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Original Research Paper

Effect of Enclosure Period on Soil Properties and Characteristics of Plant Community in Degraded Grassland

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ABSTRACT

Artificial enclosure has been an important and practical measure widely used to restore vegetation in the ecologically degraded area. In this study, using a standard plot investigation method, we investigated the changes in biomass and species diversity of the plant communities in the desertified grassland located in Ningxia Autonomous Region, China, after enclosure for 0, 5, 15 and 25 years with fences made up of cement piles and barbed wires, with a complete exclusion of interferences from any activities including grazing. We also analysed the factors driving the changes in these parameters. The results showed that with the increase in the enclosure duration, the soil electrical conductivity and nutrient contents were significantly increased but the thickness of biological crust in the deserted area was not changed regularly and the soil pH values were changed only slightly. Furthermore, while no significant differences in plant biomass, species abundance and α-diversity were seen, significant difference in β-diversity was seen among different enclosure years. Principal component analysis showed the significant differences in species compositions in the deserted grassland among various enclosure years. The redundancy analysis revealed that the available nitrogen, available potassium, soil organic carbon and soil electrical conductivity were the major factors affecting the plant species compositions in the deserted area in the studied region. These findings can be of practical significance for formulating the measures to effectively curb the deterioration of ecological environment in grassland.

INTRODUCTION

Grassland desertification has become a prominent issue for the deterioration of the ecological environment in China. Enclosure and fencing have been widely used as an important measures to restore and reconstruct the ecologically degraded area (He et al. 2008). So far, a large number of studies have been conducted to analyse the effect of enclosure on vegetation restoration in the degraded grassland, and have found that enclosure can significantly improve vegetation and restore the soil in the degraded grassland. However, due to the universality and complexity of the distribution of enclosed deserted grasslands, the impacts of enclosure on the physicochemical properties of soil, and the biomass and species diversity of plants are still controversial (Alice et al. 2005, Matthew et al. 2006). For instance, some studies have found that enclosure has resulted in homogenized habitats after excluding the interference from grazing, which may be the main reason that long-term enclosure reduces plant diversity (Yan et al. 2009). On the other hand, after conducting a systematic study on the restoration of degraded grassland by enclosure, Su and Zhao have observed that enclosure can increase the accumulation of litter and soil organic matter, suggesting that after an appropriate enclosure, accumulation of soil nutrients can be improved in the degraded grassland to provide the necessary nutrients for plant growth and reproduction (Wang et al. 2014). Although the restoration of vegetation after enclosure can happen rapidly, the restoration of soil can be a slow process. However, other studies have also shown that due to the elimination of external interference, enclosure remarkably improves the physical properties of top soil after two and half years, with an increased soil conductivity in unsaturated soil water and reduced soil bulk density as compared with those in grazing land (Greenwood et al. 1998). Mekuria (2007) assessed the effect of enclosure in the northern hilly land in Ethiopia and also found that enclosure not only restored vegetation significantly, but also significantly increased the contents of soil organic matter, total nitrogen and available phosphorus 5 or 10 years later, compared to grazing. In contrast, other studies have shown that enclosure has caused negative effects on soil nutrition, because there are fewer plant roots in the enclosed areas, which is unfavourable for organic matters and their accumulation in the soil, leading to significantly lower soil carbon content as compared with that of the surrounding grazing grassland (Reeder et al. 2001). Therefore, complete enclosure may be not completely sound rational for resource utilization and protection of species diversity (Adler et al. 2004).

The responses of biomass, compositions and diversity of plant community to the enclosure period can reflect the interaction between plants and soil to a certain extent, and are the long-term and complex processes. In the highly ecologically degraded area, both the positive and effective measures can be taken to restore the degraded vegetation and to curb the subsequent ecological environmental problems resulted from the continuing degradation of soil. In this study, we investigated the soil property, the characteristics and biomass of vegetation in the severely degraded sandy grassland in Yanchi, Ningxia after enclosure for 0, 5, 15 and 25 years. Our results have revealed the significant changes in soil and plants over these enclosure periods and the interactions between plant and soil to some extent during restoration of grassland in the deserted grassland. The findings will provide the scientific basis for the development of measures to restore the ecological functions in the degraded grassland and will be of practical significance to curb the deterioration of ecological environment.

