Soil chemical properties, ‘Guanximiyou’ pummelo leaf mineral nutrient status and fruit quality in the southern region of Fujian province, China

Y. Li¹, M.-Q. Han¹, F. Lin¹, Y. Ten¹, J. Lin¹, D.-H. Zhu², P. Guo^{1,3}, Y.-B. Weng², L.-S. Chen^{1, 3, 4, 5*}

¹College of Resource and Environmental Science, Fujian Agriculture and Forestry University, Fuzhou 350002, PR China. ²Agricultural Bureau of Pinghe County, Zhangzhou 363700, China. ³Institute of Horticultural Plant Physiology, Biochemistry and Molecular Biology, Fujian Agriculture and Forestry University, Fuzhou 350002, China. ⁴Fujian Key Laboratory for Plant Molecular and Cell Biology, Fujian Agriculture and Forestry University, Fuzhou 350002, China. ⁵The Higher Educational Key Laboratory of Fujian Province for Soil Ecosystem Health and Regulation, Fujian Agriculture and Forestry University, Fuzhou 350002, China *Corresponding author: lisongchen2002@hotmail.com

Abstract

Three hundred and nineteen ‘Guanximiyou’ pummelo (*Citrus grandis*) orchards from Pinghe county, the southern region of Fujian province, China, were selected for this study. The objectives were to determine (i) the soil and leaf nutrient status, (ii) the relationships between leaf mineral elements and the corresponding soil elements, and (iii) the relationships between fruit quality and mineral nutrients. The results showed that soil acidification was a major problem in these orchards, with an average pH of 4.34. Soil acidification affected the availability of soil N, P, Ca, Mg, S, B, Cu and Zn and the levels of organic matter (OM) and cation exchange capacity (CEC), thus inducing soil and leaf nutrient imbalance. Indeed, severe nutrient imbalance existed in these orchard soils. 77.4% and 65.8% of soils were sub-optimum in exchangeable Mg and Ca, while 96.6% and 82.1% of soils were super-optimum in available S and P, respectively. Besides, severe nutrient deficiencies and excesses co-existed in leaves. 46.8% and 35.6% of leaves were deficient in N and Mg, while 74.8% and 70.4% of leaves were excess in B and Cu, respectively. Regressive analysis showed that leaf content of mineral elements was poorly related with the available content of the corresponding soil elements, respectively. In some orchards, severe juice sac granulation, an important factor affecting fruit quality, was observed. Regressive analysis indicated that Mg, S, Cu and Mn played a role in juice sac granulation of fruits. In conclusion, soil acidification might lead to severe soil nutrient imbalance, thus inducing leaf nutrient imbalance, eventually impairing fruit quality parameters such as sac granulation.

Keywords: *Citrus grandis*, granulation, nutrient imbalance, soil acidification

1. Introduction

Citrus is the leading fruit crop in the world, citrus production and consumption have grown strongly since the mid-1980s (FAOSTAT data). In 2013, over 140 countries produced citrus fruits. Main producing countries are China, Brazil and the United States (FAOSTAT data). In 2011, there are approximately 2.29 million ha of citrus planted in 19 provinces of China and a yield of 2944×10^4 t (Ministry of Agriculture P.R.C, 2012). Pummelo (*Citrus grandis*) is the third major types of citrus after *Citrus reticulata* (i.e., tangerines, mandarins, clementines and satsumas) and oranges (*Citrus sinensis*) with a yield of 320×10^4 t (Ministry of Agriculture P.R.C, 2012). In China, the most famous area for pummelo production is Pinghe county, Fujian province. In Pinghe, ‘Guanximiyou’ pummelo has been planted for more than 500 years and was used to be a tribute for royal. By 2013, total production of ‘Guanximiyou’ pummelo reached over 4×10^4 ha with an annual production of over 120×10^4 t (Lu, 2013). Recently, ‘Guanximiyou’ pummelo fruit quality displayed a down trend. Both maximum fruit quality and yield will occur only in the presence of optimum nutrient balance and intensity. Low fruit quality is often associated with poor soil fertility and poor nutrient management (Zhuang, 1994). Adequate nutrient management would never have been possible without the knowledge of soil fertility and plant nutrition status.

Soil testing, which is crucial for evaluating soil fertility, is believed to be a necessary complement to leaf analysis for citrus fertilizer recommendations (Du Plessis *et al.*, 1977). Citrus growers should maintain soil fertility, thus preventing nutrient deficiencies and excesses, since both affect the yield and quality of citrus fruits. Soil fertility is mainly determined by various chemical properties such as soil pH, cation exchange capacity (CEC), content of organic matter (OM) and mineral nutrients.

Citrus stores significant amounts of mineral nutrients in tree biomass, part of which can be redistributed mainly to developing organs such as fruits and young leaves. Evidence shows that leaf content of some mineral elements does not correlate with the available content of the corresponding soil elements, respectively (Huang *et al.*, 2001; Tang *et al.*, 2013). Better reliability of leaf analysis over soil analysis has diverted towards finding the cause and effect relationship on fruit quality of pummelo.

To date, the premier fruit quality parameters of pummelo which guide the marketability, through global research data on pummelo is meager. During 1998–1999, Huang *et al.* (2001) investigated mineral element content in orchard soils and leaves of ‘Guanximiyou’ pummelo, and soil pH and OM. Unfortunately, fruit quality parameters were not determined in this study. In addition, soil acidification can occur in the past decade due to acid deposition and some farming practices such as improper fertilization, intensive agriculture and monoculture (Guo *et al.*, 2010), thus affecting nutrient balance and intensity.

In this study, we measured soil pH, CEC, OM, content of mineral element in soils and leaves, and fruit quality parameters of ‘Guanximiyou’ pummelo grown in the southern region of Fujian province, China. The objectives of this study were to understand (i) the soil and leaf nutrient status, (ii) the relationships between leaf mineral elements and the corresponding soil elements, and (iii) the relationships between fruit quality and mineral nutrients.

