Assessment of the Impact of Climate Variability on Major Crops Yield over the Upper Northeast of Thailand

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ABSTRACT

This study investigated the impact of climate variability on the yield of major rice, second rice, cassava, and sugarcane using yield data of 38 years (1980–2018) and climate data of 46 years (1972–2018) in four provinces of Northeast Thailand. The results showed the increasing trend of both annual and seasonal average rainfall and minimum and maximum temperatures. The yield of all four crops found to be increasing in all provinces during the period considered. However, the fluctuation (increase or decrease) in yield was observed on an annual basis. The yield of major rice was found to be positively correlated with seasonal minimum temperature whereas the sugarcane yield was found to be negatively correlated with the seasonal rainfall in all provinces. Regression analysis of anomalies of climate variables and the average yield of four crops showed that the impact of climate variability on crop yield varied among crops as well as provinces. It was found that climate variability had a higher impact on sugarcane yield compared to other crops. Therefore, non-climatic factors such as crop management practices, seeds, and use of fertilizers could be largely responsible for yield variation of major rice, second rice, and cassava in all provinces.

1. INTRODUCTION

The Northeast of Thailand popularly known as 'Isan' consists of 20 provinces and the largest region bordering Lao PDR and Cambodia. Agriculture is the largest sector of the economy generating around 22 percent of gross regional product (compared to 8.5 percent for Thailand as a whole). Rainfed rice is the dominant agriculture crop accounting for 60 percent of cultivated land [1]. Farmers generally grow upland rice as the major crop for household consumption, or by rotation cropping with sugarcane or cassava to increase their income and improve soil fertility [2]. As a result of the poor physical endowment of the region, for example, generally poor soils, highly uneven distribution of rainfall, and very limited irrigation facilities, average rice yields in northeast Thailand (1.8 ton/ha) are the lowest in the country (average of 2.9 ton/ha in the central region) [3].

Despite the largest economy sector, agriculture in the region is often problematic. Frequent droughts, flooding in rainy season because of flat terrain, highly acidic, saline and infertile soil are some of the challenges for the sustainable agriculture and improved productivity in the region since many years. In addition, climate change and climate variability may exacerbate these challenges for improved productivity. According to the Intergovernmental Panel on Climate Change [4], the earth surface is projected to get warmer by 0.3–4.8 °C at the end of the 21st century. In case of Thailand, the climate change impact has been projected even severe at some instances for few climate variables. For instance, the average increase in surface temperature in Thailand is projected to be 2–3 °C (annually), 3–4 °C (monthly maximum) and just above 4 °C (monthly minimum) within the mid of the 21st century [5]. Similarly, the average annual rainfall is projected to increase throughout the country; however, it possesses seasonal variation i.e., −5% – 36% increase in dry and wet seasons respectively [6]. Weather and climate are prominent drivers or influencers of agricultural production systems and it has been shown that recent trends in change of climate variables may be responsible for substantially affecting crop yield trends despite advances in technology and other fronts [7].

Several studies reported the impact of climate change and climate variability in crop yields worldwide, both for historical and future climate [8, 9, 10, 11, 12, 13, 14, 15]. Yang et al., 2020 [9] reported that climate in the past four decades (1979–2014) in Ethiopia may have contributed to an increasing trend in maize yield, a decreasing trend in wheat yield, and no clear trend in the yields of barley and millet; cereal crop yield is positively correlated with growing season solar radiation and temperature, but negatively correlated with growing season precipitation.

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Prabnakorn et al., 2018 [16] assessed the impacts of the recent climate trends on rice yields in the Mun River Basin in northeast Thailand. They found that increasing trends in minimum and maximum temperatures lead to modest rice yield losses. In contrast, precipitation and SPEI-1, i.e. SPEI based on one monthly data, showed positive correlations with yields in all months, except in the wettest month (September).

Boonwichai et al. 2018 [17] estimated the climate change impact on rainfed rice yield in the Songkhram River Basin of Thailand and found that the change in rainfall have more significant influence on rice yield than temperature, possibly increasing water stress in the future. They projected that rainfed rice yield in the basin may reduce by 14% under RCP 4.5 scenario, and 10% under RCP 8.5 scenario by 2080s. Similarly, Shrestha et al. (2017) [18] studied the potential impact of climate change on rice yield in Northeast Thailand and found the decrease in yield for rice cultivars KDML105, and RD6. A decrease of yield by 37% and 38% is projected for KDML105 under RCP 4.5 and 8.5 respectively by 2080s. A decrease of yield by 13% and 18% is projected for RD6 under RCP 4.5 and 8.5 respectively by 2080s.Temperatures above 35 °C create high vulnerability of crops and could affect the ripening stage, significantly reducing rice production [19].

