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Research article

Seasonal variation of fruit yield and leaf macronutrient concentrations of Thai aromatic coconut

Mesa Kueklang, Krisana Krisanapook*, Tee Havananda†, Lop Phavaphutanon†, Kietsuda Luengwilai†

Department of Horticulture, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Kamphaeng Sean, Nakhon Pathom 73140, Thailand

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Abstract

Seasonal yield variation is a major obstacle in the export of Thai aromatic coconut. Efficient nutrient management can help alleviate this problem, but it needs a crop-specific nutrient analysis as a guideline. This study established a tentative leaf nutrient concentration standard for this coconut based on a nutrient survey approach. The fruit yield and macronutrient concentrations in the index leaf were monitored monthly and bimonthly, respectively, from Thai aromatic coconut trees in 11 orchards located in the main production area between November 2015 and April 2017. The data showed that the mean (± SD) fruit yield was in the range 135–219 fruit/tree/18 mth (9 ± 1.3 fruit/bunch/month), with a low yield (lower than 8 fruit/bunch) observed in the periods between March and May 2016, November and December 2016 and March and April 2017, corresponding to dry periods in the region. Most leaf macronutrient concentrations were relatively stable throughout the entire study except for phosphorus and calcium. There was a weak correlation (correlation coefficient 0.04–0.38) between the leaf macronutrient status and the varying fruit yield. The mean (± SD) nitrogen concentration was highest (1.73 ± 0.11–1.94 ± 0.15%) followed by potassium (0.81 ± 0.23–1.00 ± 0.21%) and calcium (0.31 ± 0.08–0.90 ± 0.07%). Magnesium, sulfur and phosphorus were present in much lower concentrations (0.19 ± 0.07–0.26 ± 0.05%, 0.13 ± 0.02–0.15 ± 0.02% and 0.09 ± 0.02–0.14 ± 0.04%, respectively). Based on the results, a tentative leaf macronutrient concentration for Thai aromatic coconut was developed that could be used as a reference for farmers in this area to evaluate the health status of their coconut palms.

† Equal contribution.
* Corresponding author.
E-mail address: agrknk@ku.ac.th (K. Krisanapook)

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Introduction

Coconut water contains vitamins, minerals and other components that are essential to human health (Yong et al., 2009; DebMandal and Mandal, 2011). As health awareness is growing among the public, the global market potential for coconut water has significantly increased (CBI, 2020). Recently, Thai aromatic coconut ('Nam Hom') has become a major economic fruit of Thailand, especially for export (Office of Agricultural Economics, 2020). It is consumed at young age when the fruit is still green and its sweet and aromatic water is a unique characteristic of this cultivar (Krisanapook et al., 2012). Production is more intensive for Nam Hom fresh fruit compared to industrial coconut growth for mature brown fruit and copra yield (Krisanapook et al., 2016). Nam Hom is a dwarf type of coconut which grows continuously for 20–30 years, with vegetative and reproductive growth of a mature-bearing coconut tree occurring simultaneously, with a new frond and inflorescence produced monthly, yielding a harvestable fruit bunch every 20–25 d all year round (Krisanapook et al., 2012). Therefore, a continuous supply of nutrients is essential to sustain its growth, fruit quality and productivity. However, fruit yield variation occurs seasonally even in high-yielding orchards, which significantly influences market prices (Krisanapook et al., 2012). It is difficult to identify the factors affecting yield because the development from flower buds to harvestable fruit takes more than 24 mth and any factor prevailing during the long developmental period could affect the fruit yield (Krisanapook et al., 2019). Examples are abrupt changes in weather conditions, especially drought, can affect the number of female flowers, fruit setting and premature fruit drop, as well as internal competition among fruit bunches and plant nutritional status.

