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Effects of soil nitrogen and pH in tea plantation soil on yield and quality of tea leaves

Y.H. Wang, L. Hong, Y.C. Wang[1], Y.W. Yang, L.W. Lin[2], J.H. Ye[3], X.L. Jia[3] and H.B. Wang[1]*
College of Life Sciences, Longyan University, Longyan 364012, China.
E-mail: w18760012082@sina.com

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ABSTRACT

We studied the effects of soil nitrogen and pH in tea plantation soil on tea tree yield and quality in 90-tea plantations in Anxi county, Fujian province, China. The tea tree rhizosphere soil samples were collected for soil pH, ammonium nitrogen and nitrate nitrogen content from 90-tea plantations. The yield of tea tree and the contents of tea polyphenols, theanine and caffeine in tea leaves increased with the increase in soil pH. Secondly, as the soil pH increased, the content of ammonium nitrogen and the ratio of ammonium nitrogen to nitrate nitrogen in tea tree rhizosphere soil also increased, but the content of nitrate nitrogen decreased. Further the yield of tea tree and the contents of tea polyphenols, theanine and caffeine increased, with the increase in ratio of ammonium nitrogen to nitrate nitrogen in the soil. The pH of tea plantation soil was significantly positively correlated with the tea tree yield and quality, and the content of soil ammonium nitrogen, but negatively correlated with nitrate content in soil. This study provides basis for the scientific and rational use of nitrogenous fertilizers in tea plantations.

Key word: Ammonium nitrogen, nitrate nitrogen, pH, quality, rhizosphere soil, tea leaves, tea plantation soil, yield.

INTRODUCTION

Anxi County, Quanzhou City, Fujian Province is the largest tea producing county in China. It occupies an important position in the local economic development with > 40,000 hm^2 area for tea plantation and total tea production of 68,000 tons. The total output value of the tea industry reached 12.5 billion yuan with the population of > 700,000 involved in tea production. Tea crop requires acidic to slightly acidic soil (pH 4.5-6.0) to grow well (17,18). In 2010, 28 % of the 107 tea plantations in Fujian province had soil pH value below 4.0 (30). In 2018, Wang *et al*. (24) studied and analyzed the soil acidity of 363 tea plantations in 9 main tea-growing towns in Anxi County and found that 37.67 % acidic soils were not suitable for tea planting. Acidification leads to soil texture fission, which affected the crop growth and thereby reduced the crop yield and quality. Wang *et al*. (25,26) found that with the increase in tea tree age, the tea rhizosphere soil showed decreased pH and also decreased population of beneficial microorganisms, while the pathogenic microorganisms increased and all these factors decreased the tea yield and quality. Sun *et al*. (21) found that acidification reduced the root growth of tea tree seedlings, thus

*Correspondence author, [1]Fujian Provincial Key Laboratory of Agroecological Processing and Safety Monitoring, College of Life Sciences, Fujian Agriculture and Forestry University, Fuzhou 350002, China. [2]Fujian Zhongkai Testing Technology Co., Ltd, Fuzhou 35002, China. [3]College of Tea and Food, Wuyi University, Wuyishan 354300, China.

inhibiting their growth. As the soil acidification affects the normal growth of tea trees, so it is important to find its effects on tea yield and quality.

In tea trees, the young buds and leaves are harvested, hence, there is great demand for fertilizer nitrogen (13). Generally, double dose of nitrogen fertilizer is applied to tea plantations than recommended dose (1,16). The excessive use of nitrogen fertilizer enhances the yield and quality of tea but increased the soil acidification. For the growth of tea plants, ammonium nitrogen is preferred (31,33,34). In acidic soil, a small part of ammonium nitrogen is absorbed by tea trees, while the majority part was converted into nitrate nitrogen, which is leached (23). This adversely affects the nitrogen absorption and utilization efficiency of tea trees (3,5,8,12,32).

Soil acidification is common in tea plantations in China, and the degree of acidification has gradually increased in recent years (7,9,27). In 42.8 % tea plantation soils in Jiangsu Province, China, the soil pH was < 4.0 and in 38.1 % soils pH was between 4.0 and 4.5 (36). The pH of surface soil of tea plantation in Zhejiang Province, China was the lowest at 4.0 and showed decreasing trend (29). The mean pH of tea plantations soil in Jiangxi Province, China was 4.65 and the lowest is 3.51, in 43 % soils pH was < 4.5 (22).

Only few studies have studied the effects of acidification on soil nitrogen form in tea tree rhizosphere. Accordingly, 90-tea plantations were selected in Anxi county, Fujian province, China for this study. The tea tree yield and quality were measured in relation to soil pH, ammonium nitrogen and nitrate nitrogen content in tea rhizosphere soils.

