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Effect of Soil Fertilizer Application on Soil Nutrient Migration and Tea Quality of Plateau-Puerh Tea

Hao Zhang[1,2], Chunyu Dong[1,2], Lingyu Meng[1,2], Lijuan Reng[1,2], Jiaqi Li[1,2], Naiming Zhang[1,2], Li Bao[1,2*]

[1]College of Resources and Environment, Yunnan Agricultural University, Kunming, China
[2]Yunnan Engineering Laboratory of Soil Fertility and Pollution Remediation, Kunming, China
Email: *1130156335@qq.com

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Abstract

In order to solve the problem of chemical fertilizer application balance of Pu'er tea in Taiwan, the effects of different fertilization treatments on land nutrient migration and tea quality were explored, and the basis for rational fertilization of tea gardens was provided. In this study, the effects of different fertilization treatments on tea quality indexes were studied by three different sets of fertilization treatments in tea gardens. Three sets of different fertilization treatments were set up in the experiment: conventional fertilization treatment (T1), slow-release fertilizer reduction by 20% (T2) and slow-release fertilizer reduction by 30% (T3), and the quality index of tea under different fertilization treatments, as well as the alkaline nitrogen, available phosphorus and total nitrogen and total phosphorus content in surface water of the soil were measured and analyzed. The results showed that: 1) compared with T1, the soil available phosphorus in T3 decreased by 23.5%, and the alkalinelyzed nitrogen increased by 20.5%; 2) compared with T1, the total nitrogen and total phosphorus concentrations of surface water in the T2 and T3 treatments were at a low level compared with T1; compared with T1, T2 decreased by 71.4%, and T3 decreased by 68.6%; 3) compared with T1, T3 was able to maintain the quality indicators of amino acids, tea polyphenols and soluble sugars in tea in a high and stable range. Therefore, under the condition of conventional fertilization and reduction, a 30% reduction in slow-release fertilizer is currently more suitable for the fertilization technology of Menghai County Tea Garden.

Keywords

Slow Release of Fertilizer, Fertilization Mode, Tea Quality, Nutrient

Migration, Reduction of Efficiency

1. Introduction

Tea, one of the three most popular non-alcoholic drinks in the world (Wang, 2020), has been drunk since ancient times. China is the origin of tea and one of the important cash crops in China, which plays an important role in agricultural cash crops (Zhang & Su, 2007). According to statistics, the planting area of tea trees in China reached over 2.6 million hectares in 2015, and the annual tea output reached over 2 million tons, both ranking first in the world (Ni et al., 2019). With the increasing popularity of tea planting, many countries have begun to export tea products and tea culture, and China's tea market is facing such a huge challenge (Shi et al., 2021). In order to enhance the international competitiveness of Chinese tea, it is necessary to develop tea products with local characteristics, and form a green and harmonious tea planting environment while improving the quality of tea.

Menghai County of Yunnan Province is a famous tea town in China, recognized as one of the origin places of tea trees in the world tea circle and one of the birthplaces of Pu'er tea (Jiang et al., 2019). Because of its excellent natural geographical environment and tea making technology inherited for thousands of years, Menghai County has become the first tea producing county in Yunnan Province. In recent years, with the rapid development of Pu'er tea industry, the one-sided pursuit of economic benefits has resulted in uneven quality of Pu'er tea on the market, which has seriously affected the competitiveness of Pu'er tea in the market (Geng & Ma, 2021). During the rapid development of tea industry, long-term irrational fertilization resulted in the loss of nitrogen and phosphorus in soil, resulting in eutrophication of water body and acidification and consolidation of land (Shi et al., 2018; Duan et al., 2005; Dong et al., 2006). In addition, long-term large and single fertilization makes it difficult for plants to absorb nutrients and stay in the soil in large quantities, which seriously affects the quality of local tea (Li & Huo, 2019). Scientific and rational fertilization and reducing the use of chemical fertilizer are important measures to improve the environment, ensure the quality of tea, realize the technology of reducing the application of chemical fertilizer and increasing the efficiency of tea garden in China, and promote the sustainable development of tea industry.

At present, most experiments mainly focus on the effects of fertilization methods on the yield and quality of tea, and there are few studies on the relationship between the effects of different fertilization methods on soil nutrient migration in tea gardens and tea quality. This experiment mainly took The terrace Pu-erh tea in Menghai County as the research object, studied the characteristics of surface nutrient migration and the changes of tea quality indexes under different fertilization conditions, explored the economic and efficient way of tea garden fertilization, screened out the application amount of nitrogen fertilizer suitable for the environment of Menghai County tea garden, and provided the basis for rational fertilization of tea garden.

