American Journal of Biochemistry and Biotechnology

Research Article

# Classification and Spatial Distribution of Macronutrients and Micronutrients in the Soil of Greenhouse Sweet Cherries

[1]Lijin Qin, [2]Qingxiang Wang, [3]Yongli Lv, [4]Junxiang Zhang, [5]Jingsheng Wang, [1]Yangyang Xu, [1]Dingfang Zhang and [1]Jiahe Zhou

[1]*College of Agriculture, Chifeng University, Chifeng 024000, China*
[2]*Chifeng Yingrun Agricultural High-tech Development Co., Ltd, Chifeng 024000, China*
[3]*Chifeng Geographical Indication Industry Association, Chifeng 024000, China*
[4]*Research institute of Pomology of CAAS, Xingcheng 125100, China*
[5]*People's Government of Damiao Town, Songshan District, Chifeng 024042, China*

*Article history*
Received: 14-02-2025
Revised: 04-03-2025
Accepted: 15-04-2025

Corresponding Author:
Lijin Qin
College of Agriculture, Chifeng University, Chifeng 024000, China
Email: lij5546@126.com

**Abstract:** To understand the distribution of trace elements in the soil of greenhouse sweet cherry, using soil samples from solar greenhouse sweet cherry orchards in Chifeng, Inner Mongolia as the object, the trace element indicators in the soil of different sweet cherry production areas were analyzed using the "S" shaped 5-point sampling method. Descriptive statistics were conducted. The results showed that in the soil, the average value of CaO is 3.38%, level 2 and relatively abundant, relatively deficient accounting for 4.76%; that of MgO is 0.74%, level 4 and relatively deficient, relatively deficient accounting for 100%; that of total S is 293.24 mg/kg, level 2 and relatively abundant, relatively deficient accounting for 38.1%; that of total Cu is 20.61 mg/kg, level 4 and relatively deficient, relatively deficient accounting for 52.38%; that of total Zn is 62.06 mg/kg, level 3 and moderate, relatively deficient accounting for 52.38%; that of total B is 30.73 mg/kg, level 4 and deficient, relatively deficient accounting for 95.24%; that of total Mo is 0.70 mg/kg, level 2 and abundant, relatively deficient accounting for 38.1%. Although sweet cherries can be cultivated and produced normally in the sunlight greenhouse in Chifeng, the levels of trace elements in the soil are low and the variability is large. Effective measures need to be taken to improve and supplement them. In future production, it is recommended to increase the application of magnesium iron micro fertilizers to meet the demand of large cherries for trace elements.

**Keywords:** Classification, Spatial Distribution, Macronutrients and Micronutrients, Sweet Cherries, Greenhouse

## Introduction

Sweet cherry (*Prunus avium* L.) is the abbreviation of European sweet cherry, also known as large cherry, belonging to the Rosaceae family (Xin *et al.*, 2013). Sweet cherries are native to West Asia and southeastern Europe, adapted to cool and dry climates, and more suitable for cultivation in northern China, such as Liaoning in North, Northwest, and Northeast China. The cultivation of sweet cherries in protected areas in China began in the 1990s (Liu *et al.*, 2009). Due to its advantages of good quality (Bondarenko *et al.*, 2024), high economic benefits, strong resistance to adverse weather, and the ability to achieve premature and high yields, it has developed rapidly in many areas of China in the past decade. Chifeng is in the southeastern part of Inner Mongolia, between 41°17′10″N-45°24′15″N. It has an annual sunshine duration of 2700-3100 hours and an average annual temperature of 0-7 °C. It belongs to the semi-arid continental monsoon climate zone of the mid temperate zone, and is suitable for cherry growth. However, the average temperature in the coldest month of winter (January) in Chifeng is around -10 °C, and the extreme lowest temperature is below -27 °C . The cultivation of sweet cherries in the open field will suffer from freezing damage and cannot be produced.

Facility agriculture in Chifeng began in the 1990s, with facilities mainly consisting of solar greenhouses and plastic greenhouses. Main crops are eggplants, fruits, melons, and vegetables, making it one of the main pillar industries in the local area. However, with the increase of planting years, soil continuous cropping obstacles and soil borne diseases have become increasingly prominent. Coupled with the unstable vegetable market and the

**DOI: 10.3844/ajbbsp.2025.245.251**

trend of increasing labor costs, economic benefits are declining day by day. Sunlight greenhouse sweet cherries have the advantages of low artificial input cost and stable economic benefits, gradually becoming the preferred crop for structural adjustment in main production areas of facility agriculture. Researches have shown that sweet cherries can overwinter and grow normally with good quality in Chifeng (Tian *et al.*, 2024), and have gradually become one of the key characteristic industries for development.