2. Materials and Methods

Three hundred and nineteen ‘Guanximiyou’ pummelo orchards from ten townships (Jiufeng, Qiling, Xiazhai, Wenfeng, Guoqiang, Xiaoxi, Shange, Nansheng, Banzi

and Luxi) were selected for this study. The orchards were located in Pinghe county (24°02' - 24°35' N and 116°53' - 117°31' E), the southern region of Fujian province, China with an average annual rainfall of over 1600 mm. The orchards on slopes are terraced. Most of the soils are oxisols (US Department of Agriculture Soil Survey Staff) [red soil and lateritic red soil (Chinese Soil Taxonomic Classification)]. Most of the plant materials were 10 to 15-year-old 'Guanximiyu' pummelo trees grafted on 'Sour pummelo' (*Citrus grandis*) rootstocks. They received similar horticultural practices, and disease and insect control.

Soil samples (one composite sample per orchard) were collected from September to October 2011. Each composite soil sample (500 - 1000 g per sample) was consisted of 10 sub-samples (two sub-samples per plant, five plants per orchards) taken from 0 - 40 cm depth near the canopy drip line. After air drying, the samples were gently ground, sieved (2 mm) and properly stored for analysis (Gil *et al.*, 2012; Lu, 1999).

Leaf samples (one composite sample per orchard) were collected from the same plants chosen for collecting soil samples from September to October 2011. Each leaf sample was consisted of 100 leaves, 20 leaves from each of five plants. The second - third leaves from the top part of the spring vegetative shoots (non-fruiting terminals) were collected from the exterior of mid canopy. Leaf samples were first washed in 0.2% HCl (ca. 30 s), then rinsed in tap water, finally washed in distilled water. After being wiped with towel, leaf samples were first oven-dried at 105 °C for 30 - 60 min, then at 65 °C for 48 - 72 h, ground and stored for analysis.

Fruit samples (five fruits each sample, one fruit per plant) were collected from the same plants chosen for collecting soil and leaf samples during the fruit maturation (from October to November). Fruits bearing on the spring shoots were collected from the southern aspect of the exterior of mid canopy. Fruit quality parameters [i.e., fresh weight per fruit, edible rate, fruit shape index, sac granu-

lation, total soluble solids (TSS), titratable acidity (TA) and Vc] were immediately assayed after being brought to our laboratory.

Soil analysis was performed according to Lu (1999) except for B. Briefly, pH was determined in 1: 2.5 (soil : water) soil water suspensions using pH-meter. OM was determined on the basis of oxidation with $K_2Cr_2O_7$ in a heated oil bath. CEC was determined by the ammonium acetate displacement method. Hydrolysable N was determined with alkaline hydrolysis diffusion method. Available P was extracted from the soil with 0.5 M $NaHCO_3$ (pH 8.5) and determined spectrophotometrically as blue molybdate- phosphate complexes under partial reduction with ascorbic acid. Available K, exchangeable Mg, Ca and Mn were extracted from soil with 1 M ammonium acetate (pH 7.0) and were assayed using atomic absorption spectrophotometry (Ca, Mg and Mn) or flame spectrophotometry (K). Available S was extracted with mono calcium phosphate-acetic acid and determined using the simple turbidimetric method based on the formation of $BaSO_4$ precipitate in colloid form. Available Cu and Zn were extracted by solutions of diethylene triamine pentaacetic acid (DTPA) at pH 7.3 and determined using atomic absorption spectrophotometry. Water-soluble B was extracted by hot water and measured using the curcumin method (Kowalenko and Lavkulich, 1976).

Leaf N, P and S were extracted and measured according to Lu (1999). Briefly, leaf N and P were assayed by semi-micro distillation titration and determined colorimetrically as blue molybdate-phosphate complexes, respectively after samples being digested with H_2SO_4 and H_2O_2 . Leaf S was determined by X-Ray fluorescence spectrometry after samples being digested with HNO_3 - $HClO_4$. Leaf K, Ca, Mg, Mn, Cu and Zn were extracted with 1 M HCl and assayed using atomic absorption spectrophotometry (Chen *et al.*, 2011). Leaf B was measured by the curcumin method after leaf sample was ashed at 500 °C for 5 h, and dissolved in 0.1 M HCl (Kowalenko and Lavkulich, 1976).

TA of fruit juice was titrated with 0.1 N NaOH to the end point pH 8.1 using a Microprocessor-based Bench pH/mV/°C Meter (pH 211, Henna Instruments, Italy) and the total acidity calculated as malic acid. TSS of fruit juice was determined with WYT-4 refractometer (Quanzhou Zhongyou Optical Instrument Co., Ltd., Quanzhou, China). Vc content of fruit juice was determined according to the 2, 6-dichlorindophenol titration method (GB6195-86; a national standard determination of Vc in vegetables and fruits in China). Juice sac granulation degree was calculated as follow: the number of juice sac granulated segments/total number of segments $\times$ 100%. The fruit-shape index was calculated as the ratio of fruit length to diameter. Fruit edible rate was calculated as follow: fresh weight of juice sacs/fresh weight of whole fruit $\times$ 100% (GB8210-87; a national standard method of inspection for export citrus fruit in China).

Range, mean, standard deviation and coefficient of variation were calculated using Microsoft Excel (Microsoft, WA, USA) spread sheet. Pearson correlation coefficient matrix was calculated using SigmaPlot 10.0 (Systat Software Inc., CA, USA).

3. Results

3.1. Soil pH, CEC, OM and mineral elements

Citrus does not like strong acid soils, because in soils of pH 5.0 or less, serious problems may arise, such as excessive solubility of Al and Mn, or low availability of P, Ca, Mg and Mo (Chapman, 1968). Soil pH of 319 samples ranged from 3.26 to 6.22, with an average value of 4.34. Out of these samples, the pH for 90% soils was less than 5.0 (Table 1), which is lower than the optimum range of 5.0 - 6.5 for pummelo growth (Xie *et al.*, 1997).

CEC ranged from 6.6 to 35.5 cmol kg⁻¹, with an average value of 17.7 cmol kg⁻¹ after (Table 1) Out of

the 319 samples, the CEC value for 67.1% soils was more than 15 cmol kg⁻¹, indicating that two-thirds of soils have medium or higher ability to hold positively charged ions (data not shown).

The average content of exchangeable Mg was 57.0 mg kg⁻¹ DW, which was less than the optimum range of 80 to 125 mg kg⁻¹ DW and 77.4% of soils were sub-optimum in exchangeable Mg, followed by exchangeable Ca (65.8%), hydrolysable N (48.6%), water-soluble B (43.9%), exchangeable Mn (29.2%) and available Cu (24.1%). The average content of available S, however, was 55.7 mg kg⁻¹ DW, which was much more than the optimum range of 12.4 to 16.1 mg kg⁻¹ DW and 96.6% of soils were super-optimum in available S, followed by available P (82.1%), exchangeable Mn (43.3%), available Cu (28.3%), water-soluble B (22.9%) and OM (21.9%) (Table 1).