At present, nutrient management for 'Nam Hom' coconut is mostly based on grower experience and general recommendations from the Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand; however, the existing nutrient status of the plant and soil is rarely considered. According to a Nam Hom coconut orchard survey in Damnoen Saduak district, Ratchaburi province, central Thailand (Saradhuldhat et al., 2013), the orchard soils were typically heavy clay with a pH of 7.46, low in organic matter and very high in phosphorus (261 mg/kg), potassium (360 mg/kg), calcium (10,548 mg/kg), magnesium (2,407 mg/kg), zinc (8.9 mg/kg) and copper (3.61 mg/kg), respectively, whereas iron was moderate (13.5 mg/kg) and manganese was low (6.9 mg/kg). The very high concentration of certain nutrients in these coconut orchards was partly associated with the long-term over application of chemical fertilizer.

Plant nutrient analysis can be used as a guideline for the effective nutrient management of many fruit trees, providing that the reference leaf nutrient concentration specific to the fruit tree species is available (Reuter and Robinson, 1986). Leaf nutrient concentration standards have been developed for local cultivars of economic fruit crops in Thailand, such as durian and longkong (Poovarodom et al., 2002; Onthong et al., 2006) but they are not available for Nam Hom coconut. The leaf nutrient concentration standards have been well established for the tall type, dwarf type and hybrids of both types (Frémond et al., 1966; Magat, 1979; Chew, 1982; Magat, 1988) of coconut grown for copra production. The optimal ranges for leaf P, K and Ca differ among these three types of coconut, suggesting the importance of the specific leaf nutrient concentration standard for each type. It might well be the case that such standards are not applicable to Nam Hom coconut, which has a different genetic background, and the aim is to produce fresh, young fruit. While leaf nutrient concentrations vary with the age of the tree, variation due to the age of the coconut tree is often less after canopy closure at 3–6 yr after field transplanting (Pushparajah, 1994). Large variations may occur due to the sampling time and seasonality in oil palm (Foster and Chang, 1977). To establish leaf nutrient concentration standards for fruit tree species, a nutrient survey approach is commonly used to obtain the nutritional information from healthy trees with normal growth and high fruit yields under well-managed conditions. The leaf nutrient concentrations in high-yielding orchards are presumed to be optimal and this approach is the most common source of tree crop nutritional information (Krisanapook et al., 2019).

The aim of the current study was to report the seasonal variation of fruit yield and leaf macronutrient concentrations of Nam Hom coconut palms grown in a major production area in central Thailand over 18 mth and to investigate whether the macronutrient concentration range from high-yielding orchards could be used as a tentative leaf macronutrient concentration standard for this type of coconut.

Materials and Methods

Study sites and general orchard management

Nutrient surveys were conducted of healthy and high-yielding Nam Hom coconut orchards in the major production areas in the central region of Thailand in Ratchaburi province (four orchards), Samut Sakhon province (four orchards) and Nakhon Pathom province (three orchards). Healthy and high-yielding trees were characterized by year-round continuous growth and production of a new frond with a fruit bunch every 20–25 d with an average of at least 8 harvestable fruit/mth. The sampled lowland delta area was situated among main rivers and canals which provide ample water for irrigation all year round. The area was not so far from the Gulf of Thailand and was exposed to brackish water during the dry season. The tasty aromatic coconut and other fruits produced in this area might be partly associated with the local high soil fertility and brackish water.

The mean air temperature and precipitation were obtained from the nearest weather stations of the Thai Meteorological Department. Orchards in Nakhon Pathom and Samut Sakhon provinces shared weather information from a meteorological station in Nakhon Pathom province. Orchards in Ratchaburi province used data from a meteorological station in Ratchaburi province.

The ditch and dike system is commonly practiced by most orchards in this lowland area where a planting plot (dike) of 4 m wide is alternated with a water canal that serves as a water reservoir and provides drainage. The water level in the canal is maintained about 50 cm below the soil surface of the planting plot all year round. Ditch dredging is done every 1–2 yr to move mud from the bottom of the canal back to the planting plot. Dried fronds are laid on the soil surface as mulch. Chicken manure and sea salt are applied annually at the rate of 20 kg/tree and 1–2 kg/tree, respectively. The common practice for chemical fertilizer application is 15-15-15 or 16-16-16 (N-P-K, respectively) granular fertilizer at the rate of 2 kg/tree/year (0.5 kg/tree every 3 mth) and may be alternated with 8-24-24 at the rate of 1 kg/tree/year (0.5 kg/tree every 6 mth). According to grower interviews, the application of chemical fertilizer (formulae, rate and frequency) varied among the orchards in the current study. The age of the coconut palms among orchards was in the range 8–20 yr. In each orchard, five healthy representative trees of uniform size (based on trunk circumference and height) and age were chosen for measuring the fruit yield and leaf macronutrient concentrations over a period of 18 mth from November 2015 to April 2017.

