Open Journal of Ecology, 2023, 13, 334-344
https://www.scirp.org/journal/oje
ISSN Online: 2162-1993
ISSN Print: 2162-1985

Effects of Different Planting Years on Physicochemical Properties and Enzyme Activities in Soil of Rice-Cherry Tomato Rotation

Xiao Deng[1,2,3,4,5]*, Chunyuan Wu[1,2,3,4,5], Yi Li[1,2,3,4,5], Huadong Tan[1,2,3,4,5], Jiancheng Su[6]

[1]Environmental and Plant Protection Institute, Chinese Academy of Tropical Agricultural Sciences, Haikou, China
[2]Hainan Danzhou Tropical Agro-Ecosystem National Observation and Research Station, Danzhou, China
[3]Key Laboratory of Low-Carbon Green Agriculture in Tropical Region of China, Ministry of Agriculture and Rural Affairs, Haikou, China
[4]Hainan Key Laboratory of Tropical Eco-Circular Agriculture, Haikou, China
[5]National Agricultural Experimental Station for Agricultural Environment, National Long-Term Experimental Station for Agriculture Green Development, Danzhou, China
[6]Hainan Star Farmer Ecological Technology Co., Ltd., Haikou, China
Email: *dx0928@foxmail.com

How to cite this paper: Deng, X., Wu, C.Y., Li, Y., Tan, H.D. and Su, J.C. (2023) Effects of Different Planting Years on Physicochemical Properties and Enzyme Activities in Soil of Rice-Cherry Tomato Rotation. *Open Journal of Ecology*, **13**, 334-344.
https://doi.org/10.4236/oje.2023.136021

Received: April 25, 2023
Accepted: June 11, 2023
Published: June 14, 2023

Abstract

Crop rotation periodicity has always been one of the research focuses currently. In this study, the physicochemical properties, nutrient contents and enzyme activities were investigated in soils from rice-cherry tomato rotation for one year (1a), three years (3a), five years (5a), seven years (7a) and ten years (10a), respectively. The major objective was to analyze the optimal rotation years of rice-cherry tomato from soil perspective, so as to provide theoretical basis for effectively avoiding continuous cropping obstacles of cherry tomato via studying the response characteristics of soil physicochemical properties, nutrient contents and enzyme activities to planting years of rice-cherry tomato rotation system. The results were as follows: 1) Soil pH value was increased year by year during 1a to 5a, reached the highest value 5.32 at 5a. However, soil acidity was sharply enhanced during 7a to 10a ($P < 0.05$), the pH value began to decline below 5.0 at 7a of rice-cherry tomato rotation. 2) The content of soil organic matter decreased by 11.2% to 50.4% with the increasing of crop rotation years during 3a to 10a ($P < 0.05$), and began to reduce below 2.0 $g \cdot kg^{-1}$ at 5a. 3) The content of soil available phosphorus was increased year by year with increasing of crop rotation years, and increased by 110% to 173% during 3a to 10a ($P < 0.05$). However, the contents of soil available iron and available zinc decreased gradually with increasing of crop rotation years, and decreased by 17.2% to 53.2% and14.9% to 23.9%, respectively, during 3a to 10a ($P < 0.05$). 4) The activities of soil urease, acid phosphatase and catalase were all the highest at 5a. However, those were obviously decreased year by year after 5a of rice-cherry tomato rotation ($P < 0.05$). In conclusion, long-term single rotation pattern of rice-cherry tomato would aggravate soil acidification, prompt soil nutrient imbalance and reduce soil enzyme activity. 5a to 7a would be the appropriate rotation period for rice-cherry tomato, or else it would reduce soil quality, resulting in a new continuous cropping obstacle of cherry tomato.

Keywords

Rice-Cherry Tomato Rotation, Planting Years, Soil, Physicochemical Properties, Enzyme Activity

1. Introduction

Cherry tomato (*Lycopersicon esulentum* Mill) is one of the most important vegetables or fruit due to increasing international demands, great economic value, and massive nutritional benefits [1]. Since 1997, its planting area has been expanding and it has become the pillar industry of Lingshui County, Hainan Province, China. However, the soil quality is gradually deteriorating due to the long-term continuously cultivation of rice-cherry tomato rotation, which has become a bottleneck restricting the sustainable development of cherry tomato industry [2]. Previous studies have shown that the continuous cropping obstacles have significant adverse effects on plant growth and development, which mainly manifest in weaker photosynthesis, retarded growth, reduced resistance, and decreased yield and harvest quality [3] [4] [5]. There are many reasons for continuous cropping obstacles, such as soil nutrient imbalance, accumulation of toxic allelopathic substances, propagation of soil-borne pathogens, destruction of soil microbial community, etc. [3] [6]. It is also believed that the causes of continuous cropping obstacles vary markedly among different crops, and the underlying mechanism depends on soil characteristics [3]. Appropriate crop rotation can alleviate continuous cropping obstacles via regulating nutrition and water balance, improving soil enzyme activity, preventing and controlling diseases, pest insects, weeds etc. [7] [8] [9]. However, previous studies have shown that different rotation years have different effects on soil properties improvement [10]. To date, there is limited information for the effects of long-term rotation between the same crops on soil properties. It is lacking for the effects of long-term continuously cultivation of rice-cherry tomato rotation on soil physicochemical properties, nutrient contents and enzyme activities. To study the periodicity of single crop rotation pattern and determine the reasonable crop rotation years according to local conditions is a problem that the majority of researchers have been concerned about. Therefore, in this study, soils from rice-cherry tomato rotation for one year (1a), three years (3a), five years (5a), seven years (7a) and ten years (10a) were selected to as study objects, the major objective was to analyze the optimal rotation years of rice-cherry tomato from soil perspective, so as to provide theoretical basis for effectively avoiding continuous cropping obstacles of cherry tomato via studying the response characteristics of soil physicochemical properties, nutrient contents and enzyme activities to planting years of long-term single cultivation pattern of rice-cherry tomato rotation.

