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Analysis of Nutrient Input and Soil Nutrient Profit and Loss of Pear Orchards in Beijing

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Abstract. **To understand the soil nutrient status of pear orchards in Beijing, we investigated their fertilization situation, including the fertilizer type, amount, and period. Furthermore, soil samples were collected at a depth of 0 to 40 cm to determine the contents of soil nitrogen, phosphorus, and potassium. The status of nutrient profits and losses was analyzed. The results showed that 50% of the pear orchards received organic fertilizer as a single nutrient source, and 35.7% of the pear orchards received a combined application of organic fertilizer and chemical fertilizer. Most pear orchards received organic fertilizer in autumn, but the application of chemical fertilizer occurred mainly before germination and during fruit expansion. The average nutrient input to the investigated pear orchards was 569.6 kg/ha for N, 855.0 kg/ha for P_2O_5, and 448.1 kg/ha for K_2O, and the corresponding proportion of organic fertilizer was 76.9%, 88.0%, and 85.8%, respectively. However, the pear orchards had surpluses of nitrogen, phosphorus, and potassium, with average surplus amounts as high as 445.5, 794.3, and 321.4 kg/ha, respectively. Among all pear orchards surveyed, 93.33% faced environmental risks and 37.04% faced leaching risks. The average content of soil phosphorus was 2.23 times its critical value, and 64.29% of the studied pear orchards exceeded the critical value. Most pear orchards had surplus potassium, with 26.92% exceeding 500 kg/ha. This study provides a basis for soil improvement, high-quality production of fruits, and efficient utilization of pear orchards in Beijing.**

Soil is the basis of crop growth, yield, and quality formation. A sufficient soil nutrient supply guarantees the high quality, safety, and yield of crops and the sustainable development of the agricultural industry (Janssen and de Willigen, 2006). Fruit trees are perennial woody crops, mostly distributed in hilly, mountainous areas and on river beaches in China, where the soil organic matter content is low and the nutrient supply capacity is generally insufficient. To ensure that the soil can continuously provide the necessary nutrients for the growth of fruit trees, fertilization has become the main approach for supplementing soil nutrients and increasing the yield of fruit trees (Slavkovic et al., 2016). In addition, most fruit tree species have the following characteristics: high loads, low root density, low nutrient utilization, and high energy consumption. Therefore, it is necessary to maintain a high root zone nutrient supply to ensure good tree growth and high fruit yields and quality (Ge et al., 2018).

The benefit of fruit tree planting is directly related to yield, but it is difficult to popularize scientific and reasonable fertilizer application technology under the current small-scale fruit tree planting mode that farmers primarily implement in China. Inappropriate fertilizer application by farmers is common in fruit production, leading to soil nutrient deficiency or surplus, as well as high environmental risks (Imtiaz et al., 2016; Ji et al., 2014; Liu et al., 2016; Wang et al., 2020). Lu et al. (2008) showed that there was a significant positive correlation between nitrogen application and nutrient surplus in orchards in Hebei Province, and excessive nitrogen application was the main reason for the high nitrogen surplus. Zhu et al. (2017) found that 97.82% of apple orchards in Shandong Province had phosphorus surpluses due to the inappropriate application of phosphorus nutrients. Bai et al. (2011) found that most peach orchards in Beijing also had a phosphorus surplus, and a considerable proportion of peach orchards had a phosphorus deficit. The investigation by Zhao et al. (2017) also showed that grape soil nutrients in Shanghai also posed great environmental risks.