Coconut fruit yield

Nam Hom coconut fruit is commercially harvested at a young green age when the fruit is aged 7 mth and a healthy tree bears a fruit bunch every 20–25 d all year round (Krisanapook et al., 2012). The fruit yield was monitored during 18 mth by counting fruit number in the two lowest bunches on a bi-monthly basis. Fruit in the lowest bunch were ready to be harvested in the week of the orchard visit and fruit in the bunch immediately above the lowest bunch (the 2nd lowest bunch) would be ready to be harvested in the following 3–4 wk.

Orchard soil properties and macronutrient analysis of soil and leaf tissues

Soil and plant analyses were conducted in the laboratory following standard protocols (Jones, 2001). In each orchard, soil samples were collected at a depth of 0–40 cm within the palm canopy where most feeder roots were observed. Soil at a depth below this level tends to be too wet due to the high water table of the ditch and dike orchard system. After being dried in the shade and crushed to pass through a 2.0 mm sieve, the soil samples were determined for pH (1:5 water; PB 20 Sartorius pH Meter; Sartorius AG, Goettingen, Germany), electrical conductivity (EC 1:5 water; Suntex Conductivity Meter SC-170; Suntex Instruments Co., Ltd., New Taipei City, Taiwan) and organic matter using the loss in ignition method (Vulcan Furnace 3-550; Pacific Combustion Engineering, Torrance, CA, USA). Soil available phosphorus was extracted using the Bray II method and analyzed using the colorimetric method (T80 UV/VIS Spectrometer; PG Instruments Ltd., Alma Park, Leicestershire, LE17 5BE, UK). Soil exchangeable potassium, calcium and magnesium were extracted using ammonium acetate at pH 7 and were analyzed using the atomic absorption spectrophotometry method. Available sulfur was analyzed using the turbidity method (T80 UV/VIS Spectrometer; PG Instruments Ltd., Alma Park, Leicestershire, LE17 5BE, UK).

The leaf samples for nutrient analysis were taken every 2 mth from the index leaf (the 14th leaf from the top of the palm) according to Frémond et al. (1966). Three leaflets from each side of the leaf were collected and only central segments (10 cm) of the leaflets without the midrib were taken and washed with 0.1N HCl and deionized water, dried in a forced-air oven at 70°C and then ground to pass through a screen (mesh 40; approximately 0.40 mm in diameter). N in the ground leaf samples was determined using the combustion method (LECO FP-528 Nitrogen/Protein Determinator; LECO Corporation, Miami, FL, USA). A subsample was digested in HNO_3-$HClO_4$ acid mixture (5:2 ratio by volume) and then P and S were analyzed using colorimetric and turbidity methods, respectively (T80 UV/VIS Spectrophotometer; PG Instruments Ltd., Alma Park, Leicestershire, LE17 5BE, UK).

K, Ca and Mg of the digested samples were analyzed using atomic absorption spectrophotometry (AAS Vario® 6; Analytik Jena, Jena, Germany).

Data analysis and tentative leaf macronutrient concentration standard

Fruit yield was presented on a monthly basis as mean ± SD values of each production site. Seasonal changes in the leaf macronutrient concentration were presented as mean ± SD values across the three production sites. Data of leaf macronutrient concentrations were subjected to analysis of variance and Tukey's multiple range test to determine the period when most nutrient concentrations were relatively stable. Data from the high-yielding orchards during the period that leaf nutrient concentrations were relatively stable were proposed to use as a tentative leaf macronutrient concentration standard based on 95% confidence intervals. All statistical analysis was performed using the SPSS software (version 16; SPSS Inc., Chicago, IL, USA).

