Litter Accumulation Characteristics and Water-Holding Capacity of Poplar Plantations in the Lhasa River Valley: Postprint

Authors: Liu Lin

Date: 2021-12-12T00:00:00+00:00

Abstract

Investigating the litter accumulation and water-holding capacity of typical poplar plantations in the Lhasa River Valley is of great significance for deeply exploring the water conservation capacity of artificial forests on the Qinghai-Tibet Plateau. This study selected five poplar plantations of different stand ages (12 a, 15 a, 19 a, 27 a, and 32 a) in the Lhasa River Valley as research objects, and conducted quantitative investigations on litter accumulation and water-holding performance indicators—including maximum water-holding capacity (rate) and effective interception capacity (rate) for different stand ages—through field observation and indoor immersion methods. The results show that: (1) Litter accumulation, maximum water-holding capacity, and effective interception capacity across different stand ages follow the order 27 a > 15 a > 32 a > 19 a > 12 a, ranging from 8.32~26.12 $t \cdot hm^{-2}$, 24.03~60.89 $t \cdot hm^{-2}$, and 19.85~49.15 $t \cdot hm^{-2}$, respectively, with the litter of the 27 a mature forest consistently demonstrating the best performance. Litter accumulation and stand characteristics are the main factors affecting maximum water-holding capacity and effective interception capacity. (2) The maximum water-holding rate and effective interception rate of litter follow the order 12 a > 19 a > 15 a > 27a > 32 a, with ranges of 228.37%~288.67% and 188.18%~238.48%, respectively; stand age has no significant effect on maximum water-holding rate and effective interception rate, which are mainly influenced by tree species type. The research results can provide a scientific basis for ecological engineering construction of sand fixation and desertification control and its ecological benefit evaluation in this region.

Full Text

Litter Storage Characteristics and Water-Holding Capacity of Poplar Plantations in the Lhasa River Valley

LIU Lin[1,2,3], XIONG Donghong[1,2], ZHANG Baojun[1,2], YUAN Yong[1,2,3], ZHANG Wenduo[1,2,3]

[1]Key Laboratory of Mountain Hazards and Earth Surface Processes, Chinese Academy of Sciences, Chengdu 610041, Sichuan, China
[2]Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu 610041, Sichuan, China
[3]University of the Chinese Academy of Sciences, Beijing 100049, China

Abstract

Investigating litter accumulation and water-holding performance in typical poplar plantations of the Lhasa River Valley is crucial for understanding the water conservation capacity of artificial forests on the Tibetan Plateau. This study examined five different stand ages (12, 15, 19, 27, and 32 years) of poplar plantations in the Lhasa River Valley region. Through field observations and laboratory immersion methods, we quantitatively analyzed litter storage capacity and water-holding performance indicators including maximum water-holding capacity (rate) and effective interception amount (rate) across different stand ages. The results revealed: (1) Litter storage, maximum water-holding capacity, and effective interception amount across the five stand ages all exhibited the pattern 27 a > 15 a > 32 a > 19 a > 12 a, ranging from 8.32-26.12 $t \cdot hm^{-2}$, 24.03-60.89 $t \cdot hm^{-2}$, and 19.85-49.15 $t \cdot hm^{-2}$, respectively. The 27-year-old mature forest consistently demonstrated the optimal litter water-holding capacity. Litter storage and stand characteristics were the primary factors influencing maximum water-holding capacity and effective interception amount. (2) Maximum water-holding rate and effective interception rate of litter showed the pattern 12 a > 19 a > 15 a > 27 a > 32 a, ranging from 228.37%-288.67% and 188.18%-238.48%, respectively. Stand age did not significantly affect maximum water-holding rate and effective interception rate; these were mainly influenced by tree species. The findings provide a scientific basis for ecological engineering construction and ecological benefit evaluation of sand control projects in this region.

