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ORIGINAL PAPER

RESPONSES OF THE GROWTH AND NUTRIENT STOICHIOMETRY IN *RICINUS COMMUNIS* SEEDLINGS ON FOUR SOIL TYPES*

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Abstract

Responses of the growth and nutrient stoichiometry in *Ricinus communis* seedlings were assessed by culturing seedlings on the plant acid purple soil (ACS), alkaline purple soil (ALS), yellow soil (YS) and red soil (RS). The results showed that soil types may significantly affect the basal diameter, total biomass, root-shoot ratio, C, N and P contents, P and K accumulation, N allocation ratio and N and P use efficiency in *R. communis* seedlings (P<0.05). However, there were no significant differences in terms of the root length, specific leaf area, robustness and C and K use efficiency (P>0.05). The order of seedlings' height and basal diameter were ALS>RS>ACS>YS, and the order of total biomass was ALS>ACS>RS>YS. The N, P contents and total accumulation of C, N, P and K in the stem were the highest in ALS. The use efficiency of C, N, P and K in different soil types was C>K>P>N, and the N and P use efficiency in purple soil was significantly higher than those of in YS and RS. The roots, stems, leaves and total N:P ratio of *R. communis* seedlings were far lower than 14, indicating that the seedlings growth on four soil types was severely restricted by nitrogen. Compared with the other three soil types, ALS was more suitable for the early cultivation management of *R. communis* seedlings, and the appropriate increase of nitrogen fertilizer was conducive to the more efficient growth and development of *R. communis* seedlings. The results will help to provide theoretical basis and reference for site selection, cultivation and fertilization management of *R. communis*.

Keywords: soil types; castor; biomass; accumulation; stoichiometric ratio.

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INTRODUCTION

Soil may provide water and nutrients for plants to survive, and hence it plays an extremely important role in plant growth and development (Kahkashan et al. 2016). As the most important means of agricultural production, soil may not only provide the environmental conditions for plants to absorb nutrients, but also act as one of the constraints for plant growth and yield (Sherrard et al. 2015, Gachuiri et al. 2016). Different soil types have different physical and chemical properties due to their different texture, structure and nutrient content, among which the most direct factor is the difference of soil nutrient supply, which further affects the nutrient uptake of plants, so that plants show different characteristics of morphology, growth and material metabolism (Melander, Kristensen 2011). Plants in different soils need different soil fertility, and the accumulation and distribution of nutrient elements show great differences in the process of growth and development. Plants adapt to the changing soil environment through their own regulatory mechanisms (Truong et al. 2017). The effects of different soil types on plant biomass and nutrient accumulation and distribution do not only affect their growth and development characteristics, but also promote seedling establishment and growth by regulating the changes of soil nutrients (Wang et al. 2013). Therefore, it is helpful to understand the relationship between the supply and demand of nutrient elements in soil and plants, and provide a scientific basis for nutrient management.

Carbon (C), nitrogen (N), and phosphorus (P) are important components of soil for plant growth. Their content and availability in plants have an important impact on plant growth and productivity (Li et al. 2017, Hu et al. 2019). Plants absorb from soil nutrients such as N and P, which are used for material transformation through photosynthesis, chlorophyll synthesis and physiological growth metabolism of plants, thus playing an important role in the process of plant morphogenesis and metabolism (Hou et al. 2017). Ecological stoichiometry is the study of the balance of multiple chemical elements in ecological interactions and processes. It is also a means to determine the nutrient allocation, nutrient use efficiency and limiting elements of plants. It can reflect the internal stability and relationship of plant organs, and help to solve some scientific problems of the balance of plant nutrient supply and demand (Sardans, Penuelas 2012, Song et al. 2014). Different organs of plant have different structural and functional properties, and C, N and P concentrations in different organs of the same plant are different (Kerkhoff, Enquist 2006, Yuan et al. 2011). Using the method of ecological stoichiometry to study the content and stoichiometric characteristics of C, N and P in different organs of plant is of great significance in gaining an insight into the ecological strategy and environmental adaptability of the species, quantitative evaluation of the limiting nutrient elements in plants, and the optimal management and reasonable protection of plant resources (Zhang et al. 2013).