2. Materials and Methods

2.1. Overview of the Study Area

Menghai County is the hometown of the famous "Pu'er tea" at home and abroad and the earliest place of tea production in China. There are wild "tea king" 1,700 years ago and ancient tea trees scattered all over the country. The climate in this region is subtropical plateau monsoon climate, with an annual average temperature of 15.5˚C and an annual precipitation of 1065 mm, which is mainly concentrated in June to October. The soil type of tea garden is red soil. The monitoring test site is a concentrated and continuous hilly tea garden in Manzhen Village at the intersection of the upper reaches of mengpang Reservoir area, with 100.337471˚ EAST longitude and 22.184598˚ north latitude (Figure 1). The tea garden covers an area of 0.65 mu. The tested tea tree variety is "large-leaf tree tea" and the planting year is 20 years.

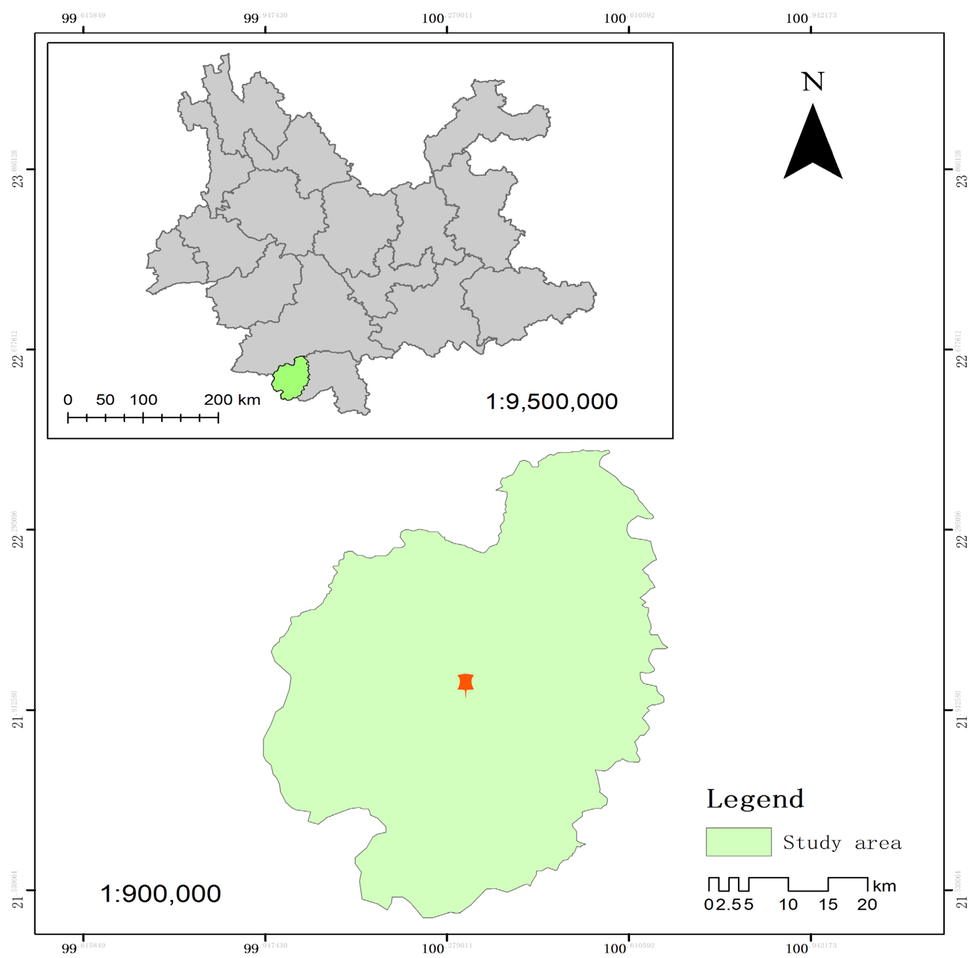

Figure 1. Geographical map of Menghai County.

