Changes in Soil Labile Organic Carbon and Carbon Pool Management Index under Different Ecological Restoration Patterns in Desertified Zoige Grasslands (Postprint)

Authors: PU Yulin, YE Chun, ZHANG Shirong, LONG Gaofei, YANG Lirong, JIA Yongxia, XU Xiaoxun, LI Yun

Date: 2017-02-09T00:00:00+00:00

Abstract

Investigating changes in soil labile organic carbon and carbon pool management index under different ecological restoration patterns in degraded forest-grasslands can provide important references for evaluating the effectiveness of ecological restoration measures in improving soil quality and for optimizing the selection of ecological restoration patterns. Based on field surveys and laboratory analyses, this study examined changes in soil organic carbon fractions and carbon pool management index under different ecological restoration patterns in the desertified grasslands of Zoige. The ecological restoration patterns for Zoige desertified grassland include: shrub-grass intercropping pattern I (strip-shaped Tamarix ramosissima interplanted with herbaceous plants, SG), shrub-grass intercropping pattern II (ring-shaped Tamarix ramosissima interplanted with herbaceous plants, SG), and sand barrier + shrub-grass pattern (Tamarix ramosissima sand barrier + Tamarix ramosissima interplanted with herbaceous plants, SBSG). The results showed that, compared with desertified grassland (DG), all three restoration patterns could increase soil organic carbon and its labile component contents. In the SG pattern, the whole-profile soil microbial biomass carbon (MBC), dissolved organic carbon (DOC), readily oxidizable organic carbon (EOC), and particulate organic carbon (POC) contents increased by 36.6%, 139.0%, 89.4%, and 130.9%, respectively; in the SG pattern, they increased by 2.7%, -43.9%, 15.0%, and 49.7%, respectively; and in the SBSG pattern, they increased by 82.4%, 21.8%, 56.2%, and 170.3%, respectively. This indicates that the effects of SG and SBSG in improving soil organic carbon are similar, and both are substantially greater than that of SG . The differences in soil labile organic carbon distribution proportions among the three ecological restoration patterns compared with DG were inconsistent, with a notable man-

ifestation being the fractionation phenomenon in the vertical variation of soil DOC distribution proportion in the SG pattern. The soil carbon pool management index (CPMI) of all three ecological restoration patterns exceeded 100%, capable of improving soil quality to varying degrees, with the effect magnitude following the order SG > SG > SBSG. Readily oxidizable organic carbon can serve as a preferred indicator for reflecting soil quality changes under desertified grassland ecological restoration patterns, and CPMI can also be used to characterize the effectiveness of ecological restoration measures in improving desertified grassland soil quality.

Full Text

Preamble

ACTA ECOLOGICA SINICA
ChinaXiv Partner Journal
Vol. 37, No. 2, Jan. 2017
DOI: 10.5846/stxb201508163635

Effects of Different Ecological Restoration Patterns on Labile Organic Carbon and Carbon Pool Management Index of Desertification Grassland Soil in Zoige

PU Yulin[1], YE Chun[1], ZHANG Shirong[2*], LONG Gaofei[3], YANG Lirong[4], JIA Yongxia[1], XU Xiaoxun[2], LI Yun[2]

[1]College of Resources, Sichuan Agricultural University
[2]College of Environment, Sichuan Agricultural University
[3]Chengdu Hydrogeological and Engineering Geological Team, Sichuan Bureau of Geology and Mineral Resources Exploration
[4]Zoige County Bureau of Environmental Protection and Forestry, Sichuan

---

Abstract

Changes in soil labile organic carbon and carbon pool management index (CPMI) under different ecological restoration patterns provide valuable information for evaluating the effects of ecological restoration measures on soil quality improvement and for screening optimized restoration patterns for desertified forest and grassland. This study investigated soil organic carbon fractions and CPMI in desertified grasslands under different ecological restoration patterns in Zoige using field investigations and laboratory analyses. Three main restoration patterns were employed to control grassland desertification: shrub-grass intercrop pattern I (strip Tamarix ramosissima intercropping with herbs, SG), shrub-grass intercrop pattern II (circular Tamarix ramosissima intercropping with herbs, SG), and sand-barrier plus shrub-grass intercrop pattern (SBSG).