Ricinus communis L. is an annual or perennial evergreen shrub herb, and is an emerging special cash crop and bioenergy oil plant (Saadaoui et al. 2017, Song et al. 2021). *R. communis* is widely planted in tropical, subtropical and temperate countries due to its specially developed and large roots, strong resistance to drought, barren resistance, strong self-control of growth, extensive management, less labor, low investment and higher income (Ramanjaneyulu et al. 2017). A large number of previous studies have reported that the application of *R. communis* in the fields of industry, medicine, agriculture and textile has reflected its huge economic benefits (Bauddh et al. 2015). Moreover, *R. communis* is warm and drought tolerant, salt tolerant, adaptable and highly resistant. It is a pioneer crop for improving ecological environment and improving soil (Al-Hilali et al. 2021). However, the responses of growth and nutrient stoichiometry in *R. communis* are still unclear. The aim of this study was to investigate the effects of four soil types on the growth and nutrient accumulation in *R. communis* seedlings.

MATERIAL AND METHODS

Study area overview

The experimental site is the roof of No.5 teaching building of Sichuan Agricultural University, Wenjiang district, Chengdu, China. It lies in the mid--latitude inland subtropical monsoon climate with mild climate, four distinct seasons and abundant rainfall. The average annual rainfall is 896.1 mm, the rainy season is mainly from June to September; the annual average temp. is 16.4°C, the annual average relative humidity is 84%, the average annual sunshine hours are 1104.5 h, and the annual frost-free period is 282 days.

Experimental material

R. communis seeds were collected from Sichuan University, Chengdu, China in Oct., 2019. They were shelled, sorted, placed in labelled net bags, and then stored in ventilated, dry and cool places. The red soil (RS), yellow soil (YS), alkaline purple soil (ALS) and acid purple soil (ACS) needed in this experiment belong to the main types of soil widely distributed and representative in Sichuan Province, China. Alkaline purple soil, yellow soil, red soil and acid purple soil were collected at Town Ji-feng, County Zhongjiang, Deyang, China (N31°03′ E104°68′, altitude 900 m), Village Bai-sheng, Town Bao-lin, Qiong-lai, China (N 30°21′ E103°30′, altitude 552 m) and Village San-xing, Town Feng-le, Shi-mian, Yaan, China (N 29°32′E 102°54′, altitude 878 m), Lao-ban-shan Reading Park, Yu-cheng District, Ya′an, China, (29°58′N, 102°58′E, altitude 679 m), respectively. The basic physical and chemical properties of the four soils were shown in Table 1. The soil was

Table 1

The basic physical and chemical properties of four soil types (means ± SE, n=3)

Soil type	pH	Organic carbon ($g\ kg^{-1}$)	Bulk density ($g\ cm^{-3}$)	Total nitrogen ($g\ kg^{-1}$)	Total phosphorus ($g\ kg^{-1}$)	Total potassium ($g\ kg^{-1}$)
YS	4.79^{B}±0.12	33.50^{A}±0.64	1.32^{A}±0.07	1.89^{A}±0.11	0.08^{C}±0.00	2.21^{B}±0.09
ACS	5.12^{A}±0.14	35.51^{A}±0.74	1.29^{A}±0.04	1.67^{A}±0.09	0.83^{A}±0.03	2.49^{B}±0.06
RS	5.14^{A}±0.16	16.64^{C}±0.66	1.30^{A}±0.06	1.14^{B}±0.07	0.07^{C}±0.00	3.15^{A}±0.08
ALS	8.67^{A}±0.23	20.99^{B}±0.91	1.25^{B}±0.08	1.65^{A}±0.15	0.30^{B}±0.01	3.56^{A}±0.10

Values followed by the same letter in the same column are not significantly different according to the Tukey's test (α=0.05).

classified, crushed, screened and tilled for 4 days under strong light for further use.

Seed germination and seedling cultivation

Healthy plump seeds were bathed at 35°C for 24 h, and germinated seeds were selected and seeded in 10 kg soil pots (28 cm × 21 cm) on 20 April, 2020. The experiment adopted a split-plot randomized design. The soil was kept moderately moist during the trial period. Manual weeding was done to keep trials free from weeds during the experiment. If pests and diseases occurred, they could be timely treated according to their types. This assay was repeated three times with similar results.

Seedling collection and biomass determination

After 30 days, seedlings were collected and calculated. The height was measured with a tapeline, the basal diameter was measured with a digital vernier caliper, and the leaf area was measured with a leaf area scanner. 3 seedlings with good growth and consistent height of were selected, and samples were taken according to the division into roots, stems and leaves. After cleaning with deionized water, the surface water was sucked dry, and putting into the oven at 105°C for 30 min, and then adjusting to 65°C for drying to constant weight, and the dry matter of roots, stems and leaves were weighed.

Determination of nutrient element content

The dried roots, stems and leaves were placed in a crusher (FW80, Taisite, China) for crushing and sieving samples. Then, concentrated H_2SO_4-$HClO_4$ was used for making measurement liquid, and the potassium dichromate oxidation method, semimicro-Kjeldahl method and Mo-Sb colorimetric method were used to determine the C, N and P content, respectively (Hu et al. 2019). The K content was determined by atomic absorption spectrophotometry (Hu et al. 2016).