2. Materials and Methods

2.1. Description of Study Area

The plots of rice-cherry tomato rotation for 1 year (1a), 3 years (3a), 5 years (5a), 7 years (7a) and 10 years (10a) were respectively selected to as the study area in Guangpo Town, Lingshui County, Hainan Province, China. Three plots were selected to as triple repetitions in each crop rotation year. And the cherry tomato variety, cultivation conditions and management methods of each plot was basically consistent. The soil type of 15 plots is all paddy soil developed from laterite, which texture is all sandy loam. The study area has a typical tropical maritime monsoon climate with sufficient light and heat conditions and the annual precipitation is approximately 1718 mm, and the annual average sunshine duration is approximately 2262 hours. The mean annual air temperature is 25.4˚C, with a minimum temperature 20.6˚C in January and a maximum temperature 28.6˚C in June.

2.2. Soil Sample Collection

Soil samples were taken from 0 - 20-cm tillage layer during the flowering fruit-bearing stage of cherry tomato in mid-January 2022. To avoid effects from adjacent plots, samples were taken from the core area of each plot from five points using the equidistant sampling method. The samples were well mixed into one composite sample (about 500 g per plot), sealed in sterile bags, and transported in an ice cube-filled box to the laboratory within two days. A total of 15 soil samples were obtained for subsequent analysis. Each soil sample was divided into two parts. One subsample was air-dried, passed through a 2-mm sieve to remove large particles and plant debris, and then analyzed for soil pH. The subsample was then sieved again (<0.15 mm) and used for analyses of other physicochemical properties. The second subsample was stored at 4˚C and then used for detecting soil enzyme activities.

2.3. Analyses of Soil Physicochemical Properties and Enzyme Activities

Soil pH, organic matter (OM), alkali-hydrolyzed nitrogen (AN), available P (AP), and available K (AK), were measured using routine methods described by Lu [11]. Soil pH was measured using a pH electrode (Leici, Shanghai, China) at a soil: water ratio of 1:2.5. The OM content was measured using a potassium dichromate volumetric method. The AN, AP, and AK contents were analyzed using a diffusion method, the Olsen method, and ammonium acetate extraction flame photometry, respectively. The contents of exchangeable calcium (Ca) and exchangeable magnesium (Mg) were analyzed by atomic absorption spectrophotometry. The content of available sulfur (AS) was determined by phosphate-acetic acid-barium sulfate turbidimetric method. The contents of available iron (Fe), available zinc (Zn) and available copper (Cu) were determined by DTPA extraction and atomic absorption spectrophotometry. The available manganese (Mn) was determined by ammonium acetate extraction and atomic absorption spectrophotometry. The available boron (B) was determined by boiling water extraction and curcumin colorimetry. The activities of soil urease, catalase and acid phosphatase were determined by kit (Suzhou Keming Biotechnology Co., LTD.).

2.4. Statistical Analyses

Data from replicates are expressed as the mean ± standard deviation (SD). Statistical analyses of the experimental data including averages, standard deviations and other significance were performed using SPSS v.17.0 software package (IBM Corp., Armonk, NY, United States). Statistical significance was kept at $P < 0.05$ for all analyses, and the error bars in each figure represented the standard deviation.

3. Results and Discussion

3.1. Effects of Different Rotation Years of Rice-Cherry Tomato on Soil Physicochemical Properties

3.1.1. pH and Organic Matter

The soil pH value was increased year by year during 1a to 5a (**Figure 1(a)**), reached the highest value of 5.32 at 5a. However, it was sharply reduced at 7a, dropped below 5.0. And soil acidity was sharply enhanced during 7a to 10a ($P <$ 0.05). The inflow of cations was limited after decreasing of soil pH, which leading to a significant reduction in the adsorption capacity of K^+, Ca^{2+}, Mg^{2+} and other nutrient ions, and accelerated leaching of soil nutrients [12]. Soil organic carbon can be used as an ideal indicator to assess soil quality and health. The OM content affects the potential for the sequestration of soil nutrients, especially N, by altering cation exchange capacity and mineralisation-immobilisation turn over. In this study, the soil OM content was obviously decreased by 11.2% to 50.4% with the increase of rotation years (**Figure 1(b)**), during 3a to 10a ($P <$ 0.05). Notably, the content of soil organic matter was began to reduce below 2 $g \cdot kg^{-1}$ at 5a of rice-cherry tomato rotation ($P < 0.05$), which would not be suitable for the growth and development of crops.

