

Changes of Plant Nutrients Concentration in Soils and Trees of Mangosteen (*Garcinia mangostana* L.) during the Fruit Development

Surachart Pechkeo^{1*}, Sayan Sdoodee¹ and Chairatna Nilnond²

ABSTRACT

Translucent flesh disorder (TFD) and gamboge disorder (GD) are major problems limiting marketable yield of mangosteen (*Garcinia mangostana* L) in Thailand. The imbalance or deficiency of essential nutrients in soils and plants may cause poor fruit quality. To classify this issues, the pattern of plant nutrient accumulation and nutrient requirement in soils and mangosteen trees during fruit development period were investigated. An experiment was established in a mangosteen orchard with 2 main factors: 1) Fruit positions in the canopy of mangosteen trees (outer and inner canopy fruits) and 2) concentration of plant nutrients in soils and trees. Soil sampling was taken at 2 depths; 0-15 and 15-30 cm from soil surface, around the middle of the tree canopy in blooming and harvesting periods and analyzed for some important chemical and physical properties. Leaves and fruits sampling were taken during fruit development period, every 2 weeks from blooming to harvesting, and analyzed in relation to the changes of soil nutrients. Results indicated that the soil textures varied from sandy loam to sandy clay loam, and the natural soils in the mangosteen orchard was very extremely acid to moderately acid (pH 4.86-5.61, soil: water=1: 5). Most of the soils in the mangosteen orchard had very low level essential nutrients for plant growth. Mangosteen fruit qualities were not significantly different between the outer and inner canopy fruits. Likewise, most of the plant nutrients accumulation in mangosteen leaf, peel and flesh were not significantly different between two fruit positions. It was remarkable that nutrient accumulation in the fruit decreased from blooming to harvesting period. Mangosteen (leaf, peel and flesh) required higher amounts of N, P, K, Ca and Mg for growth in the early stage of fruit development period (from bloom to 6th week after bloom) and S and B in the late stage of fruit development period (from 6th week after bloom) compared with other growth periods. Potassium and Ca contents in the peel of normal fruits (NF) were higher than TFD and GD fruits, whereas P and Mg contents in the flesh of TFD fruits were higher than NF and GD fruits.

Key words: mangosteen (*Garcinia mangostana* L.), nutrients accumulation, translucent flesh disorder, gamboge disorder, fruit development

¹ Department of Plant Science, Faculty of Natural Resources, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand.

² Department of Earth Science, Faculty of Natural Resources, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand.

* Corresponding author, e-mail: surachart.p@psu.ac.th

INTRODUCTION

Mangosteen (*Garcinia mangostana* L.) is an important tropical fruit in southern and eastern Thailand, and it has high potential for export. However, high quality fruits for export are limited by fruit defects such as translucent flesh disorder (TFD) and gamboge disorder (GD). The imbalance or deficiency of essential nutrients in soils and plants may cause TFD and GD fruits.

Lim *et al.* (2001) reported that N, P, K and Ca concentrations in longkong leaves tended to decrease at bloom stage and fruit-setting. In mangosteen, leaf nutrients transferred to accumulate in fruits leading to increase in fruit size and peel thickness (Patarapiyapun, 1995). Poowarodom *et al.* (2002) also reported that N, P, K and Mg concentration in the mangosteen leaf decreased with increasing leaf age. However, in durian Ca and B concentration increase and accumulate in the mature leaf (Ngamsaeng and Poowarodom, 2003), because Ca and B are immobile nutrients (Osotsapar, 2000). Fruits required K during fruit development, therefore, K in leaves decrease with the progress of fruit development. From results of nutrients analysis in mangosteen leaves, Poowarodom *et al.* (2002) reported that N, P, K, Ca and Mg concentrations were 1.33, 0.09, 1.27, 1.01 and 1.05 g/100g (dried weight), respectively, and Fe, Mn, Cu and Zn concentrations were 32.05, 90.60, 22.30 and 22.20 mg kg⁻¹, respectively. Department of Agriculture, Malaysia (2001) reported that P, K, Ca, Mg, Fe and Na concentrations in mangosteen fruits were 0.013, 0.045, 0.007, 0.013, 0.001 and 0.007 g/100g, respectively.

To alleviate the problem of fruit defects, a preliminary study of plant nutrients accumulation and nutrient requirement in soil and mangosteen trees during fruit development period was done. Therefore, the results from this research will form a basis for fertilizer management in soils and mangosteen trees.

MATERIALS AND METHODS

The experimental site

The experiment was established in the mangosteen orchard at Hat Yai district, Songkhla province, southern Thailand; (7°00'08"N, 100°30'28"E) (Figure 1) during March to July 2003. Five 13-year old mangosteen trees were selected for taking fruits and leaf samples whereas soil samples were taken from the area covered by these plants' canopy.

