Climate Change Affecting Mangosteen Production In Thailand

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Abstract: - This study investigated the effect of climate change (i.e. changes in rainy days, dry days, maximum and minimum temperature) on mangosteen production in three regions of Thailand, which grow mangosteen: southern, eastern and north-eastern regions. In the eastern region, the number of rainy days decreased and the number of dry days increased over a period of more than twenty years. There was no trend in changes in maximum and minimum temperature over the years in all three regions, except for the minimum temperature in the eastern region, which increased over the years. Mangosteens in the southern region tended to flower off-season, with two harvest periods in December-February and June-August and a shorter harvesting duration than in the eastern region. On the other hand, mangosteen in the eastern region flowered in season, and had one harvest period between February-April. The amount of mangosteen production in the southern region did not differ from the eastern region. The soil depth in the southern region was shallower than in the north-eastern region. Plant Available Water (PAW) in the southern region was lower than in the north-eastern region. PAW decreased and stayed low for a period of time before the flowering time in the southern and eastern regions. The mangosteen production in the southern and eastern regions increased as the drought period before flowering increased.

Key-Words:-Climate change, Rainy day, Dry day, Temperature, GAPS Model, Plant Available Water.

1 Introduction

Climate change has a major impact on the hydrological cycle and consequently on available water resources, flood and drought potentials and agricultural productivity [1]. The impact of future climate change on water resources and agriculture have become of world concern. The critical agro-meteorological variables associated with agricultural production are precipitation, air temperature, and solar radiation [2]. Air temperature is the main weather variable that regulates the rate of vegetative and reproductive development [3]. In most cases, an increase in temperature causes an increase in the developmental rates. At extremely high temperatures, the inverse occurs, and developmental rates slow down as the temperature further increases [4].

Tropical-fruit production is normally limited by available soil moisture. The stage of growth or development at which water stress occurs greatly affects the final yield. Many factors influence the amount of rainfall available to plants including evaporation and transpiration rates, surface runoff, soil water-holding capacity and percolation through the soil profile beyond the rooting area. Excessive rainfall causes major problems with flowering, pests, diseases and fruit quality. Many trees such as mango and lychee require a dry period to stop vegetative growth and induce flowering [4].

The impact of global change on agriculture has been studied extensively for various crops at many different scales. Future climate change could have significant impacts on agriculture, especially the combined effects of elevated temperatures, increased probability of droughts and reduced Plant Available Water (PAW) [5], [6]. However little has been done on the effects of climate change to study mangosteen production. This study aims to investigate the effect of climate change on mangosteen production. We investigate the effect of climate change (i.e. changes in rainy days, dry days, maximum and minimum temperature) on mangosteen production. We predict that (1) if climate changes occur in mangosteen orchard areas, then there should be some changes in the number of rainy days, the number of dry days, changes in maximum temperature and/ or changes in minimum temperature in mangosteen orchard areas, and (2) if the drought period before flowering affects mangosteen production, then (2a) mangosteen should start flowering right after a drought period, and (2b) mangosteen production should increase as the drought period before flowering increases. We use the amount of PAW generated from GAPS model as an indicator of a drought period. PAW in a drought period will be less than in a rainy period

Mangosteen (*Garcinia mangostana* L.) is one of eight in 35 genera producing edible fruit native to Malaysia, Thailand, Myanmar and the Indian sub-continent [7], [4]. Mangosteen grows well under conditions of flooding and a high water table [4]. The mangosteen fruit is 2-3 inches in diameter and has a thick reddish-purple rind that covers the segmented pulp [8]. The edible fruit aril is white, soft and juicy with a sweet, slightly acid taste and pleasant aroma [9]. Mangosteen is an allopolyploid hybrid between *Garcinia hombroniana* Pierre and *Garcinia malaccensis* [10]. The crop is found in the humid tropics that have a short dry season (15-30 days) to stimulate flowering and then an uninterrupted water supply. Stress is to be avoided and irrigation may be needed during the dry season if the annual rainfall is less than 1270 mm. Growth is slow below 20 °C and the trees are killed at 3-5 °C. The upper temperature limit is 38-40 °C with leaves and fruit being susceptible to sunburn. In the southern region, the mangosteen-harvesting period is between June-August but in the eastern region, the mangosteen harvesting period is from February-April (Pers. Obs.).