MATERIALS AND METHODS

Experimental

Anxi County, Fujian Province is the origin of Tieguanyin tea tree in China. The county area is 117°36 '-118°17' E, 24°50 '-25°26' N, with mean altitude : 600 m, average annual rainfall : 1,800 mm, average annual relative humidity : 80 % and average annual temperature of 18 °C. From March to May 2019. We collected rhizosphere soil samples of tea trees from 90-tea plantations in Anxi County to determine the soil pH and contents of soil ammonium and nitrate forms of nitrogen. During sampling, the leaves of tea trees were also collected for tea yield and quality. Each of the 90-tea plantations selected for this study had an area of over 1 hm^2 (Fig. 1). The S-type sampling method was adopted for soil sampling in each tea plantation and 5 points (namely 5 replicates) were taken. For each point, 10 adjacent tea trees were selected, and the rhizosphere soil of tea trees was collected and mixed. The total soil collected from one point was about 1.0 Kg. The rhizosphere soil of tea trees was sampled as under : (i). surface deciduous leaf removal, (ii). light digging of tea trees, (iii). removal of soil attached around the root system of tea trees, (iv). separately shaking off the soil within 1 cm of root surface and collecting it.

Soil pH value

The pH meter (PB-10; Sartorius, Shanghai, China) was used to detect soil pH in water to soil solution 2.5:1 ratio.

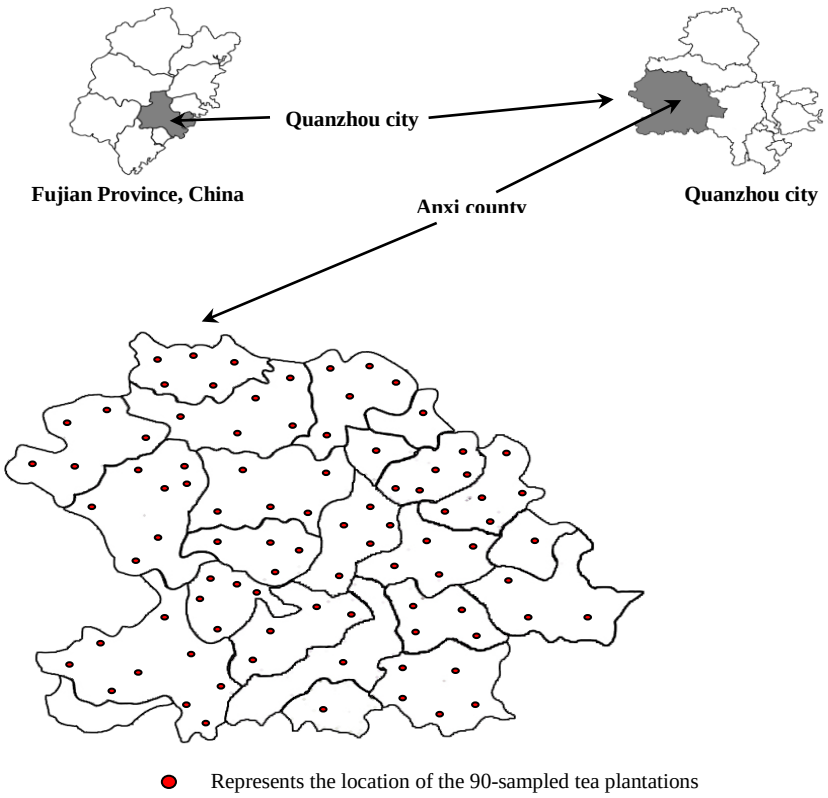

Figure 1. Distribution map of sampling sites

Soil ammonium and nitrate nitrogen content

The contents of nitrate and ammonium nitrogen in soil were determined as per method of Li *et al*. (10). Briefly, the soil was extracted by 2 mol/L KCl solutions for 1 h, and the solutions were filtered by a 0.45 μm membrane. The ammonium nitrogen and nitrate nitrogen content in solution were determined by a continuous flow analyzer (SA5000, Skalar Company, Netherlands).

Tea yield and quality

The yield of tea tree in each tea plantation was recorded separately. The yield of tea tree was calculated by converting the fresh leaves into yield per hectare. The method was as under : According to the traditional picking habit of Tieguanyin tea tree, the picking standard was 3 to 4 leaves in the middle and small open buds. In determination, 1 point was selected for every 1 m^2, and then the yield of tea tree was converted to per hectare of tea plantation. In each tea garden, we measured 5 points (5 replicates). The 1 m^2 plot selected was the actual tea planting area excluding the tea ridge.