MATERIALS AND METHODS

Overview of the study site: The study site is located in Liuyangbao town in the eastern Yanchi County, Ningxia Autonomous Region (37°04'-38°10' N, 106° 30'-107°41' E), and is under the typical temperate continental climate, with the average annual temperature of 8.1°C, the average annual frost-free time of 165 days, and the average annual rainfall of only 250-350 mm at an altitude of 1582 m. The soil types are mainly sierozem, dark loessial soil and aeolian sandy soil. The types of vegetation included meadow, shrub, grassland vegetation and desert vegetation. The common plant species were xeric and xerophytic.

After considering the terrain factors, we selected the lands with relatively flat and uniform soil types for conducting the enclosure study. The lands were enclosed for 0, 5, 15 and 25 years with fences made up of cement piles and barbed wire, and were completely excluded from interference of any activities such as grazing. For each enclosure year, three randomly deployed and independent plots (10m × 10m) were used. Because the plants in the study sites were mainly herbs, three small quadrats of 1m × 1m in size were randomly selected within each 10m × 10m plot to investigate the compositions of herbaceous species.

Plot investigation: Standard plot investigation method was used to record the names of species, coverage and number of plants, average plant height and aboveground biomass. Plant height was the height measured in natural state. The above-ground biomass was the weight of plants harvested at the ground level and dried at 65°C to constant weight.

Soil sampling and determination: Five samples over an "S" shape route were collected randomly at the soil layer of 0-10 cm in depth in each 10m × 10m plot by drilling with a soil driller with internal diameter of 10 cm. The soil samples from the same plot were mixed and divided into four lots. About one kg of the mixed sample was shipped to the laboratory, air-dried, grinded to pass sieves of 2mm and 0.149 mm pore sizes, sealed and stored for subsequent analysis. The soil pH was measured by potentiometric determination after extraction with potassium chloride with the ratio of soil/water of 2.5 to 1. The content of organic carbon was determined using the combustion method. The total content of nitrogen was determined using the Kjeldahl method. Hydrolysable nitrogen was measured using alkaline hydrolysis diffusion method. The content of total phosphorus was analysed using the Kjeldahl digestion-Mo-Sb colorimetry method. Double acid extraction-Mo-Sb colorimetry method was used to determine the content of available phosphorus. Sodium hydroxide melting-flame photometric method was used to measure the content of the total soil potassium content. Ammonium acetate extraction-flame photometric method was used for the determination of available potassium.

Data analysis: To characterize plant species in the corresponding community, the importance value (IV) of species was used to measure the predominant species in the corresponding community:

IV = (relative abundance + relative coverage + relative frequency)/3 ...(1)

The species abundance and the Shannon-Weaver diversity index (α diversity index) were used to characterize the diversity in the sample plots. The Shannon-Weaver diversity index was calculated as follows:

$$H = -\sum_{i=1}^{S} \left(P_i \ln P_i\right) \qquad \text{...(2)}$$

Where, P_i represents the abundance ratio of species i,

$$P_i = \frac{N_i}{N_0}$$

β diversity index was used to describe the changes in species diversity over different environmental gradients. The Whittaker β diversity index was calculated as follows:

$$\beta = \frac{S}{A} - 1 \qquad \text{...(3)}$$

Where S is the total number of species recorded in the study system, A is the average number of species found in an environmental gradient (sample plot).