2 Methods

2.1 Study Area

Thailand extends from approximately 1.57-20.20 °N in latitude and 97.56-105.30 °E in longitude and is divided into five regions with different climatic and hydrologic characteristics: the central, the north, the northeast, the east, and the south. Thailand has a tropical climate with three distinct seasons: the hot season from March-May, the rainy season from June-October, and the cool season from November-February. While central Thailand receives most of its precipitation from June-October, rain occurs at all seasons in southern Thailand, the largest amount along the west coast from May-October, and along the east coast from October-January. For most of Thailand, the temperature rarely falls below 13 °C or rises above 35 °C, with most places averaging between 24-30 °C. The annual rainfall ranges from 1020 mm in the northeast to over 3800 mm in the south.

We selected six study sites that planted mangosteen covering three regions including the southern region: site 1 (Nakhon Si Thammarat), site 2 (Nakhon Si Thammarat Rajabhat University); for the eastern region: site 3 (Klang), site 4 (Pliu) and for the north-eastern: site 5 (Bankruat), and site 6 (Kantaluk) (Fig. 1). All climate data were obtained from the Meteorological department, Ministry of Information and Communication Technology, Thailand, except at site 2 that was obtained from Nakhon Si Thammarat Rajabhat University weather station. The period of climatic data that were available varied among study sites: site 1 from 1976-2004, site 2 from 1994-2004, site 3 from 1977-2004, site 4 from 1976-2004, site 5 from 1983-2004 and site 6 from 1979-2004. Climatic data used in this study composed of the amount of precipitation, the number of rainy days, maximum and minimum temperature.

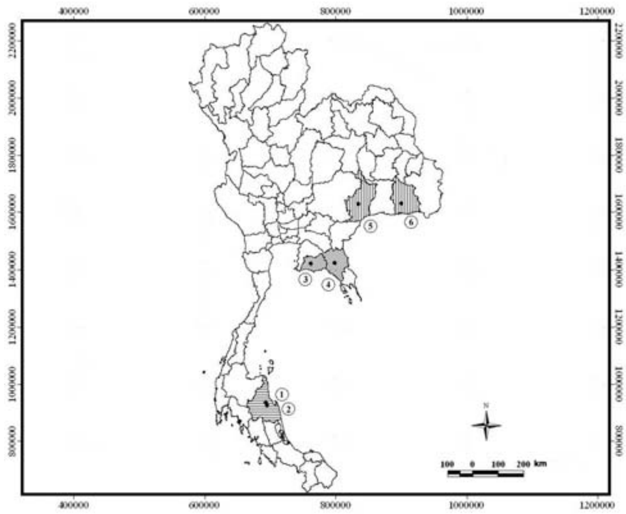

Fig. 1 Study sites (shown in circles) in three regions in Thailand. ▤, ■ and ■ represent southern, eastern and north-eastern Thailand. ①-⑥ represent Nakhon Si Thammarat, Nakhon Si Thammarat Rajabhat University, Klang, Pliu, Bankruat, Kantaluk weather stations, respectively.

There were two sources of mangosteen production data: the Office of Agricultural Economics, the Ministry of Agriculture and the cooperatives of orchard owners. Mangosteen production data obtained from Office of Agricultural Economics was the averaged mangosteen productions in the southern and eastern regions. Mangosteen production data obtained directly from the orchard owners were composed of flowering times, harvesting duration, the onset of the harvesting period, and the harvesting season in the southern and eastern regions from 1999-2004. We selected and collected mangosteen production data from two sites in each region that were representative of the southern (1999-2004) and eastern regions (1995-2004) of Thailand. In the north-eastern region, mangosteen has only been planted for eight years and only began producing fruit in 2005. Therefore, mangosteen production in the north-eastern region was not included in the analysis.

