.77	9.45 ± 0.04	0.9948 ± 0.0010	0.9908 ± 0.0037
D	3156.13 ± 406.64	9.84 ± 0.13	0.9966 ± 0.0002	0.9877 ± 0.0025
E	3543.95 ± 119.51	9.82 ± 0.07	0.9943 ± 0.0024	0.9858 ± 0.0010
F	3073.08 ± 36.85	9.80 ± 0.13	0.9955 ± 0.0009	0.9895 ± 0.0007
G	2476.46 ± 182.20	9.51 ± 0.04	0.9959 ± 0.0002	0.9916 ± 0.0026
H	1975.14 ± 128.57	9.07 ± 0.10	0.9947 ± 0.0007	0.9944 ± 0.0024

Table 3 compared the soil fungal diversity index under different modes. It can be seen that the Chao1 index, the Shannon index and the Simpson index of the fungi were the highest in the combination mode of brush straw checkerboard barrier and *Corethrodendron scoparium*, and the Chao1 index, the Shannon index, and the Simpson index of fungi were the lowest in bare sandy land, the improvements were 7.30 times, 3.84 times, and 1.74 times, respectively. The Coverage index of fungi was over 99%.

Table 3
Soil fungal diversity index of different modes

Mode	Chao1	Shannon	Simpson	Coverage
A	149.17 ± 27.39	3.63 ± 0.19	0.7677 ± 0.0051	0.9999 ± 0.0000
B	196.29 ± 31.77	4.68 ± 0.01	0.9092 ± 0.0001	0.9998 ± 0.0001
C	153.03 ± 38.83	3.71 ± 0.16	0.8293 ± 0.0179	0.9998 ± 0.0000
D	140.32 ± 59.82	4.09 ± 0.41	0.8671 ± 0.0121	0.9999 ± 0.0000
E	170.13 ± 39.75	3.91 ± 0.43	0.8561 ± 0.0299	0.9999 ± 0.0000
F	112.56 ± 12.83	4.04 ± 0.73	0.8139 ± 0.0932	0.9999 ± 0.0000
G	92.06 ± 44.46	3.22 ± 0.54	0.7899 ± 0.0498	0.9999 ± 0.0000
H	26.90 ± 7.87	1.22 ± 0.11	0.5218 ± 0.0375	0.9999 ± 0.0000

Effects of different straw checkerboard barriers combined with plants on soil bacterial and fungal species composition

The relative abundances of soil bacterial and fungal communities across treatments were analyzed at the phylum level (Fig. 3). In terms of bacterial classification, the top 10 bacterial phyla included *Actinobacteriota*, *Proteobacteria*, *Bacteroidota*, *Chloroflexi*, *Gemmatimonadota*, *Acidobacteriota*, *Firmicutes*, *Myxococcota*, *Armatimonadota*, *Deinococcota*, and others. Dominant bacterial phyla (with relative abundance > 1%) were *Actinobacteria*, *Proteobacteria*, *Bacteroidetes*, *Chloroflexi*, and *Gemmatimonadetes*, which together accounted for over 88% of the total abundance, with *Actinobacteria* having the highest relative abundance at 43–63%.

In fungal classification, the top 10 fungal phyla included *Ascomycota*, *Basidiomycota*, *Chytridiomycota*, *Mucoromycota*, *Calcarisporiellomycota*, *Olpidiomycota*, *Mortierellomycota*, *Aphelidiomycota*, *Rozellomycota*, and others. Dominant fungal phyla (with relative abundance > 1%) were *Ascomycota* and *Basidiomycota*, which accounted for over 66% of the total abundance, with *Ascomycota* having the highest relative abundance at 64–99%.

A comparative analysis with bare sandy land showed an increase in the proportion of *Proteobacteria* and *Bacteroidetes* within the soil bacteria after treatment, while the total proportion of *Basidiomycota* within the soil fungi showed an increase.

Differences in the abundance of amplicon sequence variants (ASVs) of soil bacterial and fungal were observed in different modes (Fig. 5). It was evident that 36 bacterial ASVs are present in the different modes, with the highest number of bacterial ASVs detected in bare sandy land (1455), and the lowest in sandy land bacteria ASVs (105) observed in combination mode with artificial straw checkerboard barrier and *Artemisia desertorum*. Regarding fungal ASVs, 2 variants were identified in the different modes. The combination mode of brush straw checkerboard barrier and *Corethrodendron scoparium* had the highest number of ASVs (21), while the modes without plant cover, both with brush straw checkerboard barrier and artificial straw checkerboard barrier, had the lowest number of ASVs (3).

