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DOI: 10.2478/eces-2022-0031 ECOL CHEM ENG S. 2022;29(3):419-430

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ANALYSIS OF THE INFLUENCE OF SOIL FERTILITY FACTORS ON HIGH-YIELDING CULTIVATION TECHNIQUES

Abstract: Soil is the material base of soil fertility. It can not only fix the root system but also provide nutrients, water, and other necessary conditions for crops to promote growth of crops. As a characteristic agricultural product in the Yanbian area, the production of 'Pingguoli' is related to the development of the agricultural economy in the Yanbian area. To solve the agricultural problems caused by excessive fertilisation in 'Pingguoli' orchards in the Yanbian area and to study the correlation between rare elements and soil properties. Based on the collection of regional natural economic background and soil data in the study area, four treatments were set up: The soil and 'Pingguoli' samples were collected, and the total amount of rare earth elements in the soil samples and the related indexes of 'Pingguoli' fruit were detected. Soil is the material basis of soil fertility, and soil management determines crop growth. CF1 treatment could increase 'Pingguoli' yield and significantly improve fruit quality. The rate of fruit softening and bad fruit decreased significantly after storage. Reduction of fertilisation can improve quality and save cost, among which CF1 has the best effect and can obtain more benefits when applied in production. Implications: Through experiments, agricultural workers can be more deeply aware of the importance of soil to crops; reducing fertilisation can lead to better crop yield and quality while achieving greater benefits, and consumers can get healthier food.

Keywords: Yanbian area, 'Pingguoli' cultivation, soil factors, reducing fertilisation

Introduction

'Pingguoli' (*Pyrus Bretschneider* Read. 'Pingguoli') is shaped like an apple, similar to an oblate cone. Its fruit is large and small, the pulp is white and crisp, the juice is sweet and sour, and the peel is red. It belongs to the white pear system and is one of China's excellent pears varieties [1]. Introduced in North Korea in 1921, it has a history of 100 years. 'Pingguoli' pulp contains Ca, P, Fe, vitamins B1, B2, C, and other nutrients needed by the human body [2]. 'Pingguoli' have a wide range of plantings and strong cold resistance. 'Pingguoli' tree likes the cold and humid climate, they can be safely overwintered within -32℃ and are extremely resistant to storage. It is suitable for planting on hilly slopes with an altitude of about 300 meters and a large temperature difference between day and night [3]. The cellar storage period can reach 8-9 months, and the cold storage can be stored until the next year's fruit market period. 'Pingguoli' are an important part of China's pear

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resources and can provide good genetic resources for new varieties. Among the existing new pear varieties in China, there are more than 60 varieties with 'Pingguoli' blood, most of which are obtained from hybridisation. The important value of Yanbian 'Pingguoli' in breeding. In 2009, Yanbian 'Pingguoli' became one of the "China Geographical Indication" products [4], and its cultivation system has been included in the "National Important Agricultural Cultural Heritage". The planting area of 'Pingguoli' in Yanbian Korean Autonomous Prefecture has reached more than 55 km^2 (5500 ha), with an annual output of nearly 100,000 tonnes (tonne = 10^6 g = Mg) of 'Pingguoli'. The annual output value of 'Pingguoli' exceeds 220 million yuan. The production of 'Pingguoli' has quickly become a pillar industry in the development of Yanbian, increasing farmers' income, mobilising farmers' enthusiasm, greatly promoting the economic and cultural development of Yanbian Korean Autonomous Prefecture, and playing an important role in promoting the construction of new rural areas [5].

Rare earth elements mixed with soil can show similar effects as micro-fertilisers, which can increase crop yield, accelerate crop maturity and improve the quality of certain crops. With the in-depth development of instrument detection technology and soil chemical environment background, the research on rare earth elements in soil has received more and more attention, and relevant research results have been released one after another [6, 7]. Many experts and scholars at home and abroad have researched rare earth elements in soil from different fields. They have conducted various research on improving the yield and quality of characteristic agricultural products [8, 9]. Relevant scholars use nitrogen, phosphorus, and potassium in agriculture, followed by trace elements such as copper, zinc, and molybdenum, and then use rare earth microelements and have conducted many demonstration studies [10, 11]. The study found that rare earth fertilisers are effective, and the application of rare earth fertilisers in China is about 8,000 tonnes, and the agricultural economic benefit exceeds one million yuan. At the same time, the researchers also found the influence of soil environment on crops. The soil environment can promote or inhibit crops' growth, development, and quality, and differences in soil types can also cause differences in the content of a series of elements.

