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Effects of three typical grass cultivation patterns on the community structure of soil mites in rocky desertification control area, Guizhou, China

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Abstract

The use of grass cultivation in the restoration of degraded ecosystems is widespread, in order to reveal the effect of different grass cultivation patterns on the community structure of soil mites in the integrated management area of rocky desertification. In April and July 2021, a total of 2782 soil mites belonging to 3 orders, 42 families, and 73 genera were captured from three typical grass cultivation, Lolium perenne, Dactylis glomerata and Trifolium repens, and the traditional Zea mays as a control sample, in the integrated management area of potential-light rocky desertification in the karst plateau mountains of Salaxi, Guizhou Province. The soil mite community structure was analyzed using number of taxa (genera), number of individuals, diversity index, community similarity index, MI index of predatory mites, and MGP analysis of oribatid mite ecological taxa. The results showed that:

1) The summer has a more prosperous composition and diversity of soil mites across habitats, while the dominant genera of soil mites show a differential distribution across habitats; the number of soil mite genera, individuals and individual densities was significantly higher in the three grass cultivation habitats than the Zea mays habitat, and surface aggregation of soil mites is more pronounced. (2) There were differences in soil mite community structure among the three grass cultivation patterns, with a regularity of Lolium perenne > Dactylis glomerata > Trifolium repens in the composition of soil mites genera and the number of individuals, and the proportion of shared genera was not high. (3) The diversity of soil mites varied according to the environment and season, with the highest diversity of soil mites in Lolium perenne habitats; both the community similarity analysis and the CCA analysis showed that Lolium perenne and Dactylis glomerata habitats had the highest similarity of soil mite communities (4) Predatory mites were dominated by r-selective ecotypes, and oribatida were dominated by O and P type ecotypes under the three habitat patterns. (5) Soil nutrient conditions were more favorable in Trifolium repens habitats, while soil water content was higher in Dactylis glomerata environment, and correlation analysis indicated that TK was a key environmental factor influencing soil mite community composition and diversity. Based on the above results, it is further elaborated that the artificial grass restoration model not only improves the nutrient supply of soil N, P, and K but also significantly increases the composition and diversity of soil mite species, which is beneficial to the restoration of soil mite communities and is very helpful in terms of achieving self-sustainability and restoration of soil functions in rocky desertification areas.

Keywords: Soil mites, community difference, grass cultivation patterns, karst rocky desertification, Guizhou
1. Introduction

As an essential performer of soil food web functions, soil mites are an indispensable component of karst ecosystems and play a critical regulatory role in promoting the generation and decomposition of substances subsurface ecosystem substances, accelerating the circulation and flow of energy, and improving soil structure and texture in rocky desertification management areas (Xiang et al. 2007, Arroyo et al. 2005, Wardle et al. 2004, Fu et al. 2009); in addition, soil mites are a vulnerable group of organisms to disturbance in nature, and their species composition and diversity can respond sensitively to changes in the soil environment (Andrés and Mateos 2006). Hence, soil mites have become one of the critical indicator organisms for evaluating soil environmental quality and monitoring ecological restoration effects in the restoration of degraded ecosystems (Manu and Ion 2014). It has been shown that in the karst region of southwest China, the increase of rocky desertification is not conducive to the stability and diversification of soil mite community structure, while the ecological management of rocky desertification can increase the number of species and individuals of soil mites, and the composition and structure of soil mite communities show specific differences under different vegetation restoration modes, therefore, the differences in the dominant genera and bioecological groups of soil mites can be used as a preliminary indicator of the process and effect of ecological restoration of rocky desertification (Chen et al. 2018a, 2018b). However, most studies on soil mites in rocky desertification ecological management areas have been carried out under different mixed agroforestry ecological management models (Liu et al. 2020), and there are few reports on the investigation of soil mite community structure and its relationship with environmental factors under different grass cultivation patterns environments in rocky desertification ecological management areas.

As an important means of plant diversification, grass cultivation are widely used in the restoration of degraded ecosystems (Xiong et al. 2016). In response to the fragility and vulnerability of the karst environment (Wang et al. 2004, Du et al. 2019), since the 13th Five-Year Plan, with the support of the National Science and Technology Program, in the demonstration area of rocky desertification in the karst plateau of Bijie Salaxi, which is dominated by potential-light rocky desertification, Lolium perenne, Dactylis glomerata, and Trifolium repens with frost and drought resistance have been deployed to restore and protect the degraded karst environment (Xiong et al. 2012). Studies have shown that the different grass cultivation patterns not only allow for differences in soil environmental factors but also create diverse microhabitats for soil fauna, which in turn affects the distribution of soil mite communities (Gardí et al. 2002, De Deyn et al. 2003, Dong et al. 2012). However, there is a lack of comprehensive knowledge on whether the variation in grass cultivation patterns affects the community structure of soil mites in this particular ecosystem of rocky desertification ecological management areas.

Based on this, this study was conducted in April (spring) and July (summer) 2021 in the demonstration area. Three typical grass cultivation patterns habitats of Lolium perenne, Dactylis glomerata, and Trifolium repens were selected, and the traditional Zea mays habitat was used as a control sample to conduct a comparative study of soil mite community structure, aiming to investigate the change characteristics of soil mite community structure and its correlation with environmental factors under different grass cultivation patterns in the rocky desertification ecological management area, to provide comparative soil biological data for the subsequent evaluation of environmental management benefits in rocky desertification areas, and to provide a reference for scientific restoration and establishment of vegetation in rocky desertification areas.

