

Long-term effects of thinning on non-structural carbohydrate and stoichiometric characteristics of *Pinus yunnanensis*

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Abstract

The effects of long-term thinning on the nonstructural carbohydrates (NSC) and stoichiometry of trees are poorly understood. Here, root, stem, and leaf samples were collected from a middle-aged *Pinus yunnanensis* forest thinned in 2012 to determine the content of carbon (C), nitrogen (N), phosphorus (P), sugar, and starch. Our findings revealed that (1) the NSC of the roots and needles increased by 18.94% and 46.95% after thinning, respectively. (2) The P content increased by 36.30%, 63.50%, and 52.16% in the roots, stems, and needles after thinning, respectively. (3) Thinning had no significant effect on the N content in any organ. (4) Long-term thinning affected the distribution of soluble sugars and starches, as well as the content of C and P in different organs. (5) The N:P ratio was 17.96 in the control group and 12.32 in the thinned group, which indicates that P and N were limited in the former and latter, respectively. (6) The phenotypic plasticity index of the stoichiometric characteristics of *P. yunnanensis* after thinning was lower than that of NSC, and the coefficients of variation of these characteristics in the stems were larger than the coefficients of variation of these characteristics in the organs. Thinning altered the distribution of C and P among the organs, and the stand changed from P-limited to N-limited after thinning. Our findings suggest that appropriate applications of N fertilizer after thinning would improve the quality of the stand.

1 Introduction

Thinning is an important measure in the cultivation and management of existing forest resources. Thinning reduces the density of forest stands, which alters their spatial structure and affects competition for light and water [1]. These changes in growing conditions in turn affect the physiological processes involved in the acquisition, distribution, and utilization of nutrients in plants [2, 3], all of which play important roles in forest regeneration, restoration, and reconstruction [4]. The storage of nonstructural carbohydrates (NSC) is determined by the supply of and demand for carbon (C) [5]. NSC include soluble sugars and starches. Starches are polymeric carbohydrates that are used for long-term energy storage [6, 7]. Under certain conditions, NSC can undergo mutual transformation and play important roles in plant metabolism and resistance to stress [8]. Most recent studies of NSC have focused on characterizing variation in NSC among forest types [9, 10], major forest tree species [11], and changes in NSC among seasons [12, 13]; however, few studies have evaluated the relationship between NSC and long-term thinning.

Ecological stoichiometry can provide insights into the adaptive responses of terrestrial plants to the environment [14]. The content of nutrients in different organs is determined by the nutrient requirements of plants at different growth stages and environmental conditions; the distribution of nutrients among organs can provide insights into nutrient usage [30]. Current research on the effects of thinning has focused on the effects of thinning on stand structure, biodiversity, and nutrients; however, few studies have evaluated the effects of long-term thinning on stoichiometric ratios. For example, Liu et al. [16] found that leaf C and N mass fractions in plantations of northern Chinese larch (*Larix principis-rupprechtii*) were highest under three years of moderate thinning (intensity of 35%), and needles and root C, N, and P were significantly correlated with soil nutrients. Thinning significantly increases the C, N, and P content of leaves, litter, and soil in *Pinus massoniana* plantations [17]. This may be due to thinning-induced reductions in competition and improvements in the availability of nutrients and space for the retained trees, which can promote stand growth.

Pinus yunnanensis is endemic to southwest China and an important afforestation tree species, and it also performs important soil and water conservation functions [18]. Most studies of *P. yunnanensis* forests have focused on community structure [18], the adaptive characteristics of the seeds [19], and the effects of climate change. Wang et al. [20] studied the NSC and stoichiometric properties of *P. yunnanensis* trees after short-term thinning and found that short-term thinning increased the content of NSC in the main stem, needles, and roots, as well as the C content in all organs; the content of NSC in the needles and the P content

in all the organs decreased, and the distribution of C, N, and P in all the organs was altered. However, few studies have evaluated the effects of long-term thinning on NSC and stoichiometric ratios. Here, we measured the NSC and content of C, N, and P in *P. yunnanensis* forests after 10 years of thinning and unthinned forests. The main aims of this study were to (1) determine the effects of thinning on C, N, and P stoichiometry and the NSC of *P. yunnanensis*; (2) characterize the distribution of NSC and the C, N, and P content in different organs after thinning; and (3) measure the degree of phenotypic plasticity in the content of NSC, C, N, and P after thinning.

2 Research Subjects And Research Methods

2.1 Study Area

The study was conducted in Dutian Forestry Farm, Dutian Township, Shuangbai County, Chuxiong Yi Autonomous Prefecture (Fig. 1). Shuangbai County (24°13' to 24°55' N, 101°03' to 102°02' E) is located in southern Chuxiong Prefecture, east of Ailao Mountain, and south of the Jinsha River and Honghe River systems. The average annual rainfall is 927 mm, the average annual temperature is 15°C, and the average number of annual sunshine hours is 2,355 h. The area experiences distinct dry and wet seasons, an abundance of light resources, and a diversity of climatic conditions.

Sampling was conducted at Dutian Forestry Farm, which is a state-owned artificial forest. The elevation of the study area ranges from 1,360 to 1,850 meters above sea level. The main tree species is *P. yunnanensis*, and the forest is mainly used for the production of wood.

2.2 Sample plot setups

The sampling sites were all located on upper, sunny slopes; the slopes ranged from 15 to 25 degrees, and the elevation of the sites was near 1,600 m (Table 1). In early 2012, thinning was carried out by retaining the most healthy trees, removing the worst growths, and ensuring that the retained trees had sufficient growth space and the density of trees was even. The actual average harvesting intensity of plants was 31.7%, and the harvesting intensity in terms of forest volume was 19.0%. Stand conditions were similar across all sampling sites, and no fertilization or watering was conducted within 10 years after thinning.

In November 2021, a survey was carried out, and plots were selected. There were two treatments (CK, unthinned stands, control group; FY, thinned stands, thinned group), with three replications of each treatment and a total of six plots. The standard sample plots (25.82 m × 25.82 m) were rectangular, and the boundaries were measured using a compass meter (closure difference 1/200).

