RESEARCH ARTICLE

Effects of inherent soil fertility on peach orchard yield and quality in different regions of China

Hailong Zhang[1], Dandan Deng[2], Chaoyi Guo[3], Shuang Li[1], Yuheng Wang[1], Jiawei Xie[1], Yuehong Wang[4, *]

[1]College of Resources and Environment, Southwest University, Chongqing, China. [2]Agricultural Technical Service Center of Fengjie County, Chongqing, China. [3]School of Civil Engineering, Chongqing Jiaotong University, Chongqing, China. [4]Agricultural and Rural Committee of Hechuan District, Chongqing, China.

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Quantifying the inherent fertility level of soil nutrients in China's main peach-producing areas is of great significance for scientific fertilization and increasing peach orchard yields. In this study, peach orchards of different varieties in Hebei, Shandong, and Shanxi provinces of North China were selected for comparative analyses with conventional fertilization treatments, no fertilization treatments, and no nitrogen, phosphorus and potassium fertilizer treatments, respectively. The results showed that fertilization in the peach production areas of North China had a relatively low contribution rate to the current year's yield of peach orchards. The average contribution of fertilizer to the current year's yield of 12 orchards in three provinces in North China was 17.7%. The contribution rates from high to low in each province were: Hebei 27.6% > Shanxi 16.8% > Shandong 8.6%. Fertilization had no significant effect on the fruit shape index of mature fruits, but it had a more pronounced effect on single fruit weight with phosphorus fertilizer having a greater impact than nitrogen and potassium fertilizers. Compared with no fertilization treatment, conventional fertilization could significantly reduce titratable acid in fruits, increase Vitamin C (Vc), reduce sugar content, increase the hardness of mature fruits, and improve storage resistance. The results found that the soil base fertility of peach orchards in China was high, which could provide support for nutrient management and weight loss and efficiency in peach orchards.

Keywords: inherent soil fertility; peach orchard; yield; quality; scientific fertilization.

***Corresponding author:** Yuehong Wang, Agricultural and Rural Committee of Hechuan District, Chongqing, China. Email: kkkytw324@163.com.

Introduction

Nitrogen (N), phosphorus (P), and potassium (K) are the core mineral elements necessary for the growth and development of fruit trees. Plants mainly absorb these elements from the soil through their root systems and can also absorb a portion of nutrients through their branches and leaves. Nitrogen is the foundation of life substances. It is not only the main constituent element of plant cell proteins, but also a component of chlorophyll, vitamins, enzymes and coenzyme systems, as well as many important metabolic organic compounds in plants. Research has found that the absorption of nitrate nitrogen by fruit trees is more beneficial for their growth and development [1]. Peach trees are very sensitive to nitrogen. The application of nitrogen fertilizer within a certain range has a positive effect on the growth of peach tree roots and the enhancement of photosynthesis, which can promote vigorous growth of peach trees, thereby increase yield and improve fruit quality [2]. When peach trees are deficient in nitrogen, they will experience a significant decrease in growth rate, weakening of tree vigor, reduced growth of new shoots, and old leaves will first show varying degrees of yellow-green or red spots [3]. Phosphorus is an important structural substance in cells and a crucial mediator for storing, transmitting, and utilizing energy. The phosphorus absorbed by peach tree roots from the soil is mainly in the form of phosphates. The appropriate use of phosphate fertilizer for peach trees can effectively promote their growth, enhance tree vitality, make the trees robust, and improve yield and quality [4]. When phosphorus is deficient, peach trees become dwarfed, have fewer flower buds, bloom late, and suffer from flesh browning in the peaches [5]. Potassium is an activator for many enzyme systems and plays a crucial role in promoting the transport, storage, and synthesis of sugars, starches, and proteins. It also enhances the stress resistance of plants and improves fruit quality, thus having a significant impact on fruit quality. A lack of potassium in peach trees can result in small fruit size, increased susceptibility to fruit cracking, low sugar content, and a decrease in yield and quality. Brown spots first appear on the tips and edges of old leaves [6]. However, excessive application of N, P, and K nutrients can also have a series of adverse effects on fruit yield and quality [7]. An oversupply of nitrogen can lead to excessively vigorous vegetative growth in peach trees, causing the tree to produce many new shoots and resulting in dense canopies [8], which can reduce yield and lead to the occurrence of physiological disorders. Additionally, during fruit development, excessive nitrogen fertilizer can lead to thick and rough skin, poor coloring, and reduced sugar content, thereby affecting fruit quality [9]. Excessive potassium content can reduce the sugar and soluble solid content in fruits, leading to poor storage quality and inferior flavor. Furthermore, it can also affect fruit yield [10].

Currently, in most orchards in China, there are issues such as insufficient application of organic fertilizers, excessive use of nitrogen fertilizers, environmental pollution caused by the heavy use of chemical fertilizers, resource waste, exacerbation of environmental pollution, soil hardening, *etc*. [11]. These factors further constrain the improvement of peach fruit quality in China [12], while the North China production area is the most severe part [13]. Researchers conducted studies on peach orchards in Shandong, China revealed that the application rates of N, P, and K nutrients in these orchards were 842, 290, and 398 kg/ha, respectively [14]. Other studies have reported average surpluses of N and P in Shandong peach orchards to be 984.40 kg/ha and 608.78 kg/ha, respectively [15]. Research findings from Hebei, China indicated that the average nitrogen fertilizer application rate in peach orchards was as high as 438.0 kg/ha with an average surplus reaching 1,611.3 kg/ha [16], significantly exceeding the recommended suitable fertilization rates for peach orchards by domestic experts [17], while the recommended application rates for N, P, and K fertilizers in China are 180 - 320 kg/ha, 60 - 160 kg/ha, and 90 - 320 kg/ha, respectively [18]. The international recommendations for peach orchards are even lower with N, P, and K application rates of 100 - 200 kg/ha, 30 - 100 kg/ha, and 50 - 300 kg/ha, respectively [19, 20]. Compared to the United States, the utilization rate of nitrogen fertilizer in orchards in China is relatively low. Research findings indicated that the N efficiency in American orchards was 220 kg/kg during 2008 - 2009, while in China, it was only 70.3 kg/kg [21]. Low fertilizer utilization rates lead to a significant surplus of nutrients in orchard soils. Through surveys and soil sample collection, the estimated N surpluses in over 800 peach orchards in southern, central, eastern, and northern regions of Hebei, China were 314, 822, and 173 kg/ha, respectively [15]. The measurement results of soil samples from 34 peach orchards in the northwest of Shandong, China indicated that the N surplus in peach orchards in this region was 746 kg/ha [13]. The N surpluses in the Weibei dryland and Guanzhong irrigation area of Shaanxi, China were 1,046 and 673 kg/ha, respectively [22]. The surplus of phosphorus in orchards should not be neglected as well. The P surpluses in orchards in the Jiaodong, central-southern, and southwestern regions of Shandong, China were 616, 342, and 264 kg/ha, respectively [23]. The investigation results of soil P surplus in ten major pomelo-producing townships in Pinghe County, Fujian, China showed a surplus of 671.2 kg/ha [24]. Additionally, the high pH of soils in northern regions limits the utilization rate of phosphorus. By applying bacterial fertilizers and decomposed straw, the soil pH can be reduced, promoting an increase in available P content. With the prolongation of planting years, the surplus nutrients in the soil can lead to changes in soil physical and chemical properties, causing issues such as acidification and secondary salinization [25]. Simultaneously, N can volatilize in gaseous form, contributing to the greenhouse effect, and can also be lost through leaching in the form of NO_3^-, leading to a series of environmental issues such as eutrophication [26]. Although a large amount of surplus P is held by soil colloids [27], once it exceeds the environmental threshold, it can transfer to surrounding water bodies, leading to eutrophication [28]. Therefore, clarifying the comprehensive effects of fertilization on peach yield and quality, as well as its influencing factors, and reducing nutrient surpluses in orchards play an extremely important role in ecological environment protection and sustainable development of orchards [29]. It is also significant for optimizing nutrient management in peach trees, improving fertilizer utilization rate, and protecting the ecological environment [30].