Results showed that all three restoration patterns increased soil organic carbon and its labile fractions compared to desertified grassland without restoration measures (DG). Specifically, the whole-profile contents of microbial biomass carbon (MBC), dissolved organic carbon (DOC), easily oxidized organic carbon (EOC), and particulate organic carbon (POC) under SG increased by 36.6%, 139.0%, 89.4%, and 130.9%, respectively; under SG by 2.7%, -43.9%, 15.0%, and 49.7%, respectively; and under SBSG by 82.4%, 21.8%, 56.2%, and 170.3%, respectively. The SG and SBSG patterns showed similar effectiveness in improving soil organic carbon, both superior to SG . The distribution proportions of soil labile organic carbon differed among the three restoration patterns and DG, with DOC in SG showing vertical fractionation. CPMI values under all three restoration patterns exceeded 100%, indicating improved soil quality, with the improvement level following the order: SG (CPMI, 182.5%) > SG (CPMI, 157.1%) > SBSG (CPMI, 129.9%). Easily oxidized organic carbon can be used as an optimized index to reflect soil quality changes in restored desertified grasslands, and soil CPMI can characterize the effectiveness of restoration measures on soil quality improvement.

Keywords: Zoige; desertification grassland; ecological restoration; soil; labile organic carbon; carbon pool management index

---

Introduction

Soil organic carbon serves as the energy source for plant nutrients and soil microbial life activities, playing a crucial role in improving soil fertility, reducing soil inorganic pollution, and mitigating global greenhouse effects. Although labile organic carbon generally constitutes a small proportion of total organic carbon, it significantly influences soil formation and biochemical processes. Soil labile organic carbon, particularly microbial carbon and dissolved organic carbon, is affected by ecological restoration measures, fertilization, and tillage practices on degraded land, and can more sensitively reflect soil quality changes before total organic carbon shifts, making it an important indicator for soil quality evaluation.

The carbon pool management index (CPMI) is calculated as the product of the ratio of soil organic carbon to reference soil organic carbon and the soil organic carbon activity index. It comprehensively considers both total and labile organic carbon, and can more sensitively reflect the degree of soil quality decline or improvement caused by various land use or management measures than individual labile carbon fractions.

The Zoige Plateau wetland, located on the northeastern edge of the Tibetan Plateau, serves as a water source conservation area and an effective isolation zone for dust storms in the arid northwestern region of China, as well as a natural carbon reservoir. With Quaternary loose sediments as soil parent material and a warming-drying climate, grassland desertification has become a major ecological problem. According to Zoige County's desertification monitoring, sandy land continues to increase, accounting for 7.69% of the county's total land area (58,713.8 hm^2). Since the mid-1980s, the Sichuan Provincial Government has launched comprehensive desertification control research and demonstration projects, which have shown initial success with the annual increase rate of desertified land gradually decreasing from 11.65% (1999-2004) to 10.88% (2004-2009) and 4.84% (2009-2014).

In the early stages of desertification control, especially on mobile dunes, artificial ecological restoration measures can only achieve good results when soil conditions become suitable for plant growth. How to reflect the restoration of soil environment to conditions suitable for plant growth in the short term is key to evaluating restoration effectiveness. Labile organic carbon and CPMI are important sensitive indicators for this purpose. However, to date, research on desertified grasslands in the Zoige Plateau and the entire Tibetan Plateau has mainly focused on soil under different desertification degrees or changes in total organic carbon and some labile fractions under different restoration years, with some studies only mentioning soil organic carbon content characteristics when analyzing effects of restoration patterns on soil physicochemical properties. No studies have reported on soil labile organic carbon and CPMI under different restoration patterns in desertified grasslands.

This study takes desertified grassland soils under different ecological restoration patterns in the key desertification control areas of Zoige County (Xiangman Township and Heihe Ranch) as research objects to explore the variation characteristics of soil organic carbon and its labile fractions and CPMI. This research is significant for promoting optimized ecological restoration patterns, achieving sustainable management of alpine grassland ecosystems, and mitigating global warming.