Results and Discussion

Coconut fruit yield

The fruit yield was in the range 135–219 fruit/tree/18 mth (9 ± 1.3 fruit/bunch/month), which was comparable to the average yield of Nam Hom coconut reported from another survey (Krisanapook et al., 2016). In all three provinces, the periods of low yield (lower than 8 fruit/bunch) occurred in a similar pattern during March–May and November–December 2016 and March–April 2017 (Fig. 1). However, the low yield period shifted in different years. For example, the fruit yield was relatively high during November–December 2015 but was relatively low during the same period in the following year. The average fruit yield of orchards in Nakhon Pathom was generally lower than for the other two provinces (Fig. 1). Thailand is located in the tropical zone and the study sites were in the central region with three seasons (summer, rainy and cool). March–May 2016 and March–April 2017 were hot-dry periods in the summer, the average air temperatures for Nakhon Pathom in these periods were 31.6°C and 30.3°C, respectively, and the average air temperatures for Ratchaburi were 31.3°C and 30.3°C, respectively. November–December 2016 was a cool-dry period in the cool season; the average air temperatures in this period for Nakhon Pathom were 26.7°C and 26.1°C, respectively, and the average air temperatures in this period for Ratchaburi were 27.3°C and 26.4°C, respectively (Figs. 2A and 2B). Hence, a low fruit yield seemed to occur during the dry periods of the year due to the effects during the flower bud and fruit development periods such as water, temperature, nutrient, plant diseases and insect pests. Rainfall and temperature are climatic factors that affect coconut growing (Paull and Duarte, 2012). Low yield was characterized by a low fruit number per bunch, a bunch without fruit and no harvestable fruit bunch on a sampling date.

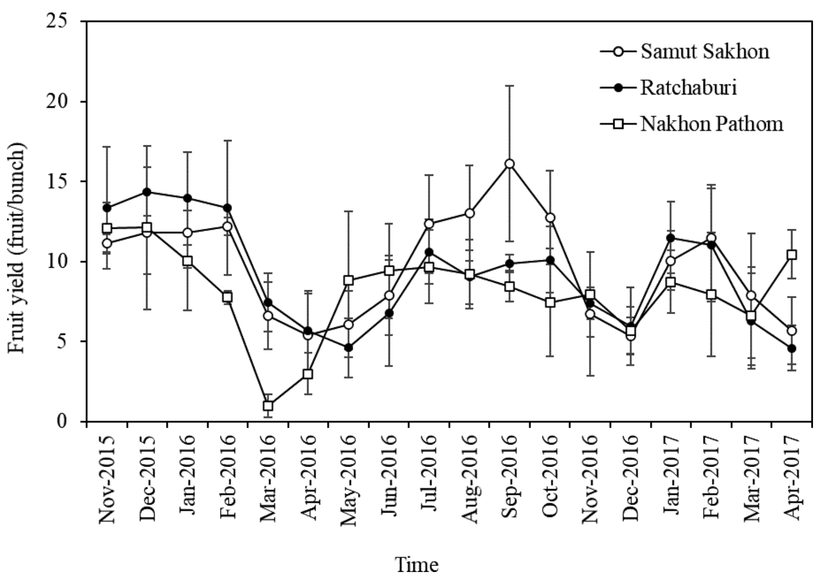

Fig. 1 Seasonal variation of fruit yield of 'Nam Hom' coconut trees from high-yielding orchards in Samut Sakhon, Ratchaburi and Nakhon Pathom provinces, where each data point is mean ± SD of harvestable fruit yield (fruit number/tree) from 3–4 orchards in each province

A study (Krisanapook et al., 2016) on the flowering pattern of Nam Hom coconut in Thailand indicated seasonal variation of spadix emergence from 0.8–2.4 spadices/mth, low spadix numbers in November (dry period) and high numbers (flowering more frequently) in May (beginning of the rainy season). A decrease in the number of female flowers per spadix was also observed from August to November. It is generally cool and dry in November. The high temperature and low rainfall in the dry season (March–April) had a negative impact on the development of flower buds inside the shoot apex, resulting in less emergence of spadices and low numbers of female flowers on the spadices between August and November. Consequently, a low yield could be expected 7 mth later (Krisanapook et al., 2016). Of the climatic factors, rainfall and temperature seem to have a prominent effect on flower bud and fruit development in coconut (Patel and Pandalai, 1936; Ranasinghe et al., 2010). The current results were consistent with this, as during the study, the highest temperature together with less rain occurred during March–April 2015, resulting in a lower yield in March–April of the following year (Fig. 2).