The primary environment for crop growth is soil, and soil quality and fertility are prerequisites for ensuring high crop yield and quality. Sweet cherries have relatively high requirements for soil conditions. When building a garden, fertile soil, deep soil layers, neutral or slightly acidic sandy loam soil should be selected (Xiao *et al.*, 2023; Desie *et al.*, 2023). There have been reports on the nutrition status of trace elements in sweet cherry soil. Using the "S" shaped 5-point sampling method, Wang *et al.* (2025) found that the content of exchangeable Ca and Mg in Zaozhuang, Shandong Province is relatively high, and there is no need for fertilization and improvement. The content of effective Zn and B is relatively low, belonging to level 4. Zheng analyzed the chemical properties of greenhouse sweet cherry soil in Dalian using the "S" shaped 5-point sampling method. It was found that in the soil, Fe was low, and Mn was low or very low (Zheng, 2021). Liu *et al.* (2009) investigated the soil of protected sweet cherries in five regions of Liaoning Province using the "S" shaped multi-point (8-16) sampling method. The soil is abundant in nutrients such as available Ca, Mg, and Zn, with 62.61% having an effective content exceeding 20 mg/kg, and the highest reaching 132 mg/kg. It has been found that the content of trace element nutrients in sweet cherry soil varies significantly depending on the geographical location of the planting area. With the large-scale development of greenhouse sweet cherry industry in Chifeng, Inner Mongolia, the current content of trace elements in the soil and whether it can meet the growth and development needs of sweet cherries are urgent problems that need to solve. This study sampled the soil of the main production area of sweet cherries in solar greenhouses in Chifeng, Inner Mongolia, and measured the trace element indicators in the soil. Through descriptive statistical analysis and grade evaluation of the above indicators, the spatial variation characteristics are elucidated, providing a reference for soil improvement and fertilization techniques for sweet cherry planting in this city and surrounding areas in the future.

## Materials and Methods

### *Soil Sample Collection*

In May 2024, representative sweet cherry greenhouses were selected for sampling in the main production areas of sunlight greenhouses in Chifeng, including Ningcheng County, Hongshan District, Songshan District, Aohan Banner, Wengniute Banner, Kalaqin Banner, and Linxi County. The large cherry variety was 'Meizao', with a tree age of more than 3 years, and a total of 21 samples. There were 5 soil samples from Ningcheng County, 3 from Hongshan District, 2 from Songshan District, 7 from Aohan Banner, 2 from Wengniute Banner, 1 from Kalaqin Banner, and 1 from Linxi County. In the same greenhouse, the "S" shaped sampling method is used. Five trees were selected from each greenhouse, and three points were taken from each tree. The soil was drilled from 0-40 cm using stainless steel soil. After mixing the soil samples collected from multiple points, 1 kg was left according to the quartering method, air dried naturally, and finely ground with a wooden stick through a 1 mm diameter nylon sieve. After sieving, mixing, bagging and labeling, it was ready for testing. The map of Chifeng is shown in Figure 1.

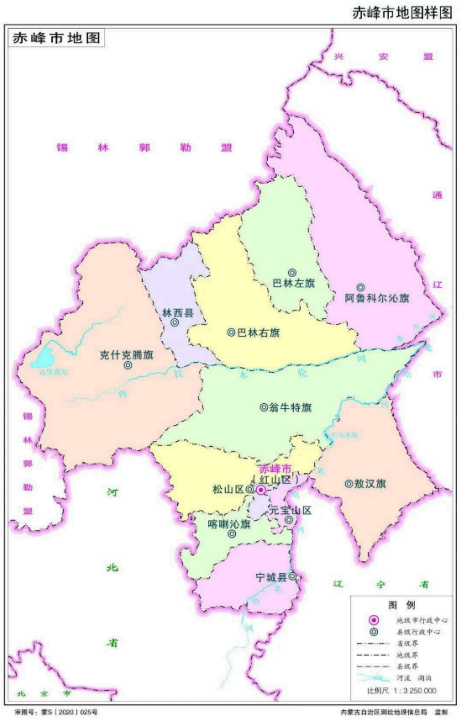


**Fig. 1:** Chifeng

### *Measurement Parameters and Analytical Methods*

Soil calcium oxide, magnesium oxide, ferrous oxide, and total zinc were analyzed using the inductively coupled plasma atomic emission spectroscopy;