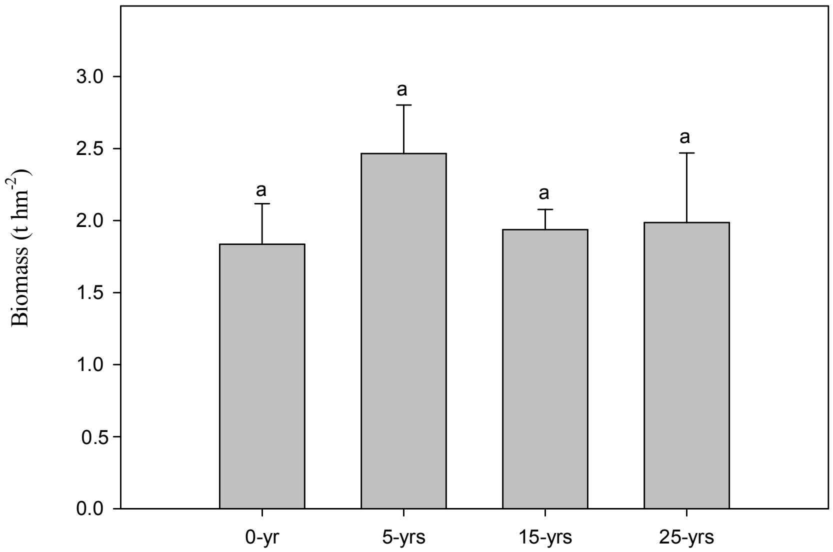

Fig. 1: Plant biomass after different years of enclosure.

Using single factor analysis of variance (one-way ANOVA), the differences in soil physicochemical properties, plant biomass, species abundance and community diversity among different enclosure periods were compared. All the analyses were performed using the software SPSS 17.0 for Windows. LSD program was used to compare differences of means. The difference between groups with $P<$ 0.05 was considered statistically significant.

Redundancy analysis (RDA) was used to determine the main factors that determine the species variations in the degraded grassland. For this purpose, Monte Carlo iterations in the RDA program were run against all biotic or abiotic factors surveyed or determined. The factors with significant effect ($P < 0.05$) were used as the environment variables in final RDA. All the data analysed were log transformed.

RESULTS AND ANALYSIS

Effects of enclosure periods on physicochemical properties of soil: ANOVA results showed that within the experimental periods tested, the duration of the enclosure had significant impact on soil physical properties, including crust thickness, conductivity and chemical properties, including the contents of organic carbon, total nitrogen, available nitrogen, available phosphorus, available potassium and carbon/nitrogen ratio) ($P< 0.05$). With the increase in enclosure duration, the soil electrical conductivity, contents of organic carbon, total nitrogen, available nitrogen, available phosphorus and available potassium all exhibited obviously increasing trends whereas the ratio of soil carbon/nitrogen showed a decreasing trend. The thickness of soil crust and pH value did not show regular change over the enclosure periods (Table 1).

Effects of enclosure periods on the biomass and species diversity of plants: The analysis results showed that within the enclosure periods observed, enclosure for 5 years generated the maximum plant biomass, followed by enclosure for 25 years. Un-enclosed land produced the smallest biomass. However, the differences in biomass among different years of enclosure were not statistically significant (Fig. 1) ($P >$ 0.05).

The data showed that the abundance of species in the sample plots after different years of enclosure was not significantly different, and the same was true for α diversity index. On the other hand, β diversity index was significantly different among different years of enclosure with the maximum value occurring in the plots enclosed for 15 years and 0 years, and the minimum value occurring in the plots enclosed for 25 years.

The major factors influencing the species compositions following different years of enclosure: Principal component analysis (PCA) showed that the first and second principal component axes accounted for 33.1% and 21.2% of variations in species compositions, respectively. Plant communities in different plots enclosed for the same enclosure years were concentrated in the same quadrant, while those with different years of enclosure were scattered in different quadrants (Fig. 2).

The plant communities in the plots enclosed for 0 and 5 years were separated from those enclosed for 15 and 25 years by the first principal component axis. The plant communi-

Table 1: The variations of soil physicochemical properties after different years of enclosure (mean ± S.E., n=3).

Variables	Years of enclosure			
	0	5	15	25
Thickness of crust (cm)	0.53±0.03ab	0.37±0.07b	0.63±0.09a	0.33±0.03b
Electrical conductivity (μS/cm)	26.33±0.33d	30.47±0.19c	38.50±0.12b	43.63±0.15a
pH value	8.63±0.03b	8.40±0.02c	8.68±0.01ab	8.73±0.02a
Total organic carbon (g)	3.58±0.08d	4.54±0.08c	4.99±0.03b	9.76±0.15a
Total nitrogen (g)	0.39±0.02d	0.51±0.01c	0.64±0.01b	1.37±0.03a
Carbon/nitrogen ratio	9.18±0.18a	8.92±0.33a	7.84±0.04b	7.14±0.22b
Available nitrogen (g)	23.37±0.26d	27.87±0.23c	38.50±0.12b	66.10±0.57a
Available phosphorus (g)	5.40±0.15c	9.70±0.06a	5.57±0.09c	8.43±0.15b
Available potassium (g)	34.90±0.12d	37.40±0.32c	75.83±0.23b	69.33±0.23a

