EFFECTS OF SOD CULTIVATION ON STOICHIOMETRIC CHARACTERISTICS AND NUTRIENT CONTRIBUTION RATE OF SOIL AGGREGATES IN *ROSA ROXBURGHII* TRATT. ORCHARD

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Abstract. In order to determine the stoichiometric characteristics of soil aggregates and their relationship with soil nutrients, three sod cultivation treatments (intercropping of natural grass and *Rosa roxburghii*; intercropping of artificial grass and *Rosa roxburghii*; *Rosa roxburghii* monoculture) were set in Longli County, Guizhou Province, China. The aggregate distribution, ecological stoichiometry, and nutrient contribution rate of each particle sizes under different sod cultivation treatments were studied. Based on the results it can be concluded that both NG and AG treatments could enhance the number of macro aggregates. The contents of SOC, TN of aggregate under NG and AG treatments were higher than that of CK, while the contents of TP were lower than that of CK. The aggregate C/N of >0.5mm was NG>AG>CK. The C/P of aggregate was NG > AG > CK. The N/P of aggregate was NG>AG>CK. Under the AG treatment, 45% of the soil nutrients came from >5 mm and 5~2 mm aggregates. Under the CK treatment, 45% of the soil nutrients came from >5 mm and ＜0.25 mm aggregates. Sod cultivation was beneficial to increase the amount of macroaggregates and the contribution rate of macroaggregates to soil nutrients. The results provide the basis for regulating the soil fertility of *Rosa roxburghii* orchard.
Keywords: *ecostoichiometry, intercropping, artificial grass, natural grass, nutrient contribution rate*

Introduction

Rosa roxburghii Tratt., commonly known as a kind of fruit with high economic benefits and rich in nutrition, is a unique wild resource of the Yunnan-Guizhou Plateau of China. *Rosa roxburghii* Tratt. has the reputation of "the king of vitamin C". Processing and production of *Rosa roxburghii* Tratt. is a new characteristic industry developed vigorously in Guizhou Province in recent years. In China, studies on *Rosa roxburghii* Tratt. mainly focus on quality nutrition (Wang et al., 2020; Lu and Zhu, 2020; Li et al., 2021), medicinal value (Wu et al., 2020a; Xu et al., 2021), pest control (Wu et al., 2020b), nutrient utilization and processing technique improvement (Chen et al., 2019; Zou et al., 2020), breeding and cultivation techniques, resource and industrial development (Zhou and Fan, 2021). In China, although the industrialized cultivation of *Rosa roxburghii* Tratt. is extensive, monoculture (clear tillage) is still the main planting method, which leads to excessive dependence on the regulation of chemical fertilizers and pesticides in the cultivation process. These lead to serious degradation of land quality, which is not conducive to the sustainable utilization of land resources and reduce the quality and yield of *Rosa roxburghii* Tratt. fruit.

Sod cultivation is a kind of orchard management measure adopted by many developed countries. Sod cultivation refers to the method of intercropping natural grass or artificial

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grass in the orchard to maintain and improve the soil quality, increase soil fertility, and reduce the loss of soil nutrients in the orchard. Planting grass in the orchard made the trees and grass coexist harmoniously under the standardized management mode (Fu et al., 2020). Studies have shown that sod cultivation increased the absorption and utilization rate of nitrogen fertilizer, and slow down the loss of nitrogen and phosphorus in apple orchard (Li et al., 2014; Peng et al., 2015). Sod cultivation also could increase the contents of main nutrients in peach orchard (Li et al., 2008; Jiang et al., 2019). It is generally accepted that sod cultivation can improve the content of soil organic matter in orchards. However, there is no unified conclusion on whether the effect of sod cultivation on phosphorus availability is positive or negative. This may be related to the different orchard types, soil properties and grass species. In addition, planting grass in orchards can also reduce the loss of nutrients by resisting rain erosion and reducing soil loss (Li et al., 2014). Therefore, the application of sod cultivation in *Rosa roxburghii* Tratt. orchard has important implications in improving soil physical and chemical properties, regulating ecological environment, controlling diseases and pests, and producing high-quality fruits.

At present, the research on the application of sod cultivation in *Rosa roxburghii* Tratt. planting mainly focuses on the soil microbial characteristics, enzyme activity (Xiang et al., 2018), and aggregate stability (He et al., 2020). While the research on the ecological stoichiometry characteristics of C, N and P in soil aggregate, and their contributions to soil nutrients in *Rosa roxburghii* Tratt. orchard under sod cultivation have not been reported. Therefore, the effects of sod cultivation on soil aggregate distribution, ecological stoichiometry ratio and nutrient contribution rate of *Rosa roxburghii* Tratt. orchard in Gujiao Town, Longli County, Guizhou Province were studied in this paper. The research's main aims were: 1) to study the concentration characteristics and stoichiometry of C, N and P under different sod cultivation treatments; 2) to reveal the contributions of aggregates to soil nutrients under the sod cultivation modes; 3) to understand the relationship between C/N, C/P, N/P and soil nutrient supply capacity, and reveal the limitation of soil nutrients in *Rosa roxburghii* Tratt. orchard. The study can provide a certain basis for regulating soil fertility and providing a reasonable planting mode for *Rosa roxburghii* Tratt. orchard.