After determining the tea tree yield, the collected tea leaves were used to determine the tea polyphenols, theanine and caffeine, with 5 repetitions for each sample. The extraction and detection methods of tea polyphenols and catechins were based on the National Standards of the People's Republic of China (GBT 8313-2018) (2). The determination of theanine was based on the National standard of the People's Republic of China (GBT 23193-2017) using high Performance liquid Chromatography (15). The determination of caffeine was based on the National Standards of the People's Republic of China (GBT 8312-2013-Tea caffeine measurement) (4).

Data analysis

SPSS Software Package 16.0 (SPSS Inc., Chicago, IL, USA) was used for data classification, linear equation regression analysis and correlation analysis.

RESULTS AND DISCUSSION

SOIL pH

Tea yield and quality

Soil is the medium for growing tea trees. The change in soil acidity influences the yield and quality of tea leaves. In this study, the pH value of tea tree rhizosphere soil was taken as the X-axis, and the measured values of yield, tea polyphenol content, theanine content and caffeine content in the corresponding tea plantations were taken as the Y-axis for linear equation regression analysis (Figure 2). Results showed that the linear equation

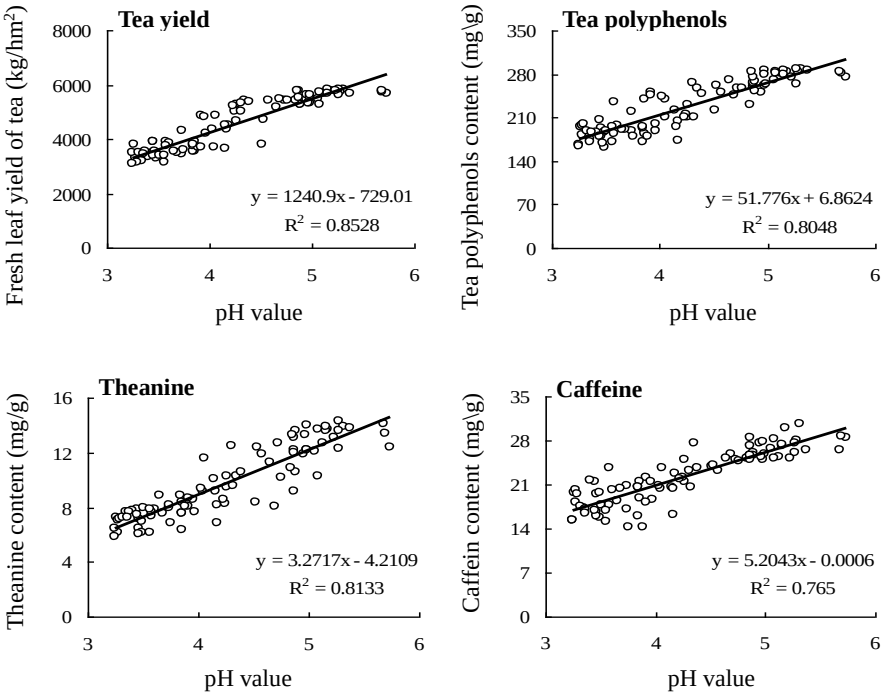

Figure 2. Effects of soil pH value on tea yield and quality

regression R^2 value of each factor and the pH value of tea tree rhizosphere soil ranged from 0.7650 to 0.8528 (Figure 2). The results indicated that the linear equation fitting degree between each factor was good, which could be used for further analysis. Secondly, this study found that as soil pH increased, the yield of tea leaves and the content of tea polyphenols, theanine and caffeine in tea leaves also increased. Sun *et al*. (21) studied the effects of acidity on the growth of tea trees in hydroponics method and found that when the pH value of the culture medium was < 4.5, the number and area of new roots of tea trees decreased significantly, leading to decreased plant height and biomass of tea leaves. Soil pH value significantly affected the yield and quality of tea, and with the decrease in soil pH, the yield and quality of tea also decreased.

Ammonium and nitrate nitrogen content in tea plantation soil

Soil nitrogen pool mainly consists of organic and inorganic nitrogen. The nitrogen absorbed by plants is mainly inorganic nitrogen in soil, including ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) (33,34). In this study, the linear equation regression R^2 value of each factor and the pH value of tea tree rhizosphere soil ranged from 0.4978 to 0.7610 (Figure 3). The results indicated that the linear equation fitting degree between each factor was good, which could be used for further analysis. Furthermore, the results showed that the content of ammonium nitrogen in rhizosphere soil of tea tree showed upward trend with the increase in soil pH, while the content of nitrate nitrogen decreased. The results also showed that the ratio of ammonium nitrogen to nitrate nitrogen content in tea tree rhizosphere soil increased.

