Tropical Grasslands-Forrajes Tropicales (2022) Vol. 10(2):89–97
doi: 10.17138/TGFT(10)89-97

Research Paper

Land use effects on soil macrofauna communities in a mountainous region of southwest Guizhou, China

Efectos de los usos contrastantes de la tierra sobre las características del suelo y la macrofauna en una región montañosa del condado de Xingren, Guizhou, China

XUEDONG YANG[1,2], LEILEI DING[3], JIAJIA LIU[3], LI LI[4], JINGZHONG CHEN[1], JIMING LIU[1] AND PUCHANG WANG[3]

[1]*College of Forestry/Forest Ecology Research Center, Guizhou University, Guiyang, Guizhou, China.* gzu.edu.cn
[2]*Guizhou Extension Station of Grassland Technology, Guiyang, Guizhou, China.*
[3]*Guizhou Academy of Agricultural Sciences, Guiyang, Guizhou, China.* aas.guizhou.gov.cn
[4]*Guizhou Vocational College of Agriculture, Guiyang 551400, Guizhou, China.* gznyzyxy.cn

Abstract

An experiment to compare the effects of land use types on soil and macrofauna characteristics was conducted in a mountainous region of southwestern China. Soil physical and chemical properties and soil macrofauna were investigated in four land use types: natural grassland, mixed pasture of *Dactylis glomerata* L. and *Trifolium repens* L., mixed pasture of *Holcus lanatus* L. and *Trifolium repens* L., and cropland planted with annual *Brassica napus* L. and *Zea mays* L. rotation. The results showed that natural grassland, mixed pasture and cropping increased soil pH (23.0%–36.0%), soil organic matter (69.1%–73.9%, except the cropland with a decrease of 18.9%), total nitrogen (346.2%–738.5%), available nitrogen (389.9%–482.7%), available phosphorus (61.9%–303.6%) and available potassium (326.2%–481.4%). The taxonomic richness of macrofaunal communities was lower in the mixed pasture and cropped land than in natural grassland, with the Shannon's index and Menhinick index being negatively related to soil organic carbon content. The mixed pasture maintained the abundance and diversity of soil macrofauna. The short-term cessation of utilization and management facilitated the restoration of soil macrofaunal communities. This study shows that pasture/grazing or leaving fallow for a year after cropping were able to better sustain macrofaunal communities in this mountainous region.

Keywords: Grassland, soil disturbance, soil properties.

Resumen

Se realizó un experimento para comparar los efectos de los tipos de uso de la tierra sobre las características del suelo y la macrofauna en una región montañosa del suroeste de China. Se investigaron las propiedades físicas y químicas del suelo y la macrofauna del suelo en cuatro tipos de uso de suelo: pastizal natural, pastizal mixto de *Dactylis glomerata* L. y *Trifolium repens* L., pastizal mixto de *Holcus lanatus* L. y *Trifolium repens* L., y tierras de cultivo sembradas con rotación anual de *Brassica napus* L. y *Zea mays* L. Los resultados mostraron que los pastizales naturales, los pastos mixtos y los cultivos aumentaron el pH del suelo (23.0%–36.0%), la materia orgánica del suelo (69.1%–73.9%, excepto la tierra de cultivo con una disminución de 18.9%), nitrógeno total (346.2%–738.5%), nitrógeno disponible (389.9%–482.7%), fósforo disponible (61.9%–303.6%) y potasio disponible (326.2%–481.4%). La riqueza taxonómica de las comunidades de macrofauna fue menor en los pastos mixtos y tierras de cultivo que en los pastizales naturales; el índice de Shannon y el índice de Menhinick se relacionaron negativamente con el contenido de carbono orgánico del suelo. El pasto mixto

Correspondence: J.M. Liu, College of Forestry, Guizhou University, Guiyang, 550025, Guizhou, China; E-mail: karst0623@163.com

mantuvo la abundancia y diversidad de la macrofauna del suelo. El cese a corto plazo de la utilización y manejo facilitó la restauración de las comunidades de macrofauna del suelo. Este estudio muestra que el pastoreo, del barbecho por un año permitió sostener mejor las comunidades de macrofauna en esta región montañosa.

Palabras clave: Alteración del suelo, pradera, propiedades del suelo.

Introduction

More than 90% of natural grasslands in Guizhou province were formed by destruction of the original forests or woodlands and are dominated by dwarf shrubs (*Salix inamoena* Hand.-Mazz., *Vaccinium fragile* Franch.), *Eragrostis nigra* Nees ex Steud. and other minor grass species (Ding et al. 2020). The natural shrubby tussock type grassland was further transformed to pasture and cropland because of the rapid increase in the local human population and the need for increased agricultural output over the past 30 years (Peng 2006). This resulted in the cultivation of nearly 20% of farming land on slopes steeper than 25 degrees (Long et al. 2002). This land was often abandoned after a few years due to the decline in soil quality, falling into a vicious cycle of cultivation-degradation-discarding-reclamation (Wan et al. 2004). This cycle results in rapid changes in soil quality and soil macrofauna communities (Long et al. 2006; Ye and Zhou 2009).