2.2. Test Design

The experiment was carried out in the field from July to November in 2020. Three treatments were set up in the test site, and each treatment was repeated three times, with a total of 9 cells. Each treatment was randomly distributed, and the area of each cell was 48 m^2 (6 m × 8 m). Each area is separated by cement baffle with a buried depth of 0.5 m to prevent the phenomenon of water running between each area. The design principle of chemical fertilizer reduction treatment was based on the baseline application of chemical fertilizer in tea garden with annual pure nitrogen amount of 300 kg/hm^2 and the application ratio of N, P and K was 3:1:1. The selected fertilizers in the experiment were urea with N content ≥ 46.4% and purity ≥ 99.4%; calcium superphosphate, effective P_2O_5 content ≥ 12%; potassium sulfate, K_2O content ≥ 50.0%; compound fertilizer, N-P_2O_5-K_2O = 15-15-15, total nutrient ≥ 45%; controlled release fertilizer, N-P_2O_5-K_2O = 28-5-5. According to the fertilization habits of local tea farmers, the base fertilizer was applied in early July, and the top fertilizer was applied at the end of September, with 60% as the base fertilizer and 40% as the top fertilizer. Each time, the furrow was fertilized at the vertical downward place of the edge of the tea canopy surface, and the depth of fertilization was 10 - 20 cm. After fertilization, the soil was covered in time.

2.3. Test Sample

2.3.1. Surface Water Collection

Tea garden runoff monitoring sampling time for the August 2020-September 2020, menghai county into the rainy season, at this time every time collecting tea surface runoff water samples, first remove tea plantations litter of runoff collecting barrel, then runoff with a clean plastic barrels of water, fully mixing, then use polyethylene plastic bottles collected 500 ml water sample. Finally, all the water in the runoff bucket is poured out and the inner wall of the runoff bucket is cleaned with clean water to prepare for the next runoff collection. After water samples were collected, they were transported back to the laboratory in time and stored in a refrigerator at 4˚C. All indicators were determined within three days after water samples were collected.

2.3.2. Soil Samples Collected

The tea garden soil is acid red soil. The sampling time of soil samples is from August 2020 to November 2020, and soil samples are taken for 4 times. About 1 kg of soil samples with the same thickness, width and depth as possible shall be collected according to the "five point mixed sampling method" (Bao, 2013). After the soil samples are mixed evenly, they shall be dried and ground by natural air and screened for 2 mm and 0.149 mm respectively for analysis and determination.

2.3.3. Tea Samples Collected

The tea was collected in September 2020. It was picked on the 10th, 20th and

30th of that month for three times. One bud and two leaves were picked each time. After picking, the tea was steam killed. After killing, the dry weight of the tea was recorded accordingly, and some of the killed tea was dried and ground for indoor analysis.

2.3.4. Determination Method

The test adopts the soil sample determination method: pH: determined by pH meter; alkali-hydrolyzed nitrogen: determined by alkali-hydrolyzed diffusion method; available phosphorus: molybdenum antimony anti-chromogenic spectrophotometric determination;

Water sample determination method: pH: determined by pH meter; total nitrogen: alkaline potassium persulfate digestion UV spectrophotometry (HJ636-2012);

Total phosphorus: ammonium molybdate spectrophotometry (GB11893-89);

Determination of amino acids in tea samples: according to the determination method of total free amino acids in the experimental course of tea Biochemistry (edited by Zhang Zhengzhu);

Tea polyphenols: GB/T8313-2008 method for determination of tea polyphenols and catechins in tea;

Caffeine: determination of caffeine in tea (GB\T8312-2002), UV spectrophotometry.

2.4. Statistical Analysis

Qualitative analysis: use Excel 2016 edition to conduct basic calculation and standard error processing on the original data, combined with chart comparison, and qualitatively analyze the impact of different fertilization treatments on surface nutrient migration.

3. Results and Analysis

3.1. Effects of Different Fertilization Treatments on Soil Available Phosphorus

It can be seen from **Figure 2** that different fertilization treatment conditions have different effects on the content of available phosphorus in soil. One month after the application of base fertilizer, the content of soil available phosphorus in T1 treatment was the highest and that in T3 treatment was the lowest, which was 31.96% lower than that in T1; the soil available phosphorus content of T2 treatment was in the middle, which was 20.31% lower than that of T1. After topdressing in September, the content of soil available phosphorus in T1 treatment decreased significantly, while the content of soil available phosphorus in T2 and T3 treatment increased significantly, especially in T3 treatment. With the passage of fertilization time, the content of soil available phosphorus in T2 and T3 treatment decreased gradually. Compared with the content of soil available phosphorus after topdressing, T2 decreased by 14.4% and T3 decreased by 23.5%. The results showed that reducing the application of slow-release fertilizer by 30%