The aforementioned studies improved the understanding of the linkage between climate change, climate variability and crop yields. However, many of these studies investigated the potential impact of climate change and climate variability on crop yields using crop simulation models and global climate models. Investigating the observed (historical) climate change and climate variability and linking it to the observed (historical) change in crop yield in specific location is very important to formulate and implement adaptation strategies to offset the negative impacts and harness the positive impacts. Therefore, this study aims to first analyze the long-term change in observed (historical) climate variables (rainfall, minimum and maximum temperature) and observed (historical) yield of four crops, major rice, second rice, cassava and sugarcane in four provinces of the Northeast Thailand namely Nakhon Phanom, Sakhon Nakhon, Nong Kai and Udon Thani. Thereafter, the study investigates the impact of change in climate variables to yield of four crops. The study uses long term and very recent data of crop yield and climate variables. The duration of crop yield is about 38 years (1980–2018) and climate data of about 46 years (1972–2018) of 37 stations located in four provinces.

2. STUDY AREA

The study area consists of four provinces of Northeast Thailand namely: Nakhon Phanom, Sakhon Nakhon Nong Khai and Udon Thani (Figure 1). The Northeast of Thailand has been transformed from one of the poorest region into Thailand's fastest growing economy. Agriculture sector has the major contribution to the economic development of this region. The agriculture is mainly practiced under rain-fed conditions. The predominance of sandy soils with low water and nutrient holding capacities and low fertility, along with variability in rainfall, is considered to cause low agricultural productivity. The rainfed rice (major rice) cultivation is the dominant crop (accounting for 60% of cultivated area) whereas farmers are also diversifying into cassava, sugar cane and other crops.

The Northeast of Thailand has a tropical semi-humid dry-savannah climate with three seasons (viz. summer, rainy and winter). The precipitation normally occurs during the southwest monsoon, the Inter Tropical Convergence Zone (ICTZ) and the tropical cyclone which start from mid-May to mid-October. May is the period of the first arrival of southwest monsoon and the ITCZ, rainfall occurs periodically, at the end of June until the beginning of July the amount of rainfall will reduce due to the northward movement of the ICTZ to southern China. Afterward during middle July till September or October, the amount of rainfall increases again because of tropical cyclone [20]. The average annual rainfall during 1981–2017 of four provinces is 1800 mm, 1600 mm, 1650 mm and 1350 mm in Nakhon Phanom, Sakhon Nakhon, Nong Khai and Udon Thani respectively. Almost 90% of rainfall occurs in the rainy season from May through October. Similarly, the maximum temperature is 32°C and minimum temperature is 22°C in these four provinces during 1981–2017. January is the coolest month and April is the hottest month.

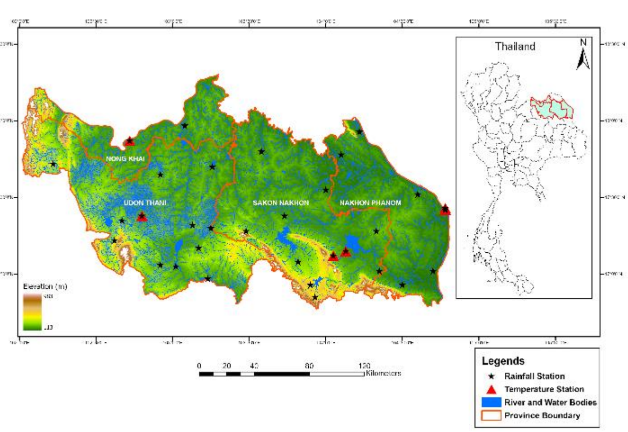

Fig. 1: Location of four provinces and corresponding rainfall and temperature stations in the Northeast of Thailand.

3. DATA AND METHODS

The data used and the methodology adopted in this study is depicted in Fig. 2.