Blindly increasing the application of chemical fertilisers and increasing the cost input of orchards will also cause soil environmental load, which will easily lead to diseases of fruit trees and seriously affect the productivity of orchards [12]. Fertilisation reduction is one of the important measures for the scientific management of orchards. Proper application of nitrogen fertiliser can make plants grow vigorously [13], which is beneficial to sugar accumulation in fruits. The sugar-acid ratio and soluble solids content are higher than those of conventional fertilisation treatment, which is beneficial for improving fruit flavour [14]. The test results of Ma and Zheng [15] showed that the yield, internal quality, and single fruit weight of navel orange and mandarin orange were improved by reducing 25 % and 50 % water-soluble fertiliser compared with traditional fertilisation. Li et al. [16] found that the application of 100 kg/10000 m^2 nitrogen fertiliser was the appropriate application amount for young apple trees, which was conducive to improving fertiliser utilisation rate and promoting good root growth. When the application amount exceeded 200 kg/10000 m^2, the fertiliser utilisation rate decreased to 50 %. Reducing fertilisation can not only meet the nutrients needed for fruit tree growth but also reduce the harm of excessive fertilisation to the environment and promote the green production of orchards. Based on this, this experiment reduced fertilisation based on the current fertilisation amount and studied the influence of reduced fertilisation on the yield, quality, and economic

benefits of 'Pingguoli' in order to achieve the purpose of improving quality and saving cost and provide a theoretical basis for rational fertilisation in Yanbian area.

Methods and materials

At present, 'Pingguoli' have poor quality, low yield, poor post-harvest treatment, low commodity rate, serious pests and diseases, and low income, which lead to poor farmers' planting enthusiasm and seriously affect the long-term development of 'Pingguoli' in Yanbian. The roadmap of key techniques for high-yield cultivation of 'Pingguoli' in the Yanbian area is shown in Figure 1.

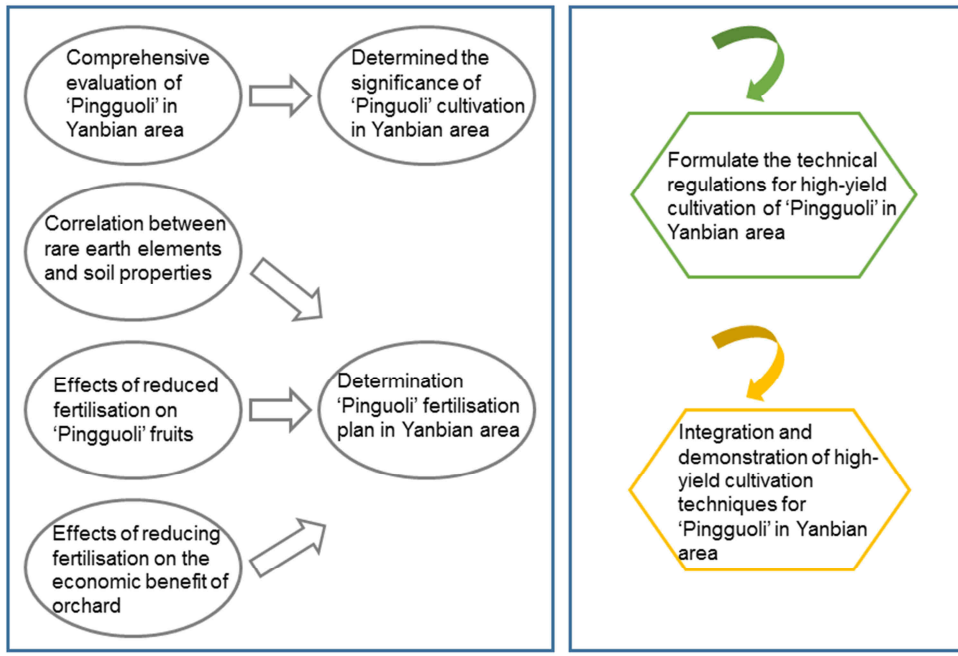


Fig. 1. Roadmap of key technologies for high-yield cultivation of 'Pingguoli' in Yanbian area

The experiment was selected in the Yanbian Fruit Tree Farm Sixth Branch (42.77°N, 129.42°E), which is located in the southeast of Jilin Province, with a mid-temperate monsoon climate with an annual average temperature of 5.8 °C. The average annual rainfall is about 550 mm, and the precipitation is mainly concentrated in June-August. Without irrigation, the soil is sandy dark brown soil with an area of 2 ha. The basic properties of the soil in the experimental site are shown in Table 1.

