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Soil nutrient status and the relation with planting area, planting age and grape varieties in urban vineyards in Shanghai

Zheng Zhao [a,1], Changbin Chu [a,1], Deping Zhou [a], Zhimin Sha [b], Shuhang Wu [a,*]

[a] *Eco-environmental Protection Institute of Shanghai Academy of Agricultural Science, Shanghai 201403, China*
[b] *School of Agriculture and Biology, Shanghai Jiao Tong University, Shanghai 200240, China*

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ABSTRACT

Soil nutrient characteristics are key factors that regulate grape growth and fruit quality. To investigate soil nutrient characteristics, 73 typical vineyards in Shanghai suburbs were selected for this study. The impacts of different planting areas, planting ages and grape varieties on soil characteristics were studied. The Agro Services International (ASI) analysis method was adopted to measure the levels of soil nutrients. The results indicated that soil nutrient characteristics varied greatly across the 73 selected vineyards in Shanghai suburbs. Planting area and planting age were the major factors that significantly affected soil nutrient characteristics. However, no significant differences were observed among the 5 major cultivated grape varieties. Significant differences in soil pH were only observed in different planting areas. Soil nutrients in the selected vineyards were mainly at a high level or extra-high level, which means that the current amount of fertilizer in these vineyards exceeds the actual demands of the grapevines and should be reduced. Meanwhile, the intermediate soil organic matter (OM) content indicated that more organic fertilizer should be applied to the soil in these vineyards. Optimized fertilization based on soil nutrient levels plays an essential role in sustaining production resources, increasing economic benefits and improving environmental conditions of vineyards.

1. Introduction

Table grape (*Vitis vinifera L.*) is one of the major tree fruits species planted in Shanghai city. In 2014, the planting area of grapes in Shanghai city was 5267 ha, which accounted for approximately 25% of the total fruit planting area [1]. Vineyards in Shanghai are mainly distributed in Jiading, Jinshan and Fengxian Districts, where Kyoho, Summer-Black and Fragrant-Kyoho are the primary varieties cultivated [2]. In terms of high economic value, the cultivation of grapevines plays an important role in Shanghai agriculture even though grape production in Shanghai city accounted for only 0.8% of the total grape production in China [3].

Soil properties and nutrient characteristics are the key factors that regulate grapevine growth [4]. Suitable soil conditions and sufficient nutrient supplies are essential for grape yields and quality [5]. Fertilization is the basic management practice in modern agriculture that significantly affects soil nutrient supply and soil properties, such as soil pH, salinity and porosity [6]. The fundamental functions of macronutrients in grapevine growth, including nitrogen (N), phosphorus (P) and potassium (K), have been examined in many previous studies [7]. For example, the application of K fertilizer at veraison is an essential measure to guarantee the fragrance and sweetness of grapes [8]. Organic fertilizer is usually applied as basal fertilizer to ensure that soil organic matter and micronutrients are supplied during grapevines growing period [9]. Each micronutrient plays a unique role during the grapevines growth and development [10, 11]. For instance, Zn is a vital element for the synthesis of plant enzymes and hormones, which are involved in grapevine differentiation and development [12]. Cu and Mn are related to plant metabolic and photosynthetic functions, which could significantly influence grape yield and quality [12]. Therefore, deficiency of soil nutrients limits grapevine growth and deteriorates fruit quality. However, an excess of soil nutrients could also lead to problems in grapevine cultivation [13, 14]. Phytotoxins can be formed when some nutrients reach high concentration. Soil conditions with excess nutrients can result in the occurrence and spread of more diseases in vineyards. In addition, an abundance of soil nutrients can result in potential loss into the environment, causing widespread environmental issues [15, 16]. Many studies have indicated that the nutrients lost from vineyards have seriously affected nearby water quality [17, 18]. Therefore, scientific fertilization

* Corresponding author.
E-mail address: wushuhang88@foxmail.com (S. Wu).
[1] Zheng Zhao and Changbin Chu contributed equally.

