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EFFECT OF CLIMATE VARIABILITY ON RICE PRODUCTION OF NORTHEASTERN THAILAND

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ABSTRACT: Rainfed rice cultivation is the key agricultural practice in the Northeast of Thailand. Climate variability is the main cause affecting rice production. The climatic water balance index namely standardized precipitation evapotranspiration index (SPEI) indicates a variety of climate conditions, whether the area is wet (positive) or dry (negative). Our study concerned the effect of climate variability on the production and yield of rice cultivation in five provincial stations in the northwestern of the Northeast which has one of the most extreme climatic conditions in Thailand. El Nino Southern Oscillation (ENSO) is also related to SPEI and related to rice production and yield. For the study rainfall and meteorological data between 2005 to 2016 were used for analyses. Changes of monthly SPEI over all stations were abrupt compared to ENSO changes which were gradual. During the rice cultivation period, May to September, 1-month SPEI fluctuated from month to month. The summation SPEI values within that 5 months were compared to rice production and yield from each station. All of rice productions increased with SPEI values but only three stations had yields agreeing with SPEI. This shows that the amount of production always relates to wetness but not the yield which depends on other factors such as soil fertility and good management. In marginal paddy fields, cultivation is limited to positive wet conditions. Production may increase depending on the area cultivate, but yields will reduce.

Keywords: Climate variability, Standardized precipitation evapotranspiration index, Rice production and yield

1. INTRODUCTION

Rice is the main staple food of Southeast Asia and some other parts of the world. It has been believed that rice was originated from the Southeast Asia region then spreading throughout the world [1]. Rice is a special crop that needs much more water than any other cereal crops it can survive even in standing water as long as the whole plant does not inundate [2]. The benefit of the standing water is that it controls weed growth. The climate of Southeast Asian countries is one of the best regions for cultivating rice crops since it has a large amount of rain during the wet season. The Northeast of Thailand is such a place that has plenty of rain during May to October each year [3]. It receives rain from two sources the southwest monsoon from the Indian Ocean and the tropical cyclone from the Pacific Ocean [4]. The northwestern part of the Northeast is quite a special place because it has an orographic effect from the Phetchabun, Dong Phaya Yen, and Sankambeng mountain ranges to retard the flow of Southwest monsoon into the region. In the case of the tropical cyclone from the Pacific, before reaching the region, the cyclone has to travel passing Vietnam, Laos, Cambodia, the eastern part of the Northeast before reaching the northwestern region. The region normally receives less rainfall than the other parts of Thailand even worse when the southwest monsoon is weak, and no tropical cyclone occurred. However, the area can be flooded during a year of strong summer monsoon and coupling with a large number of tropical cyclones. These dry and wet years are the result of atmospheric and the Pacific Ocean interaction indicated by El Nino Southern Oscillation (ENSO) [5].

The majority type of rice growing in the region is glutinous (*Oriza Sativa var. Glutinosa*) [6]. Rice culture in the northwestern part of the Northeast, Thailand, mainly is planted in a paddy lot of irregular size, rectangular shape, and surrounding with small earth bunds to confine water in the paddy. These lowland rainfed paddy fields receive water from rainfall and runoff and loss water through evapotranspiration, the combination of evaporation and crop transpiration. The indicator of water availability for rice crop is the difference between rainfall and evapotranspiration, namely standardized precipitation evapotranspiration index (SPEI) [7], [8]. The SPEI index is superior to other indices that can detect both extremes, flood and drought. Our objectives are to compare and correlate the rice productions and yields of the five northwestern provincials of the Northeast, Thailand, to their SPEI's then to ENSO.

2. STUDY AREA AND DATA COLLECTION

Our study area is in the northwestern part of Northeast, Thailand, between $15^{\circ}31'$ -$18^{\circ}21'$N and

$100^{Ò}83'$-$103^{Ò}66'$ W. It covers 5 provincial areas namely Chaiyaphum, Nongbualamphu, Khonkaen, Udonthani, and Loei. The whole Northeast is one of the large sub-basin on the right bank of the Mekong River called the Khorat Plateau. The plateau is separated into two basins by the Phu Phan mountain range lying in the west to east direction. The upper (northern) basin is Sakol Nakhon Basin and the lower (southern) one is Khorat Basin. Interestingly, our study area involves both basins, the Khorat Basin comprises Chaiyaphum and Khonkaen; whereas Udonthani and Loei are in the Sakol Nakhon Basin however, Nongbualamphu covers both basins.