Soil management

PVC pipes (5 cm diameter and 1 m length) were installed in soils at the middle of the tree canopy, then soil moistures were measured at 2 depths (30 and 60 cm from soil surface) by using a depth moisture gauge (Troxler model 4300). Composite soil sampling (4 cores/tree) were taken at 2 depths; 0-15 and 15-30 cm, from soil surface around the middle of the tree canopy at the blooming and harvesting periods. The soils were air-dried, passed through a 2-mm sieve and analyzed for some chemical and physical properties as follows: soil texture (hydrometer) (Gee and Bauder, 1986), soil reaction (soil pH) (soil: water=1: 5) (Mclean, 1982), soil electrical conductivity (EC) (soil: water =1: 5) (Rhoades, 1982), soil organic matter (OM) (rapid wet oxidation of Walkley and Black) (Nelson and Sommers, 1982), total N (Kjeldahl) (Dennis, 1982), exchangeable cations; Ca, Mg and K (1M ammonium acetate pH 7.0) (Thomas, 1982), available P (Bray 2) (Olsen and Sommers, 1982), available S [0.01 M Ca(H₂PO₄)₂] (Tabatabai, 1982) and available B (azomethine-H) (Aitken, *et al.*, 1987).

Plant management

Five leaves and 5 fruits/time/tree were taken during fruit development period, every 2 weeks from blooming to harvesting. Mangosteen leaves and fruits (peels and fleshes) were cleaned

by deionized water, oven-dried at 68-80°C for 24-48 hours, passed through a 1-mm sieve and analyzed for total N (Kjeldahl), total P and S ($\text{HNO}_3/\text{HClO}_4$), total K, Ca and Mg (wet digestion) and total B (azomethine-H) (Maneepong, 1994; Onthong, 2002). Fruit quality assessed was fresh fruit weight, fruit diameter, peel thickness, peel moisture, flesh moisture, flesh firmness, total soluble solid (TSS) and titratable acidity (TA) of outer and inner canopy fruits.

RESULTS AND DISCUSSION

Soil properties

Soil texture (0-30 cm) was sandy loam to sandy clay loam. The percentage of soil moisture values during fruit development period were 32.32-38.55 and 36.09-42.73 at 30 and 60 cm from soil surface, respectively (Figure 2). Soils were very extremely acid to moderately acid with soil pH (soil: water=1: 5) ranged from 4.86-5.61. Soil



Figure 1 The experimental site at Hat Yai district, Songkhla province, southern Thailand.

pH was decreasing at harvesting period (Figure 3A) as reported by Nilnond *et al.* (1995) and Pechkeo (1999) that mangosteen soils in southern Thailand had soil pH ranged from 3.50-5.72. Both EC and OM were reduced in harvesting period, and very low for EC (0.04-0.12 dS m⁻¹) (Figure 3B), moderately for OM (15.37-28.64 g kg⁻¹) (Figure 3C) (Division of Land Use Planning, Department of Land Development, 1992). Total

N (0.58-1.36 g kg⁻¹) (Figure 3D), exchangeable Ca (0.66-6.11 cmol_c kg⁻¹) (Figure 3G), exchangeable Mg (0.12-0.79 cmol_c kg⁻¹) (Figure 3H), available S (0.17-0.38 mg kg⁻¹) (Figure 3I) and available B (0.06-0.34 mg kg⁻¹) (Figure 3J) in soils were decreased in harvesting period, except available P (1.80-14.80 mg kg⁻¹) (Figure 3E) and exchangeable K (0.21-1.15 cmol_c kg⁻¹) (Figure 3F). In fact, the level of essential nutrients in

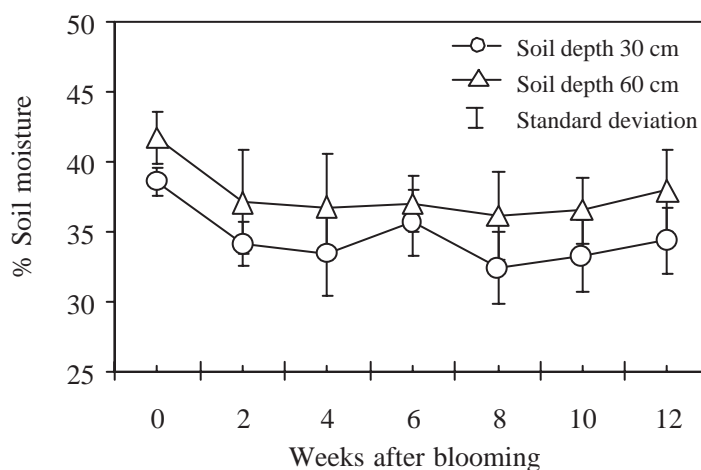


Figure 2 Changes of soil moisture during fruit development period.