The existing research results show that fertilization has shown good effects on peach fruit yield. Soil pH is one of the key factors affecting soil nitrification and regulating chemical transformation processes among substances in the natural environment [31]. Currently, the amount of fertilizer applied in peach orchards in China is much higher than the recommended nutrient input, and the fertilizer utilization rate is low compared to foreign orchards. The surplus of excessive nutrients in orchard soils poses a series of potential environmental impacts. Therefore, it is of great significance to explore the inherent fertility level of soil nutrients in peach orchards in major production areas in China for scientific fertilization. Soil inherent fertility refers to the soil's production capacity under specific site conditions, soil profiles, and farmland infrastructure levels, after years of fertilization, with no water and fertilizer input in dryland and no nutrient input in paddy fields in the current year [32]. It is commonly estimated using crop yield under no-fertilization conditions [33]. Soil organic matter content is one of the important parameters that characterize soil fertility and has a positive correlation with crop yield. Currently, there is a lack of research on the inherent fertility of peach orchard soils in China. This study selected peach orchards of different varieties in Hebei, Shanxi, and Shandong provinces in the North China production region and set up treatments with conventional fertilization, no fertilization, and treatments with no N, P, or K fertilization, respectively, to understand the relationship between soil inherent fertility and yield, explore the production potential of peach orchards, increase yield, and reduce environmental risks.

Materials and methods

Experimental sites

This research was conducted in Jiuzhou Village, Shenzhou City, Hebei Province, Dongqi Village, Pinglu County, Shanxi Province, and Taoyuan Town, Feicheng City, Shandong Province from October 2017 to July 2018. The peach varieties included Shenzhou Honey Peach, Okubo, and Feicheng Peach, respectively. Jiuzhou Village is located at 115°32' E, 38°01' N with an altitude of 19 meters and belongs to the warm temperate semi-arid monsoon climate zone with significant continental climate characteristics, abundant light resources, synchronous rainfall and heat, an annual average temperature of 13.4°C, a large diurnal temperature difference, and an annual precipitation of 486 mm. Dongqi Village is located

Table 1. Cultivation of peach orchard and soil chemical properties.

Province	Cultivated varieties	Site	Cultivation situation			Soil chemical properties				
			Maturity period	Line space (m × m)	Ages (year)	pH	Organic matter (g/kg)	Alkeline-N (mg/kg)	Olsen-P (mg/kg)	Available K (mg/kg)
Hebei	Honey peach	1	Late	6 × 6	15	7.8	14.9	117	86.9	441
		2	Late	6 × 6	15	8.0	12.3	101	111	301
Shanxi	Okubo	3	Medium	3 × 3	12	8.4	6.7	85	69.9	226
		4	Medium	3 × 3	11	7.6	11.3	108	52.8	221
		5	Medium	5 × 4	8	8.3	8.2	72	69.0	276
		6	Medium	4 × 4	10	8.3	10.9	105	53.4	246
		7	Medium	3 × 3	10	8.2	10.4	91	65.0	247
		8	Medium	3 × 3	11	8.4	7.7	55	60.3	119
		9	Medium	3 × 3	10	8.3	7.6	111	35.6	167
Shandong	Feicheng peach	10	Late	4 × 5	14	6.4	10.4	121	65.1	228
		11	Late	4 × 4	10	7.8	9.2	87	63.2	272
		12	Late	3 × 4	12	8.1	8.0	94	67.4	287

at 111°10' E, 34°53' N with an altitude of 663 meters and belongs to the warm temperate continental climate zone with an annual average temperature of 13.8°C, synchronous rainy and warm seasons, and an annual rainfall of 600 - 700 mm. Taoyuan Town is located at 116°37' E, 36°08' N with an altitude of 82 meters and belongs to the temperate continental semi-humid monsoon climate zone with synchronous light and temperature, synchronous rainfall and heat, an annual average temperature of 26.4°C, and an annual average precipitation of 646.9 mm. The cultivation conditions and soil chemical properties of each experimental peach orchard were shown in Table 1.

Experimental design

The experiment consisted of five treatments that included no fertilization (CK), recommended fertilization (OPT), recommended fertilization without N (OPT-N), optimized fertilization without P (OPT-P), and optimized fertilization without K (OPT-K). Five mature peach trees with uniform growth were selected for each treatment. The experiment was replicated three times using a randomized complete block design across twelve trial locations, all of which were situated in well-established orchards containing mature fruit trees. The nutrient input for each treatment was shown in Table 2. The annual nutrient allocation for mid-season varieties involved applying N fertilizer three times as 20% during the budding stage (mid-to-late March), 30% during the fruit expansion stage (mid-June), and 50% during the nutrient return stage (early October). Phosphorus fertilizer was applied twice as 30% as budding fertilizer (mid-to-late March) and 70% during the nutrient return stage (early November). K fertilizer was applied three times as 20% as budding fertilizer (mid-to-late March), 50% during the fruit expansion stage (mid-June), and 30% during the nutrient return stage (early October). For late-season varieties, N fertilizer was applied four times as 20% during the budding stage (mid-to-late March), 30% during the hard pit stage (mid-June), 20% during the fruit expansion stage (mid-July), and 30% during the nutrient return stage (early November). Phosphorus fertilizer was applied twice as 30% as spring fertilizer (mid-to-late March) and 70% during the nutrient return stage (early November). Potassium fertilizer was applied four times as 10% as budding fertilizer (mid-to-late March), 20% during the hard pit stage (mid-May), 40% during the fruit expansion stage (early July), and the remaining amount during the nutrient return stage.

Sampling and analysis determination

During the fruit harvest period, the fruit yield of each treatment was recorded. Then, one fruit was picked from the upper, middle, and lower parts of the peach tree in the east, south, west, and north directions, respectively. Half of the fruits from each treatment sample were kept fresh for measuring single fruit weight using a

Table 2. Annual nutrient input of different peach orchards.

Site	Treatment	Annual nutrient input (kg/ha)		
		N	P_2O_5	K_2O
1	OPT	315	142	418
2	OPT	315	142	418
3	OPT	372	174	468
4	OPT	372	174	468
5	OPT	351	164	441
6	OPT	372	174	468
7	OPT	302	142	380
8	OPT	337	158	423
9	OPT	337	158	423
10	OPT	407	191	511
11	OPT	301	141	378
12	OPT	278	130	349

scale accurate to one-hundredth of a gram (Shanghai Jing Tian Electronics Instrument Co., Ltd. Shanghai, China), vertical and horizontal diameters using a vernier caliper (Chengdu Chengliang Measuring Tools Co., Ltd. Chengdu, Sichuan, China), fruit hardness using a GY-1 hardness tester (Zhejiang Top Cloud Agriculture Technology Co., Ltd. Hangzhou, Zhejiang, China), soluble sugar content using the 3,5-dinitrosalicylic acid colorimetric method [34], soluble solids content using a handheld refractometer (Shenzhen Measuring Friends Technology Co. Shenzhen, Guangdong, China), titratable acid content using the sodium hydroxide titration method [34], and Vitamin C content using the 2,6-dichlorophenol indophenol titration method [34]. Meanwhile, the other half of the fruits of each treatment sample were dried to a constant weight to determine the fruit moisture coefficient. After digestion with H_2SO_4-H_2O_2, the total N content was measured using a Kjeldahl N analyzer (Hanon Advanced Technology Group Co., Ltd. Jinan, Shandong, China), while the total P content was determined using the ammonium molybdate colorimetric method [35], and the total K content was measured using a flame photometer (Sherwood Scientific Ltd. Cambridge, UK).

Data processing and analysis

The peach orchard yield was calculated as follows.

