Journal of Agricultural Science; Vol. 8, No. 1; 2016
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Nutrient Uptake and Fruit Quality of Pummelo as Influenced by Ammonium, Potassium, Magnesium, Zinc Application

Hien Huu Nguyen[1], Somsak Maneepong[1] & Potjamarn Suranilpong[1]

[1] School of Agricultural Technology, Walailak University, Nakhon Si Thammarat, Thailand

Correspondence: Somsak Maneepong, School of Agricultural Technology, Walailak University, Nakhon Si Thammarat 80161, Thailand. E-mail: msomsak@wu.ac.th

Received: October 18, 2015 Accepted: November 14, 2015 Online Published: December 15, 2015

doi:10.5539/jas.v8n1p100 URL: http://dx.doi.org/10.5539/jas.v8n1p100

Abstract

Pummelo-growing soils in southern Thailand are usually low concentrations of potassium, calcium, magnesium and zinc; therefore, the roles of these elements are essential and their effects on nutrient uptake and fruit quality that should be considered in this area in current and future pummelo orchard. The study was carried out during 2013 to 2014 production year on a 17 year pummelo (*Citrus maxima* Merr.). The objective of the study was to examine the effects of ammonium (NH_4), potassium (K), magnesium (Mg) and zinc (Zn) fertilization over the farmer practice on nutrient uptake and fruit quality. The experiment comprised of 5 treatments; apply all, not apply NH_4, not apply K, not apply Mg and farmer practice. Application of fertilizer increased N, Ca and Mg concentrations in the leaves, but K and Zn concentrations in leaves decreased after application. However, their concentrations were in optimum ranges. High K/Ca, K/Mg mole ratios and low exchangeable Mg in soil positively affected on K uptake. Low Ca/Mg mole ratio and low exchangeable Ca in soil negatively affected on Ca uptake. The TSS and TSS/TA tended to decline when the treatments were not applied K-fertilizer. The fruit qualities were greater in the treatments with K/Ca, K/Mg and Ca/Mg mole ratios in soil were 0.23 to 0.27, 0.63 to 0.71 and 2.35 to 3.08, respectively. This study showed that K and Zn still required for pummelo growing in this soil.

Keywords: pummelo, plant nutrition, nutrient uptake, fruit quality

1. Introduction

Pummelo (*Citrus maxima* Merr.) is an indigenous citrus to Southeast Asia. It is grown in many countries in the world such as China, Thailand, Japan, India, Bangladesh, Vietnam, Malaysia and Indonesia (Morton, 1987). Nitrogen (N), potassium, calcium (Ca), magnesium and Zinc are important nutrients for citrus growth, fruit production and fruit quality. They are needed in adequate amounts, especially at critical crop growth stages, fruit initiation and development (Alva et al., 2005). N is the prerequisite and most important nutrient for citrus cultivation (Alva & Tucker, 1999), especially in the soil which contains small amounts of available N. It is essential to enhance plants, biological processes and enables plants to use the energy in the photosynthesis process (Abbas & Fares, 2008). K requires for several physiological functions, such as, sugars and starch metabolism, synthesis of proteins, cell division (Abbas & Fares, 2008). It increases fruit size, yield, TSS and reduces peel thickness (Fernandez & Guzman, 2013). Mg is involved in photosynthesis, carbohydrate metabolism, synthesis of nucleic acids, related to movement of carbohydrates from leaves to upper parts, and stimulates P uptake and transport; in addition it becomes an activator of several enzymes (Fageria & Gheyi, 1999). Zn is an important micronutrient that is closely involved in the metabolism of RNA and ribosomal content in plant cells; also it leads to stimulate carbohydrates, proteins and the DNA formation. It is required for the synthesis of tryptophan, a precursor of the IAA which acts as a growth promoting substance (Sparrow & Graham, 1988). Deficiencies of K, Ca and Mg usually occur due to undersupply or antagonistic effects on each other, thus decreasing growth, yield and fruit quality of citrus. A lack of a specific element is not only restricted to bad management of fertilizer program, but also to antagonism between elements that is sometime difficult to prevent. That is the case for K, Ca and Mg that strongly interfere with each other during the uptake process (Voogt, 1987). Pummelo is the biggest fruit producing citrus. A 10 to 20 year-old pummelo planted from air-layering stock, with proper growing practice is able to bear 200 to 250 fruits/year or 200 to 300 kg/year. Large amounts of nutrients are removed from soil; consequently, concentrations and balance of the nutrients are changed. The quality of the fruit declines and nutrient disorder occurs in a short period. According to Tongleaw et al. (2012), nutrient loss for every 1,000 kg of fresh 'KhaoYai' variety was 1.92 kg-N; 0.27 kg-P; 2.80 kg-K; 1.16 kg-Ca and 0.19 kg-Mg. Quantities of N, P, K, Ca, Mg and Zn which required for fruit growth were 1716, 252, 3005, 1506, 228 and 1.43 mg/fruit, respectively (Maneepong, 2009).