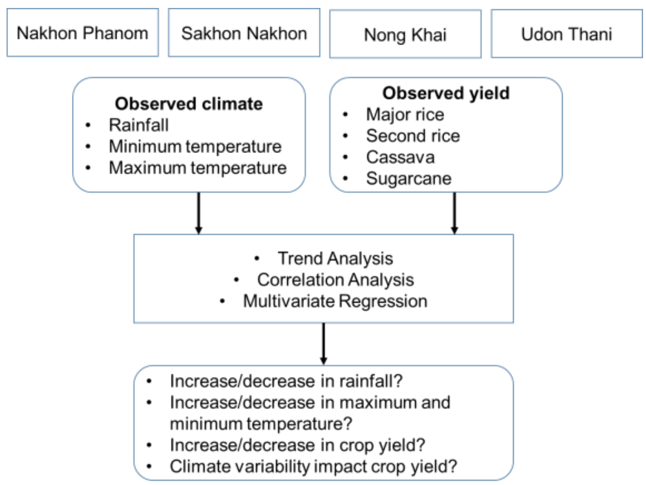

Fig. 2: The flow chart of methodology adopted in this study.

3.1 Data

This research primarily utilized the long terms datasets collected from several government departments of Thailand. Before using these data for the analysis, several tests were performed to check the quality and reliability of the data.

Climate data

Climatic data of 37 stations were collected from Thai Meteorological Department (TMD). Among those stations, 6 stations record both the rainfall and temperature. The data consists of daily rainfall, daily maximum and minimum temperature of 46 years (1979–2018). The location of rainfall and temperature stations is shown in Figure 1. The average daily rainfall of each province was calculated using Thiessen Polygon method. To estimate the impact of climate variability on the yield of selected crops, the annual and seasonal climate was calculated to the corresponding growing seasons of four selected crops (May to October, November to April and October to September of the following year).

Table 1: Selected crops and corresponding cultivation period data availability

Crop	Cultivation Period	Data Available
Major Rice	1 May to 31 October	1981–2017
Second Rice	1 November to 30 April	1981–2017
Cassava	1 October to 30 September of the following year	1980–2017
Sugarcane	1 October to 30 September of the following year	1989–2017

Crop yield data

Four major crops: major rice, second rice, cassava and sugarcane were selected for this study. These data were collected from Office of Agricultural Economics (OAE) of Thailand. The crop cultivation, growth period and data availability are presented in the Table 1.

3.2 Trend Analysis

The trend analysis was performed for the following variables in all four provinces:

- Temperature (Annual and seasonal maximum and minimum temperature)
- Precipitation (Annual and seasonal)
- Yield of major rice, second rice, cassava and sugarcane

The Mann-Kendall test [21, 22, 23] was performed to examine the existence of monotonic upward or downward trend among all variables over the time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear. In this test, the null hypothesis (H0) was that there has been no trend in precipitation over time; the alternate hypothesis (H1) was that there has been a trend (increasing or decreasing) over time. The mathematical equations for calculating Mann-Kendall Statistics, S and standardized test statistics, Z are as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sig}\left(X_j - X_i\right),$$

$$\operatorname{sgn}\left(X_j - X_i\right) = \begin{cases} +1 & \text{if } \left(X_j - X_i\right) > 0 \\ 0 & \text{if } \left(X_j - X_i\right) = 0 \\ -1 & \text{if } \left(X_j - X_i\right) < 0, \end{cases}$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right]$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{VAR}(S)}} & \text{if } S < 0, \end{cases} \qquad (1)$$

In these equations, X_i and X_j are the time series observations in chronological order, n is the length of time series, t_p is the number of ties for p^{th} value, and q is the number of tied values. Positive Z values indicate an upward trend in the hydrologic time series; negative Z values indicate a negative trend. If $|Z| > Z_{1-\alpha/2}$, (H_0) is rejected and a statistically significant trend exists in the hydrologic time series. The critical value of $Z_{1-\alpha/2}$ for a p value of 0.05 from the standard normal table is 1.96.