3.1.2. Macro Nutrients

The influence of the contents of AN, AP and AK on the plant growth and development is very great. It can be seen from **Figure 2(a)** that the soil AN contents were significantly increased by 24.4% to 60.4% during 3a to 5a ($P < 0.05$).

And there was no significant difference between during 7a to 10a and at 1a. However, they were all at the enrichment level. The soil AP contents were all very high at different rotation years and significantly increased year by year with the extension of rotation years ($P < 0.05$), especially increased by 110% to 173% during 3a to 10a (**Figure 2(b)**). The soil AK contents were also very high at different rotation years, and increased year by year with the increase of rotation years during 3a to 7a, with the increase rate of 36.1% at 7a (**Figure 2(c)**).

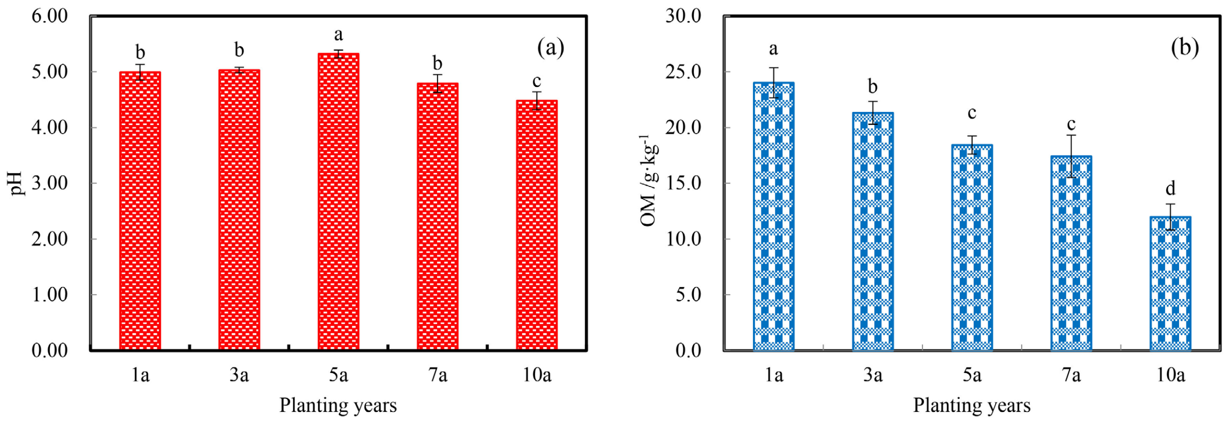

Figure 1. The pH and OM contents in soils from different rotation years of rice-cherry tomato. Different lowercases indicate significant differences at $P < 0.05$ level.

