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Yield and quality responses of citrus (*Citrus reticulate*) and tea (*Podocarpus fleuryi* Hickel.) to compound fertilizers*

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Abstract: Experiments were carried out with citrus (*Citrus reticulate*) and tea (*Podocarpus fleuryi* Hickel.) to study the effects of compound fertilizers on their yields and quality. In the citrus experiment, application of compound fertilizers increased available P, K and Mg contents in soil but decreased alkali-hydrolyzable N contents in soil and N, P and K contents in leaves. In the tea experiment, application of compound fertilizers increased available P, K and Mg contents in soil and N, P, K and Mg contents in leaves but decreased alkali-hydrolyzable N in soil compared with the urea treatment. Application of compound fertilizers could improve the quality of citrus and tea, increase their yields and enhance their economical profits significantly. Compared with the control, application of compound fertilizers increased citrus yields by 6.31, 12.94 and 17.69 t/ha, and those of tea by 0.51, 0.86 and 1.30 t/ha, respectively. Correspondingly, profits were increased by 21.4% to 61.1% for citrus and by 10.0% to 15.7% for tea. Optimal rates of compound fertilizers were recommended for both crops.

Key words: Citrus, Tea, Compound fertilizers, Quality, Yield
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INTRODUCTION

Zhejiang Province lies in Southeast China where the monsoon climate has relatively high annual mean temperature and large annual mean rainfall, favors the mineralization of soil organic matter and minerals, and thus increases the risk of nutrients leaching, which has become one of the predominant degradation processes of soil fertility (Sun *et al.*, 2000). Citrus (*Citrus reticulate*) and tea (*Podocarpus fleuryi* Hickel.) are two important economical crops in the region. Best fertilization strategies to increase yields and quality of these two crops are of great significance to economical growth. Citrus is perennial and evergreen plant with many flowers and requires a large amount of nutrients. Applying proper compound fertilizers has been shown to enhance the growth, increase yield and improve quality of citrus (Yu, 2000; Wen and Cai, 2001; Chen, 1990).

Tea is a perennial evergreen shrub belonging to the Camellia genus of the Theaceae family (Ravichandran, 2002). Tea is one of the most popular beverages consumed in the world (Ohe *et al.*, 2001). Green tea, which is the favorite type consumed in Japan and China, has been increasingly used also in Western countries in recent years (Majchrzak *et al.*, 2004). Farmers usually apply urea for tea production, and apply organic manures for P, K and Mg nutrition. In fact, tea plants need large amounts of N, P, K and Mg for growth. The deficiency of these nutrients could drastically adversely affect yield and quality (Zheng, 1999; Yu *et al.*, 1997; Li and Pan, 1991). Nutrient deficiency in soils and poor fertilization are

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two causations for low yield and quality of teas (Yuan *et al*., 2000). In order to study the effects of different nutrient ratio and fertilization methods of compound fertilizers on yields, quality and economical profits of citrus and tea, two field experiments were conducted from 2003 to 2004.

MATERIALS AND METHODS

Experimental materials and sites

The compound fertilizers in the experiments were imported form Finland, have not yet been utilized in China. The citrus experiment was carried out in 2003 on a citrus orchard of Zhejiang Institute of Citrus, citrus breed was Bendizao mandarin. The soil type was degleyed paddy soil. The soil alkali-hydrolyzable N (mg/kg), available P, K and Mg (mg/kg) and pH were 73.39, 53.56, 121.40, 89.19 and 8.10, respectively. The tea experiment was conducted on the experimental tea garden of Hangzhou Tea Research Institute, tea breed was Longjing tea 43. The soil type was red soil. The soil alkali-hydrolyzable N (mg/kg), available P, K and Mg (mg/kg) and pH were 172.20, 17.22, 188.90, 33.29 and 5.10, respectively.