Similarly, the trend was quantified using Sen's slope method. Sen Slope quantifies the trend using the nonparametric procedure developed by Sen [24]. The slope is computed by using following equation:

$$Qi = \frac{Xj - Xk}{j - k} \text{ for } i = 1, 2, 3, \ldots, N \qquad (2)$$

where x_j and x_k are data values at time j and k (j > k), respectively. The median of these N values of Q_i is Sen's estimator of slope. If N is odd, then Sens's estimator is computed by $Q_{med} = Q(N+1)/2$,and if N is even, the Sen's estimator is computed by $Q_{med} = [QN/2 + Q(N+2)/2]/2$. Finally, Q_{med} is tested by a two-sided test at a 100% (1 – α) confidence interval, and the true slope is obtained.

3.3 Climate-Crop Yield Relationship

Correlations of rice yield with climatic variables were estimated following an established approach as described in [25, 26, 27, 28]. This approach removes confounding effects of long-term variations in yields, such as cultivars, crop management and fertilizers, by calculating the first differences in the yield, climatic variables and drought index (VARt−VARt −1). Correlation coefficient and multivariate regression analyses have been performed to examine the climate-crop yield relationship using the Statistical Package for Social Sciences (SPSS). The Pearson's correlation coefficient was used to determine the strength of relationships between crop yield and climate variability. The range of correlation coefficients is -1 to +1. The following equation was used to calculate the correlation coefficient, where x represents the independent variable and y represents the dependent variable:

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2}\ \sqrt{\sum_i (y_i - \bar{y})^2}} \qquad (3)$$

where r is correlation coefficient, $\bar{x}$ and $\bar{y}$ are mean values of independent and dependent variables respectively.

The relationship between climate variability and crop yield change were investigated using Multivariate regression model. Although less complex than crop simulation models, the multiple regression model is capable to capture the net climate effects of combined climate variables at monthly time scale during the growing season (Lobell and Field, 2007). The intercept was forced through zero to avoid trend effects (Nicholls, 1997). The multivariate linear regression is of the following form:

$$\Delta Yi = \gamma 1i * \Delta Tmin + \gamma 2i * \Delta Tmax + \gamma 3i * \Delta Prec \qquad (4)$$

where ΔYi is first differences in annual crop yield of province i (t/ha), ΔTmin and ΔTmax are first differences in minimum and maximum temperatures (°C), ΔPrec is first differences in precipitation (mm), and γ is a vector of estimated coefficients.

4. RESULTS AND DISCUSSION

The annual and seasonal (according to crop growth period) trend analysis of rainfall and maximum and minimum temperatures of four provinces have been analyzed using Sen's Slope and Man- Kendall methods. Similarly, trend analysis of crop yield and the relationship with the climate variables have been carried out. The regression analysis was performed between annual crop yield anomalies and climate anomalies. The de-trended time series data of seasonal precipitation, seasonal maximum temperature and seasonal minimum temperatures for respective crop growing seasons were considered the explanatory variables and de-trended crop yield was considered dependent variable.

4.1 Rainfall trend

The average annual rainfall of all four provinces shows the increasing trend from 1981–2017. The higher increase in average annual rainfall was observed in Sakhon Nakhon province (10.65 mm/yr) and Nakhon Phanom province (9.34 mm/yr) whereas the lower increase was observed in Nong Khai (7.43 mm/yr) and Uodn Thani Province (7.46 mm/yr) (Figure 3).

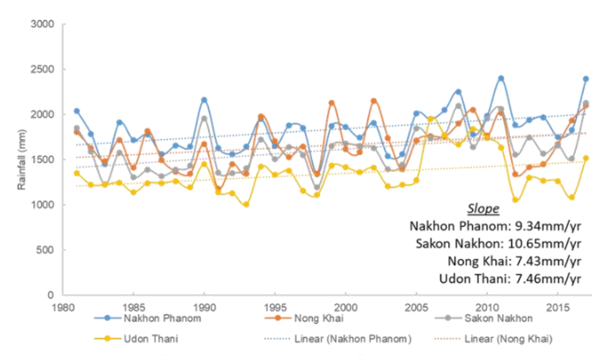

Fig. 3: Trends of annual average precipitation in Nakhon Phanom, Sakon Nakhon, Nong Khai and Udon Thani Provinces from 1981 –2017.