Standard recommendations for pummelo growing soil and nutrient concentrations in pummelo leaves were established in our previous study (Maneepong, 2008, 2013; Zhuang et al., 1991). However, nutrient response base on the recommendations is not clearly understood. This study was carried out in order to examine the effects of ammonium, potassium, magnesium, and zinc fertilization over the farmer practice on nutrient uptake and fruit quality.

2. Materials and Method

2.1 Experimental Design

A representative pummelo plantation in Khanom district, Nakhon Si Thammarat Province, Thailand (latitude 9°19′43.2″N, longitude 99°78′91.3″E) was selected for the present study. Most of the pummelo trees were planted in 1997, but some of them were re-planted later. Only KhaoThongdee variety is grown on this plantation. The pummelo was grown in blocks of land. Each block was separated by a furrow of 1 m width, and 0.5 m depth. Twelve trees were arranged in double row in each block. Spacing between trees was 8 m, and between rows was 9 m. Five trees which had a similar canopy volume, and equal age from each block were selected for placing into each treatment (Table 1). Ammonium sulfate, potassium chloride, magnesium sulfate and zinc sulfate were applied on top of farmer practice for the treatment 1 (T1). Ammonium sulfate was omitted for the treatment 2 (T2). Potassium chloride was omitted for the treatment 3 (T3). Magnesium sulfate was omitted for the treatment 4 (T4). No additional fertilizers were applied for the treatment 5 (T5). The study was carried out during June, 2013 to November, 2014.

Table 1. Fertilizer rates and number of application times in a year for each treatment (fertilizer weight x times of application). The first application was performed in June, 2013

Treatments	$(NH_4)_2SO_4$ (21-0-0)	KCl (0-0-60)	$MgSO_4{\cdot}7H_2O$	$ZnSO_4{\cdot}7H_2O$
T1 (All)	4 kg (1×4)	2 kg (1×2)	4 kg (1×4)	250 g
T2 (-N)	0	2 kg (1×2)	4 kg (1×4)	250 g
T3 (-K)	4 kg (1×4)	0	4 kg (1×4)	250 g
T4 (-Mg)	4 kg (1×4)	2 kg (1×2)	0	250 g
T5 (Farmer practice)	0	0	0	0

2.2 Soil Sampling and Analysis

Soil samples were taken twice before treatment application and after treatment application one year. Soil samples were taken from 4 positions directly beneath of outer canopy of each tree between 0 to 20 cm depth by a sampling tube. The samples were mixed, air-dried, ground and gravel and debris were removed by sieving through a 2 mm screen. Soil pH was measured using 1:2.5 soil: water ratios. Available P was extracted by 0.03 M NH_4F in 0.10 M HCl (Bray II solution), and its concentration was analyzed using the molybdenum blue method. Exchangeable K, Ca and Mg were extracted with 1 M NH_4OAc at pH 7.0. Concentration of K was analyzed by a flame photometer. Concentrations of Ca and Mg were analyzed by an atomic absorption spectrophotometer (AAS). Zn was extracted with diethylenetriaminepentaacetic acid (DTPA) solution, and its concentration was analyzed by an AAS (Jones, 2001, 2003).

2.3 Leaf Sampling and Analysis

Pummelo leaves were sampled 5 times (June and September, 2013; March, June, and September, 2014). The leaves were sampled from 3rd or 4th position of 3-5 months old, newly flush, and non-fruiting twig on the outer canopy. The samples were dried at 65 °C, ground, passed through a 1mm sieve. N was analyzed by the Kjeldahl method. The samples were digested with 2:1 HNO_3: $HClO_4$ for K, Ca, Mg and Zn analysis. Concentration of K was analyzed by a flame photometer. Concentrations of Ca, Mg and Zn were analyzed by an AAS (Soil and Plant Analysis Council, 1998).

2.4 Fruit Sampling and Analysis

Pummelo fruits were sampled twice in November, 2013 and November, 2014. A medium size of fully ripen pummelo fruit was sampled from each replication (one fruit from each tree). Fruit weight and endocarp (pulp) weight were determined, and edible portion was calculated from their ratios. Thickness of flavedo and albedo (peel) was measured at four points equatorially using a ruller. The pummelo juice was extracted by a blander and the juice ratio was calculated from juice volume and fruit weight (ml/kg). The total soluble solid (TSS) was determined by using a hand refractometer. The titratable acidity (TA) was determined by titration of 50 ml juice with 0.1 M NaOH and calculated by assuming that all acids in the juice are equivalent to citric acid (Boland, 1995). The test index (TSS/TA) was calculated from the ratio of TSS and TA.

2.5 Analysis of Experimental Data

The data were subjected to an analysis of variance (ANOVA) in a completely randomized design that contained five treatments and five replicates per treatment. The mean separation was performed by Duncan's multiple range tests at the 5% level of significance.

3. Results and Discussion

3.1 Effects of Fertilizer Application on Soil Chemical Properties

The soil pH was significantly lower in T5 than in the other treatments before application. Additional fertilizers tended to decrease soil pH in T1 (T1 was applied all of fertilizers), soil pH slightly increased in the other treatments. However, soil pH had no significant differences among treatments after application. It was in optimum ranges for pummelo (5.5 to 6.5; Maneepong, 2008) in both before and after application. It was lower than its optimum ranges only in T5 before treatment application.