---

1. Study Area Overview

The study area is located in Xiangman Township and Heihe Ranch, Zoige County (33°33 -33°54 N, 102°26 -102°35 E, elevation 3400-3600 m). This region has a continental monsoon plateau climate with cold climate characteristics, average annual temperature of 1.6°C, average frost-free period of 15 days, annual precipitation of 464.8 mm, and annual evaporation of 1013.0 mm. The landscape consists of plateau hills, low-lying lake areas, and river plain marshes. Soils are mainly meadow soil and subalpine meadow soil, with some marsh soil and patchy sandy soil. Vegetation is dominated by meadow and subalpine meadow plants, with small amounts of helophytes and hydrophytes. Due to natural and human factors, desertified land is increasing, with sand dunes swallowing grasslands, increasing toxic and harmful plants, declining forage quality, and hindering livestock production.

---

2. Materials and Methods

2.1 Sample Collection

The main ecological restoration patterns for desertified grassland in the study area are: - **SG** : Shrub-grass intercrop pattern I (strip Tamarix ramosissima intercropping with herbs such as Poa pratensis, Elymus nutans, and Ajuga lupulina) - **SG** : Shrub-grass intercrop pattern II (circular Tamarix ramosissima intercropping with herbs such as Poa pratensis, Cremanthodium reniforme, Cirsium japonicum, and Daucus carota) - **SBSG**: Sand-barrier plus shrub-grass intercrop pattern (Tamarix ramosissima sand barriers intercropping with herbs such as Daucus carota, Poa pratensis, and Vicia sepium)

Typical sample plots for each restoration pattern were selected through field surveys combined with Google Earth remote sensing images, recording topography, vegetation coverage, and vegetation type. Based on microtopography changes, three 10 m × 10 m plots were established for each pattern. Within each plot, three 1 m × 1 m subplots were set up between Tamarix trees and under Tamarix canopies. Soil samples were collected from depths of 0-5, 5-10, 10-20, 20-30, 30-50, and 50-80 cm using the profile excavation method. Soils from the same depth in each subplot were mixed. Simultaneously, extremely severely desertified grassland or bare sand without restoration measures (DG) with similar environmental conditions and near-zero vegetation coverage was selected as reference. Basic conditions are shown in .

2.2 Laboratory Analyses

Soil total organic carbon (TOC) was determined by the potassium dichromate volumetric method. Dissolved organic carbon (DOC) was measured by the 1 mol/L KCl (5:1) extraction-colorimetric method. Microbial biomass carbon (MBC) was determined by chloroform fumigation-potassium dichromate volumetric method. Easily oxidized organic carbon (EOC) was measured by 333 mmol/L $KMnO_4$ oxidation-colorimetric method. Particulate organic carbon (POC) was separated by ultrasonic vibration with 5 g/L $(NaPO_3)_6$. Alkali-hydrolyzable nitrogen and available phosphorus were determined by alkali diffusion method and $NaHCO_3$ extraction-molybdenum antimony colorimetric method, respectively. Microbial biomass nitrogen and phosphorus were determined by chloroform fumigation-K_2SO_4 extraction semi-micro Kjeldahl digestion-ninhydrin colorimetric method and molybdenum antimony colorimetric method, respectively.

2.3 Carbon Pool Management Index Calculation

CPMI was used to reflect soil quality changes under different restoration patterns. The average values of soil carbon and total organic carbon content without restoration measures were used as reference soil values. The calculation formulas are:

Carbon pool activity index (CA) = EOC / (TOC - EOC)
Carbon pool index (CPI) = TOC_{restoration} / TOC_{reference}
Carbon pool management index (CPMI) = CPI × CA × 100%

2.4 Statistical Analysis

Data were analyzed using Excel 2003 and SPSS 11.0 software. One-way ANOVA and Duncan's new multiple range test ($\alpha = 0.05$) were used for significance testing of differences in soil organic carbon and its labile fractions among different restoration patterns.

