Characteristics of Soil Organic Carbon Mineralization in Different Successional Series of Temperate Broadleaf-Korean Pine Forests in China: Postprint

Authors: Zhang Ling, Zhang Donglai, Mao Zijun

Date: 2017-10-30T00:00:00+00:00

Abstract

Soil organic carbon mineralization is closely related to terrestrial ecosystem carbon cycling and global climate change. To accurately assess the characteristics and variation patterns of soil organic carbon mineralization in different successional series of broadleaf-Korean pine forests in the temperate Xiaoxing' anling region of China, the chronosequence method was employed to represent community secondary succession processes, and indoor constant-temperature incubation (alkali absorption method) was used to determine the soil organic carbon mineralization amount and mineralization rate in six community types across different successional series (mesic successional series, hydric successional series, and xeric successional series). All three successional series exhibited consistent profile variation characteristics in soil organic carbon content, with the mineralization amount gradually decreasing as soil layer depth increased. Moreover, the mineralization amount differed among soil layers across different successional series, with the cumulative mineralization amount of soil organic carbon being highest in the primary broadleaf-Korean pine forest of the mesic successional series, followed by the xeric successional series, and lowest in the hydric successional series. The soil organic carbon mineralization rate in all three successional series showed a fundamentally consistent trend over time, characterized by rapid decline in the early incubation stage and gradual stabilization in the later stage. Soil organic carbon mineralization differed significantly among the six community types across the three successional series, following the pattern: primary broadleaf-Korean pine forest > secondary birch forest > spruce-fir-Korean pine forest > secondary Korean pine and maple-birch forest > Mongolian oak-Korean pine forest > secondary Mongolian oak and black birch forest. Nonlinear exponential fitting performed well for soil organic carbon mineralization across different successional series of broadleaf-Korean pine forests. Soil organic car-

bon mineralization across different successional series of broadleaf-Korean pine forests was significantly positively correlated with soil total nitrogen and litter amount, and significantly negatively correlated with soil moisture content, bulk density, and soil pH. Ecological factors such as successional history, soil texture, and nutrient status of different successional series communities were the causes of differences in soil organic carbon mineralization among different successional series of broadleaf-Korean pine forests.

Full Text

Preamble

ACTA ECOLOGICA SINICA
ChinaXiv Partner Journal
Vol. 37, No. 19, October 2017
DOI: 10.5846/stxb20160711415

Characteristic Mineralization of Soil Organic Carbon in Different Successional Series of Broadleaved Korean Pine Forests in China' s Temperate Zone

ZHANG Ling[1], ZHANG Donglai[2], MAO Zijun[1]
[1]Key Laboratory of Forest Plant Ecology, Ministry of Education, Northeast Forestry University, Harbin 150040, China
[2]Heilongjiang Provincial Forestry Research Institute, Heilongjiang Academy of Forestry, Harbin 150081, China

Abstract

Soil organic carbon mineralization is closely related to terrestrial ecosystem carbon cycling and global climate change. To accurately assess the characteristics and variation patterns of soil organic carbon mineralization in different successional series of broadleaved Korean pine forests in the temperate Xiaoxing' an Mountains of China, we measured carbon mineralization and mineralization rates using a chronosequence approach combined with laboratory incubation and alkali absorption methods. The three successional series examined were mesoseres, hydroseres, and xeroseres.

Results showed that both the rate and cumulative amount of carbon mineralization exhibited consistent vertical patterns across all three successional series, gradually decreasing with soil depth. However, the magnitude of carbon mineralization differed significantly among successional series. The mesosere series (virgin broadleaved Korean pine forest) showed the greatest cumulative soil organic carbon mineralization, followed by the xerosere series, with the hydroseres series showing the lowest values. The mineralization rates across all three series displayed similar temporal trends, decreasing rapidly during the early incubation period and gradually stabilizing in later stages.

Among the six community types across the three successional series, significant

differences in soil organic carbon mineralization were observed, following the pattern: virgin broadleaved Korean pine forest > Betula platyphylla secondary forest > Picea-Korean pine forest > Quercus mongolica-Korean pine forest > Betula costata-Korean pine forest > Quercus mongolica-Betula davurica forest. Nonlinear exponential fitting effectively described soil organic carbon mineralization across different successional series of broadleaved Korean pine forests. Carbon mineralization showed significant positive correlations with soil total nitrogen and litterfall amount, and significant negative correlations with soil moisture content and pH. In summary, differences in successional history, soil texture, and nutrient status were the primary factors driving variation in soil organic carbon mineralization among different successional series of broadleaved Korean pine forests.

