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Effects of Potassium, Calcium, and Magnesium Ratios in Soil on Their Uptake and Fruit Quality of Pummelo

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Abstract

Potassium (K), Calcium (Ca), and Magnesium (Mg) are essential nutrients for pummelo. These nutrients are strongly antagonistic to each other. In case of excess concentration of one element, the uptake of the other elements is inhibited. This study was conducted on 17-year-old pummelo (*Citrus maxima* Merr.) during production year 2013 to 2015 to examine the effects of K, Ca, and Mg in soil on their uptake and fruit quality. The experiment was performed using six treatments with five replications. $(NH_4)_2SO_4$, KCl, $CaSO_4{\cdot}2H_2O$, and $ZnSO_4{\cdot}7H_2O$ were applied on top of farmer practice for the T1. $(NH_4)_2SO_4$ was omitted for the T2, KCl was omitted for the T3, $CaSO_4{\cdot}2H_2O$ was omitted for the T4, no additional fertilizers were applied for the T5 (farmer practice), $(NH_4)_2SO_4$ and $CaSO_4{\cdot}2H_2O$ were omitted for the T6, but $5Ca(NO_3)_2{\cdot}NH_4NO_3{\cdot}10H_2O$ were applied instead. The soil pH was neutral and salinity was slight. Exchangeable K, Ca and Mg were higher than their optimum ranges. The extractable Zn in the soil and Zn in the leaves were lower than their optimum ranges. However, the problem can be solved by a single application 250 g tree^{-1} of $ZnSO_4{\cdot}7H_2O$. Pummelo cannot uptake K to a sufficient level, even though it is abundant in the soil. High exchangeable Na and low K/Mg mole ratio in soil inhibited K uptake. Concentration of Ca in leaves corresponded to Ca and Ca/Mg mole ratio in the soil. Concentrations of Mg and K in leaves negatively correlated with each other. High Mg and Na in the soil inhibited the uptake of K and Ca, thereby causing extravagant consumptions of Mg. The fruit qualities were better in the treatment which mole ratios of K/Ca, K/Mg and Ca/Mg were 0.24 to 0.44, 0.31 to 0.44 and 0.89 to 1.29, respectively. Juice ratio of the pummelo positively correlated with the edible portion and negatively correlated with peel thickness.

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

1. Introduction

Pummelo (*Citrus maxima* Merr.) is a plant with vigorous growth and high yield, which requires a large amount of nutrients. According to Maneepong (2009), the quantities of N, P, K, Ca, Mg required for fruit production were 1.72, 0.25, 3.00, 1.51, 0.23 g/fruit, respectively. Nutrient concentrations in pummelo growing soil decline rapidly. Nutrient supplements are important for maintaining nutrient concentration and balance. Improper maintenance will effect fruit quality such as sweetness and peel thickness, and glutinous texture in severe cases. K, Ca and Mg uptake do not depend only on their concentrations in the soil, but also on their ratios. An excess application of one nutrient may induce deficiency of the others. K, Ca and Mg strongly interfere with each other during the uptake process (Voogt, 1987). High Mg concentration in soil inhibits the uptake of K and Ca (Nguyen, Maneepong, & Suraninpong, 2015), whereas high K concentration in nutrient solution inhibits the uptake of Ca and Mg (Jones, 1999; Voogt, 1987; Nukaya, Goto, Jang, Kano, & Ohkawa, 1995; Bar-Tal & Pressman, 1996). Mg deficiency may occur when the soil has high Ca:Mg ratio (Bergmann, 1992). Increasing K concentration in the nutrient solution increased the incidence of Ca deficiency of tomato. Occurrence of the Ca deficiency correlated to K:Ca ratio in tomato leaves (Bar-Tal & Pressman, 1996). Increasing the Mg concentration in low Ca nutrient solution increased the Ca deficiency of tomato (Hao & Papadopoulos, 2003). Pummelo can be grown on non-saline upland soil and slight saline soil. Its growth rate is retarded on saline soil, but the fruit test is more favourable by consumers.

The objective of this study was to evaluate the effects of K, Ca and Mg ratios on nutrient uptake and fruit quality of pummelo growing on salt marsh soil.

2. Materials and Methods

2.1 Experimental Design

A representative pummelo orchard in Pakpanang district, Nakhon Si Thammarat Province, Thailand (latitude 8°31′07″ N, longitude 100°12′55″ E) was selected. Most of the pummelo trees were planted in 1997, but some of them were re-planted later. Only Tuptim Siam variety was grown on this orchard. The pummelo was grown in blocks of land. Each block was separated by a furrow of 8.8 m wide and 1.5 m deep. Thirty trees were arranged in double rows in each block. Spacing between two adjacent trees was 5.3 m, and between rows was 5.2 m. Five trees from each block with a similar canopy volume and equal age were selected for placing into each treatment (Table 1). Ammonium sulfate, potassium chloride, calcium sulfate and zinc sulfate were applied on top of farmer practice for treatment 1 (T1). Ammonium sulfate was omitted for treatment 2 (T2). Potassium chloride was omitted for treatment 3 (T3). Calcium sulfate was omitted for treatment 4 (T4). No additional fertilizers were applied for treatment 5 (T5). Potassium chloride and Calcium ammonium nitrate were applied for the treatment 6 (T6). The study was performed during June 2013 to March 2015.