Materials and Methods

Experimental Site

The field site selected for the research is located in Gujiao Town, Longli County, Guizhou Province (106°45'18"~107°15'1"E, 26°10'19"~26°49' 33"N), which is called the hometown of *Rosa roxburghii* Tratt. The area is located in the middle of Guizhou Province with an altitude of 1280~1500 m. This region has a subtropical monsoon humid climate with the average annual precipitation of 1088 mm, the average annual temperature of 13.9℃, the average annual frost-free period of 280d, and the average annual sunshine of 1060~1265 h. Yellow soil is the main soil type, with good climate and non-pollution environment, which is suitable for planting *Rosa roxburghii* Tratt.

Experimental Design

Three treatments were set in the *Rosa roxburghii* Tratt. orchard. Treatment 1: Intercropping of natural grass and *Rosa roxburghii* Tratt (NG, weeds grew naturally in the orchard, the main types of weeds include *Oxalis corymbosa*, *Oxalis*, *Medicago*,

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Trifolium, Eleusine indica). Treatment 2: Intercropping of artificial grass and *Rosa roxburghii* Tratt. (AG, ryegrass was planted and harvested artificially in May, July and October every year, three rows of ryegrass were sown in strips between *Rosa roxburghii* Tratt, with a spacing of 30 cm between the rows of ryegrass). Treatment 3: *Rosa roxburghii* Tratt. monoculture (CK, clear tillage, weeds in the garden were removed artificially in May, July and October every year). The variety of *Rosa roxburghii* Tratt. was Gui-nong No.5. *Rosa roxburghii* Tratt. was planted in the north-south direction in December 2011 with the 2 m×3 m of plant spacing and row spacing. The orchard was managed by conventional methods, and other management measures of each experimental plot were consistent.

Sample Collection

Soil samples were collected in July 2019. In each experimental plot, five sampling points were selected according to the "S" shape, and about 1 kg undisturbed soil samples of 0~20 cm layer was taken by the quartering method. The undisturbed soil samples packing in bags and taking back to laboratory were gently broken into small soil blocks along its natural structure, and the animal and plant residues and crushed stones were discarded. Then the soil samples were naturally dried in the shade.

Aggregates Isolation

The distribution of soil aggregates was separated by wet sieving into six fractions: >5 mm, 5~2 mm, 2~1 mm, 1~0.5 mm, 0.5~0.25 mm, and <0.25 mm. The aggregates of each size fraction were dried in evaporator at 70 °C, then weighed. Then the weight percentages and moisture content of each size aggregate were calculated. The dried soil samples which were used to determine soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP), available nitrogen (AN) and available phosphorus (AP), were ground and sieved by 0.25 mm and 2 mm, respectively.

Determination Methods

The content of SOC was determined by $K_2Cr_2O_7$ oxidation method (Walkley and Black, 1934). The content of TN was determined by Kjeldahl digestion method (Bao, 2000). The content of AN was determined by alkali hydrolyzed diffusion method. The content of TP was determined by colorimetric measurement after digestion with $HClO_4$–H_2SO_4 (Motomizu et al., 1984). The content of AP was determined by the colorimetric method developed by Murphy and Riley (1962).

Each particle size aggregate's mass percentage was calculated by *Eq.1*. The nutrient contribution rate of each particle size aggregate was calculated by *Eq.2*.

$$\text{Particle size aggregate's mass percentage} = \text{the weight of per particle size aggregate} / \text{the weight of dried soil sample} \times 100\% \quad \text{(Eq.1)}$$

$$\text{Nutrient contribution rate} = (\text{the nutrient content in the aggregate} \times \text{the aggregate content}) / \text{the nutrient content in the soil} \quad \text{(Eq.2)}$$

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Statistical Analysis

The results were expressed as mean ± SD. C / N, C / P, and N / P were all mass ratios. Excel 2010 was used for data processing. ANOVA and LSD of SPSS 20.0 were used for significance test and multiple comparison. The significance was set at the 0.05 level.

Results

Distribution Characteristics of Soil Aggregates in Rosa roxbunghii *Orchard under Sod Cultivation*

The distribution of soil aggregates was significantly affected by sod cultivation (*Table 1*, $P<0.05$). Under NG and AG treatments, the surface soil aggregates mainly concentrated in > 5 mm and 5-2 mm particle size, accounting for 47.70% and 46.78% of the total aggregates, respectively. Under NG treatment, the aggregate content of > 5 mm was 43.85%, 105.78%, 65.94%, 106.99% and 246.18% higher than that of other particle sizes, respectively ($P<0.05$). Under AG treatment, the aggregate contents of > 5 mm and 5~2 mm were 33.21%, 32.66%, 117.10%, 139.91% and 45.73%, 33.25%, 137.51%, 162.51% higher than that of other particle sizes, respectively ($P<0.05$). Under CK treatment, the surface soil aggregates mainly concentrated in < 0.25 mm particle size, accounting for 31.86% of the total aggregates, which was higher than that of other particle sizes, significantly ($P<0.05$).