Pear is the third most cultivated fruit tree in China after apple and citrus. With the adjustment of the agricultural industrial structure, pear garden areas have been expanding and become an important industry in some rural areas. Intensive production of pear orchards has increased with the inputs of nitrogen and phosphate fertilizer increasing such that these inputs are excessive in many areas, and problems such as orchard soil acidification, salinization, groundwater nitrate, organophosphorus, among other concerns, are becoming increasingly serious (Lu et al., 2008). In addition, a low yield per unit area, poor yield quality, many physiological diseases, a low storage tolerance, poor resistance to stress, and other problems directly affect the economic benefits to pear farmers. During their annual growth cycle, pear trees need to consume many nutrients. Therefore, different fertilizers should be added according to the different growth periods and the type of fertilizer needed by pear trees to meet their needs (Mitcham and Elkins, 2007). The results of one study indicate that a main domestic pear fertilization system and the production of fertilization technology are still underdeveloped; growers generally apply fertilizer with their hands, and fertilization is at an inadequate nutrient ratio, which affects the growth of trees, flower bud differentiation, fruit growth, and fruit quality (Tian et al., 2013; Wei et al., 2012); this scenario has become an important obstacle limiting pears in China in terms of industrialization development factors. At present, there is a large difference between the organic fertilizer application amount per unit area and a single plant in pear orchards in China, and the organic fertilizer application amount in most pear orchards is insufficient. The amount of chemical fertilizer varies greatly, and the phenomenon of blind fertilization or experiential fertilization is a serious issue (Dong et al., 2012).

Pear ranks second in terms of fruit production in Beijing. The pear industry has become one of the main economic sources for farmers in Beijing suburbs, and this industry also fully meets the needs of citizens for high-quality fruits and scenic areas. Over the years, earlier than other provinces and cities in China, Beijing pear production took the lead in emphasizing quality and safe production, paying attention to the application of organic fertilizers and achieving good results (S.Z. Liu et al., 2012a, 2012b, 2015). To further understand the soil nutrient profit and loss status of pear orchards in Beijing, we investigated the fertilization and production of pear orchards based on previous research (S.Z. Liu et al., 2012a, 2012b, 2015). Soil samples were collected, measured, and analyzed. This research provides a detailed basis for the high-quality and safe production of pears

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and quality and efficiency improvements in the pear industry in Beijing.

Materials and Methods

Orchard selection. According to the distribution of pear orchards in Beijing and the planting area of pear orchards in each district, 52 pear orchards with a special administrator and agricultural machinery that were 10 to 20 years old and had an area of more than 0.8 ha were selected from July to Oct. 2019 in Daxing, Fangshan, Mentougou, Shunyi, Pinggu, and Miyun districts. The investigation included the yield and fertilization in the past 3 years (including base fertilizer and top dressing type, fertilizer type, period, annual application rates, and method).

Soil sample collection method. At the time of the questionnaire survey, three to five sampling plots were randomly selected in each pear orchard, and three trees were selected in each plot. Soil samples from the 0- to 40-cm soil layer were collected with soil drills 50 cm from the outer edge of each tree crown, in the eastern, western, southern, and northern directions. The soil samples were evenly mixed, and 500 g was retained by the quartering method; these samples were air-dried, ground, and passed through 2-mm and 0.25-mm sieves, respectively.

Sample determination and data analysis. Total soil nitrogen was determined by the Kjeldahl method (Liang et al., 2021). Samples (1 g) were weighed and placed in a digestion tube, and 5 g of catalyst (K_2SO_4: $CuSO_4 \cdot 5H_2O$ = 10:1) and 10 mL of concentrated sulfuric acid were added; each sample was shaken well and digested at 420 °C for ≈1 h in the digestion furnace. After the dissolving solution turned bright green and became clear and transparent, the samples were removed and cooled. Approximately 20 mL of water was added slowly. After the liquid was cooled, it was distilled with alkali on an automatic Kjeldahl nitrogen analyser for 3.5 min. NH_3 in the sample was directly absorbed by boric acid solution through condensation, and the H_3BO_3 absorption solution was titrated with HCl standard solution. The volume of the HCl titration was recorded to calculate the total nitrogen content in the sample. Each sample was tested three times, and five blank samples were tested simultaneously. A total of 20.0, 30.0, 40.0, 50.0, and 60.0 mg of ammonium sulfate standard were weighed and titrated by distillation to obtain the standard curve.