Data processing and statistical analysis

The root-shoot ratio, specific leaf area and robustness were calculated according to the root, stem and leaf biomass, saplings' height, basal diameter and leaf area. The calculation formulas were as follows: root-shoot ratio = root biomass / stem biomass, specific leaf area = unifoliate area / total biomass, robustness = stem and leaf biomass / saplings height. According to the calculation of biomass increment and element accumulation, the calculation formula is as follows: element accumulation = organ element content × organ biomass, elements allocation ratio in different organs = (element accumulation in root / stem / leaf) / total element accumulation, nutrient use efficiency = total biomass increase / total nutrient accumulation. Excel and SPSS 20.0 were used for data statistics and analysis. One way ANOVA and LSD (least significant difference) methods were used to test the significance of the difference among different soil types (α=0.05). Origin 8.5 served to plot diagrams, and Canoco 5.0 software was used to perform redundancy analysis on the relationship between growth indices, stoichiometric characteristics and environmental factors. Data are expressed as means ± SE (n=3).

RESULTS

Effects of four soil types on growth indices

As shown in Tables 2 and 3, the results suggested that soil types have significant effects on the basal diameter, stem biomass, leaf biomass, total biomass, and root shoot ratio (P<0.05), but soil types had no significant effects on the height, root biomass, root length, specific leaf area, and robustness of seedlings (P>0.05). The seedling height and basal diameter showed the same overall trend in the four soil types, and the order was: ALS>RS>ACS>YS, with the maximum difference of 30.4% and 1.2 times, respectively. Moreover, the variation trend of root, stem, leaf and total biomass of *R. communis* seedlings in different soil types was basically similar, and the order of total biomass was: ALS>ACS>RS>YS, with a maximum difference of 61.8%. The variational tendency of root length and specific leaf area was the same: ACS>YS>ALS>RS, with the maximum difference of 48.6% and 21.7%. The root to shoot ratio was the highest in YS and the lowest in ALS, with a maximum difference of 51.5%. The robustness was the highest in ACS and the lowest in YS, with a maximum difference of 32.5%.

Effects of soil types on C, N, P and K contents

As shown in Figure 1 and Table 2, soil type had significant effects on the C, N and P contents (P<0.05), and there were no significant effects on the K content of *R. communis* (P>0.05). The C content in roots and leaves was the highest in ACS and the lowest in YS, with the maximum difference of 29.1%

Table 2

One-way ANOVA of soil types on the growth indices, content of elements, allocation, stoichiometric ratios, and use efficiency of *Ricinus communis* seedlings

Source of variation	Soil type		
	df	*F*	*P*
Root biomass	3	3.168	0.085
Stem biomass	3	19.651	<0.001
Leaf biomass	3	43.652	<0.001
Total biomass	3	31.130	<0.001
Saplings height	3	2.740	0.113
Basal diameter	3	6.694	0.014
Root length	3	2.859	0.104
Root shoot ratio	3	8.026	0.009
Specific leaf area	3	3.267	0.080
Robustness	3	2.292	0.155
C content	3	3.061	0.047
N content	3	10.244	<0.001
P content	3	8.825	<0.001
K content	3	3.333	0.036
C accumulation	3	42.775	<0.001
N accumulation	3	24.408	<0.001
P accumulation	3	19.671	<0.001
K accumulation	3	22.152	<0.001
C allocation proportion	3	0.000	1.000
N allocation proportion	3	0.000	1.000
P allocation proportion	3	0.000	1.000
K allocation proportion	3	0.000	1.000
C use efficiency	3	2.969	0.097
N use efficiency	3	5.709	0.022
P use efficiency	3	7.056	0.012
K use efficiency	3	2.605	0.124
C:N	3	31.972	<0.001
C:P	3	8.647	0.007
N:P	3	0.279	0.839

and 20.7%. The N and P contents in stems were the highest in ALS and the lowest in ACS, with a difference of 1.1 times and 73.7%. The N and P contents in leaves were the highest in RS, and the lowest in ALS, with the maximum difference of 52.3% and 51.6%, while the K content in roots, stems and leaves showed little difference in the four soil types.