The community heatmap and species composition differential analysis of soil bacteria and fungi at the genus level under different conditions were shown in Fig. 6. It was obvious that the species composition of soil bacteria and fungi in bare sandy land changed after treatment. Regarding the bacterial species composition at the genus level, *Geodermatophilus* and *Rubellimicrobium* were found to be as dominant species with increased abundance in brush straw checkerboard barrier environments, whereas their abundance was comparatively low in bare sandy land. Conversely, the abundance of *Cellulomonas* was significantly higher in environments with artificial straw checkerboard barriers, in contrast to its lower abundance in bare sandy land. Regarding the composition of fungal species at the genus level, *Pseudopeyronellaea* were found to be as the predominant species with a significant abundance. Furthermore, *Comoclathris* showed high abundance in environments with artificial straw checkerboard barriers, suggesting dominance under these conditions.

Discussion

The combined use of sand barriers and vegetation represents a mutually reinforcing approach to sand fixation. Based on the ecological technique of a straw checkerboard barrier in combination with native vegetation, there was an improvement in the physical properties and water retention capacity of sandy soil (Wang et al., 2012). Compared to bare sandy land, the installation of a straw checkerboard barrier resulted in increased soil moisture, indicating an obvious accumulation effect (Li et al., 2020). Obviously, moisture levels in the 0 ~ 10 cm soil layer were lower than in the 10 ~ 20 cm layer, and within the 0 ~ 10 cm layer, the presence of vegetation reduced moisture compared to areas without vegetation. This suggests that plants such as *Artemisia desertorum*, *Corethrodendron scoparium*, *Caragana korshinskii*, and *Calligonum mongolicum* rely primarily on and utilize moisture in the 0 ~ 10 cm soil layer before deeper soil moisture becomes available (Lv et al., 2017). Furthermore, soil organic matter, total nitrogen, and electrical conductivity increased overall in sandy soils after sand-fixing measures, which is consistent with the results of previous studies by Shi et al. (2021), Gao et al. (2006), and Chang et al. (2018). Overall, the combined mode of artificial straw checkerboard barrier with *Calligonum mongolicum* showed the highest improvements in soil organic matter, total nitrogen, and electrical conductivity. As artificial straw checkerboard barriers usually decompose within 1 to 2 years, this decomposition enriched the nutrient content in sandy soils, while *Calligonum mongolicum* effectively contributed to ecological restoration (Guo et al., 2024), which made this mode for improving the soil nutrients.

Compared to bare sandy land, soil bacterial and fungal diversity indices increased after sand fixation measures. The combination of brush straw checkerboard barrier with *Artemisia desertorum* and artificial straw checkerboard barrier with *Artemisia desertorum* showed the highest bacterial diversity in the soil, indicating that *Artemisia desertorum*, as a pioneering sand-fixing plant species, plays a significant role in improving soil bacterial diversity (Luo et al., 2019). Meanwhile, the combination of brush straw checkerboard barrier with *Corethrodendron scoparium* had the highest fungal diversity index and the highest number of fungal amplicon sequence variants (ASVs), suggesting that the brush straw checkerboard barrier creates a microclimate near the soil surface that favored fungal growth (Dehkordi et al., 2023). Studies by Sun et al. (2012) and Li et al. (2010) also found that *Corethrodendron scoparium* improved soil and increased fungal abundance, suggesting that the combination of brush straw checkerboard barrier with *Corethrodendron scoparium* promoted fungal growth more effectively.