Yield = Average single fruit weight (g) × Fruit quantity per plant (number/plant) × Planting density (plants/ha) × 10^{-6}

The fruit shape index was calculated as below.

Fruit shape Index = fruit horizontal diameter (mm) / Fruit vertical diameter (mm)

The soil contribution rate to yield was calculated as follows.

Soil contribution rate = Yield in the no-fertilizer area / Yield in the recommended fertilization treatment × 100%

The chemical fertilizer contribution rate to yield was calculated as below.

Chemical fertilizer contribution rate = (Yield in the recommended fertilization treatment - Yield in the no-fertilizer area) / Yield in the recommended fertilization treatment × 100%

The data were processed using IBM SPSS Statistics 20 (IBM, Armonk, New York, USA), and t-test was used to check the difference between

Table 3. Yield of each treatment site (t/ha).

Site	Treatments				
	CK	OPT	OPT-N	OPT-P	OPT-K
1	35.4^{a}	42.3^{a}	31.4^{a}	34.6^{a}	32.0^{a}
2	24.8^{b}	40.8^{a}	33.9^{ab}	35.3^{ab}	32.8^{ab}
3	32.6^{c}	45.0^{a}	43.0^{ab}	41.8^{ab}	38.7^{b}
4	32.3^{a}	36.8^{a}	32.9^{a}	36.7^{a}	34.6^{a}
5	20.5^{b}	26.2^{a}	24.1^{ab}	23.7^{ab}	24.1^{ab}
6	28.0^{a}	29.7^{a}	28.5^{a}	22.7^{b}	22.2^{b}
7	24.3^{b}	29.7^{a}	21.6^{bc}	27.7^{a}	21.1^{c}
8	36.8^{b}	48.0^{a}	39.5^{ab}	35.2^{b}	41.5^{ab}
9	26.5^{ab}	29.2^{a}	27.9^{a}	22.0^{b}	26.6^{ab}
10	32.5^{b}	36.6^{a}	33.3^{ab}	32.1^{b}	37.4^{a}
11	34.9^{ab}	36.3^{a}	32.4^{ab}	35.7^{a}	31.3^{b}
12	31.9^{a}	35.7^{a}	30.7^{a}	33.6^{a}	32.9^{a}
Average	30.0^{b}	36.3^{a}	31.6^{b}	31.8^{b}	31.3^{b}

Note: Values followed by different letters in a row were significant differences among treatments at P <0.05.

groups. The graphs were created using Excel 2010 (Microsoft, Redmond, WA, USA).

Results

The impact of inherent fertility levels on the yield of different peach varieties

The yields from 12 peach orchards in three provinces indicated that, compared to no fertilization and various nutrient deficiencies, conventional fertilization significantly increased peach orchard yield with an average yield of 36.3 t/ha. The yield was the lowest in the no-fertilization treatment at 30.0 t/ha. Compared to no fertilization, the yield increase in each peach orchard under conventional fertilization ranged from 1.4 to 15.9 t/ha with 7 orchards reaching significant levels. The lack of a single nutrient led to varying degrees of yield reduction in peach orchards. The fertilizer without N resulted in an average yield reduction of 4.75 t/ha across 12 orchards with a reduction range of 1.2 to 10.9 t/ha. The fertilizer without P led to an average yield reduction of 4.6 t/ha with a reduction range of 0.1 to 12.8 t/ha. The fertilizer without K led to an average yield reduction of 5.3 t/ha with a range of 2.1 to 10.2 t/ha (Table 3). The contribution rate of fertilizer to the current year's yield in peach orchards was relatively low in the three regions, averaging 17.7%. The contribution rates varied across regions as the order from high to low being Hebei > Shanxi > Shandong at 27.6%, 16.8%, and 8.6% with the ranges of 16.3 - 38.9%, 5.7 - 27.6%, and 3.9 - 11.2%, respectively. The average contribution rates of N, P, and K fertilizers to yield in the three production areas from the highest to the lowest were K fertilizer > N fertilizer > P fertilizer at 15.3%, 14.5%, and 12.2%, respectively. Among them, the contribution rates of N and K fertilizers to the current year's yield in Hebei peach orchards were close and both higher than that of P fertilizer at 21.4% and 21.8%, respectively. The contribution rates of P and K fertilizers to the current year's yield in Shanxi peach orchards were close and both higher than that of N fertilizer at 14.1% and 14.9%, respectively. The contribution rate of N fertilizer in Shandong peach orchards was relatively high at 11.2% (Figure 1).

The impact of inherent fertility on nutrient content in mature fruits

The nutrient content of N, P, and K in mature fruits from various peach orchards showed that there were significant differences in N content among different peach varieties with the order from the highest to the lowest being Honey Peach > Okubo > Feicheng Peach with average N contents of 16.8, 7.15, and 6.43 g/kg,

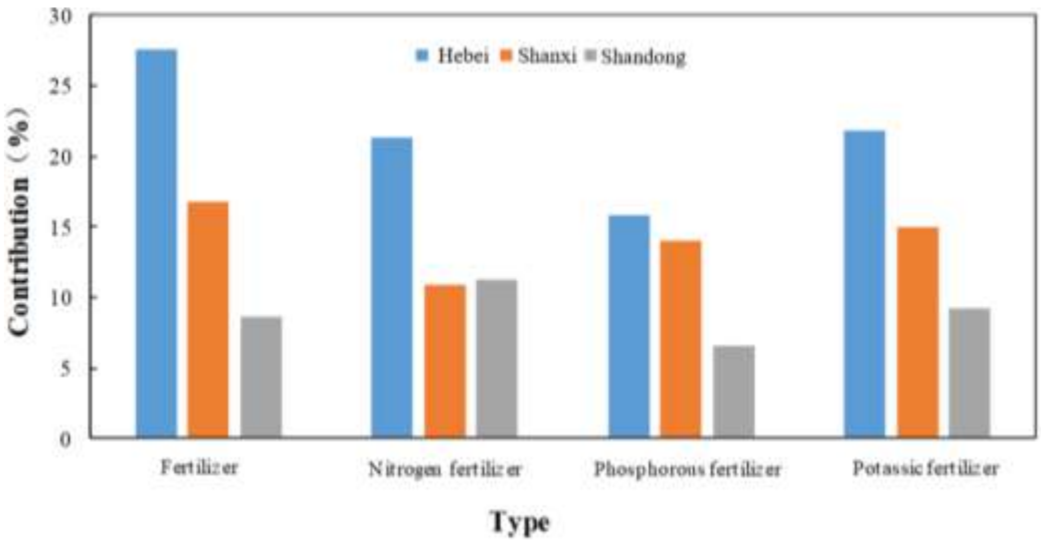

Figure 1. Contribution rate of fertilizer to yield of peach orchards.

respectively. Compared to the control, conventional fertilization resulted in increased N content in fruits from all 7 orchards with an average increase of 8.87% and a range of 0.50% to 23.1%. Compared to conventional fertilization, the lack of N, P, or K fertilization had a relatively small impact on fruit N content with 3, 5, and 10 orchards showing a decrease in fruit N content, respectively. There were no significant differences in P content among different peach varieties during the mature stage with average P contents of 1.69, 1.91, and 1.64 g/kg in Honey Peach, Okubo, and Feicheng Peach, respectively. Compared to no fertilization treatment, conventional fertilization resulted in increased P content in fruits from 7 orchards with an average increase of 34.0%. Compared to conventional fertilization, the lack of N fertilization led to a decrease in fruit P content in 7 orchards with an average reduction of 8.2%. Under no P or K fertilization, half of the orchards showed a decrease in fruit P content. There were significant differences in K content among different peach varieties during the mature stage with the order from the highest to the lowest being Feicheng Peach > Honey Peach > Okubo and the average K contents of 36.7, 26.2, and 14.9 g/kg, respectively. Compared to no fertilization treatment, conventional fertilization resulted in increased K content in fruits from 7 orchards, with an increase range of 2.98% to 36.1%. Compared to conventional fertilization, the lack of K fertilization led to a decrease in fruit K content in 5 orchards with an average reduction of 14.2%, while only Orchard No. 8 showed a significant reduction of 28.3%. Under no N or P fertilization, half of the orchards showed a decrease in fruit K content compared to conventional fertilization. The decrease range was 0.78 to 25.9% under no N fertilization, and 1.61 to 20.0% under no P fertilization (Table 4).