Experimental design

Each experiment on tea or citrus included four treatments, at equal total doses of N. Farmers' conventional fertilization was designed as the control in the citrus experiment, and the control in the tea experiment used N fertilizer in the form of urea. The other treatments in the two experiments uniformly used different ratio of compound fertilizers, as shown in Tables 1 and 2.

Application rate of oil-seed cake was 1.875 t/ha in winter fertilization in the citrus experiment, and 2.999 t/ha oil-seed cake was applied as winter fertilization in the tea experiment. The main characteristics of oil-seed cake were as follows: total N 53.48 g/kg, total P 6.17 g/kg, total K 10.20 g/kg and total Mg 3.48 g/kg. The treatments were arranged at random in the field for citrus and replicated six times. The plots were 4 m×4 m in size, one plot included one plant. The application time was November, February and July, respectively. And the treatments were arranged in Latin square in the field for tea and replicated four times. The plots were 4.4 m×4.5 m in size. The application time was February, May, June and October, respectively.

Yields and economical profits calculation

Citrus fruits were hand-picked after they were mature, and their weights were recorded for every plot. Spring tea leaves were picked manually, Summer and August tea leaves with machines. Weights were recorded for every plot. The yields of early Spring tea and the whole year were calculated. Economical benefit of citrus and tea were computed from the cost and output of the experiments, respectively.

Measurement methods

Laboratory analyses were carried out on soil and leaf sampled on September 9th, 2004 for citrus and

Table 1 Application rates of fertilizers in the treatments of the citrus (*Citrus reticulate*) experiment

Treatment	Winter fertilization (t/ha)	Spring fertilization (t/ha)	Summer fertilization (t/ha)
1 (control)	0.328 (FC)+0.125 (urea)+1.875 (oil-seed cake)	0.221 (FC)+0.094 (urea)	0.334 (FC)+0.156 (urea)
2	0.712 (15-15-15)*+1.875 (oil-seed cake)	0.509 (15-15-15)	0.814 (15-15-15)
3	0.712 (15-15-15)+1.875 (oil-seed cake)	0.381 (20-10-10)	0.814 (15-15-15)
4	0.712 (15-15-15)+1.875 (oil-seed cake)	0.381 (20-10-10)	0.938 (13-10-21)

FC: Means farmers' conventional fertilization, the doses of N, P_2O_5 and K_2O were 154.5, 85.8 and 85.8 g/kg, respectively; There were five farmers that participated in the experiment; *The figures in bracket represent the percentages of N, P_2O_5 and K_2O, respectively

Table 2 Application rates of fertilizers in the treatments of the tea (*Podocarpus fleuryi* Hickel.) experiment

Treatment	Spring fertilization (t/ha)	Summer fertilization (t/ha)	August fertilization (t/ha)
1 (control)	0.450 (urea)	0.450 (urea)	0.450 (urea)
2	0.690 (15-15-15)*+0.225 (urea)	0.690 (15-15-15)+0.225 (urea)	0.690 (15-15-15)+0.225 (urea)
3	0.828 (25-5-5-1)**	0.828 (25-5-5-1)	0.828 (25-5-5-1)
4	1.592 (13-10-21-2)	1.035 (20-10-10)	1.035 (20-10-10)

*The figures in bracket represent the percentages of N, P_2O_5 and K_2O, respectively; **The figures in bracket represent the percentages of N, P_2O_5, K_2O and MgO, respectively

April 9th for tea. Alkali-hydrolyzable N, available P, K and Mg contents in soil and N, P, K and Mg contents in leaves were analyzed. Skin thickness of mature citrus fruits, edible percentage, dissolvable solid matter contents, soluble sugar contents, Vitamin C contents and titratable acidity were determined. Polyphenol contents, total amino acid contents, caffeine contents, soluble substance contents and water contents of tea leaves were determined to study the effects of compound fertilizers on quality of tea.