Previous studies have suggested that mountainous ecosystems are vulnerable to human disturbances such as land use change and related management practices and the status of soil nutrients, which is closely related to land use type (Zhang et al. 2013; Gao et al. 2014; Bing et al. 2016). Land use is considered the primary driver of soil nutrient levels due to the overlying vegetation and resulting inputs and outputs of nutrients (Long et al. 2006; Wang et al. 2014). In most cases, soil nutrient content decreased and bulk density increased after the conversion of natural soils to farming systems, the destruction of virgin vegetation or the erosion of topsoil (Liu et al. 2009; Ouyang et al. 2013; Poeplau and Don 2013; Yang et al. 2012). However, the content of soil organic carbon, soil total nitrogen, and soil available phosphorus have also been shown to increase after grassland was converted to cropland in an intensive agricultural region (Kong et al. 2006). Both the density and storage of the soil carbon and nitrogen are significantly higher in farming systems than in forests of subtropical China (Gao et al. 2014). From a soil resource conservation perspective, adjusting land use was the preferred method of achieving regional ecological reestablishment and sustainable agriculture development (Long et al. 2006). Therefore, it is important to know how soil quality is affected through changing land use in the eco-fragile mountainous regions of Guizhou.

Soil macrofauna are considered as one of the most sensitive indicators of changes in soil quality and has a significant impact on soil formation (Edwards et al. 1990). They are also important in ecosystem functioning because they improve nutrients by the regulation of nutrient cycling through decomposition processes and modification of physical properties of the soil (de Bruyn 1997; Ekschmitt and Griffiths 1998; Lavelle et al. 2001; Wolters 2001). Soil macrofauna communities are best conserved when the derived system has a similar structure with the original system, demonstrated in pastures and agroforestry systems established in savanna areas and the western Brazilian Amazonia (Fragoso et al. 1997; Barros et al. 2002; Decaëns et al. 2004).

The purpose of this study was to understand how land use influences soil quality and optimizes the use of scarce land in Guizhou, China through a study on soil properties and macrofauna communities in different farming systems derived from shrubby tussock type grassland. We hypothesized that the introduction of grass-based land use systems would have a favorable effect on the development and abundance of diverse soil macrofauna and assist in the conservation of soil quality.

Materials and Methods

Study site

The experimental site (25.56°N, 105.17°E, 1678 m) selected was in the transition zone of the Yunnan–Guizhou plateau to Guangxi's low hills, 24 km southwest of Xingren County. The climate is humid sub-tropical with an annual mean temperature of about 12 °C, an annual mean rainfall of 1300 mm, about 280 frost-free days and 1100 h of annual mean sunshine. The main soil type is Udalf.

Experimental plots

Experiments were carried out in August at the Fangmaping Goat Breeding Farm of Xingren County, Guizhou, China, which has a karstic landscape. The following 4 land use types were examined: natural grassland (NG), mixed pasture of cocksfoot and white clover (CP), mixed pasture of Yorkshire fog and white clover (YP), and cropland (C). NG is a dwarf shrubby grassland and consists mainly of *Eragrostis nigra* Nees along with secondary species of *Imperata cylindrica* (L.) Raeusch. and *Potentilla siemersiana* Lehm, and other minor grass species. The average height was 40 cm and vegetation coverage was 90% in August over an area of more than 100 hectares. The land was occasionally grazed by buffaloes, local beef cattle and goats in spring and winter, with a grazing intensity equivalent to 1 sheep/ha. The CP mixed pasture covering about 100 ha was converted from natural grassland 20 years earlier. The dominant *Dactylis glomerata* L. and the secondary species of *Trifolium repens* L. account for 95% of the coverage. The pasture was rotationally grazed by goats during all seasons for more than ten years with a grazing intensity equivalent to 9.5 sheep/ha. The pasture received fertilizer twice annually in March and October, with 180 kg urea/ha (N ≥ 46.4%) and 225 kg compound fertilizer/ha (N:P:K=10:7:8). The mixed pasture YP of about 100 ha was converted from natural grassland 20 years earlier. The dominant *Holcus lanatus* L. and the secondary species of *Trifolium repens* L., account for 100% of the coverage. The grazing pattern and fertilization practices were similar to those of CP. The cropland was about 50 ha and converted from natural grassland more than 20 years earlier and subjected to a rotation of rape (*Brassica napus* L.) and maize (*Zea mays* L.). The maize was sown in late April after ploughing (with a depth of 10–15 cm) and harvested in late October, while rape was sown in mid-November and harvested in the following mid-April. The field was prepared with 780 kg urea/ha and 450 kg compound fertilizer/ha.

Farming activities, including fertilizer application, grazing, sowing, harvest and cultivation, were not considered treatments in this study. Therefore, the periods when these farming activities could have had a dramatic effect on the soil in the short term were avoided. In addition, studies were only done in summer when soil macrofauna are most active.

