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Response of forest growth to C:N:P stoichiometry in plants and soils during *Robinia pseudoacacia* afforestation on the Loess Plateau, China

Wei Zhang[a,b], Weichao Liu[a,b], Miaoping Xu[a,b], Jian Deng[c], Xinhui Han[a,b,*], Gaihe Yang[a,b,*], Yongzhong Feng[a,b], Guangxin Ren[a,b]

[a] College of Agronomy, Northwest A&F University, Yangling 712100, Shaanxi, China
[b] Shaanxi Engineering Research Center of Circular Agriculture, Yangling 712100, Shaanxi, China
[c] College of Life Science, Yanan University, Yanan 716000, Shaanxi, China

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ABSTRACT

C:N:P stoichiometry in the plants and soils is an important indicator of biogeochemical cycles and functioning in ecosystems; however, the response of plant growth to ecological stoichiometry following afforestation remains unclear. To illustrate the C:N:P stoichiometry connections between the plants and soils and their effects on the growth of plants, soil and plant samples were collected from one farmland site and four *Robinia pseudoacacia* (RP) forests that were planted for 10, 15, 25, and 35 years. Plant community characteristics, growth of overstory trees and understory plants, physical and chemical properties of the soil, and C:N:P stoichiometry in plants and soil were measured. The results revealed that soil organic C, total N, total P, dissolved organic N, C:P and N:P ratios, and water content significantly increased, whereas soil bulk density, available P, and pH decreased with afforestation age. Leaf C:P and N:P ratios in RP were significantly higher than that in understory biomass because P concentrations gradually decreased in RP leaves and increased in understory biomass. The C, N, and P contents and stoichiometry in the soils and plants were significantly correlated, particularly for N:P ratio that can be used to reveal close coupling between plant and soil nutrients. The N:P ratio in RP leaf and understory biomass increased with afforestation age and varied from 14.44 to 20.81 and 7.59 to 10.96, respectively, suggesting that P limitation gradually increased in RP, and N limitation gradually declined in understory biomass. Furthermore, the responses of overstory trees and understory plant growth to N:P ratios were contradictory, because of their different nutrient acquisition patterns and nutrient-use efficiencies. Therefore, this finding provides evidence that the strong correlation between the plants and soils were tightly coupled to N and P concentrations and N:P ratios, and therefore, have the potential to influence the growth of forests on the Loess Plateau.

1. Introduction

Afforestation is one of the most effective ways to deter soil degradation, improve the ecological environment, and promote the restoration of degraded ecosystems (Ren et al., 2017; Zhang et al., 2011; Zhao et al., 2015b). Anthropogenic activities have greatly affected above-ground vegetation and underground soil ecosystems (Cao and Chen, 2017; Ren et al., 2017), and the change between above- and below-ground ecosystems is closely linked, because of the circulation and feedback of mineral nutrients and moisture between them (Peichl et al., 2012; Wang et al., 2009). C:N:P stoichiometry, focusing on the interaction and balance of chemical elements in the ecological processes (Mooshammer et al., 2014; Ren et al., 2016c) has been often used in studies on the feedbacks and relationships between above- and below-ground components of the ecosystems. For instance, C:N, C:P, and N:P ratios of the soil may vary with dynamic variation in the plant community because of different substrate inputs (leaf litter and rhizodeposition) during afforestation (Fanin et al., 2013; Zechmeister-Boltenstern et al., 2015). Numerous studies have analyzed the stoichiometric characteristics of plant tissues at both regional and global

Abbreviations: OC, organic carbon; TN, total nitrogen; TP, total phosphorus; DON, soil dissolved organic nitrogen; AP, soil available phosphorus; SWC, soil water content; SBD, soil bulk density; pH, soil pH; DBH, diameter at breast height; UB, understory biomass; UC, understory coverage; TCD, tree crown density; LB, litter biomass; IV, species important value; SN, species number; H, Shannon-Wiener index; RP, *Robinia pseudoacacia*; FL, farmland; LPC, Loess Plateau of China; GTGP, Grain to Green Project; LSD, least significant difference; RDA, redundancy analysis

* Corresponding authors at: College of Agronomy, Northwest A&F University, Yangling 712100, Shaanxi, China.
E-mail addresses: dengjian@nwsuaf.edu.cn (J. Deng), hanxinhui@nwsuaf.edu.cn (X. Han), ygh@nwsuaf.edu.cn (G. Yang), fengyz@nwsuaf.edu.cn (Y. Feng), rengx@nwsuaf.edu.cn (G. Ren).