2. Materials and methods

2.1. Overview of the region under study

The Salaxi Karst Plateau Mountain Rock Desertification Comprehensive Control Demonstration Zone (27°13′38.08″-27°14′10.64″N, 105°05′4.32″-105°05′27.87″) (from now on referred to as the demonstration area) is located in Qixingguan District, Bijie City, Guizhou Province, mainly potential and light rocky desertification, and is one of the main areas for the implementation of comprehensive management of rocky desertification in the country’s ‘13th Five-Year Plan’. The total area of the demonstration area is 86.27 km², and the karst geomorphological distribution area accounts for 73.94% of the total area. It has an altitude of 1498-2180m. The area belongs to the typical subtropical monsoon climate, cold and dry in winter and spring, warm and dry in summer and autumn, with an average annual rainfall of 984.4mm, an average annual temperature of 12.8 °C, and a frost-free period of more than 245 days. The land-use type is mainly woodland and cultivated land; the vegetation type is coniferous and broad-leaved mixed forest and secondary shrubland, the zonal soil is mainly yellow, interspersed with mountain yellow-brown soil and limestone soil, the soil thickness is generally 5-20cm, with severe soil erosion, shallow surface layer, and low fertility.

The experiment was set up with four experimental treatments: Lolium perenne, Dactylis glomerata, and Trifolium repens, and traditional monoculture Zea mays. The three grass cultivation cover an area of approximately 400-600m², are sown uniformly, at an average seeding rate of 3 g m⁻², and are maintained for six years, and are
never treated with any insecticide and are managed in a generally consistent manner across the grass cultivation. Of these, the *Lolium perenne* and *Dactylis glomerata* samples were above 95% cover and the *Trifolium repens* sample ranged from 60% to 75% cover. Due to the constraints of the karst background of water and soil resources scarcity and the lack of refined scientific manual management, the growth of tree and irrigation vegetation and the standard ecological benefits are to a certain extent restricted. This is reflected in the fact that the forest and irrigation plants are generally short and dominated by high-coverage forage grasses.

### 2.2. Sample setting and sample collection

In April (spring) and July (summer) of 2021, five sampling points were set up in relatively stable areas of each site according to the ‘*Z*’ sampling method, with a spacing of approximately 10 m. A cylindrical soil ring knife with a size of 10 cm (D) × 5 cm (H) was used to collect two consecutive soil samples from each sample point in the upper (0-5 cm) and lower (5-10 cm) layers, a total of 80 soil samples were collected for soil mite analysis (2 seasons × 4 sample plots × 5 sample points × 2 soil layers). We packed the soil mite samples in cotton bags with good air permeability and returned them to the laboratory for separation and identification.

In addition, during the summer sampling period, six samples of soil for physical analysis were collected near each sampling site using a soil ring knife with a volume of 100 cm³, following the soil mentioned above layers, for a total of 24 samples (4 sample plots × 3 sample points × 2 soil layers). In the same period, approximately 500 g of soil was collected from the upper and lower layers in a homogeneous mixture with a shovel near each sampling site, with three samples taken from each sample plot, for a total of 12 samples for chemical analysis (4 sample plots × 3 sample points × 1 mixed sample), which were transported back to the laboratory in self-sealing bags for a natural drying and grinding before testing.

### 2.3. Separation and identification of soil mites specimens

Isolation and preservation of soil mite specimens: Soil mites were separated using a Tullgren separating funnel and baked continuously for 48 h in a light cabinet fitted with several 45 W incandescent bulbs, keeping the temperature inside the cabinet at no more than about 35 °C. After baking, the soil mites were selected from the soil animals under a microscope (Olympus SZX2-FOF), and the specimens were cleaned and fixed in 70% alcohol. For room temperature transparency, the fixed mite specimens were stored in small plastic test tubes containing lactic acid solution.

Identification of mite specimens: the transparent mite specimen after 15d was made into a temporary tablet, then the mounted specimen was placed under the microscope (Olympus CX41RF), and the soil mite morphology was viewed in combination with 10 and 40 times, referring to ‘Soil Gamasid Mites in Northeast China’ (Yin et al 2013), ‘Pictorial Keys to Soil Animals of China’ (Yin 1998), ‘Acarology’ (Li and Li 1989) ‘A Manual of Acarology’ (Third Edition) (Krantz and Walter 2009), as well as other monographs, perform morphological identification of specimens, and the classification order is mainly based on the classification system of A Manual of Acarology (Third Edition). Except for some nymphs and incomplete specimens, all specimens are identified to the genera level.

### 2.4. Determination of soil environmental factors

Determination of the physical factors of the soil: soil bulk density, saturated water content, and natural water content were determined using the *in situ* ring knife method; total porosity is calculated using \( P = 93.947 - 32.995 \times BD \) \( \times \) BD, BD is the bulk density, and P is the total porosity.

Determination of soil chemical factors: pH by potentiometric method; soil organic matter by potassium dichromate oxidation method; total nitrogen by semi-micro Kjeldahl method; alkaline nitrogen by alkaline diffusion method; total phosphorus by sulphuric acid-perchloric acid digestion, molybdenum antimony anti-colorimetric method; available phosphorus by sodium bicarbonate leaching, molybdenum antimony anti-colorimetric method; total potassium by hydrofluoric acid-perchloric acid digestion, flame photometric method; available potassium by neutral ammonium acetate leaching and flame photometry. The above determination methods are the *Soil and Agricultural Chemistry Analysis* (Lu 2000)

### 2.5. Data analysis

(1) Community dominance Degrees: More than 10% of the total number of individuals is the dominant groups (+++), 1% to 10% is the common groups (++), and less than 1% is the rare groups (+) (Zheng et al 2005).