After sand fixation measures, there was an overall increase in the proportion of *Actinobacteria* and *Proteobacteria* among soil bacteria and an increase in the proportion of *Basidiomycota* among soil fungi. *Actinobacteria* was often dominant bacterial groups in plant rhizosphere soils (Dai et al., 2019), with many strains capable of nitrogen fixation, thereby promoting nitrogen cycling in soil (Delmont et al., 2018). *Proteobacteria* played a crucial ecological role in soil function by acting as major degraders of carbon compound (Kruczyńska et al., 2023) and promotting plant growth. *Basidiomycota* were involved in the decomposition of wood residues and contributed significantly to plant nutrient cycling (Beimforde et al., 2014). These results suggest that sand fixation measures promote nitrogen cycling and degradation of carbon compounds, leading to soil restoration and facilitating plant growth. At the genus level, sand fixation measures resulted in changes in the composition of soil bacterial and fungal species. *Geodermatophilus* and *Rubellimicrobium* were the dominant bacterial genera in brush straw checkerboard barrier environments, while *Pseudopeyronellaea* emerged as the dominant fungal genus. In artificial straw checkerboard barrier sand environments, *Cellulomonas* and *Comoclathris* were dominant bacterial and fungal genera, respectively, suggesting differences in the composition of soil bacterial and fungal communities across different sand barrier types (Wang et al., 2024).

Conclusion

(1) Combined implementation of sand barriers with vegetation demonstrates superior effectiveness compared to single sand control measures. Overall, the combination of artificial straw checkerboard barrier and *Calligonum mongolicum* showed the best effect in improving soil organic matter, total nitrogen, and electrical conductivity, thereby facilitating soil nutrient accumulation.

(2) The implementation of sand control measures resulted in an improvement in soil bacterial and fungal diversity. Specifically, the presence of *Artemisia desertorum* promotes soil bacterial diversity, while the combination mode of brush straw checkerboard barrier and *Corethrodendron scoparium* helped improve soil fungal diversity.

(3) After sand control measures, there was an overall increase in the proportion of *Proteobacteria* and *Bacteroidetes* in soil bacteria, along with a corresponding increase in the proportion of *Basidiomycetes* in soil fungi compared to bare sandy land. At the genus level, noticeable differences in the composition of soil bacterial and fungal communities were observed in different sand barrier environments.

Declarations

Acknowledgements: The research is based on the patent of brush straw checkerboard barrier(C.N. Patent 210766711U). The first inventor is the co-first author (J. Qu).

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Zhihao Zhu]. Article direction and fund acquisition were performed by [Jianjun Qu] and [Chen Meng]. The first draft of the manuscript was written by [Zhihao Zhu] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