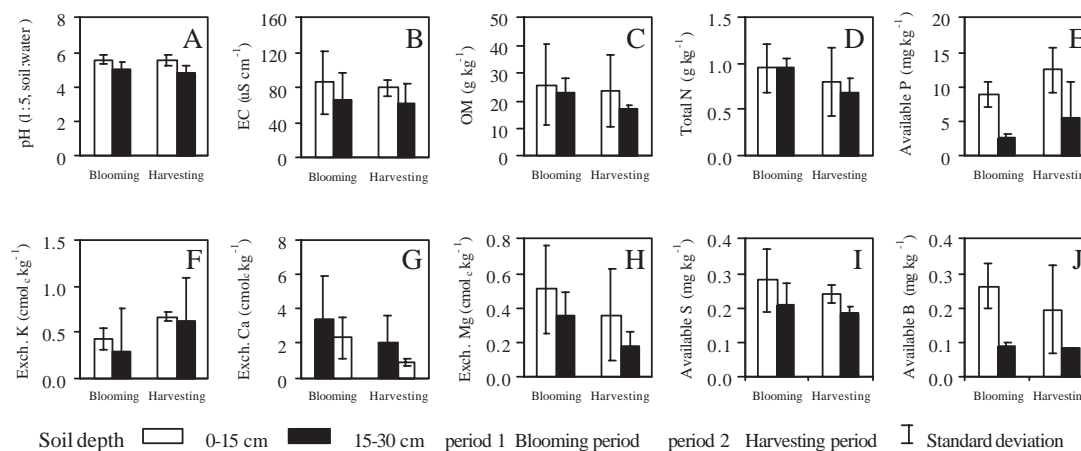


Figure 3 Average values of some soil chemical properties at the experimental site. [(A) Soil pH (B) Soil EC (C) Organic matter (D) Total nitrogen (E) Available phosphorus (F) Exchangeable potassium (G) Exchangeable calcium (H) Exchangeable magnesium (I) Available sulphur and (J) Available boron].

mangosteen soils were low for plant growth, while the chemical fertilizers had applied in soils in the last harvesting period. Heavy rain might caused nutrients leaching from soils (Moncharoen, 2002) and the strongly acid soils condition were unsupported some of essential nutrients to dissolved into the available forms for plant growth (Department of Soil Science, 1998). Phosphorus was the high accumulate nutrient in soils because it was the hardly moved nutrient and was continuously added to the soils every year. The nutrients content in mangosteen soils as reported by Nilnond *et al.* (1995) and Pechkeo (1999) that mangosteen soils in southern Thailand were P, K, Ca, Mg, S and B concentrations about 2.45-61.69 mg kg⁻¹, 0.10-0.26, 0.09-2.43, 0.05-0.50 cmol_c kg⁻¹, 1.85-15.32 and 0.16-0.84 mg kg⁻¹, respectively.

Fruit qualities in the field

Average yield in the Normal (NF), TFD and GD fruits were 64.25±28.29, 12.25±5.85 and 2.50±0.71 fruits/tree, respectively. Fresh fruit

weight, fruit diameter, peel and flesh moisture, flesh firmness, TSS and TA of mangosteen fruits at harvesting period (Table 1 and 2) were not significantly different compared between outer and inner canopy fruits. The comparison of fruit quality between NF or TFD or GD fruits and among them, of outer and inner canopy fruits were not significantly different, except flesh water content of inner canopy fruits and flesh firmness of outer canopy fruits.

Plant nutrient concentrations in leaves

The results in Figure 4 showed that plant nutrient concentrations in leaves of outer and inner canopy were not significantly different except Ca (at 6th week of fruit development) and B (at harvesting period). In the leaf, mangosteen tree required highest amounts of N, P, K and S for fruit growth at the 10th week of fruit development and at the harvesting period (Figure 4A, 4B, 4C and 4F); Ca and B in the 4th-6th week of fruit development (Figure 4D and 4G) as compared

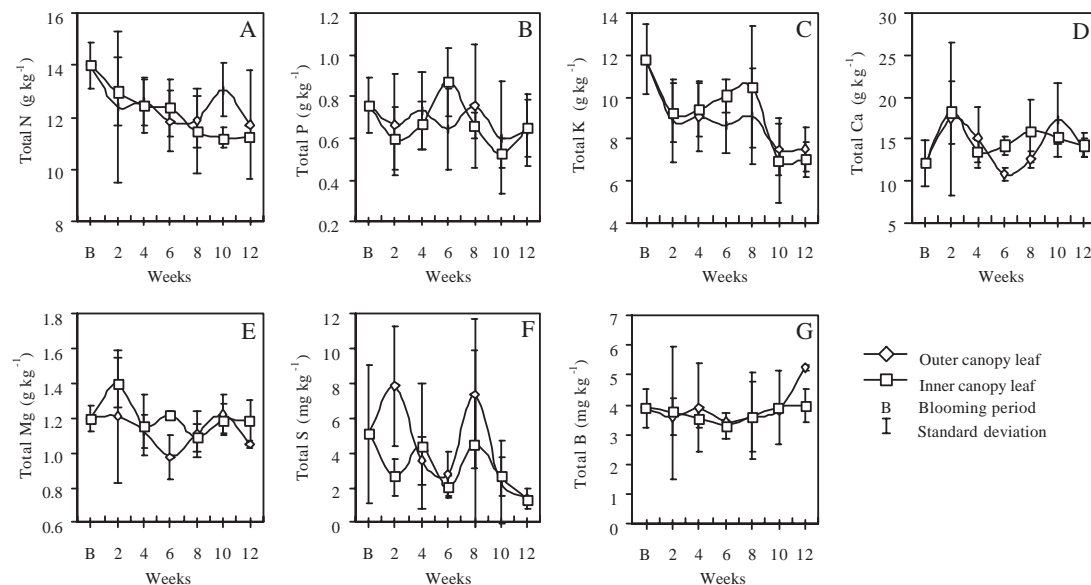


Figure 4 Concentration of plant nutrients in mangosteen leaves during fruit development period. [(A) Total nitrogen (B) Total phosphorus (C) Total potassium (D) Total calcium (E) Total magnesium (F) Total sulphur and (G) Total boron].