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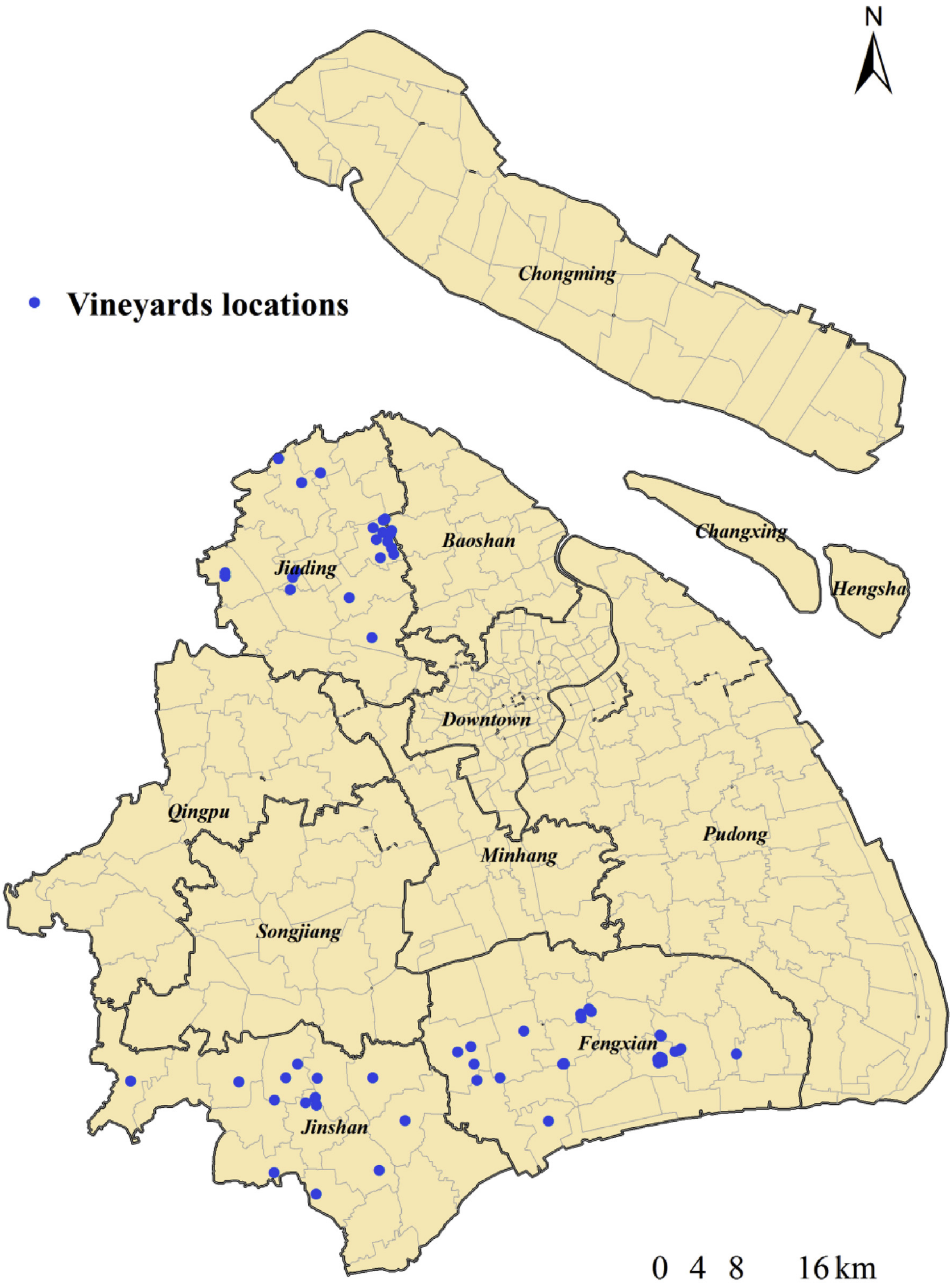

Fig. 1. The locations of the selected vineyards in the Shanghai suburb.

methods based on soil nutrient status should be applied in vineyards to balance grapevine demand and environmental impacts [19].

In recent years, grape production in Shanghai has rapidly developed to meet the demand of the large population in the city. A large amount of chemical fertilizer has been put into soil, leading to large variations in soil nutrient. Our previous investigations showed that N fertilization levels in some vineyards have exceeded 500 kg N/ha. Consequently, nutrients have accumulated in the soil after long-term cultivation of grapevines, resulting in great risk of nutrient loss into the surrounding environment. Therefore, an urgent task for grape production in Shanghai is to understand the current soil nutrient status of the vineyards and set out corresponding scientific fertilization schemes to realize a balance between sustainable grape production and the environment. The objective of this study was to investigate the soil nutrient