Rainfall of the study area is in the range of 1146 mm for Chaiyaphum to 1457 mm for Udonthani. Since the western part of our study area is a rather rain shadow therefore, the amount of rain is increasing in the northeastern direction toward the Mekong River. Due to the Phu Phan Range, the topography of Loei and Udonthani is sloping down northward to the Mekong while that of the other two provinces, Chaiyaphum and Khonkaen is descending southward to the Chi River. Nongbualamphu is a special one because its northern part drains northward to the Mekong River while the southern drains southward to the Chi River. Drainage channels of the northern area are the Loei and the Huai Luang Rivers and those of the southern areas are the Nam Pong River and its tributaries. Undulating terrain is the typical landscape with the majority of sandy soil which derived from the sandstone of the Khorat Group. Saline soil and groundwater are the environmental problems of the area.

The main land-uses are upland crops and forest covering the upper terrains and paddy fields on the lower and swampy areas. The main type of rice is glutinous rice of more than 80 % and the other is white rice [6], [9], [10]. The major variety is RD6 which is a short plant and photosensitivity therefore, it must be transplanted as early as possible to obtain higher production. Since being rain-fed agriculture, it is sensitive to both drought and flooding, especially drought at the vegetative period (first half) and flooding at the maturing period (later half) [9].

Three types of data to be used namely rice production and yield, hydrometeorological, and ENSO index data. The data of rice cultivation during 2005 to 2015 were obtained from the Office of Agricultural Economics (http://www.oae.go.th) for each province and nationwide. The data are planted areas, harvested areas, production, and yield. The hydrometeorological data for 2005 to 2016 were collected from the Department of Alternative Energy Development and Efficiency (DEDE) of Thailand and the Thai Meteorological Department (TMD). These data are essential for SPEI evaluation which are daily precipitation and referent crop evapotranspiration (ETo). The precipitation data were collected from provincial rain gauges. The ETo has to be determined from FAO-Penman-Monteith formula refer to Eq. (11) which is required a range of meteorological data, e.g. maximum and minimum temperatures, solar radiation, relative humidity, and wind speed, etc. The last set of data is ENSO indices which comprise several indices. We decided to use the Oceanic Nino Index (ONI), which is the atmospheric pressure anomaly at Nino 3.4, for its simplicity and effectiveness. The ONI data set for 2005 to 2016 were retrieved from NOAA's National Weather Service's Climate Prediction Center [11].

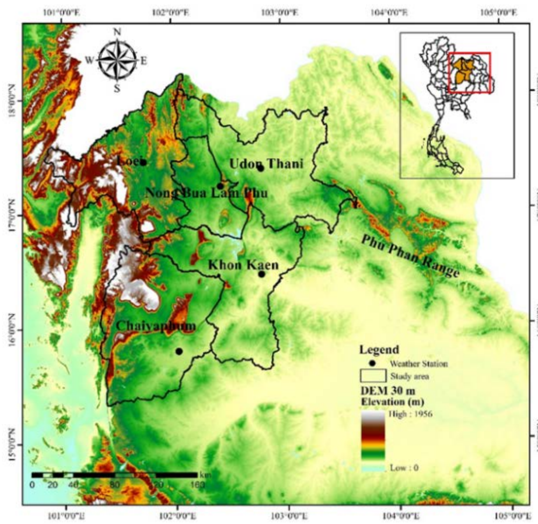

Fig. 1 Topography area of the five-province study region in Thailand.

3. METHODOLOGY

We hypothesized that the rice production and yield of the northwestern region of Northeast, Thailand should be related to the appropriated amount of water availability for rice growing. The crop water supply for rain-fed agriculture depends on the timing amount of rainfall and evapotranspiration. Too much rain creates flooding whereas too much ET creates drought. Both flooding and drought deteriorate rice production and yield. We tied rainfall and ET together using an index of SPEI which is the function of the difference of rainfall and ET [12]. We also presumed that SPEI is related to ONI index, if so ONI can be used as a proxy to forecast the rice production and yield of the interested area.