Soil sampling and analyses

In each land use type, 3 sampling sites were randomly selected, with the distance between soil sampling sites more than 50 m. Three 1 m × 1 m sampling points with a distance of about 10 m between each were randomly selected in each site. Soil was sampled at a depth of 30 cm from the three sampling points and mixed as a soil sample. Soil samples were sieved through a 2 mm mesh, all large root debris removed and then air-dried. The soil was tested for bulk density (BD, using the cutting-ring method and the weighted average of soil bulk density in 0–10, 10–20 and 20–30 cm layers), pH (1:2.5 H_2O w/v), soil organic carbon content (SOC, Walkley–Black), total nitrogen (TN, Kjeldahl), available nitrogen (AN, alkaline hydrolysis diffusion), available phosphorus (AP, photocolorimetery) and available potassium (AK, flame photometry). These analyses were conducted by the analytical laboratory of Beijing Academy of Agricultural and Forestry Science.

In addition, plots of 1,000 m^2 were protected near the soil sampling points from CP, YP, and C and left ungrazed and/or fallow for one year before the sampling date. The corresponding fallow lands were denoted as CPs, YPs, and Cs, respectively. Only soil macrofauna were collected and analyzed from these plots.

Macrofauna collection

Collection of soil macrofauna was completed in two days following a protocol described in Anderson and Ingram (1994). In this study, soil macrofauna were not investigated by stratified sampling because of the strongly vertical migration ability of the macrofauna. Macrofauna sampling for each land use type was based on three soil monoliths of 50 cm × 50 cm × 30 cm that were at least 10 m from each other and at least 30 m from soil sampling points. Existing plants were cut and removed from the soil surface. The macrofauna were excavated, hand-sorted in a box, and stored in a 75% ethanol solution. After transport to the laboratory, the macrofauna were dried by blotting with filter paper and identified according to 'Entomology' (Nankai University 1980) and 'Pictorial Keys to Soil Animals of China' (Yin 1998) and the fresh biomass was then counted and weighed. Sampled macrofauna individuals were identified at the level of order. If present, larvae and adults of the same taxonomical order were counted separately. Earthworms were classified as Oligochaeta. Soil macrofauna density was calculated as the individual number per square meter.

Statistical analysis

The diversity of soil macrofauna in the study area was calculated using the Shannon–Wiener diversity index and Simpson index model (Shao et al. 2019). The richness and evenness of soil macrofauna was calculated using the Menhinick index and Evenness index, respectively. The models used were as follows:

Shannon's index (H') = $-\Sigma\, Pi \ln Pi$

Evenness index (E) = $H'/\ln S$

Simpson index (C) = $\Sigma\, (ni/N)^2$

Menhinick index (D) = $\ln S/\ln N$

where:

$Pi = ni/N$;

ni is the individual density of each group;

N is the total individual density; and

S is the species richness (the number of taxonomic groups).

Macrofauna groups present in each land use system were classified into three dominance groups according to their relative density; as dominant groups ($P_i \geq 10.0\%$), common groups ($10\% \geq P_i \geq 1.0\%$), and rare groups ($P_i \leq 1.0\%$) where P_i is the relative density of group i.

As soil macrofauna can be directly related to soil properties, Redundancy analysis (RDA) is considered as a direct gradient analysis method. Therefore, RDA was used for relationship building between the total individual number of each group of soil macrofauna and the average soil properties to study the effect of land use on soil macrofauna.

Differences between means were analyzed by analysis of variance (ANOVA) followed by the least significant difference (LSD) test at a significant level of P<0.05 using IBM SPSS version 16.0.

Results

Soil physical and chemical characteristics

Soils from the natural grassland and the cropland had the highest soil bulk density (1.41 g/cm^3) among all samples (Table 1). All soils were acidic (pH 3.5–4.8) with the soil sampled from natural grassland having the lowest pH value. Soil organic C content was highest in the pastures and lowest in the cropland. Total N content and available nutrient content increased significantly after the conversion of natural grassland to pasture or to cropland. In particular, TN, AN, and AK contents were greatest in CP soils.

Soil macrofauna community composition and abundance

Soil macrofauna were collected and identified from 21 soil monoliths of 7 sample plots. These individuals belonged to 3 phyla, 5 classes and 8 orders. Among all sampling sites, the dominant groups were Haplotaxida (49.9%) and Coleoptera (34.3%). At the class level, Oligochaeta (49.9%) and Insecta (47.5%) dominated. Detritivores (49.9%) and herbivores (47.0%) were the two main functional groups in this area.

The lowest individual density and biomass were recorded in C (15/m^2, 3.8 g/m^2) and Cs (28/m^2, 2.6 g/m^2). The highest density (256/m^2) and biomass (59.9 g/m^2) were found in CPs, partly due to the large number of earthworms (180/m^2, 49.4 g/m^2). The pasture and cropland had lower macrofauna richness than the natural grassland. Discontinued utilization and management for one year increased the macrofauna richness in the pasture and cropland (Table 2).

The dominant groups were Haplotaxida (49.9%) and Coleoptera larvae (25.2%, excluding adults), accounting for 75% of all soil macrofauna individuals in the study area. The proportion of detritivores and herbivores were 49.9% and 47.8%, respectively. The rhizophagous groups had the lowest densities in cropland with

Table 1. Soil chemical and physical characteristics (mean ± SD) of 4 different land use types.