3. Results

3.1 Soil Total Organic Carbon Changes

The vertical variation of soil total organic carbon content under SG showed an initial increase followed by decrease, while SG and SBSG patterns showed gradual decrease with soil depth. Except for 0-5 cm and 5-10 cm layers where SG had similar organic carbon content to DG, other layers under all restoration patterns had significantly higher organic carbon content (15.9%-271.7% increase, $P < 0.05$). The whole-profile soil total organic carbon content followed the order: SBSG (5.82 g/kg) > SG (5.96 g/kg) > SG (3.41 g/kg) > DG (2.97 g/kg) [Figure 1: see original paper].

3.2 Microbial Biomass Carbon

The active layer for soil microorganisms is the root distribution layer. The desertified grassland without restoration had minimal herbaceous plants, while restored patterns had Tamarix ramosissima and herbaceous plants with roots concentrated in 0-50 cm depth. This study focused on analyzing MBC in 0-50 cm soil layers.

MBC content showed an initial increase followed by decrease vertically, peaking at 5-10 cm depth. All layers under SG and SBSG had higher MBC content than DG (increases of 67.4%-136.6% and 6.4%-55.1%, respectively, $P < 0.05$). SG had slightly higher MBC than DG in 5-10 cm layer (2.5%-14.3% increase). Whole-profile MBC followed the order: SBSG (44.63 mg/kg) > SG (33.42 mg/kg) > SG (25.13 mg/kg) > DG (24.47 mg/kg) [Figure 2: see original paper].

3.3 Dissolved Organic Carbon

DOC content showed an initial increase followed by decrease vertically under SG , while SG and SBSG showed gradual decrease with depth. All layers under SG had higher DOC than DG (45.5%-185.9% increase, $P < 0.05$). SG had lower DOC than DG in 0-5, 10-20, 30-50, and 50-80 cm layers (68.9%-93.9%

decrease), but higher in 20-30 cm layer. SBSG had higher DOC than DG in all layers (29.0%-87.6% increase). Whole-profile DOC followed the order: SG (38.89 mg/kg) > SBSG (19.83 mg/kg) > DG (16.27 mg/kg) > SG (9.13 mg/kg) [Figure 3: see original paper].

3.4 Easily Oxidized Organic Carbon

EOC content showed an initial increase followed by decrease vertically under SG , peaking at 10-20 cm, while SG and SBSG showed gradual decrease with depth. All layers under SG had higher EOC than DG (47.0%-162.8% increase, $P < 0.05$). SBSG had higher EOC than DG in 10-20 and 50-80 cm layers (16.1%-90.8% increase). SG had higher EOC than DG in all layers (14.3%-75.0% increase). Whole-profile EOC followed the order: SG (2.25 g/kg) > SBSG (1.86 g/kg) > SG (1.37 g/kg) > DG (1.19 g/kg) [Figure 4: see original paper].

3.5 Particulate Organic Carbon

POC content showed an initial increase followed by decrease vertically under SG , peaking at 10-20 cm, while DG, SG , and SBSG showed gradual decrease with depth. All layers under SG , SG , and SBSG had higher POC than DG (increases of 61.1%-300.7%, 110.1%-234.2%, and 14.3%-75.0%, respectively, $P < 0.05$). Whole-profile POC followed the order: SBSG (3.99 g/kg) > SG (3.41 g/kg) > SG (2.21 g/kg) > DG (1.48 g/kg) [Figure 5: see original paper].

3.6 Distribution Proportions of Soil Labile Organic Carbon

The distribution proportion of a labile organic carbon fraction refers to its ratio to total organic carbon. Statistical results showed no clear vertical pattern for labile organic carbon distribution proportions in the study area, so only ranges and whole-profile means are presented .

The MBC:TOC ratio (microbial quotient) reflects the conversion efficiency of input organic matter to microbial biomass carbon. Overall, microbial quotients were low (0.09%-2.18%), lower than in desertified grasslands of the Xilin River Basin (1.7%-4.8%) but similar to soils on the northern Tibetan Plateau (0.32%-1.09%). The unique low-temperature and sandy conditions help convert input organic matter to EOC and POC. All three restoration patterns slightly reduced microbial quotient compared to DG, but differences were not significant.