The impact of inherent fertility on fruit morphology and individual fruit weight during the mature stage

There were differences in fruit shape index among different peach varieties during the mature stage. The transverse diameter of Honey Peach was smaller than its longitudinal diameter, resulting in a fruit shape index greater than 1, indicating that mature Honey Peaches were elongated. Conversely, Feicheng Peach and Okubo had a fruit shape index less than 1, indicating a flatter shape. Except for Orchard No. 2 and Orchard No. 3, various fertilization treatments had little impact on the fruit shape index with no significant differences observed. Compared to no fertilization treatment,

Table 4. N, P, K contents (dry weight) in mature period of peach under different treatments.

Sites	Treatments	Total N (g/kg)	Total P (g/kg)	Total K (g/kg)
1	CK	14.3^{a}	1.60^{ab}	24.7^{a}
	OPT	13.2^{a}	1.68^{ab}	28.4^{a}
	OPT-N	15.2^{a}	1.81^{ab}	28.1^{a}
	OPT-P	14.1^{a}	1.39^{b}	22.2^{a}
	OPT-K	17.5^{a}	2.17^{a}	27.9^{a}
2	CK	19.3^{a}	1.5^{a}	20.0^{a}
	OPT	19.4^{a}	1.71^{a}	23.4^{a}
	OPT-N	19.9^{a}	1.64^{a}	25.5^{a}
	OPT-P	17.2^{a}	1.54^{a}	25.7^{a}
	OPT-K	18.3^{a}	1.79^{a}	25.6^{a}
3	CK	8.90^{a}	2.59^{a}	18.6^{a}
	OPT	7.04^{a}	2.07^{a}	18.0^{a}
	OPT-N	8.28^{a}	2.06^{a}	16.9^{ab}
	OPT-P	7.58^{a}	2.52^{a}	15.0^{b}
	OPT-K	7.02^{a}	1.86^{a}	16.8^{ab}
4	CK	6.33^{ab}	1.60^{a}	10.0^{a}
	OPT	7.79^{a}	1.76^{a}	14.0^{a}
	OPT-N	6.24^{ab}	1.60^{a}	10.4^{a}
	OPT-P	6.07^{ab}	1.10^{b}	11.2^{a}
	OPT-K	5.79^{b}	0.98^{b}	10.5^{a}
5	CK	8.99^{a}	0.95^{b}	15.1^{a}
	OPT	6.86^{ab}	2.59^{a}	15.7^{a}
	OPT-N	7.24^{a}	2.57^{a}	14.9^{a}
	OPT-P	6.13^{ab}	2.41^{a}	13.0^{a}
	OPT-K	4.26^{b}	1.94^{ab}	14.0^{a}
6	CK	6.91^{a}	3.16^{a}	14.5^{a}
	OPT	6.99^{a}	1.89^{ab}	14.4^{a}
	OPT-N	7.13^{a}	2.13^{ab}	15.4^{a}
	OPT-P	4.62^{b}	2.10^{ab}	14.1^{a}
	OPT-K	4.24^{b}	1.46^{b}	16.8^{a}
7	CK	7.75^{ab}	1.68^{a}	11.4^{a}
	OPT	5.70^{b}	2.01^{a}	10.3^{a}
	OPT-N	8.53^{a}	2.10^{a}	11.4^{a}
	OPT-P	9.12^{a}	2.19^{a}	13.0^{a}
	OPT-K	7.40^{ab}	2.48^{a}	13.5^{a}
8	CK	7.22^{b}	2.65^{a}	19.0^{ab}
	OPT	7.91^{b}	1.32^{b}	22.6^{a}
	OPT-N	8.34^{ab}	2.10^{a}	18.9^{ab}
	OPT-P	9.00^{a}	1.76^{ab}	19.0^{ab}
	OPT-K	8.43^{ab}	1.81^{ab}	16.3^{b}
9	CK	6.59^{a}	1.81^{a}	15.3^{a}
	OPT	7.05^{a}	1.81^{a}	14.5^{a}
	OPT-N	8.12^{a}	1.25^{b}	15.2^{a}
	OPT-P	6.61^{a}	1.09^{b}	16.3^{a}
	OPT-K	7.96^{a}	1.40^{ab}	14.9^{a}
10	CK	9.03^{a}	2.14^{a}	36.4^{a}
	OPT	8.49^{a}	2.22^{a}	37.6^{a}
	OPT-N	7.31^{ab}	2.00^{a}	35.7^{a}
	OPT-P	6.46^{b}	2.07^{a}	38.9^{a}
	OPT-K	7.54^{ab}	2.17^{a}	38.5^{a}
11	CK	4.50^{a}	1.20^{a}	28.8^{b}
	OPT	5.32^{a}	1.19^{a}	32.0^{ab}
	OPT-N	5.98^{a}	1.51^{a}	35.9^{ab}
	OPT-P	5.91^{a}	1.64^{a}	37.8^{a}
	OPT-K	6.07^{a}	1.42^{a}	38.3^{a}
12	CK	5.53^{ab}	1.12^{b}	36.1^{a}
	OPT	5.67^{ab}	1.29^{b}	33.9^{a}
	OPT-N	4.89^{b}	1.26^{b}	35.3^{a}
	OPT-P	5.91^{ab}	1.42^{b}	37.4^{a}
	OPT-K	7.87^{a}	1.97^{a}	38.0^{a}

Note: Values followed by different letters in a row were significant differences among treatments at $P < 0.05$.

Table 5. Fruit shape and fruit weight of different peach orchards at the ripening stage.

