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Effects of forest plantation types on leaf traits of *Ulmus pumila* and *Robinia pseudoacacia* on the Loess Plateau, China

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ABSTRACT

Understanding the physiological response mechanisms of plant leaf traits to forest plantation types in semi-arid regions is of vital importance to better understanding the interplay between ecological process and plant resource-allocation strategies of different tree species. Experimental forest plantations were constructed on the Loess Plateau of China in order to study leaf morphological, physiological and stoichiometric traits among four forest plantation types of *Ulmus pumila* and *Robinia pseudoacacia*: a single-species *Ulmus pumila* plantation (SP-U), a single-species *Robinia pseudoacacia* plantation (SP-R) and three mixed plantation ratios of *U. pumila-R. pseudoacacia* (UR) [2:1 (2U1R), 1:1 (1U1R) and 1:2 (1U2R)]. Leaf morphological traits examined include: specific leaf area (SLA), leaf dry mass (LM), leaf area (LA) and leaf dry matter content (LDMC); physiological traits: net photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance (Gs) and instantaneous water use efficiency (WUE); and stoichiometric traits: leaf nitrogen content (LNC), leaf phosphorus content (LPC), leaf carbon content (LCC), N:P, C:N and C:P were examined for the four plantation types on the Loess Plateau of China. The results indicate SLA, Pn, Tr, Gs, LPC, LCC, C:N and C:P of *R. pseudoacacia* and *U. pumila* varied significantly among the four plantation types (SP, 2U1R, 1U1R and 1U2R). However, LA, LM, LDMC, WUE, LNC and LPC differed little among forest plantation types. The relationships between leaf morphological and physiological traits, in particular SLA revealed a significantly negative correlation with LDMC, but a positive correlation with Pn, Tr and Gs. With regard to the leaf morphological and stoichiometric traits in the study area, SLA was positively correlated with LNC and LPC, but negatively correlated with LCC. As a nitrogen fixation species, *R. pseudoacacia* always showed higher SLA, Pn, Tr, Gs, LNC and LPC while *U. pumila* showed higher LDMC, WUE, LCC, C:N, C:P and N:P. This may reflect different environmental adaption strategies between the two tree species. Compared with *R. pseudoacacia*, *U. pumila* responded to the arid habitats by increasing leaf thickness and thus reducing water loss, showing potential physiological plasticity in adapting to dry environments. Regarding the four forest plantation types, the mixed plantation displayed increased plant leaf nutrient content and photosynthetic rate when compared to the SP treatment, especially the mixed 1U2R treatment. Based on the results herein, the mixed plantation of *R. pseudoacacia* and *U. pumila* could effectively improve leaf nutrient contents and photosynthetic capacity of both tree species, with the optimal planting ratio studied here being the 1U2R treatment of *R. pseudoacacia* and *U. pumila* among the four forest plantation types on the Loess Plateau of China.

1. Introduction

The study of patterns and variations in plant traits along environmental and resource gradients is fundamental to understand both ecological (Silvertown, 2004; Westoby and Wright, 2006; Wu et al., 2015) and evolutionary processes (Ackerly et al., 2000). Ecophysiological theory predicts, in order to maintain fitness and improve adaptiveness, leaf traits need to exhibit plasticity in response to environmental demands (Zdravko, 2011). Past research activities have focused on plant functional traits, because these traits are considered to reflect the adaptations to environmental change and trade-offs among different functions within a plant, and thus can better link environmental drivers and plant responses to

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ecosystem structure and functioning (Díaz et al., 1998; Reich et al., 2003; Wright et al., 2004; Lavorel et al., 2007). Especially at the community scale, plant traits are strongly correlated with soil resources, plant nutrients and water use efficiency (Cornwell and Ackerly, 2010), thus they have been widely used in explaining community assemblage processes among different forest types (Villeger et al., 2008). In recent years, many studies attempted to predict plant responses in terrestrial ecosystems, such as forest ecosystems (Valera-Burgos et al., 2013; David et al., 2013; Bussotti et al., 2015); agro-forestry ecosystems (Okubo et al., 2012); and grassland ecosystems (Zheng et al., 2010). These studies have focused on using plant functional traits, especially for some easily and quickly measured leaf traits ("soft" traits), such as leaf size, leaf area, leaf dry mass, leaf dry matter content, and specific leaf area (Reich et al., 1998a, 2007). In a diverse range of plant communities, these 'soft' traits are found to be closely related to plant functions because they are highly correlated with "harder" traits, such as relative growth rate, photosynthetic capacity, leaf nutrient concentration, and leaf turnover rate, which further reflect the fundamental trade-offs between fast growth and nutrient storage (Grime, 2001; Westoby et al., 2002; Wright et al., 2004) in plant functioning. SLA, the ratio of leaf area to leaf dry mass, is an important leaf trait that integrates plant investment into growth and storage and has been widely used to predict growth strategy (Poorter and Jong, 1999). SLA, measures the amount of leaf area available for light capture per unit of biomass of investment. Leaf N and P concentrations are a proxy for the leaf's photosynthetic capacity and is therefore strongly positively correlated with photosynthetic rate (Reich et al., 1999). The relationship between SLA and both leaf N and P concentrations is well known for forest ecosystem (Reich et al., 1997). SLA captures the fundamental trade-off between resource acquisition and conservation in plants; therefore species with a high SLA typically have high leaf N and P, and consequently exhibit a higher photosynthetic capacity (Westoby et al., 2002). Leaf N and P are also positively related to stomatal conductance and relative growth rates (Reich et al., 1992; Westoby et al., 2002).