Table 1

Basic characteristics of the experiment location

Soil layer [cm]	Organic matter [g/kg]	Total N [g/kg]	Available P [mg/kg]
0-20	17.13	0.46	48.13
20-40	15.98	0.44	37.61

'Pingguoli' trees with 30-year-old trees, 5 m × 6 m planting density and basically the same growth potential were selected as experimental materials. The compound fertiliser is 'Beifeng' brand compound fertiliser with the ratio of N : P_2O_5 : K_2O = 15 : 15 : 15 and the price of 2.90 yuan/kg.

The chemical properties of soil mainly refer to the chemical composition of the soil, the synthesis and decomposition of organic matter, the transformation and release of mineral elements, and the pH value of the soil. Nutrient elements provide the basis. Minerals are the material basis of plant life activities. Plants have different requirements for large or small amounts of mineral elements. Too much or too little or improper distribution may disrupt their normal life activities. Different organisms have very different types and needs of minerals and different accumulation of minerals in the body.

Soil organic matter is an important indicator of soil fertility, which can improve soil's physical and chemical properties, facilitate the formation of soil aggregates, and promote plant growth and nutrient absorption. Soil organic matter is also an important source of mineral nutrients that plants need while increasing the availability of trace elements.

The content of soil organic matter is related to the species and quantity of soil animals. In soils rich in organic matter, the species and quantity of soil animals are more abundant, but soil animal richness is also lower in areas with low organic matter content.

There are four treatments in this experiment, namely, no fertilisation (CK), 80 % fertiliser reduction (CF1), 40 % fertiliser reduction (CF2) and conventional fertilisation (CF3), which have been continuously treated for 3 years. See Table 2 for details of the application amount of chemical fertiliser 3 tonnes in each treatment, with 10 'Pingguoli' trees in each treatment, repeated forimes.

Table 2

Fertiliser application amount of each treatment

Treatment	Compound fertiliser [kg/plant]
CK	0
CF1	1
CF2	3
CF3	5

The fertilisation period is after the soil is thawed, and the CF2 and CF3 treatments are applied with compound fertiliser twice in April and July, and each application accounts for 50 % of the total amount. CF1 was applied once in April, and furrowing and fertilising are carried out along the drip line part of the crown. Calcium ammonium nitrate (0.3 %) + potassium dihydrogen phosphate (0.1 %) was sprayed on the leaves twice before the new shoots stopped growing, and calcium ammonium nitrate (0.2 %) + potassium dihydrogen phosphate (0.3 %) was sprayed twice from mid-August to one month before harvesting. Other field management is consistent with conventional fertilisation.

In early October, a total of 20 medium-sized disease-free fruits were picked in the east, south, west, and north directions of each 'Pingguoli' tree, put in an ice box, and brought back to the laboratory, some of which were used to determine the fruit quality and mineral elements, and some of which were stored at room temperature for 30 days and then analysed their storability.

The root system of 'Pingguoli' is deep. The vertical roots are well developed, with a depth of 2.5 m - 3 m. The horizontal root distribution is generally about twice the crown

width. Roots are generally distributed in fertile, loose, and moist topsoil, with the densest roots between 0 cm - 40 cm, few below 60 cm, and even fewer below 150 cm.

When analysing soil chemical properties, the soil samples were collected by the multi-point mixing method, and the soil sampling depth and the number of samples at each point should be uniform. Before sampling, the weeds on the soil surface should be cleaned, and the top layer of floating soil should be removed. The sampler should be perpendicular to the ground and sampled layer by layer. The soil samples at each point should be mixed and stored at about 1.0 kg according to the quartering method. The soil samples should be put into bags. The labels should be written inside and outside with pencils, indicating the sampling depth, sampling location, date, collector, and other necessary information.

Single fruit weight was measured by electronic balance; the number of fruits per tree is measured by counter; the longitudinal and transverse diameters of fruits were measured by vernier caliper. Fruit hardness was measured by GY-B hardness tester. The content of soluble solids (SSC) was measured by sugar meter. Titrable acid content was determined by neutralisation titration. The content of *V*c (Vitamin C) was determined by molybdenum blue colorimetry. The total N (nitrogen) content of fruits was determined by Nessler colorimetry. The total P content was determined by molybdenum antimony colorimetry. Excel 2007 (Microsoft Office Excel 2007) and SPSS Statistics (Statistical Product Service Solutions) 17.0 were used to analyse the experimental data.