N, P and K contents in plant tissues were measured with the conventional methods (Committee of Agrochem., Soil Sci. Soc. of China, 1983). Available Mg in soil was extracted by 1.0 mol/L NH_4OAC and determined using atomic absorption spectrometer (AAS). Concentration of Mg in leaves was determined using AAS after ashing at 500 °C (Committee of Agrochem., Soil Sci. Soc. of China, 1983).

Vitamin C (L-ascorbic acid) was determined according to Committee of Agrochem., Soil Sci. Soc. of China (1983). Soluble sugar was extracted in ethanol from 30 mg dry weight of samples and quantified using a phenol-sulfuric assay with glucose as a standard (Bian *et al*., 2002). The content of water was determined by oven-drying. Tea polyphenol and caffeine were determined according to Pan *et al*.(2003). Amino acid was derivatized and then the derivatives were filtered and directly analyzed by electrophoresis on a plastic microchip with a 31-mm long separation channel with fluorescence detection (Kato *et al*., 2003). Soluble substance was extracted with regurgitant boiling water, then filtered, evaporated and the dry weight was obtained.

RESULTS AND DISCUSSION

Influences of compound fertilizers on nutrient contents in soil and leaves

As shown in Table 3, nutrient contents in soil and leaves did not vary regularly in the citrus experiment. Application of compound fertilizers increased available P, K and Mg contents in soil and Mg contents in leaves, while decreasing alkali-hydrolyzable N contents in soil and N, P and K contents in leaves, compared with the contents before the experiment. And in the tea experiment, compared with the control, available P and K contents in soil increased significantly ($P<0.01$) with application of compound fertilizers, while available Mg contents also increased. In contrast, alkali-hydrolyzable N contents in soil were decreased. N, P, K and Mg contents in leaves were all significantly higher than those of the control (Table 4). The tea experiment

Table 3 Nutrient contents in soil and leaves of every treatment in the citrus experiment

Treatment	In soil (mg/kg)				In leaves (g/kg)			
	Alkali-hydrolyzable N	Available P	Available K	Available Mg	N	P	K	Mg
BE	73.39 c B*	53.56 b B	121.4 d D	89.19 c AB	27.1 b B	5.30 cd BC	13.20 bc BC	1.67 b B
1 (control)	63.28 a A	94.28 a A	308.5 a C	133.30 b A	23.5 a A	2.85 ab AB	5.49 a AB	2.30 a A
2	54.60 a A	88.63 a A	293.6 c AB	135.50 b A	24.1 a A	2.40 c B	5.80 a A	2.19 a A
3	53.55 b A	84.87 a A	253.9 c C	136.00 b A	23.8 a A	2.70 ab AB	5.07 ab AB	2.30 a A
4	53.90 b A	79.60 a A	335.4 a A	142.20 a A	22.8 a A	3.04 a A	5.26 ab AB	2.21 a A

BE: Means before experiment; *Means followed by the same small letter indicate no significant difference at $P<0.05$, and followed by the same capital letter indicate no significant difference at $P<0.01$ (Duncan's test)

Table 4 Nutrient contents in soil and leaves of every treatment in the tea experiment

Treatment	In soil (mg/kg)				In leaves (g/kg)			
	Alkali-hydrolyzable N	Available P	Available K	Available Mg	N	P	K	Mg
1 (control)	266.05 a A*	17.72 c C	189.02 d D	36.96 b A	48.90 b B	4.84 c C	16.30 d D	1.02 c C
2	201.10 b B	34.50 a A	325.20 b B	37.27 b A	51.00 a A	5.13 ab AB	17.00 c C	1.12 b BC
3	263.40 a A	24.82 b B	251.00 c C	42.11 a A	50.60 a AB	5.01 b BC	18.30 b B	1.22 a A
4	216.60 b AB	28.18 b B	488.10 a A	37.93 b A	51.60 a A	5.25 a A	19.10 a A	1.15 b AB

*Means followed by the same small letter indicate no significant difference at $P<0.05$, and followed by the same capital letter indicate no significant difference at $P<0.01$ (Duncan's test) results indicated that application of compound fertilizers not only increased available P, K and Mg contents in soil and enhanced P, K and Mg absorption by plant, but also improved greatly N absorption by plant, which was advantageous to tea plant growth.