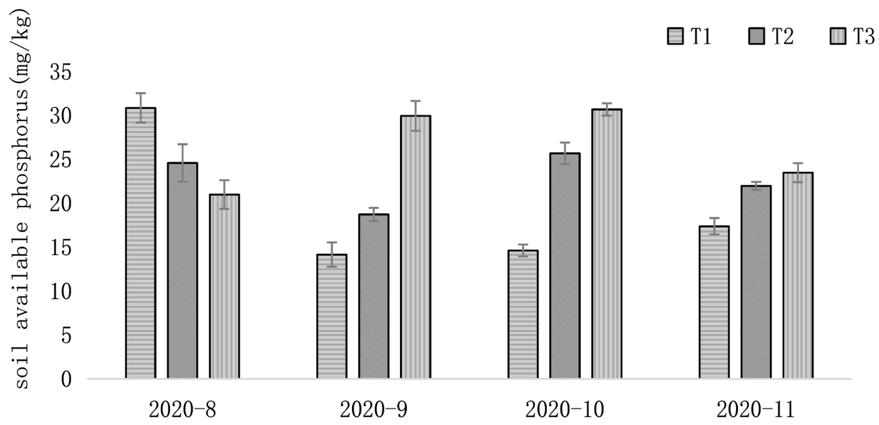

Figure 2. The content of quick-acting phosphorus in the soil under different fertilization treatments.

could increase the content of available phosphorus in soil, and the reduction of slow-release fertilizer was more conducive to the absorption of available phosphorus by plants. Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive".

3.2. Effects of Different Fertilization Treatments on Soil Alkali-Hydrolyzable Nitrogen

It can be seen from **Figure 3** that different fertilization treatments have different effects on the content of alkali hydrolyzable nitrogen in soil. One month after the base fertilizer was applied, the content of alkali hydrolyzable nitrogen in T2 treated soil was as follows: T2 (284.4 mg/kg) > T1 (231.3 mg/kg) > T3 (223.1 mg/kg). The nitrogen content of 1.5% was significantly higher than that oft 2.5% after alkali treatment. It shows that the reduced application of slow-release fertilizer can significantly improve the content of soil alkali hydrolyzable nitrogen, and the soil alkali hydrolyzable nitrogen provided by slow-release fertilizer is more lasting and not easy to lose.

3.3. Effects of Different Fertilization Treatments on Total Phosphorus in Surface Water

As can be seen from **Figure 4**, the total phosphorus content of surface water has a continuous change in a period after fertilizer application. At the initial stage, the total phosphorus content of surface water mainly showed T1 (7.4 mg/L) > T2 (2.1 mg/L) > T3 (1.8 mg/L). Compared with T1, total phosphorus content of surface water in T2 treatment decreased by 71.6%, and that in T3 treatment decreased by 75.7%. With the passage of time, the total phosphorus content of surface water continues to decrease, and the decreasing trend still shows the rule of T1 > T2 > T3. At the later stage of fertilization, the total phosphorus content of surface water in the three groups was significantly reduced. Compared with the

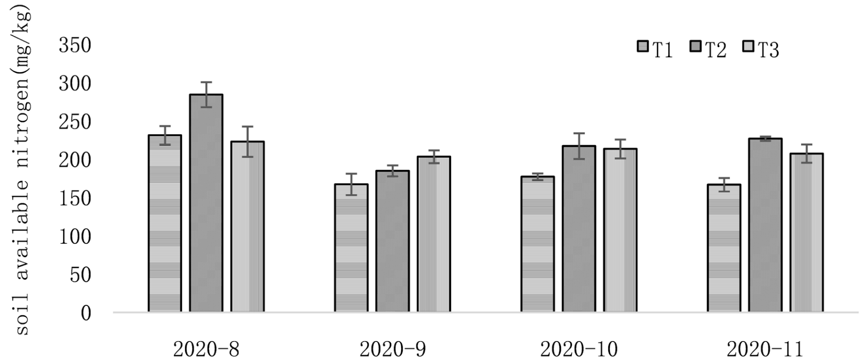

Figure 3. Nitrogen content of soil alkali de nitriding under different fertilization treatments.