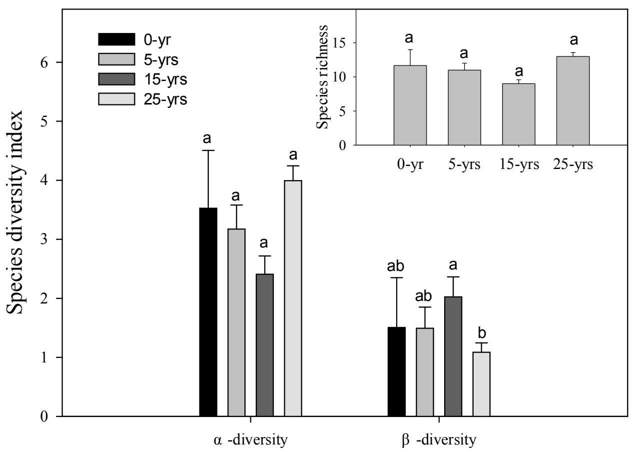

Fig. 2: Species diversity and abundance after different years of enclosure. Values are mean ± SE, n = 3. Different letters above the bars indicate significant differences among years of enclosure ($P < 0.05$).

ties in the plots enclosed for 5 and 25 years were separated from those enclosed for 5 and 15 years by the second principal component axis (Fig. 3a).

RDA results showed that first and the second principal component axes accounted for a total of 70.2% of variation in compositions of herbal plant species and environmental habitat factors. In the survey or the determination, seven factors were found to be significantly associated with environmental factors and species composition using the Monte Carlo test ($P < 0.05$) and these factors, including soil organic carbon, total nitrogen, available nitrogen, soil electrical conductivity, available nitrogen, ratio of available potassium/available phosphorus, available potassium and ratio of carbon/ nitrogen, were selected in the final model. Finally, soil organic carbon, available nitrogen, soil electrical conductivity and available potassium were determined to be the main forces driving, leading the variations of plant community compositions after different years of enclosure in the sample plots (Fig. 3b).

DISCUSSION AND CONCLUSION

As an effective measure for the restoration of the degraded grassland, the enclosure has been widely used for the management of grassland desertification in China. In-depth analysis of the effects of enclosure on soil physicochemical properties, plant community compositions and the main factors driving the changes in these parameters in desertified grassland is of practical significance for the development of scientific and sustainable measures for the restoration and reconstruction of vegetation in these regions. Since the enclosure (by fencing) is cost-effective and produces quick outcome, it has been widely used for restoration and reconstruction of grassland worldwide (He et al. 2008). Several studies have been done regarding the effects of enclosure on primary biomass in grassland, plant community structure and diversity (Zhou et al. 2004, Altesor et al. 2005, Renne & Tracy 2007, Han et al. 2007). However, due to the differences in environment, the extent of degradation or protection among the study sites, most of the results regarding the impacts of enclosure on soil and/or plants in the degraded grassland are inconsistent, controversial and have uncertainty.

The improvement of soil nutrients by vegetation restoration is a result of long-term interactions between abiotic and biotic factors. It is a complex ecological process, during which, soil degradation can change vegetation while the vegetation evolution can also change the soil property. Our study showed that with increasing duration of enclosure, soil nutrients, including organic carbon, total nitrogen, available nitrogen, available phosphorus and available potassium in the sandified grassland were increased remarkably or even significantly, indicating that during the enclosure periods studied, enclosures can significantly change the soil texture to a certain extent and improve the supply of soil nutrients. These findings are consistent with the early results reported in other studies (Greenwood et al. 1998, Reeder et al. 2001, Mekuria et al. 2007). The im-

