Distribution and Absorption Characteristics of Plant Elements in Phyllostachys glauca Forest on Limestone Mountains in Ruichang, Jiangxi (Postprint)

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Abstract

To investigate plant nutrient distribution and absorption characteristics in limestone mountain Phyllostachys glauca forests and clarify their relationship with community functional status, this study measured the contents of nine elements in different organs of the constructive species Phyllostachys glauca and the companion species Elaeagnus pungens, Camellia oleifera, and Ilex cornuta in Ruichang, Jiangxi, and comparatively analyzed element distribution and absorption characteristics. The results showed that: (1) The distribution pattern of macronutrients (N, P, K, Ca, Mg) in various organs of Phyllostachys glauca was leaf > root > stem, while that of micronutrients (Fe, Mn, Zn, Cu) was root > leaf > stem; its leaves had high contents of N [(2 ± 1.16) g·kg-1], P [(1.17 ± 0.19) g·kg-1], and Fe [(1.01 ± 0.09) g·kg-1]; the order of element biological absorption coefficients in each organ was consistent with that of element contents; (2) For companion species, the distribution patterns of both macronutrients and biological absorption coefficients followed the order: leaf > stem > root. The distribution order of micronutrients in organs varied among species; Camellia oleifera leaves had the highest Mn content [(1.88 ± 0.18) g·kg-1], while Ca, Mg, and Zn elements were most enriched in the stems of Ilex cornuta; (3) The upper canopy species Phyllostachys glauca and Elaeagnus pungens under better light conditions showed similar element contents and allocation patterns, while the understory species Camellia oleifera and Lindera glauca differed significantly in element contents. The study concluded that the differences in element distribution and absorption characteristics between the constructive and companion species of the Phyllostachys glauca forest were closely related to community light conditions.

Full Text

Elements Distribution Pattern in *Phyllostachys glauca* Forest and Plant Absorption Traits in a Limestone Mountain of Ruichang, Jiangxi Province

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Abstract

To explore the nutrient distribution and absorption characteristics of plants in a *Phyllostachys glauca* forest on limestone mountains, and to clarify their relationship with community functional status, this study measured the contents of nine elements in different organs of the constructive species *Phyllostachys glauca* and associated species *Elaeagnus pungens*, *Camellia oleifera*, and *Ilex cornuta* in a limestone mountain area of Ruichang, Jiangxi Province. Comparative analysis of element distribution and absorption characteristics revealed: (1) In *P. glauca*, the distribution pattern of macronutrients (N, P, K, Ca, Mg) across organs was leaf > root > stem, while micronutrients (Fe, Mn, Zn, Cu) followed root > leaf > stem. The leaf showed high concentrations of N [(18.82 ± 1.16) g·kg ^{1}], P [(1.17 ± 0.19) g·kg ^{1}], and Fe [(1.01 ± 0.09) g·kg ^{1}]. The bio-absorption coefficients of elements in each organ followed the same order as element concentrations. (2) In associated species, both macronutrient distribution and bio-absorption coefficients followed leaf > stem > root. Micronutrient distribution patterns varied by species: *C. oleifera* leaves had the highest Mn content [(1.88 ± 0.18) g·kg ^{1}], while Ca, Mg, and Zn were most enriched in *I. cornuta* stems. (3) The upper canopy species *P. glauca* and *E. pungens*, which received better light conditions, showed similar element concentrations and allocation patterns, whereas the understory species *C. oleifera* and *I. cornuta* differed substantially. These findings suggest that differences in element distribution and absorption characteristics between the dominant and associated species in limestone mountain forests are closely related to community light conditions.

Keywords: *Phyllostachys glauca*, organs, illumination, element uptake traits, community

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1.1 Study Area Overview

Ruichang City is located in northwestern Jiangxi Province, bordering the Yangtze River to the north and Hubei Province. Geographically situated at

29°23' -29°51' N, 115°06' -115°44' E, the city features low mountains and hills formed by the eastern extension of the Muyu Mountains. Ruichang has a mid-subtropical humid monsoon climate with an average annual temperature of 16.6 °C, extreme maximum temperature of 41.2 °C, extreme minimum temperature of -13.4 °C, average annual precipitation of 1,394 mm, average annual sunshine duration of 1,890 h, and a frost-free period of 260 days (Liu et al., 2011). Large areas of Ruichang consist of limestone mountains where severe soil erosion makes it difficult for most species to survive, yet *P. glauca* thrives and becomes the dominant species.