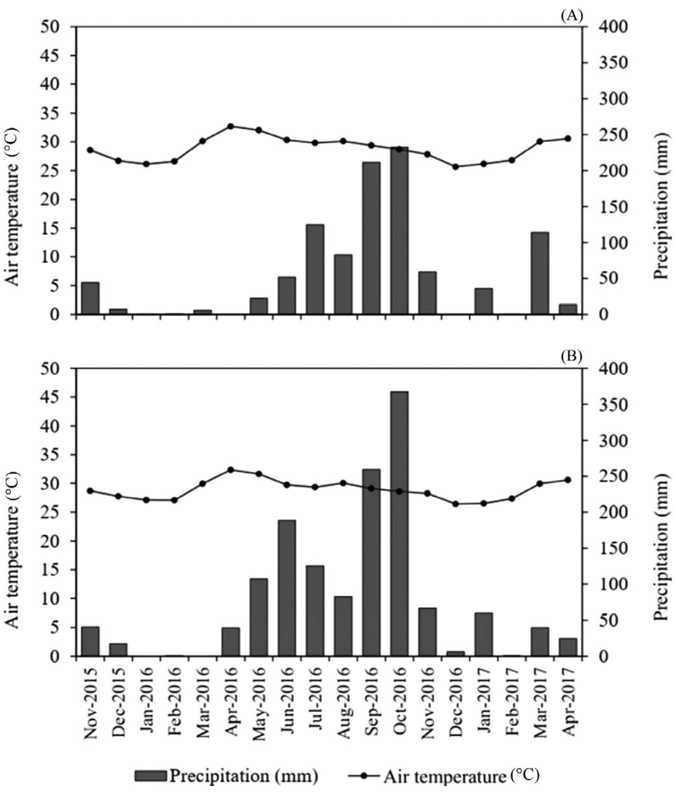

Fig. 2 Mean air temperature and precipitation in major production areas: (A) Nakhon Pathom province; (B) Ratchaburi province (Sourced: Nakhon Pathom Meteorological Station, 2020; Ratchaburi Meteorological Station, 2020)

However, there was clear relation between climatic factors and leaf macronutrient variation in each month. As a coconut can be cross-pollinated (Frémond et al., 1966), the existing genetic variation could have partly accounted for the differences in fruit yield in each production area.

Orchard soil properties and soil macronutrient concentrations

Soils in this region are classified as Hydromorphic Alluvial Soils (fsi, mixed act Typic Endoaquolls and f, smec Vertic Endoqulls) with relatively high fertility (Land Development Department, 2005). The orchard soil pH values were in the range of moderately acid to moderately alkaline, whereas the orchard soil in Nakhon Pathom was more alkaline than in the other two provinces (Table 1). This soil pH range did not have a negative effect on the availability of plant nutrients and has been reported as an acceptable range for coconut trees (Frémond et al., 1966).

Based on an equation to convert electrical conductivity values of the mass soil-to-water ratio of 1:5 extract ($EC_{1:5}$) to the electrical conductivity values of soil-saturated paste extract (EC_e) proposed by Kargas et al. (2018) for fine-texture soils, namely, $EC_e = 6.53(EC_{1:5}) - 0.108$, the orchard soil EC_e in the current study was in the range 1.9–7.1 mS/cm, covering the range from low to high salinity (Abrol et al., 1988). These values were expected and this salinity effect was associated with the application of sea salt, chicken manure and chemical fertilizer commonly practiced in Nam Hom coconut orchards, as well as the intrusion of sea water during the dry season. In addition, the application of sodium chloride as fertilizer for coconut is practiced in the Philippines (Magat and Margate, 1989).