Alkaline hydrolysis nitrogen was determined by the alkaline hydrolysis diffusion method (Lopez-Lopez et al., 2011). Samples (1 g) were weighed and evenly spread in the outer chamber of the plastic diffusion plate. The diffusion plate was gently rotated horizontally to flatten the sample. Then, 3.0 mL of H_3BO_3-indicator solution was added to the inner chamber of the diffusion dish, the seal cover was closed, and 10 mL of 1 mol/L NaOH solution was added to the outer chamber from the small opening of the seal cover with a pipette, immediately closing the seal cover. The diffusion dish was carefully rotated horizontally to mix the solution and soil completely and then incubated at 40 °C for 24 h. The seal cover was opened, and the amount of ammonia absorbed in the H_3BO_3 was titrated with HCl standard solution. When the color changed from blue to purple, the endpoint was reached. At the same time, reagent blanks and standard soil samples were analyzed.

Available phosphorus was determined by sodium bicarbonate extraction-molybdenum antimony anti-colorimetry (Meyer et al., 2020). A 2.5-g sample was weighed and placed in a 150-mL triangular flask, 50 mL of extract was added and sealed, and the flask was shaken at 25 °C for 30 min. It was then filtered with dry filter paper. A 10-mL sample was placed in a 50-mL volumetric flask, and 5 mL H_2O was added, followed by one drop of 2,4-dinitrophenol indicator. H_2SO_4 solution was then added drop by drop until the solution was nearly colorless, and 0.75 mL of ascorbic acid solution was added and mixed. Thirty seconds later, 5 mL of molybdenum antimony storage solution was added, and the water volume was constant at 50 mL. The solution was mixed and placed at room temperature for 30 min, colorimetric analysis was conducted at the 700-nm wavelength. Standard phosphorus solutions with concentrations of 0, 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 mg/L were used to measure the absorbance to construct a standard curve.

Available potassium was determined by the ammonium acetate extraction-flame photometric method (Zharikova and Golodnaya, 2009). A 5-g sample was weighed in a 150 mL triangular flask, 50 Ml of 1.0 mol/L ammonium acetate solution was added, the flask was sealed and shaken for 30 min, the sample was filtered with dry filter paper, and the concentration of potassium was determined by flame photometry. Standard potassium solutions (100 mg/mL) of 0, 1, 2.5, 5, 10, 15, and 20 mL were absorbed. Then, a flame photometer was used to construct a standard curve.

The nutrient input amount of organic fertilizer was calculated on a dry basis and converted to the pure nutrient content according to the nutrient content provided in the "Records of Nutrients in Organic Fertilizer in China" (National Agricultural Technology Extension and Service Center, 1999). The nutrient input amount of chemical fertilizer was converted to the pure nutrient amount according to the nutrient content stated on the fertilizer packaging bag.

Profit and loss of nitrogen, phosphorus, and potassium nutrients (kg/ha) = nutrient input (kg/ha) − nutrient absorption (kg/ha). Nutrient uptake was estimated according to the methods of Payn et al. (2005) and Ge et al. (2018), and the nutrient uptakes of nitrogen, phosphorus, and potassium per 100 kg of yield were 0.47, 0.23, and 0.48 kg, respectively.

All data were analyzed using SPSS statistics software version 19 (SPSS Inc., Chicago, IL).

Results

Nutrient input in pear orchards

Nutrient input structure. As shown in Fig. 1, there were four types of fertilization: organic fertilizer, chemical fertilizer, organic and chemical fertilizer, and no fertilizer. Among the investigated pear orchards, 50% received organic fertilizer as their only source of nutrients, and 35.7% received organic fertilizer in combination with chemical fertilizer, indicating that the application of organic fertilizer is emphasized in pear production in Beijing. In addition, 7.1% of the pear orchards received only chemical fertilizer, whereas 7.1% did not receive any fertilizer during the 2 years of the investigation.