2.2 Determination of Anomalies
In order to examine the effect of climate changes in the three regions of Thailand, we investigated changes in the dry and rainy durations by using computational methods to determine the length of drought and rainy duration from the amount of precipitation data for all study sites. The computational methods based on the Moving Average (MA) used in order to remove short length variation in the data. The MA parameters were deployed with the basic knowledge across a number of seasons in each site in a particular season (e.g. 1 dry and 1 rainy season for the eastern and north-eastern part of Thailand) [11]. Once the MA transformation was done, we used thresholding technique to determine when the start and end dates began in each season for the years studied (Fig. 2). The length of dry and rainy durations was computed directly from the boundaries. We used the dry and rainy duration resulting from the MA to calculate the average number of dry and rainy durations at each study site. We subtracted the length of dry and rainy duration with the average in order to detect anomalies. The same procedures were used for maximum and minimum temperature to detect temperature anomalies.

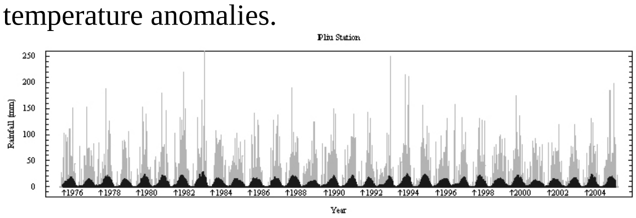

Fig. 2 The amount of daily rainfall (mm) at Pliu weather station (no. 4) from 1976-2005. Gray and black colours represent actually precipitation data and moving average data, respectively.

2.3 GAPS Model Simulation
General purpose simulation model of the Atmosphere-Plant-Soil system (GAPS) is a dynamic simulation software package of the soil-plant-atmosphere continuum [12]. The menu-driven model simulated various soil, plant, and atmospheric processes using a choice of algorithms and robust graphical displays of output. The processes were studied independently, allowing the user to compare the effects of simulating the same phenomena (i.e. evapo-transpiration, plant water uptake) in different ways [13]. The graphic display output of GAPS, both during and upon completion of a simulation run, provided a dynamic visualisation of a particular process. GAPS could display a dynamic view of up to 4, out of a possible 40 aspects, of the plant-soil-atmosphere system as it was being simulated. In this study, Plant Available Water (PAW) was calculated from the GAPS model. In GAPS model, there were four types of model input parameters: atmosphere, soil, plant and location. Atmosphere parameters included daily values of precipitation, maximum temperature and minimum temperature obtained from the Meteorological Department, Ministry of Information and Communication Technology, Thailand. Soil input parameters by horizon included slope, depth, profile, texture, bulk density and particle density. Soil data was collected from six study sites in three regions. We deployed the GLOBE soil protocol (www.globe.gov) for the soil profile characterization for the GAPS simulation. Plant input parameters included parameters estimated for vegetative cover and plant root present at each soil layer. We deployed the GLOBE landcover protocol (www.globe.gov) for the vegetative cover. Location input data included latitude, longitude and elevation by using Magellan GPS Handhelds-SporTrak Line.

2.4 Data Analysis
All variables were tested for normality using Kolmogorov-Sminov test and transformed when necessary. Independent sample *t*-tests were used to test harvesting duration and mangosteen production between the southern and eastern regions. One-way ANOVA tests were used to test soil depth and PAW among the three regions. If one-way ANOVA tests were significant, Post-hoc tests (i.e. Tukey test) were performed.

3 Results
3.1 Climate Change Detection
The changes in the number of rainy days decreased and the number of dry days increased over the years in the eastern region (Fig. 3c, d). However, there was no change in trends in the number of rainy days and the number of dry days over the years in the south and north-eastern regions (Fig. 3a, b, e, f).