Site	Treatment	Longitudinal diameter (mm)	Transverse diameter(mm)	Shape index	Weight (g)
1	CK	86.4^{b}	80.1^{b}	1.08^{a}	349^{a}
	OPT	97.9^{a}	91.5^{a}	1.07^{a}	353^{a}
	OPT-N	82.2^{b}	74.6^{c}	1.10^{a}	336^{ab}
	OPT-P	83.2^{b}	77.4^{bc}	1.08^{a}	319^{b}
	OPT-K	81.2^{b}	75.0^{c}	1.08^{a}	258^{c}
2	CK	102^{a}	89.9^{a}	1.12^{ab}	303^{c}
	OPT	98.3^{a}	83.8^{a}	1.17^{a}	361^{a}
	OPT-N	101^{a}	87.2^{a}	1.17^{a}	342^{b}
	OPT-P	89.4^{b}	88.9^{a}	1.01^{b}	341^{b}
	OPT-K	94.3^{ab}	85.6^{a}	1.10^{ab}	355^{ab}
3	CK	56.6^{c}	60.3^{b}	0.94^{b}	111^{a}
	OPT	59.8^{bc}	63.7^{b}	0.94^{b}	132^{a}
	OPT-N	59.2^{c}	63.5^{b}	0.93^{b}	124^{a}
	OPT-P	64.2^{a}	68.2^{a}	0.94^{b}	117^{a}
	OPT-K	63.4^{ab}	63.9^{b}	0.99^{a}	122^{a}
4	CK	65.1^{ab}	68.5^{ab}	0.95^{a}	145^{c}
	OPT	67.0^{a}	70.4^{a}	0.80^{a}	173^{a}
	OPT-N	60.7^{c}	64.3^{b}	0.94^{a}	122^{c}
	OPT-P	63.6^{abc}	67.9^{ab}	0.94^{a}	146^{b}
	OPT-K	62.2^{bc}	65.4^{ab}	0.95^{a}	130^{c}
5	CK	62.8^{a}	69.6^{b}	0.88^{a}	133^{d}
	OPT	66.5^{a}	76.8^{a}	0.74^{a}	222^{a}
	OPT-N	64.3^{a}	73.5^{ab}	0.88^{a}	199^{ab}
	OPT-P	65.3^{a}	71.9^{ab}	0.87^{a}	163^{c}
	OPT-K	67.9^{a}	75.0^{ab}	0.91^{a}	175^{bc}
6	CK	63.6^{a}	70.2^{ab}	0.91^{a}	139^{b}
	OPT	65.2^{a}	71.7^{a}	0.91^{a}	187^{a}
	OPT-N	64.2^{a}	71.4^{a}	0.89^{a}	144^{b}
	OPT-P	62.8^{a}	66.0^{bc}	0.96^{a}	130^{b}
	OPT-K	60.8^{a}	65.4^{c}	0.90^{a}	137^{b}
7	CK	59.3^{a}	67.2^{abc}	0.89^{a}	124^{b}
	OPT	63.6^{a}	70.9^{a}	0.90^{a}	165^{a}
	OPT-N	59.4^{a}	65.0^{c}	0.91^{a}	130^{b}
	OPT-P	60.7^{a}	69.6^{ab}	0.88^{a}	131^{b}
	OPT-K	59.4^{a}	65.6^{bc}	0.92^{a}	135^{b}
8	CK	65.2^{a}	76.8^{ab}	0.95^{a}	186^{b}
	OPT	70.9^{a}	80.1^{a}	0.92^{a}	247^{a}
	OPT-N	68.9^{a}	77.4^{ab}	0.92^{a}	192^{ab}
	OPT-P	64.4^{a}	72.7^{b}	0.93^{a}	160^{b}
	OPT-K	70.0^{a}	78.9^{ab}	0.91^{a}	200^{ab}
9	CK	62.6^{a}	65.3^{a}	0.95^{a}	145^{b}
	OPT	60.4^{a}	66.7^{a}	0.92^{a}	158^{a}
	OPT-N	61.7^{a}	66.7^{a}	0.92^{a}	138^{ab}
	OPT-P	59.6^{a}	64.6^{a}	0.92^{a}	133^{b}
	OPT-K	60.6^{a}	66.0^{a}	0.92^{a}	131^{ab}
10	CK	81.3^{b}	87.3^{b}	0.93^{a}	277^{b}
	OPT	90.4^{a}	94.0^{a}	0.96^{a}	457^{a}
	OPT-N	91.5^{a}	94.7^{a}	0.97^{a}	351^{ab}
	OPT-P	93.3^{a}	94.8^{a}	0.99^{a}	392^{b}
	OPT-K	94.6^{a}	95.8^{a}	0.99^{a}	370^{b}
11	CK	80.7^{a}	84.1^{b}	0.96^{a}	263^{b}
	OPT	84.6^{a}	89.1^{a}	0.95^{a}	331^{a}
	OPT-N	84.7^{a}	87.2^{a}	0.97^{a}	331^{a}
	OPT-P	85.4^{a}	87.1^{a}	0.98^{a}	331^{a}
	OPT-K	84.5^{a}	86.9^{a}	0.97^{a}	297^{a}
12	CK	81.1^{a}	85.7^{a}	0.95^{a}	307^{a}
	OPT	82.8^{a}	84.8^{ab}	0.98^{a}	304^{a}
	OPT-N	81.9^{a}	85.9^{a}	0.96^{a}	273^{ab}
	OPT-P	80.1^{a}	82.4^{ab}	0.97^{a}	253^{b}
	OPT-K	79.2^{a}	80.7^{b}	0.98^{a}	258^{b}

Note: Values followed by different letters in a row were significant differences among treatments at $P < 0.05$.

conventional fertilization resulted in increased individual fruit weight in 9 orchards with an increase range of 13.3 to 180 g and an average increase of 65.1 g. Under no N fertilization, 11 orchards showed a decrease in individual fruit weight compared to conventional fertilization with an average reduction of 37.1 g, while 4 of these orchards showed a significant reduction with an average decrease of 37.2 g in individual fruit weight. Under no P fertilization, 11 orchards exhibited a decrease in individual fruit weight during the mature stage compared to conventional fertilization with an average reduction of 43.1 g. 10 of these orchards showed a significant reduction with an average decrease of 45.9 g. In the case of no K fertilization, all 12 orchards showed a trend of decreased individual fruit weight with an average reduction of 42.1 g, and 8 of these orchards exhibited a significant reduction with an average decrease of 51.0 g (Table 5).

The impact of inherent fertility on fruit quality during the mature stage

The results of the main quality indicators of peach fruits during the mature stage across various orchards showed that there were significant differences in titratable acidity among different varieties as the order from the highest to the lowest being Okubo > Honey Peach > Feicheng Peach with average values of 4.78, 3.75, and 1.66 mg/g, respectively. Compared to no fertilization treatment, 8 orchards showed a decrease in titratable acidity under conventional fertilization, but only Orchard No. 1 reached a significant level with a reduction of 25.5%. Compared to conventional fertilization, no N, P, and K fertilization resulted in increased titratable acidity in 6, 4, and 7 orchards, respectively, with increase ranges of 4.72 to 25.1%, 5.56 to 18.4%, and 4.38 to 22.2%. No fertilization and deficiency of N, P, and K fertilization had little impact on soluble solids in the fruit, and there were no significant differences among varieties. Conventional fertilization in 8 orchards increased the soluble solids content. The Vc content in peaches was the highest under conventional fertilization in Orchard No. 2 and Orchard No. 5 with values of 5.93 and 6.32 mg/100 g, respectively, significantly higher than the other treatments, while conventional fertilization had no significant effect in other orchards. In Orchard No. 4, the Vc content was the highest under no P fertilization treatment and significantly higher than that under conventional fertilization. Compared to no fertilization, only Orchard No. 2 showed a significant increase in reducing sugar content under conventional fertilization. However, compared to conventional fertilization, 5, 2, and 4 orchards showed significant reductions in sugar content under no N, P, and K fertilization, respectively. Compared to no fertilization treatment, fruit hardness showed a decreasing trend in two Hebei peach orchards under conventional fertilization, while Shanxi and Shandong peach orchards showed an increasing trend in fruit hardness under conventional fertilization. Compared to conventional fertilization, all 12 orchards showed a decreasing trend in fruit hardness under no N fertilization treatment with only Orchard No. 5 reaching a significant level. Under no P fertilization, hardness decreased but did not reach a significant level. Under no K fertilization, hardness decreased with only Orchard No. 3 and Orchard No. 4 reaching a significant level (Table 6).

Discussion

In fruit tree cultivation, soil fertility management has been proven to be not only the key to increasing yield but also the core of maintaining healthy root systems [36]. The improvement of soil's inherent fertility can reduce crop yield gaps and plays a crucial role in stable and sustainable yield increase [37]. Soil's inherent yield is the most objective basis for measuring soil fertility levels [38]. Currently, research on soil's inherent fertility mainly focuses on annual field crops [39]. The results of this study indicated that the soil fertility level in peach orchards in the north was relatively high. The average contribution rate of soil fertility to peach orchard yield across 12 orchards was 83.5%, which was similar to the

Table 6. Fruit quality of different peach orchards at ripening stage.