Table 1. *Distribution of aggregates in top soil in Rosa roxburghii Tratt. orchard (%)*

Treatment	Aggregate size / mm					
	>5	5～2	2～1	1～0.5	0.5～0.25	<0.25
NG	28.11±0.81Aa	19.59±1.11Ab	13.66±0.84Bd	16.94±0.09Ac	13.58±0.95Ad	8.12±0.45Be
AG	22.34±1.28Ba	24.44±2.33Aa	16.77±0.65Ab	16.84±2.18Ab	10.29±2.24Ac	9.31±1.22Bc
CK	16.08±1.03Cb	13.50±0.92Bb	8.93±0.54Cb	13.58±0.44Ab	16.05±1.65Ab	31.86±0.93Aa

Data shown are means ± standard deviation. Values within the same columns followed by different capital letters denote significant differences among different treatments in the same particle size at p<0.05. Values within the same lines followed by different lowercase letters denote significant differences among different particle sizes in the same treatment at p<0.05

Under NG and AG treatments, the aggregate contents of >5 mm, 5~2 mm and 2~1 mm were increased 74.81%, 45.11%, 52.97% and 34.45%, 81.04%, 87.79%, respectively ($P<0.05$). At 1~0.5 mm and 0.5~0.25 mm particle size, there were no significant differences between AG, NG, and CK ($P>0.05$). Under NG and AG treatments, the aggregate content of <0.25 mm was decreased 292.36% and 242.21%, respectively ($P<0.05$).

The Content of C, N and P in Soil Aggregates of Rosa roxburghii Orchard under Sod Cultivation

Soil organic carbon content: As shown in *Figure 1*, the topsoil aggregate organic carbon content of *Rosa roxburghii* Tratt. orchard under different sod cultivation was NG > AG > CK. The range of aggregate organic carbon contents were 47.21~55.42 g/kg under NG treatment, 29.04~35.05 g/kg under AG treatment, and 13.69~16.92 g/kg under CK treatment.

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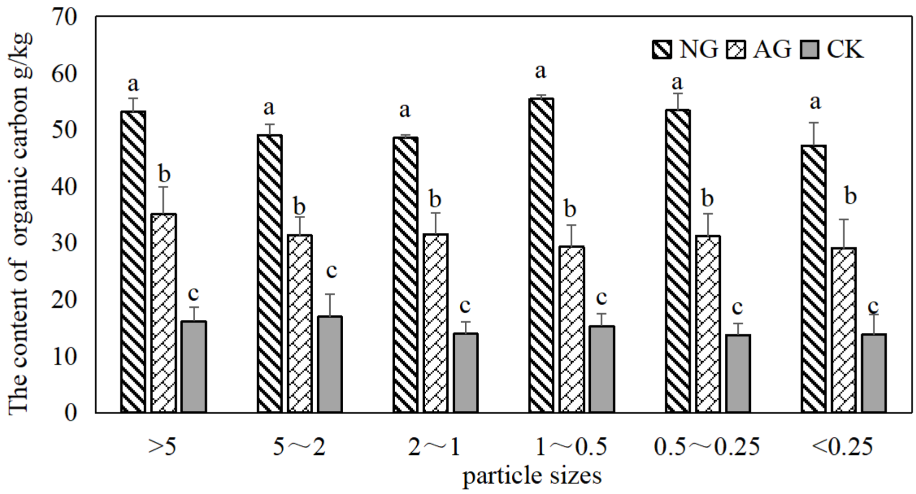

Figure 1. *Concentration of organic carbon in soil aggregates*
Diverse lowercase letters denote significant differences among different treatments in the same particle size (P<0.05). The same as below

Sod cultivation significantly influenced the organic carbon content of aggregates (*P<0.05*). Under NG treatment, the aggregate organic carbon contents of six particle sizes were 51.50%, 56.41%, 53.96%, 89.13%, 71.24%, 62.55% and 229.48%, 189.72%, 248.33%, 261.59%, 290.14%, 242.10% higher than in AG and CK treatments, respectively (*P<0.05*). Compared with CK, the organic carbon contents of six particle size aggregates in AG treatment were increased by 117.48%, 85.22%, 126.24%, 91.19%, 127.83% and 110.46% (*P<0.05*).

The total nitrogen content: As shown in *Figure 2*, the topsoil aggregate total nitrogen content of *Rosa roxburghii* Tratt. orchard under different sod cultivation was AG>NG>CK. The range of aggregate total nitrogen contents were 2.06~2.32 g/kg under NG treatment, 2.28~2.80 g/kg under AG treatment, and 1.36~1.86 g/kg under CK treatment.