Table 3

Effects of four soil types on the growth indices of *Ricinus communis* seedlings

Soil types	YS	ACS	RS	ALS
Root (g plant^{-1})	0.23±0.03	0.26±0.02	0.22±0.03	0.27±0.04
Stem (g plant^{-1})	0.16^{C}±0.03	0.28^{AB}±0.01	0.22^{BC}±0.02	0.31^{A}±0.05
Leaf (g plant^{-1})	0.30^{B}±0.02	0.44^{A}±0.04	0.29^{B}±0.03	0.51^{A}±0.07
Total biomass (g plant^{-1})	0.68^{B}±0.04	0.99^{A}±0.06	0.73^{B}±0.08	1.10^{A}±0.07
Saplings height (cm)	10.23±0.57	11.10±0.14	11.30±0.53	13.27±0.33
Basal diameter (cm)	0.22^{B}±0.01	0.38^{B}±0.03	0.40^{AB}±0.04	0.47^{A}±0.02
Root length (cm)	14.47±0.32	16.00±0.50	10.77±0.87	12.60±0.90
Root shoot ratio	0.50^{A}±0.06	0.38^{B}±0.02	0.42^{AB}±0.04	0.33^{B}±0.02
Specific leaf area (cm^2 g^{-1})	111.14±5.42	133.19±6.35	104.20±3.13	110.75±8.46
Robustness (g m^{-1})	3.75±0.35	4.97±0.26	3.94±0.45	4.50±0.82

Values followed by the same letter in the same column are not significantly different according to the Tukey's test (α=0.05).

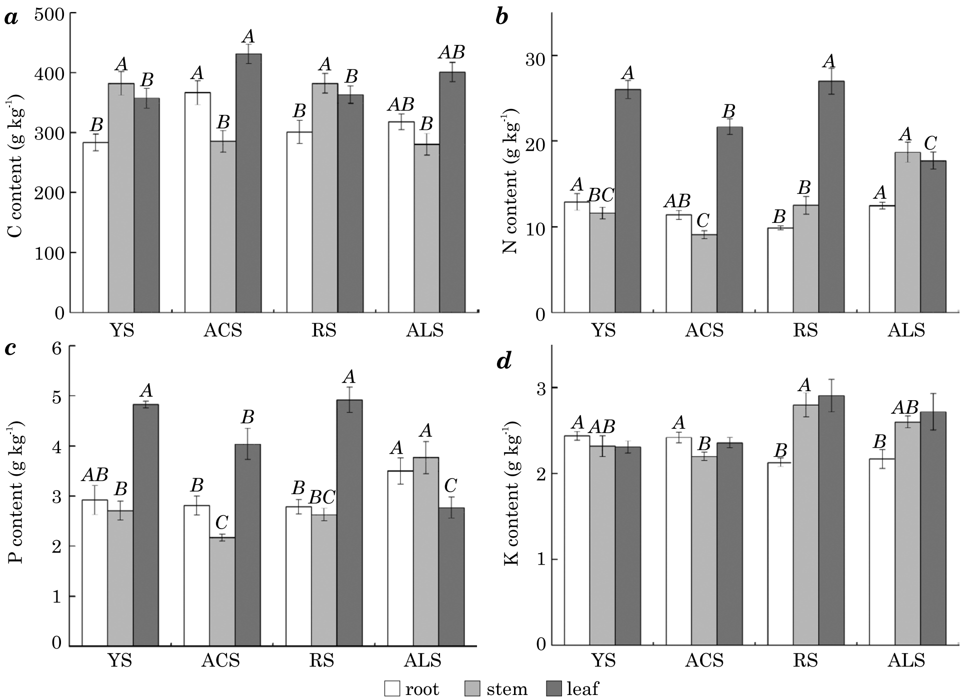

Fig. 1. Effects of four soil types on the C (*a*), N (*b*), P (*c*) and K (*d*) contents in *Ricinus communis* seedlings. Data are shown as means ± SE (*n*=3). Different uppercase letters indicate significant difference in different soil types (P<0.05)