The available P was much higher than its optimum ranges for pummelo (15 to 25 mg/kg, Maneepong, 2008) in both before and after application. It tended to increase after treatment application, although P-fertilizer was not applied by the authors, but the farmer did it. In every treatment, available P increased twice or three times compared with before treatment application, the results indicated that farmer applied a lot of P-fertilizers for pummelo trees. Therefore, pummelo growing in this area should not require additional P-fertilizer. The available P had no significant differences among treatments in both before and after application.

The exchangeable K was significantly higher in T3 than in T1 and T2 before treatment application, it had no significant differences between T3 and the other treatments. Additional K-fertilizer increased exchangeable K in soil. After treatment application, the exchangeable K was significantly lower in T3 and T5 than in T2, because T3 and T5 were not applied K-fertilizer. The exchangeable K was in optimum ranges for pummelo (100 to150 mg/kg; Maneepong, 2008) in both before and after treatment application. However, exchangeable K in T1 was slightly lower than its optimum ranges before treatment application. The exchangeable K in T5 slightly increased from 137.3 to 146.4 mg/kg after treatment application, although T5 was not applied K-fertilizer by the authors, the results indicated that the farmer also applied K-fertilizer for pummelo trees.

The exchangeable Ca was significantly higher in T1 than in the other treatments, except T4 before treatment application. It had no significant differences among treatments after application. It correlated to soil pH. Exchangeable Ca tended to increase after treatment application, although Ca was not applied by the authors, but the farmer applied Ca for pummelo trees, only exchangeable Ca in T1 decreased after treatment application. However, exchangeable Ca was lower than its optimum ranges for pummelo (1000 to 2000 mg/kg; Maneepong, 2008) in both before and after treatment application.

The highest exchangeable Mg was found in T1 (224.7 mg/kg) before treatment application. Additional Mg-fertilizer increased exchangeable Mg in soil. The exchangeable Mg was significantly lower in T4 and T5 (no additional Mg) than in the other treatments after application. It was in optimum ranges for pummelo (120 to 240 mg/kg; Maneepong, 2008) in both before and after application.

Table 2. Chemical properties of top-soils (0 to 20 cm) under pummelo canopy. The samples were taken before and after treatment application

Chemical properties	Sampling time	Treatments				
		T1	T2	T3	T4	T5
pH	Before	6.0[a]	5.8[a]	5.9[a]	5.7[a]	5.3[b]
	After	5.7[a]	5.9[a]	6.0[a]	5.7[a]	5.6[a]
Available P (mg/kg)	Before	97.4[a]	94.2[a]	138.3[a]	158.1[a]	98.3[a]
	After	220.9[a]	300.4[a]	332.8[a]	244.7[a]	213.7[a]
Exchangeable K (mg/kg)	Before	97.3[b]	106.7[b]	157.7[a]	116.5[ab]	137.3[ab]
	After	204.0[ab]	235.8[a]	154.0[b]	168.7[ab]	146.4[b]
Exchangeable Ca (mg/kg)	Before	1045.7[a]	667.2[b]	672.7[b]	757.1[ab]	499.3[b]
	After	900.4[a]	917.6[a]	979.2[a]	823.1[a]	747.0[a]
Exchangeable Mg (mg/kg)	Before	224.7[a]	131.1[b]	168.0[b]	144.3[b]	168.5[b]
	After	243.2[a]	239.7[a]	248.0[a]	162.3[b]	196.3[b]
Extractable Zn (mg/kg)	Before	2.4[b]	2.3[b]	1.4[b]	4.8[a]	1.1[b]
	After	5.5[ab]	5.4[ab]	4.8[b]	6.2[a]	2.6[c]
K/Ca mole ratio	Before	0.10[c]	0.17[c]	0.25[ab]	0.19[abc]	0.30[a]
	After	0.23[a]	0.27[a]	0.18[a]	0.23[a]	0.23[a]
K/Mg mole ratio	Before	0.28[b]	0.59[ab]	0.68[a]	0.52[ab]	0.52[ab]
	After	0.51[ab]	0.63[ab]	0.40[b]	0.71[a]	0.48[ab]
Ca/Mg mole ratio	Before	2.83[ab]	3.53[a]	2.70[ab]	3.03[ab]	1.77[b]
	After	2.25[b]	2.35[b]	2.41[b]	3.08[a]	2.25[b]

Note. Different letters within the rows indicate significant differences ($P \leq 0.05$).

Additional Zn-fertilizer increased extractable Zn in soil. The highest extractable Zn was found in T4 before application, there was a significant difference in extractable Zn between T4 and the other treatments. After treatment application, the extractable Zn was significantly higher in T4 than in T3 and T5, but it had no significant differences between T4 and T1, T2. The lowest extractable Zn was found in T5 after treatment application, because this treatment was not applied Zn-fertilizer. The extractable Zn was in optimum ranges (1.1 to 3.0 mg/kg; Maneepong, 2008) before treatment application in all treatments, except T4. It was higher than its optimum ranges in all treatments after application, except T5.