2.3 Sample collection and measurements

Plots contained middle-aged *P. yunnanensis* forest, and the age of the trees was approximately 25 years. Samples were collected in November 2021. Three standard trees with average tree height and diameter were randomly selected in each plot, and the needles, stems, and roots of each standard tree were sampled. Samples from different locations in the upper canopy were pooled and comprised a single tree needle sample. A growth cone with an inner diameter of 5 mm was used to drill the tree core vertically at a height of 1.3 m; the bark was removed, and the core was sampled. Fine roots (diameter < 2 mm) were collected by digging within 1 m of the tree trunk at a depth of 30 cm. All samples were sealed and labeled immediately after they were collected. In the laboratory, the samples were cleaned and immediately placed into an oven at 120°C for 30 min; they were then dried at 65°C until a constant weight was reached, crushed and ground through a 100-mesh sieve, and placed into sealed bags for testing. The content of soluble sugar and starch was determined using the concentrated sulfuric acid-phenol method [15]. The C content was determined

using the potassium dichromate oxidation-external heating method. The content of total N was determined using the Kjeldahl method. The total P content was determined using the Mo-Sb colorimetric method [21].

Table 1
Basic information of the sample plot

Sample Plot No.	Slope position	slope aspect	Average BDH/cm	Average tree height/m	Stand density/(tree·hm ⁻²)	Individual volume/m ³	Stand volume/m ³
CK-1	Uphill position	216°southwest	12.5	12.1	1483	0.0803	7.2853
CK-2	Uphill position	210°southwest	17.8	14.1	1232	0.1786	4.8882
CK-3	Uphill position	218°southwest	21	14.9	1075	0.2579	5.9569
FY-4	Uphill position	240°southwest	16.9	13.8	910	0.1591	7.5338
FY-5	Uphill position	232° southwest	22.1	13.8	930	0.2689	10.1259
FY-6	Uphill position	216° southwest	20.5	14.9	835	0.2445	4.6990

2.4 Statistical analyses

Independent sample *t*-tests were used to test the effects of thinning. Duncan multiple range tests were used to characterize the distribution of NSC, C, N, and P in all organs ($\alpha = 0.05$). The data were tested for normality and homoscedasticity before analysis of variance. Correlations among C, N, P, and their ratios in different organs of *P. yunnanensis* were analyzed by Pearson’s correlation analysis. All data analyses were conducted in SPSS 19.0, and all graphs were built in Origin 9.1. The plasticity index (PI) was calculated using the following formula: $PI = (min - max)/max$, where min and max are the minimum and maximum values for each parameter, respectively. The coefficient of variation ($CV = \text{Standard errors}/\text{average}$) for each trait was calculated.

3 Results

3.1 Effects of thinning on NSC the *P. yunnanensis*

Thinning had a significant effect on the content of soluble sugars, starch, and NSC, and there was a significant interaction between thinning and organ on the content of soluble sugars (Table 2). Thinning had a significant effect on the content of soluble sugars and NSC in the roots and needles and the starch content in the stems (Table 3).

Table 2
Two-factor ANOVA of the effects of thinning on the content of NSC in different organs.

Factor	Soluble sugar	Starch	NSC
thinned	7.762**	9.142**	15.307**
Organ	25.502**	16.920**	33.632**
thinned×Organ	4.786*	0.588	1.914
Notes: F value, *denotes $P < 0.05$ and **denotes $P < 0.01$.			

Table 3
Independent sample t-tests of the content of NSC in different organs in thinned and unthinned stands.

Index	Root	stem	Needle
Soluble sugar	-2.547*	1.266	-2.605*
Starch	-1.321	-2.661*	-1.980
NSC	-2.297*	-1.441	-2.846*

F value, *denotes $P < 0.05$ and **denotes $P < 0.01$.

3.2 Changes of NSC in different organs of *P. yunnanensis*

Thinning had significant effects on the content of soluble sugars in the roots and needles and the content of starch and NSC in stems (Fig. 2). The content of soluble sugars was 43.87% and 40.03% higher in the roots and needles, respectively, in thinned stands than in unthinned stands. The content of NSC was 18.94% and 46.95% higher in the roots and needles, respectively, in thinned stands than in unthinned stands. The content of starch was 60.08% higher in stems in thinned stands than in unthinned stands.

The distribution of NSC among organs in the control group and thinned group was similar; however, the distribution of soluble sugars and starch differed among organs.

3.3 Effects of thinning on C, N, and P stoichiometry in *P. yunnanensis*

The P content and ratios of C:P and N:P were strongly affected by thinning according to a two-factor ANOVA (Table 4). The N and P content and their stoichiometric ratios significantly differed among organs. Thinning had a significant effect on the P content and C: P ratio in the roots and stems, as well as the C and P content and N:P ratio in the needles (Table 5).

Table 4
Two-way ANOVA of the C, N, and P contents and their measurement ratios in different organs after thinning

Factor	C	N	P	C: N	C: P	N: P
thinned	0.470	0.425	19.741**	0.542	24.622**	6.335*
Organ	2.976	36.755**	7.444**	29.843**	13.854**	11.422**
thinned×Organ	1.812	0.061	0.017	0.350	5.798**	0.077

F value, *denotes $P < 0.05$ and **denotes $P < 0.01$.

Table 5
Independent sample *t*-test analysis of the content of C, N, and P and their ratios in different organs.

Index	Root	stem	Needle
C	0.055	0.554	-2.357*
N	0.419	0.592	0.465
P	-2.472*	-2.879*	-2.341*
C: N	-1.166	0.117	-1.918
C: P	2.626*	4.297**	0.903
N: P	1.133	1.986	2.396*

F value, *denotes $P < 0.05$ and **denotes $P < 0.01$.

3.4 Chemometric characteristics of C, N, and P in different organs of *P. yunnanensis*

The C, N, and P content and their stoichiometric ratios in each organ of *P. yunnanensis* in the thinning treatment were measured (Fig. 3). The C content was 11.87% higher in the needles in thinned stands than in unthinned stands; the P content was 63.50% and 52.16% higher in the stems and needles in thinned stands than in unthinned stands, respectively. The P content in the roots was 36.30% higher, the C: P ratio in the roots was 51.18% lower, and the C:P ratio in the stems was 19.68% lower in thinned stands than in unthinned stands.