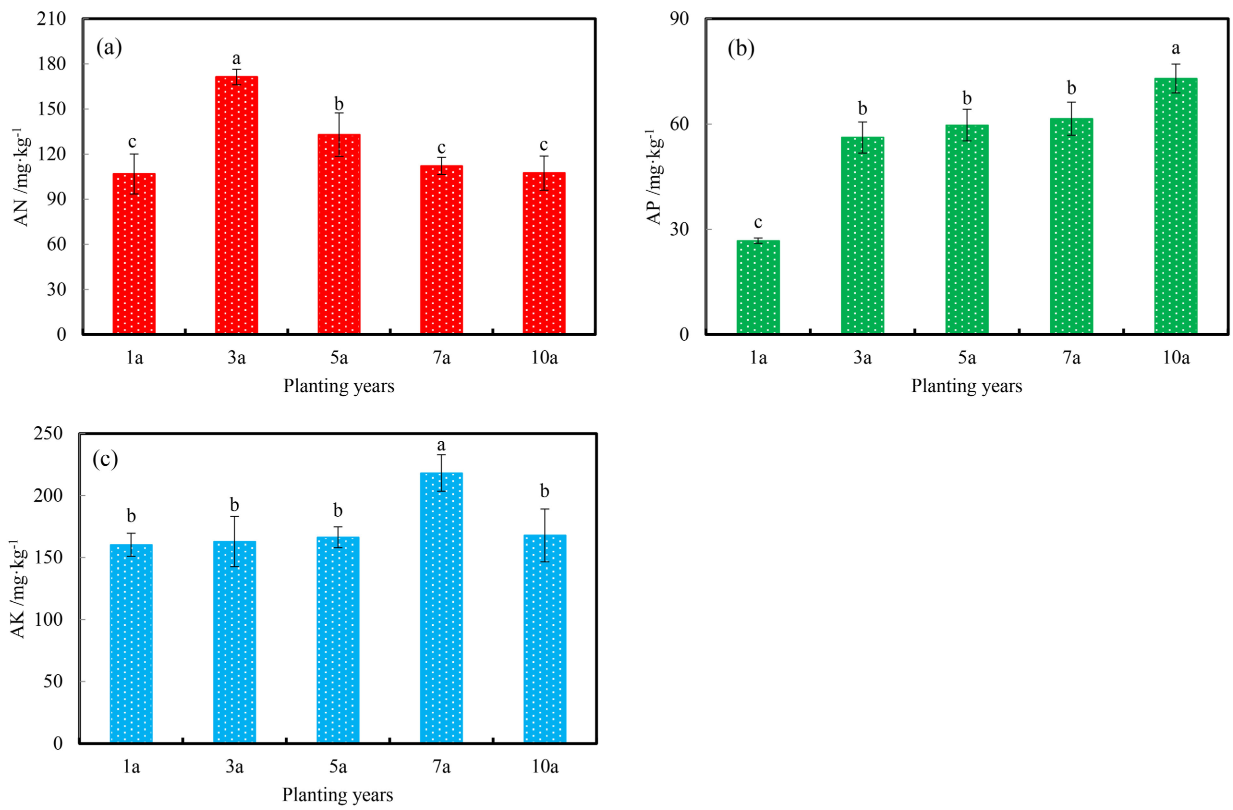

Figure 2. The contents of macro nutrients in soils from different rotation years of rice-cherry tomato. Different lowercases indicate significant differences at $P < 0.05$ level.

3.1.3. Medium Nutrients

The medium nutrients of Ca, Mg and S, as essential nutrient elements of crops, play an extremely important role in the growth and development of crops, especially the macro elements were applied a lot, exacerbates the imbalance among nutrients. The content of soil available Ca was significantly increased by 27.3% to 111% during 3a to 7a ($P < 0.05$), but the increase rate was gradually decreased with the increase of rotation years (**Figure 3(a)**). The content of soil available Ca was lower than the critical value (400 $mg \cdot kg^{-1}$) required for crop growth at 10a. The contents of soil available Mg were significantly increased by 287% to 354% during 3a to 10a ($P < 0.05$). However, which was all lower than the critical value (60 $mg \cdot kg^{-1}$) required for crop growth (**Figure 3(b)**). The content of soil available S was significantly increased at 3a. However, that was significantly decreased during 5a to 10a and were all lower than the critical value (16 $mg \cdot kg^{-1}$) required for crop growth and development during 1a to 10a (**Figure 3(c)**).

3.1.4. Micro Nutrients

The available state of micro nutrients is the part that can be directly absorbed and utilized by plants, which has a direct effect on improving crop yield and quality. **Figure 4(a)** showed that the contents of soil available Fe were decreased