Table 1 Mangosteen fruit qualities during fruit development period.

Fruit quality	Fruit position	Fruit age (weeks)					
		2	4	6	8	10	12 ^{1/}
Fresh fruit wt. (g)	Outer canopy	9.70 ± 3.56	14.54 ± 4.61	27.40 ± 12.26	34.10 ± 10.98	52.80 ± 6.78	63.31 ± 13.76
	Inner canopy	8.94 ± 2.09	12.01 ± 4.34	22.40 ± 7.99	31.54 ± 10.27	52.65 ± 8.65	55.29 ± 17.44
	T-test	NS	NS	NS	NS	NS	NS
Fruit diameter (mm)	Outer canopy	22.59 ± 4.01	27.56 ± 4.45	35.15 ± 7.80	38.56 ± 6.05	46.40 ± 2.93	49.02 ± 2.83
	Inner canopy	22.17 ± 2.50	25.39 ± 4.18	32.84 ± 6.32	35.71 ± 9.30	46.10 ± 3.61	46.91 ± 5.66
	T-test	NS	NS	NS	NS	NS	NS
Fruit thickness (mm)	Outer canopy	6.74 ± 0.92	7.44 ± 1.05	7.63 ± 0.84	8.23 ± 0.88	7.76 ± 0.95	6.30 ± 0.60
	Inner canopy	6.46 ± 0.79	7.09 ± 1.12	7.91 ± 0.88	7.69 ± 0.76	7.31 ± 0.59	6.68 ± 0.75
	T-test	NS	NS	NS	NS	NS	NS
Peel moisture (%)	Outer canopy	76.87 ± 1.45	72.45 ± 0.81	75.05 ± 4.96	74.79 ± 15.07	71.34 ± 0.58	69.89 ± 7.43
	Inner canopy	76.97 ± 1.64	71.88 ± 1.05	73.41 ± 0.91	66.08 ± 11.04	71.28 ± 0.45	63.20 ± 1.75
	T-test	NS	NS	NS	NS	NS	NS
Flesh moisture (%)	Outer canopy	ND	75.85 ± 8.14	87.11 ± 1.21	85.77 ± 0.46	86.94 ± 1.23	80.68 ± 0.10
	Inner canopy	ND	89.53 ± 5.19	86.64 ± 1.51	85.81 ± 0.76	86.61 ± 1.42	77.96 ± 1.08
	T-test	NS	*	NS	NS	NS	NS

Remark: ^{1/} = Harvesting period (12th-13th weeks after blooming)

* = Significant difference at P < 0.05

NS = non-significant; ND = Not detected

Table 2 Mangosteen fruit qualities between the normal (NF), translucent flesh disorder (TFD) and gamboge disorder (GD) at harvesting period.

Fruit quality	Fruit position	Mangosteen fruit qualities			% C.V.	F-test	Mangosteen fruit qualities			F-test	% C.V.
		NF	TFD	GD			NF	TFD	GD		
Fresh fruit wt. (g)	Outer canopy	63.31 ± 13.76	55.60 ± 8.36	66.68 ± 0.00	19.18	NS	80.68 ± 0.10	80.84 ± 0.49	80.42 ± 0.00	NS	0.52
	Inner canopy	55.29 ± 17.44	64.34 ± 7.22	64.28 ± 23.91	27.33	NS	77.96 ± 1.08 ^b	81.65 ± 0.38 ^a	79.87 ± 0.43 ^a	* ^{1/}	0.90
	T-test	NS	NS	NS			NS	NS	NS		
Fruit diameter (mm)	Outer canopy	49.02 ± 2.83	62.14 ± 8.03	50.86 ± 0.00	11.09	NS	7.08 ± 0.97 ^a	7.08 ± 0.46 ^b	4.90 ± 0.00 ^b	*	23.71
	Inner canopy	46.91 ± 5.66	49.74 ± 3.32	49.63 ± 6.19	4.99	NS	5.11 ± 2.04	5.11 ± 2.04	4.66 ± 1.04	NS	33.28
	T-test	NS	NS	NS			NS	*	NS		
Fruit thickness (mm)	Outer canopy	6.30 ± 0.60	6.28 ± 0.81	7.57 ± 0.00	13.80	NS	14.58 ± 3.31	15.80 ± 2.89	16.40 ± 0.00	NS	21.35
	Inner canopy	6.68 ± 0.75	6.38 ± 1.08	6.79 ± 0.05	11.19	NS	15.30 ± 3.11	14.68 ± 3.65	ND	NS	23.75
	T-test	NS	NS	NS			NS	NS	-		
Peel moisture (%)	Outer canopy	69.89 ± 7.43	62.02 ± 5.32	66.43 ± 0.00	10.28	NS	0.53 ± 0.11	0.58 ± 0.15	0.60 ± 0.00	NS	22.62
	Inner canopy	63.20 ± 1.75	70.19 ± 3.78	66.75 ± 1.43	12.60	NS	0.53 ± 0.11	0.50 ± 0.11	ND	NS	22.59
	T-test	NS	NS	*			NS	NS	-		