Analysis of results

Soil organic matter. Soil organic matter refers to the carbon-containing organic matter in the soil, including the residues of various animals and plants and various organic matter that will be decomposed and synthesised. Organic matter is one of the important evaluation criteria for soil fertility. It can promote crop growth, improve soil structure, and improve soil water and fertiliser retention capacity. It is significant to soil formation, properties, and sustainable agricultural development. The correlation between soil organic matter and rare earth elements in the soil. Correlation analysis between soil organic matter and rare earth elements shows that when the confidence level is 0.05, organic matter and rare earth elements are irrelevant.

Soil pH. Soil pH is one of the basic properties of soil and one of the important factors affecting soil fertility. It is one of the important indicators of soil formation process and maturation process. Conversion and effectiveness. Soil pH also has a great influence on the availability of nutrients. For example, the availability of phosphorus in neutral soil is large; the availability of trace elements in alkaline soil is poor.

Figure 2 shows the effect of reduced fertilisation on fruit appearance. The fruits treated with CF1, CF2 and CF3 were larger than CK, and the fruits treated with CF1 were more evenly coloured and more orderly in shape. It can be seen from Table 3 that the single fruit weight of 'Pingguoli' treated with CF1, CF2 and CF3 was significantly higher than CK, and showed CF3 > CF1 > CF2, but there was no significant difference among them. Under different treatments, the yield of 'Pingguoli' CF3 > CF1 > CF2 > CK, CK was slightly lower than that of conventional treatments after reduced fertilisation, but there was no significant difference. The fruit diameter of CF2 is the largest, followed by CF3, and the difference between them is not significant, but both of them are significantly higher than CK and CF1 treatments. Different treatments have little effect on the fruit transverse diameter. According to the fruit shape index, there was no significant difference in

'Pingguoli' fruit shape index among CK, CF1 and CF2 treatments, but they were all higher than CF3 treatments, and CK and CF1 were significantly different from CF3 treatments. This shows that fertilisation affects fruit yield and single fruit weight, and the yield increases with the increase of fertiliser application, but there is no significant difference between reducing fertilisation and conventional fertilisation.



Fig. 2. Effects of reduced fertilisation on fruit appearance

Table 3

Effects of reduced fertilisation on fruit yield and appearance quality

Treatment	Fruit weight [g]	Yield [kg/plant]	Transverse diameter [cm]	Longitudinal diameter [cm]	Fruit type index [-]
CK	282.6 ±4.4 b	74.4 ±4.3 a	8.60 ±0.13 b	7.00 ±0.07 a	0.82 ±0.01 a
CF1	301 ±18 a	83.6 ±4.0 a	8.60 ±0.22 b	6.93 ±0.30 a	0.81 ±0.02 a
CF2	299.7 ±9.1 a	81.2 ±6.0 a	8.90 ±0.14 a	7.11 ±0.11 a	0.80 ±0.01 ab
CF3	307 ±12 a	85.0 ±0.5 a	8.79 ±0.04 ab	6.89 ±0.02 a	0.78 ±0.01 b

Different lowercase letters indicate significant differences between treatments ($P < 0.05$), the same below

Table 4 shows the effect of reduced fertilisation on the internal quality of fruit.

The hardness of CK was the highest, significantly higher than that of other three treatments, and the hardness of reduced fertilisation treatment was lower than that of conventional fertilisation. The soluble solids content of 'Pingguoli' was significantly different among different treatments, and CF1 treatment was significantly higher than the other three treatments, which was 14.0 %. CF2 and CF3 treatments were significantly higher than CK treatments, but there was no significant difference between them. Its content is CF1 > CF2 > CF3 > CK, and the soluble solids content of CF1 treatment is 5.0 % and 10.0 % higher than that of CF3 and CK treatment respectively. The titratable acid

content of different treatments was negatively correlated with the soluble solids content, and its content was CF1 < CF2 < CF3 < CK. The ratio of soluble solids to titratable acid is positively correlated with the content of soluble solids, and the overall trend is CF1 > CF2 > CF3 > CK. CF1 treatment was significantly higher than the other three treatments, and the ratio of soluble solids to titratable acid of CF1 treatment was 48.2, which was 16.6 % and 31.1 % higher than that of CF3 and CK treatment. This indicated that different fertilisation rates had obvious effects on the soluble solids, titratable acid and the ratio of soluble solids to titratable acid of fruits. Fertilisation could increase the sugar content of fruits and reduce the acidity of fruits, but fertilisation exceeding a certain amount would reduce the taste of fruits. There were differences in vitamin C content among different treatments. CF3 and CF1 were significantly higher than CK and CF2, but there was no significant difference between CF3 and CF1 treatments. On the whole, fertilisation can improve the internal quality of fruits and reduce the hardness of fruits. Reducing fertilisation can obviously improve the quality of fruits, and CF1 has the most obvious effect.