(2) Community diversity: Shannon-Wiener diversity index \( (H) \), Margalef richness index \( (SR) \) and Pielou evenness index \( (J) \) were used to analyze soil mite community diversity (Yeates 2007).

\[
H = - \sum_{i=1}^{s} P_i \ln P_i
\]  

(1)
Table 1. Ecological types assigned to soil mites (Oribatida) community.

| Community types                      | Abbreviation | Value ranges of mites (Oribatida) group |
|--------------------------------------|--------------|----------------------------------------|
| Macropylina type                     | M            | M > 50%                                 |
| Gymnonota type                       | G            | G > 50%                                 |
| Poronota type                        | P            | P > 50%                                 |
| Overall type                         | O            | 20% < M, G, P < 50%                     |
| Macropylina-Gymnonota type           | MG           | M, G = 20%–50%, P < 20%                |
| Gymnonota-Poronota type              | GP           | G, P = 20%–50%, M < 21%                |
| Macropylina-Poronota type            | MP           | M, P = 20%–50%, G < 22%                |

\[
SR = \frac{(S - 1)}{\ln N} \quad (2)
\]

\[
J = H / \ln S \quad (3)
\]

Where: \( P_i = \frac{n_i}{N} \), \( n_i \) is the number of individuals in genus \( i \); \( N \) is the total number of individuals of all taxonomic orders in the sample; and \( S \) is the number of sample groups (genera).

(3) Analysis of mite community differences: Jaccard similarity coefficient (\( q \)) was used to characterize similarity between the communities (Fu and Yin 1999).

\[
q = c / (a + b - c) \quad (4)
\]

Where: \( a \) represents the number of genera of the community \( A \); \( b \) represents the number of genera of the community \( B \); and \( c \) represents the number of the commonly shared genera of the two communities. 0.75-1 is much similar, 0.3-0.75 is medium similar, 0.25-0.5 is medium dissimilar, and 0-0.25 is much unlikely.

(4) The predatory mites ecological taxa: The predatory mites maturity index (\( MI \)) was used to characterize the community structure of predatory mites (Ruf 1998, Wu et al 2006).

\[
MI = \sum_{i=1}^{S} K_i / \left( \sum_{i=1}^{S} K_i + \sum_{i=1}^{S} r_i \right) \quad (5)
\]

Where: \( S \) is the genera of gamasid mites; \( K_i \) is the \( K \)-value of the family where the genus \( i \) belongs, and \( r_i \) is the \( r \)-value of the family where the genus \( i \) belongs.

(5) MGP ecological taxa of oribatida: MGP analysis was carried out on the taxonomic taxonomy of oribatida of Li (Li and Li1989), and the percentage of soil mite genera and the percentage of mite individuals corresponding to each group were carried out (Aoki 1983, Xie et al 2004), as a consequence the taxonal discrimination thresholds are shown in the table 1.

2.6. Data processing and analysis

The use of Microsoft Excel 2019 software for the collation of the underlying data; One-way analysis of variance was conducted in IBM SPSS 20.0 software for soil environmental factors and soil mite community diversity in different habitats, with multiple comparisons using the LSD method and Tamhane’s T2 test for data not normally distributed at a significance level of \( P < 0.05 \) (Li et al 2019); Soil mite community data from two seasons were combined, and Canonical Correspondence Analysis (CCA) of soil mite communities, sample plots, and soil physicochemical factors was carried out using CANOCO 5.0 software (Ter Braak 1986); histograms, box plots, and correlation heat maps were produced using Origin 2021 software.

3. Analysis and results

3.1. Soil mite community composition and dominance

During the study period, a total of 2782 soil mites were captured in four habitats in spring and summer, belonging to 3 orders, 42 families, and 73 genera (table 2). From the perspective of the number of soil mite genera, the number of individuals, and the dominant genus in each habitat, 950 soil mites were captured in the Lolium perenne habitat, belonging to 30 families and 57 genera, Oppiella is the dominant genus; 825 soil mites were captured in the Dactylis glomerata habitat, belonging to 24 families and 45 genera, Parholaspulus, Geolaelaps and Scheloribates are the dominant genera; 747 soil mites were captured in the Trifolium repens habitat, belonging to 25 families and 37 genera, Parholaspulus and Scheloribates are the dominant genera; 260 soil mites were captured in the Zea mays, belonging to 18 families and 30 genera, Tectocephus is the dominant genus. It can be seen that the number of soil mites and the number of genera from more to less are Lolium perenne > Dactylis glomerata > Trifolium repens > Zea mays; the ratio of three grass cultivation patterns to the individual numbers.
Table 2. Community compositions of soil mites under different grass cultivation patterns.