Table 1. Fertilizer rates in a year for each treatment. Application of $(NH_4)_2SO_4$ and $5Ca(NO_3)_2{\cdot}NH_4NO_3{\cdot}10H_2O$ were splitted equally 4 times a year, KCl twice a year, and $CaSO_4{\cdot}2H_2O$ and $ZnSO_4{\cdot}7H_2O$ once a year. The first application was performed in June 2013

Treatment	$(NH_4)_2SO_4$	KCl	$CaSO_4{\cdot}2H_2O$	$5Ca(NO_3)_2{\cdot}NH_4NO_3{\cdot}10H_2O$	$ZnSO_4{\cdot}7H_2O$
T1 (All)	4 kg	2 kg	5 kg	0	250 g
T2 (-N)	0	2 kg	5 kg	0	250 g
T3 (-K)	4 kg	0	5 kg	0	250 g
T4 (-Ca)	4 kg	2 kg	0	0	250 g
T5 (Farmer practice)	0	0	0	0	0
T6 (All:15-0-0)	0	2 kg	0	5.6 kg	250 g

Note. Fertilizers were not applied for treatment T5 by the authors, but the farmer applied NPK and sprayed KCl.

2.2 Soil Sampling and Analysis

Soil samples were taken twice, before treatment application and one year after treatment application. The samples were taken from 4 different positions directly beneath the 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 ratio. Electrical conductivity was measured using 1:5 siol:water ratio and the value was multiplied by 6 to obtain electrical conductivity at saturation (ECe) (Shaw, 1999). Available P was extracted with 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 0.05 M di-ethylene tri-amine pentaacetic acid in 0.01 M tri-ethanolamine and 0.05 M $CaCl_2$ (DTPA solution), and its concentration was analyzed by an AAS (Jones, 2001, 2003).

2.3 Leaf Sampling and Analysis

Pummelo leaves were sampled five times (June and November, 2013; June and October, 2014; and January, 2015). The leaves were sampled from the third or fourth position, 3 to 5 months old, newly flush, and non-fruiting twig on the outer canopy. The samples were dried at 65 °C, ground, and passed through a 1 mm 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, on March 2014 and February 2015. 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 the 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. Total soluble solid (TSS) was determined using a hand refractometer. 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 analysis of variance (ANOVA) in a completely randomized biock design that contained six 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 Treatments on Soil Properties

Soil of this orchard was derived from marine sediment. Therefore, concentrations of K, Ca and Mg were high, and pH value was close to neutral. No significant differences were found in soil pH among treatments before application of the different fertilizers (Table 2). However, pH tended to decrease after their application except on T6. The pH from T6 was significantly higher than those from T1 and T4. Increasing soil pH of the T6 may due to application of calcium ammonium nitrate (15-0-0). The optimum pH range for pummelo growing soil was suggested to be 5.5 to 6.5 (Maneepong, 2008), which is lower than the pH range of the soil in this study.

Soil ECe did not significantly differ among treatments at the beginning of experiment, but it significantly differed after treatments (Table 2). The ECe tended to increase, except on T2 (no additional $(NH_4)_2SO_4$). Slightly saline soil is recommended for pummelo growing (2.0 to 3.0 mS/cm), although the soil tends to retard growth rate, but better fruit quality will be obtained (Maneepong, 2008; Samarankoon, Weerasinghe, & Weerakkody, 2006). A large over recommended range was found in T1 and T3; this may be caused by a large amount of fertilizer application (Tables 1 and 2).

The available P of the soil was found to be very high in all treatments due to its nature, although phosphorus fertilizer was not applied (Table 2). The optimum range was suggested only 15 to 25 mg/kg (Maneepong, 2008), therefore pummelo in this orchard should not require additional P fertilizer.

Exchangeable K varied in a wide range between treatments both before and after the treatment application (Table 2). Pummelo trees were grown on raise beds and K fertilizer is frequently applied by a farmer, therefore the soil K was not homogeneously distributed. Application of $(NH_4)_2SO_4$ and KCl at the same time did not increase K concentrations in the soils (T1 and T4), whereas application of KCl alone increased the K concentration (T2). This may due to leaching and surface erosion during the flooding period. The optimum range recommended was only 100 to 150 mg/kg (Maneepong, 2008), which was lower than K in the soils both before and after the treatment application.