Total S was analyzed using infrared absorption spectroscopy;

Total Cu and Mo were determined using inductively coupled plasma mass spectrometry;

The total B was determined using photoelectric direct reading emission spectroscopy.

The grading standards for soil nutrient element content refer to Zheng (2021), Li *et al.* (2009), and Wang *et al.* (2025).

### *Data Processing*

Data processing was performed using Microsoft Excel 2007 software and SPSS 23.0.

## Results

### *Descriptive Statistical Characteristics of Trace Element Indicators in Soil*

According to Table 1, the average values of CaO, MgO, and total S in the soil of greenhouse cherry in Chifeng are 3.38%, 0.74%, and 293.24 mg/kg, respectively. The coefficients of variation are moderate (Zhou *et al.*, 2019), with MgO having the smallest coefficient of variation at 18.92%. CaO and total S have larger coefficients of variation at 49.11% and 63.16%, respectively. For trace elements, the average values of total Cu, total Zn, total B, and total Mo are 20.61, 62.06, 30.73, and 0.70 mg/kg, respectively, with coefficients of variation ranging from 20.86% to 37.14%. The average value of FeO is 2.32%, with a coefficient of variation of 21.98%. The coefficient of variation for all five trace elements is moderate. The larger the coefficient of variation, the greater the difference in the content of trace elements in the soil of different sweet cherry areas, and the more uneven the distribution.

**Table 1:** Descriptive statistical characteristics of trace elements in the soil of main cherry areas Evaluation of Trace Element Index Grades in Soil

| Categories | Soil nutrient indicators | Sample size | Minimum | Maximum | Range | Mean | Standard deviation | Coefficient of variation (%) |
|---|---|---|---|---|---|---|---|---|
| Secondary Elements | CaO (%) | 21 | 1.02 | 6.78 | 5.76 | 3.38 | 1.66 | 49.11 |
| | MgO (%) | 21 | 0.43 | 0.94 | 0.51 | 0.74 | 0.14 | 18.92 |
| | Total S (mg/kg) | 21 | 142.00 | 886.00 | 744.00 | 293.24 | 185.21 | 63.16 |
| Trace elements | Total Cu (mg/kg) | 21 | 13.9 | 27.20 | 13.30 | 20.61 | 4.30 | 20.86 |
| | FeO (%) | 21 | 1.42 | 3.30 | 1.88 | 2.32 | 0.51 | 21.98 |
| | Total Zn (mg/kg) | 21 | 42.20 | 117.00 | 74.80 | 62.06 | 17.57 | 28.31 |
| | Total B (mg/kg) | 21 | 17.60 | 54.60 | 37.00 | 30.73 | 8.00 | 26.03 |
| | Total Mo (mg/kg) | 21 | 0.37 | 1.24 | 0.87 | 0.70 | 0.26 | 37.14 |

**Table 2:** Nutrient content of trace elements in the soil of sweet cherry production areas

| Soil nutrient indicators | Change range | Abundant Level 1 | Relatively abundant Level 2 | Moderate Level 3 | Relatively deficient Level 4 | Deficient Level 5 |
|---|---|---|---|---|---|---|
| CaO (%) | 1.02~6.78 | 3 | 11 | 6 | 1 | 0 |
| MgO (%) | 0.43~0.94 | 0 | 0 | 0 | 16 | 5 |
| Total S (mg/kg) | 142~886 | 5 | 2 | 6 | 3 | 5 |
| Total Cu (mg/kg) | 13.9~27.2 | 0 | 7 | 1 | 11 | 2 |
| FeO (%) | 1.42~3.3 | 0 | 0 | 0 | 0 | 21 |
| Total Zn (mg/kg) | 42.2~117 | 1 | 3 | 6 | 4 | 7 |
| Total B (mg/kg) | 17.6~54.6 | 0 | 0 | 1 | 11 | 9 |
| Total Mo (mg/kg) | 0.37~1.24 | 5 | 6 | 2 | 3 | 5 |