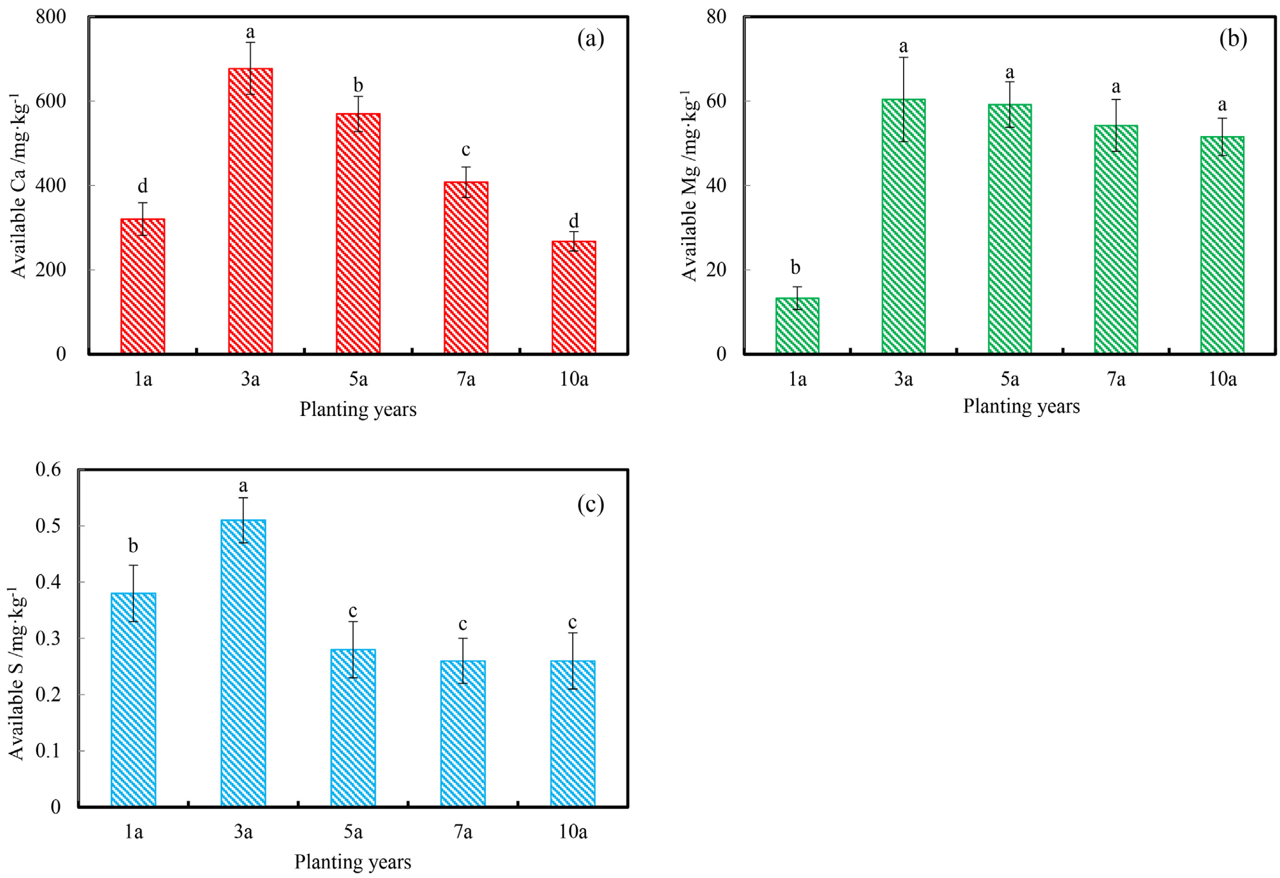

Figure 3. The contents of medium nutrients in soils from different rotation years of rice-cherry tomato. Different lowercases indicate significant differences at $P < 0.05$ level.

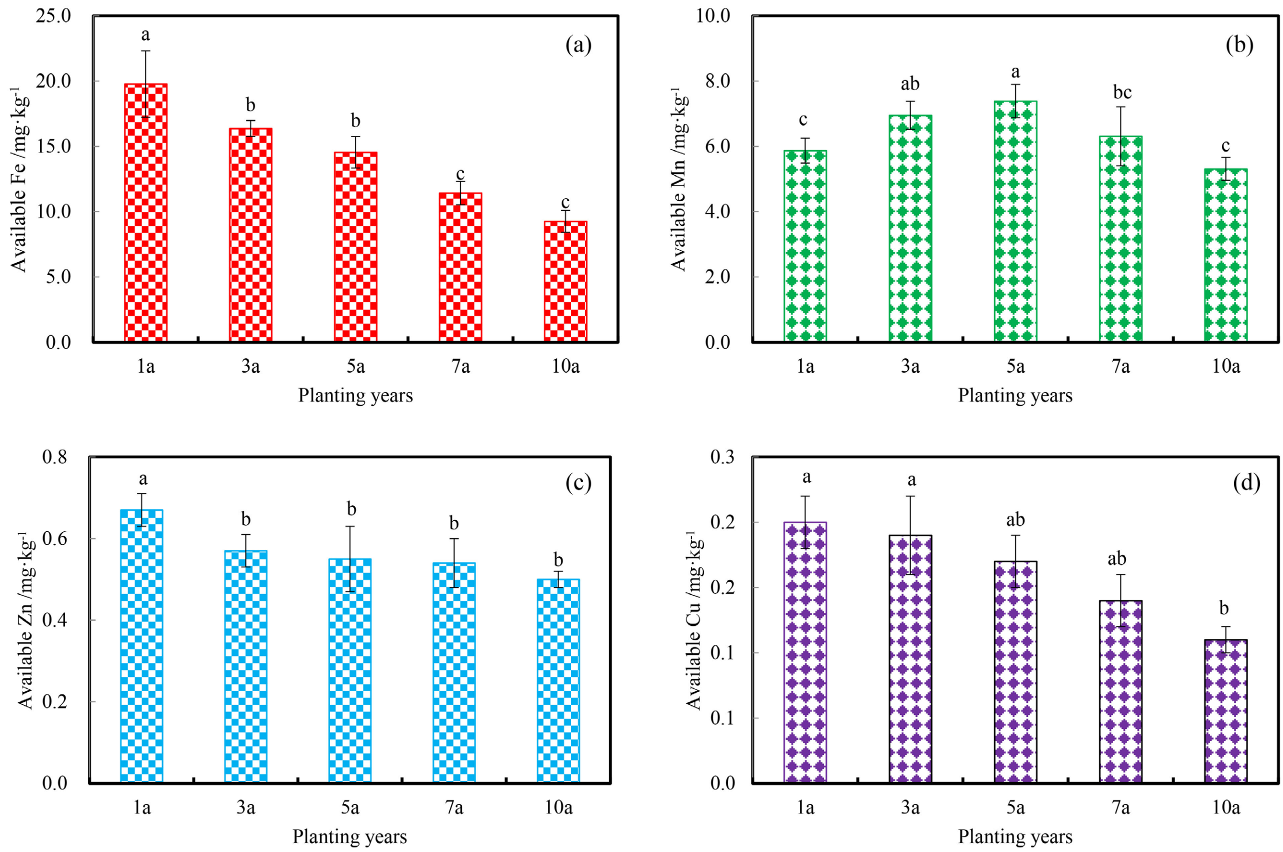

Figure 4. The contents of micro nutrients in soils from different rotation years of rice-cherry tomato. Different lowercases indicate significant differences at $P < 0.05$ level.