Exchangeable Ca varied in a wide range similar to that of K. The highest value was found on T3, which was significantly higher than that of T5 (farmer practice) both before and after treatment application (Table 2). $CaSO_4{\cdot}2H_2O$ was applied to T1, T2 and T3. However, Ca tended to decline after the application. The change may occur due to surface erosion, similar to the case of K. A large increase was found in T6, which calcium ammonium nitrate was applied. The exchangeable Ca of all plots was higher than 2,000 mg/kg both before and after the treatment application, whereas the optimum range recommended was 1,000 mg/kg to 2,000 mg/kg (Maneepong, 2008). Zamaniyan et al. (2012) found that the K uptake by chicory cultured in nutrient solution depends on K/Ca ratio. Increasing the K/Ca ratio also increased K concentrations both in leaves and root. If the K/Ca ratio was higher than 6/4, the yield decreased and caused morphological damage related to Ca deficiency, such as pith hole and tip burn.

Exchangeable Mg presented in the same order of K for T1, T2 and T3, but it tended to be higher for T4, T5 and T6 (Table 2). Mg was not applied, because the native concentration is much higher than the suggested optimum range (120 mg/kg to 240 mg/kg; Maneepong, 2008). High Mg concentration either in soil or plant often causes poor K status in plant (Kirkby & Mengel, 1976).

Exchangeable Na of T4, T5 and T6 was significantly higher than T1, T2 and T3 both before and after the treatment application (Table 2). An average of 45% of the Na was removed from the soil after the application. The result showed that the Na is loosly retained by soil. Na is not an escential nutrient element, but it affects the uptake of other cations. A negative correlation between soil salinity and uptake of P, K, Ca, Cu, Fe and Mn by maize and positive correlation with Na was observed (Hassan, Derwy, Mudren, Knadsin, & Olseon, 1970).

Zn deficiency symptom was found in this area according to our previous study. Therefore, $ZnSO_4 \cdot 7H_2O$ was applied to all treatments except T5 (farmer practice). No significant difference in the Zn concentrations were found among treatments before application (Table 2). After Zn application, the concentrations increased above its optimum range (1.1 mg/kg to 3.0 mg/kg; Maneepong, 2008) except T6, whereas that of the T5 was still lower than the range.

Table 2. Chemical properties of top-soils (0 to 20 cm) before and after treatment application

Chemical properties	Sampling times	Treatments					
		T1	T2	T3	T4	T5	T6
pH	Before	7.2±0.2a	7.1±0.1a	7.1±0.5a	6.9±0.3a	7.1±0.3a	7.1±0.1a
	After	6.6±0.3b	6.8±0.4ab	7.0±0.3ab	6.7±0.3b	6.8±0.7ab	7.3±0.1a
ECe (mS/cm)	Before	2.4±0.3a	3.4±1.6a	2.2±0.9a	3.1±0.9a	2.8±0.2a	2.6±1.0a
	After	3.5±0.7ab	2.1±0.7c	4.7±1.8a	3.1±0.3bc	3.1±0.4bc	2.8±0.3bc
Avai. P (mg/kg)	Before	185±30ab	190±114ab	279±93a	201±132ab	107±27b	103±40b
	After	262±65ab	308±74a	301±71a	206±67b	208±96b	162±21b
Exch. K (mg/kg)	Before	1402±475a	975±407ab	1172±95ab	975±587ab	628±270b	924±296ab
	After	1062±242ab	1149±255a	827±240ab	879±167ab	944±302ab	773±150b
Exch. Ca (mg/kg)	Before	3207±466ab	3752±1124ab	4179±1791a	3305±293ab	2487±689b	2412±418b
	After	2963±260b	3433±1144ab	4146±727a	2821±99b	2544±745b	3363±402ab
Exch. Mg (mg/kg)	Before	1465±72bc	1482±29bc	1378±189c	1564±162b	1768±31a	1751±105a
	After	1520±146b	1185±148c	1227±181c	1641±120a	1742±128a	1595±139ab
Exch. Na (mg/kg)	Before	490±56b	464±41b	470±29b	603±78a	709±26a	705±48a
	After	256±16b	250±26b	249±25b	358±57a	410±82a	368±12a
Extr. Zn (mg/kg)	Before	1.0±0.3a	0.7±0.1a	0.7±0.2a	0.9±0.2a	0.8±0.1a	1.0±0.1a
	After	4.4±3.4ab	3.9±3.0ab	6.0±5.7ab	8.7±5.6a	1.0±0.2b	2.4±1.6b

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

3.2 Mole Ratios of K, Ca and Mg in Soil

Mole ratios of K/Ca, K/Mg and Ca/Mg are shown in Table 3. The K/Ca before treatment application ranged from 0.28 to 0.47 and no significant difference was found between the treatments. After treatment application; T1, T3 and T6 tended to decrease, whereas the other treatments increased. Increasing of K concentration (Table 2) and K/Ca tatio of T5 indicate that a farmer applied a significant amount of K. Ca application reduced K/Ca ratios of T1, T3 and T6, but not that of T2. The K/Mg varied from 0.22 to 0.60 before treatment application. The K/Mg of the T1 was significantly higher than that of T5 before treatment application. Application of KCl increased the K/Mg ratio of T2 only, whereas the others tended to declined (T1, T4 and T6). The Ca/Mg varied from 0.84 to 1.93 before treatment application. The Ca/Mg of T3 was significantly higher than those of the T5 and T6. The results indicated that soils were not homogeneous for these two elements. The Ca/Mg tended to increase after Ca application (T2, T3 and T6) except for that of T1. The Ca/Mg of the T1 and T4 declined after treatment application.

