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Ecological stoichiometry homeostasis of *Leymus chinensis* in degraded grassland in western Jilin Province, NE China

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ABSTRACT

The natural *Leymus chinensis* grassland in western Jilin Province of NE China has been extensively degraded, thereby restricting the development of animal husbandry. Using theory of ecological stoichiometry homeostasis, this study investigated the homeostasis of *L. chinensis* at different degradation stages in the research area using a homeostasis model. Results showed that the degraded grassland generally had lower soil carbon (C), nitrogen (N) and phosphorus (P) compared with normal *L. chinensis* grassland. In particular, the degraded grassland exhibited severe shortage of P, but *L. chinensis* showed strong homeostasis. Except for C in the roots and leaves and P in stems, the N, P and corresponding ratios had higher homeostasis than 1, between 1.53 and 15.92. The homeostasis of N in *L. chinensis* was higher than that of P, and the homeostasis of C/P was higher than that of C/N and N/P. *L. chinensis* absorbs and uses nutritive elements in a conservative manner, which enables it to remain productive during changes in the external environment. Therefore, grassland degradation control should prioritize the protection of dominant species. Appropriate use of N and P fertilizers is suggested for the recovery of the seriously degraded *L. chinensis* grassland ecosystem.

1. Introduction

Grassland is one of the most widespread vegetation types and an important component of the terrestrial ecosystem (Fan et al., 2003; Qi et al., 2010; Wu et al., 2014). It covers an area of 3.3×10^9 hm^2, taking up 25.0% of the world's land area. China has about 4×10^8 hm^2 of grassland, which accounts for 41.7% (Fan et al., 2003) of China's land area and 12.5% (Wang et al., 2010) of the world's grassland area. At present, 50–60% of the natural grasslands of China are degrading to different extents.

The natural grassland in western Jilin Province is located southwest of the Songnen Plain and is one of the most important animal husbandry bases in China. *Leymus chinensis* is the local dominant species that has wide ecological adaptability, strong plasticity and high tolerance to arid and salt environments (Ba et al., 2005). However, different degrees of soil salinization occurred in the past five decades because of global climate changes and human activities, which reduced the production of *L. chinensis*, destroyed the stability of the grassland ecosystem and inhibited the development of animal husbandry. $NaHCO_3$ and Na_2CO_3 in saline-alkali soil damage physicochemical properties and reduce nutrient contents in the soil (e.g., organics, N and P), causing soil nutrient imbalance (Gilbert et al., 2003; Wang et al., 2011).

To solve this problem, the present study used homeostasis in ecology, which is a very important concept. Homeostasis is the ability of organisms to maintain relatively stable chemical compositions regardless of environmental changes. Species with strong homeostasis play an important role in maintaining the structure, function and stability of an ecosystem. Researchers reported that homeostasis is gradually enhanced from prokaryotic to eukaryotic organisms. Higher plants possess higher homeostasis than lower plants (Xing et al., 2015). Species with higher homeostasis take the dominant role and help the community maintain high and stable production (Yu et al., 2011). With intensifying soil salinization, the ecological environment of grasslands worsens, accompanied with changes in *L. chinensis*. The biomass of *L. chinensis* is reduced, and the species is gradually replaced by *Chlorisvirgata*, *Puccinellia* and *Suaedaglauca* (Tang et al., 2010). This study focuses on the changes in the C, N and P contents in soil and *L. chinensis*, as well as C/N, C/P and N/P homeostatic difference of nutrient elements, to prevent the degradation of *L. chinensis* and grassland ecosystems.

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2. Materials and methods

2.1. Research area

Western Jilin Province (123°09′E–124°22′E, 44°57′N–45°46′N) is located southwest of the Songnen Plain, has two prefecture-level cities (Songyuan City and Baicheng City) and 10 counties (town and districts) and covers an area of about 47,000 km^2. The highest temperature is in July (23 °C) and the lowest is in January (−17.5 °C), showing an average annual temperature of approximately 4.5 °C. The average annual precipitation is approximately 400 mm, and the average evaporation capacity is 1600 mm. The dryness is 1.2, which is typical of a semi-humid and semi-arid monsoon climate. The Second Songhua River and Nen River are the main rivers in the research area. Despite their high annual runoff, these rivers have low altitude and are inconvenient for use. The research area lacks surface water because of limited tributaries, most of which are seasonal rivers. Low river terrace, high river terrace, flood plain, river plain and sand dunes are the major geomorphic types in the research area. The grasslands in the research area are mainly identified as natural *L. chinensis* meadow. Soil types present include light chernozem, meadow soil, sandy soil, chernozem, alkali soil and chestnut soil. Small and large salt-alkali lakes are distributed in the lowland and are surrounded by saline-alkali soils and salinizing soils. Agro-pastoral economy is the main economic form in the area.