Keywords: stand age; Populus plantations; litters; water-holding capacity; Lhasa River Valley

Introduction

Hydrological function represents a crucial aspect of forest ecosystem services [1]. Forest ecosystems regulate precipitation through canopy, litter, and soil layers, playing unique ecological and hydrological roles in intercepting and redistributing rainfall, conserving soil and water, delaying surface runoff, and inhibiting soil water evaporation [2]. Previous studies have extensively documented litter hydrological effects across various regions, including the Loess Plateau [3], northern Hebei mountainous areas [4], Beijing region [5], eastern Liaoning low mountainous region [6], and Liupan Mountains of Ningxia [7]. For instance, Zhang et al. [8] compared water conservation capacity of five typical shrub forests in the Qilian Mountains, finding that *Salix gilashanica* had the strongest litter water-holding capacity while *Caragana tangutica* was the weakest. Zhang et al. [9] demonstrated that mixed forests possess greater capacity to intercept heavy rainfall than pure stands. Yang et al. [10] reported that water conservation capacity of *Cryptomeria fortunei* plantations in central Guizhou initially increased then decreased with stand age, with mature forests showing optimal performance. Gao et al. [11] found positive correlations between litter water-holding capacity and stand age for *Larix principis-rupprechtii* plantations in Liupan Mountains, Ningxia. Fu et al. [12] noted that 15-year-old apple orchards on the Loess Plateau of eastern Gansu exhibited significantly higher litter water conservation function than other ages. These studies indicate that litter hydrological function depends on both standing biomass and water-holding characteristics, with species composition and stand age exerting important influences on litter accumulation and water-holding properties.

The Tibetan Plateau, known as the "Asian Water Tower," constitutes a vital water source region for China and Asia [13]. The Lhasa River Valley serves as a critical ecological security barrier zone and important water replenishment area on the Tibetan Plateau. With scarce precipitation in winter and spring, high evaporation rates, and frequent strong winds, the valley' s floodplains and river terraces predominantly consist of sandy soils with erodible particle content reaching 69.46% [14], resulting in severe sand hazards. Since the 1980s, a series of afforestation projects for sand control have been implemented, rapidly expanding artificial forest area, increasing vegetation coverage, and significantly enhancing litter accumulation. The litter layer effectively increases surface roughness and topsoil moisture content, reducing wind erosion [15] while playing important roles in water conservation and soil property improvement [16]. Poplar plantations represent the primary afforestation vegetation type in the Lhasa River Valley. However, few studies have evaluated the ecological effectiveness of these plantations regarding water conservation and sand control, particularly concerning litter accumulation and hydrological effects across different growth stages. Therefore, this study investigates typical poplar plantations of different stand ages in the Lhasa River Valley to understand litter water source conservation characteristics during various growth stages, providing reference for scientific forest management and ecological project evaluation, which holds significant importance for ecological security barrier construction on the Tibetan Plateau.

1.1 Study Area Overview

The study area is located in the middle and lower reaches of the Lhasa River Valley (29°21 -29°90 N, 90°45 -91°48 E) at elevations of 3500–3850 m. The region experiences a plateau temperate semi-arid monsoon climate with maximum temperatures of 29.6 °C, minimum temperatures of -16.5 °C, and mean annual temperature of 7.4 °C. Annual sunshine duration exceeds 3000 h, precipitation is highly unevenly distributed throughout the year and concentrated in June-September, accounting for over 85% of annual rainfall. Annual precipitation is approximately 440 mm, while evaporation reaches 2198 mm. Soil types are mainly shrub steppe soil, meadow soil, fluvo-aquic soil, and aeolian sandy soil [17]. The vegetation belongs to the midstream Yarlung Zangbo River valley shrub steppe zone, dominated by subalpine shrubs, meadows, and valley artificial forest communities. After decades of artificial afforestation, the valley section has formed artificial forest systems primarily composed of poplar and willow species.

1.2 Sample Plot Selection

According to the State Forestry Administration' s "Main Technical Regulations for Forest Resource Planning and Design Survey," poplar plantation age groups are defined as: young forest \$ \$10 a, middle-aged forest 11–15 a, near-mature forest 16–20 a, mature forest 21–30 a, and over-mature forest \$ \$31 a. Based on preliminary field surveys and tree-ring data, combined with historical afforestation archives and imagery data from forestry departments, we conducted detailed field investigations from July to August 2019. We selected poplar plantations with similar habitat, soil type, and topographic conditions across the Lhasa River Valley (Mozhugongka to Qushui section), specifically five typical stands aged 12, 15, 19, 27, and 32 years. Within each stand age, we established 20 m × 20 m standard plots, recording elevation, tree height, DBH, crown width, and stand density. Detailed plot information is presented in .