The distribution of N and the C:N and N:P ratios in different organs were similar in the control and thinned groups, and the distribution of C and P and the C:P ratio varied among organs. The C contents control group was ordered root = stem = needle, and the thinned group was root = stem < needle (Fig. 3a); the P contents control group was ordered root = needle > stem, and the thinned group was root = stem = needle (Fig. 3b); the N contents were ordered needle > root > stem (Fig. 3c), C: N was ordered stem > root = needle (Fig. 3e); C:P in the control group was ordered stem > root = needle (Fig. 3d) and the thinned group was stem = needle = root (Fig. 3d), The stems were significantly higher than the other organs in the control group ($P < 0.05$), while there was no significant difference between the organs in the control group; N:P was ordered needle = root > stem (Fig. 3f), where needle content was significantly higher than stem content ($P < 0.05$), and there was no significant difference between needle and root.

3.5 Relationships between C, N, and P in each organ, and relationships between NSC and C, N, and P stoichiometric ratios in *P. yunnanensis*

Correlation analysis showed that the content of N in the different organs was positively correlated, P in the roots and needles was positively correlated, and no significant correlations were observed in the C content of different organs (Fig. 4A). Significant positive correlations were observed between root C and stem P, between root P and needle C, and between needle C and needle P.

Next, we determined correlations of NSC with C, N, and P and their stoichiometric ratios among organs (Fig. 4B, C, D). In the roots, starch was significantly positively correlated with the content of C and the C:N ratio and significantly negatively correlated with the N: P ratio. Starch was significantly positively correlated with the P content and significantly negatively correlated with the N content. NSC in the roots was significantly positively correlated with the C content but negatively correlated with the N content (Fig. 4B). In the stems, starch was significantly positively correlated with NSC and significantly negatively correlated with the C:N ratio, and NSC was significantly negatively correlated with the C:N ratio (Fig. 4C). In the needles, starch was significantly negatively correlated with the N content and N:P ratio and significantly positively correlated with the C:N ratio; NSC was significantly positively correlated with the C:N ratio and significantly negatively correlated with the N:P ratio (Fig. 4D).

3.6 PI of NSC

The highest CV of soluble sugars was observed in stems (Table 6). PI values are shown in Fig. 5. Soluble sugar, starch, NSC, and the soluble sugar:starch ratio in each organ ranged from 0.08 to 0.75; the PI values of root starch and NSC were low (PI < 0.20).

Table 6
CVs of the soluble sugar, starch, NSC, and soluble sugar:starch ratio in *P. yunnanensis*.

Organ	Coefficient of Variance (%)				
	Soluble sugar	Starch	NSC	Soluble sugar:Starch	Average
root	43.43	5.63	8.56	27.14	21.19
stem	59.76	60.68	38.08	85.55	61.02
Needle	31.73	24.33	26.65	46.67	32.35
Average	44.97	30.21	24.43	53.12	38.19

3.7 PI of C, N, and P and their stoichiometric ratios

CV was highest for N:P, and the organ with the highest CV for N:P was the stem (Table 7). PI values are shown in Fig. 6; the content of C, N, and P of each organ ranged from 0.05 to 0.59. The PI index was low (< 0.20) for the C and N content and C: N ratio of stems and the C:P ratio of the roots and needles and high (> 0.40) for the P content, C:P ratio, and N:P ratio in stems.

Table 7
CVs of the C, N, and P mass fractions and their stoichiometric ratios in
P. yunnanensis.

Organ	Coefficient of Variance (%)						
	C	N	P	C:N	C:P	N:P	Average
root	6.64	7.03	20.76	25.83	14.26	23.42	16.32
stem	14.84	3.96	35.78	12.76	46.93	59.50	28.96
Needle	11.80	4.32	19.64	16.25	7.45	22.18	13.61
Average	11.09	5.10	25.39	18.28	22.88	35.03	27.05

4 Discussion

4.1 Effect of thinning on the content of NSC in *P. yunnanensis*

The hydrological properties and light environments within the stands were altered after thinning. The growth of *P. yunnanensis* stands was not depressed after thinning because the amount of light per individual increased, which might enhance photosynthetic activity and starch accumulation. The increase in starch in all organs after thinning provides a surplus of energy that can help plants withstand adverse conditions (e.g., drought or cold) [19]. In our study, the content of soluble sugars and NSC in the roots of *P. yunnanensis* were 43.87% and 18.94% higher after thinning, respectively; the content of soluble sugars and NSC in the needles of *P. yunnanensis* were 40.03% and 46.95% higher after thinning, respectively (Fig. 1). The increase in soluble sugars in the needles might stem from the fact that the needles are the primary photosynthetic organs and a source of carbohydrates [18]. The growth rates of trees and nutrient uptake of the root system increased after thinning. Li et al. [22] found that the removal of the understory of fir forests resulted in a decrease in the content of NSC in the roots, which was not consistent with the findings of our study. Huo et al [23] found that shade treatment significantly reduced the content of NSC in *Fraxinus mandshurica* leaves, and this was consistent with our findings. Increases in NSC in the leaves and roots indicate that the physiological activity of the roots and leaves was enhanced after thinning, and this resulted in an increase in the starch content in stems. This might explain the accelerated growth observed after thinning.

The PI values of morphological and physiological characteristics are indicators of the adaptability of organisms to changing environments [34]. In our study, the CV values of most characteristics were highest in stems. This suggests that *P. yunnanensis* adapts to the post-thinning environment by regulating various physiological indicators in the stem. The CV of sugar was highest, and this probably stems from increases in photosynthetic activity and metabolic physiological activity after thinning. What's more, additional research is needed to clarify alternative means by which *P. yunnanensis* adapts to the post-thinning environment.