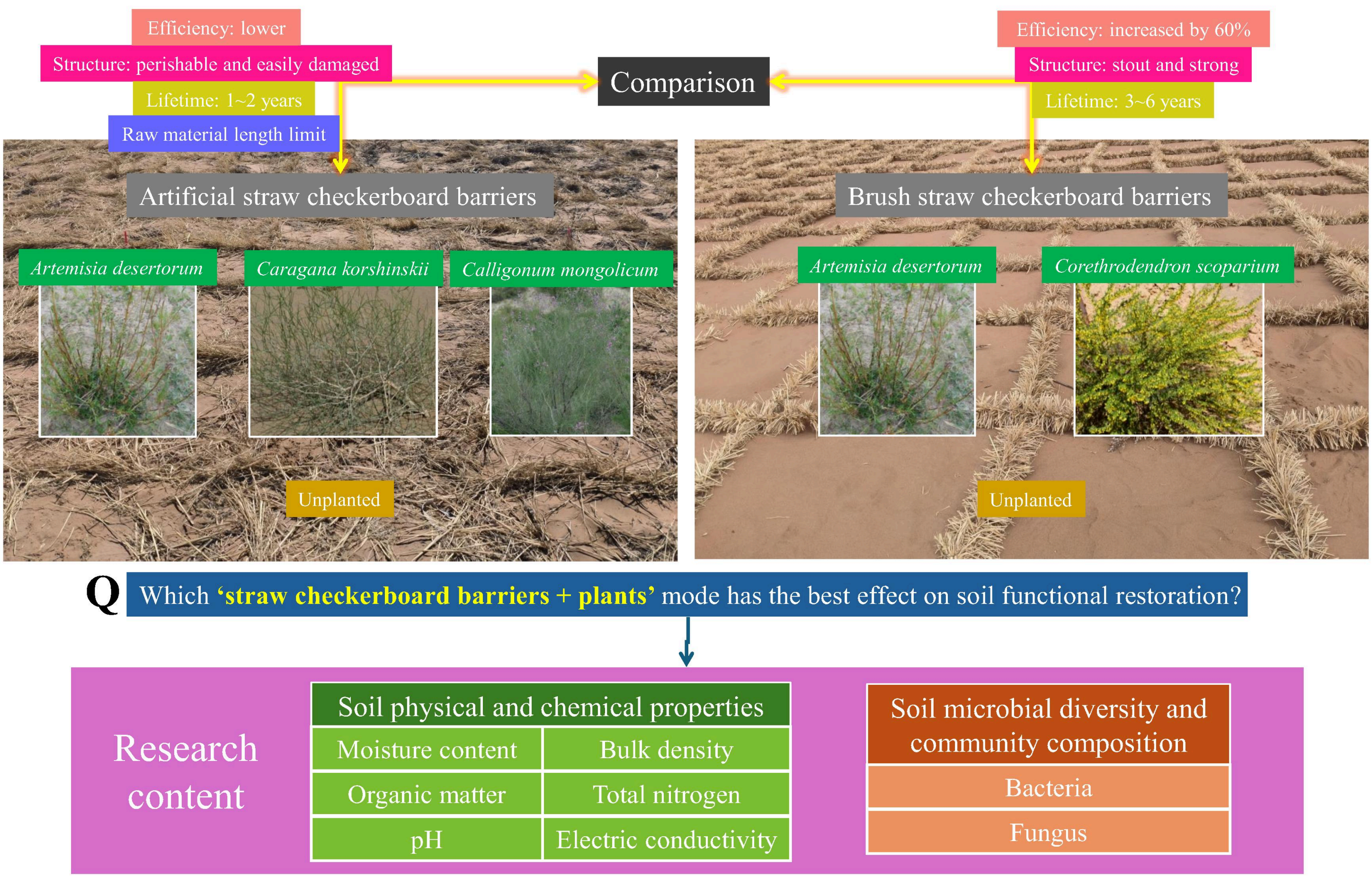

Figure 1

Image summarization

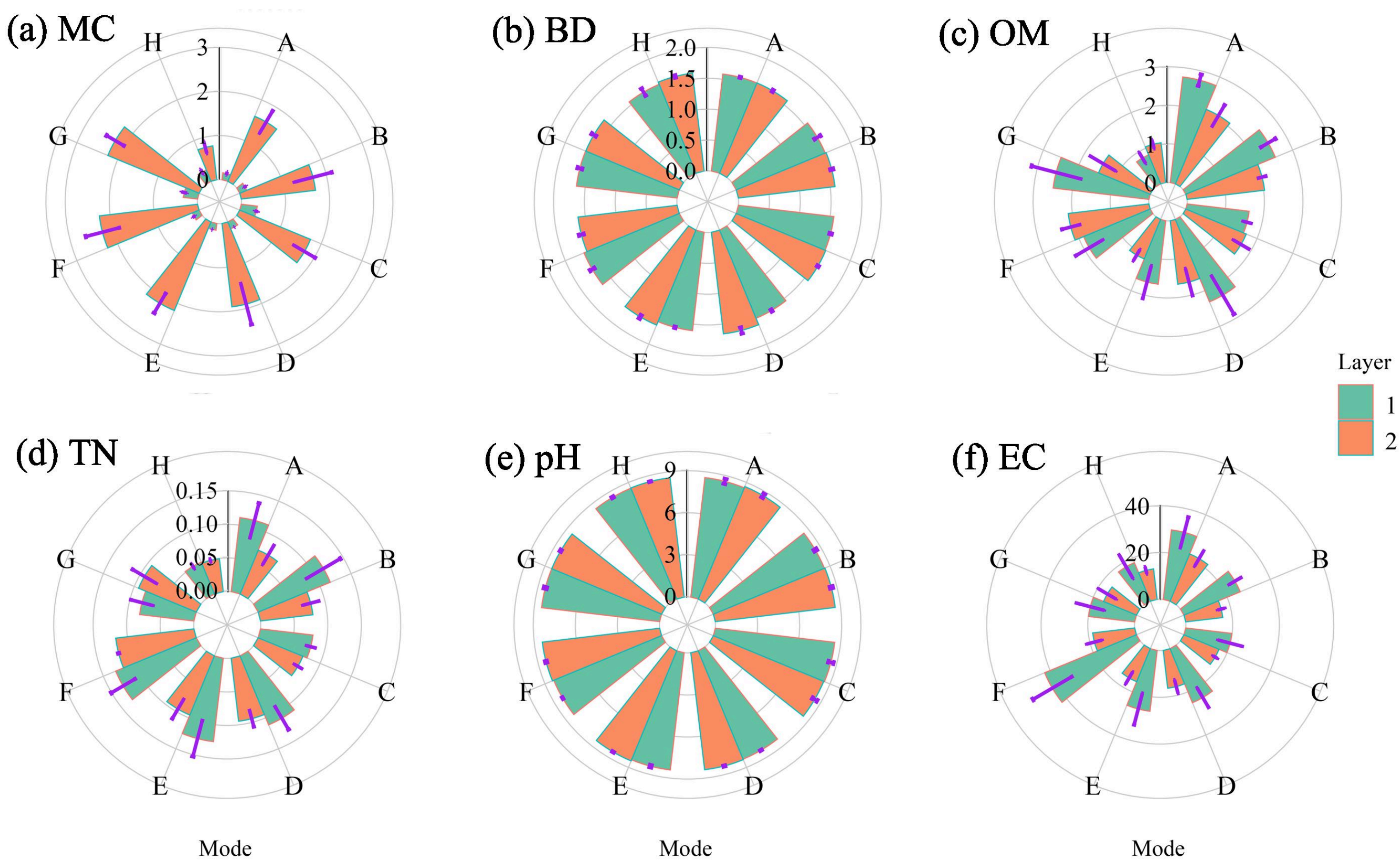

Figure 2

Effects of different modes on soil physical and chemical properties. MC: Moisture content, %; BD: Bulk density, $g \cdot cm^{-3}$; OM: Organic matter, $g \cdot kg^{-1}$; TN: Total nitrogen, $g \cdot kg^{-1}$; EC: Electric conductivity, $\mu s \cdot cm^{-1}$. Layer1: 0~10 cm soil layer; Layer2: 10~20 cm soil layer. The same below.

