Effects of Applying Humic Fertilizers on Tea's Yield , Nutritional Quality and Soil Fertility in a Tea Garden

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Abstract. A field trial with 2 kinds of humic acid fertilizers (i.e., humic acid and weathered coal) being added to the balance use of nitrogenous, phosphorus and potassium fertilizers for 3 years was carried out to test effects of tea's yield, nutritional quality and soil fertility in a tea garden. And 4 treatments were designed, i.e., (1) Chemical fertilizers (N 103 $kg\cdot hm^{-2}\cdot a^{-1}$, P_2O_5 34 $kg\cdot hm^{-2}\cdot a^{-1}$ and K_2O 34 $kg\cdot hm^{-2}\cdot a^{-1}$, following was the same); (2) Chemical fertilizers (same as (1))＋Humic acid（2000 $kg\cdot hm^{-2}\cdot a^{-1}$）, (3) Chemical fertilizers (same as (1))＋weathered coal(1500 $kg\cdot hm^{-2}\cdot a^{-1}$), (4) Chemical fertilizers (same as (1)) ＋ Humic acid(1000 $kg\cdot hm^{-2}\cdot a^{-1}$) ＋ weathered coal(750 $kg\cdot hm^{-2}\cdot a^{-1}$). Results show that, under the condition of humic acid fertilizers being used in tea garden, tea's yield and tea polyphenols were increased by 3.19%~14.24% and 5.21%~10.73%, respectively; Soil pH, organic matter, total nitrogen, total phosphorus, total potassium, alkali-hydrolyzable nitrogen, available phosphorus and potassium were increased by 2.97%~18.61%, 8.86%~27.22%, 9.80%~45.10%, 6.12%~40.82%, 4.52%~40.16%, 8.81%~45.75%, 0.62%~67.55% and 5.56%~36.09%, respectively. Whereas, effects of increasing tea's yield, tea polyphenols and soil alkali-hydrolyzable nitrogen by treatment of "chemical fertilizer + humic acid + weathered coal" were better than other treatments; Effects of increasing soil organic matter, total nitrogen, total phosphorus, total potassium, available phosphorus and potassium by treatment of "chemical fertilizer + humic acid" were better than other treatments; And the effect of enhancing soil pH by treatment of "chemical fertilizer + weathered coal" was better than other treatments.

Introduction

Tea production and consumption, as a kind of healthy drink, has increased sharply fast in China, recently. And its status for improving agricultural yield and peasant's incoming is increasingly prominent. As data released by Ministry of Agriculture of the People's Republic of China[1], tea garden area and dry tea yield have been increased to 2.579 million hm^2 and 1.89 million tons in 2013, grew by 16.9 ten thousands hm^2 and 11.5 ten thousands tons year-on-year, respectively. The total output value of tea has reached a historical new high of RMB 110620 hundred millions yuan in China[1], whereas, tea's yield level of average per unit area has continued to decline in China. According to tea garden area, the average tea yield is only 732 $kg\cdot hm^{-2}$, reaching a year-on-year fall of 3 $kg\cdot hm^{-2}$, and the average tea yield is 972 $kg\cdot hm^{-2}$ accounted by picking tea garden area, getting a year-on-year fall of 18 $kg\cdot hm^{-2}$. Primary reasons leading to the above two problems are that some tea farmers pay more attention on extending tea garden's area than tea's unit yield or quality. For a long time, Chinese farmers widely adopt some extensive managements in matured tea garden, with a disconnection between land use and conservation, chemical fertilizers (mainly on nitrogen fertilizer) are blindly and excessively used, and organic fertilizers are applied rather insufficiently. Thus, some serious problems, such as soil's increasingly acidification, degradation on soil's physical and chemical characteristics, stunted growth on tea tree, decline in yield and quality of tea, and so on, are evident, which seriously hinder the sustainable utilization of soil in tea garden[2-3].