Soil pH was negatively related with soil hydrolysable N, available P, exchangeable Ca, exchangeable Mg, available S or water-soluble B, and positively related with soil OM, available Cu, available Zn or CEC, respectively. There were positive correlations between CEC and OM as well as mineral elements except for Mn. Soil OM was positively related with soil hydrolysable N, available P or exchangeable Ca, respectively (Table 2).

3.2. Mineral nutrient content in leaves

Leaf N-deficiency was the most severe among the 11 mineral elements tested and 46.8% of samples were deficient in N, followed by Mg (35.6%), P (32.3%), K (22.3%) and Cu (14.0%). However, the average leaf content of B and Cu was 72.5 and 44.9 mg kg⁻¹ DW, which was much more than the optimum range of 15 to 50 and 8 to 17 mg kg⁻¹ DW, respectively. Among these leaf samples tested, 74.8% and 70.3% of pummelo leaves were excess in B and Cu, respec-

tively, followed by Ca (13.4%), S (12.1%) and Mn (11.4%) (Table 3).

Leaf N showed a positive correlation with leaf P, K or S, and a negative correlation with leaf Ca or Mg, respectively. Leaf P was positively related with leaf K, Mg or S, and negatively related with leaf Ca or

K, Mg or S, and negatively related with leaf Ca or Mn, respectively. Leaf K was negatively related with leaf Ca, Mg or Mn, and positively related with leaf S or Zn, respectively. There was no significant correlation between leaf Ca and Mg (Table 4).

Table 1. Average pH, CEC and content of OM and mineral elements in ‘Guanximiyou’ pummelo orchard soils, and the distribution of samples.

	Total samples	Range	Mean $\pm$ SD	Coefficient of variation (%)	Sub-optimum		Optimum		Super-optimum		Optimum range
					Samples	%	Samples	%	Samples	%	
pH	319	3.26 – 6.22	4.34 $\pm$ 0.44	10.2	287	90.0	32	10.0	0	0.0	5.0 – 6.5
CEC (cmol kg ⁻¹ DW)	319	6.6 – 35.5	17.7 $\pm$ 5.7	32.0							
OM (g kg ⁻¹ DW)	319	0.65 – 36.79	23.2 $\pm$ 7.9	34.2	44	13.8	205	64.3	70	21.9	15 – 30
Hydrolysable N (mg kg ⁻¹ DW)	319	21.4 – 262.4	104.3 $\pm$ 35.5	34.0	155	48.6	159	49.8	5	1.6	100 – 200
Available P (mg kg ⁻¹ DW)	319	0.5 – 806.2	184.1 $\pm$ 155.3	84.4	14	4.4	43	13.5	262	82.1	10 – 40
Available K (mg kg ⁻¹ DW)	319	35.0 – 645.0	214.2 $\pm$ 110.6	51.6	35	11.0	226	70.8	58	18.2	100 – 300
Exchangeable Ca (mg kg ⁻¹ DW)	319	90.5 – 2705.8	495.4 $\pm$ 317.2	64.0	210	65.8	107	33.5	2	0.6	500 – 2000
Exchangeable Mg (mg kg ⁻¹ DW)	319	0.5 – 272.3	57.0 $\pm$ 48.3	84.7	247	77.4	45	14.1	27	8.5	80 – 125
Available S (mg kg ⁻¹ DW)	319	11.0 – 116.7	55.7 $\pm$ 24.5	43.9	1	0.3	10	3.1	308	96.6	12.4 – 16.1
Water-soluble B (mg kg ⁻¹ DW)	319	0.05 – 4.61	0.77 $\pm$ 0.68	88.9	139	43.6	107	33.5	73	22.9	0.5 – 1.0
Available Cu (mg kg ⁻¹ DW)	315	0.01 – 29.62	5.20 $\pm$ 4.83	92.9	76	24.1	150	47.6	89	28.3	2 – 6
Available Zn (mg kg ⁻¹ DW)	319	1.7 – 32.5	5.52 $\pm$ 3.92	70.9	8	2.5	258	80.9	53	16.6	2 – 8
Exchangeable Mn (mg kg ⁻¹ DW)	319	0.3 – 170.4	11.8 $\pm$ 17.7	150.2	93	29.2	88	27.6	138	43.3	3–7

Optimum ranges were referred to the classification standard of citrus (Xie *et al.*, 1997; Zhuang *et al.*, 1995).

Table 2. Pearson correlation coefficient matrix for soil pH, CEC, OM and mineral elements.

	pH	CEC	OM	N	P	K	Ca	Mg	S	B	Cu	Zn	Mn
pH	1	-0.2035***	0.1538**	-0.2062***	-0.2861***	-0.0940	0.5207***	0.3703***	-0.3679***	-0.1776**	0.1260*	0.2499***	0.0283
CEC	-0.2035***	1	0.1411*	0.4107***	0.3620***	0.3465***	0.2512***	0.3329***	0.1594**	0.2351***	0.1673**	0.1323*	0.0306
OM	0.1538**	0.1411*	1	0.2915***	0.1691**	0.1059	0.1197*	0.0932	-0.0543	-0.0683	0.0788	0.0071	0.0757

*, ** and *** indicate a significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 3. Average mineral content of ‘Guanximiyou’ pummelo leaves and the distribution of samples.