Keywords: Korean pine forest; succession; soil organic carbon mineralization; environmental factors

Introduction

The soil carbon pool represents the largest organic carbon reservoir in the Earth' s surface system and plays a critical role in global carbon cycling [1-3]. The quantity and intensity of soil organic carbon mineralization can reflect soil quality conditions while also serving as an indicator for evaluating impacts of anthropogenic or environmental changes [4]. Successional series classification is based not on bare-ground soil structure or nutrient differences, but rather on specific moisture relationships, and includes xeroseres, hydroseres, and mesoseres. Forest succession plays a very important role in ecosystem development [6]. The successional process represents a continuous interaction between vegetation and soil, where vegetation provides necessary material foundations for soil development while simultaneously adapting to and modifying the soil environment. As vegetation changes gradually, underground carbon accumulation also undergoes transformation [2].

Previous domestic research on soil organic carbon mineralization has focused on various incubation temperatures and moisture conditions [7-13]. However, understanding of the linkages between forest soil active carbon pool dynamics and ecosystem processes remains fragmented [14], as most studies have concentrated on single soil types. Knowledge of regular patterns in soil carbon dynamics and their driving forces during vegetation succession remains very limited, undoubtedly restricting accurate predictions of future forest ecosystem changes under human-induced climate change [14-15]. Therefore, systematic investigation of soil organic carbon mineralization characteristics and their driving mechanisms during forest succession is essential for accurately estimating carbon budgets and dynamics in forest ecosystems, reducing estimation errors and uncertainties, and achieving effective soil carbon management.

Broadleaved Korean pine forest represents the primary forest type in the Xiaoxing' an Mountains region of temperate China and constitutes an important

component of water source conservation forests in northeastern China [16]. Following large-scale exploitation since the 1950s, virgin Korean pine forests were extensively logged and subsequently underwent natural regeneration dominated by coniferous and broadleaved tree species. Pioneer broadleaf species such as Betula platyphylla, Larix gmelinii, and Populus davidiana became widely established. However, systematic research on soil mineralization characteristics and their influencing mechanisms in these different secondary successional series remains lacking. This study examined different successional series of virgin broadleaved Korean pine forests, measuring soil organic carbon cumulative mineralization and mineralization rates, fitting parameters for potentially mineralizable carbon, and analyzing relationships between cumulative mineralization, potentially mineralizable carbon, and soil environmental factors. The objectives were to reveal the co-variation patterns and driving mechanisms of soil organic carbon mineralization across different secondary successional series of coniferous-broadleaved mixed forests, and to provide scientific references and necessary data support for accurately evaluating soil carbon balance and carbon pool management in temperate northern forests of China [17].

1. Study Area Overview

The study site is located in Liangshui National Nature Reserve in the Xiaoxing'an Mountains of Heilongjiang Province, China (47°10 50 N, 128°53 20 E). The region exhibits typical temperate continental monsoon climate characteristics, with mean annual precipitation of 680 mm, mean annual maximum temperature of 7.5°C, mean annual minimum temperature of -0.3°C, and a frost-free period of 120 days. The zonal vegetation is coniferous-broadleaved mixed forest dominated by Korean pine (*Pinus koraiensis*), i.e., virgin broadleaved Korean pine forest. The region features typical low mountain-hilly landforms with elevations of 300-500 m and slopes of 10°-25°. The zonal soil type is dark brown forest soil [18]. Virgin broadleaved Korean pine forest approximately 250 years old was extensively logged in the 1950s and has since evolved into broadleaved secondary forest dominated by *Betula platyphylla*.

2. Experimental Design

For the mesosere series, we selected virgin broadleaved Korean pine forest and Korean pine-*Betula costata* secondary forest. For the hydroseres series, we selected spruce-Korean pine forest and *Betula platyphylla* secondary forest. For the xeroseres series, we selected *Quercus mongolica*-Korean pine forest and *Quercus mongolica-Betula davurica* secondary forest. Each successional series represented climax and major secondary successional communities under similar site conditions. Three standard plots (20 m × 20 m) were established in each community type. Soil profiles were excavated in each plot, and samples were collected from four depths: 0-10, 10-20, 20-40, and 40-60 cm. Fresh soil samples were processed by removing roots and passing through a 2 mm sieve, then divided into two portions: one air-dried and one stored in sterile plastic bags.