Characteristics	Land use types			
	NG	CP	YP	C
BD (g/cm^3)	1.41 ± 0.03^a	1.02 ± 0.01^c	1.07 ± 0.02^b	1.41 ± 0.02^a
pH ($_{1:2.5,\ water}$)	3.53 ± 0.16^c	4.34 ± 0.11^b	4.80 ± 0.19^a	4.42 ± 0.19^b
SOC (g/kg)	5.67 ± 0.21^b	9.59 ± 0.26^a	9.86 ± 0.27^a	4.60 ± 0.21^c
TN (g/kg)	0.13 ± 0.01^d	0.96 ± 0.02^a	0.80 ± 0.02^b	0.45 ± 0.01^c
AN (mg/kg)	64.77 ± 1.37^c	312.66 ± 5.72^a	252.56 ± 5.68^b	258.50 ± 1.95^b
AP (mg/kg)	1.97 ± 0.09^c	3.37 ± 0.15^b	3.19 ± 0.13^b	5.98 ± 0.16^a
AK (mg/kg)	31.61 ± 1.15^d	152.17 ± 3.77^a	103.10 ± 3.22^c	118.37 ± 3.84^b

NG = natural grassland; CP = mixed pasture of cocksfoot and white clover; YP = mixed pasture of Yorkshire fog and white clover; C = cropland.

Within a row, means followed by different lowercase letters are significantly different at P<0.05 (LSD). BD is soil bulk density, SOC is soil organic carbon, TN is total nitrogen, AN is available nitrogen, AP is available phosphorus, and AK is available potassium.

Table 2. Density (individual numbers/m²), dominance and biomass (g/m²) distribution of the soil macrofauna in different land use types.

Macrofauna group	Land use types							Total (%)
	NG	CP	YP	C	CPs	YPs	Cs	
Coleoptera larvae	40 (47.62)	28 (49.12)	53 (45.69)	3 (20.00)	19 (7.42)	20 (19.42)	3 (10.71)	166 (25.19)
Oligochaeta	5 (5.95)	17 (29.82)	52 (44.83)	0 (0)	180 (70.31)	72 (69.90)	3 (10.71)	329 (49.92)
Lepidoptera larvae	24 (28.57)	8 (14.04)	7 (6.03)	1 (6.67)	13 (5.08)	0 (0)	5 (17.86)	58 (8.80)
Coleoptera	8 (9.52)	4 (7.02)	4 (3.45)	9 (60.00)	21 (8.20)	3 (2.91)	11 (39.29)	60 (9.10)
Araneae	5 (5.95)	0 (0)	0 (0)	1 (6.67)	1 (0.39)	0 (0)	3 (10.71)	10 (1.52)
Orthoptera	0 (0)	0 (0)	0 (0)	1 (6.67)	19 (7.42)	4 (3.88)	0 (0)	24 (3.64)
Scutigeromorpha	1 (1.19)	0 (0)	0 (0)	0 (0)	0 (0)	3 (2.91)	1 (3.57)	5 (0.76)
Stylommatophora	1 (1.19)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.57)	2 (0.30)
Dermaptera	0 (0)	0 (0)	0 (0)	0 (0)	3 (1.17)	1 (0.97)	1 (3.57)	5 (0.76)
Total	84	57	116	15	256	103	28	659
Taxonomic Richness	7	4	4	5	7	6	8	9
Total biomass (g/m²)	23.59	10.32	53.15	3.85	59.93	41.64	2.68	195.16
Earthworm biomass (g/m²) (% Total biomass)	10.00 (42.40)	5.48 (53.10)	42.33 (79.65)	0 (0)	49.40 (82.42)	38.77 (93.12)	0.53 (19.90)	146.52 (75.08)

CPs, YPs and Cs correspond to CP, YP and C with discontinued utilization and management for one year, respectively. The relative percentage of each macrofauna group for each land use type is in parentheses.

Coleoptera larvae and Lepidoptera larvae having 3 and 1 individuals/m², respectively. The relative density of Coleoptera larvae in relation to total individual density was highest in natural grassland and mixed pastures. Earthworms were not found in the cropland but in mixed pastures were found with a high relative density and biomass of 29.8%–70.3% and 53.1%–93.1%, respectively (Table 2).

The diversity of soil macrofauna in different land use systems (Figure 1) shows that the Shannon's index of the macrofauna communities in the natural grassland (1.42) was higher than in the farming systems, but the highest diversity and lowest Simpson index in the Cs (1.77 and 0.22) was due to a high group number and a low number of individuals. The Simpson indices in the pastures with no grazing and management were higher than those of the other systems but had the lowest evenness index. The highest Menhinick indices were in C and Cs with 0.59 and 0.63, respectively.