Mineral elements	Total samples	Range	Mean $\pm$ SD	Coefficient of variation (%)	Deficiency		Sufficient		Excess		Sufficient range
					Samples	%	Samples	%	Samples	%	
N (g kg ⁻¹ DW)	316	14.0 – 31.5	25.1 $\pm$ 2.1	8.5	148	46.8	167	52.8	1	0.3	25 – 31
P (g kg ⁻¹ DW)	316	0.87 – 1.93	1.42 $\pm$ 0.17	11.7	102	32.3	211	66.8	3	0.9	1.4 – 1.8
K (g kg ⁻¹ DW)	314	8.5 – 22.5	15.4 $\pm$ 2.0	13.1	70	22.3	243	77.4	1	0.3	14 – 22
Ca (g kg ⁻¹ DW)	314	10.3 – 56.3	31.1 $\pm$ 7.1	22.8	15	4.8	257	81.8	42	13.4	20 – 38
Mg (g kg ⁻¹ DW)	314	1.70 – 7.15	3.51 $\pm$ 0.88	25.2	112	35.6	177	56.4	25	8.0	3.2 – 4.7
S (g kg ⁻¹ DW)	314	2.41 – 5.33	3.40 $\pm$ 0.49	14.3	0	0.0	276	87.9	38	12.1	2.0 – 3.9
B (mg kg ⁻¹ DW)	314	9.6 – 252.0	72.5 $\pm$ 32.6	44.9	1	0.3	78	24.8	235	74.8	15 – 50
Cu (mg kg ⁻¹ DW)	313	2.82 – 180.46	44.9 $\pm$ 37.4	83.3	40	14.0	49	15.7	220	70.3	8 – 17
Zn (mg kg ⁻¹ DW)	313	23.1 – 53.8	35.0 $\pm$ 5.9	16.8	9	2.9	281	89.8	23	7.3	24 – 44
Mn (mg kg ⁻¹ DW)	316	5.5 – 365.2	78.0 $\pm$ 61.7	79.1	6	1.9	273	86.7	37	11.4	15 – 140

Optimum ranges were referred to the classification standard of ‘Guanximiyou’ pummelo leaves (Zhuang *et al.*, 1991)

Table 4. Pearson correlation coefficient matrix for leaf content of mineral elements.

	N	P	K	Ca	Mg	S	B	Cu	Zn	Mn
N	1									
P	0.3241***	1								
K	0.1983***	0.4424***	1							
Ca	-0.1740**	-0.3583***	-0.4316***	1						
Mg	-0.1257*	0.1588*	-0.4316***	0.0168	1					
S	0.3087***	0.2688***	0.2909***	-0.0241	0.0500	1				
B	-0.0534	-0.0063	0.0082	-0.0065	0.2014***	0.1150*	1			
Cu	0.0139	-0.0712	-0.0264	-0.0122	-0.1789**	-0.0579	-0.0043	1		
Zn	-0.0550	-0.0152	0.1611**	-0.0969	-0.0493	0.1229*	0.0498	-0.1343*	1	
Mn	-0.0165	-0.1861***	-0.2014***	0.1730**	0.0740	-0.1664**	0.0256	0.0121	0.1267*	1

*, ** and *** indicate a significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively

3.3. Fruit quality characteristics

We found that the coefficients of variation (CVs) for all fruit quality parameters were less than 10% except for fresh weight per fruit, fruit granulation and TSS/TA (Table 5), meaning that fruit quality from different orchards is relatively identical, and that many of soil and leaf parameters are not related with these fruit

quality parameters. There were significant relationships between most of the fruit quality parameters. For example, fruit edible rate displayed significant positive correlations with other quality parameters except for a negative correlation with TA. TSS and TA were significantly related with other parameters except for fresh weight per fruit. The best relationship existed between TSS/TA and TSS (Table 6).

Table 5. Fruit quality characteristics of ‘Guanximiyou’ pummelo.

	Total samples	Range	Mean $\pm$ SD	Coefficient of variation (%)
Fresh weight per fruit (g)	304	467 - 1946	1125 $\pm$ 240	21.3
Edible (%)	304	40.5 - 76.7	66.5 $\pm$ 5.1	7.6
Fruit shape index	303	0.77 - 1.19	0.96 $\pm$ 0.06	6.3
Fruit granulation (%)	304	4.7 - 78.5	40.8 $\pm$ 9.0	22.1
TSS (%)	303	6.7 - 13.4	10.7 $\pm$ 0.8	8.0
TA (%)	303	0.66 - 1.05	0.83 $\pm$ 0.06	7.5
TSS/TA	302	6.6 - 19.2	12.9 $\pm$ 1.6	12.4
Vc (mg/100 mL)	304	30.7 - 50.2	42.4 $\pm$ 2.4	5.7

Table 6. Pearson correlation coefficient matrix for parameters of fruit quality

	Fresh weight per fruit	Edible	Fruit shape index	Fruit granulation	TSS	TA	TSS/TA	Vc
Fresh weight per fruit	1							
Edible	0.1199*	1						
Fruit shape index	-0.2307***	0.2000***	1					
Fruit granulation	0.2124***	0.3463***	0.1450*	1				
TSS	-0.0397	0.3943***	0.2120***	0.2494***	1			
TA	-0.0259	-0.2292***	-0.0628	-0.0780	-0.3294***	1		
TSS/TA	-0.0068	0.3685***	0.1693**	0.2161***	0.8306***	-0.7872***	1	
Vc	0.0371	0.1408*	0.0469	0.2039***	0.2938***	-0.1410*	0.2741***	1

*, ** and *** indicate a significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively

3.4. Leaf mineral nutrients in relation to soil pH, CEC, OM and mineral elements

Leaf P and Ca displayed positive relations with soil pH. Leaf N and Cu were positively related with soil CEC. Leaf Mg had a negative relation with soil OM. Except for N, P and K, leaf Ca, Mg, S, B, Cu, Zn and Mn displayed positive relations with the corresponding soil elements, respectively (Table 7).

3.5. Fruit quality parameters in relation to soil pH, CEC, OM and mineral nutrients

Fresh weight per fruit was negatively with soil available P. Fruit edible rate was negatively related with soil OM and hydrolysable N, but positively related with soil available Cu, respectively. Fruit shape index showed a negative relation with soil

exchangeable Mg, available Zn and exchangeable Mn, respectively. Fruit TSS was negatively correlated with soil exchangeable Mg. Fruit Vc was negatively related with soil pH and available Cu, respectively (Table 8).

3.6. Fruit quality parameters in relation to leaf mineral nutrients

Fresh weight per fruit was positively related with leaf S. Fruit edible rate was negatively related with leaf N and positively related with leaf Mg, respectively. Juice sac granulation degree was positively related with leaf Mg, S, Cu and Mn, respectively. TSS displayed a negative relation with leaf Ca. TA was positively related with leaf S and negatively related with leaf Ca and Cu, respectively. TSS/TA ratio was negatively related with leaf Ca and positively related with leaf S, respectively (Table 9).