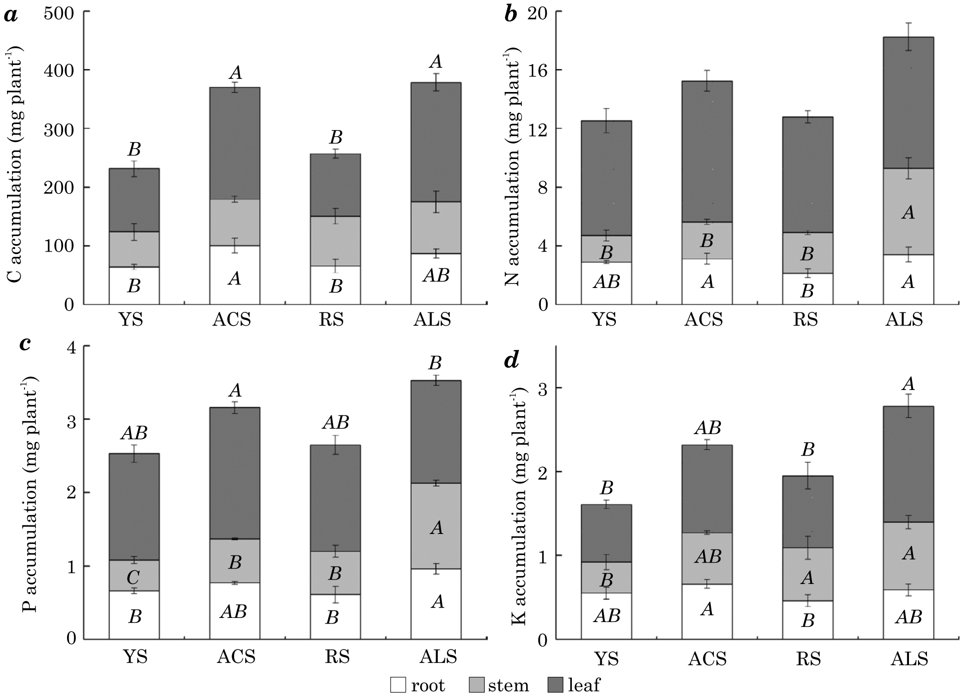

Fig. 2. Effects of four soil types on C accumulation (*a*), N accumulation (*b*), P accumulation (*c*), and K accumulation (*d*) of *Ricinus communis* seedlings. Data are shown as means ± SE (n=3). Different uppercase letters indicate significant difference in different soil types (P<0.05)

Effects of soil types on C, N, P and K accumulation

As shown in Figure 2 and Table 2, different soil type had significant effects on P and K accumulation in roots, stems and leaves (P<0.05), but different soil type had no significant differences on the C accumulation i n stems and N accumulation in leaves (P>0.05). The total accumulation of C, N, P and K in different soil types showed the same trend: ALS>ACS>RS>YS. However, the change trend of P accumulation in stems and K accumulation in leaves was consistent with the total accumulation. The N and P accumulation in roots was similar to C accumulation in leaves: ALS>ACS>YS>RS, while the C accumulation in roots was the same as N accumulation in leaves: ACS>ALS>RS>YS, and the C, N and K accumulation in stems was consistent: ALS>RS>ACS>YS.

Effects of soil types on C, N, P and K allocation proportion

As shown in Figure 3 and Table 2, different soil type had significant effects on the N allocation in roots, stems and leaves of *R. communis* seedlings (P<0.05), but soil type had no significant effect on the C and P allocation in roots, and the K allocation in leaves (P>0.05). The N and K allocation in roots in YS was significantly higher than that in roots in RS, the C alloca-

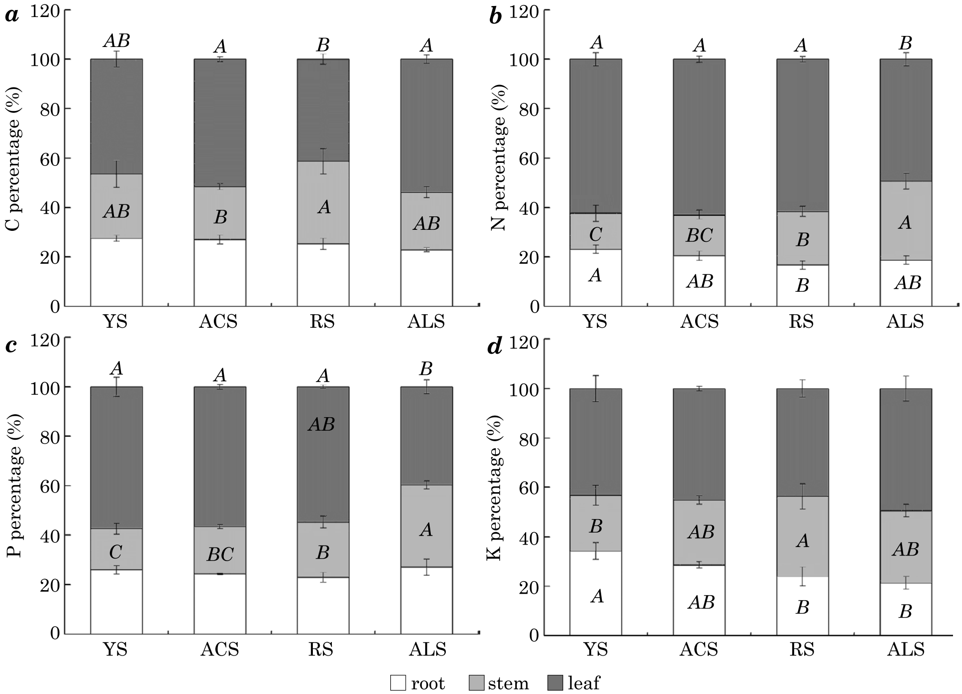

Fig. 3. Effects of soil types on C allocation proportion (*a*), N allocation proportion (*b*), P allocation proportion (*c*), and K allocation proportion (*d*) of *Ricinus communis* seedlings. Data are shown as means ± SE (n=3). Different uppercase letters indicate significant difference in different soil types (P<0.05)