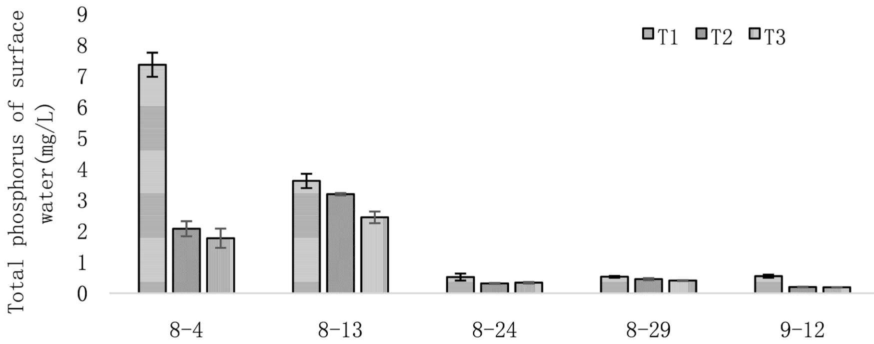

Figure 4. The total phosphorus content of surface water under different fertilization treatment.

initial stage, the total phosphorus content of T1, T2 and T3 decreased by 91.9%, 90.5% and 89.4% respectively. The results showed that in this fertilization period, the surface loss could be reduced by slow release fertilizer reduction, and the effect of 30% slow release fertilizer reduction was more obvious.

3.4. Effects of Different Fertilization Treatments on Total Nitrogen in Surface Water

As can be seen from Figure 5, the total nitrogen content of surface water is significantly correlated with fertilization time. From the whole sampling period, the total nitrogen content of surface water in the three groups showed a high level at the beginning of fertilizer application. With the passage of fertilization time, the total nitrogen content of surface water decreased gradually. Compared with the initial stage of fertilizer application, the total nitrogen content of surface water decreased by 96.4% in T1, 98.7% in T2 and 94.8% in T3. In this experiment, the surface water content of the three groups at the beginning of fertilization showed that T1 (19.5 mg/L) > T2 (15.9 mg/L) > T3 (11.6 mg/L). Compared with T1, T2 decreased by 18.5% and T3 decreased by 40.5%. At the late fertilization stage, the total nitrogen content of surface water treated by the three groups was T1 (0.7 mg/L) > T3 (0.22 mg/L) > T2 (0.2 mg/L). Compared with T1, T2 decreased by 71.4% and T3 decreased by 68.6%. The results indicated that the reduction of

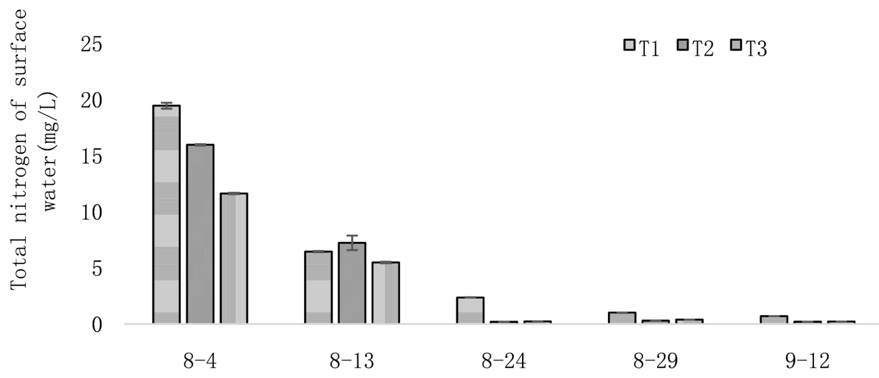

Figure 5. The total nitrogen content of surface water under different fertilization treatments.

slow release fertilizer application could reduce the total nitrogen concentration in surface water, that is, reduce the migration of surface nutrients.

3.5. Effects of Different Fertilization Treatments on Soluble Sugar in Tea

The influence of different fertilization treatments on soluble sugar content in tea is shown in **Figure 6**. During the tea collection cycle, the soluble sugar content of tea leaves in the three treatments showed a trend of gradual decrease, which is shown as follows: T1 (26.9%) > T2 (11.9%) > T3 (6.3%). Compared with T1, the soluble sugar content of tea treated by T2 and T3 was relatively stable and maintained at a certain high content level, indicating that slow release fertilizer could continuously provide nutrients for tea growth to a certain extent.