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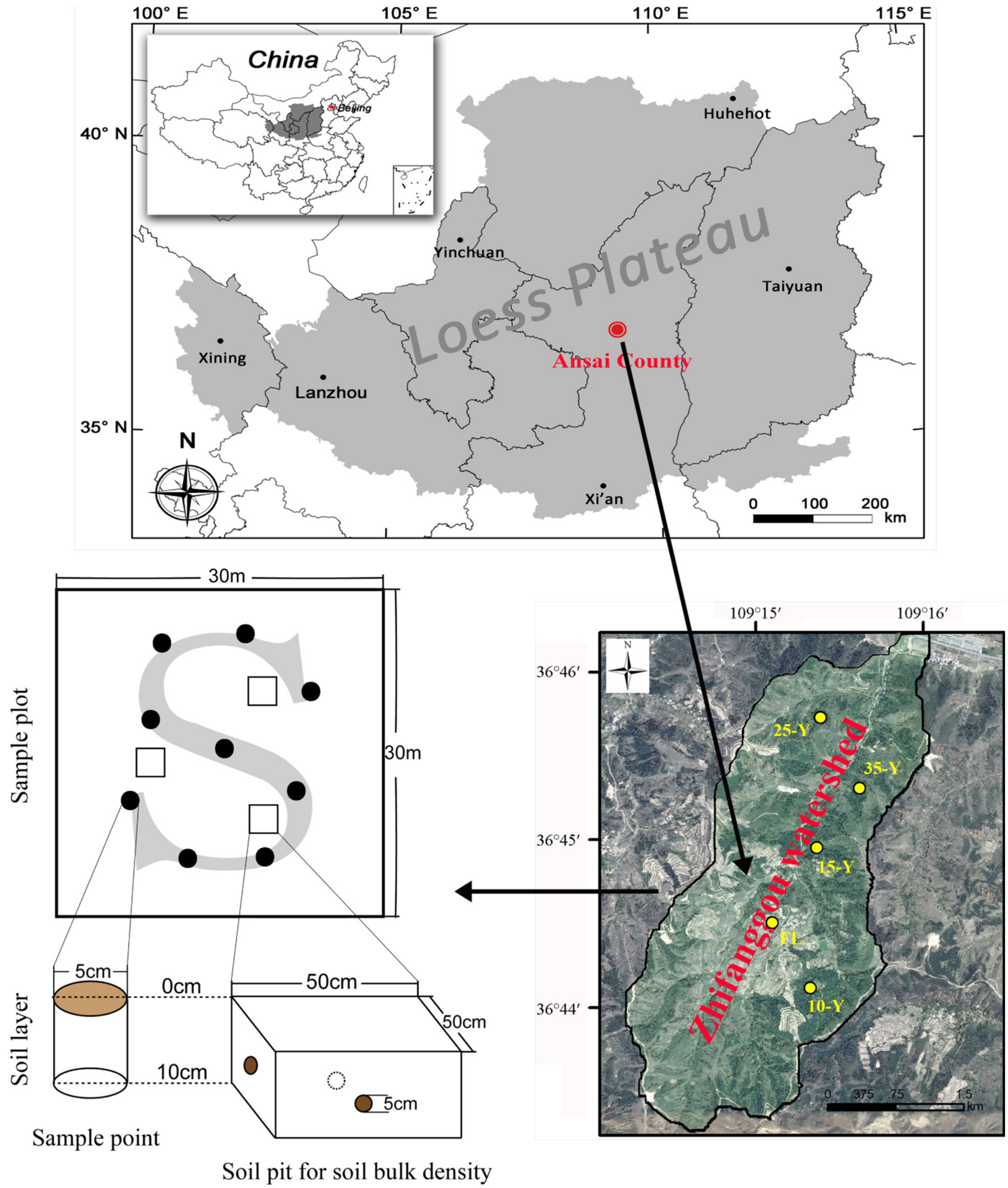

Fig. 1. Location of the Zhifanggou catchment in Loess Plateau of China and the sampling process (plotted by Arcgis9.3).

scales to reveal biomass production, nutrient cycling, and elemental limitations of plants (Elser et al., 2007; Güsewell and Verhoeven, 2006; Huang et al., 2013; Lebauer and Treseder, 2008). Researchers have also shown that soil C:N:P ratio can not only reflects soil fertility but also regulates plant growth and indicates plant nutrient status (Bui and Henderson, 2013; Fan et al., 2015). However, determination of the imbalance of stoichiometry in plant–soil subsystems still remains to be elucidated (Bell et al., 2014; Mooshammer et al., 2014), such as how tree species, successional stage, vegetation composition, and environmental factors influence nutrient (C, N, and P) redistribution between the plants and soils (Ågren and Weih, 2012), and how the stoichiometric relationship between the plants and soils affects ecosystem processes. Therefore, a better understanding of the C:N:P stoichiometry among the plants and soils will provide further insights into nutrient cycling and sustainable development of afforestation in the ecosystems.

Previous studies have shown that stand structure, primary productivity, and resource utilization efficiency of plant communities varies continuously with afforestation age (Cao and Chen, 2017; Fisher et al., 2010), which then leads to alterations in the soil physicochemical properties (Zhao et al., 2015b). However, these studies generally concentrated on the dominant tree species and neglected the contribution of understory plants (Tian et al., 2017). Understory herbaceous plants, which are not only the producers of forest ecosystems but also compete with overstory tree species for nutrient resources (Tessema and Belay, 2017), are crucial for improving the primary productivity of the forest vegetation, enhancing the soil nutrient content and affecting nutrient cycling between plants and soils during afforestation (Wu et al., 2011). For instance, it was demonstrated that understory plants and overstory trees had opposite responses to changes in the soil nutrients by studying