The DOC:TOC ratio ranged from 0.16% to 1.62%, lower than microbial quotient and EOC:TOC. The EOC:TOC ratio (20.02%-59.43%) and POC:TOC ratio (11.76%-88.59%) were much higher than microbial quotient and DOC:TOC. The whole-profile EOC:TOC and POC:TOC ratios under restoration patterns were 22.92%-26.46% and 25.73% higher than DG, respectively.

3.7 Soil Carbon Pool Management Index Changes

Carbon pool activity index (CA) showed no clear vertical pattern, with whole-profile values of 0.35-2.05 under the three restoration patterns. Carbon pool index (CPI) also showed no clear vertical pattern, with most layers >1 except 0-5 cm and 20-30 cm layers in some patterns.

All three restoration patterns increased CPMI values above 100%, with whole-profile CPMI following the order: SG (182.5%) > SG (157.1%) > SBSG (129.9%) . This indicates all patterns improved soil quality to varying degrees.

3.8 Correlations Between Labile Organic Carbon, CPMI and Other Soil Properties

Correlation analysis showed that all labile organic carbon fractions and CPMI were positively correlated with organic matter and nitrogen-phosphorus nutrients. MBC, DOC, EOC, and POC had significant or extremely significant correlations with microbial nitrogen and phosphorus. EOC and POC had correlation coefficients of 0.630 ($P < 0.001$) and 0.235 ($P < 0.05$) with organic matter, respectively, indicating they can indicate changes in soil nutrient fertility .

---

4. Discussion

4.1 Differences in Soil Organic Carbon Improvement Effects Among Restoration Patterns

Soil organic carbon content depends on the balance between organic matter input and loss. All three restoration patterns increased total organic carbon content to varying degrees (SG : 100.6%, SG : 14.7%, SBSG: 96.0% increase compared to DG), consistent with previous studies. The patterns can fix sand, increase water infiltration, provide suitable soil conditions for plant growth, increase litter return and root biomass, and enhance microbial activity, resulting in higher organic matter input than mineralization loss.

The effects differed among patterns: SG and SBSG were similarly effective and superior to SG . For labile fractions, SBSG showed the greatest increase in MBC, DOC, and POC (82.4%, 21.8%, and 170.3%, respectively), while SG showed the greatest increase in DOC (139.0%). The strip intercropping pattern of Tamarix with herbs (SG) is the most effective restoration pattern because the strip sand barriers fix sand while the intercropped herbs input organic matter, creating suitable conditions for plant growth and rapid recovery of subalpine meadow ecosystems.

The vertical distribution of soil organic carbon and its fractions did not uniformly decrease with depth. TOC, MBC, DOC, and EOC under SG and SBSG first increased then decreased, peaking at 5-10 cm or 10-20 cm depths. This differs from some previous studies and may be due to wind erosion and deposition causing more sand particles in surface soils than subsurface layers, with negative effects outweighing positive effects even under restoration.

4.2 Differences in Labile Organic Carbon Distribution Proportions Among Restoration Patterns

The low-temperature and arid environment resulted in low microbial quotient (0.09%-2.18%) and DOC:TOC ratio (0.16%-1.62%). However, EOC:TOC (13.68%-68.88%) and POC:TOC (11.76%-88.59%) ratios were high, likely due to low total organic carbon levels (mostly 2.0-6.0 g/kg) and high sand content (8.20%-95.83% sand particles) in study area soils.

All restoration patterns slightly reduced microbial quotient compared to DG, indicating lower conversion rates of input organic matter to microbial carbon, possibly requiring longer restoration periods. The EOC:TOC and POC:TOC ratios increased under restoration patterns, with SG showing the highest increase (26.46% for EOC:TOC). The vertical fractionation of DOC distribution in SG , where DOC is preferentially adsorbed in surface layers while more complex components leach to deeper layers, reflects different restoration mechanisms.

4.3 Indicative Role of Labile Organic Carbon and CPMI on Soil Quality

CPMI values exceeding 100% under all restoration patterns indicate improved soil quality, with effectiveness following the order: SG > SG > SBSG. This is consistent with previous studies showing CPMI can reflect differences in soil quality under various conditions and the ability of restoration measures to improve soil quality.