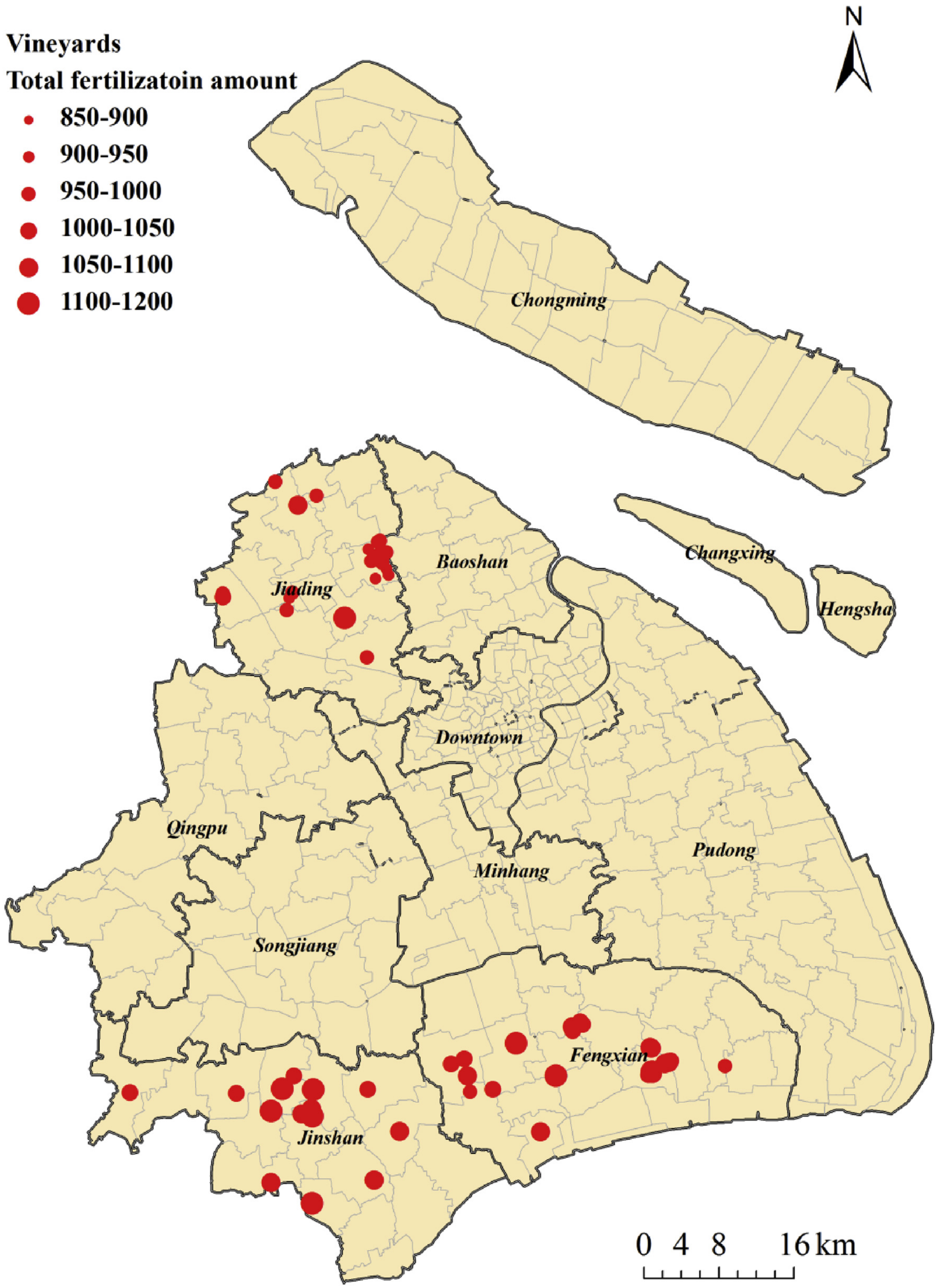

Fig. 2. The total annual amounts of fertilizer in the selected vineyards (kg/ha).

characteristics in Shanghai vineyards. The impacts of cultivation area, planting age and grape variety on soil nutrient status were also evaluated. The study results will be used to guide fertilization, which is extremely important for the ecological and sustainable development of grape cultivation.

2. Materials and methods

2.1. Study area

Shanghai (31°N, 121°E) is located in the Yangtze River Delta in East

China. The climate in Shanghai is classified as subtropical humid monsoon, with a daily average air temperature of 15.6 °C and an annual precipitation of 1120 mm (from 2010 to 2015). Fruit cultivation is an important part of Shanghai agriculture. Grapes, peaches, citrus and pears are the four major fruits cultivated in Shanghai. The cultivation area of grape accounts for approximately 25% of the city's total fruit cultivation area and is mainly cultivated in Jiading, Fengxian and Jinshan Districts. Shanghai city consists of 16 Districts, while Jiading District is located in the north of the city, and Fengxian and Jinshan Districts are located in the south of the city. Grape production in these areas accounted for 80% of the total grape production of Shanghai. Therefore, these 3 Districts were chosen as the major study areas.

2.2. *Investigation scheme*

Seventy-three typical vineyards across Jiading, Fengxian and Jinshan Districts were selected to investigate soil nutrient characteristics. More than 10 varieties of table grapes are cultivated in the selected vineyards. The locations of the selected vineyards are shown in Fig. 1. Soil sampling and management practices were recorded for each vineyard during the study. According to our investigation of local farmers for each vineyard, the fertilization history (planting years ranged from 1 to 18 years) for each vineyard was recorded, and the annual amounts of fertilizer applied were calculated (based on N, K_2O and P_2O_5 amounts), as presented in Fig. 2. Three factors, including planting area, planting age and grape variety, were chosen to assess the impacts on soil nutrient characteristics. Agricultural management practices, such as fertilization and irrigation, are generally established based on the local climate conditions, planting age and plant variety. Thus, the impacts of management practices and climate conditions on soil nutrient characteristics are already considered in the selected impact factors. In the results analysis and comparison, the 73 selected vineyards were divided into several groups based on different planting areas, planting ages and grape varieties.

2.3. *Sampling and analysis*

The soil types across the selected vineyards were relatively homogeneous and were classified as Anthrosols based on the Chinese Soil Taxonomy and classified as Entisols based on the USDA Soil Taxonomy [20]. Soil samples were taken from the top layer (0–20 cm) in the 73 selected vineyards in the winter of 2014, prior to basal fertilizer application. Each soil sample was collected from 5 positions with the “S” shape sampling method and then mixed to form a compound sample. Five sample duplicates were randomly collected for each vineyard. All soil samples were immediately taken to the lab and air dried at room temperature. After being ground by hand, soil samples were sieved through a 2-mm sieve and then used to determine the soil nutrient content. In this study, the Agro Services International (ASI) analysis method, which was developed by Hunter et al. in 1980, was employed to measure the available nutrient contents of the vineyard soils [21]. The items measured included soil pH, OM content, available N, available P and available K. Published studies have demonstrated that the available soil nutrient content detected by the ASI method shows a clear relationship with the total soil nutrient content detected by the traditional analysis method [22, 23, 24]. The ASI analysis method is an appropriate choice for evaluating soil nutrient status and for making fertilization recommendations. According to the grading standard of the ASI method (Table 1), soil nutrients have been divided into 4 levels, including a low level, medium level, high level and extra-high level.