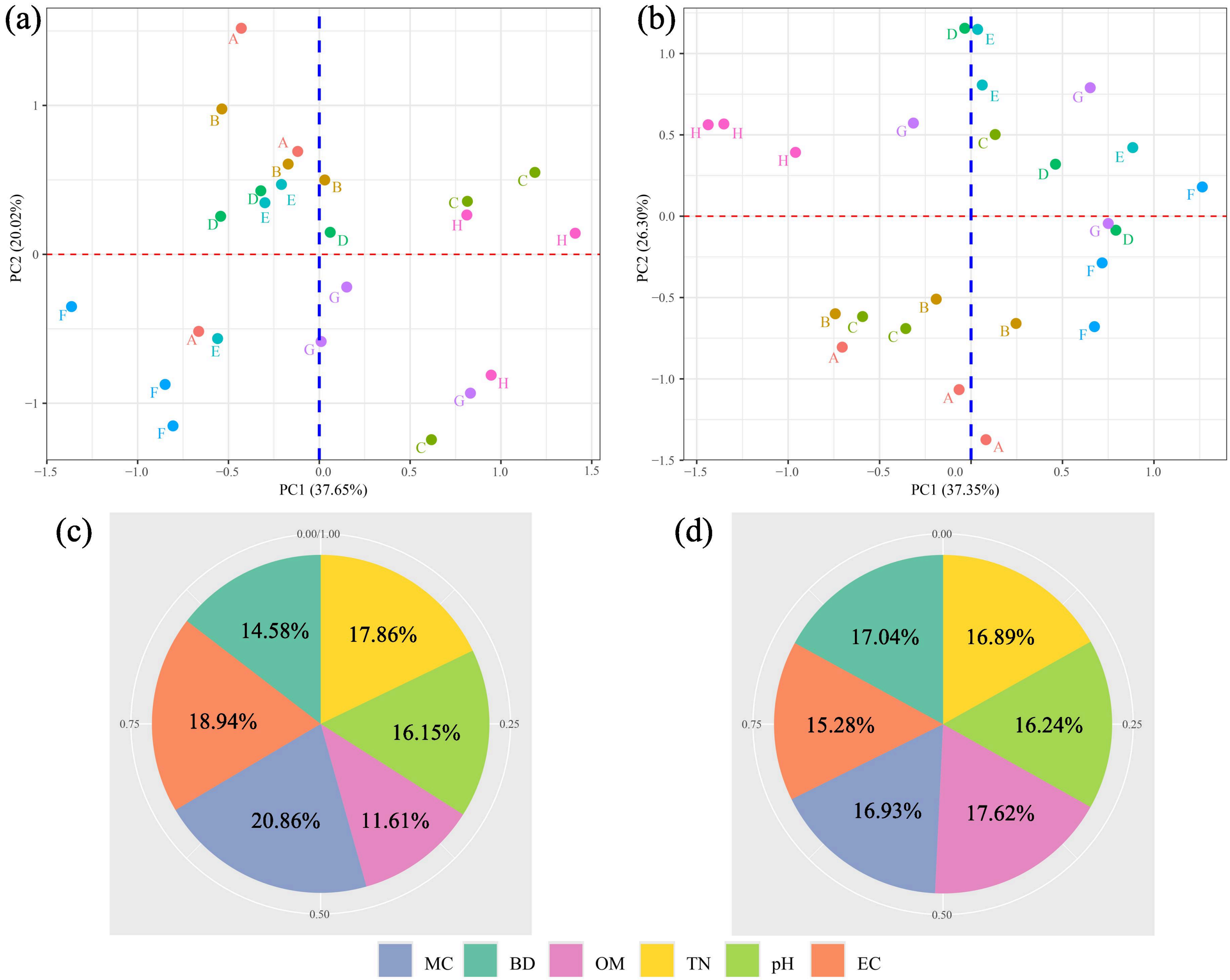

Figure 3

Principal component analysis and weight of soil physical and chemical properties (a) Principal component analysis of 0~10 cm soil layer; (b) Principal component analysis of 10~20 cm soil layer; (c) Weight of soil physical and chemical properties in 0~10 cm soil layer; (d) Weight of soil physical and chemical properties in 10~20 cm soil layer.