| Family          | Genus      | L. | D. | T. | L.+D.+T. | Z. |
|-----------------|------------|----|----|----|----------|----|
| Trematuridae    | Nenteria   | 84 | 63 | 27 | 174(++)  | 20 |
|                 | (++)       |    | (++)|   | (+)      |    |
| Dinychidae      | Dinychus   | 1(+) | 4(+) | 1(+) | 6(+) |
| Uroobovella     | 6(+)       |    |    |    | 9(+) |
| Oplitidae       | Oplitis    | 1(+) |    |    | 1(+) |
| Zerconidae      | Zercon     |    | 3(+) |    | 3(+) |
| Parasitidae     | Parasitus  | 69 | 46 | 46 | 161(++)  | 8  |
|                 | (++)       | (++)|   |   | (+)      |    |
| Neogamasus      | 24         | 6(+) | 38 |    | 68(++)  |
|                 | (++)       |    | (++)|   | (+)      |    |
| Valgarogamasus  | 3(+)       | 11 |    |    | 14(+)   |
|                 | (++)       |    |    |    | (+)     |
| Veigaidae       | Veigaia    |    |    |    | 1(+) |
| Rhodacaridae    | Rhodacarus | 2(+) | 43 |    | 45(++) |
|                 | (++)       |    |    |    | 2(+) |
|                 | Rhodacarellus | 2(+) | 4(+) |    | 6(+) |
| Ologamasida     | Gamasiphis | 34 | 13 | 3(+) | 50(++) |
|                 | (++)       |    | (++)|   | 1(+) |
| Macrochelidae   | Glypholaspis | 2(+) |    | 1(+)| 3(+) |
|                 | Macrocheles | 1(+)| 4(+) |    | 6(+) |
| Parholaspididae | Parholaspus | 57 | 90 | 177 | 324(++) |
|                 | (++)       | (+) | (+) | ++ | 11 |
| Parholaspulus   | 1(+)       |    |    |    | 3(+) |
|                 | 11         | 5(+) |    |    | 24(+) |
| Parholaspulus   | Knarthzospus | 1(+) |    |    | 1(+) |
| Gamasiphis      | 11         | 5(+) |    |    | 24(+) |
| Pachylaelapidae | Pachylaelaps | 2(+) | 1(+) | 6(+) | 9(+) |
| Parholaspulus   | Knarthzospus | 1(+) |    |    | 30(++) |
| Ascidae         | Asca       | 21 | 9  |    | 30(++) |
| Ameroseiidae    | Ameroseius | 2(+) | 6(+) |    | 8(+) |
|                 | Epicriopsis | 2(+) | 6(+) |    | 12(+) |
| Family          | Genus           | L.  | D.  | T.  | L.+D.+T. | Z.  |
|-----------------|-----------------|-----|-----|-----|----------|-----|
| **Blattisocidae** | **Lasioseius**  | 5(+) | 15  | 9   | 29(++)   | 22  |
|                 | **Cheiroseius** | 16  | 2(+) | 2(+) | 20(+)    | 3   |
| **Laelapidae**  | **Cosmolaelaps**| 1(+)| 95  | 66  | 238(++)  | 2(+)|
|                 | **Geolaelaps**  | 77  |     |     |          |     |
|                 | **Ololaelaps**  | 1(+) |     |     | 1(+)     | 5(+)|
| **Microtrombidiidae** | **Microtrombidium** | 3(+) |     |     | 4(+)     |
| **Stigmaeidae** | **Stigmaeus**   |     |     |     |          | 4   |
| **Phytoseiidae** | **Amblyseius**  |     |     |     |          |     |
| **Mesoplophoridae** | **Archoplophora** | 1(+) |     |     | 1(+)     |
| **Hypochthoniidae** | **Hypochthonius** | 7(+) |     |     | 13(+)    | 4   |
|                 | **Hypochthoniella** |     | 1(+) |     |          |     |
| **Lohmanniidae** | **Mixacarus**   | 2(+) |     |     | 8(+)     | 1(+)|
|                 | **Papillacarus**| 8(+) |     |     | 1(+)     |
| **Perlohmanniidae** | **Perlohmannia** | 3(+) |     |     | 3(+)     |
| **Euphthiracaridae** | **Rhysotritia** | 1(+) |     |     | 2(+)     | 6(+)|
| **Camisiidae**  | **Heminothrus** | 5(+) |     |     | 7(+)     |
|                 | **Platynothrus**| 69  | 15  |     | 43       | 25  |
|                 | **Camisia**     | 1(+) |     |     | 9(+)     |
| **Nothridae**   | **Nothrus**     | 28  | 5(+) |     | 33(++)   | 3   |
| **Nanhermanniidae** | **Nanhermannia** | 4(+) | 12  | 1(+) | 17(+)    |
| **Hermanniiidae** | **Hermannia**   | 4(+) |     |     | 3(+)     | 7(+)|
| Family          | Genus      | L. | D. | T.   | L.+D.+T. | Z.   |
|-----------------|------------|----|----|------|----------|------|
| Hermanniellidae | Hermanniella | 1(+) |    | 1(+) |          |      |
| Eremulidae      | Eremulus   | 2(+) | 6(+) | 16   | 24(+)    | 20   |
| (++)            |            |    |     |      |          |      |
| Eremobelbidae   | Eremobelba | 14  | 1(+) | 15(+) |          |      |
| (++)            |            |    |     |      |          |      |
| Fosseremus      |            | 19  | 4(+) | 23(+) |          |      |
| Liacardidae     | Liacarca   | 1(+) | 1(+) | 2(+) |          |      |
| Astegistidae    | Caltroribula | 4(+) | 4(+) |      |          |      |
| Carabodidae     | Carabodes  | 3(+) | 1(+) | 4(+) |          |      |
| (++)            |            |    |     |      |          |      |
| Suctobelbidae   | Suctobelbella | 3(+) | 3(+) | 10(+) |          |      |
| Suctobelba      |            | 7(+) | 3(+) |      |          |      |
| Oppiidae        | Lauroppia  | 13  | 13(+) |      |          |      |
| Lasiobelba      |            | 1(+) |      |      | 1(+)    |      |
| Oppella         |            | 136 | 33  | 35   | 204(++)  | 24   |
| (++)            |            |    |     |      |          |      |
| Medioppia       |            | 4(+) | 19  | 23(+) |          | 7(++)|
| (++)            |            |    |     |      |          |      |
| Ramuella        |            | 19  | 14  | 33(++)|          |      |
| (++)            |            |    |     |      |          |      |
| Tectocephidae   | Tectocephus| 14  | 29  | 53(++)|          | 53   |
| (++)            |            |    |     |      |          |      |
| (++)            |            |    |     |      |          |      |
| Phenopelopidae  | Eupelops   | 21  |    | 21(+)|          |      |
| Pelopelus       |            |    |     |      |          |      |
| (++)            |            |    |     |      |          |      |
| Achipteria      |            | 28  | 2(+) | 30(++)|          |      |
| (++)            |            |    |     |      |          |      |
| Oribatulidae    | Domotorina | 3(+) |    |      | 3(+)    | 1(+) |
| Scheloribatidae | Scheloribates | 84  | 190 | 187  | 461(++)  | 4(++)|
| (++)            |            |    |     |      |          |      |
| (++)            |            |    |     |      |          |      |
| Family       | Genus          | L.       | D.       | T.       | L.+D.+T. | Z. |
|-------------|----------------|----------|----------|----------|----------|----|
| Haplozetidae| Vilhenabates   | 1(+)     |          |          | 1(+)     |    |
|             | Incabates      | 4(+)     |          |          | 4(+)     |    |
|             | Peroxylobates  | 3(+)     | 3(+)     |          | 6(+)     | 2(+)|
|             | Xylobates      | 6(+)     |          |          | 15(+)    | 1(+)|
| Xylobatidae |                |          |          |          |          |    |
| Galumnidae  | Galumna        | 3(+)     |          |          | 3(+)     |    |
|             | Trichogalumna  | 14       | 25       | 12       | 51(++)   | 11 |
|             | Pergalumna     | (++      | (++      | (++      | 3(++)    |    |
|             | Anachipteria   | 6(+)     |          |          | 6(+)     |    |
| Genera numbers |              | 57       | 45       | 37       | 70       | 30 |
| Individual numbers |             | 950      | 825      | 747      | 2522     | 260|