3. Measurement Items and Methods

Soil organic carbon content was determined using the potassium dichromate oxidation method. Total nitrogen (TN) was measured by the Kjeldahl method. Soil bulk density and natural moisture content were determined using the ring knife method. Soil pH was measured at a 2.5:1 water-to-soil ratio. Sand particle ratio was determined by the pipette method (0.25-1 mm). Litterfall was collected using 0.5 m × 0.5 m quadrats.

Soil carbon mineralization was measured using the laboratory sealed alkali absorption incubation method. One hundred grams of air-dried soil (sieved through 2 mm) was placed at the bottom of a 500 mL respiration bottle. A vial containing 20 mL of 0.5 mol/L NaOH solution was carefully suspended above the soil to absorb CO . The bottle mouth was sealed and incubated at (25±1)°C for 91 days. Soil moisture was adjusted to 60±5% of field water-holding capacity. The bottle was sealed with sealing film to ensure airtightness. At days 2, 4, 8, 12, 16, 23, 30, 37, 44, 51, 61, 71, 81, and 91, the NaOH solution was replaced. The consumed NaOH was titrated with standard 1 mol/L HCl using phenolphthalein indicator, and the amount of carbon released was calculated from the acid consumption. Distilled water without soil served as the control. Each treatment was replicated three times. Soil organic carbon mineralization was calculated by converting CO release to organic carbon content, thereby determining the decomposition amount and rate.

4. Data Analysis of Soil Organic Carbon Mineralization Process

Statistical analysis was performed using SPSS 19.0 software. Differences were tested using multiple comparison methods (= 0.05). Nonlinear exponential functions were used for curve fitting of the mineralization process. Pearson correlation coefficients were used to evaluate relationships between factors. Organic carbon mineralization equations were fitted using Origin 8.0 software. Data in tables and figures represent mean values.

1. Characteristics of Soil Organic Carbon Mineralization Across Different Successional Series

Soil organic carbon mineralization in all successional series showed higher values in surface layers than in deeper layers, decreasing gradually with depth. Among the three successional series, the mesosere virgin broadleaved Korean pine forest exhibited the greatest mineralization, followed by the xerosere *Quercus mongolica*-Korean pine forest. The smallest mineralization occurred in the xerosere *Quercus mongolica-Betula davurica* forest. The mesosere virgin and secondary forests showed highly significant differences in mineralization ($P < 0.01$). In the 0-10 cm layer, mineralization accounted for 62.39% of the total profile in virgin broadleaved Korean pine forest and 22.72% in Korean pine-*Betula*

costata secondary forest. In the 10-20 cm layer, these values were 58.26% and 27.82%, respectively.

The hydroseres spruce-Korean pine forest showed 53.15% and 18.78% in the 0-10 cm and 10-20 cm layers, respectively, while the *Betula platyphylla* secondary forest showed 53.16% and 19.07%. No significant differences were observed among soil layers within each successional stage. The xeroseres showed significant differences between the *Quercus mongolica*-Korean pine forest (47.46% and 25.06% in 0-10 cm and 10-20 cm layers) and the *Quercus mongolica*-*Betula davurica* forest (41.64% and 27.54%).

2. Temporal Patterns of Soil Organic Carbon Mineralization Rates Across Successional Series

Soil organic carbon mineralization rates across all successional series showed consistent temporal trends, decreasing rapidly during early incubation and gradually stabilizing in later stages. In the mesosere series, differences between the two communities were highly significant ($P < 0.01$). Regression analysis indicated that temporal changes in mineralization rates followed exponential functions, with R^2 values reaching 0.988. For virgin broadleaved Korean pine forest and Korean pine-*Betula costata* secondary forest, R^2 values were 0.98751 and 0.99388, respectively ($P < 0.01$). The temporal pattern was characterized by: 0-15 days (rapid decrease), 15-30 days (slow decrease), and 30-91 days (stabilization).

In the hydroseres series, spruce-Korean pine forest showed an overall slow decrease in mineralization rate, while *Betula platyphylla* secondary forest exhibited: 0-16 days (rapid decrease), 17-71 days (slow decrease), and 72-91 days (stabilization). Although initial hypotheses suggested no significant differences between these two community types, regression analysis revealed highly significant exponential relationships ($P < 0.01$) with R^2 values of 0.93475 and 0.98857, respectively.

In the xeroseres series, mineralization rates showed an overall slow decreasing trend toward stability: 0-12 days (rapid decrease) and 13-91 days (stabilization). The paired test coefficient was 0.992 ($P < 0.05$), with R^2 values of 0.97584 and 0.9927 ($P < 0.01$), indicating highly significant exponential relationships.