Table 3. Mole ratios of K/Ca, K/Mg and Ca/Mg in soil before and after treatment applications

Mole ratios	Sampling times	Treatments					
		T1	T2	T3	T4	T5	T6
K/Ca	Before	0.47±0.20a	0.28±0.13a	0.34±0.18a	0.31±0.20a	0.29±0.19a	0.39±0.12a
	After	0.37±0.09ab	0.39±0.20ab	0.21±0.06b	0.32±0.06ab	0.44±0.28a	0.24±0.06ab
K/Mg	Before	0.60±0.20a	0.41±0.18ab	0.54±0.10ab	0.41±0.29ab	0.22±0.09b	0.33±0.11ab
	After	0.44±0.14ab	0.60±0.09a	0.43±0.16ab	0.34±0.09ab	0.34±0.12ab	0.31±0.08b
Ca/Mg	Before	1.33±0.17ab	1.54±0.49ab	1.93±0.97a	1.29±0.11ab	0.85±0.23b	0.84±0.20b
	After	1.19±0.17c	1.85±0.89ab	2.12±0.65a	1.05±0.11c	0.89±0.25c	1.29±0.19bc

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

3.3 Effects of Treatment Application on Nutrient Uptake

3.3.1 Effect of Treatment Application on N Uptake

Pummelo leaves were collected once before treatment application and at 5, 12, 16 and 19 months after application. Concentrations of N in the leaves are shown in Table 4. The N concentration of T5 leaves was significantly higher than that of T3 leaves before the application, whereas theresults for other treatments were not significantly different. The N concentrations tended to increase after 5 months in all treatments including treatments of no N application (T2 and T4). Only the N concentration of leaves from T1 was above the optimum ranges (27 g/kg to 30 g/kg according to Maneepong, 2008 and 25 g/kg to 31 g/kg according to Zhuang et al., 1991) at 5 months. No significant difference was found between treatments at 12 months. At 16 months, the N concentration of T1 ($(NH_4)_2SO_4$ was applied on top of farmer practice) was significantly higher than that of T2 (no additional N). At 19 months, the N concentrations of all treatments tended to decline. The change may due to pummelo leaves were collected one month prior to harvesting time. Therefore, a large portion of N was transferred from leaves to fruits. The N concentration of T5 (farmer practice) was the lowest and significantly lower than that of the T1. After the treatment application, the N concentrations of almost all treatments fell in the optimum range and were not clearly distinct between the treatments although the N fertilizer was not applied.

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

Treatments	Sampling times				
	Before	5 months	12 months	16 months	19 months
T1	26.4±0.2ab	32.5±0.1a	27.9±0.1a	30.5±0.1a	28.4±1.9a
T2	26.1±0.2ab	29.3±0.1b	28.0±0.1a	28.3±0.3b	27.8±1.7ab
T3	25.5±0.0b	30.2±0.0b	27.5±0.1a	29.0±0.1ab	28.3±1.8ab
T4	26.6±0.0ab	29.6±0.2b	28.7±0.1a	29.1±0.1ab	26.5±1.2ab
T5	27.0±0.1a	30.0±0.2b	28.4±0.2a	29.0±0.1ab	25.7±1.4b
T6	25.2±0.1ab	30.8±0.2ab	29.3±0.1a	28.8±0.1ab	26.7±1.9ab

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

3.3.2 Effect of Treatment Application on K, Ca and Mg Uptake

KCl was applied to T1, T2, T4 and T6 plots, although exchangeable K in soil was higher than the sufficient range (Table 2). Most of the K concentrations in leaves did not significantly differ between the treatments, except that of T1, which was significantly higher than those of T4, T5 and T6 at 12 months (Table 5). The K of T1 exhibited the highest values compared with other treatments. Before treatment application, only the K of the T1 was in the optimum range suggested by Maneepong (2008) (15 g/kg to 20 g/kg). The highest value of K/Mg mole ratio in T1 soil allowed better K uptake (Table 3). At 19 months, the K concentrations declined to lower than the optimum range in all treatments. The K of T3 (no KCl applied by authors) showed the lowest value. Application of KCl on top of the farmer practice did not show a clear improvement of K status in the leaves. The exchangeable Na was significantly higher in T4, T5, T6 than in the other treatments (Table 2). The inhibition of K uptake by Na was clearly showed at 12 months. The K concentrations of T4 and T6 (KCl was applied) were lower than that of the T3 (KCl was not applied). Pummelo cannot uptake K to a sufficient level despite the excessive K in the soil. High concentration of Mg and low K/Mg ratio in soil negatively affected K uptake by pummelo. An antagonism between K and Mg was previously described (Jones, 1999; Kasiath & Senthikumar, 2015; Kirkby & Mengel, 1976).