Table 4

Effects of reduced fertilisation on the intrinsic quality of fruits

Treatment	Hardness [kg · cm^{-2}]	Soluble solids [%]	Titrable acid content [%]	Soluble solid-titratable acid ratio [-]	Vitamin C [mg/g]
CK	9.72 ±0.12 a	12.6 ±0.2 c	0.38 ±0.02 a	33.2 ±1.8 c	2.57 ±0.07 c
CF1	9.00 ±0.37 b	14.0 ±0.4 a	0.29 ±0.02 c	48.2 ±6.9 a	3.06 ±0.04 a
CF2	8.97 ±0.31 b	13.4 ±0.2 b	0.32 ±0.04 b	41.9 ±3.6 b	2.87 ±0.25 b
CF3	9.16 ±0.26 b	13.3 ±0.3 b	0.33 ±0.03 b	40.2 ±2.4 b	3.13 ±0.01 a

From Table 5, it can be seen that there are differences in mineral element contents of fruits under different fertilisation rates. There was no significant difference in the total N content of fruits among different treatments. The total Ca content of CF1 treatment was significantly higher than that of other treatments, 22.8 % higher than that of CF3 treatment, and that of CF3 treatment was significantly higher than that of CK. The total P content of CF1 treatment was the highest, reaching 0.69 mg/g, which was not significantly different from CF2 treatment, but significantly higher than CF3 and CK treatment, and there was no significant difference between them. The total Mg content of CF1 was not significantly different from that of CF2 and CF3 treatments, but it was significantly higher than that of CK treatment. The total K content of CF1 treatment was 3.49 mg/g, which was significantly higher than that of CF3 treatment by 16.0 %.

Table 5

Effects of reduced fertilisation on the content of mineral elements in fruits

Treatment	Total N [mg/g]	Total P [mg/g]	Total K [mg/g]	Total Ca [mg/g]	Total Mg [mg/g]
CK	1.45 ±0.09 a	0.61 ±0.03 bc	3.13 ±0.16 b	0.37 ±0.01 d	2.39 ±0.13 b
CF1	1.51 ±0.09 a	0.69 ±0.01 a	3.49 ±0.04 a	0.57 ±0.01 a	3.33 ±0.26 a
CF2	1.53 ±0.11 a	0.65 ±0.02 ab	3.47 ±0.16 a	0.52 ±0.02 b	3.32 ±0.17 a
CF3	1.50 ±0.06 a	0.58 ±0.04 c	2.93 ±0.09 c	0.44 ±0.03 c	3.29 ±0.06 a

The internal quality of fruits was measured after storage for 30 days. Table 6 shows the effect of reduced fertilisation on the internal quality of fruits after storage. The firmness of CK 'Pingguoli' was significantly higher than that of other three treatments, followed by

CF3, CF1 and CF2 treatments. After storage, the firmness of fruit decreased, and the significance and overall trend among the treatments were consistent with those before storage. After storage, the content of soluble solids in fruits increased, with the highest content of 14.2 % in CF1 treatment, followed by CF2, CF3 and CK, the overall trend is consistent with that before storage, which may be due to the post-harvest storage period promoting the transformation of starch into sugar and increasing the soluble solids content of fruits. After storage, the titratable acid content decreased, the acidity of CK treatment was the largest, that of CF1 treatment was the smallest, and that of CF2 decreased the most. This may be because titratable acid in postharvest fruits is gradually consumed as respiratory substrate, and the soluble solid-titratable acid ratio of CF1 treatment after storage is the highest, reaching 52.7, followed by CF2 treatment, which was positively correlated with the content of soluble solids. After storage, the content of vitamin C in fruits decreased, and there was no significant difference between CF3 and CF1 treatments, and there was no significant difference between CF1 and CF2 treatments, but the content of vitamin C in the three treatments was higher than CK. This is because ascorbic acid oxidase in fruits during storage is easy to react with *V*c, which leads to the decrease of its content [17].