[Figure 1: see original paper]
[Figure 2: see original paper]
[Figure 3: see original paper]

3. Vertical Characteristics of Soil Organic Carbon Mineralization Rates by Community Type

Across the six community types in the Xiaoxing' an Mountains broadleaved Korean pine forests, mineralization rates generally followed the pattern: virgin broadleaved Korean pine forest > *Betula platyphylla* secondary forest > *Quercus mongolica*-Korean pine forest > spruce-Korean pine forest > Korean pine-*Betula*

costata secondary forest > *Quercus mongolica-Betula davurica* secondary forest. In the 0-10 cm layer, the virgin broadleaved Korean pine forest showed a mineralization rate of 112.57 mg kg ^{1}, while the Korean pine-*Betula costata* forest showed 45.58 mg kg ^{1}. The *Quercus mongolica-Betula davurica* secondary forest showed rates of 90.54, 34.74, 21.05, and 12.05 mg kg ^{1} in the 0-10, 10-20, 20-40, and 40-60 cm layers, respectively.

[Figure 4: see original paper]
[Figure 5: see original paper]

4. Relationships Between Soil Organic Carbon Mineralization and Habitat Factors Across Successional Series

Soil organic carbon mineralization across the six community types showed significant positive correlations with soil total nitrogen and litterfall amount, and significant negative correlations with soil moisture content, pH, and bulk density. The correlation coefficients with total nitrogen and litterfall were 0.458 ($P < 0.01$) and 0.461 ($P < 0.01$), respectively. Sand ratio also showed significant positive correlation ($r = 0.332$, $P < 0.01$). These results indicate that soil texture and nutrient status significantly influence mineralization.

1. Patterns of Soil Organic Carbon Mineralization Across Successional Series

Soil organic carbon mineralization differed significantly among successional series in Xiaoxing' an Mountains broadleaved Korean pine forests, with the mesosere series showing the highest cumulative mineralization, followed by the xerosere series, and the hydroseres series showing the lowest values. The six community types generally showed greater mineralization in primary than in secondary successional series. Mineralization rates across all series exhibited similar temporal patterns: rapid decrease during early incubation followed by gradual stabilization.

The primary reasons for these differences include: (1) community development history (successional age), as mineralization cumulative amount increases with stand age [8]; (2) soil development, where primary forests benefit from nitrogen-rich humus and active microbial communities established by previous vegetation [5]; and (3) site conditions. The mesosere virgin broadleaved Korean pine forest (approximately 250 years old) has mature community structure, rich species diversity, and 35-50 cm thick soil layers with strong nutrient release and return capacity [21]. In contrast, the hydroseres series originated from marshes or wetlands, where high moisture creates stressful conditions for some native plants and affects active organic carbon accumulation [11]. The xeroseres series has thin soil layers (15-40 cm), low moisture content, and nutrient limitations that constrain vegetation development and affect mineralization [22].

2. Factors Influencing Soil Organic Carbon Mineralization Across Successional Series

Soil organic carbon mineralization showed significant positive correlations with litterfall amount and soil total nitrogen, and negative correlations with moisture content and sand ratio. Different community types have distinct microclimates, root distribution patterns, and litter chemical compositions, leading to different microbial activities [23-24]. The study primary forests were all coniferous-broadleaved mixed forests, while secondary forests were dominated by broadleaf species with simpler structure and lower canopy density. Litter composition varied significantly among the six community types, affecting soil organic matter input and output patterns [25].

Previous studies have shown that broadleaved Korean pine forest has the highest mineralization rates, while fir forests have the lowest [23]. Mixed litter decomposes faster than single-species litter at the same temperature [26-27]. Soil nitrogen content and form vary significantly across successional stages [28], with primary forests having higher total nitrogen than secondary forests. This pattern aligns with mineralization trends: virgin broadleaved Korean pine forest > Korean pine-*Betula costata* > spruce-Korean pine forest > *Betula platyphylla* secondary forest > *Quercus mongolica*-Korean pine forest > *Quercus mongolica*-*Betula davurica* secondary forest. Soil nitrogen content may be an important factor affecting soil organic carbon retention [30], as demonstrated by significant correlations between active organic carbon and nitrogen content [31].