Linkage between soil macrofauna groups and soil properties

RDA was used to analyze the linkage between macrofauna groups and soil properties (Figure 2). Results showed that Coleoptera larvae and Oligochaeta were positively related to soil organic matter but negatively to soil bulk density. Coleoptera and Araneae were positively related to soil bulk density but negatively to soil organic matter. Araneae and Lepidoptera larva were positively related to soil pH. Scutigeromorpha and Stylommatophora were less affected by soil properties.

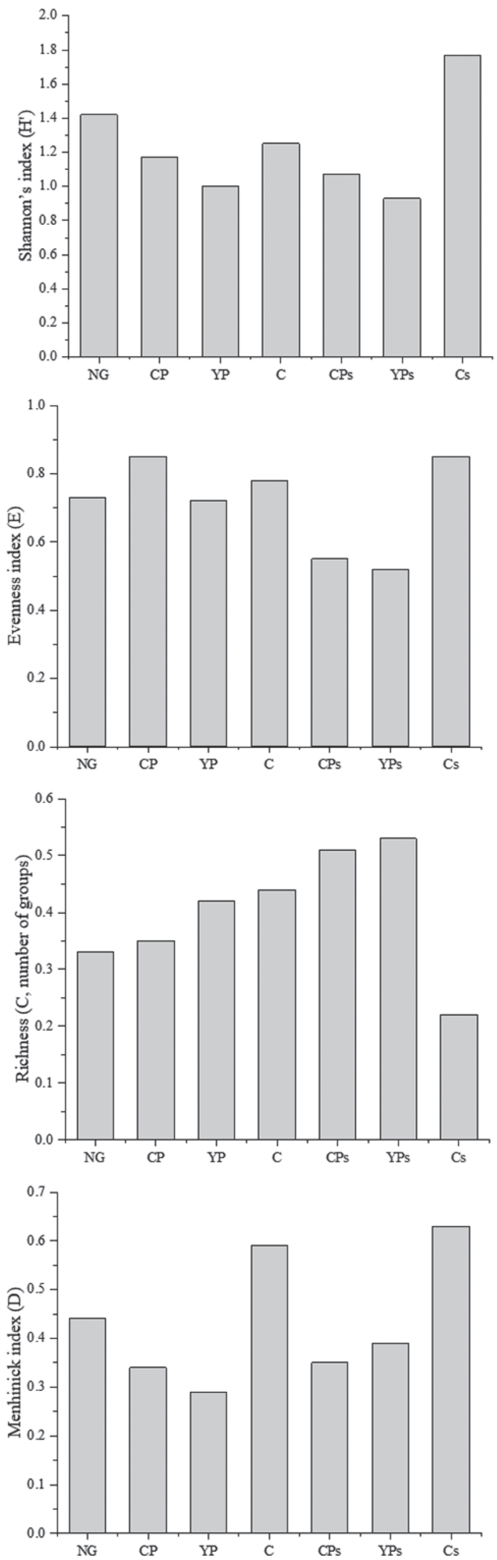

Figure 1. Indices of soil macrofauna diversity in soils of different land use types. Key to land use types: NG = natural grassland; CP = mixed pasture of cocksfoot and white clover; YP = mixed pasture of Yorkshire fog and white clover; C = cropland. «s» after the land use type denotes land was left fallow for 1 year before sampling.

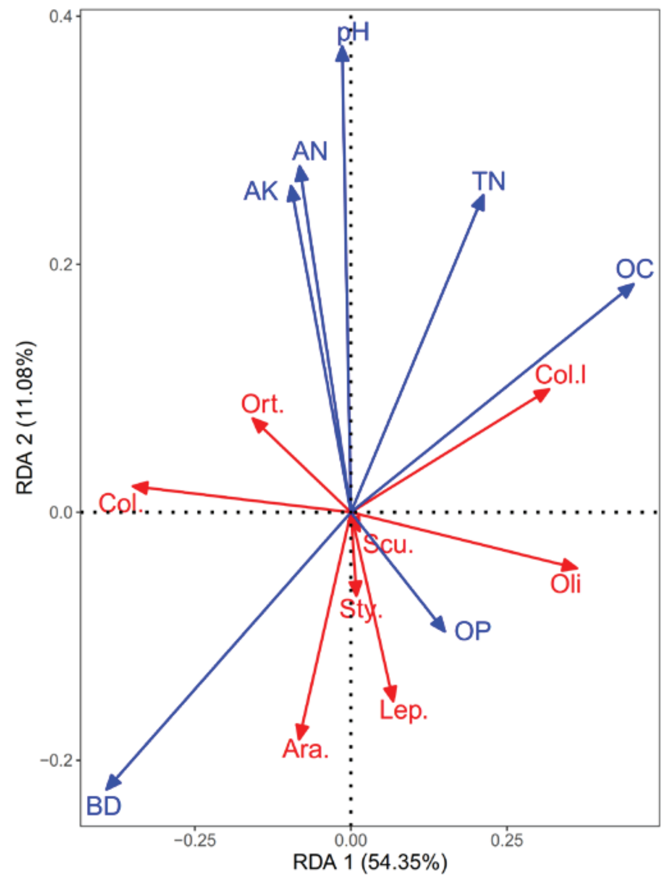

Figure 2. RDA biplot showing correlations between macrofauna groups and soil properties. Soil macrofauna and soil chemical properties are represented by red lines and blue lines, respectively. Macrofauna abbreviations: Col.l = Coleoptera larva; Oli. = Oligochaeta; Lep. = Lepidoptera larva; Col. = Coleoptera; Ara. = Araneae; Ort. = Orthoptera; Scu. = Scutigeromorpha; Sty. = Stylommatophora. For soil acronyms, refer to the Table 1 legend.