4.2 Effect of thinning on the C, N, and P content and their stoichiometric ratios

The composition, distribution, and concentrations of C, N, and P in plants are closely related to their physiological activities, such as material synthesis and metabolism [24]. The stoichiometric characteristics of C, N, and P can be used to characterize the growth, development, and nutritional status of plants [25]. Thinning enhances the availability of light in forest and accelerates the decomposition of forest floor litter, which increases soil organic matter and the content of N; thinning can thus alter the absorption of nutrients by plants from the soil. In this study, an increase in the C content in needles was observed after thinning (Fig. 2a). Wang et al. [20] found that the C content in different organs of *P. yunnanensis* was high under short-term thinning. This might stem from decreases in the number of trees after thinning, which weakens intraspecific competition and increases growing space and light penetration. The C sequestration capacity of

the needles was enhanced by increases in available living space and environmental resources. The P content of each organ was increased after thinning (Fig. 3b). Qiu et al. [26] found that the P content of the leaves of *Larix principis-rupprechtii* Mayr increased significantly after thinning, which was consistent with the results of our study. This might stem from the reduction in stand competition after thinning, improvements in nutrient availability, and increases in tree growing space, all of which promote tree growth [27]. Fast-growing trees require P-rich ribosomal RNA to support and sustain rapid growth [28]. Kume et al. [29] found that the N concentration in tissues of *Pinus sylvestris* was significantly higher in stands in which understory shrubs had been cleared, and these findings are not consistent with the results of our study. In our study, crown density was higher, the photosynthetic rate was lower, growth was slower, and nutrient use efficiency was lower in the control group than in the thinned group. This likely explains why the N content was higher in all organs in the control group than in the thinned group.

The C:N and C:P ratios in plants reflect their ability to absorb nutrients and assimilate carbon, as well as their growth rate and nutrient use efficiency [30]. The C:N and C:P ratios in plants are inversely proportional to the plant growth rate [31]. Han et al. [32] showed that when $N:P < 14$, plant growth is mainly limited by N, and when $N:P > 16$, plant growth is mainly limited by P. If $N:P$ is within 14–16, plant growth is limited by both N and P. In our study, $N:P$ was 17.96 in the control group, indicating P limitation, and 12.32 in the thinned group, indicating N limitation. This might stem from increases in nutrients and faster growth resulting from long-term thinning, and this increases the depletion of nutrients in forest. However, the nutrient limitations of the same species in the same area can vary; given that the diagnosis of limiting nutrients based on uniform criteria can be subject to bias, the identification of nutrient limitations should be conducted in conjunction with fertilization trials. The C:P ratio was lower in all organs after thinning, and the C:N ratio of the roots and needles was higher in the thinned group than in the control group; this indicates that the P-use efficiency was reduced and the N-use efficiency was increased in all organs after thinning. Bowman [33] confirmed that the nutrient use efficiency of plants tends to be higher when the supply of nutrients is deficient, and this might be a strategy for mitigating the adverse effects of nutrient stress. In our study, the environment was N-limited to some extent after long-term thinning; thus, the productivity of thinned *P. yunnanensis* plantations could be improved via N fertilizer application.

The PI values of the stem P content, $N:P$ ratio, and C:P ratio were the highest. This suggests that the P uptake of plants was enhanced after thinning; however, additional studies are needed to clarify the mechanism underlying this change. The CVs of these characteristics in the stems were higher than the CVs of these characteristics in other organs, indicating that *P. yunnanensis* adapts to the post-thinning environment by regulating the content of nutrients in the stem.

4.3 Distribution patterns of NSC and nutrients in different organs

- In our study, the distribution of NSC among organs was similar in the control and thinned groups, however, the distribution of soluble sugars and starch differed (Fig. 2). Samples were collected during the dry season, and *P. yunnanensis* allocated most NSC to needle and root growth during this period, which enhanced water and nutrient absorption and photosynthesis. The distribution of starch, which is a stable storage material, in trees might reflect a long-term energy storage strategy. The starch content of the thinned group was highest in the roots and needles, followed by the stems (Fig. 2b). This might stem from the carbon balance in *P. yunnanensis*, which is controlled by self-regulatory effects of long-term growth in arid environments. The storage of energetic substances in organs enables the easy transport and transformation of energy, which enhances various properties of the root system and the production of defensive compounds, thereby enhancing the drought resistance of trees. Additional studies are needed to clarify the effects of thinning on the drought resistance of trees.

- The NSC in the roots was positively correlated with C and negatively correlated with N (Table 4). Thinning in this area increased the photosynthetic rate in *P. yunnanensis*, which induced the storage of large amounts of C in the roots and increases in the content of NSC.

5 Conclusions

- Thinning had significant effects on the content of soluble sugars and NSC in the roots and needles and starch in stems. The content of soluble sugar and NSC in the needles was 40.03% and 46.95% higher after thinning, respectively.
- Thinning only resulted in significant differences in the P content in organs and the C content in needles. The P content in the stems and needles was 63.5% and 52.16% higher, respectively, and the C content in the needles was 11.87% higher in thinned stands. The needle N:P ratio was 17.96 in the control group, which indicates P limitation; however, the N:P ratio was 12.32 after thinning, indicating N limitation.
- Long-term thinning affected the distribution of soluble sugars, starch, and the content of C and P among organs, and it had no significant effect on the distribution of NSC and N. PI values ranged from 0.05 to 0.59 for the chemometric data and from 0.08 to 0.75 for NSC.
- In our study, we only analyzed the effect of a single thinning intensity on the content of nutrients and NSC. Additional research is needed to evaluate the long-term effects of different thinning intensities to clarify the physiology mechanisms. Both environmental and physiological indices of trees should be measured after thinning in future studies. Whether thinning reduces water stress and improves the stoichiometry of plants by enhancing P acquisition also merits further study.

Declarations

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Authors' Contribution

Chaojun Li wrote the manuscript, Junwen Wu designed the experiments, provided critical revisions and final approval of the article. Huiqing Jing, Siyi Liang and Tian Tan carried out the experiments and run the data. Wanquan Guo, Jianfeng Yang, Conghui Yang and Chengjin Han assisted with field investigations and sampling. All authors also helped to write, read and approved the final manuscript.