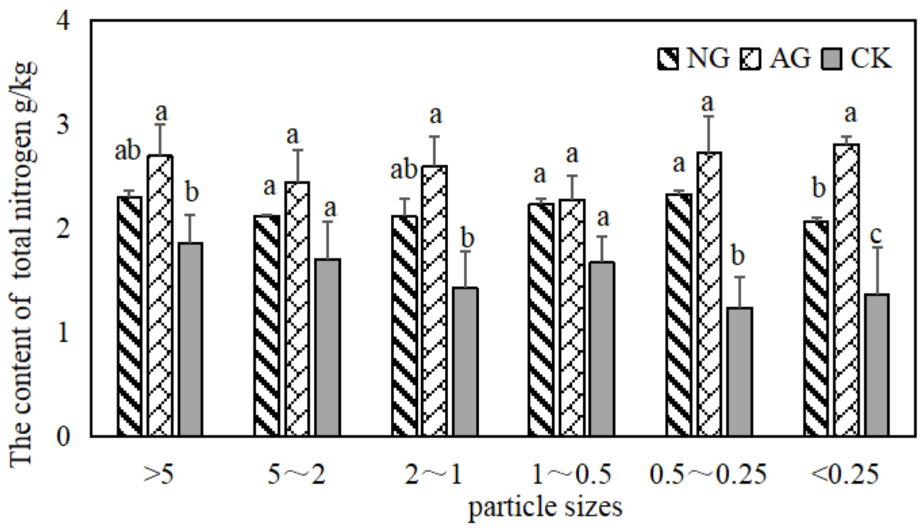

Figure 2. *Concentration of total nitrogen in soil aggregates*

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Sod cultivation had significant effect on the total nitrogen content of aggregates (*P<0.05*). Under AG treatment, the aggregate total nitrogen contents of >5 mm, 2~1 mm, 0.5~0.25 mm and <0.25 mm were 45.24%, 80.93%, 120.21% and 105.63% higher than CK (*P < 0.05*). Compared with CK, the aggregate total nitrogen content of 0.5~0.25 mm under NG treatment was increased 87.86% (*P<0.05*).

The total phosphorus content: As shown in *Figure 3*, the topsoil aggregate total phosphorus content of *Rosa roxburghii* Tratt. orchard under different sod cultivation was CK>AG>NG in >5 mm, 5~2 mm, 2~1 mm, 1~0.5 mm particle size. The range of aggregate total phosphorus contents were 0.53~0.71 g/kg under CK treatment, 0.52~0.61 g/kg under AG treatment, and 0.35~0.46 g/kg under NG treatment.

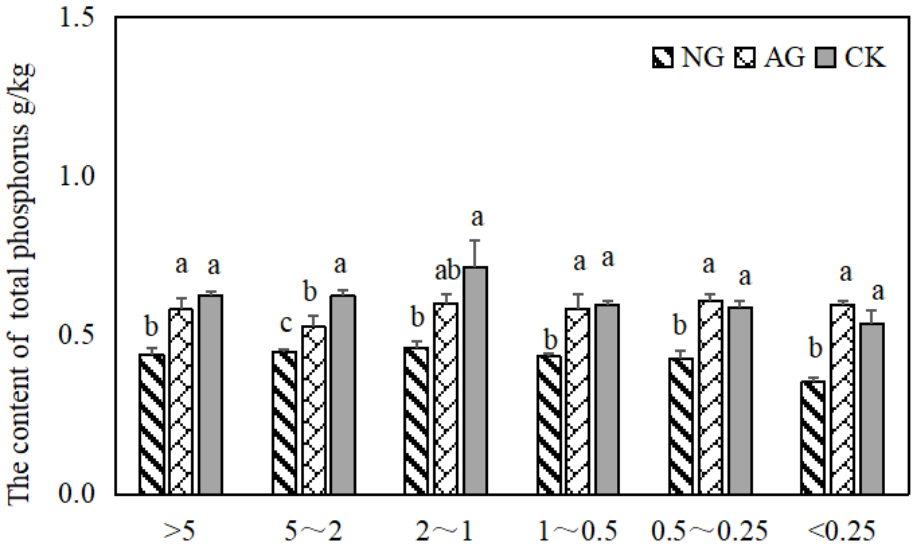

Figure 3. *Concentration of total phosphorus in soil aggregates*

Sod cultivation had significant effect on the total phosphorus content of aggregates (*P<0.05*). The aggregate total phosphorus contents of six particle sizes in CK treatment were 41.66%, 39.53%, 55.07%, 37.71%, 37.50% and 51.91% higher than that in NG treatment, respectively (*P<0.05*). The aggregate total phosphorus contents of 5~2 mm in AG treatment were significantly lower than CK (*P<0.05*). The aggregate total phosphorus contents of each particle sizes in AG treatment were 31.82%, 17.91%, 34.62%, 42.18% and 68.89% higher than that in NG treatment (*P<0.05*), except for 2~1 mm particle size.