### *Secondary Element*

According to the demand for inorganic elements during crop growth and development, Ca, Mg and S are classified as moderate elements. The content of nutrients in the soil is different in different sweet cherry producing areas of Chifeng (Table 2). According to the nutrient content grading standards of the second national soil survey (Wang *et al.*, 2025; Zhou *et al.*, 2019), there is one with a CaO content ranging from 0.42% to 1.16%, accounting for 4.76%, relatively deficient. Six are between 1.16%-2.68%, accounting for 28.57%, moderate; 11 are between 2.68% and 5.54%, accounting for 52.38%, relatively abundant; there are 3 of >5.54%, accounting for 14.29%, abundant.

There are 5 of MgO ≤ 0.70%, accounting for 23.81%, deficient; 16 between 0.70% and 1.20%, accounting for 76.19%, relatively deficient.

There are 5 of total S ≤ 172mg/kg, accounting for 23.81%, deficient; 3 between 172-219 mg/kg, accounting for 14.29%, relatively deficient; 6 samples between 219-270 mg/kg, accounting for 28.57%, moderate; 2 between 270 and 343 mg/kg, accounting for 9.52%, relatively abundant; 5 between 343 mg/kg, accounting for 23.81%, abundant.

### *Trace Element*

According to the demand for inorganic elements during crop growth and development, Cu, Fe, Zn, B, and Mg are classified as trace elements. The nutrient content of trace element in the soil varies in different main sweet cherry producing areas of Chifeng (Table 2). Based on the nutrient content grading standards of the second national soil survey (Yan *et al.*, 2024; Wang *et al.*, 2023), there are 2 samples with a total copper content of ≤16 mg/kg, accounting for 9.52%, deficient; 11 between 16-

21 mg/kg, accounting for 52.38%, relatively deficient; 1 between 21-24 mg/kg, accounting for 4.76%, moderate; 7 between 24%-29%, accounting for 33.33%, relatively abundant.

There are 21 samples with $Fe_2O_3$ ≤ 3.40 %, accounting for 100%, deficient.

There are 7 samples with total Zn ≤ 50 mg/kg, accounting for 33.33%, deficient; 7 between 50-62 mg/kg, accounting for 19.05%, relatively deficient; 6 between 62-71 mg/kg, accounting for 28.57%, moderate; 3 between 71-84 mg/kg, accounting for 28.57%, moderate; 3 between 71-84 mg/kg, accounting for 14.29%, relatively abundant; 1 with total Zn > 84 mg/kg, accounting for 4.76, abundant.

There are 9 samples with total B ≤ 30 mg/kg, accounting for 42.86%, deficient; 11 between 30-45 mg/kg, accounting for 52.38%, relatively deficient; 1 sample between 45-55 mg/kg, accounting for 4.76%, moderate.

There are 5 samples with total Mo ≤ 0.45 mg/kg, accounting for 23.81%, deficient; 3 between 0.45-0.55 mg/kg, accounting for 14.29%, relatively deficient; 2 between 0.55-0.65 mg/kg, accounting for 9.52%, moderate; 6 between 0.65-0.85 mg/kg, accounting for 28.57%, relatively abundant; 6 between 0.65-0.85 mg/kg, accounting for 28.57%, relatively abundant; 5 with total Mo > 0.85 mg/kg, accounting for 23.81%, abundant.