Table 7. Pearson correlation coefficient matrix between leaf mineral elements (first column) and soil pH, OM, CEC and mineral elements (first row)

	pH	CEC	OM	N	P	K	Ca	Mg	S	B	Cu	Zn	Mn
N	-0.0510	0.1204*	0.0500	0.0738	-0.0248	0.0497	-0.0021	0.0198	0.1162*	-0.0586	-0.0817	0.0890	0.0899
P	0.1597**	-0.0174	0.0364	-0.0325	-0.0977	-0.0538	0.0010	0.0015	-0.0753	-0.0905	-0.0466	0.0687	-0.0325
K	0.0672	-0.0567	0.0312	0.0135	-0.0935	0.0755	-0.0704	-0.0534	0.0917	0.0194	-0.1243*	0.0341	0.0082
Ca	0.1607**	-0.0640	0.0109	-0.1314*	0.0285	0.0252	0.2108***	0.1652**	-0.1290*	0.0282	0.0775	0.0702	0.0783
Mg	0.0953	0.0124	-0.1711**	-0.0706	0.0526	0.0545	0.0273	0.1785**	-0.1094	0.0844	-0.0279	0.0939	-0.0571
S	0.0336	-0.0619	0.0032	-0.1334*	-0.1573**	-0.0686	-0.0395	-0.0009	0.1395*	-0.1098	-0.1880***	0.0124	-0.0650
B	0.0805	0.0594	-0.0972	-0.0828	-0.0686	-0.0225	0.0145	0.0407	0.0719	0.2371***	-0.0580	0.0726	0.0167
Cu	-0.0718	0.2157***	-0.1092	0.0065	-0.0220	0.0342	-0.0284	-0.0138	0.1926**	0.0309	0.1821**	-0.0643	0.0610
Zn	0.0465	-0.0819	-0.0524	-0.0862	-0.0235	-0.0287	-0.0385	-0.0126	0.0203	-0.1117*	-0.0025	0.1180*	0.0418
Mn	-0.0652	-0.0322	-0.0657	0.0301	0.0456	0.1301*	-0.0514	0.0840	0.0813	0.0466	0.0194	0.0657	0.4341***

*, ** and *** indicate a significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively

Table 8. Pearson correlation coefficient matrix between soil pH, CEC, OM and mineral elements (first column) and fruit quality parameters (first row).

	Fresh weight per fruit	Edible	Fruit shape index	Fruit granulation	TSS	TA	TSS/TA	Vc
pH	0.0583	-0.0430	-0.0545	0.0035	-0.0661	0.0196	-0.0529	-0.1328*
CEC	-0.0327	-0.1099	-0.0160	-0.0376	-0.0251	-0.0401	0.0030	-0.0213
OM	-0.0382	-0.1180*	-0.0356	-0.0973	-0.1003	-0.0206	-0.0549	0.0116
N	-0.0574	-0.1189*	-0.0545	-0.0483	-0.0387	0.0068	-0.0246	0.0276
P	-0.1201*	0.0938	-0.1099	0.0093	-0.0497	-0.0265	-0.0196	0.0061
K	-0.0635	-0.0320	-0.0953	0.0018	-0.1096	0.0520	-0.1102	0.0316
Ca	-0.0058	-0.0022	-0.1016	-0.0307	-0.1003	-0.0490	-0.0406	-0.0332
Mg	0.0422	-0.0177	-0.1552**	-0.0091	-0.1152*	-0.0167	-0.771	0.0108
S	0.0533	-0.0302	0.0218	0.0206	0.0867	0.0179	0.0383	0.1114
B	-0.0567	0.0357	0.0103	-0.0144	-0.0012	0.0770	-0.0487	0.0102
Cu	-0.0912	0.1181*	0.0283	0.0729	-0.1023	0.0519	-0.1024	-0.1303*
Zn	-0.0112	0.0506	-0.1375*	0.0271	-0.0922	0.0123	-0.0756	-0.0683
Mn	0.0400	-0.1113	-0.1176*	0.0359	-0.0940	0.0441	-0.0876	0.0647

*, ** and *** indicate a significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively

Table 9. Correlation coefficient matrix between leaf mineral elements (first column) and fruit quality parameters (first row)

	Fresh weight per fruit	Edible	Fruit shape index	Fruit granulation	TSS	TA	TSS/TA	Vc
N	0.0780	-0.1447*	-0.1039	-0.0783	-0.0548	0.0385	-0.0535	-0.0372
P	0.1083	0.0260	-0.0829	-0.0301	-0.0156	-0.1098	0.0547	-0.0773
K	0.0034	-0.0771	0.0122	0.0388	0.0102	-0.0816	0.0607	0.0679
Ca	0.0153	0.0328	-0.0178	0.0377	-0.1588**	0.1217*	-0.1852**	0.0497
Mg	0.0991	0.1525**	-0.0137	0.1199*	0.0440	-0.0337	0.0465	0.0028
S	0.1749**	0.0741	0.0136	0.1348*	0.0923	-0.1843**	0.1570**	0.1109
B	0.0291	0.0234	-0.0187	-0.0091	0.0042	-0.0269	0.0184	0.0728
Cu	-0.0984	-0.0798	0.0768	0.1711**	-0.0107	0.1796**	-0.1040	0.0010
Zn	-0.0234	0.1104	-0.0268	0.0124	0.0721	-0.0643	0.0774	-0.0058
Mn	0.0485	-0.0283	-0.0879	0.1266*	0.0176	0.1104	-0.0596	0.0472

*, ** and *** indicate a significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively

4. Discussion

4.1. Soil acidification is a major problem in 'Guanxi-miyou' pummelo orchard soils

Although citrus (pummelo) can be planted in soils with either a high or low pH, the optimum pH ranges from 5.0 to 6.5 (Xie *et al.*, 1997). Rasmussen and Smith (1957) grew Pineapple orange seedlings in

combined soils with different pH levels (i.e., 4.0, 4.3, 4.6, 5.0, and 6.0). Five months after growing, growth was the best under pH 6.0 and was considerably poorer at pH 4.0. In this study, the lowest, average and highest pH values of the 319 soils were 3.26, 4.34 and 6.22, respectively, which were lower than the previous values (i.e., 3.57, 4.63 and 7.25; Huang *et al.*, 2001). In addition, up to 21.0% soils had a pH of less than 4.0 (data not shown). Obviously, soil pH is rapidly de-

creasing in the last decade. Under natural conditions, soils acidify very slowly over hundreds to millions of years (Guo *et al.*, 2010). Rapid acidification of Pinghe pummelo orchard soils might be mainly caused by improper fertilization. In Pinghe, orchard farmers usually overuse compound fertilizer containing 15% N, 15% P_2O_5 and 15% K_2O and physiological acidic fertilizers such as Mg_2SO_4 , and seldom apply basic fertilizers such as lime and $Mg(OH)_2$. In addition, the environmental problems such as acid rain and some agriculture practices also contribute to the acidification of these soils (Guo *et al.*, 2010).