3.6. Effects of Different Fertilization Treatments on Tea Polyphenols

The influence of different fertilization treatments on tea polyphenols content is shown in **Figure 7**. In the early stage of tea collection, tea polyphenols content is the highest, and tea polyphenols content in the three treatments is as follows: T2 (289.8 mg/g) > T3 (284.5 mg/g) > T1 (241 mg/g). With the passage of time, the content of tea polyphenols in tea leaves gradually decreased, and at the late collection stage, the content of tea polyphenols in the three groups was gradually flat. In the whole cycle, the content of tea polyphenols in T2 and T3 was maintained at a higher level than that in T1. In each time period of this study, application of slow release fertilizer could ensure the high level of tea polyphenol content.

3.7. Effects of Different Fertilization Treatments on Theine of Tea Leaves

The quality reversal threshold of tea caffeine ranged from 38 mg/g to 45 mg/g. By comparing the caffeine content in tea under different fertilization treatments (**Figure 8**), it can be seen that during the test period, the caffeine content in T1 treatment was significantly higher than that in T2 and T3 treatment, and showed

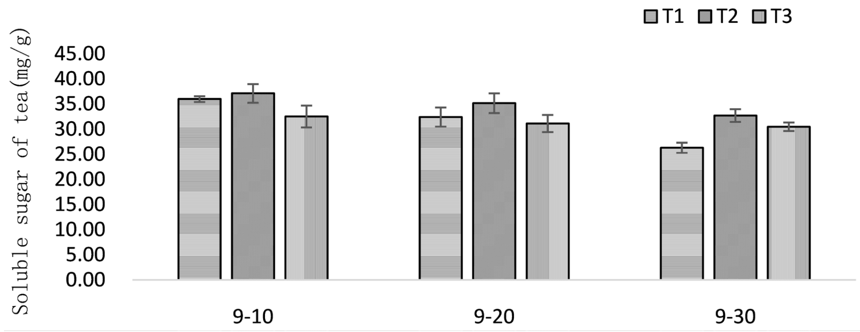

Figure 6. The soluble sugar content of tea under different fertilization treatments.

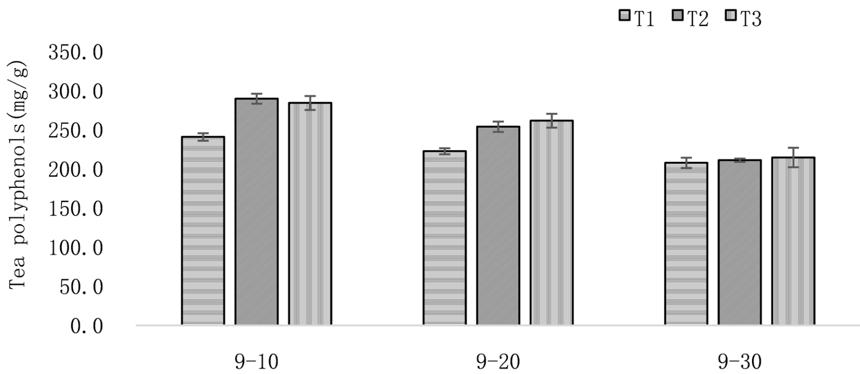

Figure 7. Polyphenols content of tea under different fertilization treatments.

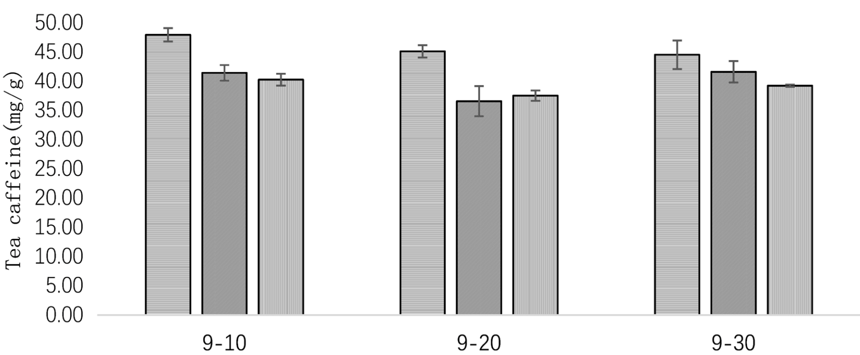

Figure 8. The content of tea coffee base under different fertilization treatments.

a trend of gradual decline, but they were all higher than the caffeine quality reversal threshold. The content of tea caffeine in T2 and T3 treatment was within the quality reversal threshold, and the content of tea caffeine in T3 treatment had the smallest fluctuation and the change was relatively stable. The results showed that the reduction of slow release fertilizer could maintain the stability of caffeine content between the quality reversal threshold and was beneficial to the improvement of tea quality.