Standardized precipitation evapotranspiration index (SPEI) is an index to classify climate variable conditions from the discrepancy of rainfall and ET. It was derived from standardized precipitation index (SPI) by adding the effect of ET. Its determination procedure is the same as that of SPI just by replacing rainfall by rainfall minus ET (D_i, mm) as:

$$\boldsymbol{D_i = P_i - ETo_i} \quad (1)$$

We used a log-logistic probability distribution to fit the monthly D data. It was found that 1-month time scale is the most appropriate for the Northeast [13]. The cumulative probability distribution function (cdf) for 3-parameter log-logistic distribution can be written as [12].

$$\boldsymbol{F(Di) = \left[1 + \left(\frac{\alpha}{D-\gamma}\right)^{\beta}\right]^{-1}} \quad (2)$$

where α, β, and γ represent the scale, shape, and location parameters, respectively. These parameters can be estimated by several methods e.g. method of moment, probability-weighted moment (PWM), maximum likelihood, and the principle of maximum entropy [14]. For PWM, we compute frequency estimator F_i from [15],

$$Fi = \frac{(i-0.5)}{N} \quad (3)$$

where i is the rank of observation in increasing order and N is a number of data points. Then w can be determined from,

$$w_s = \frac{1}{N}\sum_{i=1}^{N}(1-F_i)^s D_i \quad (4)$$

where s is the order of PWMs ranking from 0 to 3, N is the total number of data, and D_i is the data of rank i. The three parameters are now ready to be calculated from [14],

$$\beta = \frac{(2w_1 - w_2)}{(6w_1 - w_0 - 6w_2)} \quad (5)$$

$$\alpha = \frac{(w_0 - 2w_1)\beta}{\left[\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right)\right]} \quad (6)$$

$$\gamma = w_o - \alpha\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right) \quad (7)$$

where w_0, w_1, and w_2 can be obtained from Eq. 4, Γ is the gamma function.

Knowing α, β, and γ, we can calculate the non-exceedance probability of D_i, $F(D_i)$, from Eq. 2. To transform $F(D_i)$ from log-logistic probability distribution to normal distribution we should compute exceedance probability first as:

$$P = 1 - F(Di) \quad (8)$$

For P is less than or equal to 0.5, then

$$W = (-2\,ln(P))^{0.5} \quad (9)$$

otherwise, for P is larger than 0.5, then P is replaced by 1-P. The value of W gives SPEI as [16]:

$$SPEI = W - \frac{(C_0 + C_1W + C_2W^2)}{(1 + d_1W + d_2W^2 + d_3W^3)} \quad (10)$$

in which the values of the constants are C_0 = 2.515517, C_1 = 0.802853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, and d_3 = 0.001308.

Type of ET to be used in SPEI determination is critical. We decided to use crop reference ETo as in [17]. The ETo is the hypothetical ET of a large area of growing uniform grass at 12 cm high without lacking of water. It can be calculated from [18]:

$$\boldsymbol{ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}} \quad (11)$$

Where
ETo: reference evapotranspiration [mm day^{-1}],
R_n: net radiation at the crop surface [MJ m^{-2} day^{-1}],
G: soil heat flux density [MJ m^{-2} day^{-1}],
T: mean daily air temperature at 2 m height [°C],
u_2: wind speed at 2 m height [m s^{-1}],
e_s: saturation vapour pressure [kPa],
e_a: actual vapour pressure [kPa],
e_s-e_a: saturation vapour pressure deficit [kPa],
Δ: slope vapour pressure curve [kPa $°C^{-1}$],
γ: psychrometric constant [kPa $°C^{-1}$]

4. RESULT AND DISCUSSION

Climate variability is the fluctuation of the wet and dry conditions along the time period which can be shown as the time series of SPEI. The main cause of climate variability is thought to be the interaction of the Pacific Ocean and the atmosphere which reflects through ENSO index e.g. Oceanic Nino Index (ONI). We therefore, compared time series of ONI to SPEIs of the 5 provincial areas. We only illustrate the results of Udonthani province in Fig. 2a. The rice production and yield time series of the same province are also shown in Fig. 2b and 2c, respectively.