The C/N, C/P, N/P of Soil Aggregates in Rosa roxburghii Orchard under Sod Cultivation

As shown in *Figures 4, 5, 6*, sod cultivation has significant influence on the ratio of C, N, P in *Rosa roxburghii* Tratt. orchard (*P<0.05*). The range of C/N, C/P and N/P in soil aggregate were 8.83~24.82, 20.15~134.69 and 2.07~5.86, respectively. The aggregate C/N of >0.5 mm particle size was NG>AG>CK. The aggregate C/N of ≤0.5 mm particle sizes was NG>CK>AG. The aggregate C/N of >5 mm and 1~0.5 mm particle sizes in NG and AG treatments were significantly higher than that in CK (*P<0.05*). Compared with AG and CK treatments, the aggregate C/N of 5~2 mm, 2~1 mm, 0.5~0.25 mm and <0.25 mm particle sizes in NG were enhanced significantly (*P<0.05*).

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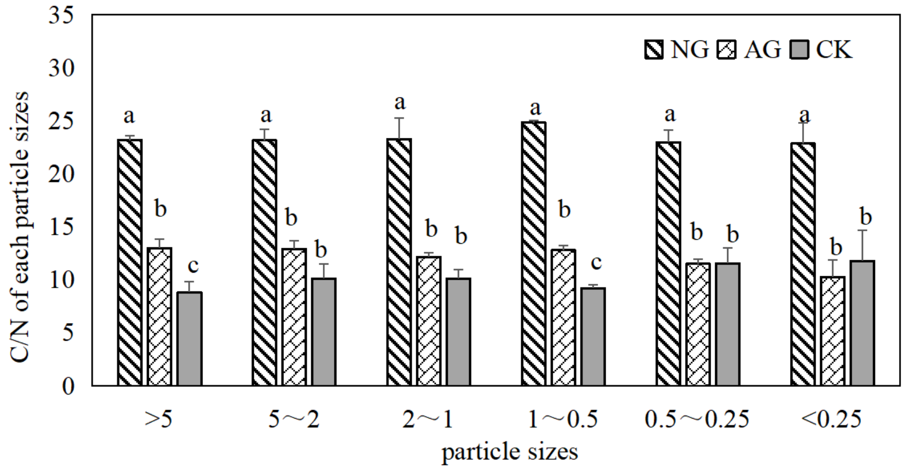

Figure 4. *C/N of aggregates in Rosa roxburghii orchard under different cultivation mode*

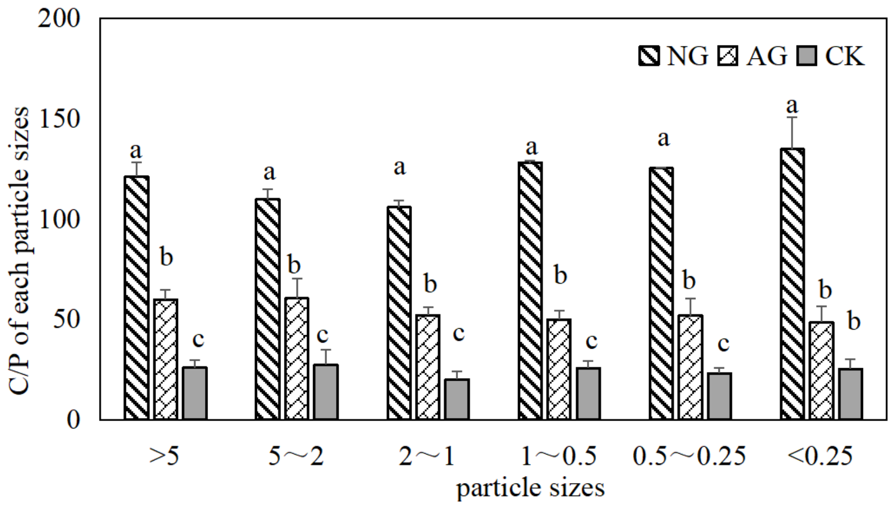

Figure 5. *C/P of aggregates in Rosa roxburghii orchard under different cultivation mode*

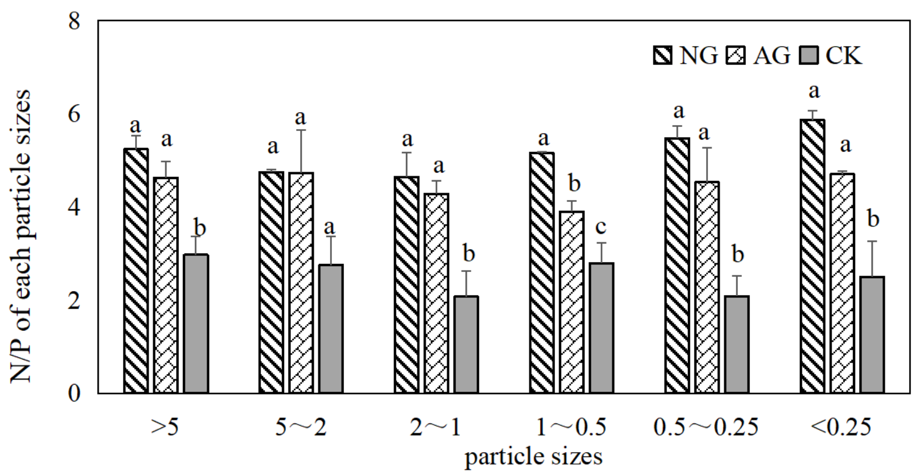

Figure 6. *N/P of aggregates in Rosa roxburghii orchard under different cultivation mode*