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Data Availability Statement

The datasets used during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Statement

All methods were carried out in accordance with relevant guidelines and regulations.

Competing interests

The authors declare that they have no competing interests.

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Figures

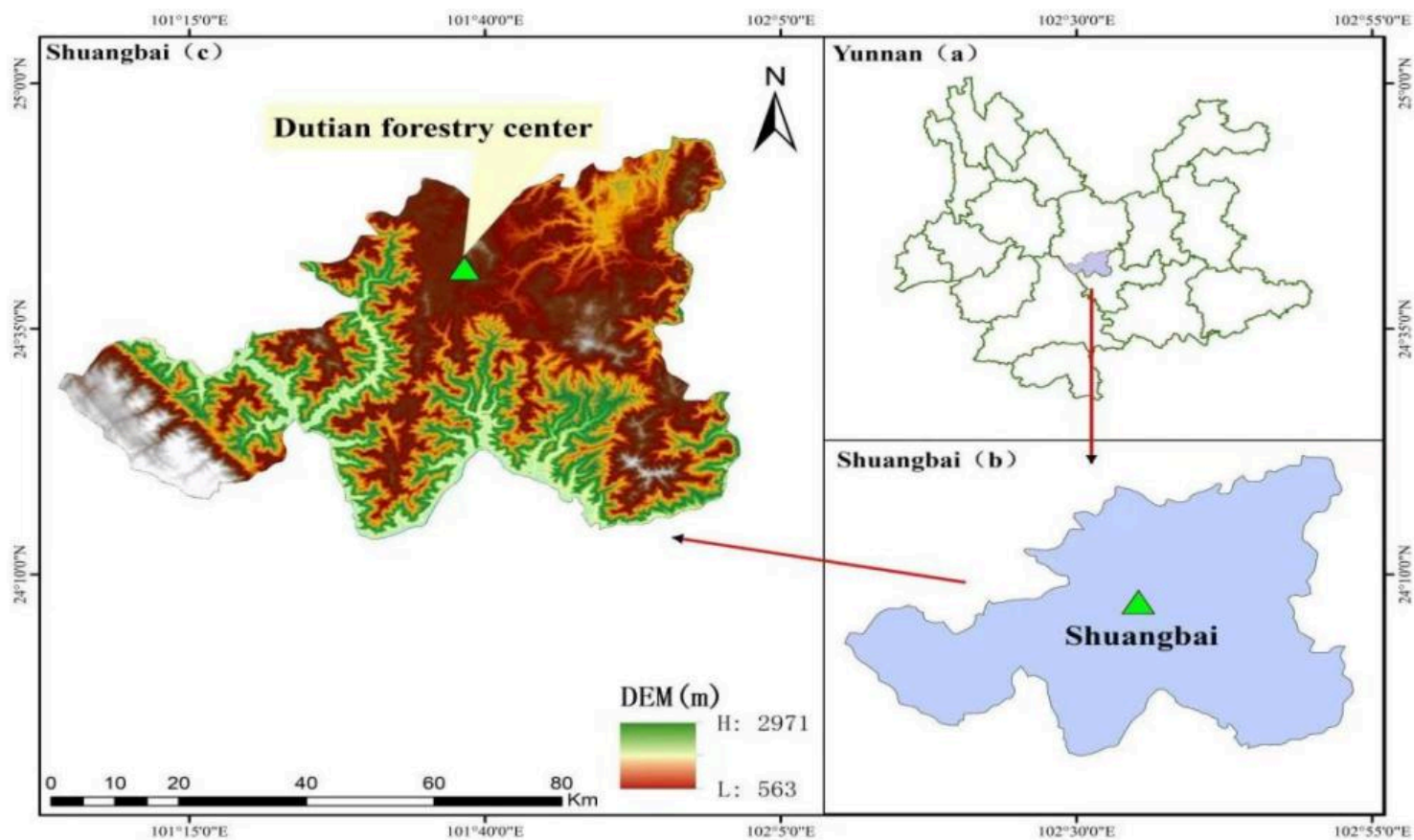


Figure 1

Location of the sample site

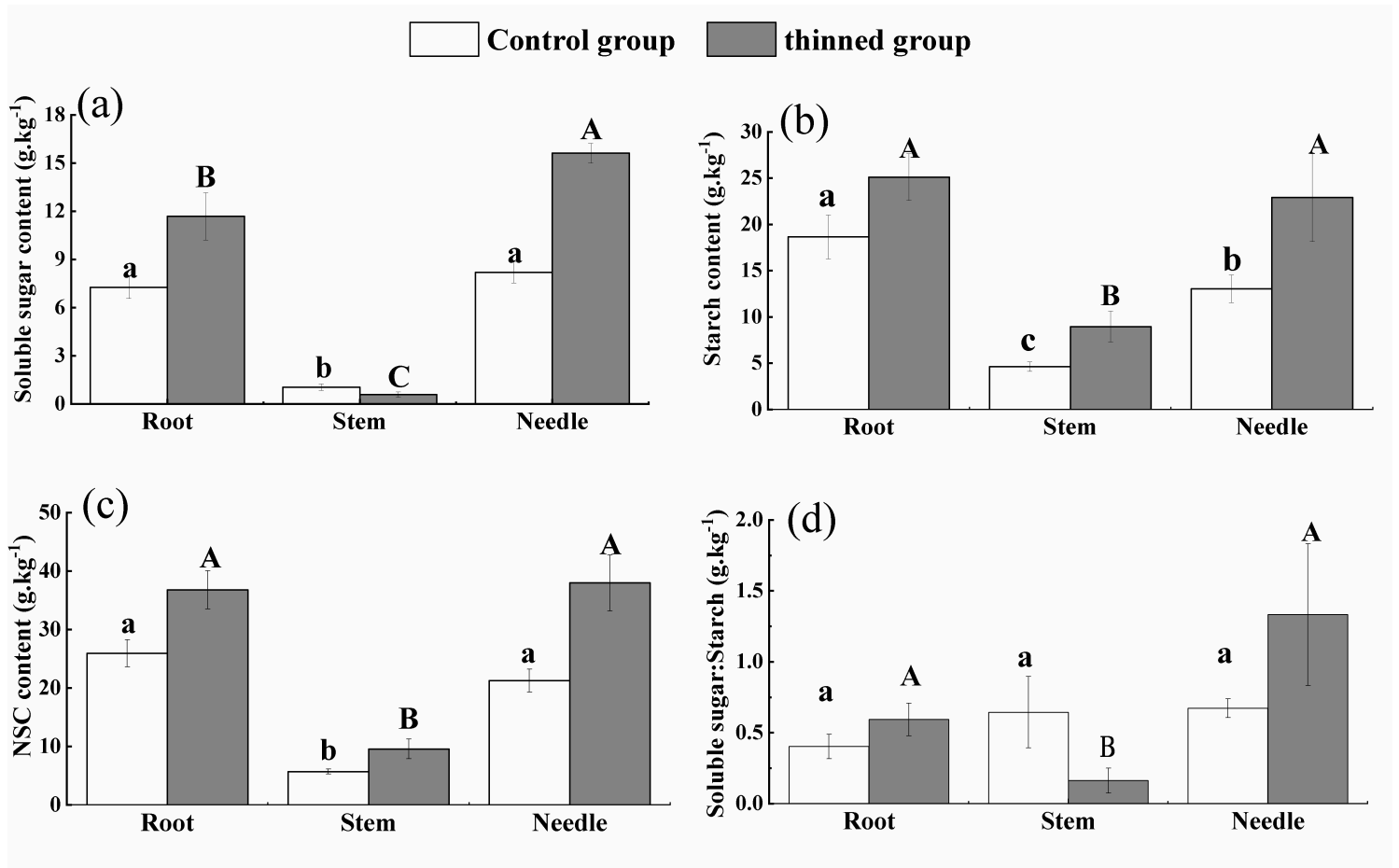


Figure 2

Distribution of NSC in different organs of *P. yunnanensis* in thinned and unthinned plots. Different lowercase