Remark: ^{1/} Values in the same row followed by different letters are significantly different at P < 0.05

* = Significant difference at P < 0.05

NF = normal fruit; TFD = translucent flesh disorder fruit; GD = gamboge disorder fruit

NS = non-significant; ND = Not detected

with other fruit growth periods. During the fruit development period, N, P and S concentrations in outer canopy leaves were likely to be higher than inner canopy leaves, but different from K, Ca and Mg. In addition, results of plant nutrient analysis in mangosteen leaves by Poowarodom *et al.*, (2002); Chomsontae and Poowarodom (2003) showed that N and Mg concentrations were similar with the results in this study. However, Ca concentration was higher, P and K concentration were lower, comparing with the results in this study. It was remarkable that S concentration was lower than those of the other plants (Sutthipradith, 1993).

Plant nutrient concentrations in peels

The results in Figure 5 showed that plant nutrient concentrations in peels were not significantly different between outer and inner canopy fruits, except N and B in the 10th week of fruit development and Ca in the 10th week of fruit development and harvesting period. In the peel, mangosteen tree required highest amounts of N,

P, K, Ca, Mg and S for fruit growth in the 2th week of fruit development period (Figure 5A-5F) and were likely to decrease accumulation at harvesting period. B in the peel was highest during the 10th week of fruit development period to harvesting period (Figure 5G) as compared with other fruit growth periods. During the fruit development period, N and S concentrations in the peel of outer canopy fruits were likely to be higher than those of the inner canopy fruits, which were different from P, Mg and B. N, P, K, Ca and Mg concentrations in peels were agreed with the report of Sdoodee and Limpun-Udom (2002).

Plant nutrient concentrations in fleshes

The results in Figure 6 showed that plant nutrient concentrations in fleshes were not significantly different between to outer and inner canopy fruits, except Ca in the 4th and 10th week of fruit development and B in the 8th week of fruit development. Plant nutrient accumulation in fleshes were likely to decrease from 4th week of fruit development period to harvesting period. In

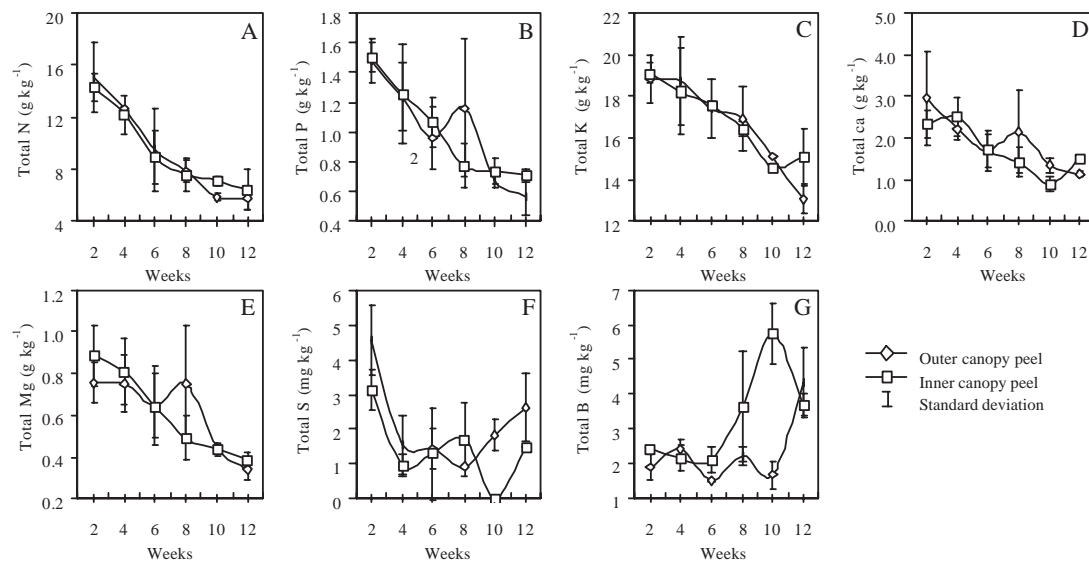


Figure 5 Concentration of plant nutrients in mangosteen peels during fruit development period. [(A) Total nitrogen (B) Total phosphorus (C) Total potassium (D) Total calcium (E) Total magnesium (F) Total sulphur and (G) Total boron].

the flesh, mangosteen tree required highest amounts of N, P, K, Ca and Mg for fruit growth in the 4th week of fruit development period (Figure 6A-6E); S and B in the 6th-10th week of fruit development period (Figure 6F and 6G) as compared with other fruit growth periods. In the fruit development period, Ca, Mg and B concentrations of the flesh in inner canopy fruits were likely to be higher than outer canopy fruits, in contrast with P and S. N, P, Ca and Mg concentrations in flesh were in line with the report of Sdoodee and Limpun-Udom (2002).