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

Treatments	Sampling times				
	Before	5 months	12 months	16 months	19 months
T1	15.1±2.9a	16.4±1.3a	17.1±1.6a	16.5±4.8a	14.1±0.9a
T2	12.6±1.3a	14.9±1.1a	15.4±3.6ab	16.2±4.1a	13.8±2.1a
T3	14.5±1.7a	14.1±0.9a	15.6±1.7ab	15.9±1.2a	11.9±1.4a
T4	14.0±2.7a	14.8±2.4a	13.0±3.2b	14.4±1.2a	12.8±1.0a
T5	13.6±1.2a	14.3±1.9a	14.0±1.1b	16.3±0.8a	12.0±2.2a
T6	13.6±0.9a	14.2±3.3a	14.0±1.0b	15.0±0.7a	12.0±0.6a

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

Ca was applied to T1, T2 and T3 in the form of $CaSO_4{\cdot}2H_2O$ and to T6 in the form of $5Ca(NO_3)_2{\cdot}NH_4NO_3{\cdot}10H_2O$, although the exchangeable Ca in soil was higher than the opptimum range (1,000 mg/kg to 2,000 mg/kg; Maneepong, 2008). An optimum range of Ca in pummelo leaves gieven by Maneepong (2008) was 30 mg/kg to 40 mg/kg, whereas Zhuang et al. (1991) suggested a lower range of 20 mg/kg to 38 mg/kg. Ca concentrations in leaves collected from T1, T2 and T3 tended to be higher than those from T4, T5 and T6 throughout the observation period (Table 6). The trend corresponded to exchangeable Na in the soil (Table 2). High Na in the soil inhibited Ca uptake by pummelo. B. K. Garg and O. P. Garg (1980) reported that the uptake of all nutrients except Na decreased significantly due to salt application, while the uptake of N, P and K declined at higher salt concentration and only towards later stage of plant growth; the uptake of Ca and Mg decreased right from early growth. According to Majeed et al. (2010), increase in NaCl concentration in the culture medium caused a progressive decreased of K uptake in the roots and stems of both the clones. Na concentrations increased with increasing NaCl levels, whereas K concentration and K/Na ratio decreased with increasing NaCl level (Yousufinia, Ghasemian, Safalian, & Asadi, 2013).

Ca concentration in the leaves of T3 was highest before the treatment application and significantly higher than those of T4, T5 and T6 and at 5 months (Table 6). The leaf concentration corresponded to exchangeable Ca in soil and mole ratio of Ca/Mg (Tables 2 and 3). High Ca in soil together with low Mg tended to promote Ca uptake. Schimanski (1981) also found that Mg strongly modified the uptake of Ca in case of barley seedling grown using hydroponics.

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

Treatments	Sampling times				
	Before	5 months	12 months	16 months	19 months
T1	36±13ab	31±3a	28±5ab	33±6a	39±2a
T2	37±7ab	32±6a	34±5a	27±3b	31±5b
T3	41±5a	32±4a	32±6ab	27±4b	34±6ab
T4	27±4bc	25±2b	27±6b	26±2b	28±3b
T5	25±5c	29±2ab	30±2ab	25±1b	29±4b
T6	23±3c	28±0ab	26±5b	26±1b	32±1ab

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

Mg concentrations in leaves had no significant differences between treatments both before and at 12 months of application (Table 7). It was significantly lower in T3 than in the others except T4 at 5 months. The Mg tended to increase at 19 months compared with the previous sampling times, whereas the K tended to decrease (Table 5 and 7). The Mg at nearly all sampling times were higher than their optimum ranges (3 g/kg to 5 g/kg according to Maneepong (2008) and 3.2 g/kg to 4.7 g/kg according to Zhuang et al. (1991)), indicating that the Mg uptake by pummelo was greater than its requirement. Kirkby and Mengel (1976) and Zamaniyan et al. (2012) suggested that high Mg concentration either in soil or plant is often a cause of poor K status in plant. We also found that

Mg in leaves tended to negatively correlate with K (Figure 1). This finding supports the antagonistic effect of Mg on K uptake.