Site	Treatment	Titratable acidity (mg/g)	Soluble solids (%)	Vit C (mg/100 g)	Sugar (%)	Sugar-acid ratio	Rigidity (kg/cm^2)
1	CK	4.20^{a}	11.1^{c}	5.19^{a}	12.8^{a}	30.5^{ab}	9.12^{a}
	OPT	3.13^{b}	13.6^{a}	3.87^{ab}	10.9^{bc}	34.8^{a}	8.50^{a}
	OPT-N	3.43^{b}	12.1^{b}	2.64^{bc}	10.4^{c}	30.3^{ab}	8.43^{a}
	OPT-P	3.57^{b}	12.2^{b}	2.63^{bc}	10.3^{c}	28.9^{b}	6.82^{a}
	OPT-K	3.38^{b}	12.4^{b}	1.54^{c}	10.1^{c}	29.9^{ab}	6.38^{a}
2	CK	3.57^{c}	13.1^{a}	3.36^{b}	9.54^{b}	26.7^{ab}	5.08^{a}
	OPT	4.31^{ab}	13.2^{a}	5.93^{a}	11.5^{a}	26.7^{ab}	4.63^{b}
	OPT-N	3.90^{bc}	13.0^{a}	3.33^{b}	11.2^{a}	28.7^{ab}	3.90^{b}
	OPT-P	3.41^{c}	12.0^{b}	2.62^{d}	11.7^{a}	34.3^{a}	3.41^{b}
	OPT-K	4.63^{a}	12.4^{b}	2.93^{c}	9.56^{b}	20.7^{b}	4.31^{b}
3	CK	5.02^{a}	10.6^{a}	8.76^{a}	2.45^{a}	4.88^{a}	10.3^{ab}
	OPT	5.25^{a}	10.4^{a}	7.16^{a}	3.42^{a}	6.51^{a}	12.1^{a}
	OPT-N	4.95^{a}	10.7^{a}	7.05^{a}	3.12^{a}	6.30^{a}	11.5^{ab}
	OPT-P	4.94^{a}	10.6^{a}	6.74^{a}	3.28^{a}	6.64^{a}	11.4^{ab}
	OPT-K	5.48^{a}	10.6^{a}	6.95^{a}	3.34^{a}	6.09^{a}	9.95^{b}
4	CK	5.33^{a}	11.7^{a}	5.66^{b}	3.94^{a}	7.39^{a}	11.5^{ab}
	OPT	4.79^{a}	11.3^{a}	5.63^{b}	3.75^{a}	7.83^{a}	13.1^{a}
	OPT-N	4.56^{a}	11.2^{a}	7.29^{ab}	3.61^{a}	7.92^{a}	9.77^{ab}
	OPT-P	4.72^{a}	11.6^{a}	8.10^{a}	3.59^{a}	7.61^{a}	11.7^{ab}
	OPT-K	4.41^{a}	10.8^{a}	5.84^{ab}	2.35^{a}	5.33^{a}	10.8^{b}
5	CK	5.63^{a}	11.5^{a}	4.47^{b}	2.92^{ab}	5.19^{ab}	9.76^{b}
	OPT	4.56^{a}	11.4^{a}	6.32^{a}	3.22^{a}	7.06^{a}	11.5^{a}
	OPT-N	4.56^{a}	11.2^{a}	6.24^{a}	1.61^{b}	3.53^{b}	10.0^{b}
	OPT-P	3.96^{a}	11.9^{a}	5.75^{ab}	2.96^{ab}	7.47^{a}	11.4^{ab}
	OPT-K	4.87^{a}	11.5^{a}	5.24^{ab}	3.00^{ab}	6.16^{ab}	11.1^{a}
6	CK	4.56^{a}	10.3^{a}	5.19^{a}	2.77^{a}	6.07^{ab}	10.8^{b}
	OPT	4.87^{a}	10.2^{a}	5.20^{a}	2.83^{a}	5.81^{b}	12.6^{ab}
	OPT-N	5.10^{a}	9.23^{a}	4.22^{a}	2.97^{a}	5.82^{b}	10.7^{b}
	OPT-P	4.56^{a}	10.2^{a}	5.73^{a}	2.68^{a}	5.88^{b}	13.2^{a}
	OPT-K	4.65^{a}	9.83^{a}	6.19^{a}	3.96^{a}	8.68^{a}	10.9^{b}
7	CK	5.02^{a}	10.7^{a}	5.54^{a}	3.70^{a}	7.37^{a}	9.38^{b}
	OPT	4.23^{a}	12.9^{a}	8.02^{a}	3.57^{a}	8.44^{a}	12.1^{a}
	OPT-N	5.29^{a}	11.0^{a}	6.87^{a}	3.70^{a}	6.99^{a}	10.8^{ab}
	OPT-P	4.20^{a}	11.3^{a}	8.11^{a}	3.53^{a}	8.40^{a}	9.74^{ab}
	OPT-K	5.17^{a}	11.1^{a}	5.87^{a}	3.50^{a}	6.77^{a}	10.7^{ab}
8	CK	5.33^{a}	9.23^{a}	4.55^{a}	2.72^{a}	5.10^{a}	12.5^{a}
	OPT	4.56^{a}	8.97^{a}	4.29^{a}	2.41^{a}	5.29^{a}	13.4^{a}
	OPT-N	5.17^{a}	9.00^{a}	4.79^{a}	3.17^{a}	6.13^{a}	13.2^{a}
	OPT-P	5.40^{a}	8.67^{a}	4.60^{a}	2.56^{a}	4.74^{a}	12.0^{a}
	OPT-K	4.94^{a}	8.73^{a}	4.68^{a}	2.61^{a}	5.28^{a}	12.9^{a}
9	CK	4.72^{a}	10.4^{a}	6.32^{a}	2.00^{a}	4.24^{b}	11.5^{ab}
	OPT	3.96^{a}	9.87^{a}	6.07^{a}	3.37^{a}	8.51^{a}	11.8^{ab}
	OPT-N	4.56^{a}	10.0^{a}	6.22^{a}	3.18^{a}	6.97^{ab}	9.88^{b}
	OPT-P	4.18^{a}	11.1^{a}	7.37^{a}	3.23^{a}	7.73^{a}	12.5^{a}
	OPT-K	3.96^{a}	9.67^{a}	5.68^{a}	2.52^{a}	6.36^{ab}	11.8^{ab}
10	CK	2.81^{a}	10.0^{a}	13.4^{a}	5.20^{b}	18.5^{b}	12.6^{b}
	OPT	1.85^{ab}	10.3^{a}	13.0^{a}	5.68^{ab}	30.7^{a}	14.8^{a}
	OPT-N	1.49^{b}	10.2^{a}	15.1^{a}	6.11^{ab}	41.0^{a}	13.6^{ab}
	OPT-P	2.11^{ab}	10.7^{a}	13.0^{a}	6.37^{a}	30.2^{a}	12.8^{ab}
	OPT-K	1.41^{b}	10.8^{a}	17.9^{a}	6.08^{ab}	43.1^{a}	12.8^{ab}
11	CK	1.41^{ab}	11.5^{a}	10.2^{a}	8.36^{a}	59.3^{a}	10.6^{a}
	OPT	1.41^{ab}	11.8^{a}	6.68^{ab}	8.48^{a}	60.1^{a}	11.8^{a}
	OPT-N	1.58^{a}	10.1^{a}	6.73^{b}	7.36^{ab}	46.6^{a}	12.3^{a}
	OPT-P	1.23^{b}	10.7^{a}	8.57^{b}	6.55^{b}	53.3^{a}	9.83^{a}
	OPT-K	1.28^{b}	12.5^{a}	8.14^{b}	6.76^{b}	52.8^{a}	9.95^{a}
12	CK	1.85^{ab}	12.5^{a}	6.86^{a}	8.21^{a}	44.4^{a}	9.27^{b}
	OPT	1.58^{a}	12.3^{ab}	6.36^{a}	7.81^{a}	49.4^{a}	11.8^{a}
	OPT-N	1.49^{a}	11.5^{abc}	6.05^{a}	7.68^{a}	51.5^{a}	10.5^{ab}
	OPT-P	1.58^{a}	11.0^{bc}	5.38^{a}	6.4^{b}	40.5^{a}	9.75^{ab}
	OPT-K	1.85^{a}	10.7^{c}	6.17^{a}	6.47^{b}	35.0^{a}	9.53^{ab}

Note: Values followed by different letters in a row were significant differences among treatments at P <0.05.