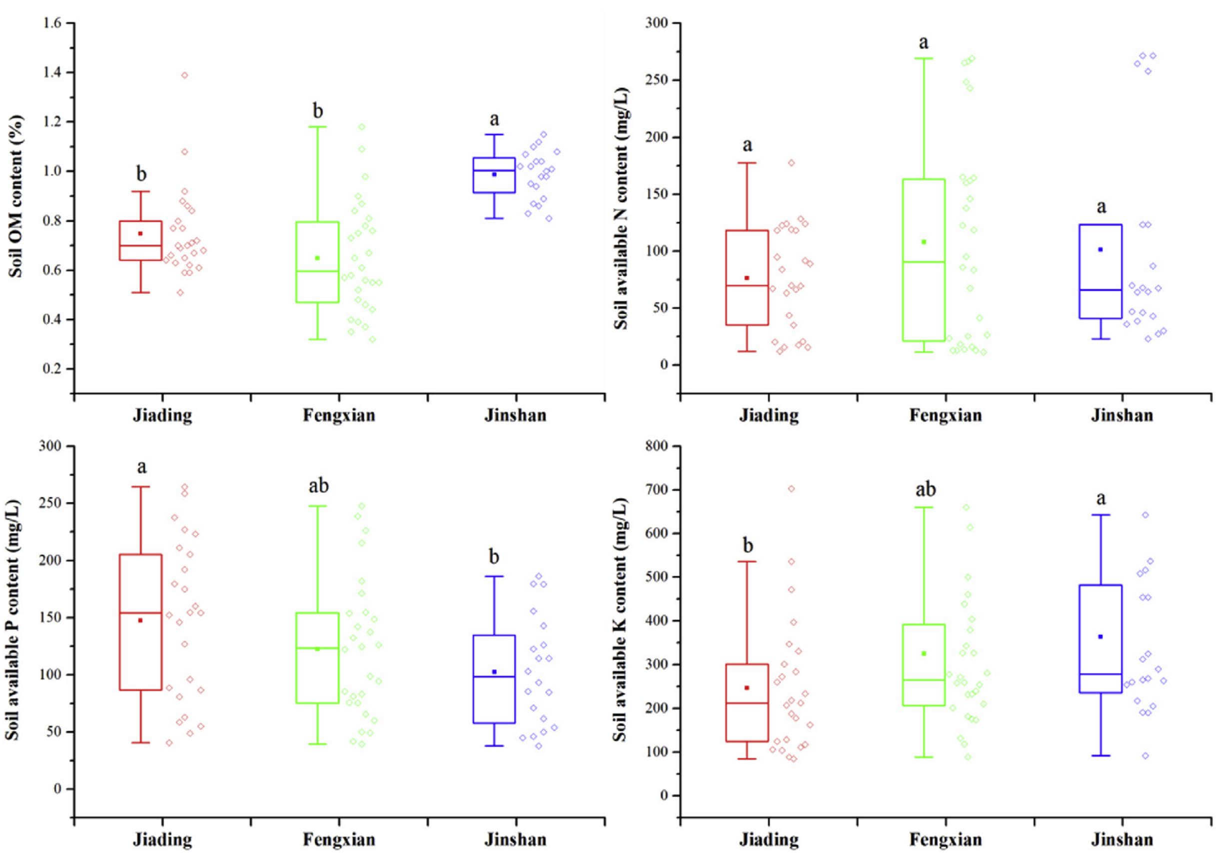

Fig. 3. Soil nutrient characteristics in the vineyards in different planting areas (Different letters in the figure indicate significant differences at a significance level of 0.05).

Table 1
The grading standard of the ASI analysis method.

Nutrients	Low level	Medium level	High level	Extra-high level
OM (%)	<0.5	0.5–1	1–1.5	>1.5
N (mg/L)	<20	20–50	50–100	>100
P (mg/L)	<12	12–24	24–60	>60
K (mg/L)	<80	80–120	120–160	>160

2.4. Statistical analysis

Data analysis was performed with Excel 2010 (Microsoft, USA) and SPSS 17.0 (SPSS Inc., USA). A Tukey test significance level of 0.05 was used for one-way ANOVA during the statistical analysis. A boxplot was adopted for comparisons between groups. Figures were produced using Origin 8.0 (Origin Lab Corporation, USA) and ArcGIS 10.0 (Esri Inc., USA).