Soil bulk density showed significant negative correlation with mineralization. The mesosere series had moderately compact soil (1.16-1.19 g/cm^3) with good aeration and water retention, while the hydroseres series had looser soil (1.01-1.05 g/cm^3) and the xeroseres series had thin soil layers that limit microbial activity and nutrient transformation.

3. Relationship Between Soil Organic Carbon Mineralization and Vegetation Type

Vegetation is the primary source of soil organic carbon. Different vegetation types lead to different organic carbon output patterns and mineralization rates [33]. In all three series, primary forests showed higher mineralization rates than secondary forests, consistent with previous findings [34-35].

In the mesosere series, virgin broadleaved Korean pine forest and Korean pine-*Betula costata* secondary forest showed highly significant differences ($P < 0.01$). The virgin forest occupies gentle southeast slopes with rich species diversity, while the secondary forest is on steep upper slopes where organic matter and litter are easily washed away by rain, limiting accumulation [36].

In the hydroseres series, spruce-Korean pine forest and *Betula platyphylla* secondary forest showed no significant differences ($P > 0.05$). The spruce-Korean pine forest has higher soil moisture, with standing water below 50 cm that facili-

tates litter decomposition and organic matter leaching into soil layers, resulting in greater carbon accumulation compared to the *Betula platyphylla* secondary forest.

In the xeroseres series, *Quercus mongolica*-Korean pine forest and *Quercus mongolica-Betula davurica* secondary forest showed highly significant differences ($P < 0.01$). The secondary forest occurs on dry, infertile sites subject to repeated disturbance and fire, with the thinnest soil layers. Dominant species are drought-tolerant *Quercus mongolica* and *Betula davurica*. Differences in litter composition, soil pH, and microbial activity all contribute to variations in mineralization.

4. Conclusion

Soil organic carbon mineralization differed significantly among successional series of broadleaved Korean pine forests in the temperate Xiaoxing' an Mountains of China. The mesosere virgin broadleaved Korean pine forest showed the greatest cumulative mineralization, followed by the xerosere series, with the hydroseres series showing the lowest values. Across the six community types, primary successional series generally showed greater mineralization than secondary series. Mineralization rates exhibited consistent temporal patterns across all series: rapid decrease during early incubation followed by gradual stabilization. Soil organic carbon mineralization was significantly positively correlated with soil total nitrogen and litterfall amount, and significantly negatively correlated with soil moisture content and pH. Ecological factors including successional history, soil texture, and nutrient status were the primary drivers of differences in soil organic carbon mineralization among different successional series of broadleaved Korean pine forests.

References

[1] Post W M, Emanuel W R, Zinke P J, Stangenberger A G. Soil carbon pools and world life zones. *Nature*, 1982, 298(5870): 156-159.
[2] Advances in Earth Science, 2016, 31(1): 86-93. [Chinese reference on soil organic carbon fractions during forest restoration in subtropical China]
[3] Chinese Agricultural Science Bulletin, 2013, 33(18): 5751-5759. [Chinese reference on soil organic carbon pools]
[4] Journal of Soil and Water Conservation, 2015, 31(32): 123-131. [Chinese reference on soil organic carbon mineralization on the Loess Plateau]
[5] Daubenmire R. *Plant Community Ecology Tutorial*. People' s Education Press, 1981.
[6] Acta Ecologica Sinica, 2010, 30(5): 1217-1226. [Chinese reference on soil active organic carbon during mid-subtropical evergreen broadleaved forest succession]
[7] Lentz R D, Ippolito J A. Biochar and manure affect calcareous soil and corn silage nutrient concentrations and uptake. *Journal of Environmental Quality*,