Table 6

Effects of reduced fertilisation on the intrinsic quality of fruits after storage

Treatment	Hardness [kg·cm^{-2}]	Soluble solids [%]	Titrable acid content [%]	Soluble solid-titratable acid ratio [-]	Vitamin C [mg/g]
CK	9.24 ±0.28 a	13.1 ±0.3 c	0.37 ±0.04 a	35.5 ±2.9 c	2.29 ±0.01 c
CF1	8.78 ±0.07 b	14.2 ±0.3 a	0.27 ±0.02 c	52.7 ±1.9 a	2.85 ±0.04 ab
CF2	8.78 ±0.08 b	13.8 ±0.3 b	0.28 ±0.03 c	49.3 ±1.7 b	2.78 ±0.05 b
CF3	8.81 ±0.19 b	13.7 ±0.3 b	0.31 ±0.03 b	44.2 ±2.0 c	2.94 ±0.09 a

Fruit softening rate and bad fruit rate are important indexes to reflect fruit storability. The softening rate of CF1 treatment after storage is the lowest, only 2.51 %. CK, CF2 and CF3 treatments were 5.0 %, 2.8 % and 3.6 % respectively. After storage, CK treatment had the highest rate of bad fruit, reaching 26.3 %, followed by CF3 treatment, reaching 21.4 %. The bad fruit rate of CF1 and CF2 treatments was 65.0 % and 16.2 % lower than that of CF3, respectively. This shows that reasonable fertilisation can slow down the softening speed of fruit and improve the storability of fruit, and excessive fertilisation will reduce its storability.

Table 7 is the correlation analysis between mineral elements and fruit storability.

The table shows that the contents of mineral elements N, P and K in fruits are negatively correlated with softening rate and bad fruit rate, and the contents of Ca and Mg in fruits are negatively correlated with bad fruit rate, but not significant. However, the contents of Ca and Mg in fruits are negatively correlated with the softening rate of fruits. This indicated that the relative content of Ca and Mg in fruits was higher, and the softening rate was lower, and the fruit with better storage effect can prolong the storage period. Mineral element content of fruit is related to its storability. fertilisation has a great influence on mineral element content of fruit, and excessive fertilisation may reduce the storability of fruit.

Table 7

Correlation between fruit mineral element content and softening rate and bad fruit rate

Element	Softening rate [-]	Bad fruit rate [-]
N	–0.638	–0.088
P	–0.667	–0.484
K	–0.656	–0.679
Ca	–0.972*	–0.697
Mg	–0.955*	–0.789

* means that the correlation is significant at 0.05 level (two-tailed)

Table 8 is the result of the investigation on the economic benefits of orchards. It can be seen from the table that fertilisation can obviously improve the output value of 'Pingguoli', and the output value after fertilisation treatment is 8.4 % - 12.5 % higher than CK.

The fertiliser input is proportional to the amount of fertiliser applied, and the order is CF3 > CF2 > CF1 > CK. The benefits of different fertilisation treatments are different, and CF1 treatment has the highest benefit, reaching 56,984 yuan/10000 m^2, and CF1 > CF3 > CF2 > CK, CF1 treatment is 5.0 % higher than CF3 treatment. It can be seen that the output value of CF1 treatment is slightly lower than that of CF3, but the input of chemical fertiliser is less than that of CF3, and the overall income is higher than that of CF3 treatment.

Table 8

Effects of reduced fertilisation on the economic benefits of orchards

Handle	Yield [kg/10000 m^2]	Output value [yuan/10000 m^2]	Fertiliser input [yuan/10000 m^2]	Profit [yuan/10000 m^2]
CK	24565.2	51586	0	51586
CF1	27591.3	57941	957	56984
CF2	26819.1	56320	2871	53449
CF3	28066.5	58939	4785	54154

Pingguoli's production is related to the development of the agricultural economy in the Yanbian area and even more to the economic benefits of farmers. Farmers use a large number of chemical fertilisers to increase the yield of fruit trees, but at the same time, it also leads to poor fruit quality and storage problems. The low economic income of farmers leads to a vicious circle for a long time, which seriously affects the development of the 'Pingguoli' industry.

The decline of soil organic matter content will directly lead to soil fertility decline, thereby affecting agroecosystems' productivity. Soil organic matter is of great significance for improving soil's physical and chemical properties, soil structure, and soil fertility. Soil pH is one of the important chemical indicators that determine soil quality. It affects soil fertility and the availability of macro-, micro-, and heavy-metal elements in the soil. Soil pH is not only closely related to fertilisation methods, fertiliser types, and heavy metal content but also to soil management methods and planting systems.

Nitrogen fertiliser can promote plant growth, but excessive application increases the cost input of orchard and reduces the internal and external quality of fruit. Wei et al. [18] found that proper fertilisation can significantly improve the yield and quality of Guangxi honey pomelo fruit, and excessive fertilisation will reduce the yield. In this experiment, the yield and single fruit weight of CF1 and CF2 treatments are lower than those of conventional treatments, but there is no significant difference, which may be due to the fact

that the fertilisation amount of conventional treatments is still within the suitable range of 'Pingguoli' fertilisation.