3. Results

3.1. Soil nutrient variations among different grape production areas

The 73 selected vineyards were divided into 3 groups based on the different planting areas, with 25 vineyards located in Jiading, 28 vineyards located in Fengxian and 20 vineyards located in Jinshan. Soil nutrient status is associated with many factors, such as soil climate, crop plantings and agricultural management practices. The results in Fig. 3 indicate that the soil OM contents in Jinshan were significantly higher than those in Jiading and Fengxian. The average soil OM contents in Jiading, Fengxian and Jinshan were 0.75%, 0.65% and 0.99%, respectively. The available N contents in the soil were not significantly different among the different planting areas. The average available N contents in soil in Jiading, Fengxian and Jinshan were 76.39, 107.78 and 101.25 mg/L, respectively. The available P and K contents in Fengxian vineyards were not significantly different compared with the vineyards in Jiading and Jinshan, while the Jiading vineyards possessed significantly higher soil available P and significantly lower soil available K than the Jinshan vineyards. The highest average P and K contents were found in the Jiading and Jinshan vineyards, at 147.46 mg/L and 363.76 mg/L, respectively. The results demonstrated that grape planting area has a clear impact on vineyard soil nutrient characteristics, which may be attributed to the different soil climate conditions and local management practices in the different regions of the Shanghai suburbs.

3.2. Soil nutrient variations among different grapevine ages

Considering soil nutrient accumulation and plant growth conditions in different periods, planting age is another important factor that affects soil nutrient status in vineyards. The planting ages of the selected vineyards ranged from 2 years to 28 years. Based on different planting years, the selected vineyards were divided into 3 groups, i.e., 1–5 years (26 vineyards), 6–10 years (31 vineyards) and >10 years (16 vineyards). As shown in Fig. 4, the soil OM contents were not significantly different among the different grape planting ages. The mean soil OM content levels for the 1–5 year, 6–10 year and over 10 year planting ages were 0.82%, 071% and 0.84%, respectively. The vineyards over 10 years old contained significantly higher soil available P and K contents than the other vineyards. The highest mean soil available P and K contents in the vineyards over 10 years old were 172.98 mg/L and 425.60 mg/L, respectively. The highest mean soil available N content (123.99 mg/L) was observed in vineyards that were 6–10 years old, which was significantly higher than that in vineyards that were 1–5 years old; however, no significant differences were observed in vineyards that were more than

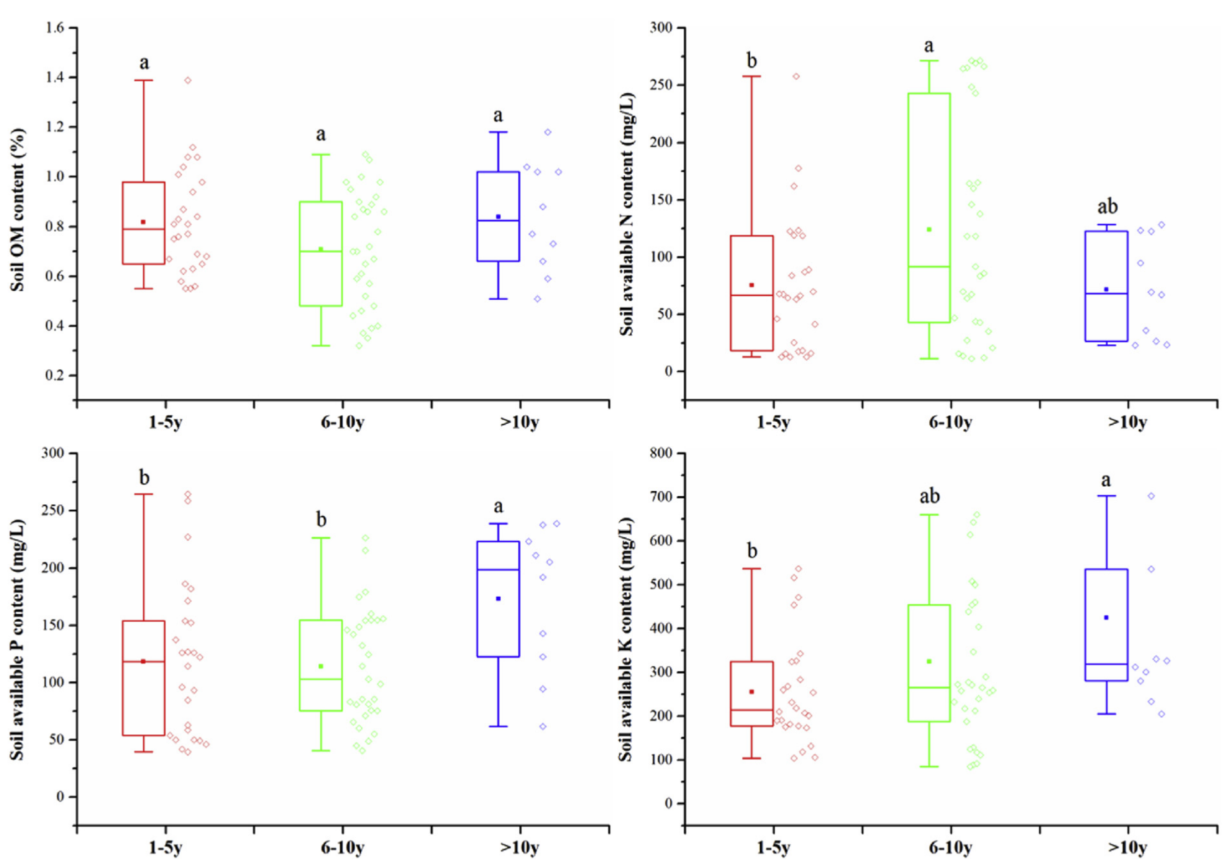

Fig. 4. Soil nutrient characteristics in vineyards with different planting ages (Different letters in the figure indicate significant differences at a significance level of 0.05).