2 Materials and Methods

In October 2014, three forest stands were randomly selected in typical limestone mountain *P. glauca* forests in the study area, with each stand separated by more than 50 m. In each stand, three individuals of the constructive species *P. glauca* and three individuals each of the associated species *E. pungens*, *C. oleifera*, and *I. cornuta* were randomly selected. Whole-plant harvesting was conducted for sample collection. For associated species, samples were separated into leaves, stems, and roots. For *P. glauca*, harvesting followed the method described by Fan et al. (2016): roots were a mixture of rhizome and root samples; due to the large biomass of bamboo leaves, branches, and culms, partial sampling was employed. Specifically, branches were selected from four cardinal directions and both upper and lower canopy layers, with all leaves on the selected branches collected as a leaf composite sample, the branches themselves as a branch composite sample, and culms sampled by longitudinally splitting them in half for a composite sample. To facilitate interspecies comparison, bamboo branches, culms, and rhizomes were combined as "stem," with element concentrations calculated using a weighting method based on the biomass proportions of each component (Fan et al., 2016).

Soil samples were collected at three slope positions (upper, middle, and lower) in each sampling stand using a diagonal sampling method. At each position, three points were sampled and combined into one composite sample, with a sampling depth of 0-30 cm. Soil samples were air-dried in the laboratory, impurities removed, and passed through a 100-mesh sieve. Plant samples were cleaned, killed at 105 °C for 5 min, then dried at 80 °C to constant weight, ground, and stored for analysis. Total N content was determined using the semi-micro Kjeldahl method. Contents of P, K, Ca, Mg, Fe, Mn, Cu, and Zn were measured using ICP-MS (Agilent 7700, Agilent Technologies, USA) with a relative standard deviation (RSD) less than 5%. Data were processed using Excel 2010.

The bio-absorption coefficient (A), which represents a plant' s ability to absorb and accumulate chemical elements from the environment, was calculated as follows (Ning et al., 2009):

$$A = (C_p/C_n) \times 100$$

where A is the bio-absorption coefficient, C is the element content in the plant organ, and C is the element content in the soil layer.

3 Results

3.1.1 Macronutrient Content

Nitrogen content was highest in leaves across all four species (*P. glauca*, *E. pungens*, *C. oleifera*, and *I. cornuta*). Leaf N concentrations in *P. glauca* and *E. pungens* were similar at (18.82 ± 1.16) g · kg^{1} and (18.96 ± 1.38) g · kg^{1}, respectively, while *C. oleifera* had the lowest leaf N content at only (8.97 ± 0.85) g · kg^{1}. Root N contents were low across all species, ranging from (4.14 ± 0.62) to (4.90 ± 0.43) g · kg^{1}, less than half of leaf N concentrations [Figure 1: see original paper]. Unlike the pattern in *E. pungens*, *C. oleifera*, and *I. cornuta* (leaf > stem > root), *P. glauca* stems had the lowest N content among all organs at only (2.86 ± 0.49) g · kg^{1}.

Leaf P concentrations were high in all four species, though *C. oleifera* had the lowest leaf P content [(0.66 ± 0.15) g · kg^{1}], which was even lower than its stem P content [(0.84 ± 0.18) g · kg^{1}]. Except for *C. oleifera*, the other three species showed organ distribution patterns of leaf > root > stem for P, while *C. oleifera* exhibited stem > leaf > root [Figure 1: see original paper]. For K distribution, all four species had the lowest concentrations in stems. *Phyllostachys glauca*, *E. pungens*, and *I. cornuta* showed highest K concentrations in leaves, but *C. oleifera* leaf K content was only (4.63 ± 0.64) g · kg^{1}, lower than its root K content of (7.41 ± 1.29) g · kg^{1} [Figure 1: see original paper].

Magnesium concentrations were highest in leaves of *P. glauca*, *E. pungens*, and *C. oleifera*, following the pattern leaf > root > stem. However, *I. cornuta* had the highest Mg content in stems [(2.96 ± 0.68) g · kg^{1}], with leaf and root Mg contents of (2.75 ± 0.52) g · kg^{1} and (2.43 ± 0.42) g · kg^{1}, respectively [Figure 1: see original paper]. Calcium concentrations were lowest in *P. glauca* stems at only (0.31 ± 0.05) g · kg^{1}. *Phyllostachys glauca* and *E. pungens* shared the same Ca distribution pattern of leaf > root > stem. While leaves of *P. glauca*, *E. pungens*, and *C. oleifera* had the highest Ca concentrations, *I. cornuta* stems contained the highest Ca content among all species and organs [(29.86 ± 3.49) g · kg^{1}], exceeding its leaf Ca content of (17.62 ± 2.00) g · kg^{1}. Moreover, all *I. cornuta* organs had higher Ca concentrations than corresponding organs in the other three species [Figure 1: see original paper].