We only show Udonthani's results however the other four provinces' results are very similar. ONI changes gradually with time while SPEI changes rapidly (Fig. 2a). The La Nina condition is represented by negative ONI whereas EL Nino by positive. For climatic conditions, the wet one is shown by positive SPEI but the dry condition is by negative SPEI. Fig. 2a shows strong La Nina years at 2 periods 2007-2008 and 2010-2011, it shows El Nino at 2 periods at 2009-2010 and 2014-2015. Fig. 2a shows opposite signs for most of the time, by showing wet condition for La Nina and dry one for El Nino periods. When considering the time series of production and yield in Fig. 2b and 2c, both curves show their increases at the periods of La Nina at 2007 and 2011. The rising trends in both production and yield indicate the progress of rice breeding and modern technology e.g. RD6 variety and combine harvesting have been popularly increasing [9], [10].

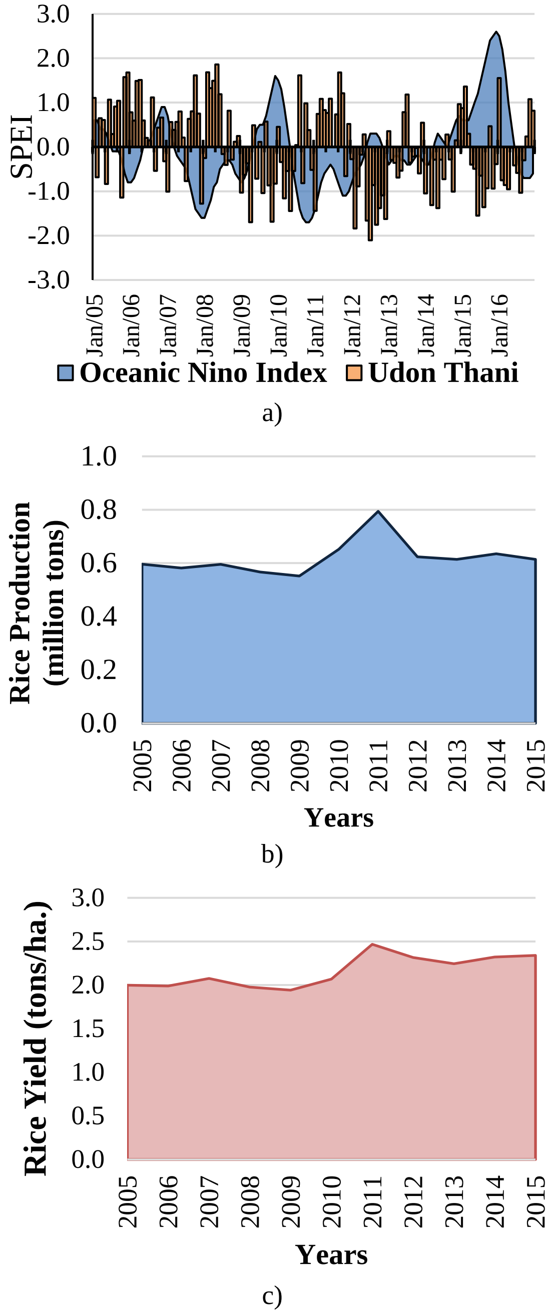

Fig. 2 The time series of a) ONI and SPEI, b) rice production, and c) rice yield of Udonthani Province.

The spectral analyses were performed to the time series of ONI and SPEIs to see the dominated spectrums as shown in Fig. 3. The highest peaks together with second and third of these curves are shown as wavelengths in Table 1. The dominant return periods of ONI and SPEIs of the five provinces are shown in Table 1.

Table 1. The wavelengths of the highest, second, and third highest peaks of the spectrums of ONI and SPEIs.

		Return Period (year)		
		λmax	**λ2nd**	**λ3rd**
ENSO index		3.00	1.50	12.0
	Udonthani	3.00	12.00	1.71
	Loei	0.21	3.00	0.86
SPEI	Khonkaen	0.17	4.00	0.23
	Chaiyaphum	12.0	0.48	0.60
	Nongbualamphu	6.00	12.00	1.50