Fruit hardness, soluble solids, titratable acid, *V*c content and other intrinsic qualities directly affect fruit taste, and then affect consumers' choice. This experiment shows that: fruit firmness CF2 < CF1 < CF3 < CK, CF1 treatment has the highest soluble solid content of 14.0 %. Titrable acid content is negatively correlated with soluble solids content, and soluble solid-titratable acid ratio is positively correlated with soluble solids content.

The soluble solid-titratable acid ratio treated with CF1 is 16.6 % higher than that treated with CF3.

In this experiment, the highest total nitrogen content of fruits treated with CF1 was 1.53 mg/g, but there was no significant difference among treatments. The highest total phosphorus content of CF1 was 0.69 mg/g, significantly higher than that of CF3, and the total potassium content was 3.49 mg/g, significantly higher than that of CF3 by 16.0 %. Pampana et al. [19] also found that reducing nitrogen fertiliser application did not significantly affect the nitrogen content of fruits, and the phosphorus content of fruits treated with N2 was the highest, which was 0.77 g/kg. Previous studies have found that the content of Ca and Mg in apples is related to the quality and storability of apples which has also been verified in this experiment [20, 21].

Conclusion

Soil organic matter content is of great significance to soil productivity, soil physicochemical properties and soil fertility. Soil pH is one of the important chemical indicators to determine soil quality, it not only affects soil fertility, but also affects the availability of macro, micro and heavy metal elements in the soil. Compared with conventional fertilisation, the yield and single fruit weight of CF1 treatment were lower than those of conventional treatment, but there was no significant effect, and the fruit shape index was significantly higher than that of conventional treatment. The fruit quality was significantly improved after fertilisation reduction, and the content of soluble solids in CF1 treatment was the highest, reaching 14.0 %, which was 5 % and 10 % higher than that in CF3 and CK treatment respectively. The titratable acid content is negatively correlated with the soluble solids content, while the soluble solid-titratable acid ratio is positively correlated with the soluble solids content. The soluble solid-titratable acid ratio of CF1 treatment is 16.6 % higher than that of CF3, and the fruit hardness and vitamin C content of CF1 treatment are slightly lower than that of CF3, but there is no significant difference. Compared with conventional treatment, the contents of P, K and Ca in fruits were significantly increased, and the contents of calcium and magnesium were negatively correlated with the softening rate of fruits. After storage, the soluble solids and soluble solid-titratable acid ratio of fruits were 3.8 % and 16.2 % higher than that of CF3 treatment, respectively, and the softening rate and bad fruit rate of fruits were significantly lower than that of CF3 treatment. The benefits of CF1 treatment reached 56,984 yuan/10000 m^2, which reduced the cost of fertiliser and significantly improved the comprehensive benefits. Overall, reducing fertilisation can achieve the goal of improving quality and saving cost, and 80% reduction of chemical fertiliser (CF1) has the best effect, which can be used to guide actual production. Reducing fertilisation has far-reaching significance for improving fruit quality and economic benefits.

Acknowledgements

This work was supported by the Department of Science and Technology of JiLin Province: Study on green production and cultivation techniques of 'Pingguoli' (20200402071NC), supported by the earmarked fund for China Agriculture Research System (CARS-28), and Yanbian University School-Enterprise Cooperation Project ((2019) No. 2), Application of "Double-reduction" Technology in 'Pingguoli' Production.

References

[1] Tsujimoto Y, Horie T, Randriamihary H, Shiraiwa T, Homma K. Soil management: The key factors for higher productivity in the fields utilizing the system of rice intensification (SRI) in the central highland of Madagascar. Agric Syst. 2009;100(1-3):61-71. DOI: 10.1016/j.agsy.2009.01.001.

[2] Berenguer P, Santiveri F, Boixadera J, Lloveras J. Nitrogen fertilisation of irrigated maize under Mediterranean conditions. Eur J Agron. 2009;30(3):163-71. DOI: 10.1016/j.eja.2008.09.005.

[3] Chen X, Zhang Q, Zeng S, Chen Y, Huang X. Rain-shelter cultivation affects fruit quality of pear, and the chemical properties and microbial diversity of rhizosphere soil. Can J Plant Sci. 2020;100(6). DOI: 10.1139/CJPS-2018-0249.

[4] Peil A, Bus VG, Geider K, Richter K, Flachowsky H, Hanke MV. Improvement of fire blight resistance in apple and pear. Int J Plant Breed. 2009;3(1):1-27. Available from: https://www.academia.edu/25661033/Improvement_of_Fire_Blight_Resistance_in_Apple_and_Pear.

[5] Khan T, Sherazi HHR, Ali M, Letchmunan S, Butt UM. Deep learning-based growth prediction system: A use case of China agriculture. Agronomy-Basel. 2021;11(8):1551. DOI: 10.3390/agronomy11081551.