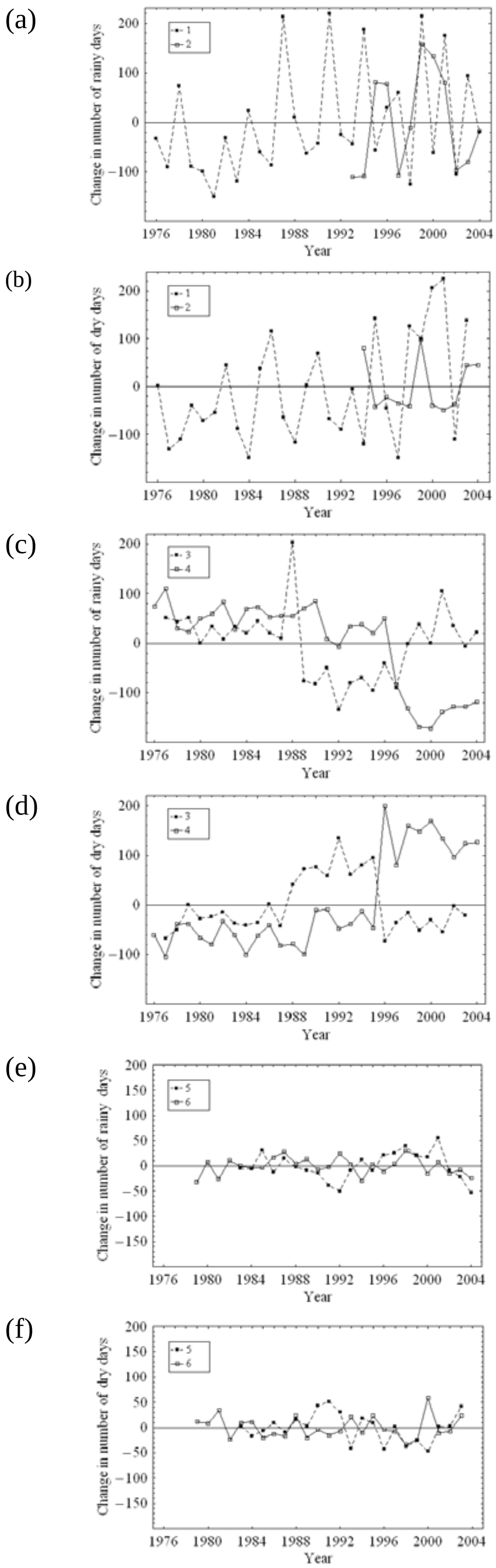

Fig. 3 Changes in the number of rainy days in (a) southern, (b) eastern, (c) north-eastern regions and changes in the number of dry days in (d) southern, (e) eastern, and (f) north-eastern regions.

There was no change in trends in maximum temperature over the years in all three regions (Fig. 4a, c, e). Minimum temperature increased over the years in the eastern region (Fig. 4d). However, there was no change in trends in minimum temperature over the years in the southern and north-eastern regions (Fig. 4b, f).