tion in stems in RS was significantly higher than that in stems in ACS, and the N and P allocation in stems in ALS was significantly higher than that in stems in YS. The C allocation in leaves in RS was significantly lower than that of other soil types, and the N and P allocation in leaves in ALS was significantly lower than that of other soil types.

Effects of soil types on C, N, P and K use efficiency

As shown in Tables 2 and 4, soil type had significant effects on the N and P use efficiency by *R. communis* seedlings (P<0.05), but soil type had no significant effect on the C and K use efficiency (P>0.05). The order of C, N, P and K use efficiency in different soil types was C>K>P>N. The N and P use efficiency by *R. communis* seedlings in ACS and ALS was significantly higher than that in YS and RS, with the maximum difference of 18.2% and 12.9%, respectively. The C use efficiency was the highest in YS and the K use efficiency was the highest in ACS.

Table 4

Effects of soil types on the C, N, P stoichiometric ratio and C, N, P, K use efficiency of *R. communis* seedlings

Index	Organ	YS	ACS	RS	ALS
C:N	root	22.04^{B}±0.83	32.14^{A}±0.50	30.48^{A}±1.07	25.52^{B}±1.56
	stem	32.93^{A}±1.24	31.47^{A}±2.09	30.89^{A}±0.96	15.06^{B}±0.76
	leaf	13.73^{B}±0.37	19.91^{A}±1.19	13.47^{B}±0.33	22.75^{A}±1.52
	total	20.25^{B}±0.35	25.69^{A}±1.05	21.23^{B}±0.91	20.43^{B}±0.64
C:P	root	97.32^{B}±0.95	131.00^{A}±1.85	107.83^{AB}±0.43	91.42^{B}±0.89
	stem	141.83^{A}±1.19	131.95^{A}±1.09	146.00^{A}±1.03	75.25^{B}±0.44
	leaf	73.92^{C}±1.08	107.00^{B}±0.94	74.14^{C}±0.31	145.45^{A}±0.35
	total	97.86^{B}±0.87	120.37^{A}±1.01	101.47^{B}±0.50	99.70^{B}±1.09
N:P	root	4.42^{A}±0.08	4.07^{AB}±0.45	3.55^{B}±0.20	3.58^{B}±0.28
	stem	4.30±0.40	4.21±0.33	4.77±0.68	4.99±0.65
	leaf	5.38±0.16	5.38±0.23	5.52±0.66	6.46±0.50
	total	4.83±0.11	4.68±0.16	4.79±0.49	4.88±0.14
C use efficiency	total	2.95±0.16	2.69±0.06	2.85±0.09	2.92±0.14
N use efficiency	total	0.06^{B}±0.01	0.07^{A}±0.02	0.06^{B}±0.01	0.07^{A}±0.01
P use efficiency	total	0.27^{B}±0.02	0.32^{A}±0.01	0.28^{B}±0.03	0.31^{A}±0.02
K use efficiency	total	0.42±0.07	0.43±0.01	0.38±0.04	0.40±0.02

Values followed by the same letter in the same column are not significantly different according to Tukey's test (α=0.05). Different uppercase letters indicate significant difference in different soil types (P<0.05).

Effects of soil types on C, N and P stoichiometry

As shown in Tables 2 and 4, soil type had significant effects on the C:N and C:P ratios in *R. communis* seedlings (P<0.05), but soil type had no significant effect on the N:P ratio in stems, leaves and total (P>0.05). The change trends in roots, leaves and total C:N and C:P ratios in different soil types were similar. In different soil types, the root and total C:N and C:P ratios were the largest in ACS, and leaf C:N and C:P ratios were the largest in ALS, and the stem C:P ratio was the largest in RS. The N:P ratio in roots, stems and leaves in different soil types had no obvious change trend, but the leaf N:P ratio was greater than that in roots, stems and total N:P ratio.