4.2. Severe soil and leaf nutrient imbalance

Organic manures were heavily applied in recent years. As expected, the average content of soil OM (23.2 g kg^{-1} DW) was higher than the previous value (17.7 g kg^{-1} DW), and the percentage of sub-optimum soils (13.8%) was lower than the previous report (29.5%) (Table 1; Huang *et al.*, 2001). Soil OM increases soil fertility by providing cation exchange sites and acting as reserve of essential nutrients, especially N and P, which are slowly released upon soil OM mineralization (Tarrasón *et al.*, 2007). This agrees with our data that soil CEC, hydrolysable N, available P and exchangeable Ca were positively related with soil OM (Table 2). It has been known that strong acidification can be buffered by OM (Aitken *et al.*, 1990). The negative relationship between soil OM and pH (Table 2) means that soil acidification caused by improper fertilization and environmental problems can not be completely buffered by increased OM.

Our finding that soil CEC was negatively related with pH (Table 2) agrees with the view that as soil pH decreases, more H^+ ions are attached to the colloids and push other cations from the colloids and into the soil solution (CEC decreases). The optimum soil CEC for citrus ranges from 12 to 16 $cmol\ kg^{-1}$ DW (Li *et al.*,

2001). Based on the criterion, only 11.9% soil samples had sub-optimum CEC. This disagrees with our data that 77.4% and 65.8% of soils had sum-optimum Ca and Mg, respectively (Table 1) and soil CEC was positively related with exchangeable Ca and Mg (Table 2). Soil OM has a particularly high CEC ranging from 250 to 400 $cmol\ kg^{-1}$ DW, and can account for 30 - 60% or more of CEC (Loveland and Webb, 2003). Our results showed that soil CEC was positively correlated with soil OM (Table 2), and that only 13% of soils had sub-optimum OM (Table 1). Thus, it is reasonable to assume that the differences between soil CEC and exchangeable Ca and Mg are caused mainly by the relatively higher soil OM (Table 1).

Like that of the previous workers (Huang *et al.*, 2001), our results showed that soil sub-optimum Mg and Ca were the two most widespread nutrient constraints in pummelo orchard soils (Table 1). Soil exchangeable Ca and Mg were positively related with soil pH (Table 2). Thus, it is reasonable to assume that soil acidification might be the major factor contributing to low levels of soil exchangeable Mg and Ca. It is worth noting that sub-optimum Mg soils (77.4%) was higher than sub-optimum Ca ones (65.8%; Table 1). Poss and Saragoni (1992) showed that exchangeable Mg was less adsorbed by the solid phase of the soil (xoisol) than exchangeable Ca, and that exchangeable Mg was preferentially leached from the upper layers of the soil than the exchangeable Ca. This can, at least in part, explain the higher percentage of sub-optimum Mg in 'Guanximiyu' pummelo orchards with heavy application of Mg fertilizers.

The average content of soil hydrolysable N was 104.3 $mg\ kg^{-1}$ DW, which was lower than the previous report (121.0 $mg\ kg^{-1}$ DW), and 48.6% of soils was sub-optimum in hydrolysable N, which was higher than the previous report (44.0%; Huang *et al.*, 2001). This means that soil hydrolysable N sub-optimum status was not improved over the last decade. According to

our investigation, most of orchards were applied with sufficient N fertilizers (600 kg ha⁻¹ or more per year). The observed increase in N sub-optimum soils might be caused by low N use efficiency due to improper application such as broadcasting. Leaching of N in the nitrate form is a very important factor leading to soil acidity (Huang *et al.*, 2014). Soil acidification in recent years implies that N leaching may be increased, which may contribute to the low availability of soil N. Available S content in 99.6% of soils was higher than the optimum range (Table 1). This might be mainly caused by the long-term and heavy application of MgSO₄. Application of 2 kg MgSO₄·7H₂O tree⁻¹ year⁻¹ is very common for most of orchards. In addition, the application of fungicides containing S (i.e., lime sulphur) may contribute to the accumulation of soil available S.

Available P content in 82.1% of soils was higher than the optimum range (Table 1), which was higher than the previous result (70.5%). Also, the average content of soil available P (184.1 mg kg⁻¹ DW) was much more than the previous report (112.3 mg kg⁻¹ DW; Huang *et al.*, 2001). The observed increase in soil available P might be caused by the heavy application of compound fertilizer containing 15% N, 15% P₂O₅ and 15% K₂O.

We found that 46.8% of leaf samples were deficient in N, which were much higher than the previous result (7.0%), and that the average content of leaf N (25.1 g kg⁻¹ DW) was lower than the previous result (28.6 g kg⁻¹ DW) (Table 3; Huang *et al.*, 2001). Obviously, N-deficiency was becoming more and more widespread. Although the degrees of soil N sub-optimum (48.6%) and leaf N-deficiency were basically similar (Tables 1 and 3), the relationship between leaf N and soil available N was poor (Table 7). However, Yu *et al.* (2007) reported that Ponkan (*Citrus reticulata*) leaf N was positively related with soil hydrolysable N.

Although only 4.4% of and up to 82.1% of soils were sub-optimum and super-optimum in available P, respectively (Table 1), up to 32.3% of and only 0.9% of leaf samples were deficient and excess in P, respectively (Table 2). This agrees with our data that leaf P was not related with soil available P (Table 7). Thus, leaf P-deficiency was not mainly caused by lower soil available P and other factors might contribute to the exacerbation of leaf P-deficiency. Also, no significant relation was observed between leaf P and soil available P on 'Guanximiyou' pummelo (Huang *et al.*, 2001), *C. sinensis* (Tang *et al.*, 2013) and Ponkan (Yu *et al.*, 2007). This demonstrates the complexes of citrus P uptake.