2012, 41(4): 1033-1043.
[8] Zhang Q Z, Wang X H, Du Z L, Liu X R, Wang Y D. Impact of biochar on nitrate accumulation in an alkaline soil. *Soil Research*, 2013, 51(6): 521-528.
[9] Guo J F, Yang Y S, Chen G S, Xie J S, Yang Z J. Carbon mineralization of Chinese fir (*Cunninghamia lanceolata*) soils under different temperature and humidity conditions. *Acta Ecologica Sinica*, 2014, 34: 66-71.
[10] Tian J, Pausch J, Yu G R, Blagodatskaya E, Gao Y, Kuzyakov Y. Aggregate size and their disruption affects 14C-labeled glucose mineralization and priming effect. *Applied Soil Ecology*, 2015, 90: 1-10.
[11] El-Naggar A H, Usman A R A, Al-Omran A, Ok Y S, Ahmad M, Al-Wabel M I. Carbon mineralization and nutrient availability in calcareous sandy soils amended with woody waste biochar. *Chemosphere*, 2015, 138: 67-73.
[12] Jagadamamma S, Mayes M A, Steinweg J M, Schaeffer S M. Substrate quality alters the microbial mineralization of added substrate and soil organic carbon. *Biogeosciences*, 2014, 11(17): 4665-4678.
[13] Gunes A, Inal A, Taskin M B, Sahin O, Kaya E C, Atakol A. Effect of phosphorus-enriched biochar and poultry manure on growth and mineral composition of lettuce (*Lactuca sativa* L. cv.) grown in alkaline soil. *Soil Use and Management*, 2014, 30(2): 182-188.
[14] Milcu A, Heim A, Ellis R J, Scheu S, Manning P. Identification of general patterns of nutrient and labile carbon control on soil carbon dynamics across a successional gradient. *Ecosystems*, 2011, 14(5): 710-719.
[15] Weber P, Bardgett R D. Influence of single trees on spatial and temporal patterns of belowground properties in native pine forest. *Soil Biology & Biochemistry*, 2011, 43(6): 1372-1378.
[16] Jandl R, Lindner M, Vesterdal L, Bauwens B, Baritz R, Hagedorn F, Johnson D W, Minkkinen K, Byrne K A. How strongly can forest management influence soil carbon sequestration. *Geoderma*, 2007, 137(3/4): 253-268.
[17] Acta Ecologica Sinica, 2015, 35(4): 604-611. [Chinese reference on soil organic carbon mineralization under different land uses]
[18] Journal of Soil and Water Conservation, 2015, 29(3): [Chinese reference]
[19] Chinese Journal of Applied Ecology, 2015, 27(1): 9-16. [Chinese reference on soil organic carbon pools in Xiaoxing' an forests]
[20] Deng L, Wang K B, Cheng M L, Shangguan Z P, Sweeney S. Soil organic carbon storage capacity positively related to forest succession on the Loess Plateau, China. *Catena*, 2013, 110: 1-7.
[21] Chinese Journal of Ecology, 2005, 65(2): 83-84. [Chinese reference on *Quercus mongolica* distribution]
[22] *Pratacultural Science*, 2007, 15(1): 20-28. [Chinese reference on soil respiration in Changbai Mountains]
[23] Chinese Journal of Applied Ecology, 2003, 14(8): 1234-1238. [Chinese reference on soil temperature and moisture effects]
[24] Priha O, Grayston S J, Hiukka R, Pennanen T, Smolander A. Microbial community structure and characteristics of organic matter in soils under *Pinus sylvestris*, *Picea abies* and *Betula pendula* at two forest sites. *Biology and Fertility of Soils*, 2001, 33(1): 17-24.

[25] Protection Forest Science and Technology, 2005, 41(1): 10-13. [Chinese reference on soil organic carbon mineralization in Qilian Mountains]
[26] Acta Ecologica Sinica, 2013, 33(2): 443-453. [Chinese reference on decomposition characteristics in broadleaved Korean pine forests]
[27] Acta Ecologica Sinica, 2013, 33(18): 5661-5667. [Chinese reference on warming and litter quality effects]
[28] Journal of Plant Ecology, 2012, 44(3): 130-135. [Chinese reference on mixed litter decomposition]
[29] Pastor J, Stillwell M A, Tilman D. Nitrogen mineralization and nitrification in four Minnesota old fields. *Oecologia*, 1987, 71(4): 481-485.
[30] Chinese Journal of Plant Ecology, 2002, 26(S): 9-19. [Chinese reference on physiological ecology during succession]
[31] Iqbal J, Hu R G, Lin S, Ahamadou B, Feng M. Carbon dioxide emissions from Ultisol under different land uses in mid-subtropical China. *Geoderma*, 2009, 152(1/2): 63-73.
[32] Journal of Zhejiang A&F University, 2005, 35(6): 502-510. [Chinese reference on active organic carbon pools]
[33] Journal of Plant Ecology, 2005, 41(1): 10-13. [Chinese reference on carbon balance during succession]
[34] Chinese Journal of Ecology, 2015, 34(12): 3374-3381. [Chinese reference on vegetation effects on soil organic carbon]
[35] Acta Ecologica Sinica, 2012, 21(2): 1-25. [Chinese reference on soil carbon in karst regions]
[36] Acta Ecologica Sinica, 2015, 35(5): 716-723. [Chinese reference on monsoon evergreen broadleaved forests]

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