3.8. Effects of Different Fertilization Treatments on Phenol/Ammonia Ratio of Tea

Aminophenol specific content of tea under different fertilization treatments is shown in Figure 9. The content of aminophenol ratio in tea has a certain relationship with fertilization methods. In the experimental period, the ratio of phenol-ammonia in T1 treatment was 7.15, 6.99 and 6.81 mg/g, respectively. The ratio of phenol-ammonia in T2 treatment was 7.54, 6.94 and 6.03 mg/g, respectively. The phenol/ammonia ratios of T3 treatment were 7.40, 7.23 and 6.18 mg/g, respectively. At the initial stage, there was no significant difference in phenol-ammonia ratio between the three groups, while over time, the phenol-ammonia ratio of T2 and T3 treatment was at the lowest level. Generally speaking, the quality of tea leaves is higher when ammonia phenol is low. Therefore, the fertilization method of slow release fertilizer reduction is beneficial to promote the content coordination of amino acids and tea polyphenols of tea trees, and has a certain effect on improving the quality of tea trees.

3.9. Effects of Different Fertilization Treatments on Amino Acids of Tea

As can be seen from Figure 10, different fertilization treatments affect the amino acid content in tea. During the test period, with the change of fertilization time,

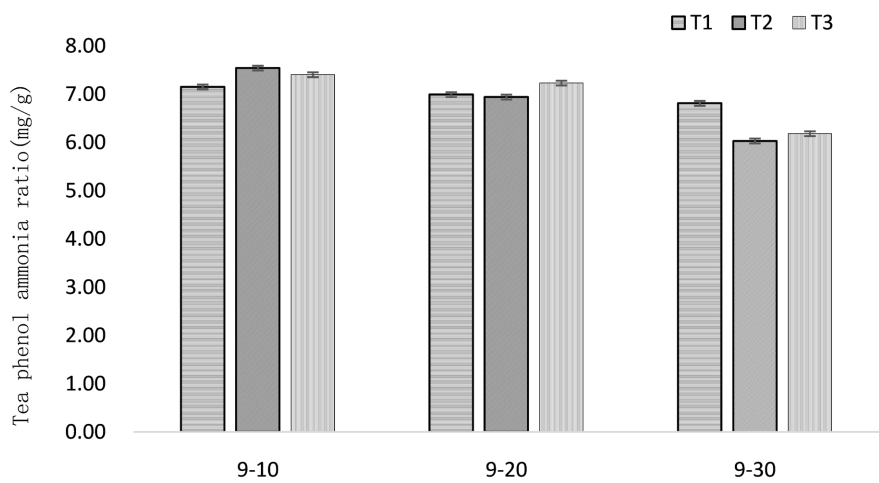

Figure 9. The content of phenolic ammonia in tea under different fertilization treatments.

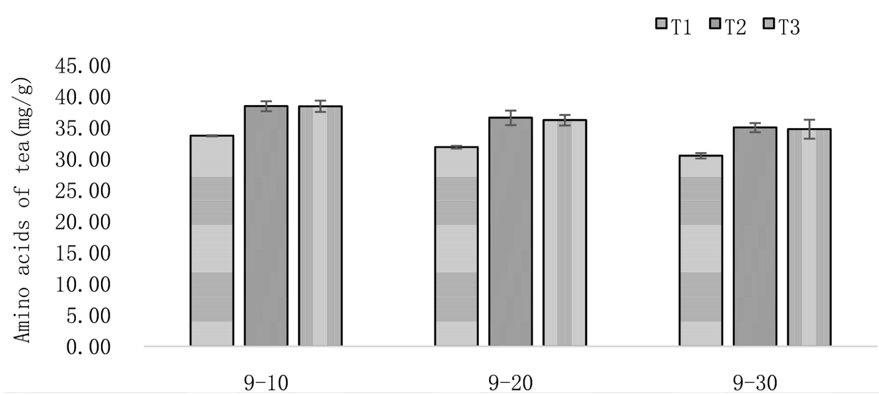

Figure 10. The amino acid content of tea under different fertilization treatments.

the amino acid content in tea leaves after fertilization showed a downward trend, and the amino acid content in T2 and T3 treatments maintained a higher level than that in T1. Compared with T1, the contents of amino acids in T2 treatment were increased by 14.1%, 14.8% and 14.8%, respectively. Compared with T1, the contents of amino acids in T3 treatment were increased by 14.0%, 13.6% and 13.9%, respectively. The results showed that T2 and T3 treatments could effectively improve the utilization rate of nitrogen fertilizer and promote the nitrogen metabolism of tea plants with lasting fertility.