Additional K-fertilizer increased the K/Ca mole ratios in soil. The T3 and T5 were not applied K-fertilizer, therefore the K/Ca mole ratios decreased after treatment application. The K/Ca mole ratio was significantly higher in T5 than in T1 and T2 before application. It had no significant differences among treatments after application. The K/Mg mole ratios tended to increase in the treatment applied K-fertilizer. It decreased in the treatments were not applied K-fertilizer (T3 and T5). Although, Mg-fertilizer was applied for pummelo trees in T1, T2 and T3, but K/Mg mole ratios did not decrease in T1 and T2, it decreased only in T3. The K/Mg mole ratio was significantly higher in T3 than in T1 before application, it had no significant differences between T3 and the other treatments. It was significantly higher in T4 than in T3, but it had no significant differences between T4 and the other treatments after application.

Additional Mg-fertilizer decreased the Ca/Mg mole ratios in soil. The Ca/Mg mole ratio slightly increased in T4 and T5, because these treatments were not applied Mg-fertilizer. The Ca/Mg mole ratio was significantly higher in T2 than in T5 before application, but it had no significant differences between T2 and the other treatments. The highest Ca/Mg mole ratio in soil was found in T4 after application.

3.2 Effects of Fertilizer Application on Nutrient Uptake

3.2.1 Effects of Fertilizer Application on N Uptake

Application of N-fertilizer increased N concentration in the leaves. However, the N concentration had no significant differences among treatments and sampling times. It was in optimum ranges according to Maneepong (2008) and Zhuang et al. (1991), who recommended that the optimum ranges for pummelo was 27 to 30 g/kg. But N concentration was higher than its optimum ranges according to Fernandez and Guzman (2013) (24 to26 g/kg). Treatment T2 and T5 did not apply N-fertilizer, but the N concentration in leaves did not differ from the other treatments. In this study, the N-fertilizer was not only applied by the author but also farmer did it. Therefore, pummelo growing in this orchard should not require additional N-fertilizer. Application of N-fertilizer did not affect on N concentration in leaves and fruits. It had also no effect on concentrations of Ca, Mg and K in apple leaves in the soil containing high organic matter was reported by Erani et al. (2008). However, according to Huet (1988), the increased amount of N application increased N, P, K, Ca, and Mg uptake by tomato. Increase of N application up to 290 kg/ha also resulted in a decrease of N concentration in orange leaves (Hammami et al., 2010).

Table 3. N concentrations in leaves before and after treatment application (g/kg)

Treatments	Sampling times				
	Before	3 months	9 months	12 months	15 months
T1	26.2^{a}	27.8^{a}	28.3^{a}	27.4^{a}	28.5^{a}
T2	27.1^{a}	27.3^{a}	27.6^{a}	27.1^{a}	28.6^{a}
T3	25.8^{a}	27.7^{a}	28.9^{a}	28.0^{a}	29.5^{a}
T4	27.5^{a}	27.8^{a}	29.1^{a}	27.9^{a}	28.6^{a}
T5	26.8^{a}	27.3^{a}	27.8^{a}	27.7^{a}	28.9^{a}

Note. Different letters within the columns indicate significant differences ($P \leq 0.05$).

3.2.2 Effects of Fertilizer Application and Basic Cation Ratios in Soil on K, Ca and Mg Uptake

The K concentration was significantly higher in T4 (23.0 g/kg) than in T2 (20.7 g/kg), it had no significant differences between T4 and the other treatments before application (Table 4). It was significantly higher in T5 (22.9 g/kg) than in T1, T2 and T3 after 3 months, although T5 was not applied K-fertilizer, but the low exchangeable Mg and high K/Ca mole ratio in soil positively affected on K uptake. Treatments T1 and T2 were applied K-fertilizer, but high leaf Ca concentration in these treatments (42.0, 34.5 g/kg, respectively) and low K/Ca mole ratios in soil (0.10, 0.17, respectively) negatively affected on K uptake. After 9 and 12 months, K concentration had no significant differences among treatments. K concentration of the T4 was significantly higher than that of T3 after 15 months, because T3 was not applied K-fertilizer and K/Mg mole ratio was also low in soil after treatment application. Additional K-fertilizer did not increase K concentration in the leaves, K concentration tended to decrease after treatment application. Especially, leaf K concentration decreased during fruit development (after 3 and 15 months application). Although, exchangeable K; mole ratios of K/Ca and K/Mg in soil increased after K-fertilizer application. The mole ratios of K/Ca and K/Mg in leaves (data were not shown) were higher than that in soil, indicating that pummelo prefers K over Ca and Mg. Therefore, pummelo growing in this area should require additional K-fertilizer. High K concentration was found in T4 in both before and after treatment application, although exchangeable K of T4 in soil was lower than that in T1 and T2, but high K/Mg mole ratio (0.71) and low exchangeable Mg in soil positively affected on K uptake. K-fertilizer was not applied to the T5 and the exchangeable K in soil was lower than the others, but the leaf K of T5 did not differ from the other treatments, the process of K uptake was affected by low exchangeable Mg in soil. Low K concentration was found in the T3 after 15 months, this treatment was not applied K-fertilizer and the K/Ca, K/Mg mole ratios were also low 0.18, 0.40, respectively. The K concentration was in optimum ranges for pummelo (15 to 20 g/kg; Maneepong, 2008; Zhuang et al., 1991) in both before and after application.