Soil organic matter was high for all three production sites, in the range 2.76–6.44% (in general, a sufficient soil organic matter level is greater than 1.5%; Land Development Department, 2005). Mulching with dry fronds, the application of chicken manure and annual ditch dredging could have accounted for the high organic matter (Table 1). Both fronds and roots have appreciable amount of biomass and nutrients and their contribution to soil organic matter and nutrients after decomposition has been considered significant (Somasiri et al., 2003). Low soil organic matter (1.4%) was reported by Saradhuldhat et al. (2013) in low input Nam Hom coconut orchards (limited application of both manure and chemical fertilizer) in Ratchaburi province.

The amounts of available P and S and exchangeable K, Ca and Mg in orchard soils varied considerably among orchards and production areas (Table 1) and the observed range of available soil nutrients was high to very high compared to the sufficient range for crop production (in general, sufficient available P, S and exchangeable K, Ca and Mg are at least 11 mg/kg, 7 mg/kg, 60 mg/kg, 1,000 mg/kg and 120 mg/kg, respectively; Central Laboratory and Greenhouse Complex, 2006). Although soils in this region of Thailand have high fertility, such a high concentration of macronutrients was likely the consequences of long-term over-fertilization (Krisanapook et al., 2019). Such a nutrient imbalance in these orchard soils is of concern. A coconut palm requires lesser P than either N or K (Saradhuldhat et al., 2013); thus, N-P-K applications of 15-15-15 or 16-16-16 and 8-24-24 in a regular fertilization program for Nam Hom coconut would lead to increased P accumulation in orchard soils. An increase in K fertilizer application would substantially affect the plant Mg status as reported in coconuts grown in lateritic soils despite Mg fertilizer application (Somasiri, 1997). The soil analysis results indicated that reducing the amount of chemical fertilizer applied would be possible. Further testing would be needed to determine a reduced rate of fertilization that could effectively maintain optimal tree nutritional status, growth, yield and quality of Nam Hom coconut.

Leaf macronutrient concentrations

As the concentrations of each macronutrient were comparable among orchards and locations at each sampling date, the data were presented as an average concentration (Fig. 3). The abundance of macronutrients in Nam Hom coconut leaves was in the following order: N > K > Ca > Mg > S > P. This order agreed well with reports for tall coconut (Frémond et al., 1966; Broschat, 1997), dwarf coconut (Chew, 1982) and hybrids between tall and dwarf coconuts (Magat, 1988). The leaf N concentration of Nam Hom coconut was in the range 1.73 ± 0.11–1.94 ± 0.15% followed by K and Ca, in the ranges 0.81 ± 0.23–1.00 ± 0.21% and 0.31 ± 0.08–0.90 ± 0.07%, respectively. There were much lower leaf concentrations of Mg, S and P (0.19 ± 0.07–0.26 ± 0.05%, 0.13 ± 0.02–0.15 ± 0.02% and 0.09 ± 0.02–0.14 ± 0.04%, respectively), as shown in Fig. 3. These leaf macronutrient concentration ranges were comparable to those of the existing standards for