Table 2: Man-Kendall Z and Sen's Slope values and their significance for seasonal rainfall in four provinces

Rainfall	Province	Man-Kendall Trend , Z	Significant	Sen's Slope, Q
May–Oct	Nakhon Phanom	2.63	**	8.05
	Sakon Nakhon	3.02	**	10.37
	Nong Khai	1.53	ns	6.70
	Udon Thani	1.32	ns	4.28
Nov–April	Nakhon Phanom	0.99	ns	1.26
	Sakon Nakhon	2.01	*	2.50
	Nong Khai	1.26	ns	1.81
	Udon Thani	0.81	ns	1.16
Oct–Sep	Nakhon Phanom	2.19	*	10.68
	Sakon Nakhon	2.39	*	11.79
	Nong Khai	1.36	ns	11.17
	Udon Thani	0.85	ns	3.62

Z is the direction of the trend; positive Z is upward and negative Z is downward. ***trend at α = 0.001 level of significance.

**trend at α = 0.01 level of significance. *trend at α =

0.05 level of significance. + trend at α = 0.01 level of significance.

Sen's slope estimate Q is a true slope of the linear trend of non-parametric data (change/year or change/season)

Table 2 shows the trend analysis result of seasonal rainfall in four provinces. The seasonal rainfall shows an increasing trend similar to average annual rainfall. The higher increase of rainfall is observed in Nakhon Phanom and Sakon Nakhon which are significant (**trend at α = 0.01 level of significance) where lower increase is observed in Nong Khai and Udon Thani but are not significance in wet season (May to October). Similarly, the increasing trend of rainfall is observed in dry season (November to April). The change is only significant (*trend at α = 0.05 level of significance) at Sakon Nakhon.

4.2 Temperature trend

The annual and seasonal minimum and maximum temperature trends (1981– 2018) of four provinces were analyzed using Man-Kendall and Sen's Slope methods. The results show that the temperatures increased in all seasons and in all provinces during 1981 to 2018. However, the rate of increase in temperature varies among seasons and provinces (Table 3). It is observed that the rate of increase in minimum temperature is higher compared to the maximum temperature of dry season (Nov- April) in Sakon Nakhon, Nong Khai and Udon Thani provinces. The highest rate of increase in minimum temperature in dry season is observed at 0.05°C/year in Nong Khai province.

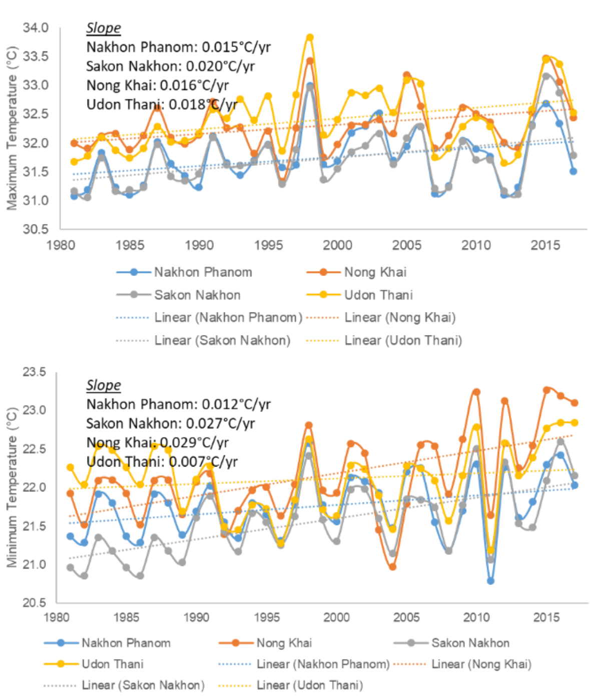

Fig. 4: Trends of annual maximum and minimum temperatures in Nakhon Phanom, Sakon Nakhon, Nong Khai and Udon Thani Provinces from 1981-2017.

Table 3: Man-Kendall Z and Sen's Slope values and their significance for seasonal maximum and minimum temperatures in four provinces