Concentration of plant nutrients in peel of NF, TFD and GD fruits

From Figure 7, plant nutrients concentrations in peel of NF, TFD and GD fruits were not significantly different when compared between outer and inner canopy fruits, except Ca in peel of NF fruits. In NF fruits, P and S concentrations (outer canopy peel) and K and Ca concentrations (inner canopy peel) were likely to be higher than those of TFD and GD fruits,

respectively (Figure 7B, 7F, 7C and 7D). N concentration (outer canopy fruits) and B (inner canopy fruits) of NF fruits were likely to be higher than GD and TFD fruits, respectively. In addition, N, K, Ca and B concentrations in peel of NF fruits were accumulated higher than those of TFD fruits as reported by Sdoodee and Limpun-Udom (2002).

Concentration of plant nutrients in flesh of NF, TFD and GD fruits

From Figure 8, most plant nutrients concentration in flesh of NF, TFD and GD of the outer and inner canopy fruits were not significantly different except S in flesh of NF fruits. In NF fruits, N, P and K concentrations (outer canopy flesh) and N, Ca, Mg, S and B concentrations (inner canopy flesh) were likely to be higher than TFD and GD fruit, respectively (Figure 8A-8G). The results were similar to N, K and Mg concentrations in flesh of TFD fruits which accumulated higher than NF fruits Sdoodee and Limpun-Udom (2002).

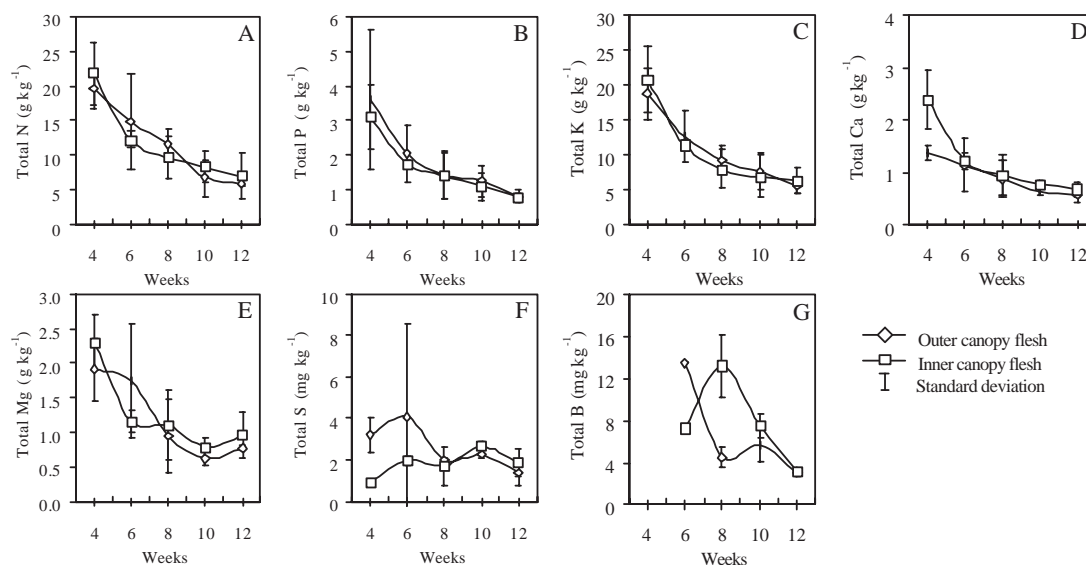


Figure 6 Concentration of plant nutrients in mangosteen fleshes during fruit development period. [(A) Total nitrogen (B) Total phosphorus (C) Total potassium (D) Total calcium (E) Total magnesium (F) Total sulphur and (G) Total boron].

Plant nutrient concentrations during fruit development period

During the development of mangosteen fruits, it was found that the requirements of N, P, K, Ca and Mg in the leaf, peel and flesh of mangosteen (Figure 4, 5 and 6) were higher at the 1st half of fruit development period (bloom to 6th week of fruit development) comparing with the other periods. While the requirement of S and B

were high in the 2nd half of fruit development period (6th week of fruit development to harvest) compared to other growth periods. Poowarodom *et al.* (2002) reported that N, P and K concentrations in mangosteen leaves decreased with leaf age. Calcium and B were phloem immobile nutrients, therefore, they were not directly transferred from leaves to fruits (Osotsapar, 2000). In addition, fruits required