Table 4. K concentrations in leaves before and after treatment application (g/kg)

Treatments	Sampling times				
	Before	3 months	9 months	12 months	15 months
T1	22.1^{ab}	19.1^{c}	20.5^{a}	18.8^{a}	17.9^{ab}
T2	20.7^{b}	18.2^{c}	19.3^{a}	17.5^{a}	16.8^{ab}
T3	21.6^{ab}	19.8^{bc}	20.9^{a}	18.0^{a}	15.1^{b}
T4	23.0^{a}	22.2^{ab}	22.0^{a}	21.0^{a}	18.5^{a}
T5	22.6^{ab}	22.9^{a}	19.8^{a}	21.0^{a}	17.1^{ab}

Note. Different letters within the columns indicate significant differences ($P \leq 0.05$).

The Ca concentration was significantly higher in T1 than in T4 and T5, it was lower than its optimum ranges for pummelo (30 to 40 g/kg; Maneepong, 2008) before application (Table 5), because high K concentration in leaves before treatment application affected on Ca uptake. According to Bergmann (1992) high K causes indirect damage by including Ca and Mg deficiencies. The Ca concentration in leaves tended to increase after treatment application, although Ca was not applied, but the farmer did it. The Ca concentration was in optimum ranges after treatment application. Although, exchangeable Ca in soil was lower than its optimum ranges. The Ca/Mg mole ratios in leaves (data were not shown) were higher than that in the soil. Therefore, pummelo prefers uptake Ca over Mg. Ca concentration was slightly lower than optimum ranges only in T5, although K/Ca mole ratio of the T5 in soil did not differ from the other treatments, but low Ca/Mg mole ratio in soil was observed in T5.

Table 5. Ca concentrations in leaves before and after treatment application (g/kg)

Treatments	Sampling times				
	Before	3 months	9 months	12 months	15 months
T1	25.4^{a}	42.0^{a}	30.8^{a}	35.6^{a}	39.8^{a}
T2	22.7^{ab}	34.5^{b}	30.0^{a}	33.0^{ab}	36.3^{ab}
T3	22.5^{ab}	30.7^{bc}	27.0^{a}	31.2^{ab}	34.3^{ab}
T4	21.4^{bc}	32.6^{b}	30.2^{a}	31.0^{ab}	36.9^{ab}
T5	18.2^{c}	26.0^{c}	27.9^{a}	29.5^{b}	30.5^{b}

Note. Different letters within the columns indicate significant differences ($P \leq 0.05$).

The Mg concentration had no significant differences among treatments before application (Table 6). It tended to increase after treatment application, and it slightly decreased in the T2 after 15 months. The K/Mg and Ca/Mg mole ratios in leaves (data were not shown) were higher than that in soil, indicating that pummelo trees prefer uptake K and Ca over Mg, but pummelo trees required small amounts of Mg. Therefore, Mg concentration was in optimum ranges (3 to 5 g/kg; Maneepong, 2008; Zhuang et al., 1991) in both before and after treatment application. It was slightly over optimum ranges in T1 and T5 after 15 months. Treatments T4 and T5 were not applied Mg-fertilizer and exchangeable Mg in soil was lower than the others, but the Mg concentration in leaves did not differ from the other treatments. The moderate of exchangeable K, Ca and the K/Mg, Ca/Mg mole ratios in soil positively affected on Mg uptake.

Table 6. Mg concentrations in leaves before and after treatment application (g/kg)

Treatments	Sampling times				
	Before	3 months	9 months	12 months	15 months
T1	4.6^{a}	4.7^{a}	4.4^{ab}	4.9^{a}	5.1^{a}
T2	4.1^{a}	4.3^{a}	4.2^{b}	4.4^{b}	4.0^{b}
T3	4.6^{a}	4.8^{a}	4.5^{ab}	4.7^{ab}	4.9^{ab}
T4	4.7^{a}	4.7^{a}	4.7^{a}	4.7^{ab}	4.9^{ab}
T5	4.6^{a}	4.9^{a}	4.7^{a}	4.7^{ab}	5.2^{a}

Note. Different letters within the columns indicate significant differences ($P \leq 0.05$).