We found that leaf K was not related with soil available K (Table 7), as previously reported on Ponkan (Yu *et al.*, 2007), 'Guanximiyou' pummelo (Huang *et al.*, 2001) and *C. sinensis* (Tang *et al.*, 2013). In our study, 11.0% and 18.2% of orchard soils were sub-optimum and super-optimum in soil available K, respectively (Table 1), while up to 22.3% and only 0.3% of leaf samples were deficient and excess in leaf K, respectively (Table 3). Therefore, soil available K level was not the major factor affecting leaf K content.

In China, leaf Mg-deficiency is frequently observed in citrus plantations, including 'Guanximiyou' pummelo orchards (Huang *et al.*, 2001; Zhuang, 1994). As expected, 35.6% of leaves were deficient in Mg (Table 3). Regressive analysis showed that soil exchangeable Mg was positively related with soil pH (Table 2), and that leaf Mg was positively related with soil exchangeable Mg (Table 7). This drove us to conclude that soil acidification lowered soil exchangeable Mg level, thus reducing Mg²⁺ uptake, eventually resulting in leaf Mg-deficiency. However, only 4.8% of leaf samples were deficient in Ca (Table 3), although 65.8% of soils were sub-optimum in soil exchangeable Ca (Table 1). Furthermore, 13.4%

of leaf samples were excess in Ca (Table 3), although only 0.6% of soil samples were super-optimum in exchangeable Ca (Table 1). The antagonism between Ca and Mg for uptake has been known in citrus (Moss and Higgins, 1974). This is also supported by our data that leaf Ca and Mg were negatively related with leaf Mg/Ca and Ca/Mg ratio, respectively (data not shown). Thus, the difference between leaf Ca and soil exchangeable Ca can be explained in this way. Although 43.6% of soils were sub-optimum in soil water-soluble B (Table 1), up to 74.8% of leaf samples were excess in B (Table 3). This agrees with the previous result obtained on 'Guanximiyou' pummelo (Huang *et al.*, 2001). Our results showed that there was a positive between leaf B and soil water-soluble B (Table 7). However, Huang *et al.* (2001) showed that leaf B did not correlate with soil water-soluble B. Based on these results, we concluded that the observed higher leaf B excess might be mainly caused by overuse of B fertilizer through frequent foliar application rather than by high soil water-soluble B. Similarly, leaf Cu excess was more pronounced than soil super-optimum in available Cu (Tables 1 and 3). The observed higher leaf Cu excess might be mainly due to application of fungicides containing Cu (i.e., Bordeaux mixture).

To conclude, severe nutrient imbalance existed in 'Guanximiyou' pummelo orchard soils and leaves. Leaf content of mineral elements did not highly correlate with the available content of the corresponding soil elements, respectively.

4.3. Effects of mineral nutrients on fruit quality

Previous studies showed that the nutritional status of plants played a role in citrus granulation (Wang *et al.*, 2014). Our result showed that the degree of juice sac granulation was positively related with leaf S (Table 9). This agrees with our previous report

that S content was higher in granulated juice sacs of 'Guanximiyou' pummelo fruits than in normal ones (Wang *et al.*, 2014). This suggests that S might play a role in the juice sac granulation of pummelo fruits. However, no relationship was found between leaf S and the incidence of granulation in sweet orange (Awasthi and Nauriyal, 1972).

We observed a positive relationship between leaf Cu and juice sac granulation of 'Guanximiyou' pummelo fruits (Table 9), which agrees with the reports that leaf Cu increased as the fruit granulation developed in two sweet orange cultivars (Munshi *et al.*, 1978), and that granulated juice sacs of 'Guanximiyou' pummelo fruits had higher Cu content compared with normal ones (Wang *et al.*, 2014). Thus, Cu might be involved in the juice sac granulation of 'Guanximiyou' pummelo fruits. However, juice sac granulation was not significantly related with leaf Cu in 'Guanximiyou' pummelo (Xie *et al.*, 1998) and sweet orange (Awasthi and Nauriyal, 1972). In addition, no significant difference was found in Cu content between normal and granulated juice sacs of 'Guanximiyou' pummelo fruits (Xie *et al.*, 1998).

Juice sac granulation was positively related with leaf Mg. This agrees with the previous reports that Mg content was higher in granulated juice sacs than in normal ones of 'Guanximiyou' pummelo (Wang *et al.*, 2014; Xie *et al.*, 1998) and 'Valencia' orange (Sinclair and Jolliffe, 1961) fruits. However, no significant relationship was found between leaf Mg content and juice sac granulation in sweet orange (Awasthi and Nauriyal, 1972).

Our finding that juice sac granulation was positively related with leaf Mn (Table 9) disagrees with the previous result obtained on sweet orange (Awasthi and Nauriyal, 1972; Munshi *et al.*, 1978). In addition, Mn content did not significantly differ between normal and granulated juice sacs of 'Guanximiyou' pummelo fruits (Wang *et al.*, 2014).

Fruit edible rate was negatively related with leaf N, but positively related with leaf Mg (Table 9). This agrees with the previous reports that N increased citrus peel thickness (Chapman, 1968; Zhuang, 1994), and that Mg decreased citrus rind thickness (Zekri *et al.*, 2009).

We found that TSS and TA were negatively and positively related with leaf Ca respectively (Table 9), which disagrees with the results that Ca-deficiency increased TA and decreased TSS of citrus fruits (Zhuang, 1994). In addition, fruit TA was positively related with leaf Cu (Table 9), which agrees with the result that Cu-deficiency decreased the TA of orange juice (Chapman, 1968). TA displayed a negative relation with leaf S (Table 9). Our previous results showed that TA was lower in granulated juice sacs of ‘Guanximiyou’ pummelo fruits than in normal ones, while S content was higher in the former (Wang *et al.*, 2014), and that juice sac granulation was positively related with leaf S (Table 9). Thus, it is reasonable to assume that S-induced decrease in TA may be caused by increasing juice sac granulation.

5. Conclusion

Soil acidification is a major problem in ‘Guanximiyou’ pummelo orchards. Soil acidification affected the availability and uptake of mineral nutrient elements, thus inducing severe soil and leaf nutrient imbalance, eventually impairing fruit quality parameters such as sac granulation.

Acknowledgement

This work was financially supported by the earmarked fund for China Agriculture Research System.