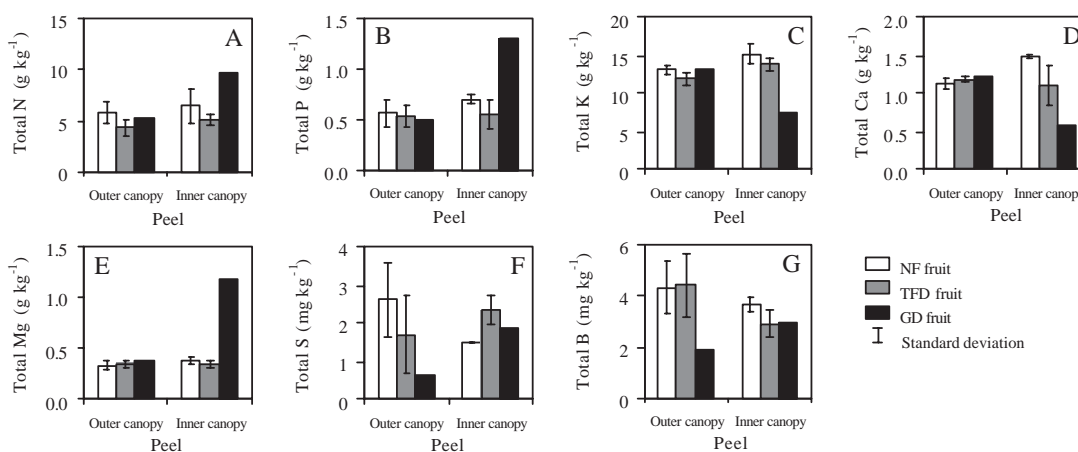


Figure 7 Concentration of plant nutrients in mangosteen peels at harvesting period of NF, TFD and GD fruits. [(A) Total nitrogen (B) Total phosphorus (C) Total potassium (D) Total calcium (E) Total magnesium (F) Total sulphur and (G) Total boron].

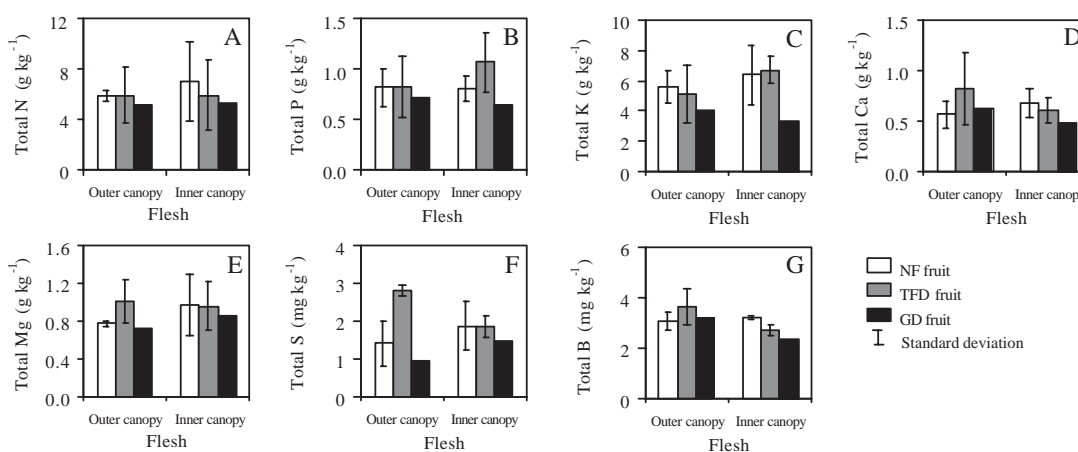


Figure 8 Concentration of plant nutrients in mangosteen flesh at harvesting period of NF, TFD and GD fruits. [(A) Total nitrogen (B) Total phosphorus (C) Total potassium (D) Total calcium (E) Total magnesium (F) Total sulphur and (G) Total boron].

amount of K during fruit development, leaf K concentration decrease with leaf age (Chomsontae and Poowarodom, 2003). Marschner (1995) suggested that K is a supporter for increasing peel and flesh Ca and B concentration on transferring through xylem.

CONCLUSIONS

The mangosteen soils were very extremely acid to moderately acid, and the most of essential nutrients in soils were low for plant growth. Mangosteen fruit qualities of the outer and inner canopy were not significantly different. Most plant nutrient accumulations in mangosteen leaf, peel and flesh were not significantly different when compared between outer and inner canopy, and accumulation decreased from blooming to harvesting period. In the leaf, peel and flesh of mangosteen required higher amounts of N, P, K, Ca and Mg for growth at the 1st half of fruit development period (bloom to 6th week of fruit development) and S and B in the 2nd half of fruit development period (6th week of fruit development to harvest) as compared with other growth periods. Potassium and Ca contents in the peel of NF fruits were higher than TFD and GD fruits, whereas P and Mg contents in the flesh of TFD fruits were higher than NF and GD fruits.

ACKNOWLEDGEMENTS

We wish to thank the Commission of Higher Education, Ministry of Education and Graduate School, Prince of Songkla University for financially support this study.