10 years old. In general, the results suggested that the planting age of the grapevine significantly affects the available nutrients in the soil, while it does not affect the soil OM content.

3.3. Soil nutrient variations among different grape cultivars

More than 10 table grape varieties were still cultivated in the selected vineyards after the study completion. Five major grape varieties, Kyoho (14 vineyards), Fragrant-Kyoho (12 vineyards), Summer-Black (10 vineyards), Muscat-Kyoho (12 vineyards) and Raisins (11 vineyards), were chosen to evaluate the impacts of grape variety on soil nutrient characteristics. However, the results in Fig. 5 indicate that no significant differences were observed among the five grape varieties, regardless of the soil OM content or the soil available nutrient content. This result suggests that the soil nutrient characteristics of the vineyards are irrelevant to the cultivated grape varieties. The average soil OM content levels in the vineyards with Kyoho, Fragrant-Kyoho, Summer-Black, Muscat-Kyoho and Raisins were 0.76%, 0.73%, 0.80%, 0.78% and 0.73%, respectively. The highest average soil available N content of 117.28 mg/L was observed in vineyards with grape varieties for Raisins, and the highest available P content of 162.48 mg/L and the highest available K content of 347.40 mg/L were observed in the Muscat-Kyoho vineyards and Summer-Black vineyards, respectively.

3.4. Soil pH among different grape production areas, grapevine ages and grape cultivars

Soil pH is one of the most important properties to regulate soil conditions and grapevine growth. During the investigation, the soil pH, shown in Fig. 6, varied greatly across the different groups. For the different planting areas, the soil pH in the Jinshan vineyards was significantly lower than that in the Jiading and Fengxian vineyards. The average soil pH values for Jiading, Fengxian and Jinshan were 7.02, 7.40 and 5.70, respectively. The soil pH decreased slowly along with grapevine planting age. The average soil pH values in the vineyards with planting ages of 1–5 years, 6–10 years and over 10 years were 7.01, 6.79 and 6.57, respectively. However, no statistically significant differences were observed among the three groups of vineyards with different planting ages. Similarly, no significant differences were observed among the five major cultivated grape varieties, with the highest average soil pH (7.43) observed in raisin vineyards and the lowest pH (6.50) observed in Summer-Black vineyards. These results suggest that planting area is the sole factor that has a clear impact on the soil pH of vineyards. However, both planting age and grape varieties in Jinshan contributed to the significantly lower pH because the proportion of old vineyards (>10 y) and Summer-Black was higher in Jinshan than in other regions. It is worth noting that the soil pH gradually decreased along with planting age, which could be attributed to the accumulation of chemical fertilizers in these vineyards. Therefore, alternative agricultural measures, such as organic manure amendments, should be applied in vineyards to adjust soil pH, thereby supporting good grape yield and quality.

4. Discussion

Soil nutrient characteristics in the vineyards of Shanghai suburbs varied greatly depending on the different planting areas, planting age and cultivated grape varieties. The results indicate that planting area and planting age of grapevines have clear impacts on soil nutrient characteristics, but no significant differences were observed among the different cultivated grape varieties. This result indicates that planting area and planting age are the major factors that significantly impact soil nutrient characteristics in the vineyards of Shanghai suburbs. These results are supported by other studies conducted in different countries [25]. Initial soil physical and chemical properties and nutrient levels are usually