4. Discussion

4.1. Effects of Different Fertilization Measures on Soil Nutrient Migration

Fertilization is an important factor affecting soil nutrient migration. Studies have shown that the main reasons for nitrogen loss in China are excessive application of nitrogen fertilizer and low utilization rate, which is far lower than the world average level (Gao, 2018). Duan Yonghui et al. believed that the main reason for soil nitrogen loss was excessive fertilization, and the experiment also showed consistent results. Studies have shown that reduction of chemical fertilizer application can effectively reduce the proportion of nutrients taken away by surface runoff (Tian et al., 2020; Tang, 2016). Application of slow release fertilizer can significantly reduce the loss of nitrogen and phosphorus in surface runoff of tea gardens, and reduce the risk of eutrophication of water bodies around tea gardens. The results of this study are consistent with this.

Different fertilization measures will affect the migration, effectiveness and persistence of nitrogen and phosphorus nutrients in the soil, thus affecting the nutrient absorption rate and effect of plants (Li et al., 2017). Relevant studies have shown that slow-release fertilizer has the characteristics of slow nutrient release, long duration and high utilization rate (Ma et al., 2020; Huang et al., 2010). The results of this study showed that compared with conventional fertilization, the application of slow release fertilizer could significantly increase the content of nitrogen and phosphorus in soil, and reduce the migration and loss of nitrogen and phosphorus in soil, and the experiment effect of 30% slow release fertilizer was more obvious.

4.2. Effects of Different Fertilization Measures on Tea Quality

Soluble sugar, tea polyphenols, theine, aminophenol ratio and amino acid content are important indexes affecting tea quality. Studies have shown that conventional fertilization reduction of 20% combined with the application of fulhuic acid biological agent has a good improvement effect on the quality indexes of free amino acids and tea polyphenols of tea (Quan et al., 2020). Wang Ziteng et al. showed that reduced fertilizer application and combined application of organic fertilizer can effectively improve soil quality, reduce nitrogen and phosphorus runoff loss, and improve tea yield and quality (Wang et al., 2018). Gao

Shuangwu (Gao, 2019) studied the replacement of chemical fertilizer by the combined application of formula fertilizer and organic fertilizer, and concluded that the combined application of formula fertilizer and organic fertilizer can meet the requirements of tea growth, tea quality is high, and the purpose of reducing fertilizer application and increasing efficiency can be achieved. Kong Xiaojun et al. (Kong et al., 2019) compared the effects of six different fertilization modes on the quality and economic effects of tea and concluded that the combination of organic fertilizer and controlled release fertilizer was the optimal fertilization measure, which could improve the quality and economic benefits of tea to the greatest extent. Han Wenyan et al. (Han et al., 2007) conducted pot and field experiments to study the influence of controlled release nitrogen fertilizer on tea quality, and concluded that controlled release nitrogen fertilizer had significant quality improvement effect on tea. The results of this experiment showed that compared with conventional fertilization, the content of soluble sugar, tea polyphenols, theine, aminophenol ratio and amino acid of tea were significantly increased by reducing application of slow release fertilizer. In general, the improvement of tea quality was more obvious by reducing application of slow release fertilizer by 30%.

5. Conclusion

Under the three different fertilization treatments in this experiment, the 30% reduction of slow-release fertilizer could reduce the amount of chemical fertilizer and increase the contents of available p and alkali-hydrolyzable N in tea garden soil and reduce the concentrations of total N and total P in surface water.

Reasonable fertilizer reduction is of great importance to the quality of tea. Compared with conventional fertilizer application, 20% or 30% reduction in slow-release fertilizer application can significantly increase the contents of amino terminal, tea polyphenols, soluble sugar and other quality indexes in tea, which is a more reasonable way of fertilizer application.

In conclusion, considering soil fertility, surface water environment and tea quality, 30% reduction of slow-release fertilizer application is a reasonable fertilization mode at present.

In this study, when the soil fertility and water environment status of the tea garden were investigated, the density of the sampling points was not enough to reflect the current soil and surface water status in Menghai County. Therefore, in subsequent studies, sampling points should be added to improve the credibility of the trial.

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Conflicts of Interest

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

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