Table 7. Mg concentrations (g/kg) in pummelo leaves before and after treatment application

Treatments	Sampling times				
	Before	5 months	12 months	16 months	19 months
T1	6.2±0.8a	6.4±0.5a	5.7±0.3a	5.9±0.5a	6.5±0.7ab
T2	6.0±0.6a	6.4±0.4a	6.1±1.1a	4.9±0.4b	5.9±0.4b
T3	5.9±0.9a	5.7±0.3b	5.4±0.9a	4.8±0.2b	5.7±0.3b
T4	6.0±0.9a	6.1±0.4ab	5.8±0.5a	5.5±0.6a	6.4±0.3b
T5	6.1±0.9a	6.7±0.5a	6.1±0.3a	5.5±0.3a	7.2±0.4a
T6	5.7±0.9a	6.5±0.4a	5.4±0.4a	5.1±0.5ab	6.5±0.8ab

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

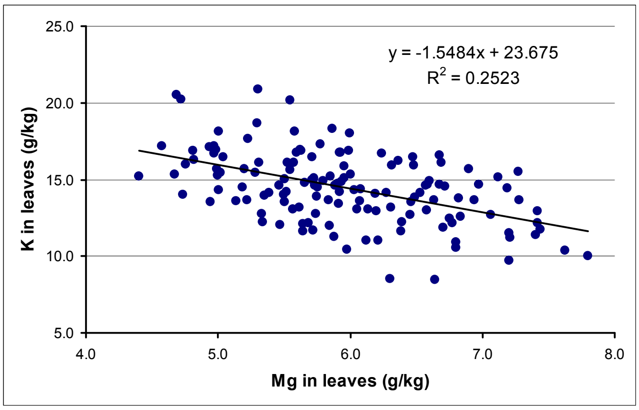

Figure 1. Correlation between concentrations of Mg and K in pummelo leaves

3.3.3 Effect of Treatment Application on Mole Ratios of K, Ca and Mg in Leaves

Mole ratios of K/Ca, K/Mg and Ca/Mg in pummelo leaves both before and 5, 12, 16 and 19 months after treatment application are shown in Table 8. The K/Ca of T5 before application was significantly higher than those of T2 and T3. After 5 months of application, the K/Ca of T4 was the highest and significantly higher than hose of T2 and T3. No significant difference was found between treatments after 5 months. KCl was not applied to T3, but the K/Ca increased possibly due to excess concentration of K in the soil.

The K/Mg ratios were not significantly different between treatments until 19 months. The K/Mg of T2 was the highest and significantly higher than those of the T5 and T6, which had high concentrations of Mg and Na in the soils (Table 2). The result indicated that both Mg and Na inhibit K uptake of pummelo.

The Ca/Mg ratios varied in a widely between treatments both before and after application. The Ca/Mg of T1, T2 and T3 tended to be higher than those of T4, T5 and T6. This may due to $CaSO_4 \cdot 2H_2O$ application together with low Mg and Na in the soils. The Ca/Mg of T6 tended to increase after treatment application, because this treatment received $5Ca(NO_3)_2 \cdot NH_4NO_3 \cdot 10H_2O$. Ca uptake tended to be faster when its concentration increased at low concentrations of Mg and Na in the soil.

Table 8. Mole ratios of K/Ca, K/Mg and Ca/Mg in pummelo leaves before and after treatment applications

Mole ratios	Sampling times	Treatments					
		T1	T2	T3	T4	T5	T6
K/Ca	Before	0.49±0.20ab	0.36±0.09b	0.37±0.09b	0.55±0.17ab	0.58±0.15a	0.61±0.11a
	5 months	0.55±0.04ab	0.49±0.08b	0.47±0.08b	0.62±0.12a	0.52±0.09ab	0.52±0.12ab
	12 months	0.64±0.16a	0.49±0.20a	0.50±0.06a	0.53±0.19a	0.48±0.05a	0.56±0.09a
	16 months	0.55±0.24a	0.61±0.15a	0.62±0.09a	0.56±0.08a	0.68±0.06a	0.60±0.05a
	19 months	0.38±0.03a	0.46±0.11a	0.36±0.06a	0.48±0.09a	0.43±0.13a	0.38±0.02a
K/Mg	Before	1.57±0.45a	1.31±0.21a	1.57±0.39a	1.49±0.48a	1.42±0.33a	1.50±0.23a
	5 months	1.61±0.20a	1.44±0.13a	1.54±0.13a	1.52±0.31a	1.34±0.25a	1.37±0.37a
	12 months	1.87±0.25a	1.65±0.69a	1.86±0.43a	1.43±0.44a	1.42±0.18a	1.60±0.09a
	16 months	1.79±0.66a	2.05±0.50a	2.08±0.21a	1.64±0.25a	1.83±0.16a	1.86±0.24a
	19 months	1.35±0.09ab	1.43±0.16a	1.31±0.21ab	1.25±0.13abc	1.04±0.20c	1.16±0.19bc
Ca/Mg	Before	3.41±0.20b	3.71±0.43ab	4.19±0.44a	2.73±0.40c	2.45±0.20c	2.46±0.33c
	5 months	2.92±0.20bc	3.00±0.04b	3.67±0.47a	2.46±0.19d	2.61±0.13cd	2.60±0.17cd
	12 months	3.01±0.36a	3.39±0.41a	3.76±1.04a	2.82±0.45a	2.97±0.18a	2.89±0.39a
	16 months	3.37±0.34ab	3.36±0.16ab	3.45±0.61a	2.93±0.19bc	2.71±0.18c	3.08±0.43abc
	19 months	3.62±0.36a	3.22±0.58ab	3.70±0.72a	2.65±0.22bc	2.45±0.35c	3.04±0.44abc