1.3.1 Litter Collection and Storage Measurement

In late August 2019, we collected litter samples by randomly selecting five 50 cm × 50 cm quadrats as litter collection areas within each plot. Litter thickness was measured at least five times per quadrat using a steel ruler. Litter storage was determined using the complete harvest method [18]. After removing soil, gravel, and other impurities, litter was bagged and weighed as wet weight, then oven-dried at 85 °C to constant weight to obtain dry weight. Litter natural moisture content and storage were calculated using the formula:

$$M = \frac{M_{lj}}{S} \times 100\%$$

where M is litter storage ($\mathrm{t \cdot hm^{-2}}$), M_{lj} is the mass of oven-dried litter (g), and S is quadrat area ($\mathrm{m^2}$).

1.3.2 Litter Water-Holding and Interception Capacity Measurement

We used the indoor continuous immersion method to determine litter water-holding capacity [11,14]. Oven-dried litter samples were randomly placed into pre-weighed nylon mesh bags (30 g per bag, three replicates per plot), immersed in clear water, and weighed at 0.08, 0.25, 0.5, 1, 2, 4, 8, 12, and 24 h to calculate maximum water-holding capacity, maximum water-holding rate, effective interception amount, and effective interception rate. The formulas are:

$$Q_i = \frac{M_i - M_{lj}}{S} \times 100\%$$

$$R_m = \frac{M_{24} - M_{lj}}{M_{lj}} \times 100\%$$

$$W = (0.85 \times R_m - M_0) \times M$$

$$R_{mi} = \frac{W}{M} \times 100\%$$

where Q_i is water-holding capacity at different immersion times ($\mathrm{t \cdot hm^{-2}}$), M_i is litter mass after i hours of immersion (g), M_{lj} is oven-dried litter mass (g), R_m is maximum water-holding rate (%), M_{24} is litter mass after 24 h immersion (g), W is effective interception amount ($\mathrm{t \cdot hm^{-2}}$), M_0 is natural moisture content (%), M is litter storage ($\mathrm{t \cdot hm^{-2}}$), and R_{mi} is effective interception rate (%).

1.4 Data Processing

Data were processed using Excel 2010. One-way ANOVA in SPSS 20.0 was employed to analyze litter storage and water-holding capacity across different stand ages, with significance level set at $P < 0.05$. Figures were generated using SigmaPlot 14.0.

2.1 Litter Storage Characteristics of Different Stand Ages

Significant differences existed in litter thickness and storage among the five stand ages ($P < 0.05$). Litter thickness ranged from 3.56–6.06 cm, with 27-year-old stands having the maximum thickness and 12-year-old stands the minimum. Litter storage ranged from 8.32–26.12 $\mathrm{t \cdot hm^{-2}}$, decreasing in the order: 27 a > 15 a > 32 a > 19 a > 12 a. The 27-year-old stand exhibited the highest litter storage (26.12 $\mathrm{t \cdot hm^{-2}}$), significantly greater than other ages ($P < 0.05$), while the 12-year-old stand had the lowest (8.32 $\mathrm{t \cdot hm^{-2}}$).

2.2.1 Maximum Water-Holding Capacity and Rate of Different Stand Ages

Maximum water-holding capacity of the five stand ages ranged from 24.03–60.89 $t \cdot hm^{-2}$, following the pattern 27 a > 15 a > 32 a > 19 a > 12 a. The 27-year-old stand showed the highest maximum water-holding capacity (60.89 $t \cdot hm^{-2}$), significantly exceeding other ages ($P < 0.05$), followed by the 15-year-old stand (29.10 $t \cdot hm^{-2}$). Maximum water-holding rate ranged from 228.37%-288.67%, with the 12-year-old stand highest (288.67%), followed by 19 a (258.45%), 15 a (243.03%), 27 a (233.12%), and 32 a (228.37%).

2.2.2 Effective Interception Capacity of Different Stand Ages

Effective interception amount ranged from 19.85–49.15 $t \cdot hm^{-2}$ across stand ages, showing the same trend as storage: 27 a > 15 a > 32 a > 19 a > 12 a. The 27-year-old stand had the highest effective interception amount (49.15 $t \cdot hm^{-2}$), significantly greater than other ages ($P < 0.05$). Litter can absorb 2.28–2.89 times its dry mass in water. Effective interception rate ranged from 188.18%-238.48%, decreasing as 12 a (238.48%) > 19 a (213.09%) > 15 a (199.36%) > 32 a (188.25%) > 27 a (188.18%). The 12-year-old stand' s effective interception rate was significantly higher than other ages ($P < 0.05$).