3.2.3 Effects of Fertilizer Application on Zn Uptake

The Zn concentration was significantly higher in T3, T4 and T5 than in T1 or T2 before treatment application (Table 7). It had no significant differences among treatments after 3 and 9 months. It was significantly lower in T5 than in T1 and T2 after 12 months. After 15 months, Zn concentration was significantly lower in T2, T3 and T5 than in T4, low Zn concentration of T3 and T5 in leaves was affected by low extractable Zn in soil. The Zn concentration was in optimum ranges (> 15 mg/kg; Maneepong, 2008) in both before and after application. Additional Zn-fertilizers did not increase the Zn concentration in the leaves. The Zn concentration tended to decrease after treatment application. Although, the extractable Zn in soil increased after application, it was also higher than its optimum ranges (Table 2). The decrease of Zn concentration in leaves may be affected by translocation of Zn from leaves to fruits. On the other hand, Zn-fertilizer was applied one time a year. Pummelo may not receive sufficient amount of Zn. Therefore, pummelo growing in this orchard should require additional Zn-fertilizer.

Table 7. Zn concentrations in leaves before and after treatment application (mg/kg)

Treatments	Sampling times				
	Before	3 months	9 months	12 months	15 months
T1	33.1^{b}	35.0^{a}	16.5^{a}	17.0^{a}	26.8^{ab}
T2	34.3^{b}	33.2^{a}	19.4^{a}	18.0^{a}	25.3^{b}
T3	53.5^{a}	35.5^{a}	17.4^{a}	15.8^{ab}	24.7^{b}
T4	53.1^{a}	38.4^{a}	16.2^{a}	16.1^{ab}	31.66^{a}
T5	49.0^{a}	33.4^{a}	18.1^{a}	14.2^{b}	22.4^{b}

Note. Different letters within the columns indicate significant differences ($P \leq 0.05$).

3.3 Effects of Fertilizer Application and Basic Cation Ratios on Fruit Qualities of Pummelo

3.3.1 Effects of Fertilizer Application and Basic Cation Ratios on Fruit Qualities of the First Year (2013)

The peel thickness of pummelo fruit ranged from 1.6 to 1.8 cm. It was fairly thick comparison to generally accepted at 1.5 cm. It had no significant differences among treatments. However, no addition of N and K (T2 and T3) tended to be thicker than the others. Low edible portion was also found in the T3 (56.4%); however, edible portion had no significant differences among treatments. Juice ratio ranged from 335.2 to 372.8 ml/kg. However, no differences in juice ratio were observed among treatments, but juice ratio tended to be lower than the other treatments when the treatment was not applied K-fertilizer (T3). The lowest TSS was found in the T3 (no additional K-fertilizer), there was a significant difference in TSS between T3 and the other treatments. The TSS was significantly higher in T5 than in the other treatments, except T1. Test indexes (TSS/TA) and TA had no significant differences among treatments. However, TSS/TA tended to be lower in T3 than in the others.

Leaf K had a significant difference between T3 and T5 at the sampling time in September 2013 (after 3 months). In addition, K-fertilizer was not applied to the pummelo of the treatment T3. Moreover, the K/Ca and K/Mg mole ratios of T3 in soil decreased after application and K/Mg mole ratio of T3 in soil after application was also lower than the other treatments. Therefore, the pummelo trees may not receive sufficient amount of K. Pummelo trees of T5 also did not receive additional K-fertilizers, but Ca in soil was lower than the other treatments and high K/Ca ratios in soil before application that affected on K uptake. Leaf K of T1 and T2 were found low at the sampling time in September 2013 (after 3 months), it negatively affected to TSS.

Table 8. Properties of pummelo fruits taken from Khanom orchard in 2013

Treatments	Peel thickness (cm)	Edible portion (%)	Juice ratio (ml/kg)	TSS (%)	TA (%w/v)	TSS/TA
T1	1.7^{a}	58.7^{a}	363.5^{a}	11.8^{ab}	0.67^{a}	17.9^{a}
T2	1.8^{a}	57.3^{a}	372.8^{a}	11.0^{c}	0.62^{a}	17.7^{a}
T3	1.8^{a}	56.4^{a}	335.2^{a}	10.4^{d}	0.69^{a}	15.5^{a}
T4	1.7^{a}	59.6^{a}	369.5^{a}	11.4^{bc}	0.65^{a}	17.6^{a}
T5	1.6^{a}	60.7^{a}	368.9^{a}	12.0^{a}	0.69^{a}	17.4^{a}

Note. Different letters within the columns indicate significant differences ($P \leq 0.05$).