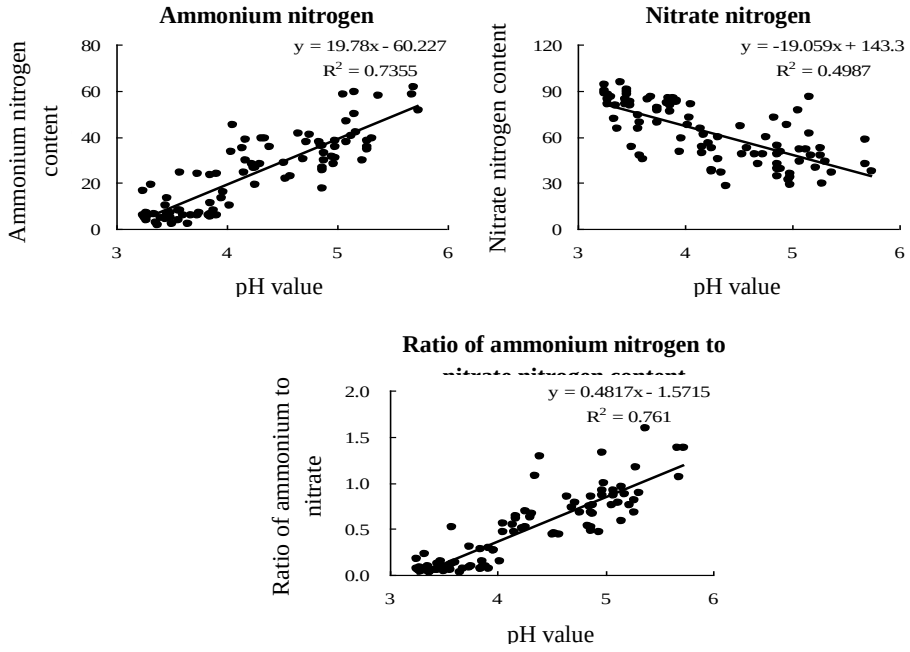

Figure 3. Effects of soil pH value on different forms of soil nitrogen content

The content of different forms of nitrogen in soil was closely related to soil texture and soil microbial activity (14,35). The ammonia-oxidizing bacteria were more suitable to live in acidic soil with low pH value, and with the increase in soil acidity, the number of ammonia-oxidizing bacteria in the soil increases, the soil nitrification enhances the nitrate nitrogen content in the soil and decreases the ammonium nitrogen content (20). Scarlett *et al*. (19) studied the changes in different nitrogen forms in soil and found that the lower the soil pH value, the lower the ammonium nitrogen content and the higher the nitrate nitrogen content in soil.

It is evident that the soil pH, and the contents of different forms of nitrogen in the soil undergoes changes. With the increase in soil pH, the contents of ammonium nitrogen increased, while the nitrate nitrogen showed decreasing trend.

SOIL NITROGEN

Tea tree morphology, yield and quality

For good quality tea, young buds and leaves are harvested from the tea plant, thus the growth of tea trees required large amount of fertilizers as the development of young buds and leaves is closely related to nitrogen availability (13). So, this study further analyzed the effects of the ratio of soil ammonium nitrogen to nitrate nitrogen content on