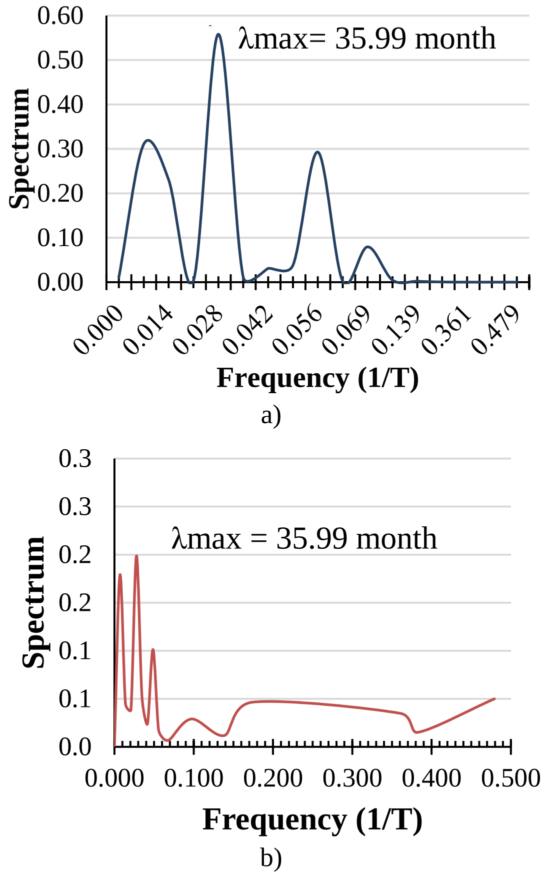

Fig. 3 Spectrums of ONI and SPEI time series of Udonthani.

Table 1 shows that the recurrent time of ONI should be approximately 3 years which is the same as the SPEIs for Udonthani and Loei, while that of Khonkaen and Nongbualamphu are 4 and 6 years, respectively. The longest return period of SPEI is that of Chaiyaphum region which is 12 years. Drought in Chaiyaphum is common because it locates in the strong rain shadow and the longest distance from the landfall of tropical cyclone (Fig. 1).

An essential characteristic of SPEI is its time scale. We did check the correlation of 5-time scales SPEIs with the rice production and yield of each provincial region using Pearson's correlation coefficient. Udonthani and Loei are both the provinces in Sakol Nakhon Basin, where Loei is mountainous but Udonthani is rather flat. For Udonthani, 2-month time scale of May-June is the best correlation at 0.66 and 0.71 for production and yield, respectively (Table 2). However, for Loei, the best ones are 5- month and 3-month time scales for production and yield. Khonkaen and Chaiyaphum are in Khorat Basin. Khonkaen is flatter whereas Chaiyaphum is rather hilly or more undulating. Khonkaen's production and yield are related to SPEI at 3- month and 2-month time scales, respectively (see Table 2). The best time scale for Chaiyaphum for both production and yield are at 2-month. The last province is Nongbualamphu which its area covers both basins (Fig. 1). Only its rice production correlates with SPEI at 0.42 of 2-month time scale, but not for the rice yield.

Table 2 The Pearson's correlation coefficients of SPEIs with rice production and yield at several time scales.

		UD	L	KK	CH	NB
Rice Production	May	-0.1	-0.3	-0.1	-0.3	-0.1
	May-Jun	0.7	0.2	0.3	0.5	0.4
	May-Jul	0.2	0.2	0.8	0.2	0.3
	May-Aug	-0.1	-0.1	0.2	-0.5	-0.2
	May-Sep	0.1	0.5	0.1	0.1	0.3
Rice Yield	May	0.0	-0.2	-0.1	-0.3	-0.1
	May-Jun	0.7	0.3	0.5	0.4	-0.2
	May-Jul	0.5	0.4	0.5	0.1	0.1
	May-Aug	-0.1	0.2	-0.2	-0.3	-0.1
	May-Sep	0.1	0.2	0.5	0.2	-0.1

5. CONCLUSION

The glutinous rice is the major staple food of the northwestern region of Northeast, Thailand. Orographic effect and the lengthy distance from tropical storm landfall render the region being drought prone. The rice productions and yields from 5 provincial regions of this northwestern part were correlated to the climatic conditions of the region using SPEIs and ENSO index using ONIs. The time series of 1-month SPEIs of all 5 provinces go against that of ONI index. This means that positive SPEI (wet condition) is agreeable with La Nina (negative ONI) and vice versa dry condition go along with El Nino. From spectral analyses of ONI and 1-month SPEI time series, we found the return period of ONI at 3 years and SPEIs at 3-12 years. Pearson correlation coefficient was used to determine the best time scale of SPEIs and found that two-month time scale is the most reasonable. The effect of climate variation on rice cultivation of the northwestern region of the Northeast of Thailand is needed to deeper study to get more information and understanding.

6. ACKNOWLEDGMENTS

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