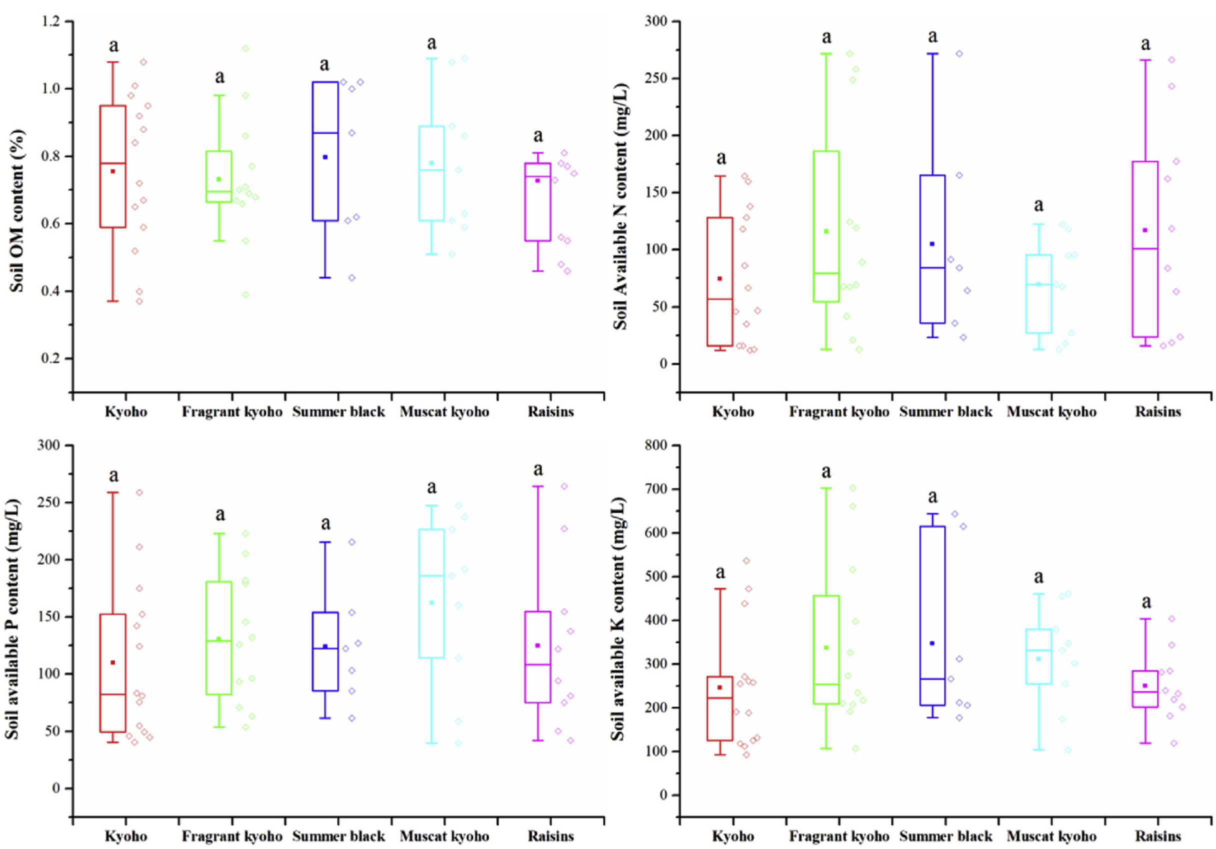

Fig. 5. Soil nutrient characteristics in vineyards with different grape varieties (Different letters in the figure indicate significant differences at a significance level of 0.05).

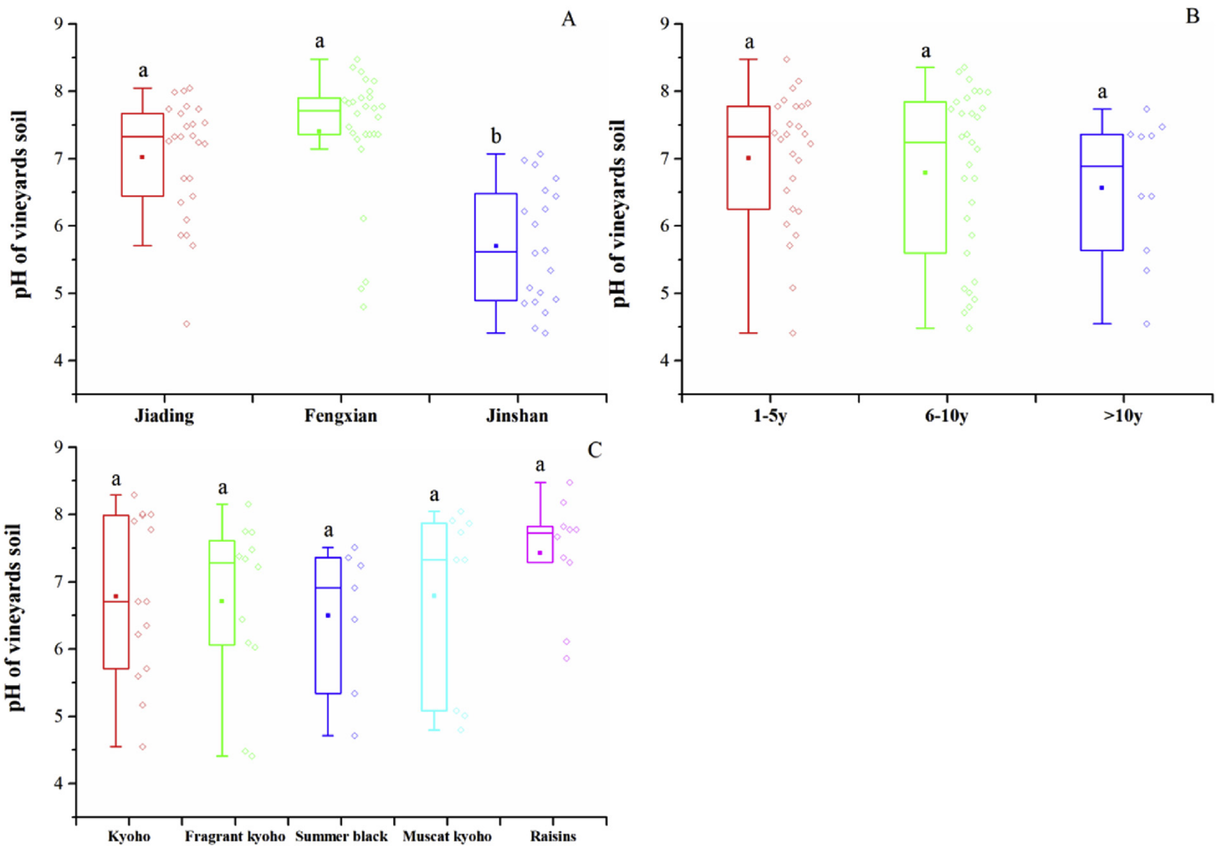

Fig. 6. The impacts of planting area (A), planting age (B) and grape varieties (C) on the soil pH of vineyards (Different letters in the figure indicate significant differences at a significance level of 0.05).

different depending on the local soil conditions in different planting areas. This discrepancy could be aggravated or eliminated after long-term artificial management practices, such as fertilization, irrigation and tillage. Thus, these types of management practices lead to the large differences observed in soil nutrient characteristics in vineyards [26]. The results of this study were consistent with the results of previous studies, which demonstrate that soil nutrient characteristics are strongly related to different planting areas and planting age, as well as the corresponding management practices [27, 28].