year by year with the extension of rotation years during 1a to 10a, with the decrease rate of 14.9% to 23.9%. The contents of available Mn were significantly increased by 18.2% to 25.7% during 3a to 5a. And there was no significant difference between during 7a to 10a and at 1a, and both were at medium level (**Figure 4(b)**). **Figure 4(c)** and **Figure 4(d)** showed that the contents of soil available Zn and available Cu were decreased year by year with the extension of rotation years during 1a to 10a, with the decrease rate of 5.00% to 40.0% and 17.2% to 53.2%, respectively. Soil available Fe and available Zn were all not deficient for the crop growth and development during 1a to 10a. However, Available Cu was deficient during 3a to 10a. The contents of soil available B were not changed significantly during 1a to 10a of rice-cherry tomato rotation and always remained at the deficiency level.

3.2. Effects of Different Rotation Years of Rice-Cherry Tomato on Soil Enzyme Activities

Soil enzyme is one of the most active parts of soil components. Soil enzyme activities play a key role in nutrients recycling [13] [14] [15] [16]. Soil urease activity reflects the intensity of nitrogen metabolism and conversion in soil. Soil phosphatase can enzymatically decompose various organophosphorus compounds and provide available phosphorus for plant growth [17]. Soil catalase can quickly transform waste generated by soil metabolism into harmless or less toxic substances, and reduce the toxicity of excessive accumulation of hydrogen peroxide to soil microorganisms and plant roots [18] [19]. Previous studies have shown that reasonable crop rotation can increase soil enzyme activity [20] [21]. In this study, the activities of soil urease, acid phosphatase and catalase were all increased year by year during 1a to 5a, reached the highest at 5a, but sharply decreased after 5a (**Figures 5(a)-(c)**). The activities of soil urease, acid phosphatase and catalase were significantly increased by 72.2% to 91.7%, 11.5% to 73.4%, and 9.67% to 11.6%, respectively, during 3a to 5a ($P < 0.05$). However, compared with 5a, those were decreased by 56.0% to 63.6%, 27.6% to 34.2% and 26.5% to 37.4%, respectively, during 7a to 10a ($P < 0.05$). It's worth noting that the soil catalase activity was significantly enhanced at 5a, which was beneficial to reduce the autotoxic effect of cherry tomato continuous planting. The three kinds of soil enzyme activities were 5a > 3a > 1a > 7a > 10a, 5a > 7a > 10a > 3a > 1a and 5a > 7a > 3a > 1a > 10a, respectively. The above results indicated that declining on activities of urease, acid phosphatase and catalase will cause the continuous cropping obstacles after 5a of rice-cherry tomato rotation. Because the decrease of soil enzyme activity is one of the important factors causing crop continuous cropping obstacles [22].