Climate Variable	Province	Average (°C)	Man-Kendall Trend , Z	Significant	Sen's Slope, Q
Tmax (May-Oct)	Nakhon Phanom	32.0	1.58	ns	0.01
	Sakon Nakhon	31.9	2.15	*	0.02
	Nong Khai	32.5	2.01	*	0.01
	Udon Thani	32.5	2.50	*	0.02
Tmax (Nov-April)	Nakhon Phanom	31.5	1.14	ns	0.02
	Sakon Nakhon	31.6	0.99	ns	0.02
	Nong Khai	32.1	1.07	ns	0.02
	Udon Thani	32.3	0.17	ns	0.00
Tmax (Oct-Sep)	Nakhon Phanom	31.8	0.69	ns	0.01
	Sakon Nakhon	31.8	0.85	ns	0.01
	Nong Khai	32.3	1.40	ns	0.02
	Udon Thani	32.5	0	ns	0
Tmin (May-Oct)	Nakhon Phanom	24.1	2.37	*	0.01
	Sakon Nakhon	24.1	5.43	***	0.02
	Nong Khai	24.3	3.21	**	0.02
	Udon Thani	24.4	0.96	*	0.01
Tmin (Nov-April)	Nakhon Phanom	19.4	0.96	ns	0.01
	Sakon Nakhon	19.1	1.26	ns	0.03
	Nong Khai	19.9	2.72	**	0.05
	Udon Thani	19.6	1.78	*	0.03
Tmin (Oct-Sep)	Nakhon Phanom	21.8	1.44	ns	0.01
	Sakon Nakhon	21.7	1.48	ns	0.02
	Nong Khai	22.2	3.10	**	0.04
	Udon Thani	22.0	2.59	**	0.03

Z is the direction of the trend; positive Z is upward and negative Z is downward. ***trend at α = 0.001 level of significance.

**trend at α = 0.01 level of significance. *trend at α = 0.05 level of significance. + trend at α = 0.01 level of significance.

Sen's slope estimate Q is a true slope of the linear trend of non-parametric data (change/year or change/season)

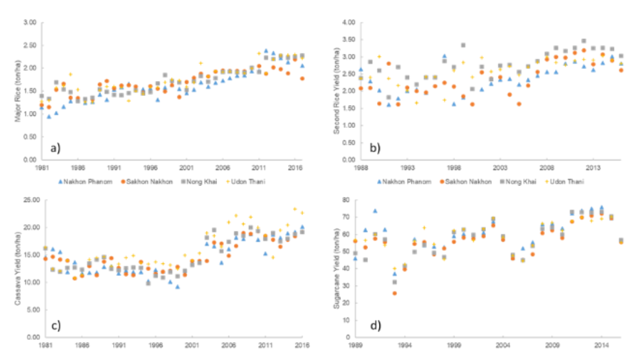

Fig. 5: Variation in yield of major rice a), second rice b), cassava c) and sugarcane d) in Nakhon Phanom, Sakhon Nakhon, Nong Khai and Udon Thani

4.3 Crop yield trend

The trend analysis of yield of four major crops: major rice, second rice, cassava and sugarcane were performed in four provinces. The results show that the yield of all four crops increased in all provinces during the period considered (Fig. 5). However, the fluctuation (both increase and decrease) is yield is observed on an annual basis that might be attributed to the climate variability or climate change, better crop management practices, increase fertilize application, increased irrigation application etc. Therefore, we have analyzed the relationship between the climate and crop yield variation using correlation and multiple regression techniques as described in section 4.5.

The Sen’s Slope value in the Table 4 shows the rate of increase of yield of crops in four provinces. The highest increase in the major rice yield was observed in Nakhon Phanom province which is 0.030 ton/ha/yr, lowest in Sakon Nakhon. Similarly, the highest increase in the second rice crop was observed in Sakhon Nakhon which is 0.043 ton/ha/yr, lowest increase in Udon Thani. The Udon Thani province witnessed the highest increase in cassava crop which is 0.270 ton/ha/yr, lowest increase in Sakon Nakhon. Whereas the highest increase in sugarcane crop was observed in Nong Khai province which is 0.777 ton/ha/yr, lowest increase in Udon Thani.

Table 4: Crop yield trend of major rice, second rice, cassava and sugarcane in four provinces