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The aggregate C/P of each particle sizes was NG > AG > CK. Compared with CK, at the particle sizes of ≥0.25 mm in NG and AG were significantly increased (*P<0.05*). At the particle sizes of <0.25 mm, the C/ P in NG treatment was increased significantly than AG and CK (*P<0.05*).

The aggregate N/P of each particle sizes was NG>AG>CK. At the particle sizes of >5 mm, 2~1 mm, 0.5~0.25 mm, and <0.25 mm, the N/P in NG and AG treatments were higher than that in CK treatment (*P<0.05*). At the particle size of 5~2 mm, there was no significant difference in the aggregate N/P among NG, AG and CK treatments (*P>0.05*). Compared with AG and CK, at the particle sizes of 1~0.5 mm, the aggregate N/P in NG was increased significantly (*P<0.05*).

The Contribution Rate of Each Particle Size Aggregate to Soil Nutrients in Rosa roxburghii Orchard under Sod Cultivation

AG and CK treatments were selected to study the relationship between soil aggregate stoichiometry and soil nutrients in *Rosa roxburghii* Tratt. orchard under sod cultivation.

It can be seen from *Table 2* that more than 45% contribution rate of SOC, TN, TP, AN and AP in the soil of *Rosa roxburghii* orchard under AG treatment were provided by >5 mm and 5~2 mm particle sizes. The contribution rate of 5~2 mm particle size to SOC, TN and AN was greater than that of >5 mm particle size. And the contribution rate of >5 mm particle size to TP and AP was larger than that of 5~2 mm particle size. More than 45% contribution rate of SOC, TN, TP, AN and AP in the soil of *Rosa roxburghii* orchard under CK treatment were provided by >5 mm and <0.25 mm particle sizes. And the contribution rate of <0.25 mm particle size to SOC, TN, TP, AN and AP was larger than that of >5 mm particle size.

Table 2. *Contribution rate of different particle sizes aggregates to soil nutrients in Rosa roxburghii Tratt. orchard under sod cultivation treatments (%)*

Index	Model	The contribution rates of aggregates fractions to soil nutrient (%)					
		>5mm	5~2mm	2~1mm	1~0.5mm	0.5~0.25mm	<0.25mm
SOC	AG	24.89±0.86a	24.28±2.34a	17.03±1.47b	15.31±2.97bc	10.49±2.92cd	8.61±1.57d
	CK	17.83±1.46b	14.85±0.24c	8.59±0.99d	14.05±0.03c	15.16±0.51bc	29.52±2.52a
TN	AG	25.12±0.90a	21.93±1.69ab	18.33±1.85b	13.66±2.01bc	11.03±2.18c	9.92±1.13c
	CK	20.02±2.83b	15.85±1.73b	9.09±1.83c	14.96±0.49b	13.1±2.43b	26.98±3.97a
TP	AG	22.12±0.39a	22.18±2.66a	17.97±0.73a	17.08±3.04a	11.23±2.03b	9.51±1.22b
	CK	18.29±1.98b	13.81±1.39b	10.59±1.57b	13.23±0.65b	15.71±1.44b	28.38±2.51a
AN	AG	25.78±3.41a	24.76±0.53a	14.08±0.54b	15.33±3.16b	8.5±1.88c	11.55±2.17bc
	CK	17.33±0.96b	12.43±1.07bc	8.48±0.37c	14.24±0.33b	15.84±1.11b	31.68±1.72a
AP	AG	22.55±1.61ab	28.85±1.61a	16.77±2.52bc	11.4±4.74c	9.3±1.25c	11.14±0.91c
	CK	19.64±1.74b	17.06±3.01bc	9.67±1.27c	11.73±1.63c	12.25±0.63c	29.65±2.73a

The contribution rate of large aggregates (>0.25 mm particle sizes) to soil nutrients was higher than that of micro aggregates (<0.25 mm particle size) under AG treatment. The contribution rate of large aggregates (>0.25 mm particle size) to soil nutrients was more than 85%, while the contribution rate of micro aggregates (<0.25 mm particle size) was only 8.61%~11.55%. Under CK treatment, the contribution rate of macro aggregates (>0.25 mm particle size) to soil nutrients was also higher than that of micro aggregates

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(<0.25 mm particle size), but the contribution rate of macro aggregate (>0.25 mm particle size) to soil nutrients was lower than that of AG treatment. While the contribution rate of micro aggregate (<0.25 mm particle size) to soil nutrients increased by 26.98%~31.68% compared with AG treatment.