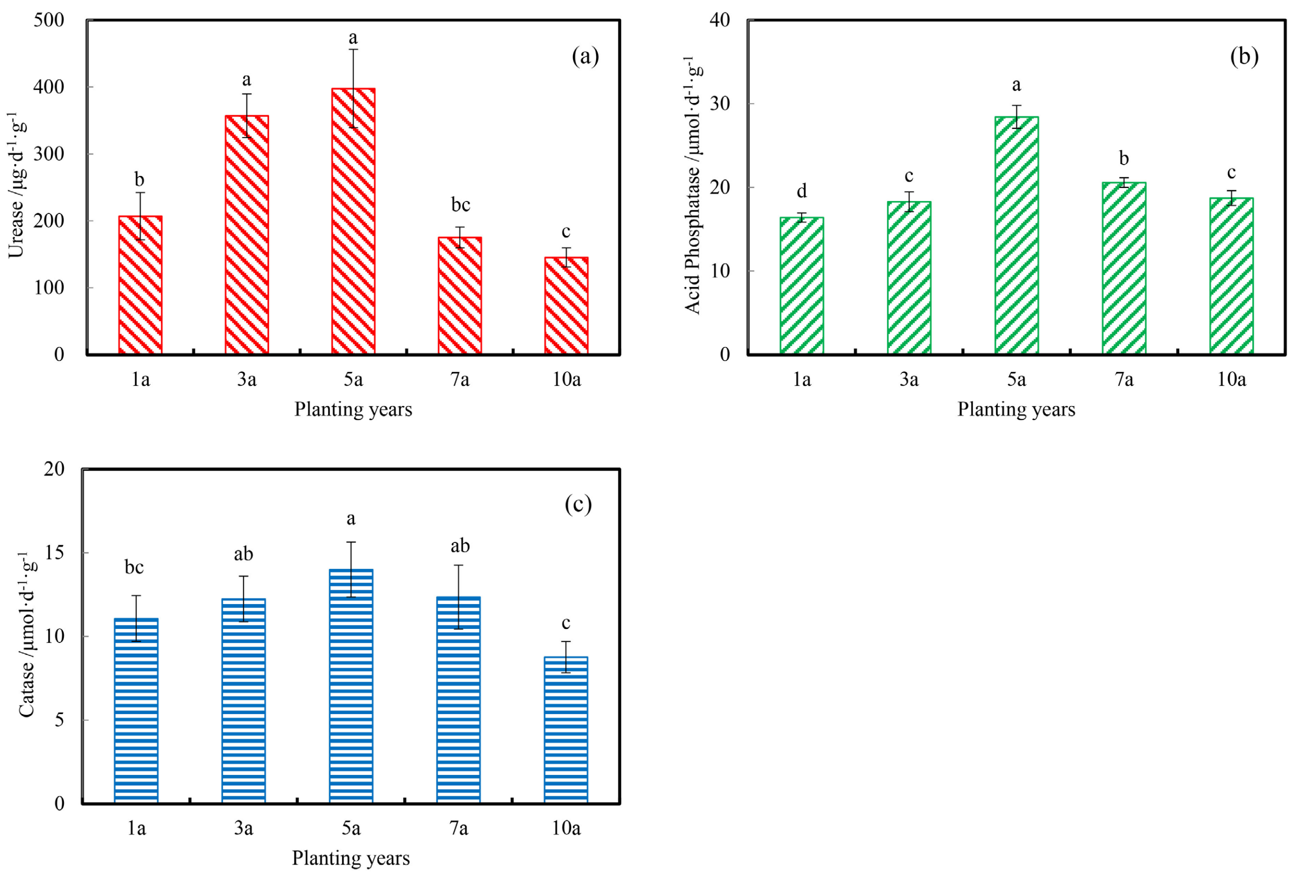

Figure 5. Enzyme activities in soils from different rotation years of rice-cherry tomato. Different lowercases indicate significant differences at $P < 0.05$ level.

4. Conclusion

Soil acidity was sharply enhanced during 7a to 10a, the pH value began to decline below 5.0 at 7a of rice-cherry tomato rotation. The contents of soil organic matter, available iron and available zinc decreased year by year, while that of available phosphorus increased year by year with the extension of crop rotation years. The content of soil organic matter began to decline below 2.0 $g \cdot kg^{-1}$ at 5a of rice-cherry tomato rotation. The activities of soil urease, acid phosphatase and catalase were all the highest at 5a. Therefore, it is concluded that long-term single rotation pattern of rice-cherry tomato would aggravate soil acidification, prompt soil nutrient imbalance and reduce soil enzyme activity, and 5a to 7a would be the potential rotation years to avoid or alleviate the continuous cropping obstacle of cherry tomato.

Acknowledgements

This work was supported by the Hainan Province Science and Technology Special Fund of China [Grant No. ZDYF2021XDNY137 and Grant No. ZDYF2022XDNY212]. We thank anonymous reviewers for their very helpful suggestions. We thank LetPub (https://www.letpub.com/) for linguistic assistance and pre-submission expert review.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Dai, Y.Q., Wang, Z., Li, J., *et al.* (2023) Tofu By-Product Soy whey Substitutes Urea: Reduced Ammonia Volatilization, Enhanced Soil Fertility and Improved Fruit Quality in Cherry Tomato Production. *Environmental Research*, **226**, Article ID: 115662. https://doi.org/10.1016/j.envres.2023.115662

[2] Zhu, Q.S. (2017) Grafting Culture Technology of Cherry Tomato in Lingshui County. *China Agricultural Technology Extension*, **33**, 32-33. (In Chinese)

[3] Ma, Z.M., Guan, Z.J., Liu, Q.C., Hu, Y., Liu, L., Wang, B., Huang, L., Li, H., Yang, Y., Han, M., Gao, Z. and Saleem, M. (2023) Chapter Four-Obstacles in Continuous Cropping: Mechanisms and Control Measures. *Advances in Agronomy*, **179**, 205-256. https://doi.org/10.1016/bs.agron.2023.01.004

[4] Ali, A., Ghani, M.I., Ding, H., Iqbal, M., Cheng, Z. and Cai, Z. (2021) Arbuscular Mycorrhizal Inoculum Coupled with Organic Substrate Induces Synergistic Effects for Soil Quality Changes, and Rhizosphere Microbiome Structure in Long-Term Monocropped Cucumber Planted Soil. *Rhizosphere*, **20**, Article ID: 100428. https://doi.org/10.1016/j.rhisph.2021.100428

[5] Chen, P., Wang, Y.Z., Liu, Q.Z., *et al.* (2020) Phase Changes of Continuous Cropping Obstacles in Strawberry (*Fragaria* × *ananassa* Duch.) Production. *Applied Soil Ecology*, **155**, Article ID: 103626. https://doi.org/10.1016/j.apsoil.2020.103626

[6] Zhao, F., Zhang, Y., Li, Z., Shi, J., Zhang, G., Zhang, H. and Yang, L. (2020) Vermicompost Improves Microbial Functions of Soil with Continuous Tomato Cropping

in a Greenhouse. *Journal of Soils and Sediments*, **20**, 380-391. https://doi.org/10.1007/s11368-019-02362-y