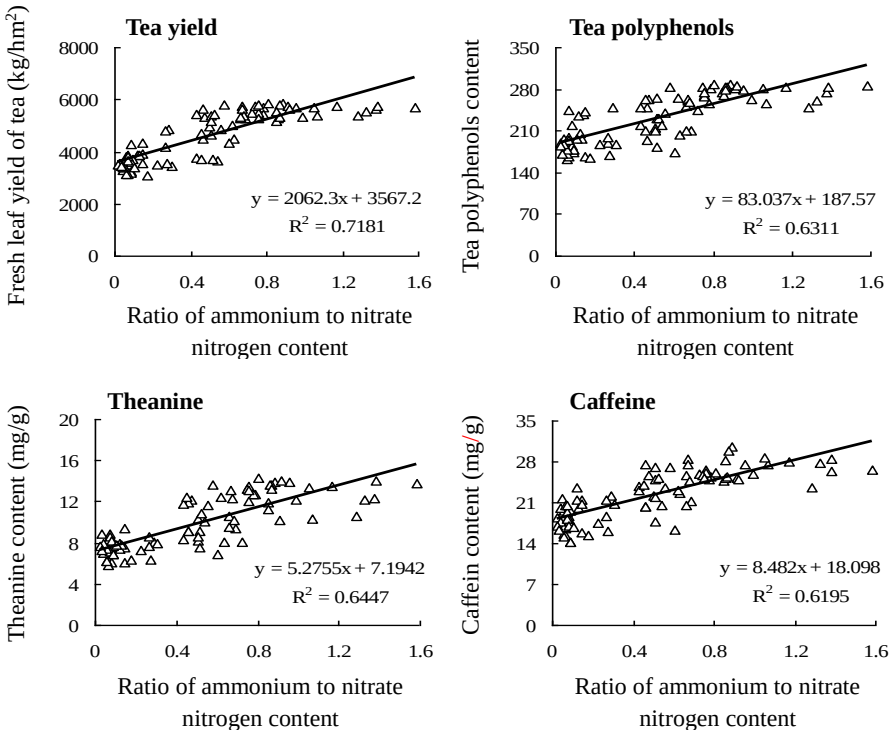

Figure 4. Effects of the ratios of soil nitrate nitrogen to ammonium nitrogen on tea yield and quality

tea yield and quality. The ratio of soil ammonium nitrogen to nitrate content was taken as the X axis, and the corresponding tea yield and quality were taken as the Y axis for linear equation regression analysis (Figure 4). The results showed that the linear equation regression R^2 value ranged among 0.6195 to 0.7181, and the linear equation had a good fitting degree, which could be used for further analysis. Further analysis showed that the ratio of soil ammonium nitrogen to nitrate nitrogen content could significantly affect the tea yield and quality, which showed that as the ratio of soil ammonium nitrogen to nitrate nitrogen content increased, the tea yield and the contents of tea polyphenols, theanine and caffeine also increased.

Tea trees are ammonia-loving plants, hence, the ammonium nitrogen was conducive to the development of tea tree roots and the accumulation of nitrogen-containing compounds (11). Tea quality indexes - theanine and caffeine are all nitrogenous compounds, and their synthesis in plants was closely related to the nitrogen absorption capacity of plants. However, as a secondary metabolite of tea tree, tea polyphenols require raw materials provided by tea tree photosynthesis (28). There was a significant positive correlation between nitrogen content and chlorophyll content in plants, while high chlorophyll content improves the photosynthetic capacity of plants (6).

It could be seen that the amount of ammonium nitrogen in the soil played an important role in tea tree nitrogen uptake and utilization, and tea quality.

Table 1. Correlation analysis between soil pH value and tea yield, quality, soil nitrogen content

Index	pH value	Fresh leaf yield of tea	Tea polyphenols content	Theanine content	Caffein content	Ammonium nitrogen content	Nitrate nitrogen content
Fresh leaf yield of tea	0.923**						
Tea polyphenols content	0.897**	0.891**					
Theanine content	0.902**	0.869**	0.916**				
Caffein content	0.875**	0.873**	0.905**	0.859**			
Ammonium nitrogen content	0.858**	0.821**	0.761**	0.772**	0.761**		
Nitrate nitrogen content	-0.706**	-0.738**	-0.663**	-0.665**	-0.652**	-0.546**	
Ratio of ammonium to nitrate nitrogen content	0.872**	0.847**	0.794**	0.803**	0.787**	0.893**	-0.785**

Note: ** indicate the significant difference at $P < 0.05$ levels between different indicators.

Correlation analysis between soil pH and tea yield, quality, soil nitrogen content

The correlation analysis (Table 1) between the tea tree rhizosphere soil pH value and tea yield, quality and the soil nitrogen content showed that the soil pH value was significantly positively correlated with the tea tree yield, quality, soil ammonium nitrogen content, and the ratio of soil ammonium nitrogen to nitrate nitrogen content. The soil nitrate nitrogen content was significantly negatively correlated with soil pH value, tea tree yield, quality, soil ammonium nitrogen content, and the ratio of soil ammonium nitrogen to

nitrate nitrogen content. It could be seen that soil pH value significantly affected the yield and quality of tea tree. Likewise, the soil nitrogen form also affected the yield and quality of tea tree.

CONCLUSIONS

The results showed that increased soil acidity decreased the yield and quality of tea, decreased the content of ammonium nitrogen and increased the content of nitrate nitrogen. Furthermore, decreased ammonium nitrogen content in soil caused reduction in yield and quality. This study laid basis for guiding the scientific and rational application of soil nitrogen fertilizer in tea plantation.

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CONFLICT OF INTEREST

The authors announce that they have no conflict of interest.

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PUBLISHER NOTE