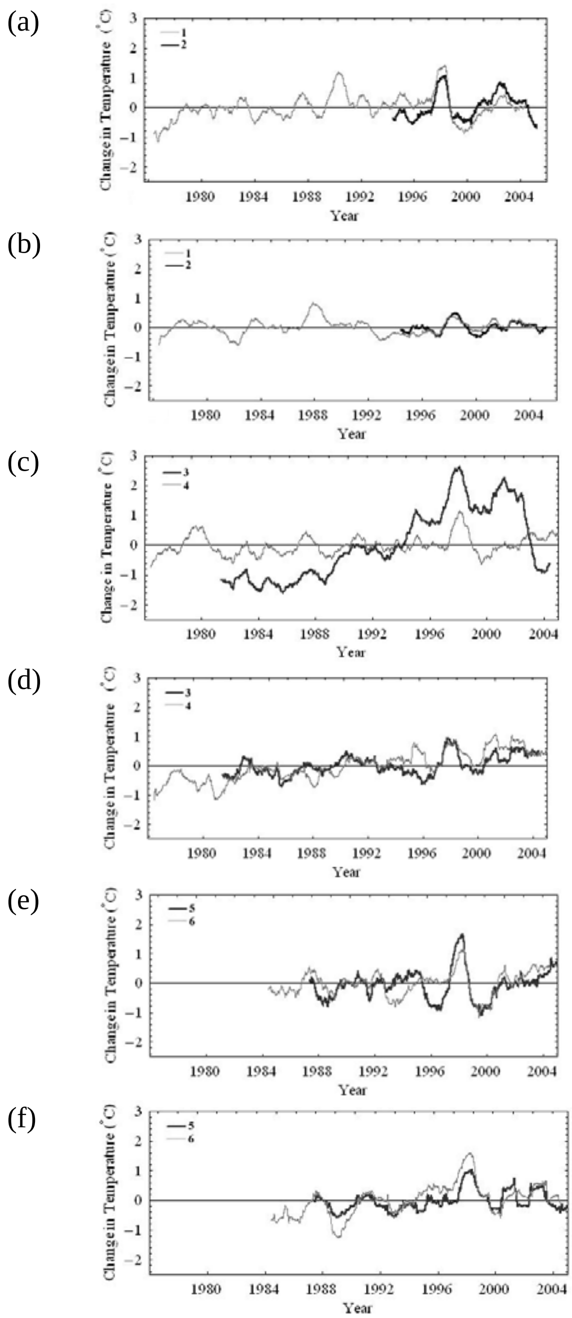

Fig. 4 Temperature anomalies (°C). Maximum temperature anomalies in (a) southern, (c) eastern, (e) north-eastern regions. Minimum temperature anomalies in (b) southern, (d) eastern, and (f) north-eastern regions.

3.2 Mangosteen Production

The harvesting duration in the southern region was shorter than in the eastern region (southern region: $\overline{x} \pm SD = 37.43 \pm 19.10$, eastern region: $\overline{x} \pm SD = 81.43 \pm 27.43$, independent sample *t*-test: $t_{12} = -3.48$, $P = 0.005$, Table 1). In the southern region, there were two harvesting periods varying from year to year between December-February and June-August (Table 1).

On the other hand, in the eastern region, there was only one harvesting period ranging from February-April (Table 1). In the southern region, mangosteen was likely to flower off-season, and in some years mangosteen was flowering twice a year if there was enough prior to duration stimulate flowering. On the other hand, in the eastern region, mangosteens always flowered in season once a year (Table 1).

The amount of mangosteen production in the southern region did not differ from the eastern region (southern region: $\overline{x} \pm SD = 5801.02 \pm 4714.06$, eastern region: $\overline{x} \pm SD = 6479.18 \pm 2635.87$, independent sample *t*-test: $t_{434} = 1.883$, $P = 0.144$, Table 1).

3.3 Soil Characteristics in Mangosteen Orchard and PAW

The soil depth in mangosteen orchards differed among regions (southern region: $\overline{x} \pm SD = 16.00 \pm 5.94$, eastern region: $\overline{x} \pm SD = 22.22 \pm 15.31$, north-eastern region:, one-way ANOVA: $F_{2,22} = 3.888$, $P = 0.036$, Table 2). When Post-hoc tests were analysed, the soil depth in the southern region was less deep than in the north-eastern region (Tukey test: -17.33, $P = 0.032$) but there were no differences in soil depth between other pairs (south & east: Tukey test = -6.22, $P = 0.818$; east & northeast: Tukey test = -11.11, $P = 0.282$).