As shown in Fig. 2A, there were also differences in the sources of organic fertilizer; of the investigated pear orchards, 39.3% received commercial organic fertilizer, 35.7% received farmyard manure composed of chicken manure, cow manure, and barnyard manure; 17.9% received only chicken manure; and the other pear orchards received only sheep manure or cow manure. The investigated pear orchards using commercial organic fertilizer as an organic fertilizer source were mainly large-scale planting companies, whereas small-scale farms and growers mostly used farmyard manure, sheep manure, and cow manure as organic fertilizer sources. In addition, most commercial organic fertilizers and farmyard manure consisted of chicken manure. The types of chemical fertilizers were relatively uniform (Fig. 2B); of the investigated pear orchards, 52.4% received compound fertilizers; 23.8% and 9.5% received urea and ammonium

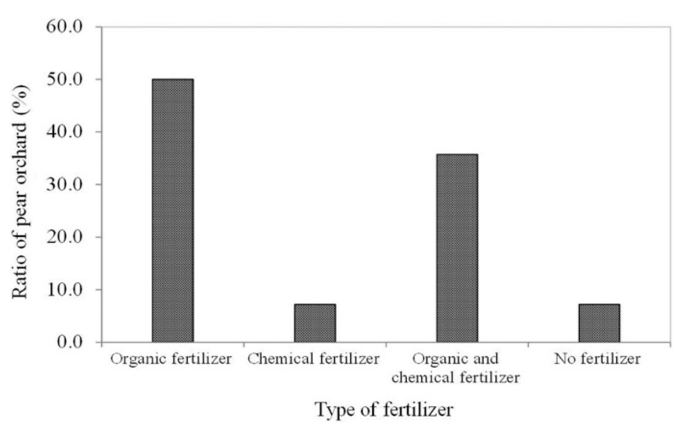

Fig. 1. Ratio of pear orchard of applying different type of fertilizer.

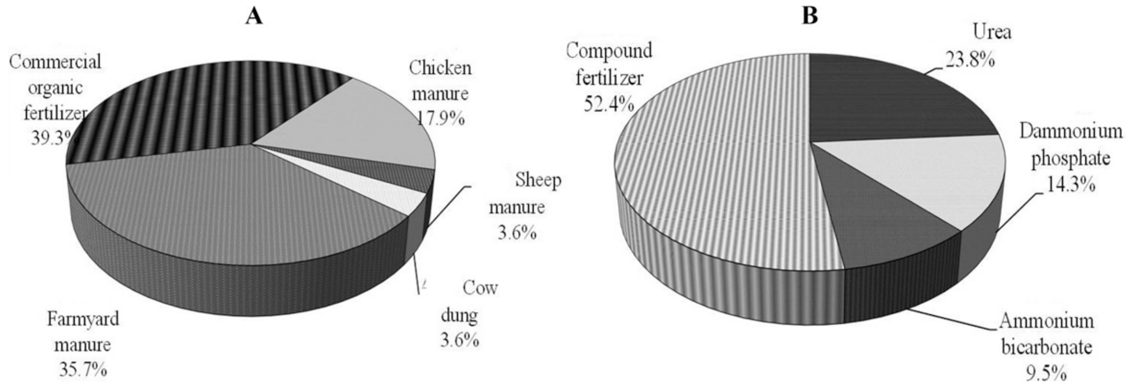

Fig. 2. The application structure of organic fertilizer (**A**) and chemical fertilizer (**B**) in pear orchard.

bicarbonate as nitrogen sources, respectively; and 14.3% received diammonium phosphate.

Nutrient input period. Among the pear orchards that received organic fertilizer (Table 1), 60.7% received fertilizer in autumn, and the others received fertilizer in spring. On the basis of the investigation of chemical fertilizer application, 38.5% of the pear orchards received a one-time fertilization during the germination period in spring that consisted mainly of chemical fertilizers rather than organic fertilizers. In addition, 38.5% of the pear orchards received chemical fertilizers during the fruit expansion period and generally received organic fertilizers in the autumn of the previous year. In addition, topdressing after anthesis, topdressing during germination and expansion, and topdressing after anthesis and expansion accounted for 7.7% of the investigated pear orchards. This result showed that most pear orchards received organic fertilizers in autumn, and the application of chemical fertilizers was mainly before germination and during fruit expansion.