Quality of citrus and tea as affected by compound fertilizers supply

Fruit quality is one of the important factors affecting China's export of citrus (Deng, 1996). It can be seen from Table 5 that application of compound fertilizers enhanced fruit quality of citrus significantly. Compared with the control, fruit weight, dissolvable solid matter contents, soluble sugar contents and Vitamin C contents in citrus fruits universally rose significantly. According to Li *et al*.(2002), the soluble sugar content in citrus consumed largely in America was 8.37%, which was much lower than that in Treatments 2, 3 and 4. The Vitamin C contents in Treatments 3 and 4 both exceeded that in the California citrus (Vanderslice *et al*., 1990). Vitamin C is the most important vitamin in fruits and vegetables for human nutrition (Lee and Kader, 2000). As an antioxidant, it reportedly reduces the risk of arteriosclerosis, cardiovascular diseases and some forms of cancer (Harris, 1996). However, edible rate and titratable acidity did not vary apparently. It was found that not only the S/A ratio (the ratio of sugar content to titratable acidity) of citrus fruits rose, but also the flavor became better, and the shape became more beautiful when compound fertilizers are used. Application of compound fertilizers can really improve citrus fruit quality.

In the tea experiment, total amino acid contents, soluble substance contents and tea polyphenol contents were all higher than those of the control, which indicated the quality of tea leaves was enhanced. Tea polyphenol has significant antioxidant activity due to its ability to scavenge reactive oxygen species and chelate metal ions (Morel *et al*., 1993), which is beneficial for human health. The same variation trend of caffeine contents is shown in Table 6. However, water contents and the P/A ratio (ratio of tea polyphenol content to total amino acid content) declined in comparison with those of the control (Table 6). The decline of the P/A ratio indicated that the palatability of tea leaves was enhanced, which favors the production of green tea (Wang *et al*., 1997). The increase of caffeine contents can also enhance the palatability of tea leaves (Werkhoven, 1975). And it was known that lower water content in tea leaves was beneficial for the maintenance of good quality of tea leaves (Werkhoven, 1975). The quality of tea leaves in Treatment 3 was especially good, which may be due to Mg supplied from compound fertilizers. It can be seen from Table 4 that Mg contents in soil and leaves in Treatment 3 were both higher than other treatments. The general point of view presented was that Mg is the fourth essential nutrient for tea plant growth, is important to the composition of chlorophyll, and

Table 5 Effects of compound fertilizers on quality of citrus fruits

Treatment	Fruit weight (g)	Thickness of fruit skin (cm)	Edible rate (%)	Dissolvable solid matter content (%)	Soluble sugar content (%)	Titratable acidity (%)	Vitamin C content (g/kg)
1 (control)	60.46 c C*	0.211 c C	76.7 a A	9.72 b B	8.75 b B	0.705 a A	0.537 b A
2	69.42 a AB	0.294 a A	75.6 a A	10.92 a A	9.81 a AB	0.759 a A	0.630 a A
3	71.79 a A	0.282 ab AB	76.2 a A	10.48 ab AB	9.44 ab AB	0.756 a A	0.856 ab A
4	72.96 a A	0.268 b AB	76.2 a A	10.97 a A	9.45 ab AB	0.730 a A	0.807 ab A

*Means followed by the same small letter indicate no significant difference at $P<0.05$, and followed by the same capital letter indicate no significant difference at $P<0.01$ (Duncan's test)