PAW in mangosteen orchards differed among regions (southern region: $\overline{x} \pm SD = 10.04 \pm 7.54$, eastern region: $\overline{x} \pm SD = 38.00 \pm 34.11$, north-eastern region: $\overline{x} \pm SD = 43.65 \pm 25.361$, one-way ANOVA: $F_{2,22} = 4.720$, $P = 0.020$, Table 2). When Post-hoc tests were analysed, PAW in the southern region was lower than in the north-eastern region (Tukey test: -33.61, $P = 0.042$) but there were no differences in PAW between other pairs (south & east: Tukey test = -27.95, $P = 0.061$; east & northeast: Tukey test = -5.66, $P = 1.000$). PAW decreased and stayed low for a period of time before flowering in the southern and eastern regions (Fig. 5a, b). Mangosteen in the southern region in some years was flowering twice, when the prior length of drought periods was long enough (Fig. 5a, b).

(a)
(b)

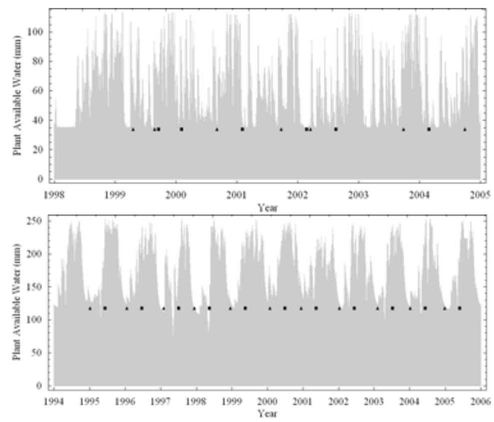

Fig. 5 Plant available water, (▲) flowering and (■) harvesting dates. (a) the southern region, and (b) the eastern region.

Mangosteen production varied depending on drought period before flowering in the southern and eastern regions (Fig. 6a, b).

(a)
(b)

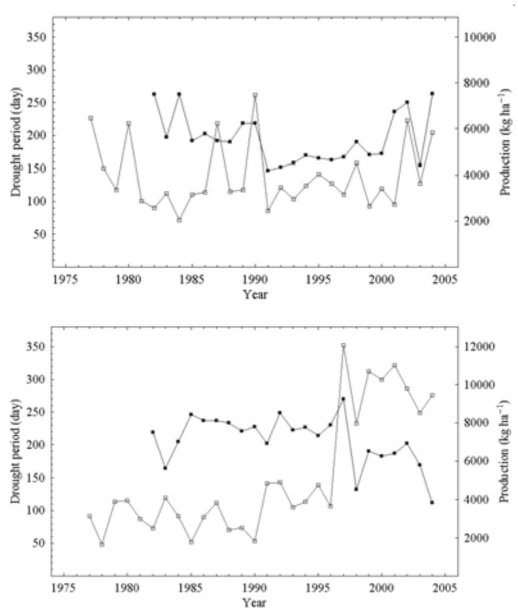

Fig. 6 (□) Drought period before flowering and (■) mangosteen production in (a) the southern region and (b) the eastern region.

Table 1. Flowering, harvesting and production of mangosteen in southern and eastern regions, Thailand. # represents the sequence of production in that year

Year	#	Flowering Time	Harvesting Duration (day)	Beginning of Harvesting Period	Harvesting Season
Southern region					
1999	1	March	28	August	In season
1999	2	August	34	January 2000	Out of season
2000	1	July	41	December	Out of season
2001	1	August	18	January 2002	Out of season
2002	1	February	39	July	In season
2003	1	September	19	February 2004	Out of season
2004	1	July	75	December 2005	Out of season
2005	1	January	39	June	In season
Eastern region					
1995	1	December	76	March	In season
1996	1	December	84	March	In season
1997	1	January	71	April	In season
1998	1	December	61	March	In season
1999	1	December	58	March	In season
2000	1	December	95	March	In season
2001	1	December	55	March	In season
2002	1	January	67	April	In season
2003	1	January	135	February	In season
2004	1	December	81	March	In season
2005	1	December	79	March	In season

4 Discussion

Our results support the hypothesis that there were climate changes occurring in mangosteen orchards. We found that climate changes occurred in mangosteen orchard areas in the eastern region, but not in the southern and north-eastern regions. In the eastern region, changes in the number of rainy days decreased, and changes in the number of dry days increased. Mangosteen production in the eastern region increased as the drought period before flowering increased. This suggests that mangosteen production increases under climate change in this region. In addition, we also found that mangosteen production in the eastern region was greater and less variable than in the southern region.