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

3.3.3 Effects of Treatment Application on Zn Uptake

The Zn concentrations in leaves before application were lower than their optimum ranges for pummelo (> 15 mg/kg according to Maneepong (2008) and 24 mg/kg to 44 mg/kg according to Zhuang et al. (1991)) (Table 9). Application of $ZnSO_4 \cdot 7H_2O$ increased Zn concentrations in soils (Table 2) and in the leaves to the optimum range suggested by Maneepong (2008). High pH and available P in soil inhibited the uptake of Zn by pummelo. According to Fageria (2000), increasing the pH in soil from 4.6 to 6.8 decreased the uptake of Zn by rice. Zn absorption capacity is reduced by high phosphorus utilization and Zn in plant and soil has an antagonism with phosphorus (Sayed, 2011). Moreover, high concentration of P in soil results in the formation of zinc phosphate, which is difficult to dissolve (Pendias, 1992).

Table 9. Zn concentrations (mg/kg) in pummelo leaves before and after treatment application

Treatments	Sampling times				
	Before	5 months	12 months	16 months	19 months
T1	13.4±1.6a	17.7±2.3ab	18.6±0.5a	18.7±3.4a	18.9±1.5ab
T2	11.7±1.4b	18.6±4.2ab	16.8±3.1a	14.1±3.3b	15.2±0.8c
T3	12.6±0.6ab	19.7±3.0a	16.6±1.7a	15.3±2.3b	15.4±3.1c
T4	12.4±1.1ab	15.9±2.8b	17.5±2.8a	18.6±1.5a	19.9±1.2a
T5	12.8±0.9ab	17.2±1.2ab	16.8±2.1a	15.2±1.2b	17.5±1.5abc
T6	12.0±0.3ab	18.1±3.5ab	16.4±0.7a	15.0±0.7b	16.8±1.2bc

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

3.4 Effects of Treatment Application on Fruit Quality

Pummelo fruits were collected twice on the first and second years of the experiment. A medium size of fully ripened pummelo fruit was collected from each replication. Peel thickness, juice ratio, pH, TSS, TA and TSS/TA were measured and analyzed. The results are shown in Table 10 and 11. Mean values of the peel thickness ranged from 0.8 cm to 1.2 cm, thinner than generally accepted at 1.5 cm (Maneepong, 2013). The peels of T2 and T5 were significantly thinner than those of T4 and T6 on the first year. The peel of T1 was significantly thinner than those of T2, T3 and T4 on the second year. Edible portions were significantly low in T4 and T6, whereas that of the T2 showed the highest mean value on the first year. The edible portions increased above 70% for all treatments on the second year. The edible portion of T1 was highest, and significantly differed from those of the other treatments. Juice ratio of T2 was the highest and significantly differed from that of the T4 on the first year. However, juice ratio of T1 was the highest on the second year. N, K, Ca and Zn fertilizers were applied on pummelo trees of T1, and the K in leaves tended to be higher than the others (Table 5). Effects of the treatments on peel thickness, edible portion, and juice ratio distinctly showed on the second year. The juice ratio tended to positively correlate with the edible portion, and negatively correlate with the peel thickness (Figures 2 and 3).

TSS of T3 was the lowest and significant difference from those of T4 and T5 on the first year. On the second year, TSS of the T3 was still lowest and significant difference from those of T4 and T5. KCl was not applied on the T3, but K in leaves did not significantly differ from the other treatments (Table 5). After application, K/Ca ratio in soil tended to be the lowest, and Ca/Mg tended to be the highest. These ion ratios may affecte the TSS.

No significant difference of TA was found between treatments, both on the first and second years (Tables 10 and 11). TSS/TA is generally used as a test index for indicating balance of sweet and sour. High TSS/TA indicates better taste of fruit juice. Fruits collected from T5 gave the highest mean value of TSS/TA on the first year, and significantly different from those of T1, T2, T3 and T6. The results were caused by relatively high TSS and low TA. Fruits collected from T6 gave the highest mean TSS/TA, and those from T1 gave the lowest on the second year. pH of the fruit juice had small difference between treatments, with no significant difference on the second year. The pH tended to positively correlate with TSS/TA and negatively correlate with TA, but the pH was not sensitive as the two parameters. Nazanza (2006) reported that high Ca/Mg ratios in solution decreased the pH of tomato fruit juice, which was also reduced by increasing of K concentration in the nutrient solution.