2.2.3 Water-Holding Dynamics of Different Stand Ages

Water-holding capacity of all stand ages increased gradually with immersion time before stabilizing. Within 0–2 h, water-holding capacity increased rapidly, with the 27-year-old stand showing significantly higher capacity than other ages ($P < 0.05$). During this period, each stand age reached approximately 85% of maximum water-holding capacity, indicating strong rainfall interception capacity during short-duration precipitation events. From 2–8 h, the increase slowed, and by 8 h all stands approached saturation. The water-holding capacity during this period decreased as 27 a > 15 a > 32 a > 19 a > 12 a. Fitting water-holding capacity to immersion time revealed logarithmic relationships for all stand ages, with correlation coefficients $R^2 \geq 0.96$ ($P < 0.01$), indicating significant logarithmic relationships [Figure 3: see original paper]. Water-holding rate decreased as a significant power function over time ($R^2 \geq 0.83$) .

2.2.4 Water Loss Process of Different Stand Ages

The air-drying process (water loss) reflects litter' s water retention capacity under natural conditions, indirectly representing its interception and conservation ability [19]. Water loss amount and rate of different stand ages increased gradually over time, divided into rapid loss (0–4 h) and slow loss (4–48 h) stages [Figure 4: see original paper]. The 27-year-old stand showed the highest water loss amount, while the 12-year-old stand showed the lowest. None of the stands reached stable state after 48 h, indicating slower water loss than absorption and good water retention capacity. Water loss rate decreased over time, with significant differences among stand ages during rapid loss (0–4 h), particularly for the 27-year-old stand ($P < 0.05$). During slow loss, rates gradually stabilized with no significant differences among ages ($P > 0.05$). Water loss rate showed significant power function decreases over time ($R^2 \geq 0.80$) .

3.1 Litter Storage Status in Typical Poplar Plantations of Different Stand Ages

Litter storage in typical poplar plantations of the Lhasa River Valley showed the pattern 27 a > 15 a > 32 a > 19 a > 12 a. Litter accumulation relates to stand age, growth status, understory vegetation type, and site conditions [20]. Previous studies indicate litter storage increases with stand age [21,22], peaking at the mature forest stage (21–30 a). At the over-mature stage ($ $31 a), trees gradually senesce, growth slows, and litter input and storage decrease. Our results align with studies by Yang et al. [10] and Fu et al. [12]. Stand density also affects litter storage, with higher density slowing decomposition [23] but increasing input [24]. The 27-year-old stand had the highest density, contributing to its maximum litter storage.

3.2.1 Maximum Water-Holding Capacity/Rate and Effective Interception Capacity/Rate

Litter water conservation capacity includes thickness, storage, water-holding capacity, water-holding rate, interception amount, and interception rate [25]. In the Lhasa River Valley, poplar plantation litter water-holding performance generally increased then decreased with stand age, peaking in mature forests. Maximum water-holding capacity and effective interception amount are commonly used to represent litter water conservation function [26]. Both showed the pattern 27 a > 15 a > 32 a > 19 a > 12 a, with the 27-year-old stand significantly outperforming others. ANOVA revealed significant positive correlations between these indicators and litter storage ($P < 0.05$), indicating storage is the main factor affecting differences. Maximum water-holding rate and effective interception rate decreased with stand age but showed no significant differences (except for the 12-year-old stand). This suggests stand age does not significantly affect these rates for poplar plantations; differences in decomposition layer proportions and decomposition degrees may be the main factors [27]. Tree species significantly affect water-holding rates—the 12-year-old stand contained *Populus alba* with some *Populus cathayana*, and the mixture likely altered litter composition and texture, resulting in higher rates. Tree type is an important factor affecting water-holding rates and should be considered in future afforestation optimization.

3.2.2 Water-Holding and Water-Loss Processes

Water absorption and loss processes directly and indirectly reflect litter interception capacity. During water-holding, initial rates are highest due to low surface water potential, decreasing as litter becomes saturated [28]. In this study, litters reached approximately 85% of maximum capacity within 2 h, demonstrating strong interception during short rainfall events. During water loss, all stands showed rapid loss within 4 h but remained unstable after 48 h, indicating good water retention. Although water loss was initially rapid, retention lasted at least 48 h, benefiting water conservation in the high-evaporation Lhasa River Valley. Litter water-holding performance relates closely to decomposition rates, with decomposed and semi-decomposed layers showing greater capacity than undecomposed layers [29,30]. This study analyzed total litter performance without considering different decomposition layers, which should be strengthened in future research. Forest hydrological effects involve precipitation redistribution through canopy, litter, and soil layers, requiring comprehensive studies of all layers and multi-species, multi-age plantations to provide scientific basis for windbreak and sand fixation water conservation functions.