Discussion

Effects of land use on soil characteristics

The natural grassland conversion had a significant effect on soil characteristics in this study. Pasture had increased soil pH, soil organic matter, total nitrogen, available nitrogen, available phosphorus and available potassium compared with cropland. This agreed with the study results of Tan et al. (2019) on the soil quality of different land uses in the karst mountainous areas, Guizhou, China. Low soil organic carbon content in cropland could perhaps be linked to the cultivation practices of local farmers and the removal of crop residues (corn and rape) prior to cultivation of the next crop. A high content of total nitrogen, available nitrogen, available phosphorus and available potassium in the pasture and cropland compared with the natural grassland could be linked to fertilizer application prior to the annual cropping cycle. Available phosphorus content was highest in cropland because of the heavy fertilizer application used for planted crops. In the mixed pastures, total nitrogen and available nitrogen contents were higher than those of the other systems studied, which could be a result of nitrogen fixation of white clover. Available nitrogen, available phosphorus, and available potassium in the CP mixed pasture were higher than in the YP mixed pasture, possibly due to the denseness of Yorkshire fog, which prevents fertilizer and animal waste entering the soil.

Effects of soil properties on soil macrofauna

Soil macrofauna were affected greatly by soil bulk density, pH and organic matter. The results in this study agreed with Lu et al. (2018), who studied soil macrofauna diversity in a degraded typical steppe of Inner Mongolia, and Mbau et al. (2015), who studied soil macrofauna diversity and abundance through compost applications in nutrient deficient soils of Kakamega County in Kenya. Soil organic matter could provide a food source for detritivores and herbivores, i.e. Oligochaeta and Coleoptera larva. However, high soil bulk density inhibited the activity and survival of macrofauna. Soil pH could affect soil macrofauna groups by affecting the survival environment of macrofauna eggs, food supply or number of pathogenic organisms, such as nematodes.

Effects of land use types and discontinued utilization on soil macrofauna

The taxonomic richness and Shannon's index decreased after the natural grassland was converted to cultivation. The same results were reported with respect to the Qinghai–Tibet Plateau, in which the density, taxonomic richness, and Shannon index of soil microarthropod communities decreased significantly in three artificial perennial grasslands compared with the natural grassland (Qiu et al. 2020). However, in the current study the total number of individuals, macrofauna biomass, and the number of earthworms in the YP mixed pasture were highest, possibly due to the moist soil and low soil bulk density, which was due to the suitable environment provided for the soil macrofauna community. The lowest macrofauna densities were registered in the cropland, which was probably related to the low root density and vegetation coverage compared to other systems, as observed during sampling. In addition, the survival of grass grubs (Coleoptera larvae) and earthworms in the cropland was seriously affected by the soil bulk density ($R_{Col.l} = -0.47$, $R_{Oli} = -0.73$) and farming activities. Yin et al. (2010) observed that intensive soil disturbances (burning, grazing, tillage, fertilization) decrease the diversity of the soil macrofauna community, especially for sensitive groups such as earthworms. Soil organic matter in cropland was reduced by removing crop residues, which decreased the food resources of some soil macrofauna. Meanwhile, the soil was so often disturbed that the soil bulk density increased, making it unsuitable for macrofauna.

Nonetheless, macrofauna density, taxonomic richness and biomass, particularly of earthworms, increased in pastures and cropland after a year of rest, suggesting that the practice of fallowing increases the abundance and diversity of soil macrofauna in intensively managed agricultural lands. A similar trend was also observed by Liu et al. (2016) for the soil mite community after short-term grazing exclosure in the Hongsongwa Natural Reserve. The number of Coleoptera larvae decreased significantly in pastures after the discontinued utilization, possibly due to the declining input of animal waste decreasing the attraction for Coleoptera female oviposition (Chen et al. 2004).

Conclusions

The rational utilization of land resources is considered an important measure to maintain ecosystem health and to sustain productive farm systems in eco-fragile regions. Our results demonstrate that farming system intensity influences soil nutrients and macrofauna through grazing, adding fertilizer and growing seasonal crops, and that cultivation can improve soil nutrients but decreases the abundance and diversity of soil macrofauna in karst areas. Pastures had increased number of individuals, biomass and richness of macrofauna, while cropping decreased the number of individuals and biomass of macrofauna, especially earthworms. Our data also suggest that stopping disturbances in the short term can increase the abundance and diversity of soil macrofauna, especially earthworms, which are essential for improving soil structure and nutrient status. The experiment should be continued over the longer term to understand the impacts of different land use types, vegetation types and soil disturbance activities on soil nutrients and macrofauna. Studies involving the interaction of different land use types and soil disturbance could help to understand soil macrofauna variation which, in turn, may assist in the conservation of soil quality and provide favorable patterns of land use. It is important that land is developed properly with both ecological and economic benefits, especially in typical eco-fragile karst areas. Conversion to pasture would have a lower negative influence on soil nutrients and macrofauna communities. Other important practices for sustaining farming systems with a higher level of soil nutrients and macrofauna communities include via fallowing/rest-grazing or via a pasture/grazing and cropping rotation.