Correlation analysis of soil nutrients and growth and nutrient indexes

As shown in Figure 4, the growth indices and stoichiometric characteristics of *R. communis* were used as the basic data to establish the response variable matrix, and soil nutrient environmental factors were used as the explanatory variables. The RDA analysis results show that the corrected R^2 was 0.504, and RDA1 axis and RDA2 axis jointly explained 57.5%

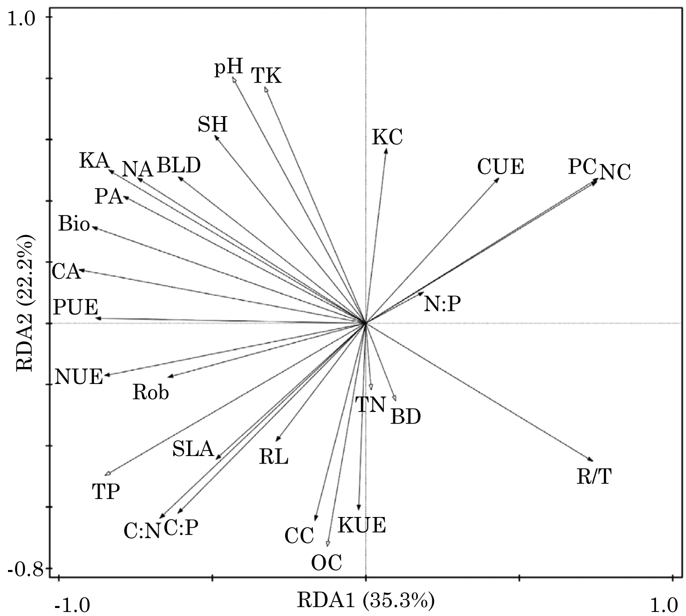

Fig. 4. Redundancy analysis (RDA) of the relationship between soil nutrient factors and growth indices, nutrient index of *Ricinus communis*: OC – organic carbon, BD – bulk density, TN – total nitrogen, TP – total phosphorus, TK – total potassium, Bio – biomass, SH – saplings height, BLD – basal diameter, RL – root length, SLA – specific leaf area, R/T – root-shoot ratio, Rob – robustness, CC – C content, NC – N content, PC – P content, KC – K content, CA – C accumulation, NA – N accumulation, PA – P accumulation, KA – K accumulation, CUE – C use efficiency, NUE – N use efficiency, PUE – P use efficiency, KUE – K use efficiency

of the total variance, 35.3% of the total variance by RDA1 axis and 22.2% of the total variance was explained by RDA2 axis. Among the soil nutrients factors, total P (F=5.4, P=0.002) and pH (F=4.7, P=0.002) significantly affected the seedlings' biomass, height, basal diameter, robustness, root to shoot ratio, accumulation and N, P use efficiency of *R. communis*. The results showed that total P and pH were significantly positively correlated with the biomass, height, basal diameter, robustness, accumulation and N, P use efficiency by seedlings, but significantly negatively correlated with the root to shoot ratio. Organic carbon and total N were positively correlated with C:N, C:P ratios and C content, but negatively correlated with the N, P content and N:P ratio. The N and P content was positively correlated with the C:N and C:P ratios, but negatively correlated with the N:P ratio in *R. communis*. The C content was negatively correlated with the N and P content in *R. communis*. The total K content in soil was positively correlated with the K content in *R. communis*, but negatively correlated with the K use efficiency.

DISCUSSION

The demand of plants for soil nutrients varies with species, so the soil fertility required by different plants is also different. Plants adapt to the changing soil environment through their own regulation mechanism. Seedlings' height, basal diameter and biomass were the most basic characteristics of plant growth, which may directly reflect the environmental conditions of plant growth (Truong, Hans 2017). Zou et al. (2010) showed that the basal diameter of *Sophora japonica* seedlings was the largest in paddy soil, and the plant height and total biomass were the largest in brown calcareous soil. Hu et al. (2008) pointed out that the height, basal diameter and biomass accumulation of *Gleditsia sinensis* seedlings are the best in calcareous dolomite soil. Wang (2018) has demonstrated that the total biomass of *Populus deltoides* and *Populus euramericana* were the largest in acid purple soil. These results showed that the growth status of different species in different soil environment showed significant differences, and their adaptability to different soil types was different as well. This is because different soil types have different physical, chemical properties and microbial community structure. Good soil structure, loose soil, good ventilation performance and high organic carbon content are conducive to the growth and development of seedlings.