4 Conclusions

Litter in typical poplar plantations of the Lhasa River Valley plays important roles in reducing wind erosion and conserving water. Across five stand ages, litter storage ranged from 8.32–26.12 $t \cdot hm^{-2}$, could absorb 2.28–2.89 times its dry mass, and had effective interception amounts of 19.85–49.15 $t \cdot hm^{-2}$, demonstrating good interception benefits. Both litter storage and water-holding performance (maximum water-holding capacity, effective interception amount) showed the pattern 12 a $<$ 19 a $<$ 32 a $<$ 15 a $<$ 27 a, with 27-year-old litter performing best. Stand age is an important factor improving water-holding performance, with mature forests having the strongest water conservation capacity. For management of poplar plantations in the Lhasa River Valley, measures should include appropriate harvesting and renewal of over-mature forests to improve productivity, strengthening forest management to protect and accumulate litter layers, and emphasizing tree species selection and rational allocation in optimizing windbreak forests. This study is significant for achieving sustainable ecological benefits in windbreak, sand fixation, and soil conservation.

References

[1] Sun X Y, Wang G X, Wu Y, et al. Hydrologic regime of interception for typical forest ecosystem at subalpine of Western Sichuan, China[J]. Acta Ecologica Sinica, 2013, 33(2): 501-508.

[2] Hu X C, Huang Q L, Jin L. Hydrological functions of the litters and soil of tropical montane rain forest in Xishuangbanna, Yunnan, China[J]. Chinese Journal of Applied Ecology, 2017, 28(1): 55-63.

[3] Zhang X M, Di L, Shi Z J, et al. Soil moisture content under artificial *Robinia pseudoacacia* forest at different slope positions in the Zhonggou minor basin, Jingchuan County, Gansu Province[J]. Arid Zone Research, 2019, 36(5): 1300-1308.

[4] Wang M L, Wang F, Yao X J, et al. Hydrological effects of forest litters and soil in Xing' an Larch Forest at different stand ages[J]. Ecology and Environmental Sciences, 2015, 24(6): 925-931.

[5] Hou G R, Bi H X, Wei X, et al. Water conservation function of litters and soil in three kinds of woodlands in gully region of Loess Plateau[J]. Journal of Soil and Water Conservation, 2018, 32(2): 357-363.

[6] Zhang X L, Jin M, Liu X D, et al. Litter storage and its water holding capacity characteristics of five typical shrubs in Qilian Mountains[J]. Ecology and Environmental Sciences, 2015, 24(5): 735-740.

[7] Zhang B B, Xu Q, Gao D Q, et al. Higher soil capacity of intercepting heavy rainfall in mixed stands than in pure stands in riparian forests[J]. Science of the Total Environment, 2019, 658: 1514-1522.

[8] Yang J H, Tan W, Mao G X, et al. Water conservation ability of litter in *Cryptomeria fortunei* plantation with different age groups in central Guizhou[J]. Journal of Soil and Water Conservation, 2020, 34(2): 296-301.

[9] Gao D, Guo J B, Wang Y H, et al. Hydrological effects of forest litters of plantations with varying *Larix principis-rupprechtii* ages in Liupanshan of Ningxia, China[J]. Forest Research, 2019, 32(4): 26-32.

[10] Fu L, Zhao J M, Li Y N, et al. Hydrological effects of litters and soil in apple tree plantation at different stand ages of Longdong Loess Plateau[J]. Bulletin of Soil and Water Conservation, 2018, 38(5): 40-45.

[11] Mo F, Yu P T, Wang Y H, et al. The water holding capacity of litter layers in the forests of *Larix principis-rupprechtii* and *Betula albo-sinensis* in Liupan Mountain and their rainfall interception process[J]. Acta Ecologica Sinica, 2009, 29(6): 2868-2876.

[12] Deng Y, Jiang Z C, Qin X M, et al. Impacts of litter on physical and chemical soil properties and its karst effects on different forested Karst ecosystem[J]. Acta Ecologica Sinica, 2009, 29(6): 3307-3315.