Soil improvers are some materials which are added into soil to improve its physical, chemical and/or biological characteristics[4]. Nowadays, humic acid and weathered coal are two kinds of soil improvers which are extensive sources, low price and easy to access[5,6]. Among them, humic acid is one kind of component complicated and inartificial organic matter which could meliorate farm soil, increase nutrients use efficiency, improve crop yield and quality, etc[7~11]. Moreover, weathered coal, which reserves up to 10^{12} tons, is abroad distributed at coal mine areas in China[12], and is a kind of inartificial and nicer soil improver, which has good capability of adsorption, complexation and exchange[13].

There are many reports about the use of humic acid and weathered coal as soil improvers, to amend soil and increase crop yield and quality[7~13]. But, it has few studies about their use on tea. In this paper, effects of applying humic acid and/or weathered coal on tea's yield, nutritional quality and soil fertility in tea garden were studied. Results will offer some scientific information on using humic acid and/or weathered coal as soil improvers on tea's production. Moreover, it will offer available references to settle some ubiquitous problems, such as soil acidification, soil physical and chemical character deterioration, tea's yield and quality descending, and so on, which are now embarrassing soil's sustainable utilization in Chinese tea garden.

Materials and methods

Experimental design

The experiment was carried out at the tea garden of Tian Xiang Tea Limited Company, which is located at Fu'an city, Fujian province in China (E119°47′16″, N27°04′11″). Four treatments were used, i.e.: CF - Chemical fertilizers (N 103 $kg \cdot hm^{-2} \cdot a^{-1}$, P_2O_5 34 $kg \cdot hm^{-2} \cdot a^{-1}$ and K_2O 34 $kg \cdot hm^{-2} \cdot a^{-1}$); CF+HA - Chemical fertilizers (as in (1))＋Humic acid （2000 $kg \cdot hm^{-2} \cdot a^{-1}$）, CF+CA - Chemical fertilizers (as in (1))＋weathered coal（1500 $kg \cdot hm^{-2} \cdot a^{-1}$）, CF+HA+CA - Chemical fertilizers (as in (1))＋Humic acid（1000 $kg \cdot hm^{-2} \cdot a^{-1}$）＋weathered coal（750 $kg \cdot hm^{-2} \cdot a^{-1}$）. Each treatment had 4 replicates, arranged in a complete randomized block design, and each plot trial had an area of 20 m^2. The chemical fertilizers used were Urea, Ammonium dihydrogenphosphate and Potassium chloride. The humic acid was produced by Fujian Zaoan Lv Zhou Biochemical Co., Ltd. And the weathered coal was supplied by Chaoda Modern Agricultural Group. Trial tea breed was Huang Guan Yin with 4 years old. Trial period was from March, 2010 to November, 2012. All chemical fertilizers and/or soil improvers for each trial plot were completely mixed and groove fertilized one-off into soil between tree lines during the middle of March each year.

Yield of tea leaves was yearly registered, during the trial period. Tea leaves samples for quality test were plucked by "S" route at each trial plot on the Apr.26th, 2012. Surface soil samples (0~20 cm) were collected by "S" route in each trial ploton the Nov.3rd, 2012.

Determining method

Soil fertility indexes were determined by using routine assaying methods[14], i.e.: pH was measured by using potentiometry (the rate of soil and water was 1:2.5); Organic matter used potassium dichromate method; Total N used Semi-micro Kjeldahl method; Total P used Molybdenum Blue Spectrophotometry; Total K used flame photometry; Alkaline hydrolysable N used alkali N-proliferation method; Available P used Molybdenum Blue Spectrophotometry after distilling by 0.05 $mol \cdot L^{-1}$ $NaHCO_3$; Available K used flame photometry. Tea leaves' quality was assayed by using Chinese national standard methods, i.e.: Tea Polyphenols used GB/T8313-2002; Water extract used GB/T8305-2002, Theine use GB/T8312-2002, Soluble sugar used GB/T8305-2002.

Data processing

Trial data were processed by Microsoft Excel-2003. And for data analysis it was used the statistic software SPSS10.0.