letters indicate significant differences in different organs in the control group ($P < 0.05$), and different uppercase letters indicate significant differences in different organs in the thinned group ($P < 0.05$).

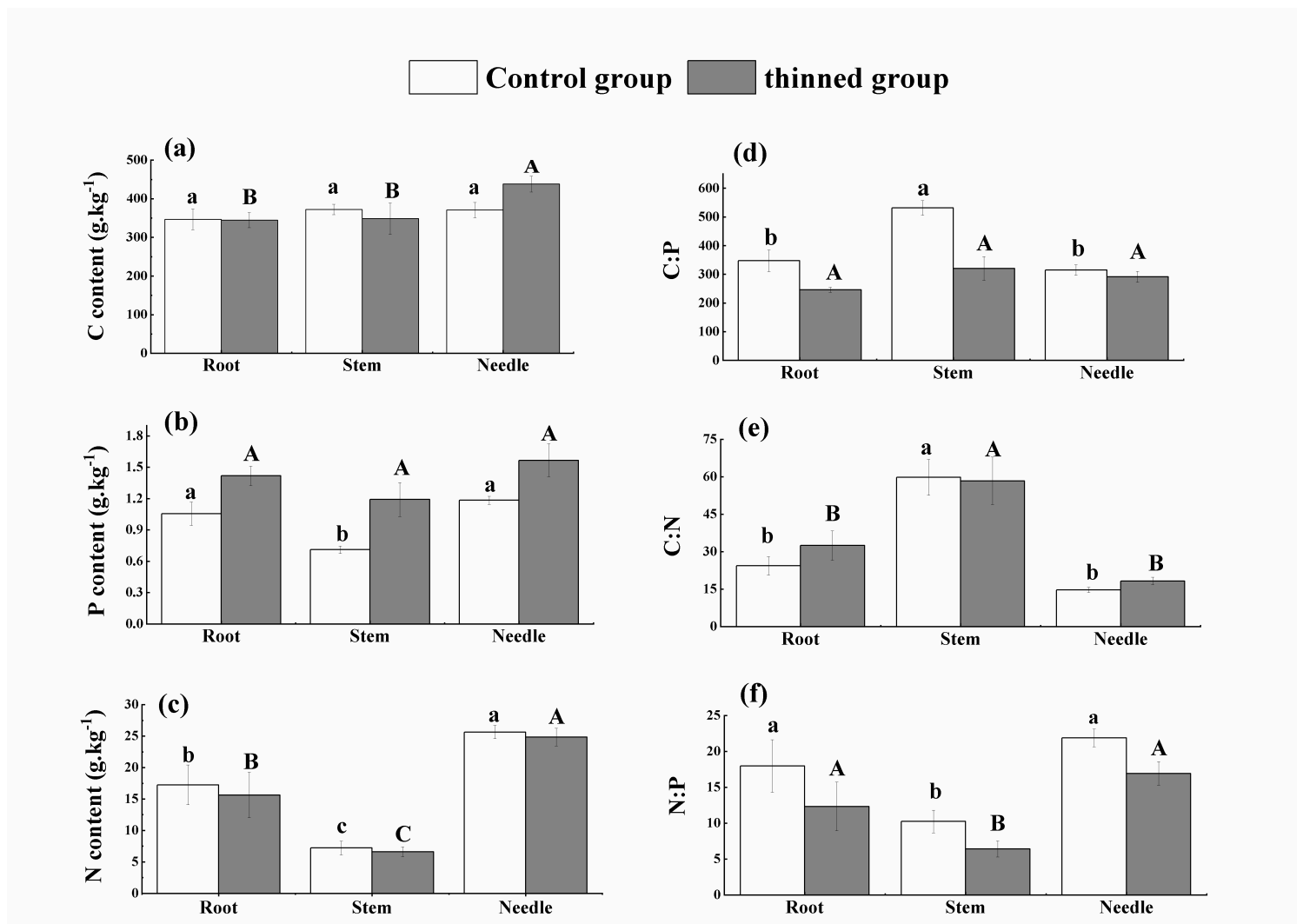


Figure 3

Changes in the content of C, N, and P and their stoichiometric ratios in different organs of *P. yunnanensis* in thinned and unthinned treatments. Different lowercase letters indicate significant differences among organs in the control group ($P < 0.05$), and different uppercase letters indicate significant differences among organs in the thinned group ($P < 0.05$).