3.1.2 Micronutrient Content

Iron distribution followed root > stem > leaf in *E. pungens*, *C. oleifera*, and *I. cornuta*. *Phyllostachys glauca* also had the highest Fe content in roots [(2.62 ± 0.56) g · kg^{1}], but its stem Fe content [(0.14 ± 0.026) g · kg^{1}] was extremely low and lower than leaf Fe content [(1.01 ± 0.09) g · kg^{1}] [Figure 2: see original paper]. Regarding leaf Fe differences, *P. glauca* had 2.24, 4.81, and 4.59

times higher leaf Fe concentrations than *E. pungens*, *C. oleifera*, and *I. cornuta*, respectively. Manganese concentrations were highest in leaves across all four species, with *C. oleifera* leaf Mn reaching (1.88 ± 0.18) g · kg^{1}. *Phyllostachys glauca* stems had the lowest Mn content [(0.03 ± 0.016) g · kg^{1}] [Figure 2: see original paper]. Zinc concentrations varied considerably among organs, with *I. cornuta* roots showing the highest Zn content at (392.97 ± 39.87) g · kg^{1} and leaves the lowest [(231.20 ± 17.33) g · kg^{1}]. Other species had organ Zn concentrations ranging from (18.23 ± 1.18) to (36.82 ± 2.54) g · kg^{1} [Figure 2: see original paper].

Copper concentrations were highest in stems of associated species, while *P. glauca* had the highest Cu content in roots [(32.75 ± 7.38) g · kg^{1}], exceeding its stem Cu content [(4.22 ± 0.80) g · kg^{1}]. Except for *P. glauca*, the other three species showed Cu distribution patterns of stem > leaf > root [Figure 2: see original paper].

3.2 Element Absorption Characteristics

Analysis of element bio-absorption coefficients in different plant organs revealed distinct patterns . For *P. glauca*, the bio-absorption coefficient order for macronutrients (N, P, K, Ca, Mg) was leaf > root > stem, with leaf N bio-absorption coefficient reaching 780.02. Associated species *E. pungens*, *C. oleifera*, and *I. cornuta* showed greater variation in macronutrient bio-absorption coefficients among organs, but all exhibited leaf > stem > root for N. While leaves generally had the highest P bio-absorption coefficients, reaching 300.37 in *I. cornuta*, *C. oleifera* showed the highest P coefficient in stems (202.65). Except for *I. cornuta* roots, which had the maximum K bio-absorption coefficient of 32.80, *P. glauca*, *E. pungens*, and *C. oleifera* showed leaf > root > stem patterns for K. *Ilex cornuta* stems exhibited exceptionally high Ca bio-absorption coefficients (1,112.79) compared to its leaves (656.76), whereas *E. pungens* and *C. oleifera* Ca coefficients ranged only from 127.21 to 356.06, and *P. glauca* stem Ca coefficient was as low as 11.60. Magnesium bio-absorption coefficients in *P. glauca*, *E. pungens*, and *C. oleifera* followed leaf > root > stem, while *I. cornuta* stems showed the maximum Mg coefficient of 49.92, higher than its leaf value of 46.26.

Unlike macronutrients, which were most strongly absorbed by leaves, micronutrient bio-absorption was strongest in roots or stems across the four species . *Phyllostachys glauca* leaves had the highest Fe bio-absorption coefficient (2.11), while its stems had the lowest (0.29). *Elaeagnus pungens*, *C. oleifera*, and *P. glauca* showed root > stem > leaf patterns for Fe. Aluminum bio-absorption coefficients were highest in roots of *P. glauca*, *E. pungens*, and *I. cornuta*, but highest in leaves of *C. oleifera* (7.88). Manganese bio-absorption coefficients were highest in leaves, with *C. oleifera* leaf Mn reaching 206.15. *Phyllostachys glauca* roots exhibited the highest Cu bio-absorption coefficient among all plant organs at 81.88, while other species showed stem > leaf > root patterns. *Ilex cornuta* roots had the maximum Zn absorption coefficient of 201.34, more than ten times higher than corresponding organs in other species, which ranged from 9.34 to 18.86.

4 Discussion

4.1 Nutrient Distribution Patterns in *P. glauca* Forest Plants

Leaves generally contain the highest nutrient concentrations among plant organs, while the relative concentrations in roots and stems vary by species and element. Deng et al. (2008) studied element distribution characteristics of 11 dominant species in typical karst areas of Guangxi and found nutrient distribution patterns of leaf > stem > root. Liu et al. (2010) investigated nutrient distribution in different-aged *Phyllostachys heterocycla* and found average contents of N, P, Ca, and Mg followed leaf > stem > root. Similarly, associated species *E. pungens*, *C. oleifera*, and *I. cornuta* in limestone mountains showed leaf > stem > root patterns for N, P, and K contents. However, the constructive species *P. glauca* differed, with root concentrations exceeding stem concentrations, following leaf > root > stem. Qi et al. (2004) also found element distribution patterns of leaf > root > stem in *Fargesia spathacea* communities.