Results and Analysis

Effect of using different kinds of humic acid fertilizers on tea's yield

Results (Fig.1) showed that, compared with treatment CF, tea leaves' yield of other 3 treatments might increase by 3.19%~14.24% or 112~500 kg·hm^{-2}·a^{-1}. Results of variance analysis indicated that, for increasing tea's yield, treatment of CF+HA+CA was significantly better (P<0.05) than CF, but it had not significant (P≥0.05) difference between CF+HA and CF+CA.

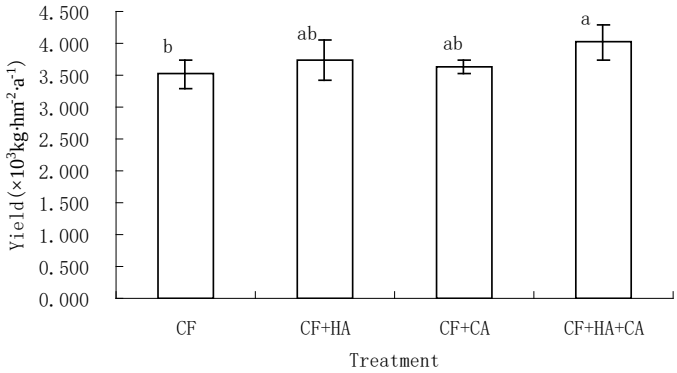

Fig.1 Effect of using different kinds of humic acid fertilizers on tea's yield

Note: Different small letters above columniation stand for significant difference（P<0.05） in above figure.

Effect of using different kinds of humic acid fertilizers on tea's quality

Results (tab.1) showed that: Compared with treatment CF, tea leaves' Tea polyphenols, Water abstract, Theine and soluble sugar could increase by 5.21%~10.73%, 2.61%~7.24%, 0.00%~2.36% and 1.07%~6.64%, respectively. Results of variance analysis indicated that: for increasing tea's Tea polyphenols, treatments of CF+HA+CA and CF+HA were notably better (P<0.05) than CF, but CF+CA had not significant (P≥0.05) difference with CF; For increasing tea's Water abstract, Theine or Soluble sugar, all designed treatments had not significant difference (P≥0.05) .

Tab.1 Effect of using different kinds of humic acid fertilizers on tea's quality

Treatments	Tea polyphenols		Water abstract		Theine		Soluble sugar	
	Content /%	Compared with CF/%	Content /%	Compared with CF/%	Content /%	Compared with CF/%	Content /%	Compared with CF/%
CF	9.60b	-	50.11a	-	3.81a	-	4.67a	-
CF+HA	10.51a	9.48	52.40a	4.57	3.89a	2.10	4.98a	6.64
CF+CA	10.10ab	5.21	51.42a	2.61	3.81a	0.00	4.72a	1.07
CF+HA+CA	10.63a	10.73	53.74a	7.24	3.90a	2.36	4.85a	3.85

Note: Different small letters after data stand for significant difference（P<0.05） in above table.

Effect of using different kinds of humic acid fertilizers on soil chemical characters in tea garden

Results (tab.2) showed that: Compared with treatment CF, other 3 treatments all could improve soil basic chemical properties to some extent. For example, soil pH, Organic matter, Total nitrogen, Total phosphorus, Total potassium, Alkaline hydrolysable nitrogen, Available phosphorus and Available potassium could increase by 2.97%~18.61%, 8.86%~27.22%, 9.80%~45.10%, 6.12%~40.82%, 4.52%~40.16%, 8.81%~45.75%, 0.62%~67.55% and 5.56%~36.09%, respectively. Results of variance analysis indicated that: for increasing soil's Organic matter, Total nitrogen, Total phosphorus, Total potassium, Available phosphorus and Available potassium, treatment of CF+HA could very significantly (P<0.01) better than CF, and significantly (P<0.05) better than CF+CA, but had not significant difference for increasing soil pH or Alkaline hydrolysable nitrogen; For enhancing soil pH, CF+CA could significantly (P<0.05) better than CF, but had not significant (P≥0.05) difference with CF+CA and CF+HA+CA; for increasing soil Alkaline hydrolysable

nitrogen, treatment of CF+HA+CA could very significantly (P<0.01) better than CF+HA and CF, and significantly (P<0.05) better than CF+CA

Tab.3 Effect of using different kinds of humic acid fertilizers on soil chemical characters in tea garden.