[7] Wang, F.Y., Zhang, X.M., Wei, M.T., *et al.* (2022) Appropriate Crop Rotation Alleviates Continuous Cropping Barriers by Changing Rhizosphere Microorganisms in *Panax notoginseng*. *Rhizosphere*, **23**, Article ID: 100568. https://doi.org/10.1016/j.rhisph.2022.100568

[8] Chongtham, I.R., Bergkvist, G., Watson, C.A., *et al.* (2016) Factors Influencing Crop Rotation Strategies on Organic Farms with Different Time Periods since Conversion to Organic Production. Biol. *Biological Agriculture & Horticulture*, **33**, 14-27. https://doi.org/10.1080/01448765.2016.1174884

[9] Larkin, R.P. (2015) Soil Health Paradigms and Implications for Disease Management. *Annual Review Phytopathology*, **53**, 199-221. https://doi.org/10.1146/annurev-phyto-080614-120357

[10] Liu, H.F., Han, H.W., Wang, Q., *et al.* (2021) Effect of Vegetables-Tomato Rotation on Soil Microbial Diversity, Enzyme Activity and Physicochemical Properties of Vegetables in Greenhouse. *Acta Microbiologica Sinica*, **61**, 167-182. (In Chinese)

[11] Lu, R.K. (2000) Analytical Methods of Soil and Agro-Chemistry. China Agricultural Science and Technology Press, Beijing. (In Chinese)

[12] Du, C., Wu, X., Yan, L., *et al.* (2019) Effects of Boron on Contents of Elements and Activities of H+ Related Enzymes at Different Parts of Trifoliate Seedlings in Low pH Environment. *Journal of Huazhong Agricultural Unversity*, **38**, 47-52. (In Chinese)

[13] Nie, Z., Qin, S., Liu, H., *et al.* (2020) Effects of Combined Application of Nitrogen and Zinc on Winter Wheat Yield and Soil Enzyme Activities Related to Nitrogen Transformation. *Journal of Plant Nutrition and Fertilizers*, **6**, 431-441. (In Chinese)

[14] Yu, P.J., Liu, S.W., Han, K.X., Guan, S. and Zhou, D. (2017) Conversion of Cropland to Forage Land and Grassland Increases Soil Labile Carbon and Enzyme Activities in Northeastern China. *Agriculture*, *Ecosystems & Environment*, **245**, 83-91. https://doi.org/10.1016/j.agee.2017.05.013

[15] Raiesi, F. and Salek-Gilani, S. (2018) The Potential Activity of Soil Extracellular Enzyme as an Indicator for Ecological Restoration of Rangeland Soils after Agricultural Abandonment. *Applied Soil Ecology*, **126**, 140-147. https://doi.org/10.1016/j.apsoil.2018.02.022

[16] Ai, C., Liang, G., Sun, J., He, P., Tang, S., Yang, S., Zhou, W. and Wang, X. (2015) The Alleviation of Acid Soil Stress in Rice by Inorganic or Organic Ameliorants Is Associated with Changes in Soil Enzyme Activity and Microbial Community Composition. *Biology and Fertility of Soils*, **51**, 465-477. https://doi.org/10.1007/s00374-015-0994-3

[17] Kromer, S. and Green, D.M. (2000) Acid and Alkaline Phosphatase Dynamics and Their Relationship to Soil Microclimate in a Semiarid Woodland. *Soil Biology & Biochemistry*, **32**, 179-188. https://doi.org/10.1016/S0038-0717(99)00140-6

[18] Gao, Z., Wang, D., Niu, L., *et al.* (2019) Catalase Activities in Salinized Rehabilitation Area of the Southern Hebei Plain. *Chinese Journal of Soil Science*, **50**, 1434-1441. (In Chinese)

[19] Yu, Y., Li, L., Yu, L., Lin, B., Chen, X., Li, H., Han, Q., Ge, Q. and Li, H. (2017) Effect of Exposure to Decabromodiphenyl ether and Tetrabromobisphenol A in Combination with Lead and Cadmium on Soil Enzyme Activity. *International Biodeterioration & Biodegradation*, **117**, 45-51. https://doi.org/10.1016/j.ibiod.2016.10.032

[20] Li, W., Cheng, Z.H., Meng, H.W., Zhou, J., Liang, J. and Liu, X.J. (2012) Effect of Rotating Different Vegetables on Micro-Biomass and Enzyme in Tomato Continuous Cropped Substrate and after Culture Tomato under Plastic Tunnel Cultivation. *Acta Horticulturae Sinica*, **39**, 73-80. (In Chinese)

[21] Dong, Y., Lu, Y., Dong, K. and Tang, L. (2010) Effect of Rotation Patterns on Soil Microbial Community and Enzyme Activities under Protected Cultivation. *Chinese Journal of Soil Science*, **41**, 53-55.

[22] Huo, L., Yang, S., Wang, C., *et al.* (2018) Effects of Continuous Cucumber Cropping on Soil Microbial Diversity and Enzyme Activity. *Gansu Agricultural Sciences and Technology*, No. 10, 30-36. (In Chinese)