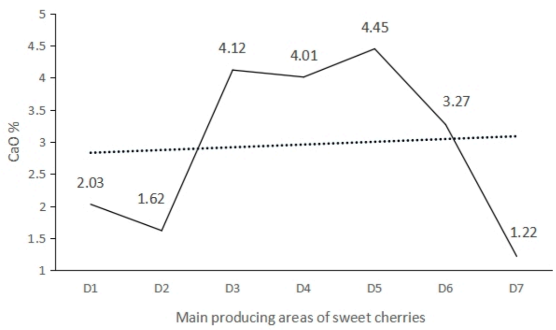


**Fig. 2:** Spatial variation of CaO in the soil from south to north in the main producing areas of sweet cherries


**Fig. 3:** Spatial variation of MgO in the soil from south to north in the main producing areas of sweet cherries


**Fig. 4:** Spatial variation of total S in the soil from south to north in the main producing areas of sweet cherries


**Fig. 5:** Spatial variation of total Cu in the soil from south to north in the main producing areas of sweet cherries

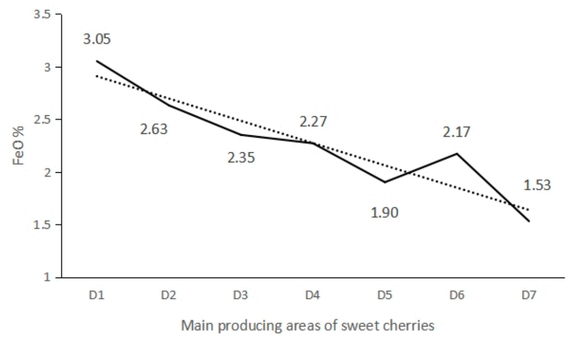


**Fig. 6:** Spatial variation of FeO in the soil from south to north in the main producing areas of sweet cherries

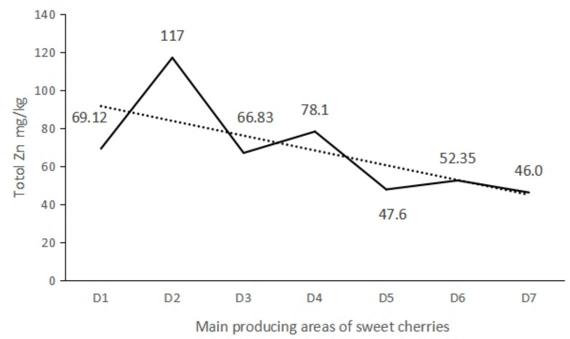


**Fig. 7:** Spatial variation of total Zn in the soil from south to north in the main producing areas of sweet cherries

*Spatial Variation of Soil Elements*

The geographical distribution of Chifeng from south to north is Ningcheng County, Kalaqin Banner, Hongshan District, Songshan District, Aohan Banner, Wengniute Banner, and Linxi County. The indicators increasing in the soil element content from south to north in different main sweet cherry producing areas include CaO (Figure 2), and the other indicators decrease (Figs. 3-9).