The data in the table uses the number of individuals (dominance). *L. Lolium perenne, D. Dactylis glomerata, T. Trifolium repens, Z. Zea mays*; Spr. spring, Sum. Summer. The same below.
of soil mites in *Zea mays* ranged from 2.87 to 3.65. It can be seen that the grass cultivation patterns had a more prosperous number of mite genera and individuals, and the *Lolium perenne* sample site had the most complex soil faunal community composition.

A total of 2522 soil mites were captured in the three grass cultivation patterns, belonging to 70 genera in 41 families. In general, the *Scheloribates* and *Parholaspulus* were the dominant genera, and 15 genera, such as *Geolaelaps*, *Oppiella*, and *Nenteria* were common genera, both of which accounted for 83.7% of the total number of captured mite individuals. It can be seen that the dominant and common genera are the main contributors to the increase in the number of individual soil mites in the demonstration area in the three grass cultivation patterns. The rare taxa of 53 genera, such as *Gamasholaspis*, *Eremulus*, and *Medioppia*, accounted for only 16.3% of the total number of captured mite individuals, thus indicating that the rare genera were the main contributors to the increase in the number of soil mite genera in the grass cultivation patterns.

In terms of the composition of genera in the three grass cultivation patterns, a total of 70 genera of mites were captured, with 22 genera in common, accounting for 31.43% of the total number of genera. Among them, 38, 30 and 23 genera were shared by *Lolium perenne* and *Dactylis glomerata*, *Lolium perenne* and *Trifolium repens*, and *Dactylis glomerata* and *Trifolium repens*, respectively, with the proportion of shared genera to the total number of genera being 54.29%, 42.86% and 32.86%, respectively. This shows a significant variation in the genus composition of mite species between the grass cultivation patterns.

### 3.2. Horizontal and vertical distribution of soil mites

From the perspective of the horizontal distribution of soil mites (figure 1), in the same habitat, the overall number of individual soil mites (regardless of the upper and lower layers) was higher in summer than in spring, and the overall number of genera and density of individuals showed a consistent pattern of variation with the overall number of individuals; the number of individuals, genera and density of individuals in the upper layer also showed a consistent pattern of variation with the overall number of individuals; while the number of individuals, genera and density of individuals in the lower layer showed a greater variation in spring than in summer in *Lolium perenne* and *Dactylis glomerata*, and a contrary variation in *Trifolium repens*.

In different habitats, the number of individuals, genera, and individual density of upper soil mites in spring and summer showed the decreasing patterns of *Lolium perenne*, *Dactylis glomerata*, *Trifolium repens*, and *Zea mays*. The *Trifolium repens* habitat has a more prosperous number of mite individuals and densities in the lower layers of the spring and summer soils. *Lolium perenne* has a more prosperous number of mite genera in the lower layers of the spring soils.
From the perspective of vertical distribution (Figure 1), except for the equal number of upper and lower layers of Zea mays genera in spring, the number of soil mites in the spring and summer of other habitats, the number of genera, and the density of individuals were all shown as the surface aggregation characteristics of the upper layer of the soil > the lower layer of the soil. Among them, Soil mites show a strong phenological aggregation under the three grass cultivation patterns, and the number of mites in the upper and lower layers of Dactylis glomerata soil in summer is 24 times different.

Except for the spring Zea mays, where the number of genera was equal in the upper and lower layers, the number of mite individuals, genera, and individual densities in spring and summer in all habitats showed that the number of mites in the upper layer of soil > the lower layer of soil, i.e. decreasing with increasing soil depth, showing obvious surface aggregation characteristics; among them, the three grass cultivation patterns had stronger surface aggregation of soil mites, with a 24 times difference in the number of mite individuals in the upper and lower layers of duckweed soil in summer.

3.3. Differences and similarities in community diversity

The variation in the Shannon diversity index \( (H) \), Margalef richness index \( (SR) \), and Pielou evenness index \( (J) \) of the soil mite community across habitats are shown in figures 2(A)–(C). The values of each index for the summer Zea mays were significantly different \( (P < 0.05) \) from the three grass cultivation patterns.