Southworth and others [6] showed that an increase in temperature increases the developmental rate of maize yields, resulting in a shorter harvesting time. We found that in the eastern region, the minimum temperature increased over the years, but there was no change in the maximum temperature.

This suggests that mangosteen grown in sites in the eastern region should have a shorter fruit development time in the near future due to climate change, than those grown in the southern region, which should have a longer fruit developmental time. However, a warmer climate scenario (2-5 °C) could yield both negative and positive impacts on crop productions depending on location, and types of crops [6]. More moderate warming produced predominately positive effects in some warm-season crops [14]. In short, there is a spatial variability of crop responses to changed environmental condition.

Table 2 Averaged annual rainfalls, soil depth, horizontal texture, and averaged PAW of the study sites.

Study Site	Annual Rainfall (mm)	Soil Depth (0-100 cm) Top Depth	Bottom Depth	Horizontal Texture	PAW (mm)
1	2485	0	16	Sandy Loam	3.52
		16	31	Loamy sand	4.60
		31	54	Loam	8.39
		54	73	Loam	15.59
		73	100	Loam	25.47
2	2707	0	12	Sandy Clay	17.52
		12	19	Loam	4.85
		19	33	Sandy Loam	1.55
		33	43	Loamy Sand	7.00
		43	60	Sand	11.90
3	2044	0	9	Sandy Loam	6.45
		9	24	Sandy Loam	20.25
		24	70	Silt	87.73
		70	100	Silt	57.17
4	3157	0	10	Sandy Loam	9.53
		10	26	Sandy Loam	17.88
		26	54	Sandy Clay	40.72
		54	97	Loam	93.47
		97	100	Clay Loam	8.71
5	1323	0	19	Silt	59.01
		19	45	Clay Loam	86.63
		45	100	Silty Clay	26.40
6	1532	0	40	Sandy Loam	23.08
		40	80	Sandy Clay	23.39
		80	100	Silty Clay	43.37

Several studies reported that mangosteen trees need a drying period to induce flowering [4], [15], [16]. Sdoodee and Chiarawipa [16] studied mangosteen from January to August 2001 and found that the drought period occurred between February to early

March in Songkla province, southern Thailand. Our results showed that the drought period in the southern region varied over the years and occurred between January to March. Our results support the hypothesis that when the drought period before flowering is longer, mangosteen should have a higher probability of flowering. Therefore, mangosteen production should be higher in a year that has a longer drought period. Our results showed that mangosteen production in the southern and eastern regions increased as the drought period before flowering increased. This is the first study that demonstrates the clear association between mangosteen production and the drought period.

PAW varied among regions. The southern region has a lower amount of PAW than the north-eastern region. It is possible that there was a higher amount of rainfall in the southern region throughout the year, therefore, there would be no need for orchard owners in the southern region to plant mangosteen in high PAW areas. On the other hand, orchard owners in the north-eastern region should plant mangosteen in high PAW areas because the rainy season in the north-eastern region is short. Therefore, only high PAW areas in the north-eastern region are suitable for mangosteen. When PAW generated from the GAPS model was decreased and stayed low for a period of time, mangosteen in the southern and eastern regions started flowering.

In conclusion, results from this study indicate that potential future adaptations to climate change for mangosteen production would require mangosteen varieties that had an increased tolerance to drought before flowering and/or an increased tolerance of minimum temperature. Understanding responses of individual orchards to changes in climate is essential to understanding the impacts of climate change on mangosteen at a regional scale. This study hopes to provide the basic understanding for strategic planning and risk management by orchard owners and the agricultural infrastructure to better adapt to changing conditions.

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