contribution rate of soil's inherent fertility to rice yield in the Chengdu Plain [40], and significantly higher than the contribution rate of soil in rice fields in Ningxia region, which ranged from 49.8 to 55.6% [41], which might be because the peach orchards in the north were relatively rich in nutrients and mostly composed of loam soil, while the hilly and low-lying areas where rice fields were located in western Sichuan were concentrated areas of water and fertilizer. In contrast, due to the poor water and fertilizer retention capacity of the soil in Ningxia region, there were differences [42]. Furthermore, the results of this study indicated that the contribution rate of fertilization to the current year's yield was relatively low with only 16.5%, which was mainly because peach trees, as perennial woody plants, stored a large amount of nutrients in their perennial roots, stems, and branches, resulting in a low utilization rate of seasonal fertilizers by peach trees [43]. Higher soil inherent fertility leads to a greater long-term effect on crop growth, thus contributing to a higher yield contribution rate, improving economic benefits, and increasing the ratio of output to input [44]. Therefore, exploring the inherent fertility levels of farmland in different regions and recommending fertilization based on target yield methods for different levels, while reasonably controlling fertilizer input in high-fertility peach orchards, can not only compensate for soil nutrient depletion and maintain soil fertility but also hold great significance for ensuring stability and soil sustainability. It is also an effective way to conserve resources and be environmentally friendly.

Peach trees are perennial fruit trees, and their nutrients come not only from absorption by the roots from the soil but also from the stored nutrients in the perennial parts of the tree. Studies showed that, under the condition of fertilization using a fertilization gun, the N utilization rate in the current season was the highest in the phloem of perennial branches of peach trees, reaching 4.23% followed by the phloem of coarse roots at 2.97%, and the flesh and pit at 1.63%. However, under the conventional fertilization method of radial broadcasting, the N utilization rate in the flesh and pit in the current season was only 0.38% [45]. The results of this study indicated that, compared to no fertilization, conventional fertilization increased the N content in mature fruits. Under the condition of no N fertilizer application, the N content in the fruit’s decreased, while the lack of P and K elements had no effect on the N content in the fruits. The application of P fertilizer in peach orchard soil had no significant effect on the P content in the fruits, which might be because peach trees had a relatively low demand for P nutrition, and P fertilizer was easily fixed by the soil, resulting in a low utilization rate in the current season, thus the effect was not significant [46]. The effect of not applying K fertilizer on the K content in fruits was relatively small. Compared to conventional fertilization, less than half of the peach orchard fruits showed a decreasing trend in K content, and only one orchard reached a significant level. This was different from previous research results [47], and might be due to sufficient soil K supply, where the contribution rate of exogenous K fertilizer to the K content in fruits was relatively low.

Fundamentally, the quality and yield traits of peach fruits mainly depend on the difference in varieties [48]. The results of this study indicated that the fruit shape of Shenzhou honey peach tended to be elongated, while the fruit shapes of Okubo and Feicheng peach tended to be flat. Fertilization had a significant impact on the single fruit weight during the mature stage, which was similar to the findings of other studies on single fruit weight in peach orchards [49]. Compared to conventional fertilization, the impact of fertilizer without P on single fruit weight was greater than that of fertilizer without N. The results might be due to the stimulation of peach tree root elongation to obtain more nutrients after applying P fertilizer, which increased the vitality of the peach tree and led to an increase in single fruit weight [50]. A complete and reasonable ratio of N, P, and K nutrients could improve fruit quality and enhance taste. Compared to no fertilization treatment, conventional fertilization could significantly reduce titratable acidity in fruits, increase Vc, reduce sugar content, and, in the case of Okubo and Feicheng peach varieties, increase fruit hardness, thereby improving fruit storage resistance. The lack of N, P, or K nutrients reduced fruit quality to varying degrees. The results showed that the reducing sugar content and fruit hardness were significantly decreased. Therefore, in production practice, attention should be paid to the sufficient supply of N, P, and K nutrients to fruit trees, avoiding nutrient imbalances caused by excessive application of a particular fertilizer.

Fertilization contributed an average of 17.7% to the annual yield of peach orchards in North China with the regional differences of Hebei > Shanxi > Shandong, the element differences of potassium fertilizer > nitrogen fertilizer > phosphorus fertilizer. Fertilization significantly improved fruit firmness, reducing sugar content, and vitamin C content, while reducing titratable acidity and improving storage quality. Phosphorus fertilizer had the most significant effect on individual fruit weight. The absence of any fertilizer reduced overall fruit quality. This study provided support for nutrient management and fertilizer reduction for efficiency in peach orchards in the North China region.

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References

1. Koyama LA, Kielland K. 2022. Seasonal changes in nitrate assimilation of boreal woody species: Importance of the leaf-expansion period. Trees. 36(3):941-951.
2. Ioannis SM, Georgia T, Athanassios M. 2018. Environmental and orchard bases of peach fruit quality. Scientia Horticulturae. 235:307-322.
3. Wu LY. Analysis of nutrient contents in leaves and soil of yellows peach orchard in Sanyuan and Jingyang. Shananxi. Northwest A & F University. 2018.
4. Zhao JY, Pan B, Qin ZY, Tang J, Wang HL, Huang XR, *et al*. 2022. Effects of long-term application of bag-controlled slow-release fertilizer on the form and availability of phosphorus in red soil of southern China. Meteorol Environ Res. 13(5):98-102.
5. Guo Z, Liu HJ, Zhou W, Chen LG, Zheng JC. 2016. Characteristics of phosphorus losses due to surface runoff in a peach orchard and the effects of inter-planting white clover (*Trifolium repens* L.) on fruit yield and quality. Fresenius Environ Bull. 25(12):5516-5527.
6. Roeva T, Leonicheva E, Leonteva L, Stolyarov M. 2022. Potassium dynamics in orchard soil and potassium status of sour cherry trees affected by soil nutritional conditions. J Cent Eur Agric. 23(1):103-113.
7. Zhang Y, Guo JY, Ren F, Jiang Q, Zhou X, Zhao JB, *et al*. 2022. Integrated physiological, transcriptomic, and metabolomic analyses of the response of peach to nitrogen levels during different growth stages. Int J Mol Sci. 23(18):10876.
8. Casamali B, van Iersel MW, Chavez DJ. 2021. Nitrogen partitioning in young "Julyprince" peach trees grown with different irrigation and fertilization practices in the southeastern united states. Agronomy. 11(2):350.
9. Cai TY, You LC, Yang X, Hao SL, Shao Q, Wang HY, *et al*. 2023. Fertilization of peach for yield and quality, and optimization of nitrogen application rates in China: A meta-analysis. Scientia Horticulturae. 313:111917.
10. Muneer MA, Afridi MS, Saddique MA, Chen XH, Zaib-Un-Nisa, Yan XJ, *et al*. 2024. Nutrient stress signals: Elucidating morphological, physiological, and molecular responses of fruit trees to macronutrients deficiency and their management strategies. Scientia Horticulturae. 329:112985.
11. Galanti R, Cho A, Ahmad A, Radovich T. 2019. Soil amendments and soil profiling impact on macadamia growth and yield performance. Hortscience. 54:519-527.
12. Li SL, Wang S, Zeng XL, Cui YX, Yu WT, Ma Q. 2022. How the development of barren land into orchards affects soil ecosystem in Tibet, China. Pedosphere. 32(4):616-628.
13. Li TT, Zhang BB, Du AQ, Yang SK, Huang KX, Peng FT, *et al*. 2023. Dynamic monitoring of nutrition inputs and fertility evaluation during a decade in the main peach-producing areas of Shandong province, China. Plants. 12(8):1725.
14. Kou CL, Ju XT, Zhang FS. 2005. Nitrogen balance and its effects on nitrate-N concentration of groundwater in three intensive cropping systems of north China. Chin J Appl Ecol. 2005(04):660-667.
15. Li GM. Evaluation of soil nutrient status in peach orchards of Shandong and studies on peach fertilizer demand characteristics. Shandong Agricultural University. 2011.
16. Lu SC, Chen Q, Zhang FS, Jia WZ. 2008. Analysis of nitrogen input and soil nitrogen load in orchards of Hebei province. J Plant Nutr Fertil. 2008(05):858-865.
17. An MY, Xie Y, Han YG, Zhou JX, Guo HL, Qu ZX. 2023. Nitrogen source and fate of typical orchard with gentle slope in semi-arid areas. Int J Agric Biol Eng. 16(6):167-175.