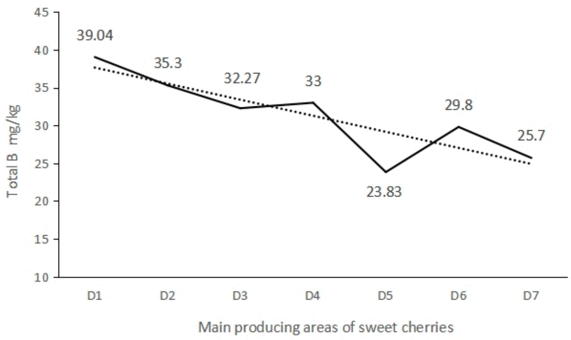


**Fig. 8:** Spatial variation of total B in the soil from south to north in the main producing areas of sweet cherries

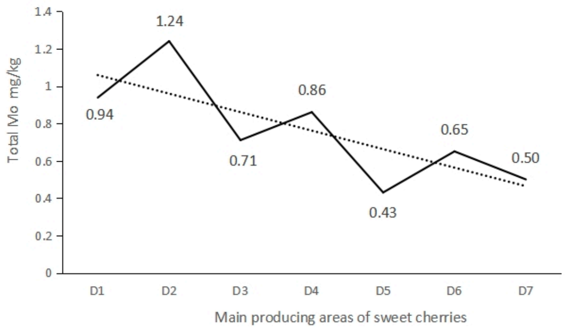


**Fig. 9:** Spatial variation of total Mo in the soil from south to north in the main producing areas of sweet cherries

## Discussion

Soil is the main source of mineral elements and water necessary for the growth of fruit trees, and is the foundation of fruit tree cultivation (Liu & Sun, 2023; Li, 2019). N, P and K are essential elements for plants (Wu *et al.*, 2021), and their deficiency in soil can lead to nutrient deficiencies (Başayiğit *et al.*, 2017), which require corresponding measures for supplementation (Saha, 2018; Zhang *et al.*, 2017). The moderate elements such as Ca, Mg, and S play a crucial role in crop photosynthesis, chlorophyll production, and catalysis of various enzymes in plants (Zheng, 2021). Insufficient supply of trace elements in soil can lead to poor growth of fruit trees, a decrease in fruit quality and yield (Desie *et al.*, 2023). The average of CaO in the sunlight greenhouse sweet cherries of Chifeng is 3.38%, which is level 2 and relatively abundant, that of MgO is 0.74%, classified as level 4 and relatively deficient; that of total S is 293.24 mg/kg, classified as level 2 and relatively abundant. The range of available Ca in the soil of Dalian is 132.6-917.8 mg/kg, insufficient. Abundant Ca in the soil is due to the fact that the previous crop planted in sweet cherry soil was tomato. Local tomato growers realize that Ca can increase the hardness of tomato fruits, which can affect tomato quality and purchase price. Therefore, sufficient Ca fertilizer applied in the early stage results in abundant Ca in the soil. The range of available Mg in the soil is 43.6-101.0 mg/kg, which is insufficient. It was found that facility agriculture growers in Chifeng have not paid enough attention to the role of medium element Mg and the application of Mg fertilizer.

Although the content of trace elements in soil is low, it is an important component of all healthy organisms and is a necessary element for promoting metabolism (Guo *et al.*, 2023). Cu participates in the respiration of plants, affects the absorption and utilization of Fe by crops, and can also improve chlorophyll stability (Sharma *et al.*, 2015). Zn (Mert & Levent, 2015) and Mn mainly act as metal activators for enzymes in plants, playing important roles in carbohydrate metabolism and auxin synthesis, and are closely related to plant photosynthesis (Yan *et al.*, 2022). The average of total Cu in solar greenhouse sweet cherries of Chifeng is 20.61 mg/kg, classified as level 4 and relatively deficient, that of FeO is 2.32%, classified as level 5 and deficient; that of total Zn is 62.06mg/kg, classified as level 3, moderate; that of total B is 30.73 mg/kg, classified as level 4, relatively deficient; that of total Mo is 0.70 mg/kg, classified as level 2 and relatively abundant. In Dalian, the range of available Cu is 0.52-10.8 mg/kg, abundant; that of available Zn varies from 0.6 to 5.1 mg/kg, 50% of severely deficiency; that of available Fe is 7.0-55.8 mg/kg, abundant; that of available B is 0.12-1.2 mg/kg, with 40% of severely deficient. The main reason for Fe deficiency in the soil of Chifeng is that the previous crop is vegetables, and most growers attach low importance to Fe element. However, fruit trees have been planted in Dalian, and their contribution to Fe element is relatively high. Farmers attach great importance to the application and supplementation of Fe fertilizer. Overall, the nutrient levels of trace elements in greenhouse sweet cherry soil in Chifeng are better than those in Dalian.

## Conclusion

Sweet cherry has a high demand for trace elements, and reasonable fertilization can help improve its yield and quality. The content and distribution of trace elements in the soil are influenced by various factors such as climate, terrain, and biology (Zhou *et al.*, 2020). The soil in Chifeng is suitable for the growth of sweet cherries. The content of CaO in different sweet cherry producing areas increases from south to north, while the other indicators decrease. Chifeng is deficient in MgO, but abundant in calcium and sulfur. Mg can promote photosynthesis and prevent leaf yellowing. Base fertilizer can be applied, with 10-20 kilograms of Mg sulfate per acre. It can also be foliar sprayed with 0.2-0.3% magnesium sulfate solution during the growth period, once every 10-15 days. Iron fertilizer can be applied with 5-10 kilograms of ferrous sulfate per mu as base fertilizer, or sprayed with 0.1-0.2% ferrous sulfate solution during the growth period, once every 10-15 days. Scientific fertilization can effectively improve the yield and quality of sweet cherries. In trace elements, except for Zn and Mo, the other indicators are deficient. It is recommended to focus on supplementing trace element fertilizers such as Mg, Cu, and B in the future, especially the application of Fe fertilizers.

## Acknowledgment

We would like to express our heartfelt thanks to all those who have supported and helped us during this period.