From the values of each index in the same season, the changes in the mean values of diversity index and richness index in spring both showed a trend of Lolium perenne > Zea mays > Trifolium repens > Dactylis glomerata and in summer both showed a trend of Lolium perenne > Dactylis glomerata > Trifolium repens > Zea mays (figures 2(A), 2(B)); the change in mean values of evenness indices in spring was Zea mays > Lolium perenne > Dactylis glomerata > Trifolium repens, and in summer was Zea mays > Dactylis glomerata > Lolium perenne > Trifolium repens (figure 2(C)).

The seasonal variation of the indices showed that the diversity index was higher in summer than in spring across all sites (figure 2(A)); the richness index showed a pattern consistent with the diversity index, except for Zea mays, where the mean value was higher in spring than in summer; the evenness index showed slight variation in spring and summer in all habitats, except for Trifolium repens, where the mean value was much higher in summer than in spring (figure 2(C)).

From the indices of the vertical layers of soil sampled during the same period (spring and summer) (figure 2(D)), the mite diversity and richness indices of the 0-5 cm soil layer (upper layer) were greater than those of the 5-10 cm layer (lower layer) under the same habitat, while the evenness indices were basically the same in

Figure 2. Seasonal and vertical changes of diversity index \( (H) \), richness index \( (SR) \) and evenness index \( (J) \) on soil mites under different grass cultivation patterns.
the upper and lower layers. The soil mite diversity and richness indices in the upper layer varied from \( \text{Lolium perenne} > \text{Dactylis glomerata} > \text{Trifolium repens} > \text{Zea mays} \) in different habitats, and the lower layer varied from \( \text{Lolium perenne} > \text{Trifolium repens} > \text{Dactylis glomerata} \), while the evenness index did not vary significantly.

The Jaccard community similarity index \((q)\) calculations for soil mites in four different habitats (table 3) showed that the similarity of soil mite communities between the two habitats was low, except for \( \text{Lolium perenne} \) and \( \text{Dactylis glomerata} \), which showed medium similarity, and all of them showed medium dissimilarity.

The box plots show the maximum and minimum values in the upper and lower horizontal lines, respectively. Boxes indicate 50% intervals of variation, and the horizontal lines in the boxes indicate the mean of the corresponding indicators. Values marked with different lowercase letters in the graph indicate significant differences between habitats in the same season.

### 3.4. Ecological group of predatory gamasid mites (Mesostigmata: Gamasina)

Assign \( K- \) or \( r- \) values to predatory gamasid mites according to the egg-laying rate per day and developmental rate; other factors are dispersal ability and stability of populations. The specific assignment criteria were carried out regarding Ruf 1998, Wu 2006 and Chen 2018c (table 4). The results of the calculation of the maturity index \( MI \) of leather mites in each habitat are shown in table 5. The results showed that the mites of \( \text{Dactylis glomerata} \), \( \text{Trifolium repens} \) and \( \text{Zea mays} \) in spring were predominantly \( K- \) selective, and \( \text{Lolium perenne} \) was predominantly \( r- \) selective; all others were predominantly \( r- \) selective. This indicates that the soil leather mites in the study area are mainly taxa that adopt a reproductive response.

### 3.5. Community structure differences in Oribatid group

The results of the soil mite community structure MGP analysis under different grassing patterns are shown in table 6. In terms of percentage of individuals, \( \text{Lolium perenne} \) was O type except for spring when it was G type; \( \text{Dactylis glomerata} \) was GP type in summer and P type in both spring and spring+summer; \( \text{Trifolium repens} \) was P type in all seasons, and \( \text{Zea mays} \) was mainly G type. In percentage of genus, \( \text{Lolium perenne}, \text{Dactylis glomerata}, \) and \( \text{Zea mays} \) were all O types; \( \text{Trifolium repens} \) was different in spring, summer, and spring+summer, and M types, O types and MG types respectively. In comparison, more significant variation in the percentage of individual numbers of soil mite ecotypes was seen between habitats.
significantly in the three grass cultivation patterns environments compared to Zea mays. This may be due to the

4.1. Effect of the grass cultivation patterns on the community structure of soil mites
The grass cultivation patterns in the rocky desertification zone had a significant impact on the structure and composition of the soil mite community. First, the number of soil mite genera and individuals increased significantly in the three grass cultivation patterns environments compared to Zea mays. This may be due to the

Table 6. Ecological groups of soil mites (Oribatida).

| Habitat | Season | Percent of individual number(%) | Community type | Percent of genus number(%) | Community type |
|---------|--------|---------------------------------|----------------|---------------------------|----------------|
| L.      | Spr.   | 17.78 56.89 25.33               | G              | 31.82 40.91 27.27         | O              |
|         | Sum.   | 28.24 34.55 37.21               | O              | 21.74 47.83 30.43         | O              |
|         | Spr.+Sum. | 23.76 44.11 32.13          | O              | 29.41 44.12 26.47         | O              |
| D.      | Spr.   | 9.24 17.93 72.83               | P              | 23.53 41.18 35.29         | O              |
|         | Sum.   | 5.61 47.66 46.73               | GP             | 26.67 46.67 26.67         | O              |
|         | Spr.+Sum. | 7.29 33.92 58.79          | P              | 25.00 45.83 29.17         | O              |
| T.      | Spr.   | 21.93 20.86 57.22               | P              | 53.33 26.67 20.00         | M              |
|         | Sum.   | 21.88 19.38 58.75               | P              | 41.67 41.67 16.67         | O              |
|         | Spr.+Sum. | 21.9 20.17 57.93          | P              | 44.44 38.89 16.67         | MG             |
| Z.      | Spr.   | 24.56 63.16 12.88               | G              | 30.00 30.00 40.00         | O              |
|         | Sum.   | 18.81 67.33 13.86               | G              | 25.00 37.50 37.50         | O              |
|         | Spr.+Sum. | 20.89 65.82 13.29          | G              | 28.27 28.57 42.86         | O              |
Table 7. Ecological groups of soil mites (Oribatida).