Treatment	pH		Organic matter		Total nitrogen		Alkaline hydrolysable nitrogen	
		Compared with CF /%	Content/ ($g\cdot kg^{-1}$)	Compared with CF /%	Content/ ($g\cdot kg^{-1}$)	Compared with CF /%	Content / ($mg\cdot kg^{-1}$)	Compared with CF /%
CF	5.05b	-	15.8Bb	-	0.51 Bb	-	47.65Bc	-
CF+HA	5.20ab	2.97	20.1Aa	27.22	0.74 Aa	45.10	51.85Bbc	8.81
CF+CA	5.99a	18.61	17.2ABb	8.86	0.56 ABb	9.80	55.98ABb	17.48
CF+HA+CA	5.69a	12.67	19.3ABa	22.15	0.68 ABa	33.33	69.45Aa	45.75

Treatment	Total phosphorus		Available phosphorus		Total potassium		Available potassium	
	Content/ ($g\cdot kg^{-1}$)	Compared with CF /%	Content / ($mg\cdot kg^{-1}$)	Compared with CF /%	Content/ ($g\cdot kg^{-1}$)	Compared with CF /%	Content / ($mg\cdot kg^{-1}$)	Compared with CF /%
CF	0.49Bb	-	41.85 Bb	-	19.25 Bb	-	180.21 Bb	-
CF+HA	0.69Aa	40.82	70.12 Aa	67.55	26.98 Aa	40.16	245.24 Aa	36.09
CF+CA	0.52Bb	6.12	42.11 Bb	0.62	20.12 Bb	4.52	190.23 Bb	5.56
CF+HA+CA	0.65Aa	32.65	68.01 Aa	62.51	23.14 Aa	20.21	203.45 Aa	12.90

Note: Different capital or small letters after data stand for very significant difference（P<0.01）or significant difference（P<0.05） in above table.

Discussion and conclusion

Effect of using different kinds of humic acid fertilizers on tea's yield and quality

Humic acid is one important organic segment for most soil, and it can separate into some sorts, such as turf, lignite, weathered coal, and so on, according to its different sources[15]. Several trial results have shown that applying humic acid fertilizers (or soil improvers) could increase tea's yield or quality. Yang *et al*'s result[16] showed that, compared with CK(spraying water) , spraying humic acid fertilizer (the content of sodium humate was 8%) on 6 year-old tea trees could increase tea's yield by 8.9%, enhance tea's amino acid by 12.0%, theine by 6.9%, water exact by 5.9%. Chen *et al*'s result[17] showed that, tea leaves' yield increased by 4.32%~12.62% after using humic acid fertilizer (75~1200 $kg\cdot hm^{-2}$). Peng *et al*'s result[5] showed that, watering humic acid fertilizer (diluted by 500 times) on tea trees, tea's yield might increase 6.5%~18.8%; and the effect of using fulvic acid was better than potassium humate. Our field trial's results showed that, under the condition of 2 kinds of soil improvers (i.e., humic acid and weathered coal) being added to the balance use of nitrogenous, phosphorus and potassium fertilizers in tea garden, tea's yield was increased by 3.19%~14.24%, tea polyphenols, water exact, theine and soluble sugar were enhanced by 5.21%~10.73%, 2.61%~7.24%, 0.00%~2.36% and 1.07%~6.64%, respectively.