## Funding Information

This work was supported by the Key R&D and Achievement Transformation Projects in Inner Mongolia Autonomous Region (2023YFDZ0052); "Youth Science and Technology Talent Development Project in Higher Education Institutions" of Inner Mongolia Autonomous Region (NJYT23078); Research and Planting Technology Development for Chifeng Facility Cherry Industry (2024XNKY083); Analysis of Soil Physical and Chemical Properties of Facility Cherry (2024XNKY127). Soil Borne Disease Biological Control Science Popularization Education Base of Chifeng University; Economic Crop Nutrition and Health Laboratory of Chifeng University, Key Laboratory of Regional Ecological Protection and Agricultural and Animal Husbandry Development of Chifeng University.

## Author's Contributions

**Lijin Qin and Qingxiang Wang:** Designed and performed the experiments, analyzed the data, and prepared the paper.

**Yongli Lv and Junxiang Zhang and Jingsheng Wang:** Participated to collect the materials related to the experiment.

**Yangyang Xu and Dingfang Zhang and Jiahe Zhou:** Designed the experiments and revised the manuscript.

## Ethics

This study complied with ethical guidelines and obtained informed consent.

## Conflict of Interest

There was no potential conflict of interest in the manuscript.

## References

Başayiğit, L., Dedeoğlu, M., Akgül, H., Ucgun, K., & Altındal, M. (2017). Investigation of N Deficiency in Cherry Trees Using Visible and Near-Infrared Spectra Part of the Spectrum in Field Condition. *Spectroscopy and Spectral Analysis*, *37*(1), 293–298.

Bondarenko, P., Yudytska, I., & Alekseeva, O. (2024). Wood age, rootstocks and cultivars drive the formation of productivity and fruit size in sweet cherry. *Canadian Journal of Plant Science*, *104*(1), 13–20. https://doi.org/10.1139/cjps-2023-0069

Desie, E., Muys, B., den Ouden, J., Nyssen, B., Sousa-Silva, R., van den Berg, L., van den Burg, A., van Duinen, G.-J., Van Meerbeek, K., Weijters, M., & Vancampenhout, K. (2023). Impact of black cherry on pedunculate oak vitality in mixed forests: Balancing benefits and concerns. *Forest Ecosystems*, *10*, 100148. https://doi.org/10.1016/j.fecs.2023.100148

Guo, Y., Du, E., Li, B., Xia, N., Wu, X., & de Vries, W. (2023). Significant urban hotspots of atmospheric trace element deposition and potential effects on urban soil pollution in China. *Journal of Cleaner Production*, *415*, 137872. https://doi.org/10.1016/j.jclepro.2023.137872

Li, D. (2019). *Investigation of Soil Nutrients and Optimization Fertilization Experiment in Cherry Orchard, Daiyue District, Tai'an City (In Chinese)*. https://doi.org/10.27277/d.cnki.gsdnu.2019.000034

Li, S., Chen, Y., Wang, J., Lv, L., Li, G., Hao, X., Zang, C., Wang, Y., & Meng, S. (2009). Study on Abundance Evaluation of Available Microelements in Soil in Liaoning Province and Its Grading Criteria (In Chinese.) *Liaoning Agricultural Science*, *2009*(1), 31–38. https://doi.org/10.3969/j.issn.1002-1728.2009.01.010

Liu, K., Zhao, Y., Yu, K., & Zhang, Q. (2009). Investigation on the Nutritional Status of Sweet Cherry Trees and Soil in Protected Areas (In Chinese). *Northern Fruits*, *152*(4), 7–8. https://doi.org/10.3969/j.issn.1001-5698.2009.04.003

Liu, Y., & Sun, S. (2023). The impact of orchard soil fertility management on the growth of fruit tree roots (In Chinese.)*Hebei Agricultural Machinery*, *2023*(24), 84–86. https://doi.org/10.15989/j.cnki.hbnjzzs.2023.24.011

Mert, D., & Levent, B. (2015). Determining the Zn Content of Cherry in Field Using VNIR Spectroscopy. *Spectroscopy and Spectral Analysis*, *35*(2), 355–361. https://doi.org/10.3964/j.issn.1000-0593(2015)02-0355-07

Saha, S. (2018). Group planting of cherry (Prunus avium L.) fosters growth and tree quality is superior to conventional row planting in Germany. *Journal of Forestry Research*, *29*(4), 1099–1110. https://doi.org/10.1007/s11676-017-0506-4