Discussion

Effects of Sod Cultivation on Ecostoichiometric Characteristics of Soil Aggregates in Rosa roxburghii Orchard

Ecostoichiometry is a discipline that combines the basic principles of biology, physics, and chemistry to study the relationship of elements in various processes of ecosystem (Elser et al., 2000). It is one of the key contents to study ecological chemometrics of carbon, nitrogen, and phosphorus for revealing the limitation of soil nutrients and the mechanism of nutrient cycling. Studies have shown that grass planting in orchards can improve the soil nutrient conditions (Liu et al., 2015; Cao et al., 2016, 2017; Wang et al., 2017; Jiao et al., 2017). The results demonstrated that the organic carbon and total nitrogen contents under sod cultivation conditions were higher than that in *Rosa roxburghii* Tratt. monoculture condition, which was because sod cultivation increased the biomass of *Rosa roxburghii* orchard, and the nitrogen in soil mainly came from the decomposition of plant residues. The nitrogen concentration of aggregate was closely related to organic carbon, so the distribution of them was consistent (Wright and Hons, 2004; Dang et al., 2007; Li et al., 2015). The phosphorus concentration of aggregates in artificial grass mode was lower than that in monoculture mode, but there was no significant difference between them. This result was consistent with the Xu and Zhang's research (2004). Because phosphorus is a sedimentary mineral with fixed source, the distribution of total phosphorus in the whole soil layer is relatively uniform (Wang and Yu, 2008). The phosphorus concentration of aggregates in each particle sizes decreased significantly under the natural grass mode, which may be due to the variety, long growth period, and large biomass of natural grass. The utilization of nutrients by grass and *Rosa roxburghii* Tratt. reduced the content of phosphorus in soil. Studies have shown that after long-term grass cultivation, the nutrients of grass could gradually release and the total phosphorus content could increase (Cao et al., 2016). Whether the same changes would occur in this study remains to be observed for a long time.

The ratio of carbon, nitrogen and phosphorus can reflect the mineralization rate of organic matter and nutrient supply capacity (Wang and Yu, 2008). They also can affect plant nutrient use efficiency (Tessier and Raynal, 2003; Deng et al., 2015) and growth rate (Agren, 2004; Matzek and Vitousek, 2009). In particular, the ratio of nitrogen and phosphorus can reflect the limitation of nutrient on plant growth and the nutrient supply of soil to plant growth (Güsewell, 2004; Sardans et al., 2012; Zhang et al., 2013). In the paper, the C/N of natural grass, artificial grass and monoculture modes were 22.85~24.82, 10.28~12.99 and 8.83~11.79, respectively. The C/P of natural grass, artificial grass and monoculture modes were 105.81~134.69, 48.50~60.47 and 20.15~27.40, respectively. The N/P of natural grass, artificial grass and monoculture modes were 4.64~5.86, 3.90~4.73 and 2.07~2.97, respectively.

C/N reflects the equilibrium state of different elements in the soil. When C/N is low, organic matter has rapid mineralization, resulting in the increase of alkali hydrolyzable nitrogen content (Wang and Yu, 2008; Xu et al., 2018). Soil C/N is closely related to soil aggregates. Because organic matter is the cementing agent to create aggregates, the higher

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the content of organic carbon, the more stable aggregates can be formed (Li et al., 2014). We studied the soil aggregates C/N at different particle sizes in *Rosa roxburghii* Tratt. orchard, and found that the C/N of natural grass mode increased, which indicated that under the natural grass treatment, the aggregates had good stabilities, rich carbon sources, slow decomposition, and mineralization of organic matter. The accumulation of organic matter was mainly due to the rich species of natural weeds, high biomass, and more nutrients returned to the field. However, under the *Rosa roxburghii* Tratt. monoculture mode, it showed a certain carbon limitation. Furthermore, our research also showed that the aggregates with different size fractions have different C/N, which indicated that the organic matter decomposition rate was different which was in different particle sizes aggregate. This may be related to the different concentration of carbon and nitrogen in each particle size aggregate and their different response to environmental changes. The specific reasons need to be further analyzed.

C/P is one of the indicators of phosphorus availability, which is used to measure the potential of phosphorus release, absorption, and fixation. The low C/P indicates that microorganisms have a great potential to release phosphorus in the process of decomposing organic matter, which promotes the increase of phosphorus availability in soil (Wang and Yu, 2008; Li et al., 2015). The C/P of aggregates with different particle under monoculture mode was much lower than that under artificial grass and natural grass modes, which was attributed to the different abilities of organic matter accumulation and phosphorus consumption among different treatments. Under the artificial grass and natural grass treatments, due to the abundant plant species and the large amount of phosphorus absorption and utilization, the C/P was higher. There would be competition between plant roots and surface microorganisms for phosphorus in soil, which was not conducive to the growth of plants (Li et al., 2017). Therefore, in the early stage of sod cultivation, we should pay attention to supplement phosphorus fertilizer to maintain the phosphorus supply of soil and ensure the normal growth and development of plants.