Crops	Province	n	Average Yield (ton/ha)	SD (ton/ha)	Man-Kendall Trend, Z	Significant	Sen's Slope, Q
Major Rice	Nakhon Phanom	37	1.62	0.36	6.94	***	0.030
	Sakon Nakhon	37	1.68	0.29	5.53	***	0.022
	Nong Khai	37	1.72	0.30	6.40	***	0.027
	Udon Thani	37	1.73	0.38	5.74	***	0.026
Second Rice	Nakhon Phanom	30	2.37	0.40	4.37	***	0.041
	Sakon Nakhon	30	2.38	0.50	3.96	***	0.043
	Nong Khai	30	2.78	0.41	4.03	***	0.033
	Udon Thani	30	2.61	0.35	3.93	***	0.025
Cassava	Nakhon Phanom	38	14.57	3.07	4.20	***	0.190
	Sakon Nakhon	39	14.93	2.80	4.09	***	0.183
	Nong Khai	38	14.98	3.09	3.67	***	0.199
	Udon Thani	38	16.26	3.61	4.83	***	0.270
Sugarcane	Nakhon Phanom	29	59.74	9.83	2.61	**	0.686
	Sakon Nakhon	29	56.33	9.67	3.36	***	0.599
	Nong Khai	29	57.55	10.25	3.21	**	0.777
	Udon Thani	29	58.62	8.44	2.72	**	0.493

Z is the direction of the trend; positive Z is upward and negative Z is downward. ***trend at α = 0.001 level of significance.

**trend at α = 0.01 level of significance. *trend at α = 0.05 level of significance. + trend at α = 0.01 level of significance.

Sen’s slope estimate Q is a true slope of the linear trend of non-parametric data (change/year).

4.4 Climate-crop yield relationship

A correlation analysis was performed to examine the relationship between climate variability and crop yields (ton/ha) in four provinces. The correlations between the climatic variables and the crop yields are presented in Figure 6. The results show that there was a moderate to strong positive correlation between major rice yield with seasonal minimum temperature and rainfall in all provinces. The yield of major rice increases with increasing minimum temperature and rainfall. A very weak to moderate negative correlation (non-significant) between second rice yield and maximum temperature was observed in Sakhon Nakhon and Udon Thani provinces. A moderate to strong positive correlations between cassava yield and seasonal minimum temperature and rainfall was observed in all provinces. However, a very weak and negative correlation (non-significant) between sugarcane yield and rainfall was observed in all provinces. It suggests that an increase in rainfall had negative impact on the sugarcane yield in all provinces.

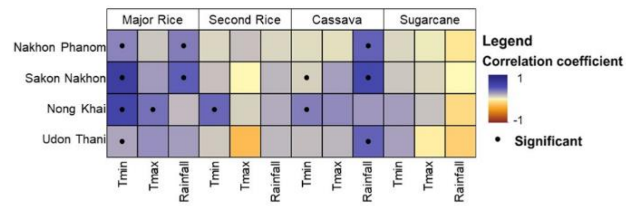

Fig. 6: Correlation between crop yield and Tmin, Tmax and rainfall (corresponding growing season) in four provinces (Correlation is significant at the 0.05 level).

4.5 Changes in yield due to climate trend

A multi-linear regression analysis between anomalies of climate variables and average yield of four crops was performed to investigate the relationship between crop yield and seasonal minimum, maximum temperatures and rainfall. The anomalies of each climatic variable and crop yield were computed using the first-difference time-series, i.e., the difference in values from one year to the next. A linear relationships between detrended crop yield, i.e., yield anomalies in four provinces, and anomalies in climate variables, such as temperature and rainfall, were developed to determine the crop yield change due to changes in climate variables during the study period using equation 4.

The results of multivariable regression analysis are shown in Table 5. The results show that the model is able to describe the variations in the yield of crops ranging from 49% (0.49) in case of sugarcane (Nakhon Phanom) to only 1.46% (0.0146) in case of second rice (Nong Khai). Although the regression analysis results show very few significant relationship between the crop yield and climate variables, the regression coefficients can be used to assess the observed impacts of climate variables in the changes in the crop yields considered in the study.

In case of major rice, climate variable accounts for 21% of yield change in Nakhon Phanom and only 5.3% in Sakhon Nakhon province. In case of second rice, climate variable accounts for 26.7% of yield change in Udon Thani and only 1.4% in Nong Khai province. Similarly, in case of cassava, climate variable accounts for 13.8 % of yield change in Udon Thani and only 3.7% in Nakhon Phanom province. Climate variation brings about highest percentage change (49.1%) in sugarcane yield in Nakhon Phanom and about 14.9% in Udon Thani. It can be explained that non-climatic factors such as better crop management practices, good quality seeds, use of fertilizers were largely responsible for yield variation of cassava in Nakhon Phanom, major rice and second rice in Sakhon Nakhon, second rice and cassava in Nong Khai and major rice, cassava and sugarcane in Udon Thani. The sign of the coefficients indicates the direction of change in the yield versus climate variable changes. It can be seen that rainfall had negative effects on sugarcane yield in all provinces. Therefore, increasing rainfall had decreased the sugarcane yield in all provinces.