| Soil environmental factors                              | L         | D         | T         | Z         | F         | P         | Abbreviations |
|---------------------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|---------------|
| **Chemistry factors (n = 3)**                            |           |           |           |           |           |           |               |
| pH value                                                | 5.48 ± 0.13 ab | 5.23 ± 0.07 b | 5.42 ± 0.17 ab | 5.84 ± 0.19 a | 2.95 | >0.05 | pH           |
| Soil organic matter (g/kg)                              | 34.97 ± 2.13 a | 39.43 ± 4.28 a | 44.63 ± 3.52 a | 37.43 ± 1.65 a | 1.77 | >0.05 | SOM          |
| Total nitrogen (g/kg)                                   | 2.07 ± 0.13 a | 2.18 ± 0.17 a | 2.37 ± 0.12 a | 2.03 ± 0.06 a | 1.43 | >0.05 | TN           |
| Total phosphorus (g/kg)                                 | 0.63 ± 0.08 a | 0.55 ± 0.04 a | 0.66 ± 0.07 a | 0.6 ± 0.04 a | 0.61 | >0.05 | TP           |
| Total potassium (g/kg)                                  | 3.27 ± 0.33 a | 2.72 ± 0.2 ab | 2.25 ± 0.16 b | 2.24 ± 0.16 b | 4.75 | <0.05 | TK           |
| Alkaline nitrogen (g/kg)                                | 0.22 ± 0.03 a | 0.19 ± 0.02 a | 0.23 ± 0.02 a | 0.19 ± 0.01 a | 1.25 | >0.05 | AN           |
| Available phosphorus (mg/kg)                            | 4.05 ± 0.44 b | 4.05 ± 0.53 b | 11.04 ± 1.84 a | 5.68 ± 0.6 b | 10.42 | <0.01 | AP           |
| Available potassium (mg/kg)                             | 37.69 ± 0.28 b | 61.65 ± 7.98 a | 70.49 ± 8.11 a | 31.86 ± 2.23 b | 10.26 | <0.01 | AK           |
| **Physical factors (n = 6)**                            |           |           |           |           |           |           |               |
| Bulk density (g/m³)                                     | 1.28 ± 0.06 ab | 1.19 ± 0.06 b | 1.18 ± 0.05 b | 1.46 ± 0.14 a | 2.27 | >0.05 | BD           |
| Saturated water content (%)                             | 33.65 ± 2.71 ab | 38.31 ± 3.12 a | 36.36 ± 1.77 a | 28.68 ± 1.89 b | 2.93 | >0.05 | SWC          |
| Natural water content (%)                               | 16.04 ± 1.72 ab | 17.37 ± 0.89 a | 14.35 ± 0.71 ab | 12.65 ± 1.27 b | 2.85 | >0.05 | NWC          |
| Porosity (%)                                            | 51.68 ± 1.99 ab | 54.67 ± 2.08 a | 54.92 ± 1.7 a | 45.79 ± 4.54 b | 2.27 | >0.05 | P            |

Values marked with different lowercase letters in the same row indicate significant differences between sites \((p<0.05)\), and data are presented as mean ± standard error.
fact that *Zea mays* under traditional tillage have undergone field management practices such as sowing, tilling, fertilizer application and weeding, and that anthropogenic disturbances have reduced the density and diversity of soil mite communities (David et al. 2002, Gormsen et al. 2005, Cao et al. 2011, Han et al. 2013), especially resulting in the reduction and even disappearance of rare groups (Beare et al., 1997, Maribie et al. 2011, Crotty et al. 2016). In addition, differences in the dominant genera of soil mites were found in this study between traditional farming environments and grass cultivation environments. Chen Hu’s study (Chen et al. 2018b) on soil mites in different types of rocky desertification zone found that *Scheloribates* and *Parholaspulus* were mainly distributed in potential and light stone desertification environments. In contrast, *Tectocepheus* was mainly distributed in intense rocky desertification environments. It was also shown *Tectocepheus* often inhabited disturbed or early
successional environments (Bedano et al. 2006, Krantz and Walter 2009). In this study, the dominant genus in the maize field was Tectocephus. In the grass cultivation restoration environment, the dominant genus were Scheloribates and Parholaspulus, with an increase in rare groups, suggesting that traditional agricultural activities have to some extent contributed to the expansion of the extent of rocky desertification and that the ecological conditions in the grass cultivation restoration are truly in the direction of initial recovery and suitable for more the gorps of soil mites.

Secondly, there were also differences in soil mite community structure between the three grass cultivation patterns. The number of genera, number of individuals, and density of individuals showed a variation of Lolium perenne > Dactylis glomerata > Trifolium repens, and the dominant genera were not wholly consistent among the different grass cultivation patterns. The proportion of common genera between the two samples was not high, indicating the differential distribution of soil mite communities under different grass cultivation patterns. It has been shown that differences in plant species, community diversity, biomass, and cover under different grass cultivation patterns influence the composition and diversity of soil faunal communities (Bardgett et al. 2010, Saitoh et al. 2014, Li et al. 2019). The Lolium perenne and Dactylis glomerata are grasses of the family gramineae, with a fibrous root system, shallow roots, and broader distribution. At the same time, Trifolium repens is a leguminous, creeping undergrowth grass with a taproot system and deep roots (Wang 2006). The different tiller characteristics and clump morphology of different forage plants affect plant community cover. An increase in forage cover can effectively reduce soil water loss and slow down soil temperature changes, leading to changes in community microclimate, which in turn has direct and indirect effects on soil mite community structure (Koricheva et al. 2000, Ammer et al. 2006, Saitoh et al. 2014, Reese et al. 2018). In addition, the higher root biomass and root density per unit volume and larger specific surface area of grassy fibrous forage grasses provide more diverse food resources and a more suitable habitat for soil mites (Crotty et al. 2006, Vannoppen et al. 2017), which is conducive to the enrichment of soil mites.