N/P is an indicator of nitrogen saturation and nutrient limitation (Wang and Yu, 2008). Generally speaking, plants with lower N/P showed nitrogen limitation, while plants with higher N/P showed phosphorus limitation (Huang et al., 2013). In our study, the aggregate N/P under different treatments was NG>AG>CK. On the one hand, this indicated that long-term sod cultivation accelerates the consumption of phosphorus in the soil, which may lead to phosphorus constraints on the growth of *Rosa roxburghii*. But on the other hand, it also suggested that monoculture of *Rosa roxburghii* may enhance the limiting effect of soil nitrogen. The difference of N/P was the result of organic carbon accumulation and phosphorus consumption under natural and artificial grass treatments. Under natural grass treatment, the N/P of <0.5mm particle sizes was larger than that of other particle sizes, indicating that phosphorus was the main nutrient limiting factor in 0.5~0.25 mm and <0.25 mm fraction. Under artificial grass cultivation and clear tillage treatments, the N/P of >2 mm particle sizes were larger than that of other particle sizes, which indicated that phosphorus was the main limiting element in aggregates of >5 mm and 5~2 mm particle sizes.

Effects of Sod Cultivation on Nutrient Contribution Rate of Soil Aggregates in Rosa roxburghii Orchard

Because aggregate is the basic unit of soil structure and the main carrier of nutrient storage. Soil nutrients are mainly supplied by soil aggregates of different particle sizes. The content of aggregates and their nutrient content can reflect the basic nutrients of the

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soil. Different particle size soil aggregates have different abilities to maintain and supply soil nitrogen, phosphorus, and potassium (Zheng et al., 2010; Wang et al., 2013). Therefore, analyzing the nutrient content of different particle size aggregates and their contribution to total soil nutrients is beneficial for evaluating the soil's ability to maintain and supply nutrients.

The contribution rates of soil aggregates with different particle sizes to soil nutrients were different in the same sod cultivation treatment. Under artificial grass treatment, the contribution rate of large aggregates (>0.25 mm) to soil nutrients was over 85%. Under clear tillage treatment, the contribution rate of large aggregate (>0.25 mm) to soil nutrients was about 75%. Compared with artificial grass treatment, the contribution rate of large aggregate (>0.25 mm) to soil nutrients decreased, and the contribution rate of microaggregate (<0.25 mm) to soil nutrients increased in clear tillage treatment. The results showed that sod cultivation can make the soil form more large aggregates and increase the nutrient content in large aggregates. Under the artificial grass treatment, 45% of the soil nutrients came from > 2 mm fraction. The contribution rate of 5~2 mm fraction to organic carbon, total nitrogen, and alkali hydrolyzable nitrogen was greater than that of ＞5 mm, and the contribution rate of >5 mm fraction to total phosphorus and available phosphorus was greater than that of 5~2 mm fraction. Under the clear tillage treatment, 45% of the soil nutrients came from >5 mm and ＜0.25 mm fraction, and the contribution rate of ＜0.25 mm fraction to soil nutrients was greater than that of ＞5 mm fraction.

Some studies have shown that the large aggregates (>0.25 mm particle sizes) are the best structure, and their quantity is positively correlated with soil nutrients (Xu and Shen, 2000). The results of this study were basically consistent with them. The soil nutrients of artificial grass treatment were significantly higher than that of clear tillage treatment, which was related to the contribution of soil macro aggregates. Because larger aggregates are the main carriers of soil carbon, nitrogen, and phosphorus (Lu et al., 2017), sod cultivation promotes the formation of large aggregates and improves the aggregates contribution rate to soil nutrients.

Conclusions

(1) Sod cultivation significantly increased the amount of large aggregates, increased the content of organic carbon, total nitrogen and available nitrogen, and decreased the content of total phosphorus and available phosphorus. (2) Under the natural grass treatment, the aggregates had good stabilities, rich carbon sources, slow decomposition, and mineralization of organic matter. It was phosphorus limitation under the natural grass cultivation treatment, while it was nitrogen limitation under the artificial grass cultivation and *Rosa roxburghii* Tratt. monoculture treatments. (3) The contribution rate of macro aggregates to soil nutrients was about 85% under artificial grass treatment. The contribution rate of >5 mm and 5~2 mm particle size aggregates to soil nutrients was the largest, and the total contribution rate was about 45%. The contribution rate of large aggregates to soil nutrients was about 75% under clear tillage treatment. The largest contribution rate of aggregates to soil nutrients was < 0.25 mm, followed by >5 mm. The total contribution rate of >5 mm and <0.25 mm particle sizes to soil nutrients was 45%. Sod cultivation was conducive to raise the content of macroaggregates and the contribution rate of macroaggregates to soil nutrients.

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In summary, under sod cultivation, we should pay attention to supplement phosphorus fertilizer to maintain the phosphorus supply of soil due to the abundant plant species and the large amount of phosphorus absorption and utilization.

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