Table 5: Multivariate regression analyses of detrended crop yields

Province	Crop		Tmin	Tmax	Rainfall	R^2
Nakhon Phanom	Major Rice	Coeff	0.024	-0.058	-0.0002	0.212
		p-value	0.721	0.092	0.012	
	Second Rice	Coeff	0.017	0.101	-0.0005	0.154
		p-value	0.824	0.240	0.577	
	Cassava	Coeff	-0.325	0.284	0.0007	0.037
		p-value	0.497	0.587	0.569	
	Sugarcane	Coeff	-8.66	-3.78	-0.031	0.491
		p-value	0.009	0.112	6.7E-05	
Sakhon Nakhon	Major Rice	Coeff	0.1170	-0.0041	0.0001	0.053
		p-value	0.3117	0.9387	0.3861	
	Second Rice	Coeff	0.0784	-0.1497	-0.0003	0.0760
		p-value	0.3930	0.1726	0.7632	
	Cassava	Coeff	0.3072	0.7669	0.0018	0.1364
		p-value	0.3896	0.0904	0.1163	
	Sugarcane	Coeff	-2.414	-4.742	-0.020	0.246
		p-value	0.402	0.124	0.013	
Nong Khai	Major Rice	Coeff	0.1225	-0.0138	-0.0001	0.2075
		p-value	0.0299	0.6735	0.1945	
	Second Rice	Coeff	-0.0355	-0.0256	-0.0001	0.0146
		p-value	0.717	0.813	0.919	
	Cassava	Coeff	-0.525	0.202	0.001	0.057
		p-value	0.320	0.704	0.476	
	Sugarcane	Coeff	-4.579	0.179	-0.015	0.323
		p-value	0.091	0.945	0.004	
Udon Thani	Major Rice	Coeff	-0.177	0.075	0.000	0.117
		p-value	0.084	0.190	0.377	
	Second Rice	Coeff	-0.065	-0.132	0.000	0.267
		p-value	0.443	0.123	0.599	
	Cassava	Coeff	-1.073	0.406	-0.003	0.138
		p-value	0.141	0.579	0.131	
	Sugarcane	Coeff	-0.763	-2.385	-0.015	0.149
		p-value	0.810	0.440	0.060	

5. CONCLUSIONS

This study investigated the historical trend of climate variability (temperature and rainfall) and its impact on four major crops namely major rice, second rice, cassava, and sugarcane in four provinces of Northeast Thailand. The results showed the increasing trend of both annual average and seasonal average rainfall and minimum and maximum temperature. However, the increasing trend was diverse both spatially and temporally. The rate of increase in minimum temperature was higher compared to the maximum temperature in the dry season (Nov- April) in Sakon Nakhon, Nong Khai, and Udon Thani provinces. The highest rate (0.05°C/year) of increase in minimum temperature in the dry season was observed in Nong Khai province. The rate of increase in average annual rainfall varied from 7.43 to 10.65 mm per year, the highest increase was observed in Sakhon Nakhon province. The results showed that the yield of all four crops increased in all provinces during the period considered. However, the fluctuation (both increase and decrease) in yield was observed on an annual basis. The yield of major rice was found to be positively correlated with seasonal minimum temperature in all provinces whereas the sugarcane yield was found to be negatively correlated with the seasonal rainfall in all provinces. Regression analysis of anomalies of climate variables and the average yield of four crops showed that the impact of climate variability on crop yield varies among crops as well as provinces. It was observed that climate variability had a higher impact on sugarcane yield compared to other crops in all provinces. Therefore, non-climatic factors such as better crop management practices, good quality seeds, and use of fertilizers could be largely responsible for yield variation of major rice, second rice, and cassava in all provinces. The results of this study can be helpful to farmers and other agencies working for the improvement in the crop yield in the Northeast of Thailand. A very detailed study such as modeling the potential impact of climate variability and change is recommended to understand the impact of climate change and formulate the adaptation strategies to offset the negative impacts on crop yield in all provinces in the Northeast of Thailand.

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