Nutrient inputs. The results showed that the average inputs of nitrogen, phosphorus, and potassium in the pear orchards in Beijing were 569.6, 855.0, and 448.1 kg/ha, respectively, and were mainly in the form of organic fertilizers (Table 2). The average nitrogen input from the organic fertilizers was 438.2 kg/ha, and 76.9% of the total nitrogen input was from organic fertilizers; however, 23.1% was from chemical fertilizers. The average inputs of phosphorus and potassium in the form of organic fertilizers were 752.3 and 384.6 kg/ha, respectively, and 88.0% of the total phosphorus input and 85.8% of the total potassium input were in the form of organic fertilizers. Although the average nutrient input to the investigated orchards was high, there was a difference in the nutrient inputs among the orchards. The nitrogen, phosphorus, and potassium inputs from organic fertilizers were 0 to 1108.8, 0 to 2576.6, and 0 to 876.0 kg/ha, respectively, among the orchards. In addition, the nutrient inputs from the chemical fertilizers were also quite different.

Analysis of the profits and losses of soil nutrients

Analysis of the soil nutrient content. The contents of nitrogen, phosphorus, and potassium in the investigated pear orchards are shown in Table 3. Among the different pear orchards, the average content of alkali-hydrolysable nitrogen in the soil was 135.7 mg/kg, with a range of 37.7 to 508.0 mg/kg; the average content of phosphorus was 111.5 mg/kg, ranging from 5.6 to 419.6 mg/kg, and the average content of potassium was 244.3 mg/kg, ranging from 37.3 to 995.9 mg/kg. The coefficients of variation of the soil nitrogen, phosphorus, and potassium nutrient contents among the different pear orchards were 83.1%, 96.3%, and 84.8%, respectively. This result indicated that the great differences among the soil nutrient contents were due to the large difference in nutrient input among the investigated pear orchards.

Profit and loss analysis of soil nutrients. On the basis of the investigation of the average yield of pear orchards in the past 3 years (Table 4), we estimated that the average absorption of nitrogen, phosphorus, and potassium was 124.1 (70.5 to 193.9 kg/ha), 60.7 (43.1 to 94.9 kg/ha), and 126.7 kg/ha (72.0 to 198.0 kg/ha), respectively (Fig. 3). The profits and losses of nitrogen, phosphorus, and potassium in pear orchards were obtained by subtracting the nutrient absorption from the nutrient input for each investigated pear orchard (Table 5). We adopted 500 kg/ha (N, P_2O_5, and K_2O) and 1000 kg/ha (N, P_2O_5, and K_2O) to reflect the environmental effects of soil nitrogen, phosphorus, and potassium. As shown in Table 4, nitrogen, phosphorus, and potassium in the pear orchards in Beijing were in a surplus state, with average surpluses as high as 445.5, 794.3, and 321.4 kg/ha, respectively. All the investigated pear orchards had surplus nitrogen, of which 62.96% had a surplus of 0 to 500 kg/ha, 33.33% had a surplus of 500 to 1000 kg/ha, and 3.71% had a surplus of more than 1000 kg/ha. The phosphorus in the investigated pear orchards was also in a surplus state; of the orchards, 48.15% had a surplus of 0 to 500 kg/ha, and 51.85% had a surplus of more than 500 kg/ha, of which 29.63% had a surplus of more than 1000 kg/ha. Unlike nitrogen and phosphorus nutrition, 3.85% of the pear orchards had a potassium deficiency, while the remaining 96.15% had a potassium surplus

Table 1. Ratio of pear orchard of applying organic or chemical fertilizer in different stage.

	Organic fertilizer		Chemical fertilizer				
Application date	Previous autumn	Spring	Before bud burst	Post anthesis	Fruit enlargement	Before bud burst and fruit enlargement	Post anthesis and fruit enlargement
Ratio (%)	60.7	39.3	38.5	7.7	38.5	7.7	7.7

Table 2. Application rate of N, P, and K.