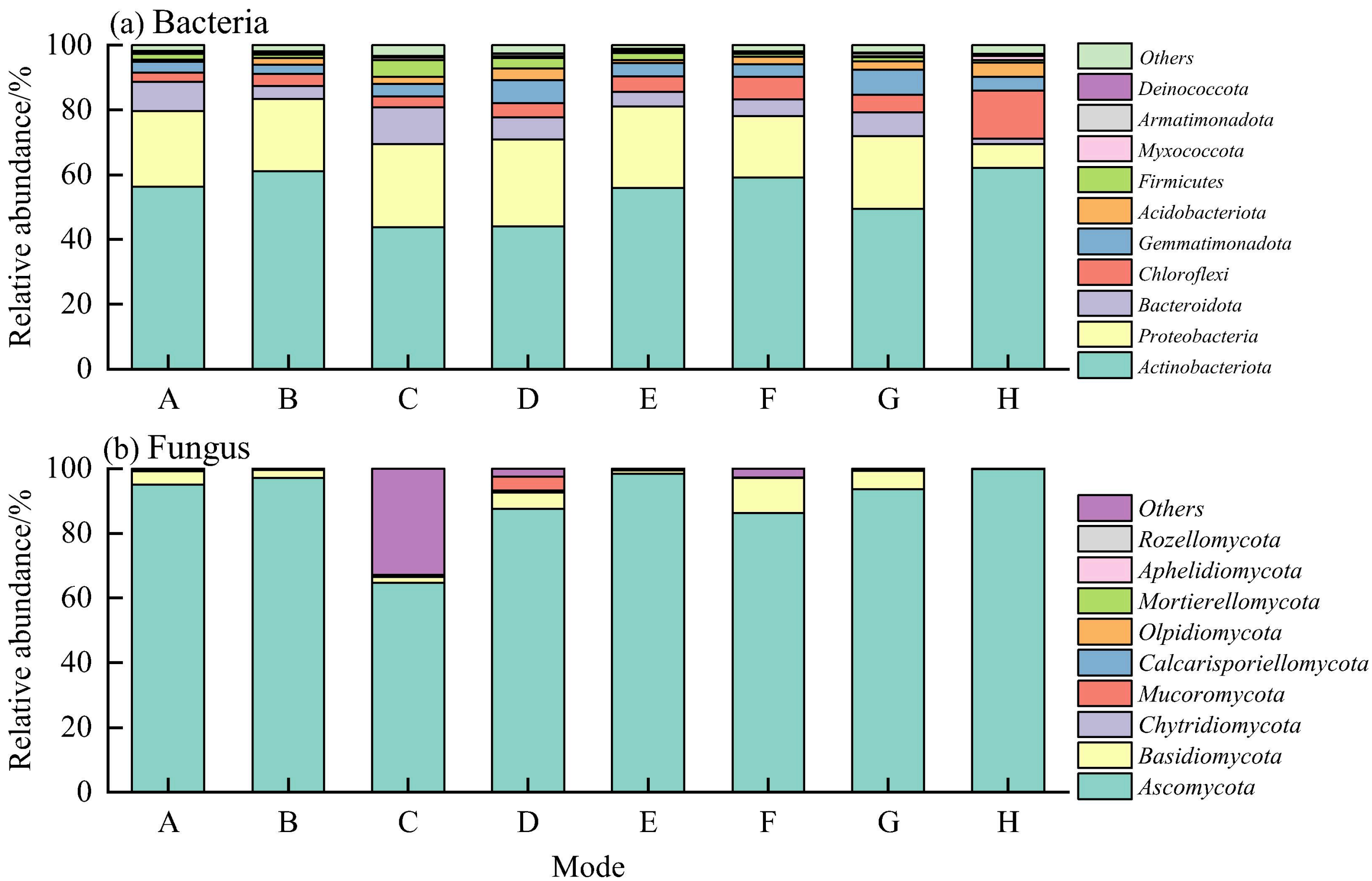

Figure 4

Effects of different modes on the horizontal distribution of soil bacterial and fungal phylum