Sharma, B. D., Brar, J. S., Chanay, J. K., Sharma, P., & Singh, P. K. (2015). Distribution of Forms of Copper and their Association with Soil Properties and Uptake in Major Soil Orders in Semi-arid Soils of Punjab, India. *Communications in Soil Science and Plant Analysis*, *46*(4), 511–527. https://doi.org/10.1080/00103624.2014.997388

Wang, H., Wang, J., Ma, R., & Zhou, W. (2025). Spatial differentiation and influencing factors of soil nutrients and trace elements in characteristic agricultural areas of the Loess Plateau. *31*(6), 1292–1304. https://doi.org/10.13745/j.esf.sf.2024.12.129

Wang, L., Zhao, W., Wang, S., Huang, Y., Li, J., & Wang, L. (2023). Content and variation characteristics of total nutrient elements in different soil layers of jujube garden in arid area of Xinjiang (In Chinese.) *Nonwood Forest Research*, *41*(1), 86–96. https://doi.org/10.14067/j.cnki.1003-8981.2023.01.009

Wu, F., Qu, D., Tian, W., Wang, M., Chen, F., Li, K., Sun, Y., Su, Y., Yang, L., Su, H., & Wang, L. (2021). Transcriptome analysis for understanding the mechanism of dark septate endophyte S16 in promoting the growth and nitrate uptake of sweet cherry. *Journal of Integrative Agriculture*, *20*(7), 1819–1831. https://doi.org/10.1016/s2095-3119(20)63355-x

Xiao, Q., Cui, J., Huang, X., Yu, J., & Liu, Y. (2023). Management Techniques for Facility Cultivation of Warm Sheded Cherry in High Cold Regions (In Chinese.) *Rural Science & Technology*, *2023*(5), 47–51. https://doi.org/10.19777/j.cnki.issn1002-6193.2023.05.016

Xin, Y., Chen, Y., Zheng, H., Li, H., & L, C. (2013). Soil conditions, fertilization strategies, and effectiveness evaluation of cherry orchards in the suburbs of Beijing (In Chinese.) *Northern Fruits*, *174*(2), 4–6. https://doi.org/10.3969/j.issn.1001-5698.2013.02.002

Yan, H., Yuan, Z., Zhang, C., Guo, T., Jiang, Y., Xu, H., Wu, C., & Zhang, Y. (2024). The spatial distribution characteristics and fertility assessment of soil nutrients in jujube-producing regions in southern Xinjiang (In Chinese.) *Nonwood Forest Research*, *42*(2), 257–266. https://doi.org/10.14067/j.cnki.1003-8981.2024.02.025

Yan, M., Chen, X., Cao, R., Lin, C., Wu, Q., Huang, D., Wu, H., & Chen, Z. (2022). The Distribution Characteristics of Soil Mn and Zn in Typical White Tea Plantation in Fujian Province (In Chinese.) *Journal of Ecological Environment*, *31*(5), 885–895. https://doi.org/10.16258/j.cnki.1674-5906.2022.05.004

Zhang, C., Yao, L., Liu, Z., Wang, L., Shan, H., & Xin, S. (2017). Application of Landfill Composed of Biogas Residue and Slurry in Cherry Production (In Chinese.) *Agricultural Science & Technology*, *18*(4), 611–614. https://doi.org/10.16175/j.cnki.1009-4229.2017.04.011

Zheng, W. (2021). Analysis on Soil Chemical Properties of Sweet Cherry in Greenhouses of Dalian (In Chinese.) *Northern Fruits*, *224*(4), 6–8. https://doi.org/10.16376/j.cnki.bfgs.2021.04.002

Zhou, J., Zhang, Y., Yuan, M., Jiang, J., Li, Y., Chen, Z., Dou, Z., & Gao, H. (2019). Study on Grade Evaluation and Spatial Variability of Soil Macro Elements and Trace Elements in Facility Agriculture (In Chinese.) *Anhui Agricultural Science Bulletin*, *25*(8), 74–77. https://doi.org/10.3969/j.issn.1007-7731.2019.08.029

Zhou, W., Han, G., Liu, M., Song, C., Li, X., & Malem, F. (2020). Vertical Distribution and Controlling Factors Exploration of Sc, V, Co, Ni, Mo and Ba in Six Soil Profiles of The Mun River Basin, Northeast Thailand. *International Journal of Environmental Research and Public Health*, *17*(5), 1745. https://doi.org/10.3390/ijerph17051745