[6] Kim H, Shim K. Land suitability assessment for apple (Malus domestica) in the Republic of Korea using integrated soil and climate information, MLCM, and AHP. Int J Agric Biol Eng. 2018;2:139-44. DOI: 10.25165/j.ijabe.20181102.2522.

[7] Yang J, Duan Y, Wang L, Kang D, Awasthi MK, Li H, et al. Seasonal variation of net ecosystem CO_2 exchange and its influencing factors in an apple orchard in the Loess Plateau. Environ Sci Pollut Res Int. 2020;35:43452-65. DOI: 10.1007/s11356-020-08526-5.

[8] Dlamini B, Malan A, Addison P. Entomopathogens from agricultural soil and their potential to control the banded fruit weevil, Phlyctinus callosus (Schönherr) (Coleoptera: Curculionidae). J Entomol Soc South Afr. 2020;2:374-84. DOI: 10.4001/003.028.0374.

[9] Wang Q, Huang B, Guan Z, Yang L, Li B. Speciation of rare earth elements in soil by sequential extraction then HPLC coupled with visible and ICP-MS detection. Fresenius' J Anal Chem. 2001;8:1041-47. DOI: 10.1007/s002160100775.

[10] Chhetri L, Kandel B. Intensive fruit cultivation technology of citrus fruits: high density planting: a brief review. J Agri Stud. 2019;2:63. DOI: 10.5296/jas.v7i1.14865.

[11] Thorat M, Dastager S. High yield production of cellulose by a Komagataeibacter rhaeticus PG2 strain isolated from pomegranate as a new host. RSC Adv. 2018;8. DOI: 10.1039/C8RA05295F.

[12] Lin X, Feng Y, Zhang H, Chen R, Wang J, Zhang J, et al. Long-term balanced fertilization decreases arbuscular mycorrhizal fungal diversity in an arable soil in North China revealed by 454 pyrosequencing. Environ Sci Technol. 2012;46(11):5764-71. DOI: 10.1021/es3001695.

[13] Vallejo F, Tomas-Barberan FA, García-Viguera C. Effect of climatic and sulphur fertilisation conditions, on phenolic compounds and vitamin C, in the inflorescences of eight broccoli cultivars. Eur Food Res Technol. 2003;216(5):395-01. DOI: 10.1007/s00217-003-0664-9.

[14] Zhao Z. Assessment and analysis of soil pollution in Shaanxi apple orchards. North Hortic. 2015;11:192-6. DOI: 10.11937/bfyy.201511048.

[15] Ma W, Zheng H. Heterogeneous impacts of information technology adoption on pesticide and fertiliser expenditures: Evidence from wheat farmers in China. Aust J Agric Resour Econ. 2022;66(1);72-92. DOI: 10.1111/1467-8489.12446.

[16] Li WF, Mao J, Su J, Li XW, Dawuda MM, Ma ZH, et al. Exogenous ABA and its inhibitor regulate flower bud induction of apple cv.'Nagafu No. 2′ grafted on different rootstocks. Trees. 2021;35(2):609-20. DOI: 10.1007/s00468-020-02063-x.

[17] Choi HR, Tilahun S, Lee YM, Choi JH, Baek MW, Jeong CS. Harvest time affects quality and storability of kiwifruit (Actinidia spp.): Cultivars during long-term cool storage. Sci Hortic. 2019;256:108523. DOI: 10.1016/j.scienta.2019.05.050.

[18] Wei G, Hu C, Tian Q, Zhu D, Li X. Effects of nitrogen and phosphorus reduction and fertilisation on fruit yield and quality of Guanxi pomelo. J Plant Nutr Fert. 2018;02:471-8. DOI: 10.11674/zwyf.17331.
[19] Pampana S, Masoni A, Mariotti M, Ercoli L, Arduini I. Nitrogen fixation of grain legumes differs in response to nitrogen fertilisation. Exp Agric. 2016;54(1);66-82. DOI: 10.1017/S0014479716000685.
[20] Wu CH, Tsai SB, Liu W, Shao XF, Sun R, Wacławek M. Eco-technology and eco-innovation for green sustainable growth. Ecol Chem Eng S. 2021;28(1):7-10. DOI: 10.2478/eces-2021-0001.
[21] Wu CH, Tsai SB, Liu W, Shao XF, Xia YK, Wacławek M. Green environment and sustainable development: methods and applications. Ecol Chem Eng S. 2021;28(4):467-70. DOI: 10.2478/eces-2021-0030.