Labile organic carbon fractions can serve as early sensitive indicators of changes in soil environmental conditions caused by management measures and vegetation cover changes. EOC, with its simple measurement method and large variation range, can be used as a preferred indicator to reflect the impact of restoration measures on soil quality in desertified grasslands. CPMI, being significantly correlated with most physical, chemical, and biological properties, can characterize the effectiveness of restoration measures on soil quality.

---

5. Conclusion

All three restoration patterns increased soil total organic carbon and its labile fractions to varying degrees. The effectiveness in increasing soil organic carbon followed the order: shrub-grass intercrop pattern I (SG) > sand-barrier plus shrub-grass intercrop pattern (SBSG) » shrub-grass intercrop pattern II (SG). The increase in labile organic carbon fractions ranged from 2.7% to 139.0%.

The distribution proportions of soil labile organic carbon differed among patterns due to arid conditions and sandy texture, resulting in low microbial quotient and DOC:TOC ratios. A significant feature was the vertical fractionation of DOC distribution in SG . All three restoration patterns improved soil quality (CPMI > 100%), with effectiveness following the order: SG (CPMI, 182.5%) > SG (CPMI, 157.1%) > SBSG (CPMI, 129.9%). Easily oxidized organic carbon can serve as a preferred indicator to reflect soil quality changes in restored desertified grasslands, and CPMI can characterize the impact of restoration measures on soil quality.

References

[1] Temporal and spatial variation of soil organic carbon and its relationship with soil physical properties in degraded alpine grassland. Chinese Journal of Applied Ecology, 2009, 20(11): 2639-2645.

[2] Miralles I, Ortega R, Almendros G, Sánchez-Marañón M, Soriano M. Soil quality and organic carbon ratios in mountain agroecosystems of South-east Spain. Geoderma, 2009, 150(1/2): 120-128.

[3] Effects of different recalcitrant organic carbon materials on cadmium speciation and bioavailability in soil. Journal of Agro-Environment Science, 2011, 30(8): 1531-1538.

[4] Gharbi L T, Merdy P, Lucas Y. Effects of long-term irrigation with treated wastewater. Part II: Role of organic carbon on Cu, Pb and Cr behaviour. Applied Geochemistry, 2010, 25(11): 1711-1721.

[5] Effects of tillage practices on soil organic carbon storage and greenhouse gas emissions in farmland of North China. Transactions of the Chinese Society of Agricultural Engineering, 2012, 28(6): 203-209.

[6] Lal R. Soil carbon sequestration to mitigate climate change. Geoderma, 2004, 123(1/2): 1-22.

[7] Wardle D A. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biological Reviews, 1992, 67(3): 321-358.

[8] Garten C T Jr, Post III W M, Hanson P J, Cooper L W. Forest soil carbon inventories and dynamics along an elevation gradient in the southern Appalachian mountains. Biogeochemistry, 1999, 45(2): 115-145.

[9] Gong W, Hu T X, Wang J Y, Gong Y B, Ran H. Soil carbon pool and fertility under natural evergreen broadleaved forest and its artificial regeneration forests in southern Sichuan Province, China. Acta Ecologica Sinica, 2008, 28(6): 2536-2545.

[10] Vieira F C B, Bayer C, Zanatta J A, Dieckow J, Mielniczuk J, He Z L. Carbon management index based on physical fractionation of soil organic matter in an Acrisol under long-term no-till cropping systems. Soil & Tillage Research, 2007, 96(1/2): 195-204.