3.3.2 Effects of Fertilizer Application and Basic Cation Ratios on Fruit Qualities of the Second Year (2014)

Peel thickness is an important parameter that determines the quality of pummelo fruits. Large fruits with thin rinds are desirable based on consumer preference. Peel thickness in T1 and T3 was higher than 0.2 cm compared with T2, T4 and T5; however, it had no significant differences among treatments. The peel thickness tended to be thicker in treatment was applied all (T1) and treatment was not applied K-fertilizer (T3), the treatment T3 was also low K concentration in leaves and low K/Mg ratio in soil. This conforms to previous reports that no application of K increases peel thickness in pummelo (Fernandez & Guzman, 2013). Edible portion had no significant differences among treatments. However, the low edible portion was found in T1 and T3 (56.6 and 57.0% respectively). The TA and pH of pummelo fruits had no significant differences among treatments. The high juice ratio was found in T4 and T5 (391.4 and 397.9 ml/kg, respectively). However, juice ratio had no significant differences among treatments. The TSS and TSS/TA of pummelo fruits were significantly higher in T2 and T4 than in T3 or T5. Treatment T5 was not applied fertilizer and exchangeable K and extractable Zn in soil were lower than others, Zn concentration in leaves was also low in treatment T5, but K concentration in leaves did not differ from the others. The TSS and TSS/TA were affected by low Zn concentration in leaves. Application of Zn increased TSS of tomato was reported by Kazemi (2013) and Kumari (2012), increase TSS of mango was reported by Bahadur et al. (1998). Treatment T3 was not applied K-fertilizer and K concentration in leaves was also lower than the others after 15 months. On the other hand, soil K/Ca, K/Mg mole ratios and exchangeable K of T3 were lower than the other treatments. Therefore, the pummelo fruit of T3 was low TSS and TA compared with T2 and T4. Previous studies also showed that K fertilization increased TSS and decreased peel thickness of pummelo fruits (Fernandez & Guzman, 2013). In some studies, there was also an increase in TSS content with an increase in K supply in papaya (Kumar et al., 2006), plum and peach (Mimoun et al., 2009). The juice acidity and TSS/TA correlated with leaf K of orange (Moss & Higgis, 1974). Treatment T2 was not applied N-fertilizer, but peel thickness, edible portion, juice ratio and TA did not differ from the others, TSS and TSS/TA of T2 were higher than that in T3. Therefore, application of N-fertilizer did not affect on fruit quality of pummelo, the same results were also found by Wrona (2004), Erani et al. (2008) in apple and Ferante et al. (2008) in melon.

Table 9. Properties of pummelo fruits taken from Khanom orchard in 2014

Treatments	Peel thickness (cm)	Edible portion (%)	Juice ratio (ml/kg)	TSS (%)	TA (%w/v)	TSS/TA
T1	1.92^{a}	56.6^{a}	364.6^{b}	9.7^{ab}	0.55^{a}	17.8^{ab}
T2	1.7^{a}	58.6^{a}	376.6^{ab}	9.8^{a}	0.52^{a}	18.8^{a}
T3	1.9^{a}	57.0^{a}	369.1^{ab}	9.3^{b}	0.56^{a}	16.7^{b}
T4	1.7^{a}	59.3^{a}	391.4^{ab}	9.8^{a}	0.53^{a}	18.6^{a}
T5	1.7^{a}	60.3^{a}	397.7^{a}	9.3^{b}	0.56^{a}	16.7^{b}

Note. Different letters within the columns indicate significant differences ($P \leq 0.05$).

The fruit qualities were greater in T2 and T4 such as TSS and TSS/TA. The soil K/Ca, K/Mg and Ca/Mg mole ratios in the soil of these treatments were 0.23 to 0.27, 0.63 to 0.71 and 2.35 to 3.08, respectively.

4. Conclusions

Application of N, K, Mg and Zn increased the exchangeable K, Mg and extractable Zn in soil. The soil pH, exchangeable K and Mg were in optimum ranges. The extractable Zn was higher than its optimum ranges after application. However, the exchangeable Ca was lower than its optimum ranges. The N, Ca and Mg concentrations in leaves increased after treatment application, their concentrations were in optimum ranges. The K and Zn concentrations decreased after application; however, their concentrations were in optimum ranges. High K/Ca, K/Mg mole ratios and low exchangeable Mg in soil positively affected on K uptake. Low Ca/Mg mole ratio and low exchangeable Ca in soil negatively affected on Ca uptake. Application of K-fertilizer positively affected on TSS and TSS/TA. The fruit qualities were greater in the treatments with K/Ca, K/Mg and Ca/Mg mole ratios in soil were 0.23 to 0.27, 0.63 to 0.71 and 2.35 to 3.08, respectively.

References

Abbas, F., & Fares, A. (2008). Best management practices in citrus cultivation. In P. Tennant & N. Benkeblia (Eds.), *Tree and Forestry Science and Biotechnology* (Vol. 3, Special Issue 1, pp. 1-11). University of the West Indies, Jamaica.

Alva, A. K., & Tucker, D. P. H. (1999). Soil and citrus nutrition. In L. W. Timmer & L. W Duncan (Eds.), *Citrus Health Management* (pp. 59-71). Minesota, America: APS Press. St. Pal.

Alva, A. K., Paramasivam, S., Fares, A., Obreza, T. A., & Schumann, A. W. (2005). Nitrogen best management practice for citrus trees I. Fruit yield. Quality and leaf nutritional status. *Scientia Horticulturae, 107*, 233-244. http://dx.doi.org/10.1016/j.scienta.2005.05.017

Bahadur, L., Malhi, C. S., & Singh, Z. (1998). Effect of foliar and soil applications of zinc sulphate on zinc uptake, tree size, yield and fruit quality of mango. *Journal of Plant Nutrition, 21*(3), 589-600. http://dx.doi.org/10.1080/01904169809365426

Bergmann, W. (1992). *Nutritional disorders of plants*. Germany: Development, visual and analytical diagnosis.