Acknowledgments

We thank Tao Wang and Richard Sim for their help in the writing process and the reviewers who provided insightful suggestions that helped to improve the manuscript. This research was funded by the National Natural Science Foundation of China (NSFC) (31960341), the Guizhou Province Key Research and Development Program of China (Qiankehezhicheng[2017]2586), the Guizhou Province Natural Science Foundation of China (Qiankehejichu[2018]1419), the Special Program for Service Enterprises of Guizhou of China (Qiankehefuqi[2018]4001), and the Program for Guizhou Province Innovative Research Team of China (Qiankeherencai[2016]5617).

References

(Note of the editors: All hyperlinks were verified 12 April 2022).

Anderson JM; Ingram JSI. 1994. Tropical soil biology and fertility: A handbook of methods. Soil Science 157(4):265. bit.ly/365cSB0

Barros E; Pashanasi B; Constantino R; Lavelle P. 2002. Effects of land use system on the soil macrofauna in western Brazilian Amazonia. Biology and Fertility of Soils 35:338–347. doi: 10.1007/s00374-002-0479-z

Bing HJ; Wu YH; Zhou J; Sun HY; Luo J; Wang JP; Yu D. 2016. Stoichiometric variation of carbon, nitrogen, and phosphorus in soils and its implication for nutrient limitation in alpine ecosystem of Eastern Tibetan Plateau. Journal of Soils and Sediments 16:405–416. doi: 10.1007/s11368-015-1200-9

Chen JM; Yu XP; Chen LZ; Lu ZX; Zheng XS; Xu HX; Zhang JF. 2004. Occurrence, damage of the soil-dwelling pests and its management strategy in China. Acta Agriculturae Zhejiangensis 16(6):389–394. (In Chinese) doi: 10.3969/j.issn.1004-1524.2004.06.010

de Bruyn LAL. 1997. The status of soil macrofauna as indicators of soil health to monitor the sustainability of Australian agricultural soils. Ecological Economics 23(2):167–178. doi: 10.1016/S0921-8009(97)00052-9

Decaëns T; Jiménez JJ; Barros E; Chauvel A; Blanchart E; Fragoso C; Lavelle P. 2004. Soil macrofaunal communities in permanent pastures derived from tropical forest or savanna. Agriculture, Ecosystems & Environment 103(2):301–312. doi: 10.1016/j.agee.2003.12.005

Ding LL; Shang YS; Zhang W; Zhang Y; Li SG; Wei X; Zhang YJ; Song XL; Chen X; Liu JJ; Yang FL; Yang XD; Zou C; Wang PC. 2020. Disentangling the effects of driving forces on soil bacterial and fungal communities under shrub encroachment on the Guizhou Plateau of China. Science of the Total Environment 709:136207. doi: 10.1016/j.scitotenv.2019.136207

Edwards CA; Lal R; Madden P; Miller RH; House G. 1990. Sustainable Agricultural Systems. St Lucie Press, Delray Beach, FL, USA. doi: 10.1201/9781003070474

Ekschmitt K; Griffiths BS. 1998. Soil biodiversity and its implications for ecosystem functioning in a heterogeneous and variable environment. Applied Soil Ecology 10(3):201–215. doi: 10.1016/S0929-1393(98)00119-X

Fragoso C; Brown GG; Patrón JC; Blanchart E; Lavelle P; Pashanasi B; Senapati B; Kumar T. 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of earthworms. Applied Soil Ecology 6:17–35. doi: 10.1016/S0929-1393(96)00154-0

Gao Y; He NP; Yu GR; Chen WL; Wang QF. 2014. Long-term effects of different land use types on C, N, and P stoichiometry and storage in subtropical ecosystems: A case study in China. Ecological Engineering 67:171–181. doi: 10.1016/j.ecoleng.2014.03.013

Kong XB; Zhang FR; Wei Q; Xu Y; Hui JG. 2006. Influence of land use change on soil nutrients in an intensive agricultural region of North China. Soil and Tillage Research 88:85–94. doi: 10.1016/j.still.2005.04.010

Lavelle P; Barros E; Blanchart E; Brown G; Desjardins T; Mariani L; Rossi JP. 2001. SOM management in the tropics: Why feeding the soil macrofauna? Nutrient Cycling in Agroecosystems 61:53–61. doi: 10.1023/A:1013368715742

Liu HL; Zhang WH; Wang K. 2009. Effect of reclamation on soil properties of zonal and intrazonal grasslands in agro-pastoral ecotone. Transactions of the Chinese Society of Agricultural Engineering 25(10):272–277. (In Chinese) doi: 10.3969/j.issn.1002-6819.2009.10.049