LITERATURE CITED

- Aitken, R.L., A.J. Jeffery and B.L. Compton. 1987. Evaluation of selected extractants for boron in some Queensland soils. **Aust. J. Soil Res.** 25: 263-273.
- Chomsontae, N. and S. Poowarodom. 2003. Seasonal changes in the leaf composition of mangosteen: macronutrients. **Agricultural Sci. J.** 34: 1-3(Suppl.): 189-192.
- Dennis, R.K. 1982. Nitrogen-availability, pp. 711-733. *In* A.L. Page, R.H. Miller and D.R. Keeney (eds.). **Methods of Soil Analysis Part 2: Chemical and Microbiological Properties.** 2nd ed. Madison Publisher Wisconsin.
- Department of Agriculture, Malaysia. 2001. **Fruit Technology Mangosteen** (*Garcinia mangostana*). [on line]. Available from http://agroling.moa.my/dao/english/croptech/mgn_gen.html [August 25, 2001].
- Department of Soil Science. 1998. **Principles of Soil Science.** 8th ed. Kasetsart University, Thailand. 547 p.
- Division of Land Use Planning, Department of Land Development. 1992. **Qualitative Land Evaluations.** Ministry of Agriculture and Cooperatives, Thailand. 65 p.
- Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis, pp. 383-412. *In* A. Klute (ed.). **Methods of Soil Analysis Part 1: Physical and Mineralogical Methods.** Madison Publisher. Wisconsin.
- Lim, M., S. Sdoodee, S. Chanawerawan and C. Onthong. 2001. Growth pattern and phonological development of longkong (*Aglaia dookoo* Griff.). **Songklanakarinn J. Sci. Technol.** 23(4): 467-478.
- Maneepong, S. 1994. **Soil and Plant Analysis.** Department of Earth Science, Faculty of Natural Resources, Prince of Songkla University, Songkhla. 200 p.
- Marschner, H. 1995. **Mineral Nutrition of Higher Plants.** 2nd ed. Academic Press, New York. 889 p.
- Mclean, E.O. 1982. Soil pH and lime requirement, pp. 199-224. *In* A.L. Page, R.H. Miller and D.R. Keeney (eds.). **Methods of Soil Analysis Part 2: Chemical and Microbiological**

- Properties.** 2nd ed. Madison Publisher Wisconsin.
- Moncharoen. P. 2002. **Soil Analysis Interpretation for Soil Improvement and Fertilizer Recommendation.** Department of Land Development Ministry of Agriculture and Co-operatives, Thailand. 216 p.
- Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter, pp. 539-579. *In* A.L. Page, R.H. Miller and D.R. Keeney, (eds.). **Methods of Soil Analysis Part 2: Chemical and Microbiological Properties.** 2nd ed. Madison Publisher Wisconsin.
- Ngamsaeng, T. and S. Poowarodom. 2003. Seasonal changes in the leaf composition of mangosteen: micronutrients. **Agricultural Sci. J.** 34: 1-3(Suppl.): 185-188.
- Nilnond, C., W. Jatupote, W. Leowarin and S. Yong. 1995. Chemical fertility status of some growing mangosteen soil in southern Thailand. **Songklanakar J. Sci. Technol.** 17(4): 381-393.
- Olsen, S.R. and Sommers, L.E. 1982. Phosphorus, pp. 403-430. *In* A.L. Page, R.H. Miller and D.R. Keeney, (eds.). **Methods of Soil Analysis Part 2: Chemical and Microbiological Properties.** 2nd ed. Madison Publisher. Wisconsin.
- Onthong, J. 2002. **Soil and Plant Analysis.** Department of Earth Science, Faculty of Natural Resources, Prince of Songkla University, Songkhla. 168 p.
- Osotsapar, Y. 2000. **Plant Nutritions.** Department of Soil science, Faculty of Agriculture, Kasetsart University, Bangkok. 424 p.
- Patarapiyapun, N. 1995. **Phenological Development of Mangosteen (*Garcinia mangostana* L.) in Changwat Nakhon Si Thammarat.** M.Sc. Thesis. Prince of Songkla University, Songkhla.
- Pechkeo, S. 1999. **Research report: Land Potential for Mangosteen Cultivation in Southern Thailand; Some Soil Properties of Mangosteen Soil in Southern Thailand; Some Soil Properties of Mangosteen Soil in Namom District, Songkhla Province.** Department of Earth Science, Faculty of Natural Resources, Prince of Songkla University, Songkhla.
- Poowarodom, S., P. Kanyawongha, P. Lertrat and N. Boonplang. 2002. Leaf age and position on mineral composition of mangosteen leaves, paper no. 2272. *In* **Transection of the 17th World Congress of Soil Science, Symposium no.16.** 14-21 August, Bangkok.
- Rhoades, J.D. 1982. Soluble salts, pp. 167-179. *In* A.L. Page, R.H. Miller and D.R. Keeney (eds.). **Methods of Soil Analysis Part 2: Chemical and Microbiological Properties.** 2nd ed. Madison Publisher. Wisconsin.
- Sdoodee, S. and Limpun-Udom, S. 2002. Effect of excess water on the incidence of translucent flesh disorder in mangosteen (*Garcinia mangostana* L.). **Acta Horti.** 575: 813-820.
- Sutthipradit, S. 1993. **Soil Fertility.** Department of Earth Science, Faculty of Natural Resources, Prince of Songkla University, Songkhla. 349 p.
- Tabatabai, M.A. 1982. Sulfur, pp. 501-538. *In* A.L. Page, R.H. Miller and D.R. Keeney (eds.). **Methods of Soil Analysis Part 2: Chemical and Microbiological Properties.** 2nd ed. Madison Publisher. Wisconsin.
- Thomas, G.W. 1982. Exchangeable cations, pp. 159-165. *In* A.L. Page, R.H. Miller and D.R. Keeney (eds.). **Methods of Soil Analysis Part 2: Chemical and Microbiological Properties.** 2nd ed. Madison Publisher Wisconsin.