Nutrient concentrations in different organs are closely related to plant physiological and ecological functions, reflecting interactions between plants and their environment (Mo et al., 2000). The variation in root versus stem concentrations appears species-specific, but the higher root nutrient concentrations in *P. glauca* likely represent an adaptation to environmental conditions. Studies on *P. glauca* in the same region showed that in continuous soil habitats with minimal exposed bedrock, P content followed leaf > stem > root (unpublished data). Compared to deep soil habitats, *P. glauca* in limestone environments with high bedrock exposure and shallow soils allocates more resources to roots (Liang et al., 2017), enhancing water and nutrient interception and absorption. This may explain why root nutrient concentrations exceed stem concentrations in this study.

Micronutrient distribution patterns showed no universal 规律 across organs and species, with enrichment varying by element and species (Ning et al., 2009; He et al., 1998), a finding confirmed by this study. Unlike macronutrients that accumulate in leaves, micronutrient concentrations were generally low in leaves. Liu et al. (1991) also found low leaf micronutrient contents in a mixed forest of coniferous and broadleaf species. Except for Mn, micronutrients in *P. glauca* and associated species *E. pungens*, *C. oleifera*, and *I. cornuta* were mainly concentrated in roots and stems, consistent with patterns observed in *Geranium robertianum* (Qin and Yang, 2015). Variation in micronutrient absorption and allocation among plants is closely related to species-specific requirements, tolerance, and storage locations (Chang and Ge, 1995).

4.2 Relationship Between Nutrient Distribution and Community Species Functional Status

The distribution patterns of chemical elements in plant organs reflect the ability of plants to absorb and accumulate mineral nutrients from soil (Liu et al., 2008). Li et al. (1999) found that upper canopy species in a *Cryptocarya concinna* community had higher leaf P contents than lower canopy species. Similarly, in this study, the constructive species *P. glauca* occupied the upper canopy, while associated species *C. oleifera*, *I. cornuta*, and *E. pungens* were in the lower canopy. Compared with associated species, *P. glauca* had higher leaf N and Fe contents than *C. oleifera* and *I. cornuta*, and leaf P content higher than *C. oleifera* and comparable to *I. cornuta* [Figure 1: see original paper]. These differences in element concentrations between *P. glauca* and associated species were consistent with their bio-absorption characteristics.

Canopy stratification primarily alters light intensity within communities (Xie et al., 2017). Nutrient contents differ significantly among canopy layers and are closely related to photosynthetic assimilation rates (Liu et al., 2001; Guan et al., 2014). Many nutrient elements, including N, P, and Fe, participate in photosynthesis, resulting in higher leaf nutrient concentrations in upper canopy species with strong photosynthesis (Li et al., 1999; Ma et al., 2008). Ji (2014) found that plant N content is closely related to photosynthetic assimilation rate, with highest leaf area-based N content and light use efficiency under full sunlight. In the *P. glauca* forest community, *P. glauca* and *E. pungens* showed similar element concentrations across organs, while *C. oleifera* and *I. cornuta* differed substantially. Field investigations revealed that *P. glauca*, as the upper canopy species, received the best light conditions, while *E. pungens* was mainly distributed in canopy gaps and edges with relatively strong light for photosynthesis. Consequently, these two species showed similar element concentrations across organs. In contrast, *C. oleifera* and *I. cornuta*, as understory species receiving weak light, had relatively low element concentrations in leaves [Figure 1: see original paper]. The physiological mechanism underlying this stratified nutrient distribution is that high light intensity and temperature in upper canopy leaves increase internal leaf vapor pressure, enhancing transpiration rates and driving substantial nutrient accumulation and upward transport through the xylem (Lambers et al., 2008).

5 Conclusions

(1) Macronutrients in *P. glauca* forest plants were most concentrated in leaves. In associated species, stem concentrations exceeded root concentrations, while in the constructive species *P. glauca*, root nutrient concentrations were higher than stem concentrations. This increase in root nutrients reflects adaptation to limestone habitats. Element absorption characteristics of *P. glauca* and associated species followed the same patterns as their concentration distributions. Micronutrient distribution patterns varied greatly among organs and species, with *C. oleifera* showing high Mn con-

tent and *I. cornuta* exhibiting high Ca, Mg, and Zn concentrations across organs, consistent with species-specific micronutrient absorption traits.

(2) The constructive species *P. glauca* had higher leaf N, P, and Fe contents than associated species, consistent with light distribution in the community. *Phyllostachys glauca*, as the upper canopy species receiving strong light, and *E. pungens*, distributed in canopy gaps and edges with good light conditions, showed similar element concentrations across organs. In contrast, *C. oleifera* and *I. cornuta* as lower canopy species receiving weak light had relatively low element contents.

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