2.2. Sample collection

Considering the degree of soil degradation and density of *L. chinensis* (Li, 1997), this investigation was based on spatial sequence instead of time sequence. The quadrats were 100 cm × 100 cm and divided into five grassland degradation groups according to *L. chinensis* biomass, plant height and total density. Each group had five to six flat quadrats with the same altitude and soil types. A total of 28 soil samples and 73 *L. chinensis* samples (including 28 roots, 17 stems and 28 leaves) were collected from representative sampling sites in the research area on June 2010 and June 2012.

Quartering sampling was adopted, and all samples were marked and stored in sample bags. The samples were divided into roots, stems and leaves as soon as they were brought back to the laboratory. Subsequently, the samples were rinsed with distilled water, dried using absorbent paper, deactivated for 15 min in an air dry oven (105 °C) and dried for 12 h under 65 °C to eliminate water completely. About 1 kg of soil samples (0–30 cm deep) was collected from every sampling site. Field samples were recorded and returned to the laboratory in sample bags.

The processed samples were tested. Using K-means cluster analysis, grassland degradation in the research area was divided into five stages (1–5) according to the absolute height of *L. chinensis*; vegetation coverage; C, N and P content of plants and soil; available N and P; and pH and soluble salt content of soil.

2.3. Testing methods

The soil and plant sample tests used conformed to the *Soil and Agricultural Chemical Analysis Method* (Lu, 2000). Soil organic carbon was tested by potassium dichromate-sulfuric acid volume method (external heating), which used NY/T 148-1990 as the reference standard. Soil total nitrogen (TN) was tested by the Kjeldahl method, which used LY/T 1228-1999 as the reference standard. Soil total phosphorus (TP) was tested by the $HClO_4$–H_2SO_4 method, which used LY/T 1232-1999 as the reference standard. Plant total carbon (TC), TN and TP were tested by high-temperature catalytic oxidation, (H_2SO_4–H_2O_2 boiling) distillation and (H_2SO_4–H_2O_2 boiling) Mo–Sb colourimetry, respectively.

2.4. Homeostasis model

The living body is an organic unit composed of various compounds that have stable chemical composition and content ratio. Therefore, the composition and proportion of elements in the living body are relatively stable (Xin et al., 2012). A homeostasis model was proposed as follows (Elser et al., 2000; Yu et al., 2011):

$$y = cx^{1/H}$$

where, H is the homeostasis index. Plants with higher H have stronger homeostasis, that is, stronger control of element change.

Linear regression analysis was employed to analyze the relationships between homeostasis and C, N and P, as well as their ratios. Statistical analysis was accomplished with SPSS 19.0.

3. Results and analysis

3.1. w(TC), w(TN), w(TP), C/N, C/P and N/P of soil and *L. chinensis* in degraded grassland

The minimum, maximum and mean TC, TN and TP of soil, root, stem and leaf samples are listed in Table 1.

In Table 1, the average w(TC) of soil in degraded grassland is 11.32 mg/g, which is lower than the national average (17.98 mg/g); the average w(TN) is 1.21 mg/g, which is lower than the national average (1.60 mg/g); and the average w(TP) is 0.31 mg/g, which is lower than the VI level of Second National Soil Survey (<0.40 mg/g). In addition, the mean C/N of soil is 9.34, which is slightly lower than the national average (11.9); the mean C/P is 35.20, which is far higher than the national average (61); and the mean N/P is 3.78, which is lower than the national average (5.2). These results showed that this degraded grassland lacked soil nutrients (Li et al., 2012).

In *L. chinensis*, the stem exhibits the highest w(TC) (448.77 mg/g), followed by the root (439.72 mg/g) and leaf (435.91 mg/g). The leaf has the highest w(TN) (21.86 mg/g) and highest w(TP) (1.60 mg/g), followed by the stem (11.40 and 1.38 mg/g, respectively) and root

Table 1
Statistics of TC, TN, TP, C/N, C/P and N/P in soil and *L. chinensis* samples (unit: mg/g).

	Minimum value	Maximum value	Mean value
Carbon in soil	3.41	28.41	11.32
Carbon in root	374.00	464.49	439.72
Carbon in stem	442.65	453.88	448.77
Carbon in leaf	350.90	479.08	435.91
Nitrogen in soil	0.35	3.06	1.21
Nitrogen in root	5.74	14.72	9.35
Nitrogen in stem	6.96	21.99	11.40
Nitrogen in leaf	6.80	35.53	21.86
Phosphorus in soil	0.20	0.47	0.31
Phosphorus in root	0.35	1.88	0.90
Phosphorus in stem	0.60	2.70	1.38
Phosphorus in leaf	0.57	3.26	1.60
C/N in soil	5.02	11.12	9.34
C/N in root	31.01	78.87	50.07
C/N in stem	20.59	64.21	44.29
C/N in leaf	10.60	63.00	22.19
C/P in soil	11.92	70.13	35.20
C/P in root	238.27	1302.97	585.15
C/P in stem	165.36	752.12	418.04
C/P in leaf	144.41	640.49	314.85
N/P in soil	1.45	7.31	3.78
N/P in root	4.75	23.32	12.17
N/P in stem	4.19	17.12	9.48
N/P in leaf	6.00	28.91	15.09