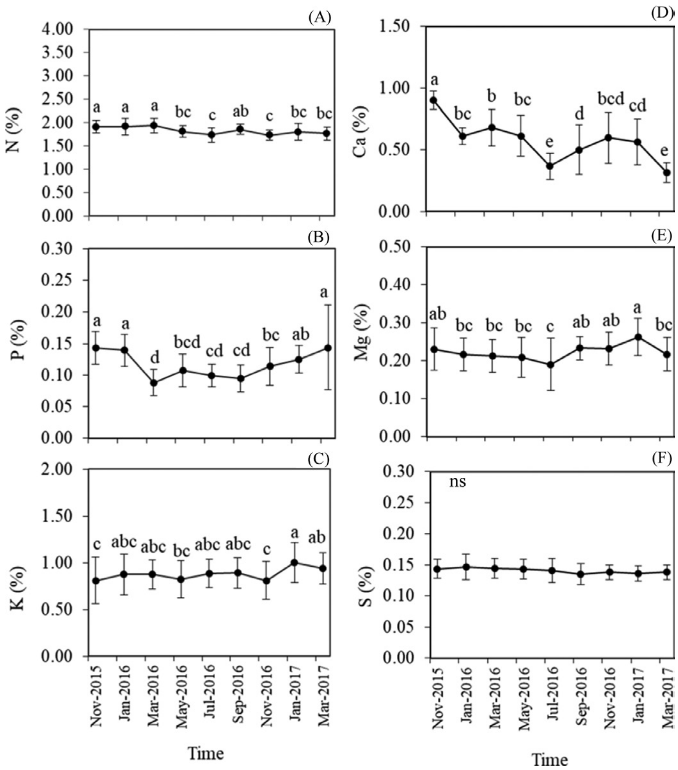

Fig. 3 Seasonal variation of leaf macronutrient concentrations of healthy and high-yielding aromatic coconut trees from orchards in Samut Sakhon, Ratchaburi and Nakhon Pathom provinces: (A) nitrogen; (B) phosphorus; (C) potassium; (D) calcium; (E) magnesium; (F) sulfur, where each data point is mean ± SD from 3–4 orchards in each province, different letters (a–e) on line graph indicate significant ($p < 0.05$) differences between time points and ns = not significant ($p > 0.05$) different

Table 1 Soil properties and macronutrients (mean ± SD) of high-yielding 'Nam Hom' coconut orchards in major production areas of Samut Sakhon, Ratchaburi and Nakhon Pathom provinces, Thailand

Soil property/macronutrient concentration	Production area (province)		
	Samut Sakhon	Ratchaburi	Nakhon Pathom
pH (1:5 water)	6.7±0.7	7.2±0.4	7.7±0.3
Electrical conductivity (mS/cm) (1:5 water)	0.76±0.19	0.58±0.36	0.66±0.33
Organic matter (%)	5.84±0.60	3.38±0.59	5.77±0.75
Available P (mg/kg)	617±225	197±311	496±181
Exchangeable K (mg/kg)	224±47	113±50	343±91
Exchangeable Ca (mg/kg)	6,052±796	6,198±645	6,845±1,677
Exchangeable Mg (mg/kg)	1,450±248	585±255	1,582±252
Available S (mg/kg)	188±54	326±147	217±145

tall, dwarf and hybrid coconuts (Frémond et al., 1966; Chew, 1982; Magat, 1988) with some modification. The standard range for optimal leaf N is 1.8–2.0% for the tall, dwarf and hybrid coconuts. However, several healthy and high-yielding Nam Hom coconut trees had leaf N below 1.8% and could have been ranked as N-deficient according to the existing standard. This was also the case for Mg and S. In contrast, leaf Ca showed the opposite trend, as the average leaf Ca of Nam Hom coconut was higher than the range for the existing standards for tall, dwarf and hybrid coconuts; therefore, several healthy and high-yielding Nam Hom coconut trees should have been considered as having excessive Ca.

The leaf N, K, Mg and S concentrations were relatively stable throughout the study period (Fig. 3A, 3C, 3E and 3F). A healthy coconut tree produces a new leaf and inflorescence simultaneously every month, all year round. Therefore, the 14^{th} leaf samples used for nutrient analysis at each sampling date (bi-monthly interval) were relatively comparable in age and physiological conditions. This may have explained the stable pattern of leaf macronutrient concentrations over the long period. Significant variation of leaf nutrient concentrations among different leaf positions (ages) in coconut has been reported (Broschat, 1997). In other tropical fruit crops such as durian and longkong, leaf flushing occurs seasonally and the variation in leaf nutrient concentrations observed at different leaf sampling times was associated with differences in leaf age (Poovarodom et al., 2002; Onthong et al., 2006). In contrast, the leaf P and Ca concentrations of Nam Hom coconut varied in the current study (Fig. 3B and 3D). The leaf P concentration was high (0.14%) between November 2015 and February 2016 and decreased to 0.09% between March and April 2016 and remained in the range 0.10–0.12% thereafter (Fig. 3B). There was a high Ca concentration (0.90%) between November and December 2015 and a low leaf Ca concentration (0.31%) between July and August 2016 and March and April 2017 (Fig. 3D). Whether the seasonal effect or difference in evapotranspiration accounted for such variation pattern is not known.