Liu MP; Qin WH; Li ZL; Wang YJ; Huang JB; Ke X. 2016. Soil mite community structure in response to short-term grazing enclosure and characteristics as indicators of environmental quality in Hongsongwa Natural Reserve. Ecology and Environmental Sciences 25(5):768–774. (In Chinese) doi: 10.16258/j.cnki.1674-5906.2016.05.006

Long J; Huang CY; Li J. 2002. Effects of land use on soil quality in karst hilly area. Journal of Soil and Water Conservation 16(1):76–79. (In Chinese) doi: 10.3321/j.issn:1009-2242.2002.01.019

Long J; Li J; Wang JR; Li YB. 2006. Effects on soil quality properties in process of karst rocky desertification. Journal of Soil and Water Conservation 20(2):77–81. (In Chinese) doi: 10.3321/j.issn:1009-2242.2006.02.019

Lu KL; Teng Y; Li JL. 2018. Influence of enclosure on the diversity of large soil animal community in a degraded typical steppe of Inner Mongolia. Chinese Journal of Ecology 37(9):2680–2689. (In Chinese) doi: 10.13292/j.1000-4890.201809.012

Mbau SK; Karanja N; Ayuke F. 2015. Short-term influence of compost application on maize yield, soil macrofauna diversity and abundance in nutrient deficient soils of Kakamega County, Kenya. Plant and Soil 387:379–394. doi: 10.1007/s11104-014-2305-4

Nankai University. 1980. Entomology. People's Education Press, Beijing, China. (In Chinese)

Ouyang W; Wei XF; Hao FH. 2013. Long-term soil nutrient dynamics comparison under smallholding land and farmland policy in northeast of China. Science of The Total Environment 450–451:129–139. doi: 10.1016/j.scitotenv.2013.02.016

Peng J. 2006. Land use/cover change in ecologically fragile karst areas — a case study in Maotiaohe River Basin. Ph.D. Thesis. Peking University, Beijing, China. (In Chinese).

Poeplau C; Don A. 2013. Sensitivity of soil organic carbon stocks and fractions to different land use changes across Europe. Geoderma 192:189–201. doi: 10.1016/j.geoderma.2012.08.003

Qiu Y; Wu PF; Wei X. 2020. Differences among three artificial grasslands in dynamics and community diversity of soil microarthropods. Acta Prataculture Sinica 29(5):21–32. (In Chinese) doi: 10.11686/cyxb2019444

Shao Y; Cao SP; Cao WW; Liu CH. 2019. Effects of degradation and management of Nanniwan Wetland on soil fauna diversity. Journal of Ecology and Rural Environment 35(5):634–643. (In Chinese) doi: 10.19741/j.issn.1673-4831.2018.0412

Tan YL; Yang F; Chen C; Mo BT; Hao J; Zhou L. 2019. Effects of different land use types on soil quality in karst mountainous area. Southwest China Journal of Agricultural Sciences 32(5):1133–1138. (In Chinese) doi: 10.16213/j.cnki.scjas.2019.5.030

Wan J; Cai YL; Zhang HY; Rao S. 2004. Land use/land cover change and soil erosion impact of karst area in Guanling County, Guizhou Province. Scientia Geographica Sinica 24(5):573–579. (In Chinese) doi: 10.3969/j.issn.1000-0690.2004.05.010

Wang W; Sardans J; Zeng C; Zhong C; Li Y; Peñuelas J. 2014. Responses of soil nutrient concentrations and stoichiometry to different human land uses in a subtropical tidal wetland. Geoderma 232:459–470. doi: 10.1016/j.geoderma.2014.06.004

Wolters V. 2001. Biodiversity of soil animals and its function. European Journal of Soil Biology 37(4):221–227. doi: 10.1016/S1164-5563(01)01088-3

Yang WJ; Cheng HG; Hao FH; Ouyang W; Liu SQ; Lin CY. 2012. The influence of land use change on the forms of phosphorus in soil profiles from the Sanjiang Plain of China. Geoderma 189:207–214. doi: 10.1016/j.geoderma.2012.06.025

Ye Y; Zhou YC. 2009. Influence of microhabitat to community structure of soil macrofauna in karst rocky desertification. Carsologica Sinica 28(4):413–418. (In Chinese) doi: 10.3969/j.issn.1001-4810.2009.04.014

Yin WY. 1998. Pictorical keys to soil animals of China. Science Press, Beijing, China.

Yin XQ; Song B; Dong WH; Xin WD; Wang YQ. 2010. A review on the eco-geography of soil fauna in China. Journal of Geographical Sciences 20(3):333–346. doi: 10.1007/s11442-010-0333-4

Zhang C; Liu GB; Xue S; Sun CL. 2013. Soil organic carbon and total nitrogen storage as affected by land use in a small watershed of the Loess Plateau, China. European Journal of Soil Biology 54:16–24. doi: 10.1016/j.ejsobi.2012.10.007

(Received for publication 29 January 2021; accepted 11 April 2022; published 31 May 2022)