Table 6 Effects of compound fertilizers on quality of tea leaves

Treatment	Soluble substance content (%)	Tea polyphenol content (%)	Total amino acid content (%)	Caffeine content (%)	Water content (g/kg)	P/A ratio
1 (control)	39.47 c C*	25.36 b B	2.13 b B	4.17 c B	775.10	11.9
2	42.50 b B	26.46 a A	2.51 a A	4.21 c B	768.00	10.5
3	43.48 a A	26.50 a A	2.59 a A	4.54 a A	773.00	10.3
4	42.38 b B	25.67 b B	2.23 b B	4.42 b A	770.80	11.5

*Means followed by the same small letter indicate no significant difference at $P<0.05$, and followed by the same capital letter indicate no significant difference at $P<0.01$ (Duncan's test) relates closely with the quality of tea leaves (Wu, 1997; Fei and Zhang, 1991). Generally, it was known that the critical value of available Mg content in soil of tea garden is 40 mg/kg (Zhu and Chen, 2000; Ruan *et al*., 1997).

Effects of compound fertilizers on yields and economical profits of citrus and tea

The yields of citrus and tea increased significantly with application of compound fertilizers (Tables 7 and 8). The increased amounts of yields compared with those of the control were 6.31 to 17.69, 0.21 to 0.27 and 0.51 to 1.30 t/ha for citrus, early Spring tea and whole year tea, respectively. With application of compound fertilizers, the economical profits of citrus ranged from RMB 186.72 to RMB 247.75 Yuan/plot, being 21.4% to 61.1% higher than that of the control, and the economical profits of tea varied from RMB 79.97 to RMB 84.13 Yuan/plot, being 10.0% to 15.7% higher than that of the control. The application methods in Treatment 4 for citrus (Table 1) and Treatment 3 for tea (Table 2) were very effective in increasing economical profits of citrus and tea, respectively. In the tea experiment, though the yield in Treatment 4 was highest, due to the relatively large cost on fertilizers, the economical profit was lower than that in Treatment 3.

CONCLUSION

In the citrus experiment, application of compound fertilizers increased available P, K and Mg contents in soil and Mg contents in leaves, while decreasing alkali-hydrolyzable N contents in soil and N, P and K contents in leaves as compared with those before experiment. In the tea experiment, available P, K and Mg contents in soil and N, P, K and Mg contents in leaves rose with application of compound fertilizers, in contrast, alkali-hydrolyzable N contents in soil declined.

Application of compound fertilizers improved the fruit quality of citrus by increasing fruit weight, Vitamin C content and the S/A ratio (the ratio of sugar content to titratable acidity) of citrus fruits. The quality of tea was also improved by application of compound fertilizers through increasing tea polyphenol contents, total amino acid contents and soluble substance contents, as well as caffeine contents, while reducing water contents and the P/A ratio (ratio of tea polyphenol content to total amino acid content) of tea leaves. Furthermore, application of compound fertilizers increased the yields and economical profits of citrus and tea greatly. In conclusion, in experimental sites, the Treatment 4 for citrus (Table 1) and Treatment 3 for tea (Table 2) were more effective than the other treatments.

Table 7 Yield and economical profits of every treatment of citrus

Treatment	Yield (t/ha)	Economical benefit (RMB Yuan/plot)	Increasing (RMB Yuan/plot)
1 (control)	29.75 c B*	153.79	0
2	42.69 b A	222.23	68.44
3	36.06 b A	186.72	32.93
4	47.44 a A	247.75	93.96

*Means followed by the same small letter indicate no significant difference at $P<0.05$, and followed by the same capital letter indicate no significant difference at $P<0.01$ (Duncan's test)

Table 8 Yield and economical benefit of every treatment of tea

Treatment	Yield of early Spring tea (t/ha)	Total yield (t/ha)	Economical benefit (RMB Yuan/plot)	Increasing (RMB Yuan/plot)
1 (control)	1.02 c*	9.32 c	72.70	0
2	1.23 b	9.83 b	79.97	7.27
3	1.27 ab	10.18 b	84.13	11.43
4	1.29 a	10.62 a	80.26	7.56

*Means followed by the same small letter indicate no significant difference at $P<0.05$ (Duncan's test)

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