[11] Effects of different crop straw returning methods on soil organic carbon

and carbon pool management index in Guanzhong Plain. Chinese Journal of Applied Ecology, 2015, 26(4): 1215-1222.
[12] Soil organic matter fractions and carbon pool management index under different enclosure years in grassland. Plant Nutrition and Fertilizer Science, 2011, 17(5): 1166-1171.
[13] Da Silva F D, Amado T J C, Ferreira A O, Assmann J M, Anghinoni I, de Faccio Carvalhod P C. Soil carbon indices as affected by 10 years of integrated crop-livestock production with different pasture grazing intensities in Southern Brazil. Agriculture, Ecosystems and Environment, 2014, 190: 60-69.
[14] Luo S S, Zhu L, Liu J L, Bu L D, Yue S C, Shen Y F, Li S Q. Sensitivity of soil organic carbon stocks and fractions to soil surface mulching in semiarid farmland. European Journal of Soil Biology, 2015, 67: 35-42.
[15] Evaluation of driving forces of climate change and livestock carrying capacity on grassland desertification in Zoige. Chinese Journal of Grassland, 2007, 29(5): 64-71.
[16] Changes in main soil labile organic carbon fractions under different conditions of alpine grassland, 2013, 50(2): 315-323.
[17] Effects of ecological restoration on soil labile organic carbon in desertified grassland of northwestern Sichuan. Journal of Soil and Water Conservation, 2014, 28(6): 251-255.
[18] Study on vegetation and soil changes during ecological restoration of desertified grassland in northwestern Sichuan. Changes in soil physicochemical properties after vegetation restoration in desertified grassland of northwestern Sichuan, 2010, (4): 1-4, 32-32.
[19] [D]. Sichuan Agricultural University, 2008.
[20] Jones D L, Willett V B. Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. Soil Biology and Biochemistry, 2006, 38(5): 991-999.
[21] Blair G J, Lefroy R, Lisle L. Soil carbon fractions based on their degree of oxidation and the development of a carbon management index for agricultural systems. Australian Journal of Agricultural Research, 1995, 46(7): 1459-1466.
[22] Methods and applications of soil microbial biomass determination. China Meteorological Press, 2006.
[23] Effects of long-term fertilization on soil organic carbon pool and carbon sequestration under double-cropping rice system. Chinese Journal of Applied Ecology, 2013, 24(3): 732-740.
[24] Methods for analysis of soil agrochemistry. China Agricultural Science and Technology Press, 2000.
[25] Kaiser K, Kalbitz K. Cycling downwards-dissolved organic matter in soils. Soil Biology and Biochemistry, 2012, 52: 29-32.
[26] Analysis of land desertification status and control countermeasures in Zoige County. Sichuan Forestry Science and Technology, 2013, 34(4): 42-46.
[27] Review of vegetation restoration and reconstruction techniques for desertified grassland in Xiaman Ranch, Zoige.
[28] Study on soil microbial and enzyme activities in artificially restored desertified grassland. Prataculture & Animal Husbandry, 2008, (7): 60-61.

[29] Grassland and Turf, 2011, 31(1): 84-88.
[30] Effects of enclosure on surface soil organic carbon, total nitrogen and labile organic carbon in mobile dunes. Journal of Soil and Water Conservation.
[31] Effects of short-term enclosure on organic carbon fractions and physical stability of desertified sierozem in desert steppe. Chinese Journal of Applied Ecology, 2012, 23.
[32] Changes in soil organic carbon and carbon pool management index in alpine grassland, 2013, 33(24): 7748-7755.
[33] Responses of soil organic matter, total nitrogen and total phosphorus contents to different land use patterns in alpine meadow of Qinghai-Tibet Plateau. Chinese Journal of Agrometeorology, 2009, 30(3): 323-326.
[34] Carbon and nitrogen contents of soil fractions and effects of meadow degradation on fraction carbon and nitrogen in alpine meadow. Earth Science, 2009, 39(5):
[35] Soil total organic carbon and dissolved organic carbon in typical temperate grassland in response to simulated nitrogen deposition, 2014, 35(8): 3073-3082.
[36] Effects of enclosure planting of Tamarix on soil particle composition and mineral nutrients in alpine sandy land of northwestern Sichuan.
[37] Effects of grassland desertification on soil particle composition and soil phosphorus and potassium nutrients in northwestern Sichuan. Journal of Arid Land Resources and Environment, 2015.
[38] Effects of fertilization on carbon pool management index and enzyme activities in grassland soils of karst region. Acta Prataculturae Sinica, 2014, 23(4):
[39] 2012, 26(6): 147-152.
[40] (12): 3325-3330.
[41] 2015, 46(1): 54-61.
[42] 29(8): 173-179.
[43] 262-268.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv — Machine translation. Verify with original.