[13] Liu Y L, Wen Y M, Li Q Y, et al. Water holding and water loss characteristics of six types of forest litter in the alpine gorge region of western Sichuan[J]. Journal of Soil and Water Conservation, 2019, 33(5): 151-156.

[14] Fan L J, Li X Y, Li C D, et al. Decomposition and nutrient release characteristics of *Karelinia caspia* and *Populus euphratica* leaf litters in extreme arid regions[J]. Arid Zone Research, 2021, 38(2): 479-486.

[15] Upton A, Vane C H, Girkin N, et al. Does litter input determine carbon storage and peat organic chemistry in tropical peatlands?[J]. Geoderma, 2018, 326: 76-87.

[16] Wang Z B, Li J X, Guo Y Q, et al. Ecological protection and restoration model of multi ecological elements in Qinghai-Tibet Plateau: A case study of Lhasa River Basin[J]. Acta Ecologica Sinica, 2019, 39(23): 8966-8974.

[17] Chang C P, Yuan L F. A discussion on the status, origin and developmental trends of blown sand in the valley of lower reaches of Lhasa River, Tibet Plateau[J]. Research of Soil and Water Conservation, 2010, 17(1): 122-126.

[18] Ma H P, Zhao K T, Yang X L, et al. Study on the ecological gain of artificial pure poplar forest in semi-arid valley region of Lhasa[J]. Journal of Anhui Agricultural Sciences, 2010, 38(32): 18204-18207.

[19] Li A, Gao T P, Zhang M, et al. Influences of vegetation cover on dynamic changes of soil wind erosion in wind erosion region of Northwest China[J]. Journal of Soil and Water Conservation, 2014, 28(6): 120-123.

[20] Liu M J, Yu L F, Du M F, et al. C, N, and P stoichiometry and their interaction with plants, litter, and soil in a *Cunninghamia lanceolata* plantation with different ages[J]. Acta Ecologica Sinica, 2018, 38(21): 7772-7781.

[21] Yang X, Chen L H, Kang Y L, et al. Water holding characteristics of litter in five typical water conservation forests in low mountainous areas of eastern Liaoning[J]. Chinese Journal of Ecology, 2019, 38(9): 2662-2670.

[22] Bao H, Zhao P W, Zhou M, et al. Water holding capacities of litters and soils in typical natural forests in south of Da Hinggan Mountains[J]. Journal of Arid Land Resources and Environment, 2020, 34(2): 175-181.

[23] Shi L, Shu Y, Zhang B, et al. Hydrological effects of litters in Xing' an larch forest at different stand ages[J]. Journal of Soil and Water Conservation, 2016, 36(5): 91-95.

[24] Guo J, Yu L H, Fang X, et al. Litter production and turnover in four types of subtropical forests in China[J]. Acta Ecologica Sinica, 2015, 35(14): 4668-4677.

[25] Li W Y, Man X L, Zhang Y W. Soil properties and water conservation function of *Betula platyphylla* secondary forest with different stand ages[J]. Science of Soil and Water Conservation, 2009, 7(5): 63-69.

[26] Yuan Y, Li X, Xiong D H, et al. Effects of restoration age on water conservation function and soil fertility quality of restored woodlands in phosphate mined out areas[J]. Environmental Earth Sciences, 2019, 78(23): 1-14.

[27] Wang L, Zhao G L, Zhou H J, et al. Hydrological characteristics of litter in a *Pinus tabulaeformis* plantation with different densities in Badaling Forest Farm[J]. Ecology and Environmental Sciences, 2019, 28(9): 1767-1775.

[28] Zhao M F, Xue F, Lyu Y, et al. The effect of environmental factors on the distribution of litter mass and litter depth in forests of Loess Plateau region[J]. Acta Ecologica Sinica, 2016, 36(22): 7364-7373.

[29] Xin F M, Yan X L, Zhang C Y, et al. Characteristics of stem sap flow of two poplar species and their responses to environmental factors[J]. Scientia Silvae Sinicae, 2019, 55(2): 22-32.

[30] Dai F Q, Lyu Z Q, Liu G C. Assessing soil quality for sustainable cropland management based on factor analysis and fuzzy sets: A case study in the Lhasa River Valley, Tibetan Plateau[J]. Sustainability, 2018, 10(10): 3477.

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