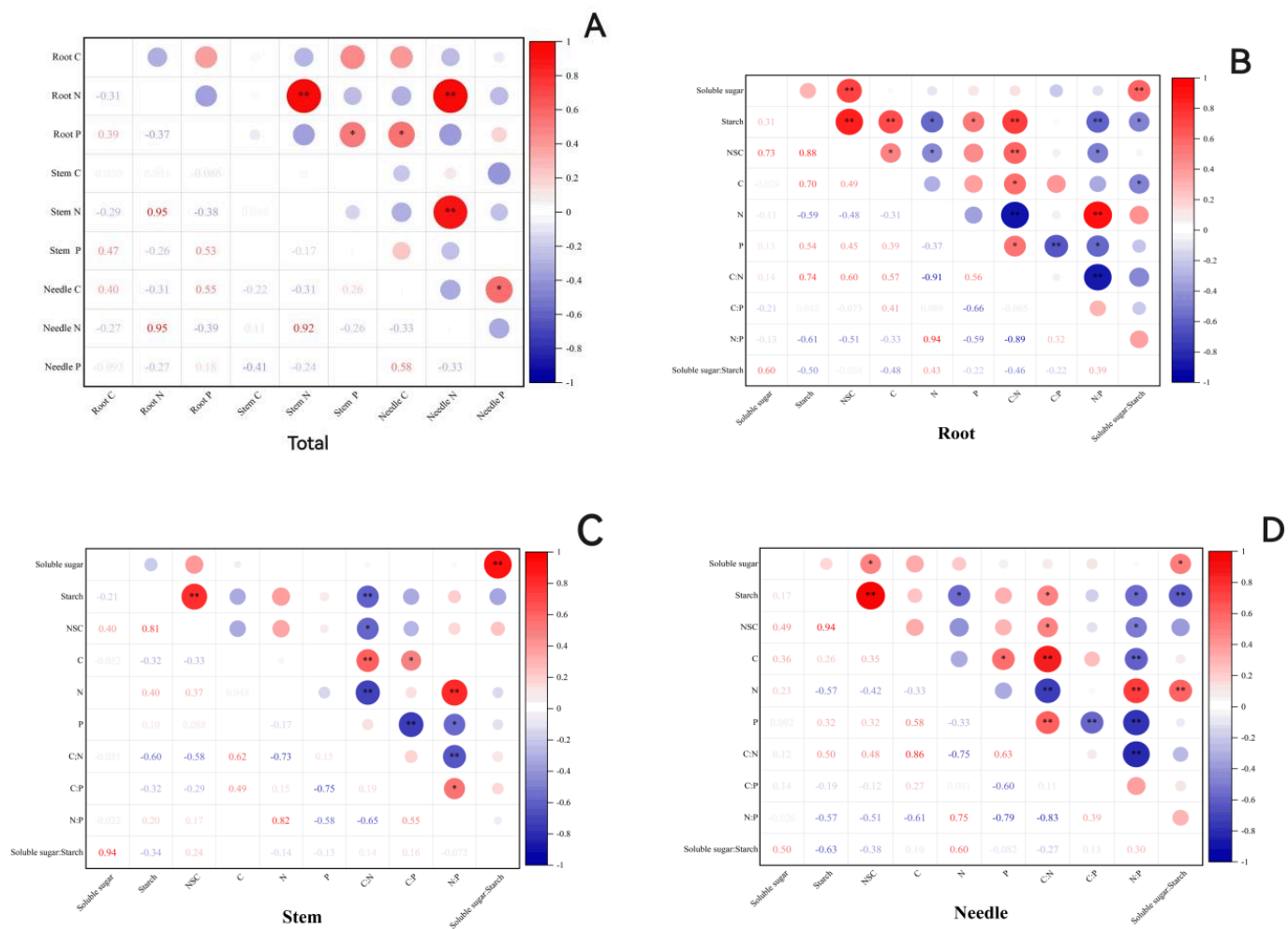


Figure 4

Figure A shows correlations in the content of C, N, and P among all organs. Figure B, C, and D show the correlation coefficients of NSC with the content of C, N, and P and their stoichiometric ratios in the roots, stems, and needles, respectively.