	Organic fertilizer			Chemical fertilizer			
Nutrient component	Application rate (kg/ha)	Avg (kg/ha)	Ratio (%)	Application rate (kg/ha)	Avg (kg/ha)	Ratio (%)	Total application rate (kg/ha)
N	0–1108.8	438.2	76.9	0–859.5	131.4	23.1	569.6
P_2O_5	0–2576.6	752.3	88	0–951.0	102.7	12	855
K_2O	0–876.0	384.6	85.8	0–525.0	63.5	14.2	448.1

Table 3. Concentration of nitrogen, phosphorus and potassium in soil.

Nutrient component	Avg (mg/kg)	Range (mg/kg)	Coefficient of variance (%)
N	135.7	37.7–508.0	83.1
P_2O_5	111.5	5.6–419.6	96.3
K_2O	244.3	37.3–995.9	84.8

Table 4. Orchard yield data.

Annual orchard yield (kg/ha)	No. of orchards	Ratio of orchards (%)	Avg annual orchard yield (kg/ha)
≤15,000	3	5.77	10,033
15,000–22,500	12	23.07	19,526
22,500–30,000	16	30.77	24,135
30,000–37,500	12	23.07	33,472
≥37,500	9	17.32	38,563
Total	52	100.00	26,432

of less than 1000 kg/ha, of which 69.23% of the orchards had values ranging between 0 and 500 kg/ha.

Discussion

Over the past 15 years, the soil quality and fertility level of orchards in Beijing have been effectively improved by the application of organic fertilizers and by the implementation of organic fertilizer subsidies in fruit tree production. Our study showed that 50% of the investigated pear orchards received organic fertilizers as a single nutrient source, and 35.7% received combined applications of organic fertilizers and chemical fertilizers. This scenario is obviously different from those of the pear orchards in Hubei Province (Tian et al., 2013), Liaoning Province (Yu et al., 2013), and Shandong Province (Xie et al., 2013), which receive chemical fertilizers as their main nutrient sources, indicating that the fertilization habit of "heavy chemical fertilizer and light organic fertilizer" has changed in the pear production in Beijing. The improvements in pear yield and quality and soil quality were also closely related to factors such as the fertilization period and fertilization quantity. In this study, most of the investigated pear orchards (60.7%) received organic fertilizers in autumn, which is different from the investigation results in central and western Shandong Province (Wei et al., 2012). Organic fertilizer application in autumn has been reported to be beneficial to the growth and development of fruit trees (Wu et al., 2019); therefore, 39.3% of the pear orchards in Beijing need to adjust their application periods for organic fertilizers. In terms of chemical fertilizer management, 38.5% of the investigated pear orchards received a one-time fertilization in spring, and 38.5% received fertilizer only during the fruit expansion period. However, due to the low nutrient utilization of the one-time fertilization in spring and the fruit expansion period of pears being in the rainy season, the absorption of fertilizers by trees was low (Janssen and de Willigen, 2006; Wu et al., 2019). Therefore, a large amount of fertilizer application increased the leaching risk (Claudia et al., 2008). There was a large difference in the nutrient input among the investigated pear orchards. Generally, the proportion of pear orchards with a high inputs was relatively large; for example, the nitrogen input to these orchards was 3 to 4 times that of orchards in developed countries under the same yield conditions (Mitcham and Elkins, 2007). However, pear orchard production in Beijing is lower than that in developed countries (Musacchi et al., 2021). Therefore, it is necessary to apply fertilizers reasonably according to the target yield and the nutrient demand characteristics of the growth in pear orchards in Beijing.

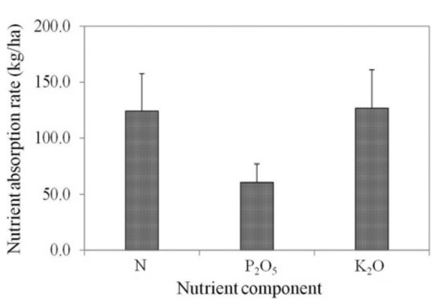

Fig. 3. The nutrient absorption rate of pear orchard in the experiment.