The fruit yield and leaf macronutrient status were poorly correlated in the current study (Table 3) as the fruit yield varied at different times of the year, whereas the leaf concentrations of most macronutrients were relatively stable (Fig. 3). The relationship between the concentrations of macronutrients in leaves and soils was also weak. Similarly, soil macronutrient concentrations varied widely among orchards (Table 1), whereas variation in leaf macronutrient concentrations was very low (Table 2). The excess macronutrient concentrations in orchard soils did not necessarily increase the leaf macronutrient concentrations of a healthy Nam Hom coconut palms. Therefore, a low fruit yield of a healthy Nam Hom coconut palm during certain periods of the year may not have been associated directly with the current status of macronutrients in the palm.

Table 2 Tentative optimal leaf macronutrient concentration range of ‘Nam Hom’ coconut based on 95% confidence intervals compared with optimum ranges from other reports

Macronutrient (%)	‘Nam Hom’ coconut (Current study)	Coconut (Frémond et al.,1966)	Dwarf coconut (Chew, 1982)	Hybrid coconut (Magat, 1988)
N	1.77−1.85	1.80−2.00	1.80−2.00	1.80−2.00
P	0.10−0.12	0.12	0.12	0.12−0.13
K	0.76−0.88	0.80−1.00	0.60−0.80	0.90−1.10
Ca	0.56−0.66	0.50	0.15-0.20	0.32−0.35
Mg	0.19−0.23	0.30	0.25	0.30−0.33
S	0.13−0.15	n/a	n/a	0.15−0.16

n/a = not applicable

Table 3 Correlation coefficients between leaf macronutrient and yield (n = 44)

Leaf macronutrient	Yield	p-value	Significant
	Correlation coefficient		
N	0.18	0.402	ns
P	0.38	0.104	ns
K	0.06	0.817	ns
Ca	0.19	0.419	ns
Mg	0.17	0.430	ns
S	0.04	0.710	ns

ns = correlation coefficient not significantly different from zero at 95% confidence level

Tentative leaf macronutrient concentration standard of Nam Hom coconut

Seasonal variation of leaf nutrient concentrations exists in various fruit crops; thus, it is important to identify the appropriate leaf sampling time or season when the variation in most nutrients is minimal. For coconut, de Taffin (1998) suggested that leaf sampling for nutrient analysis should be done during the dry season and that the rainy season should be avoided. In the current study, most leaf macronutrients were relatively stable throughout the study period except for Ca and P. According to the analysis of variance, all leaf macronutrient concentrations of Nam Hom coconut were relatively stable between May and June. It was presumed that the leaf macronutrient concentrations from the high-yield orchards in the current study were optimal and only data from trees with an average fruit yield of at least 9 fruit/bunch/month during May and June were used to construct an optimal leaf nutrient concentration range using 95% confidence intervals. The tentative leaf macronutrient concentration standard for Nam Hom or Thai aromatic coconut was proposed based on the leaf macronutrient concentration range of the healthy and high-yielding trees measured in the current study as: 1.77–1.85% N, 0.10–0.12% P, 0.76–0.88% K, 0.56–0.66% Ca, 0.19–0.23% Mg and 0.13–0.15% S (Table 2).

The proposed range of leaf macronutrient concentrations of Nam Hom coconut is lower than that of the existing standards for industrial coconut grown for copra, except for Ca (Table 2), suggesting that it is necessary to reassess the standard specific for Nam Hom coconut. The orchard soils in the current study had very high nutrient levels; however, there was no observed strong relationship between soil and leaf nutrient concentrations and yield. Therefore, the proposed range does not represent critical values for each macronutrient below which there will be reduced growth and yield of Nam Hom coconut. In addition, data from high-yielding trees, which generally had been supplied with excess fertilizer, probably included the excessive range of leaf macronutrient concentrations that did not improve the fruit yield. However, these data are currently the only estimates of the optimal leaf nutrient concentrations for Nam Hom coconut. Validation of this proposed standard will be needed for other production sites with different environmental conditions, soil types and orchard management.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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