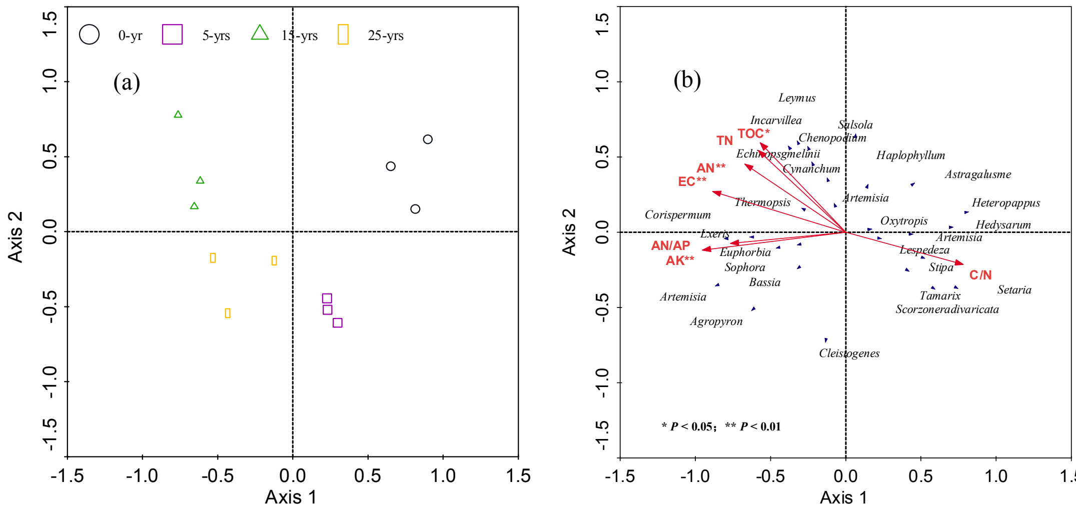

Fig. 3: The effects of different years of enclosure on plant species composition (a) and the main factors driving plant community compositional change (b).

provement may be resulted from the increased soil holding capacity by the restored vegetation after the enclosure, which can effectively prevent the loss of soil nutrients by rain. In addition, the plant litter and input of root organic matter can effectively increase soil nutrients as well. As the carrier of plants, soil provides the necessary nutrients for plant growth and reproduction. Thus, soil texture and nutrients are important for plant growth and have direct impacts on species composition, productivity and diversity of plants. They are important guarantee for the restoration and maintenance of ecosystem function (Su et al. 2002).

As an important index of productivity in an ecological system, plant biomass is the basis for material exchange and energy cycling within an ecological system. After enclosure, the vegetation in the degraded grassland can be restored well with increasing plant density and height, leading to the significantly increased biomass in enclosed grassland. In this study, no significant difference in plant biomass was observed among different years of enclosure. This might be partially due to the study period as the changes in some biotic and abiotic factors due to the enclosure are not great enough to cause the significant change in the above-ground biomass in the degraded grassland. This is different from other works which have demonstrated that enclosure can improve both the above-ground and underground biomass (Han et al. 2007, Zuo et al. 2009, Yan et al. 2011), and from the studies reporting the decreased biomass of plant community with increasing enclosure period (Cheng et al. 1995, 1998).

Numerous studies have been done regarding the impact of enclosure on plant species diversity. It is generally believed that enclosed land is free from the external interference, resulting in the predominance of some competitive species and thereby reducing the species diversity (Pykälä 2005, Peco et al. 2006, Gao et al. 2012). In this study, β plant diversity index in the grassland among different years varied significantly in different plots, with the maximum occurring after 15 years of enclosure while the minimum occurring after 25 years of enclosure. Plant diversity in the degraded grassland has been shown to change over the enclosure period in a periodic way. It is generally agreed that the moderate interference should be applied to the degraded grassland after the land has been enclosed for certain periods of time to prevent the reduction in plant species (Zhao et al. 2011, Cheng et al. 2014). However, there are also other reports showing no obvious difference in species diversity and community uniformity after enclosure. This disparity might be due to the reason that the enclosure period is too short in those studies (Zuo et al. 2009). In addition, RDA analysis revealed that the soil organic carbon, available nitrogen, conductivity and available potassium were the main factors driving the changes in plant species among different years of enclosure. These findings are similar to those made in the previous studies that soil physicochemical properties may be important factors influencing species compositions at the community level (Siefert et al. 2012).

In summary, in this study, we observed obvious changes in soil physicochemical properties over different years of enclosure, some of which are significant. We observed no significant differences in the above-ground biomass, but significant differences in the species diversity in vegetation after different years of enclosure. We found that soil organic carbon, available nitrogen, available potassium and soil electrical conductivity are the main factors driving the change in plant species compositions after different years of enclosure.

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