C, N, P and K are the four essential nutrients for plant growth, which affect the growth and development of plants and the course of physiological functions (Sardans et al. 2012). In the growth and development of plants, the available nutrient resources are limited. In order to improve their adaptability in the environment, the balance should be made among the roots for obtaining nutrient elements, the stems for supporting and transmitting water and nutrients, and the leaves for obtaining photoassimilates (Kerkhoff, Enquist 2006). The content of nutrients such as N, P, K and their accumulation and distribution of nutrient among plant organs reflect the demand and absorption capacity of plants for certain nutrients in specific habitats, and reflect the adaptation strategies of plants to the ecological environment and the physiological activities of this stage (Yuan et al. 2011). Liu et al. (2006) showed that there were differences in the growth status of *M. sativa* under different soil types, and the adaptability of different varieties to soil types was different. That study provided results similar to the results of this research. Moreover, the present study found that the total accumulation of C, N, P and K in different soil types showed the same trend: ALS>ACS>RS>YS, which indicated that the demand of C, N, P and K in different soil had a high degree of synergy. The study also determined that the N use efficiency by *R. communis* seedlings was the highest in ALS, and the P use efficiency was the highest in ACS, which was the same as that of *Populus deltoides* and *Populus euramericana* in different soil types determined by Wang (2018). These results show that each organ of the plant has different structural material and functional properties, and the demand for nutrient elements is also different, so that each organ of the same plant presents different characteristics of nutrient accumulation and distribution and nutrient use efficiency.

The C:N and C:P ratios may reflect the ability of carbon assimilation in the process of nutrient uptake by plants, and the N:P ratio critical value may reflect the nutrient supply of plants in the ecosystem, and the limitation of plant growth by nitrogen or phosphorus (Gusewell 2004). The present results showed that different soil types had significant effects on the C:N and C:P ratios in *R. communis* seedlings. The variation trend of root, leaf and total C:N and C:P ratios in *R. communis* seedlings in different soil types was similar. However, the N:P ratio had no obvious change trend in different soil types, which indicated that there was a strong correlation between N and P nutrient requirements by *R. communis* seedlings, and there was a certain coupling relationship between N and P in *R. communis*. This study was consistent with the results of leaf C:N ratio of *P. deltoides* reported by Wang (2018). This indicates that different species present different stoichiometric characteristics in the same soil environment, which may be due to the interaction between different biological characteristics of plants and specific habitats. Klausmeier et al. (2004) believed that when the N:P ratio is less than 14, plant growth is mainly restricted by N; when the N:P ratio is greater than 14, plant growth is mainly restricted by P; when N:P ratio is 14~16. In this study, the root, stem, leaf and total N:P ratio of *R. communis* seedlings ranged from 3.6 to 6.5, far less than 14, indicating that the growth and development of *R. communis* seedlings in these four soil types were seriously limited by nitrogen. Thus, an appropriate application of nitrogen fertilizer may effectively promote the growth and development in *R. communis* seedlings on different soil types.

The RDA analysis showed that N and P contents were significantly positively or negatively correlated with the C:N, C:P and N:P ratios in *R. communis* seedlings. Our results were consistent with Zhi et al. (2021) on the roots of *Zanthoxylum armatum* seedlings in different soil types, which showed that changes of the N and P contents significantly affected the stoichiometric ratio in *R. communis* seedlings. There was a significant negative correlation between the C and N, P contents in *R. communis* seedlings, which was consistent with the results of Zeng et al. (2016). The C content of *Larix gmelinii* at different ages is significantly negative correlated with the N and P content, indicating that the consumption of N and P nutrients promotes the C accumulation. In this study, there was a strong correlation among C, N, P contents and their stoichiometric ratio in *R. communis* seedlings, indicating that there was a certain coupling relationship among different nutrient elements in *R. communis* seedlings. The content of certain elements in plant organs is positively correlated with the supply capacity of the element in soil, indicating that the growth of the element is restricted by this element (Zhi et al. 2021). However, there was a negative correlation between the soil total K and K use efficiency in *R. communis* seedlings, indicating that seedlings could not efficiently assimilate K element in the transformation process of forming compounds, resulting in low K use efficiency.

CONCLUSION

The present findings showed that soil types had significant differences in the basal diameter, total biomass, root shoot ratio, C, N, P content, P and K accumulation, N allocation proportion and N, P use efficiency by *R. communis* seedlings. The results showed that the height, basal diameter, total biomass and element accumulation of *R. communis* seedlings were the largest in ALS. The order of C, N, P and K use efficiency of seedlings was C>K>P>N, but the growth and development of *R. communis* in four soil types were seriously restricted by nitrogen. Compared with the other three soil types, ALS was more suitable for the early cultivation and management of *R. communis*, and the appropriate increase of nitrogen fertilizer is conducive to the more efficient growth and development of *R. communis*. In fact, *R. communis* plants are growing in a complicated soil environment. Thus, further in-depth studies on *R. communis* plants might not only help to understand the nutritional behavior and proper nutrient management, but also help to reveal how this plant develops different nutrient acquisition strategies under field conditions.

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