References

- Aitken, R.L., Moody, P.W., McKinley, P.G. 1990. Lime requirement of acidic Queensland soils. I. relationships between soil properties and pH buffer capacity. *Aust. J. Soil Res.* 28, 695-701.
- Awasthi, R., Nauriyal, J. 1972. Studies on nutritional status of trees and carbohydrate metabolism in relation to granulation in sweet orange. *Indian J. Hort.* 29, 252-257.
- Chapman, H.D. 1968. The mineral nutrition of citrus. In: W. Reuther, H.J. Webber, L.D. Batchelor (eds). *The Citrus Industry*, Vol. 2. Division of Agricultural Sciences, University of California, Berkeley, CA, USA, pp. 127-89.
- Chen, A.H., Jiao, B.N., Wang, C.Q. 2011. Extraction of mineral elements from citrus leaves with boiling hydrochloric acid. *J. Fruit Sci.* 28, 1107-1110.
- Du Plessis, S.F. 1977. Soil analysis as a necessary complement to leaf analysis for fertilizer advisory purposes. *Proc. Int. Soc. Citriculture* 1, 15-19.
- Gill, P.M., Bonomelli, C., Schaffer, B., Ferreyra, R., Gentina, C. 2012. Effect of soil water-to-air ratio on biomass and mineral nutrition of avocado trees. *J. Soil Sci. Plant Nutr.* 12, 609-630.
- Guo, J.H., Liu, X.J., Zhang, Y., Shen, J.L., Han, W.X., Zhang, W.F., Christie, P., Goulding, K.W., Vitousek, P.M., & Zhang, F.S. 2010. Significant acidification in major Chinese croplands. *Science* 327, 1008-1010.
- Huang, Y.Z., Li, J., Wu, S.H., Pang, D.M. 2001. Nutrition condition of the orchards in the main production areas of Guanxihoney pomelo trees (Pinhe county). *J. Fujian Agri. Univ.* 30, 40-43.
- Huang, J., Mo, J.M., Zhang, W., Lu, X.K. 2014. Research on acidification in forest soil driven by atmospheric nitrogen deposition. *Acta Ecol. Sin.* 34, 302-310.

- Kowalenko, C.G., Lavkulich, L.M. 1976. A modified curcumin method for boron analysis of soil extracts. *Can. J. Soil Sci.* 56, 537-539.
- Li, Z.L., Wang, C.Q., Wang, S.L., Xie, D.T., Wei, C.F. 2001. Citrus growth and soil environment. *South China Fruits* 30(3), 17-21.
- Loveland, P., Webb, J. 2003. There a critical level of organic matter in the agricultural soils of temperate regions: a review. *Soil Till. Res.* 70, 1-18.
- Lu, R.K. 1999. *Methods of Soil and Agrochemistry Analysis*. China Agriculture Science & Technology Press, Beijing, China.
- Lu, Y.M. 2013. Occurrence and control of ‘Guanxi-miyou’ foot rot disease in Pinhe county. *Southeast Hort.* (4), 27-28
- Ministry of Agriculture P.R.C. 2012. *China Agriculture Statistical Report 2011*. China Agriculture Press, Beijing, China.
- Moss, G.I., Higgins, M.L. 1974. Magnesium influences on the fruit quality of sweet orange (*Citrus sinensis* L. Osbeck). *Plant Soil* 41, 103-112.
- Munshi, S.K., Singh, R., Vij, V.K., Jawanda, J.S. 1978. Mineral composition of leaves in relation to degree of granulation in sweet orange. *Sci. Hort.* 9, 357-367.
- Poss, R., Saragoni, H. 1992. Leaching of nitrate, calcium and magnesium under maize cultivation on an oxisol in Togo. *Fert. Res.* 33, 123-133.
- Rasmussen, G. K., Smith, P. F. 1957. Effect of subsoil type and pH on growth and macronutrient level of leaf tissue of Pineapple orange seedlings. *Soil Crop Sci. Soc. Fla. Proc.* 17, 243-248.
- Sinclair, W.B., Jolliffe, V.A. 1961. Chemical changes in the juice vesicles of granulated valencia oranges. *J. Food Sci.* 26, 276-282.
- Tang, Y.Q., Peng, L.Z., Chun, C.P., Ling, L.L., Fang, Y.W., Yang, X. 2013. Correlation analysis on nutrient element contents in orchard soils and sweet orange leaves in southern Jiangxi province of China. *Acta Hort. Sin.* 40, 623-632.
- Tarrasón, D., Ortiz, O., Alcañiz, J.M. 2007. A multi-criteria evaluation of organic amendments used to transform an unproductive shrubland into a Mediterranean dehesa. *J. Environ. Manage.* 82, 446-456.
- Wang, X.Y., Wang, P., Qi, Y.P., Zhou, C.P., Yang, L.T., Liao, X.Y., Wang, L.Q., Zhu, D.H., Chen, L.S. 2014. Effects of granulation on organic acid metabolism and its relation to mineral elements in *Citrus grandis* juice sacs. *Food Chem.* 145, 894-990.
- Xie, Z.N., Zhuang, Y.M., Wang, R.J., Xu, W.B. 1997. Correlation between soil pH and the contents of available nutrients in selected soils from three kinds of orchards at subtropical zone in Fujian. *Acta Hort. Sin.* 24, 209-214.
- Xie, Z.N., Zhuang, Y.M., Wang, R.J., Xu, W.B., Huang Y.Z. 1998. Granulation and dehiscent segments of Guanxi honey pomelo fruits and their correlation to mineral nutrients. *J. Fujian Agri. Univ.* 27, 42-46.
- Yu, H.B., Wang, R.C., Xiao, R.L., Yang, Z. 2007. Soil and leaf nutrient condition of plants from citrus orchards in demonstration area of environmental immigrants, northwest Guangxi province. *J. Hunan Agri. Univ. (Nat. Sci.)* 33, 341-344,357.
- Zekri, M., Obreza, T.A., Koo, R. 2009. Irrigation, nutrition, and citrus fruit quality. SL 207, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
- Zhuang, Y.M., Wang, R.J., Chen, L.X., Xu, W.B., Huang, Y.Z., Zhou, Z.L. 1991. Optimum range of mineral element content in the leaves of Guanxi honey pumelo (*Citrus grandis*). *J. Fujian Acad. Agri. Sci.* 6(2), 52-58.
- Zhuang, Y.M. 1994. *Citrus Nutrition and Fertilization*. China Agriculture Press, Beijing, China.

- Zhuang, Y.M., Wang, R.J., Xie, Z.N., Xu, W.B. 1995.
Study on nutrition diagnosis standard of citrus,
longan and litchi. *Fujian Fruits* (1), 6-9.