Although many studies on leaf traits exist for different forest species (Poorter and Bongers, 2006; Poorter, 2009; Coste et al., 2010; Wu et al., 2012; Russell et al., 2014), less is known about the mixed planting of tree species, especially on the Loess Plateau (China). There have been ecophysiological studies on common trees species (i.e., *Populus* L., *Pinus tabuliformis, Hippophae rhamnoides* L. and *Platycladusorientalis* (Linn.) Franco) (Liu et al., 2012). Therefore, more research on plant "integration function" studies at different organizational levels is needed on the Loess Plateau, which will likely improve our understanding regarding mechanistic links between plant functional traits and ecosystem properties (Violle et al., 2007).

The Loess Plateau in China is well known for its complex terrain, extreme drought conditions and severe soil erosion (Zhang et al., 2011; Wang et al., 2015a, 2015b). To control soil erosion and restore ecosystems, the Chinese government has instituted various erosion mitigation measures on the Loess Plateau, especially the conversion of cropland to forest or grassland ("Grain for Green" Programs (GGP)) (Zhang et al., 2015; Deng et al., 2016). In the study area, the cropland had already been abandoned, and the process of natural and artificial restoration was underway. As such, understanding the physiological characteristics and ecological adaptive strategies of different plant species or forest community types on the Loess Plateau will aid future recover and restoration in this currently damaged ecosystem. *Ulmus Pumila* L. is a widespread commercial tree species that dominates the arid region throughout its natural distribution range in northern China (Chen and Xu, 2012). For the fast-growing and high quality, *U. Pumila* is a well-adapted and extensively used tree species which is the primary afforestation tree species on the Loess Plateau (Chen and Xu, 2012). As a typical nitrogen-fixing leguminous plant, many studies indicate *R. pseudoacacia* L. can effectively improve soil quality and plant nitrogen nutrient levels in mixed forests, thus enhancing soil and water conservation efforts by improving the stability of forest structures and reducing occurrence of soil surface runoff (Shangguan, 2007). In addition, because of its resilience, fast growth, high yield, extensive root system and nitrogen fixation capacity, *R. pseudoacacia* trees are planted widely on the Loess Plateau and the northern regions of China as a means to address the intertwined environmental problems and soil and water conservation (Zhou and Shangguan, 2005; Li et al., 2015, 2016). As a result, *U. pumila-R. pseudoacacia* mixed forests are one of the most widespread mixed forest plantation types on the Loess Plateau which has been playing an important role in improving the ecological environment of the arid regions in northern China.

In this study plant leaf morphological, physiological and stoichiometric traits of *U. pumila* and *R. pseudoacacia* were studied among the four plantation types (i.e. a single-species *Ulmus pumila* plantation (SP-U), a single-species *Robinia pseudoacacia* plantation (SP-R) and three mixed plantation ratios of *U. Pumila and R. pseudoacacia* (UR) [2:1 (2U1R), 1:1 (1U1R) and 1:2 (1U2R)] in the field on the Loess Plateau. Plant leaf traits (i.e., leaf area (LA), leaf dry mass (LM), specific leaf area (SLA), leaf dry matter content (LDMC); net photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance(Gs) and instantaneous water use efficiency (WUE); and leaf N content (LNC), leaf P content (LPC), leaf C content (LCC), leaf nitrogen/phosphorus ratio N:P, leaf carbon/nitrogen ratio C:N, leaf carbon/phosphorus ratio C:P of both species present at the 15 experimental plots were systematically determined across the four plantation communities on the Loess Plateau to address the following research questions: (1) How do plant leaf traits of the two species vary with forest plantation types? (2) What are the possible physiological mechanisms underpinning the observed responses of leaf traits to the variation of different mixed ratios in the field? And (3) Which mixed ratios of *U. pumila-R. pseudoacacia* performed best within the mixed plantations?

2. Materials and methods

2.1. Study area and experimental design

This study was carried out at Xibo village in the Yangling District, Shaanxi Province, China (34°18′N, 108°15′E, and 450 m above sea level). The topography at the experimental site was flat ground. It belongs to a warm temperate-humid and semi-humid climate zone. The mean annual temperature in the area was 12.9 °C. The annual precipitation was 635 mm, with 70% occurring throughout the growing season (June–September). The average annual evaporation is approximately 1800 mm. The soil is Eum-Orthic Anthrosols. Topsoil organic matter content, total nitrogen, total phosphorus (0–30 cm) and pH are 18.3, 1.37, 0.81 g kg^{-1} and 7.96, respectively.

The forests at the study area are dominated by *U. pumila* and *R. pseudoacacia* (broadleaf tree), which is a widely distributed community type on the Loess Plateau. *U. pumila* is a common deciduous tree, which is resistant to drought, salinity and low temperature. Its roots grow profusely through soil profiles, resulting in high wind-breaking and sand-fixing capacities. As a leguminous species, *R. pseudoacacia* is typically observed as a pioneer species and used as an associated species on afforesting barren hills.

In mid-March 2007, 1-year-old *U. pumila* and *R. pseudoacacia* seedlings were planted below 30 cm soil layer in the field. The experimental treatments were composed of three management systems single-species *U. pumila* plantation (SP-U), single-species *R. pseudoacacia* plantation (SP-R) and *U. pumila–R. pseudoacacia* mixed plantation (UR). The study area was 470 m^2 and each test