In this study, although there were large differences in the nitrogen inputs among different pear orchards, there were a surpluses of soil nitrogen in all pear orchards. There was a positive correlation between the soil nitrogen surplus and application amount (Lu et al., 2008); therefore, we can infer that excessive application of nitrogen were the main reason for the soil nitrogen surpluses. Previous research showed that when a nitrogen application rate exceeded 80 kg/ha, it has a negative impact on the soil (Xu and Coventry, 2002). The proportion of pear orchards with a nitrogen application rate higher than 80 kg/ha in the Beijing area was 93.33%. A soil nitrogen surplus leads to great environmental risks. Kou et al. (2005) reported that in the fruit tree production system in northern China, the critical amount of nitrate nitrogen surplus in the 90- to 180-cm soil layer compared with that in the 0- to 90-cm soil layer was 500 kg/ha, which indicated that the environmental risks were caused by the nitrogen surplus, and 37.04% of the pear orchards in this study faced risks of nitrate leaching. Excessive phosphorus input will change the transformation balance of phosphorus in the soil and will reduce the retention capacity of soil for phosphorus, thus causing phosphorus leaching (Dou et al., 2009; Macdonald et al., 2011). Previous studies showed that the environmental risk value of phosphorus leaching from calcareous soils in northern China was 50 mg/ha (Liu et al., 2016; Yan et al., 2013). The average content of soil phosphorus in this study was 111.5 mg/ha, which is 2.23 times the critical value, indicating that the environmental risks were caused by a phosphorus surplus, and the pear orchards in Beijing faced phosphorus leaching risks. The proportion of orchards with soil phosphorus content exceeding the critical value was 64.29%, and 29.63% of the pear orchards had a phosphorus surplus greater than 1000 kg/ha. This result was related to the relatively low absorption of phosphorus by pears and the large application amount of organic fertilizers. Our results also showed that the nutrient input amount, especially the application amount of organic fertilizers, in pear orchards with a high phosphorus surplus was generally high, which should be an area of special focus in future phosphorus nutrient management, especially in the application of organic fertilizers. In this study, unlike nitrogen and phosphorus surpluses, 3.85% of the investigated pear orchards were deficient in potassium. However, most of the pear orchards still had a potassium surplus, and 26.92% had a potassium surplus that exceeded 500 kg/ha, similar to the survey results of Lin et al. (2012) for peach orchards in northern China and of F. Liu et al. (2015) for arid apple orchards in the Weibei rainfed highland, which indicated that the environmental risks were caused by potassium surplus, and the pear orchards in Beijing had potassium leaching risks. Pear orchards in Beijing are mostly sandy or hilly orchards, and the site conditions are relatively poor; thus, a higher nutrient surplus will further increase the risk of leaching.

Table 5. Nutrient surplus status of pear orchard in the experiment.

Nutrient component	Orchard proportion (%)				Avg surplus (kg/ha)
	<0	0–500	500–1000	>1000	
N	0	62.96	33.33	3.71	445.5
P_2O_5	0	48.15	22.22	29.63	794.3
K_2O	3.85	69.23	26.92	0	321.4

Conclusions

In conclusion, the application of organic fertilizers for pear production in the Beijing area is generally valued, and nutrient input is generally high. However, nutrient input varied greatly among the different pear orchards. Generally, there are surpluses of nitrogen, phosphorus, and potassium in pear orchards in Beijing, which result in environmental risks and nutrient leaching risks. Therefore, for pear orchards with substantial fertilizer application amounts, especially orchards with high organic fertilizer application amounts, we suggest an appropriate reduction in nutrient input to prevent nutrient surpluses, and the fertilizer application period and amount should be reasonably managed according to the target yield and nutrient demand characteristics of pear growth and development.

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