Table 10. Properties of pummelo fruits collected on the first year of the experiment

Fruit quality	Treatments					
	T1	T2	T3	T4	T5	T6
Peel thickness (cm)	1.1±0.1ab	0.9±0.1b	1.0±0.1ab	1.2±0.2a	0.9±0.1b	1.2±0.1a
Edible portion (%)	70.7±1.5ab	73.8±1.3a	71.7±1.7ab	69.0±3.1b	73.5±2.4a	68.0±2.2b
Juice ratio (ml/kg)	419±16ab	436±13a	428±15ab	400±36b	430±27ab	405±30ab
TSS	14.1±0.2ab	14.5±1.1ab	13.3±1.7b	15.5±0.6a	15.3±0.7a	14.2±1.5ab
TA (%w/v)	0.46±0.03a	0.44±0.08a	0.43±0.05a	0.45±0.07a	0.38±0.03a	0.41±0.02a
TSS/TA	31±2b	34±4b	31±5b	35±4ab	41±4a	35±5b
pH	4.2±0.0c	4.3±0.1bc	4.3±0.1bc	4.3±0.1bc	4.5±0.1a	4.4±0.1ab

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

Table 11. Properties of pummelo fruits collected on the second year of the experiment

Fruit quality	Treatments					
	T1	T2	T3	T4	T5	T6
Peel thickness (cm)	0.8±0.1b	1.2±0.4a	1.1±0.1a	1.1±0.1a	1.0±0.1ab	1.0±0.1ab
Edible portion (%)	75.9±2.3a	72.2±2.5b	72.4±1.2b	71.9±0.8b	71.8±2.0b	72.5±1.4b
Juice ratio (ml/kg)	512±14a	485±26b	477±25b	475±7b	484±21b	477±15b
TSS	13.0±0.2cd	13.0±0.5cd	12.6±0.4d	13.5±0.5bc	14.0±0.3ab	14.3±0.5a
TA (%w/v)	0.61±0.03a	0.58±0.08a	0.59±0.05a	0.58±0.02a	0.61±0.06a	0.57±0.08a
TSS/TA	22±2b	23±3ab	22±2b	23±2ab	23±2ab	26±4a
pH	3.8±0.1a	3.9±0.1a	3.8±0.1a	3.8±0.1a	3.8±0.0a	3.8±0.1a

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

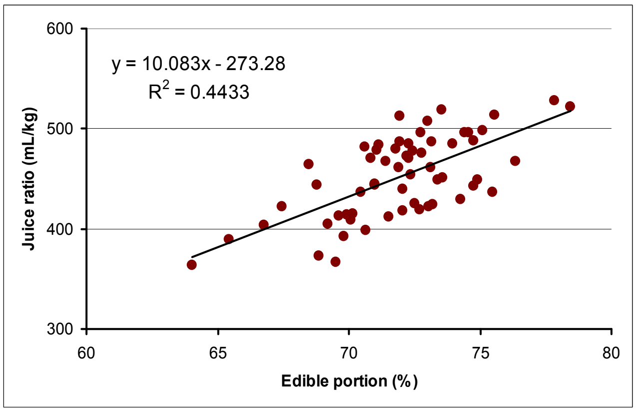

Figure 2. Correlation between edible portion and juice ratio of pummelo collected in first and second years of the experiment

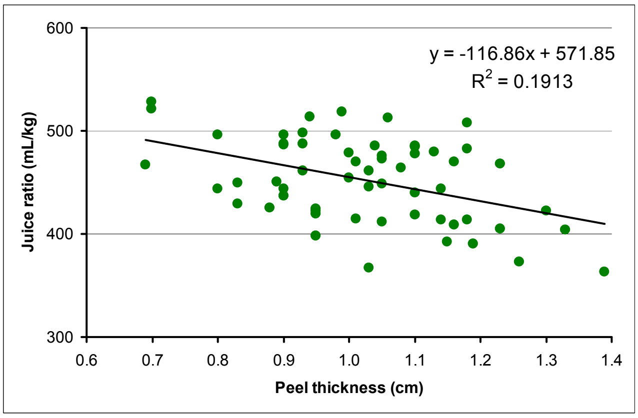

Figure 3. Correlation between peel thickness and juice ratio of pummelo collected in first year and second year of experiment

4. Conclusions

The soil pH was neutral and salinity was slightly saline. Exchangeable K, Ca and Mg were higher than their optimum ranges. The extractable Zn in the soil and Zn in the leaves were lower than their optimum ranges. However, the problem can be solved by a single application (250 g/tree) of $ZnSO_4 \cdot 7H_2O$. Pummelo can not uptake K to a sufficient level even though it is abundant in soil. High exchangeable Na and low K/Mg mole ratio in soil inhibited K uptake. Concentration of Ca in leaves correspond with Ca and Ca/Mg mole ratio in the soil. Concentrations of Mg and K in leaves negatively correlated with each other. High Mg and Na in the soil inhibited the uptake of K and Ca, thereby causing a luxury consumption of Mg. The fruit qualities were greater in the treatment with mole ratios of K/Ca, K/Mg and Ca/Mg were 0.24 to 0.44, 0.31 to 0.44 and 0.89 to 1.29, respectively. Juice ratio of the pummelo positively correlated with edible portion and negatively correlated with peel thickness.

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