Boland, F. E. (1995). Acidity (titraable) of fruit products. In P. Cunniff (Ed.), *Official Methods of Analysis of the Association Official Analytical Chemist International* (6th ed., p. 2). Virginia, America: AOAC international.

Erani, P. R., Rogeri, D. A., Proenca, M. M., & Dias, J. (2008). Addition of nitrogen had no effect on yield and quality of apple in high density orchard carrying Adwarf rootstock. *Rev. Bars. Frutic., 30*(4), 1113-1118. http://dx.doi.org/10.1590/S0100-29452008000400044

Fageria, N. K., & Gheyi, H. R. (1999). *Efficient crop production*. Campina Grande, Brazil: Federal University of Paraiba.

Fernandez, A., & Guzman, C. D. (2013). Quality and nutrition of pummelo as influenced by potassium. *Journal of Environmental Science and Engineering, 2*, 97-105.

Ferrante, A., Spinardi, A., Maggiore, T., Testoni, A., & Gallina, P. M. (2008). Effect of nitrogen fertilization levels on melon fruit quality at the harvest time and during storage. *Journal of the Science of Food and Agriculture, 88*, 707-713. http://dx.doi.org/10.1002/jsfa.3139

Hammmami, A., Rezgui, S., & Hellali, R. (2010). Leaf nitrogen and potassium concentrations for optimum fruit production, quality and biomass tree growth in Clementine mandarin under Mediterranean climate. *Journal of Horticulture and Forestry, 2*(7), 161-170.

Huett, D. O., & Dettmann, E. B. (1988). Effect of nitrogen on growth, fruit quality and nutrient uptake of tomatoes growth in sand culture. *Australian Journal of Experimental Agriculture, 28*, 391-399. http://dx.doi.org/10.1071/EA9880391

Jones, J. B. (2001). *Laboratory guide for conducting soil tests and plant analysis*. Washington: CRC Press.

Jones, J. B. (2003). *Agronomic handbook: Management of crops, soils and their fertility*. New York: CRC Press.

Kazemi, M. (2013). Effects of Zn, Fe and their combination treatments on growth and yield of tomato. *Bulletin of Environment, Pharmacology and Life Sciences, 3*(1), 109-114.

Kumar, N., Meenakshi, N., Suresh, J., & Nosov, V. (2006). Effect of potassium nutrition on growth, yield and quality of papaya (*Carica papaya* L.). *Indian Journal of Fertilizers, 2*(4), 43-47.

Kumari, S. (2012). Effect of micronutrient on quality of fruit and seed in tomato, *Solanum lycopesicum* L. *International Journal of Farm Science, 2*(1), 43-46.

Maneepong, S. (2008). A nutrient survey for establishment of standard recommendation of soil and plant analysis for pummelo. *Agricultural Science Journal, 39*, 62-65.

Maneepong, S. (2009). Nutrient requirement and fruit growth of pummelo. *Agricultural Science Journal, 40*, 412-415.

Maneepong, S. (2013). *Nutrient management for high quality pummelo production*. School of Agricultural Technology, Walailak University (in Thai), Thailand.

Mimoun, M., Ben, M., Ghrab, M., Ghane, M., & Elloum, O. (2009). *Effects of potassium foliar spray on olive, peach and plum*. Switzerland: International Potash Institute.

Morton, J. (1987). *Pummelo*. Retrieved from http://www.hort.purdue.edu/newcrop/morton/pummelo.html

Moss, G. I., & Higgins, M. L. (1974). Magnesium in fluencies on the fruit quality of sweet orange. *Plant and Soil, 41*, 103-112. http://dx.doi.org/10.1007/BF00017948

Soil and Plant Analysis Council. (1998). *Handbook of Reference Methods for Plant Analysis*. Boca Raton, America: CRC Press.

Sparrow, D. H., & Graham, R. D. (1988). Susceptibility of zinc deficient wheat plants to colonization by *Fusarium graminearum* Schw. Group 1. *Plant and Soil, 112*, 261-266. http://dx.doi.org/10.1007/BF02140004

Tongleaw, S., Krisanapook, K., & Phavaphutanon, L. (2012). Analysis of "KhaoYai" pummelo fruit to estimate nutrient losses though crop removal. *Kasetsart Journal (Nat. Sci), 46*, 827-836.

Voogt, W. (1987). The growth of beefsteak tomato as affected by K/Ca ratios in the nutrient solution. *Acta Horticulturae, 22*, 155-165.

Wrona, D. (2004). Effect of nitrogen fertilization on growth, cropping and fruit quality of 'Samoin' apple trees during 9 years after planting. *Folia Horticulturae, 16*(1), 55-60.

Zhuang, Y., Renji, W., Lixuan, C., Zhian, X., Wenbao, X., Yuzong, H., & Zhenlong, Z. (1991). Optimum range of mineral element contents in the leaves of Guanxi honey pomelo (Citrus Grandis). *Journal of Fujian Academy of Agricultural Sciences, 6*(2), 52-58.