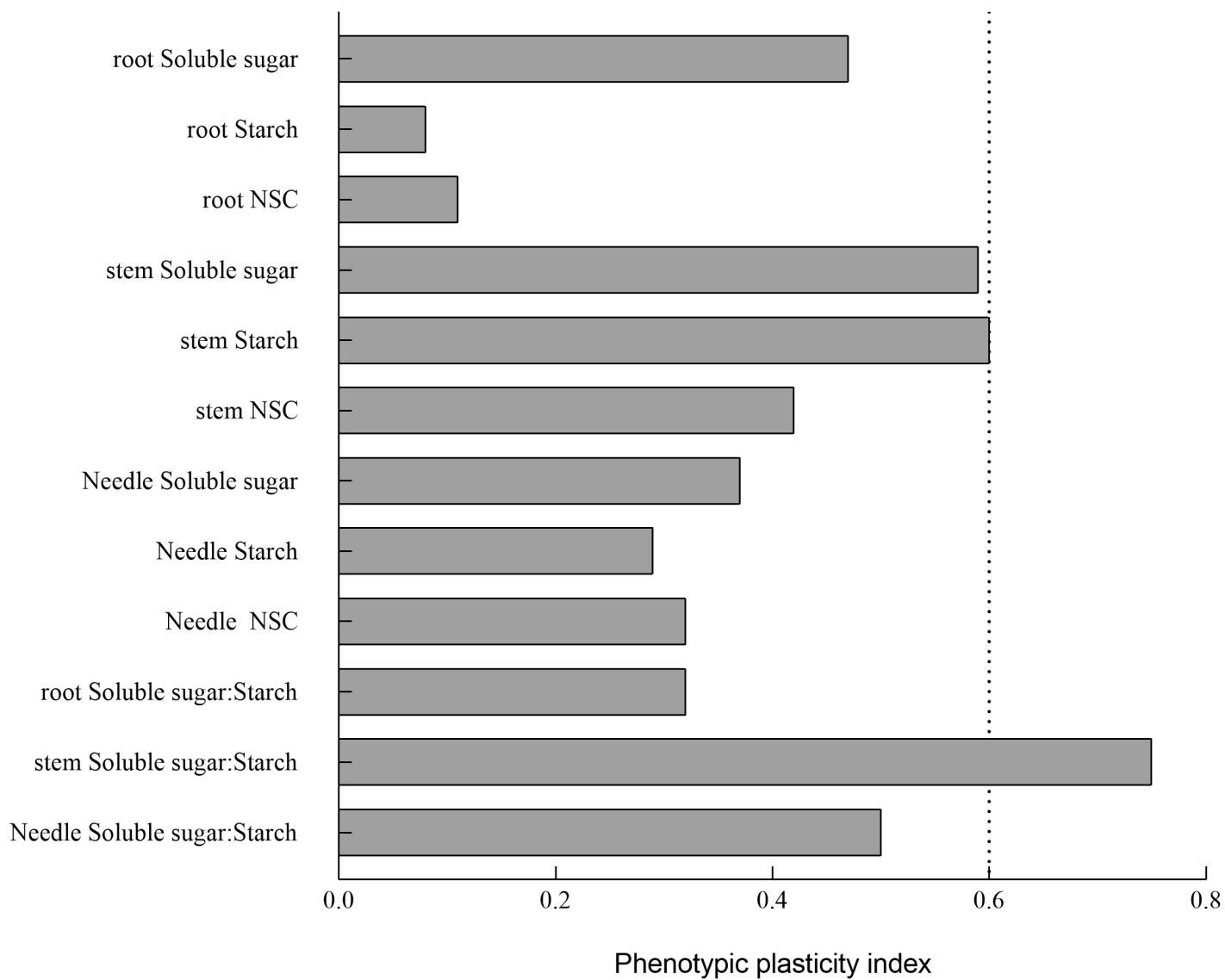


Figure 5

PI of NSC in *P. yunnanensis*

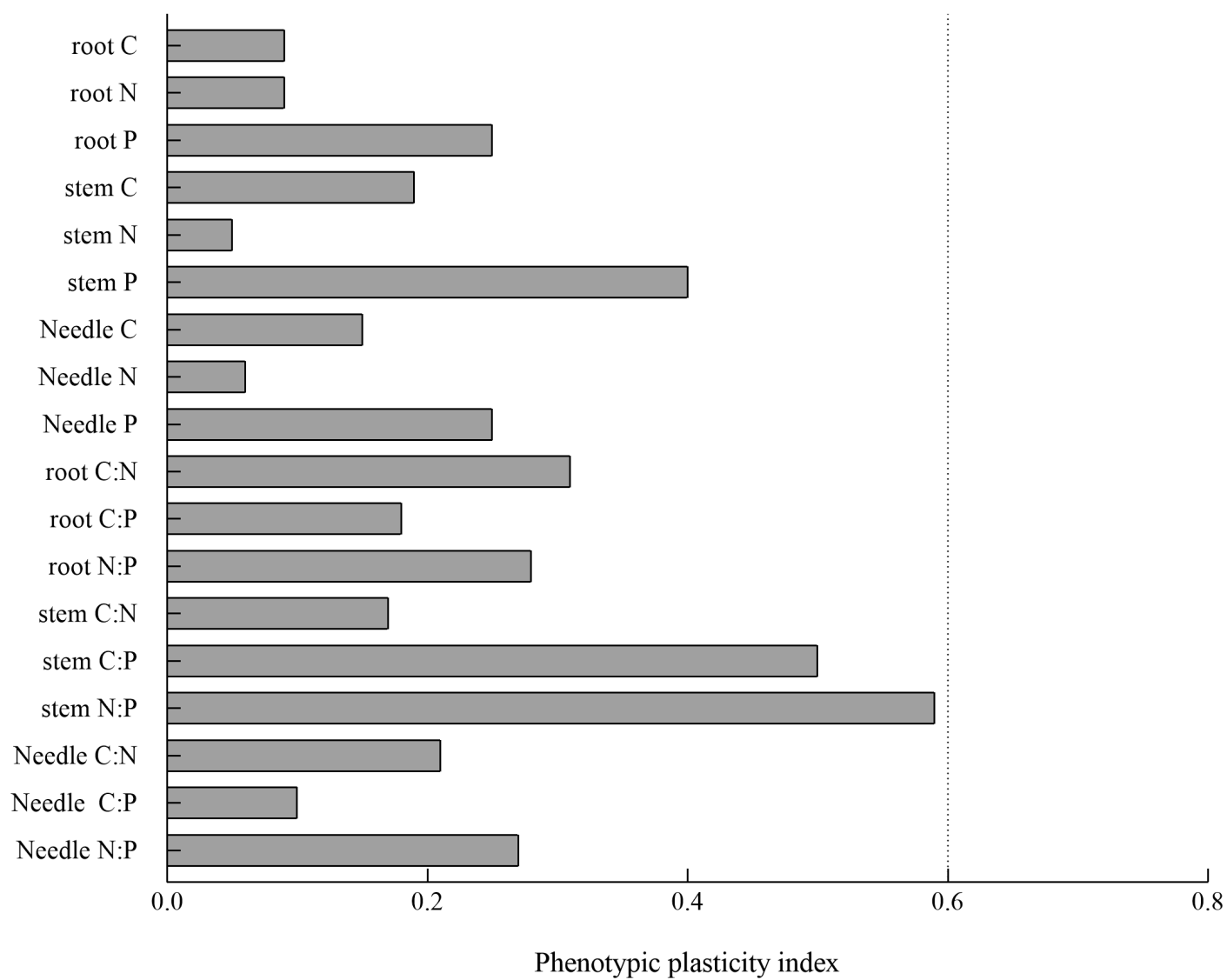


Figure 6

PI of the C, N, and P content and their stoichiometric ratios in *P. yunnanensis*.