18. Zhang FS, Chen XP, Chen Q. Guidelines for fertilization of major crops in China. Edited by Zhang FS. Beijing: China Agriculture Press. 2009.
19. Hiraoka K, Umemiya Y. 2000. Estimation of balance of nitrogen, phosphorus and potassium in relation to chemical fertilizer application in *Japanese orchard* fields. Jpn Agric Res Q. 34(2):87-92.
20. Tagliavini M, Marangoni B. 2002. Major nutritional issues in deciduous fruits orchards of northern Italy. Hort Thchnology. 12(1):26-31.
21. Wu L. Nitrogen fertilizer demand and greenhouse gas mitigation potential under nitrogen limiting conditions for Chinese agriculture production. China Agricultural University. 2014.
22. Zhao ZP. 2014. Analysis of nitrogen inputs and soil nutrient loading in different croplands in the upper Hangjiang River. Acta Scientiae Circumstantiae. 34(11):2861-2868.
23. Zhu ZL, Xia Y, Liu JJ, Ge SF, Jiang YM. 2017. Analysis of soil phosphorus input and phosphorus environment load risk in major apple production regions of Shandong Province. Acta Horticulturae Sinica. 2017(1):97-105.
24. Zhang SQ. Study on the environmental risk of nitrogen and phosphorus and its control measures in the concentrated planting region of pomelo. Fujian Agriculture and Forestry University. 2019.
25. Lu PN, Liu JH, Li LJ, Bai JH, Zhao BP, Mi JZ, *et al*. 2023. Effects of organic materials on soil properties and oat yields in a saline-alkaline environment in northern China. Soil and Fertilizer Sciences in China. 2023(02):73-86.
26. Abid AA, Yu SH, Zou X, Batool I, Castellano-Hinojosa A, Wang JW, *et al*. 2024. Unraveling nitrogen loss in paddy soils: A study of anaerobic nitrogen transformation in response to various irrigation practice. Environ Res. 252(3):118693.
27. Appelhans SC, Novelli LE, Melchiori RJM, Barbagelata PA. 2024. Does the fertilization strategy affect the long-term legacy phosphorus dynamic? Eur J Agron. 153:127035.
28. Rocabruna PC, Domene X, Matteazzi A, Figl U, Fundneider A, Fernández-Martínez M, *et al*. 2024. Effect of organic fertilization on soil phosphatase activity, phosphorus availability and forage yield in mountain permanent meadows. Agric Ecosyst Environ. 368:109006.
29. Li ZY, Chen YL, Meng FL, Shao Q, Heal MR, Ren FL, *et al*. 2022. Integrating life cycle assessment and a farmer survey of management practices to study environmental impacts of peach production in Beijing, China. Environ Sci Pollut Res. 29(38):57190-57203.
30. Chen YT, Hu SY, Guo ZG, Cui TH, Zhang LP, Lu CR, *et al*. 2021. Effect of balanced nutrient fertilizer: A case study in Pinggu District, Beijing, China. Sci Total Environ. 754:142069.
31. Ai C, Liang GQ, Sun JW, Wang XB, He P, Zhou W. 2013. Different roles of rhizosphere effect and long-term fertilization in the activity and community structure of ammonia oxidizers in a calcareous fluvo-aquic soil. Soil Biol Biochem. 57(3):30-42.
32. Sujatha M, Jaidhar CD. 2024. Machine learning-based approaches to enhance the soil fertility—A review. Expert Syst Appl. 240:122557.
33. Tirol-padre A, Ladha JK, Regmi AP, Bhandari AL, Inubushi K. 2007. Organic amendments affect soil parameters in long-term rice-wheat experiments. Soil Sci Soc Am J. 71(2):442-452.
34. Bao SD: Soil agricultural chemical analysis. 3rd Edition. Edited by Bao SD. Beijing: China Agricultural Press; 2000:263-312.
35. Pestana M, Beja P, Correia PJ, De Varennes A, Faria EA. 2005. Relationships between nutrient composition of flowers and fruit quality in orange trees grown in calcareous soil. Tree Physiol. 25:761–767.
36. Gluszek S, Sas-Paszt L, Derkowska E, Sumorok B, Sitarek M. 2021. Influence of various biofertilizers on root growth dynamics in sweet cherry (*Prunus avium* L.) cv. 'Vanda'. Hort Sci. 48(3):105-116.
37. Huang XC, Li Y, Bai YQ, Zhang YR, Liu YL, Zhang WA, *et al*. 2018. Evolution of yellow soil fertility under long-term fertilization and response of crop yield. J Plant Nutr Fertil. 2018(06):1484-1491.
38. Li HY, Zhang YH, Sun YG, Liu PZ, Zhang Q, Wang XL, *et al*. 2023. Long-term effects of optimized fertilization, tillage and crop rotation on soil fertility, crop yield and economic profit on the Loess Plateau. Eur J Agron. 143:126731.
39. David B, Victor O, Emmanuel D. 2024. Impact of integrated soil fertility management on maize yield, yield gap and income in northern Ghana. Sustainable Futures. 7:100185.
40. Zheng SH, Chen HL, Zhu MQ, Sheng XS, Chen SH, Zhang CE, *et al*. 2018. Responses of rice yields to inherent soil fertility and fertilization in Western Sichuan Plain. J China Agric Univ. 23(12):13-20.
41. Tian SC, Ma JJ. 2015. Effect of soil fertility on yield of rice and establishment of fertilization index system. Chin Agric Sci Bull. 31(27):1-4.
42. Li JM, Wang JF, Qu JT, Li QJ. 2011. Investigation of soil fertility and fertilization status of apple orchard in Luochuan, Shaanxi. Northwest Horticulture. 2011(5):45-47.
43. Zhang SS, Peng FT, Qi YJ, Li Y. 2015. Effects of different nutrition supply on growth, nitrogen uptake and partitioning of pot cultured nectarine. J Plant Nutr Fertil. 21(01):156-163.
44. Cesarano G, De Filippis F, La Storia A, Scala F, Bonanomi G. 2017. Organic amendment type and application frequency affect crop yields, soil fertility and microbiome composition. Appl Soil Ecol. 120:254-264.
45. Wu XB. Study of fertilization with fertilizer applicator on nitrogen absorption, distribution and growing characteristics of peach tree. Shandong Agricultural University. 2011.
46. Wang JY. Changes of soil nutrients and phosphorus adsorption characteristics under peach cultivation in greenhouse in Shanxi Province Shanyin County. Shanxi Normal University. 2017.
47. Barreto CF, Antunes LEC, Navroski R, Benati JA, Ferreira LV, Nava G. 2022. Potassium fertilization and its impact on production and mineral composition of peach trees. Revista Brasileira De Fruticultura. 44(4):208.
48. Manganairs GA, Minas I, Cirilli M, Torres R, Bassi D, Costa G. 2022. Peach for the future: A specialty crop revisited. Scientia Horticulturae. 305:111390.
49. Zhang GL. 2024. Effects of different fertilizers on soil properties and growth and yield of peach orchards. Special Economic Animals and Plants. 27(01):40-43.

50. Fu XF, Zhu Y, Huang J, Wang LH. 2019. Effects of N, P and K fertilization treatments on the growth and nutrient contents in leaves of *Mangifera persiciformis* C. Seedlings. J Sichuan Agric Univ. 37(5):629-635.