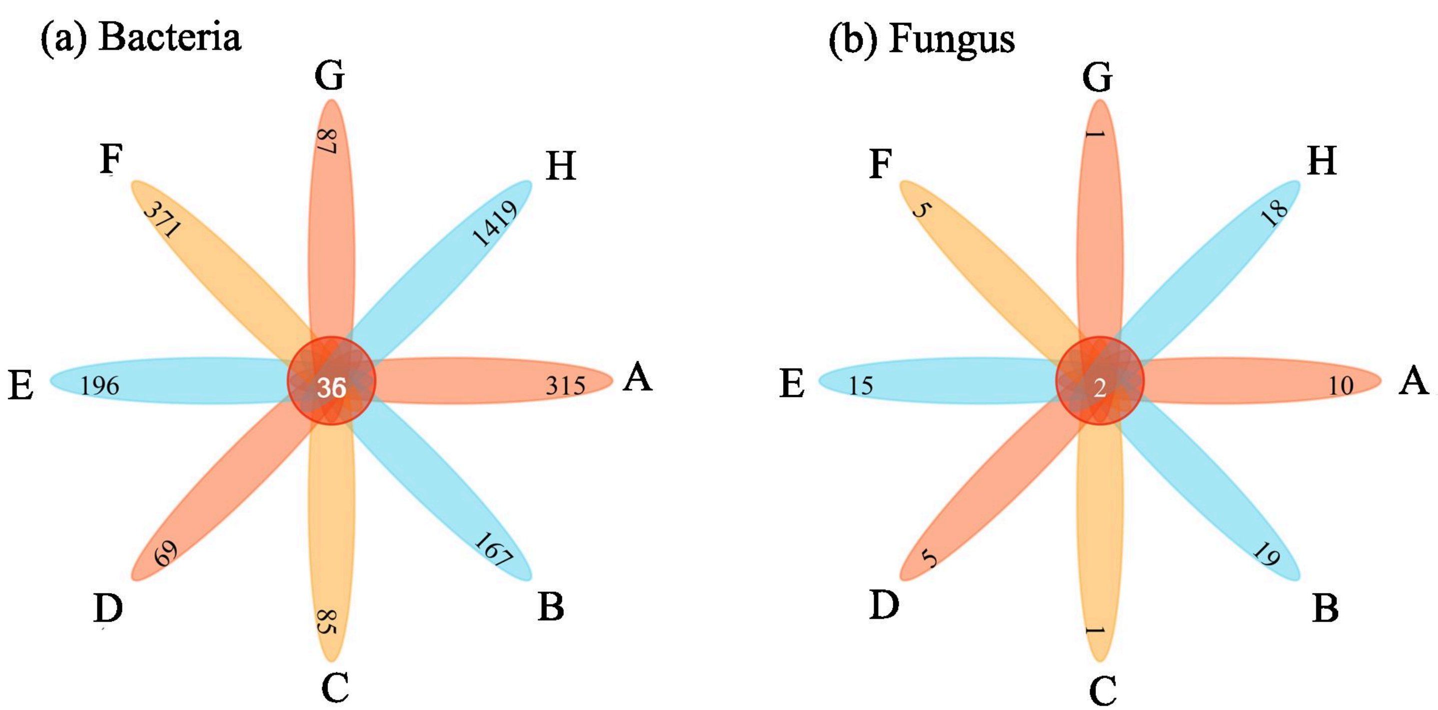

Figure 5

Petal diagrams of soil bacterial and fungi in different modes

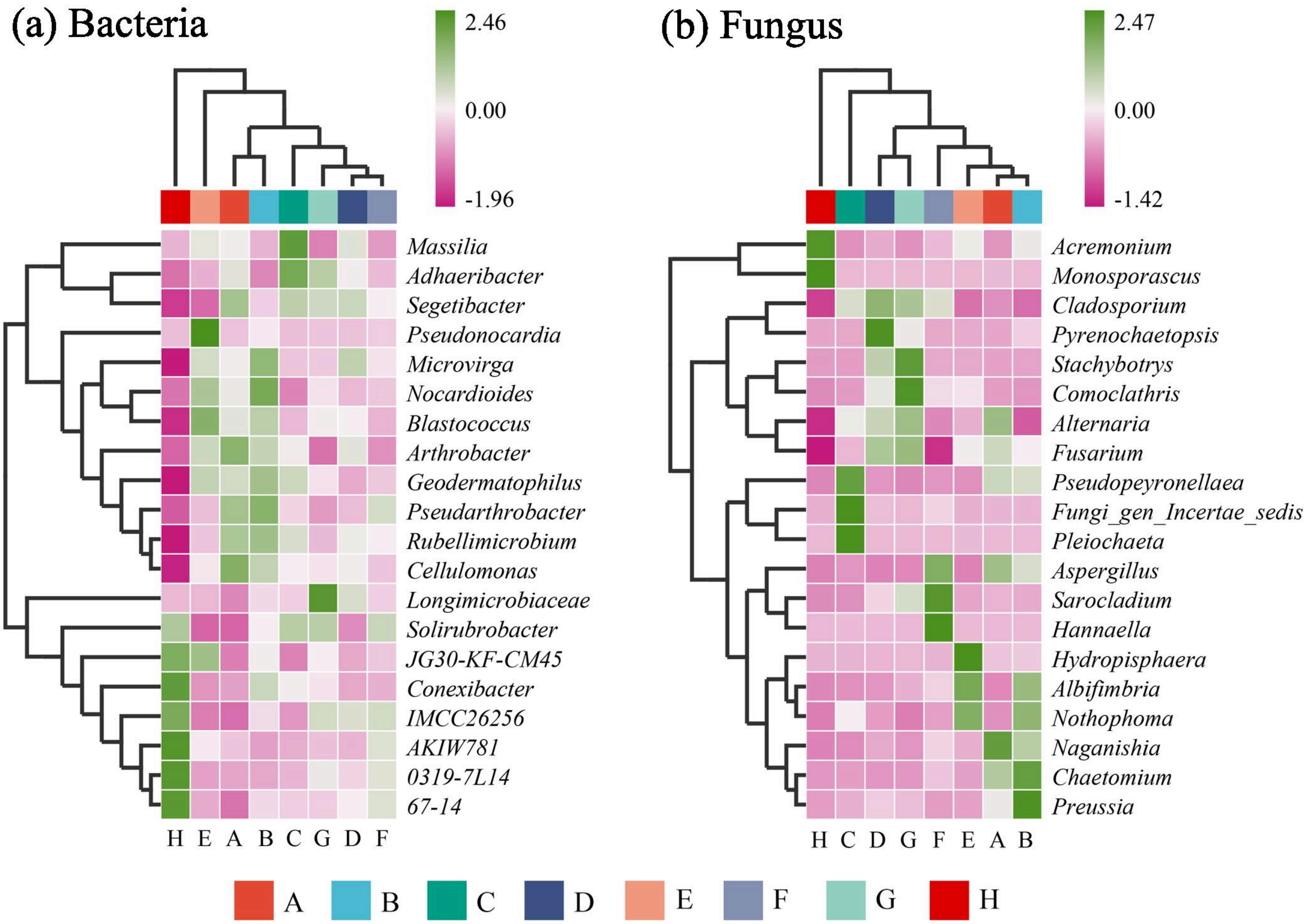

Figure 6

Different modes of soil bacterial and fungal genus level clustering heatmap