According to the grading standard of the ASI analysis method (Table 1), 4 nutrient levels, including a low level, medium level, high level and extra-high level, were defined. The results indicated that the soil OM contents in the 73 selected vineyards were mainly at the medium level. The current soil OM content was barely sufficient for grapevine growth. To provide fertile planting conditions for grapevines, soil OM storage needs to be improved. The soil available N contents in the selected vineyards were mainly high or extra high, while the soil available P and available K content were mostly classified as extra high. Specially, soil nutrients in some vineyards were 3 times higher than the extra-high threshold value. The large accumulation of nutrients in the soil could be attributed to long-term over-fertilization in vineyards. To obtain maximum grape yields and quality, orchardists usually apply much more fertilizer than the grapevines demand. Our investigation showed that the highest application rate of chemical fertilizer in Shanghai vineyards has reached up to 1200 kg/ha. Over-fertilization in Shanghai vineyards has led to excessive waste of agricultural resources. In addition, large accumulations of N and P in the soil risk great losses, leading to eutrophication of bodies of water [29]. Published studies have demonstrated that nutrient loss from vineyards is clearly related to improper fertilization methods [30, 31]. However, there is no uniform fertilization standard for vineyards in Shanghai due to the poor understanding of the soil nutrient status. Our investigation results provide a basic reference for adjusting fertilization schemes in Shanghai vineyards. Moreover, scientific fertilization technology, such as modeling simulation approaches, would be helpful in the optimization of fertilization schemes for specific crops [19, 32, 33].

The traditional fertilization methods in the vineyards of Shanghai suburbs usually involve basal fertilization and two topdressings. Basal fertilization is applied with organic fertilizer and P fertilizer in the winter after the last fruit picking. The first topdressing is applied with a compound fertilizer and urea during the fruit-set period, while compound fertilizer and K fertilizer are applied during veraison in the second topdressing. Considering economic and environmental benefits, traditional fertilization methods in the vineyards of Shanghai suburbs should be adjusted based on current soil nutrient levels. First, the total amount of fertilizer applied should be reduced, especially the amount of chemical fertilizer during the topdressings. Second, the application of P fertilizer could be eliminated over a short period of time. The available P released from soil and organic fertilizer was sufficient to meet grapevine demand. The removal of P fertilizer would substantially contribute to the control of agricultural nonpoint source pollution, given that P is the primary element leading to eutrophication [34, 35]. Finally, the amount of K fertilizer applied could be slightly reduced. K fertilizer application during veraison is a crucial practice for enhancing the flavor and sweetness of grapes [36]. A suitable amount of K fertilizer combined with the available K released from decomposing organic fertilizer guarantees improvements in grape quality. In addition, more organic fertilizer should be applied to vineyard soil, which would improve soil OM storage and macronutrient content as well as micronutrient supply. Enhancing organic fertilizer application is another alternative method to solve soil acidification issues in vineyards along with the planting years [37, 38]. Furthermore, the organic fertilizer used in Shanghai suburbs was mostly provided for free by the local government, which could save substantial economic resources for orchardists in grape production. The proper utilization of organic fertilizer in the vineyards of Shanghai suburbs could improve both economic and environmental benefits.

5. Conclusion

According to this study on 73 selected vineyards in Shanghai suburbs, the soil nutrient characteristics were highly variable across different planting areas, planting ages and cultivated grape varieties. The results indicate that planting area and planting age are the main factors affecting soil nutrient characteristics, while the cultivated grape varieties showed no significant impacts on soil nutrient characteristics. The soil pH in the selected vineyards was only sensitive to planting area and showed no direct relationship with planting age or grape variety. However, a slight decline in the soil pH along with grape planting age was observed. According to the ASI nutrients grading standard, the soil available nutrient contents in Shanghai vineyards were mainly at high or extra-high levels, which means there were still great risks of nutrient loss. Therefore, the current fertilization method in Shanghai vineyards should be adjusted based on our results. More organic fertilizer should be applied in vineyards, while the total amount of fertilizer should be greatly reduced. A scientific fertilization method is important for the sustainable development of grape production in Shanghai as well as for protection of the agricultural environment.

Declarations

Author contribution statement

Zheng Zhao: Analyzed and interpreted the data; Wrote the paper.
Changbin Chu: Performed the experiments.
Deping Zhou: Contributed reagents, materials, analysis tools or data.
Zhimin Sha: Analyzed and interpreted the data.
Shuhang Wu: Conceived and designed the experiments.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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