4.2. Effect of the grass cultivation patterns on the diversity and similarity of soil mite communities
Species diversity is an essential indicator of the biological composition of a community. It can effectively reflect the complexity and stability of the community environment as a whole, i.e. the better the habitat conditions, the greater the number and variety of soil mites, the higher diversity index and evenness index will be (Qian and Ma 1994). It is crucial to carry out relevant research to study the whole ecosystem. In this study, the diversity index and the richness index were highest in the Lolium perenne environment, and the evenness index was highest in the Zea mays environment; the diversity index and richness index showed consistent patterns of variation between different sample plots in the same season, and the upper layer was higher than the lower layer in the same habitat, indicating that there was seasonal variation and vertical soil layer variation in each index, which is generally consistent with the results of existing studies (David et al. 2002, Pazliya et al. 2019).

Community similarity is a quantitative indicator of the degree of similarity in community composition, which can reflect communities’ successional changes and interrelationships to a certain extent (Ajar et al. 2017). In this study, we found that soil mite community similarity was highest in Lolium perenne and Dactylis glomerata samples, which were medium similar, and lowest in white Trifolium repens and Dactylis glomerata samples, which were medium dissimilar; consistent results were also obtained by CCA analysis, showing that soil mite communities responded to different grass cultivation patterns in the rocky desertification area. This indicates that although soil mites are well restored under the grass cultivation restoration patterns, there were still significant variation in the effectiveness of restoration. It also demonstrates that the three selected habitat types differ significantly and are highly representative, which has particular research significance.

4.3. The effect of the grass cultivation patterns on the ecological groups of soil mites
Gamasina and Oribatida are the two main groups in the soil environment, and the type of ecological strategy of the predatory mites and oribatida are often used as an crucial indicator of the quality and stability of the ecosystem (Xie et al. 2004). In an excellent ecological environment with low disturbance, predatory mites were dominated by K-selective types, which were replaced by r-strategists with faster reproduction rates and better adaptability as the disturbance level increased, and the mite community was dominated by O and P types (Ruf 1998, Arroyo et al. 2005). The oribatida were mainly O and P type, with the Zea mays environment dominated by G type in terms of the percentage of oribatida individuals, which is more similar to the restoration characteristics of predatory mite and mite ecotypes under the ecological restoration of moderately degraded grassland in Songneng grassland and degraded red soil area in Yujiang, Jiangxi(Yin et al. 2003, Wu et al. 2006, Ding et al. 2008). This indicates that the restoration of soil mites and soil environment has been improved under the grass cultivation restoration patterns in the study area.
4.4. The effect of soil environmental factors on soil mite communities

Differences in soil environmental factors between different grassland restoration patterns can influence the community structure of soil mites. In this study, soil TK content was found to be significantly and positively correlated with the number of soil mite genera and the richness index, indicating that soil potassium content is an important environmental factor affecting soil mite communities, which is consistent with the results of other studies (Li et al 2019). It was found that within a specific range, increasing TK content could promote plant uptake of nitrogen and enhance plant quality and biomass (Liu et al 2010, Zhang et al 2011), while plants are the primary indirect and direct food source for soil mites (Yin et al 2004, Irmler 2006, Minodora 2013, Lin et al 2018); therefore, a specific range of soil environmental potassium content is beneficial to increase soil mite density and genus number. In addition, the number of soil mite genera, individuals, and diversity indicators were found to be negatively correlated with SOM, TN, TP, and AP in this study, with low correlation with soil physical properties, which is not entirely consistent with the results of existing studies (Chen et al 2018a, Liu et al 2020), indicating the complexity of the relationship between soil mite community structure and distribution and soil physical and chemical properties. Therefore, the relationship between mite community parameters and soil environment still needs long-term monitoring and in-depth research.

5. Conclusions

In summary, the implementation of grass cultivation in the degraded rocky desert ecological zone not only significantly increased the content of soil TK, AP, and AK but also improved the nutrient supply of soil nitrogen, phosphorus, and potassium; and, to a certain extent, increased the number of soil mite genera, individual numbers, individual density, diversity, and richness, which had a positive effect on the improvement of soil quality and the restoration and conservation of soil mite communities in the region. In addition, the composition and structure of soil mite communities under different grass cultivation restoration patterns showed some differences, among which the Lolium perenne restoration patterns had a more diverse and complex soil mite community composition. Still, it was not as good as Trifolium repens restoration mode in improving soil fertility; therefore, it is recommended that Lolium perenne and Trifolium repens be scientifically mixed or rotated when planting in the rocky desertification area to enhance soil biodiversity and ensure. As the soil mites were investigated at the peak of forage growth, and the relationship between soil mites and soil physicochemical properties is complex. Therefore, long-term and in-depth studies on soil mite community dynamics during vegetation restoration and their correlation with vegetation and soil environmental factors are needed in the future.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Conflict of interest statement

The authors declare no conflicts of interest.

Ethics statement

Not applicable.

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