Effect of using humic acid fertilizers on soil chemical characters in tea garden

Study on effects of using humic acid fertilizers (soil improvers) on soil basic fertility in tea

garden was less covered. Chen *et al*'s result[17] showed that, soil pH was enhanced gradually by 4.50%~14.19% with the increasing of using rates of humic acid fertilizer(75~1200 kg/hm^2), but the contents of soil organic matter, alkaline hydrolysable nitrogen, available phosphorus and available potassium were not significantly different with CK, it might for the relative short trial period (less than 1 year) . Our results concluded from about 3 years trial period showed that, under the condition of soil improvers being used in tea garden,soil pH, organic matter, total nitrogen, total phosphorus, total potassium, alkali-hydrolyzable nitrogen, available phosphorus and potassium were increased by 2.97%~18.61%, 8.86%~27.22%, 9.80%~45.10%, 6.12%~40.82%, 4.52%~40.16%, 8.81%~45.75%, 0.62%~67.55% and 5.56%~36.09%, respectively.

Tea leaves' yield and quality, soil's basic fertility can be effectively increased or improved by using humic acid fertilizers (soil improvers) into tea garden. The main reasons are as follows: (1) Humic acid is a kind of inartificial organic large molecule, which is mostly made up of C, H, O, N, S and other elements[15]. This large molecule may supply abundant nutrient elements for tea tree after being naturally mineralized and decomposed by microorganisms. Those abundant nutrient elements are essential for increasing tea's yield and quality. (2) Humic acid is a kind of macromolecule organic colloid, which contains many kinds of oxygen-containing functional groups. So, it has some special characteristics, such as, weak acid, absorbent, ion exchangeability, complexation, buffer, redox and biological activity for plant, etc[18-19]. Moreover, humic acid is rich in Humic acid and Fulvic acid, which are closely relative to some soil's properties, such as fertilizer retention, water and temperature retention, buffering, tilth, ventilation condition, etc. Therefore, applying humic acid fertilizers (soil improvers) into tea garden can construct good soil eco-environment for increasing tea leaves' yield and quality by improving soil's basic fertility and enhancing its self regulating ability to water, fertilizer, gas and heat[20]. (3) Humic acid can activate soil's nutrients and increase their biological availability. For example, Humate and Nitrohumic acid both can restrain soil fixing phosphorus to some extent. Using humic acid will promote plants to absorb nutrients for promoting difficult soluble elements' dissolution or chelation[19]. (4) Humic acid can increase chemical fertilizer's use efficiency. Some reasons are concluded as follows: Firstly, humic acid can obviously inhibit nitrification and promote plant to uptake nitrogen[18]. Secondly, adding humic acid into available phosphorus fertilizers would obviously inhibit soil fixing phosphorus and increase phosphorus fertilizers' utilization rate, because humic acid has a strong affinity for some ions, such as, iron, aluminium, calcium, etc[18]. Thirdly, potassium is easily fixed into crystal lattices of some colloidal particles like montmorillonite and change into slowly available potassium or invalid potassium, while chemical potassium fertilizers are applied into soils which are rich in clay minerals. And, while chemical potassium fertilizers are applied into arenosols, potassium is easy to be loss. Otherwise, chemical fertilizers mixed with humic substances could effectively prevent potassium being fixed or lost, then obviously improve potassium fertilizers' utilization rate[18]. (5)Using humic acid fertilizers may promote soil microbial breeding, regulate soilmicroorganisms' population structure, activate microbial enzymes, boost microorganisms' decomposing or composing, and increase soil nutrient's conversion and supply capacity[20].

To sum up, results concluded from our trial showed that humic acid fertilizers (i.e., humic acid and weathered coal) being added to the balance use of nitrogenous, phosphorus and potassium fertilizers would preferably increase tea leaves' yield and quality and obviously improve tea garden soil's basic fertility in the red soil area of China. Whereas, effects of increasing tea's yield, tea polyphenols and soil alkali-hydrolyzable nitrogen by treatment of "chemical fertilizer + humic acid + weathered coal" were better than other treatments; Effects of increasing soil organic matter, total nitrogen, total phosphorus, total potassium, available phosphorus and potassium by treatment of "chemical fertilizer + humic acid" were better than other treatments; and the effect of enhancing soil pH by treatment of "chemical fertilizer + weathered coal" was better than other treatments.

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