

Impacts of El Niño-Southern Oscillation (ENSO) on Rice Production in Thailand during 1961-2016

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ARTICLE INFO

Received: 24 Nov 2018
Received in revised:
19 Apr 2019
Accepted: 5 May 2019
Published online:
13 Jun 2019
DOI: 10.32526/ennrj.17.4.2019.29

Keywords:

Rice production/ El Niño-
Southern Oscillation/
Asymmetry/ Thailand

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ABSTRACT

The impacts of ENSO and its associated climate variability on Thailand's rice production, area harvested and yield during 1961-2016 were examined. Analysis showed that year-to-year weather-related variations in Thailand's rice production, area harvested and yield which accounted for about one third of total interannual variance tended to vary in response to the phase reversals of ENSO events, with large decreases occurred during El Niño events. Rice production, area harvested and yield also exhibited lower (higher) than normal during the years when Thailand experienced deficit (excess) rainfall and lower (greater) number of rainy days. These results in combination with the previous studies suggest that ENSO exerts its influence on rice production and yield in Thailand via inducing anomalies in rainfall and temperature. Another noteworthy finding was the asymmetrical ENSO-Thailand's rice production relationship. Significant decline was observed only during El Niño events, highlighting a much greater influence of El Niño events on Thailand's rice production, area harvested and yield than La Niña events. This observation provides additional evidence extending the previously reported asymmetry in the ENSO-rainfall relationship in Thailand to rice production and yield as well. Hence, the asymmetrical ENSO-rice relationship should be taken into account when developing linearly predictive model.

1. INTRODUCTION

Agricultural production depends strongly on climate. It is known that agriculture is adversely affected by climate variability and weather extreme events especially those associated with ENSO (Tao et al., 2004; Iizumi et al., 2014; Ray et al., 2015; Nobre et al., 2017). ENSO is the dominant mode of coupled ocean-atmosphere variability in tropical oceans on interannual timescales, strongly influencing the global climate system (Brönnimann, 2007; Sarachik and Cane, 2010; Trenberth, 2013; Zhang et al., 2016) and substantially exerting impacts on society, economy and agriculture (Marlier et al., 2012; Cashin et al., 2017; Gutierrez, 2017). Large amplitude and anomalous fluctuations of ENSO-generated climate variability and weather extreme events can lead to crop failure, food insecurity, famine and loss of property and life (Marlier et al., 2012; Trenberth, 2013; Iizumi et al., 2014; Al-Amin and Alam, 2016).

Numerous studies have demonstrated the relationships between ENSO and its associated climate variability and agricultural production in different regions around the world (Cantelaube et al.,

2004; Tao et al., 2004; Xiangzheng et al., 2010; Bhuvaneswari et al., 2013; Iizumi et al., 2014; Ray et al., 2015). In Southeast Asia (SEA), for example, ENSO-related climate variability exerts strong influences on agricultural production and food security (Naylor et al., 2007; Roberts et al., 2009; Angulo et al., 2012; Chung et al., 2015; Reda et al., 2015; Al-Amin and Alam, 2016; Pheakdey et al., 2017). Production of rice and corn in Indonesia is especially vulnerable to climate variability associated with ENSO events (Naylor et al., 2007). Roberts et al. (2009) found that Philippine rice production in both irrigated and rainfed systems is affected by an El Niño event. In addition, recent studies have shown that El-Niño generated climate variability exerts many negative impacts on the agriculture sector in Malaysia, Thailand and Cambodia (Reda et al., 2015; Al-Amin and Alam, 2016; Pheakdey et al., 2017).

In the face of on-going anthropogenic climate change, scientific knowledge of the impacts of large-scale climate variability on crop production is essential for identifying the effective adaptation options to improve current food production and to

increase resilience of crop system to future climate variability. A better understanding of plausible linking mechanisms between global and regional climate variability and crop yield is also necessary to improve model accuracy for further yield prediction. Therefore, this study is designed to address an important question as to how ENSO and its associated climate variability affect national-level rice production, area harvested and yield in Thailand where the relationships are not fully understood. Asymmetry in the relationships between ENSO and Thailand's rice production, area harvested and yield is further examined. If such a relationship exists, knowledge of the phase reversals of ENSO will be able to provide additional predictability for climate-related variability in rice production and yield in Thailand.

2. METHODOLOGY

2.1 Data and quality control tests

In this study, 46 (44) records of monthly rainfall (mean surface air temperature) data routinely measured at the surface weather stations of the Thai Meteorological Department (TMD) distributed across Thailand were used. The data were first selected on the basis of record length being available from 1961 to 2016 and completeness with missing data less than 1%. All selected data were subjected to a further statistical quality control (QC) algorithm. The most commonly used objective approaches which include tests of outliers, data missing interpolation and homogeneity checks were employed to assess the quality of data (Feng et al., 2004; Wang et al., 2007; Klein Tank et al., 2009).

A second step was to assess homogeneity of data based on the penalized t-test (Wang et al., 2007) and the penalized maximal F-test (Wang, 2008). This stepwise testing algorithm is capable for detecting single or multiple changepoints in a time series based on a two-phase regression model (Wang, 2008). Monthly total rainfall and averaged temperature series were used to analyze homogeneity, based on the relative approach as described by Limsakul and Singhruck (2016). On the basis of the intensive quality control procedures, 41 and 40 high-quality records of rainfall and mean surface air temperature, respectively, for the period 1961 to 2016 was obtained (Figure 1) for further analysis.

As long-term records of digitized rice data are not available in Thailand, the annual rice production including area harvested and yield aggregated and/or averaged for whole Thailand during 1961-2016 were then extracted from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) (FAO, 2018a). FAOSTAT is the world's most comprehensive database of food and agriculture statistics, with free access to national-level data for over 245 countries and territories from 1961 to the most recent year available. It is a major component of FAO's information system, contributing to multiple stakeholders use. The FAOSTAT database is used widely in peer-reviewed literature including many agriculture, forestry and other land use (AFOLU)-related analyses from global agriculture perspective studies (Foley et al., 2011) to land use change assessments and carbon cycle studies (Friedlingstein et al., 2011). Some of the FAOSTAT-derived indicators have been used to assess and measure progress towards the targets set in the 2030 Agenda for Sustainable Development, and to monitor national actions for climate change adaptation and mitigation in the context of Paris Agreement (FAO, 2018a). It typically receives around 200,000 visits per month from national statisticians, government officials, researchers, the private sectors, international agencies, civil society and the media from all over the world (FAO, 2018a).

In working directly with the member countries, typically via National Agriculture Statistical Offices, the Statistics Division of the FAO has been able to compile most of the official data and information. This process results in an internationally approved, coherent data platform covering key information for a large range of agriculture and forestry products worldwide (Tubiello et al., 2013; FAO, 2018a). FAO has been employing Statistics Quality Assurance Framework as a part of quality management system for statistics, and the structure for implementing quality assurance activities of the FAOSTAT (FAO, 2018a). Comparison of the rice production data extracted from FAOSTAT with the data obtained from Office of Agricultural Economics of Thailand for the short period of 2008-2016 shows that the values from both sources are almost the same.

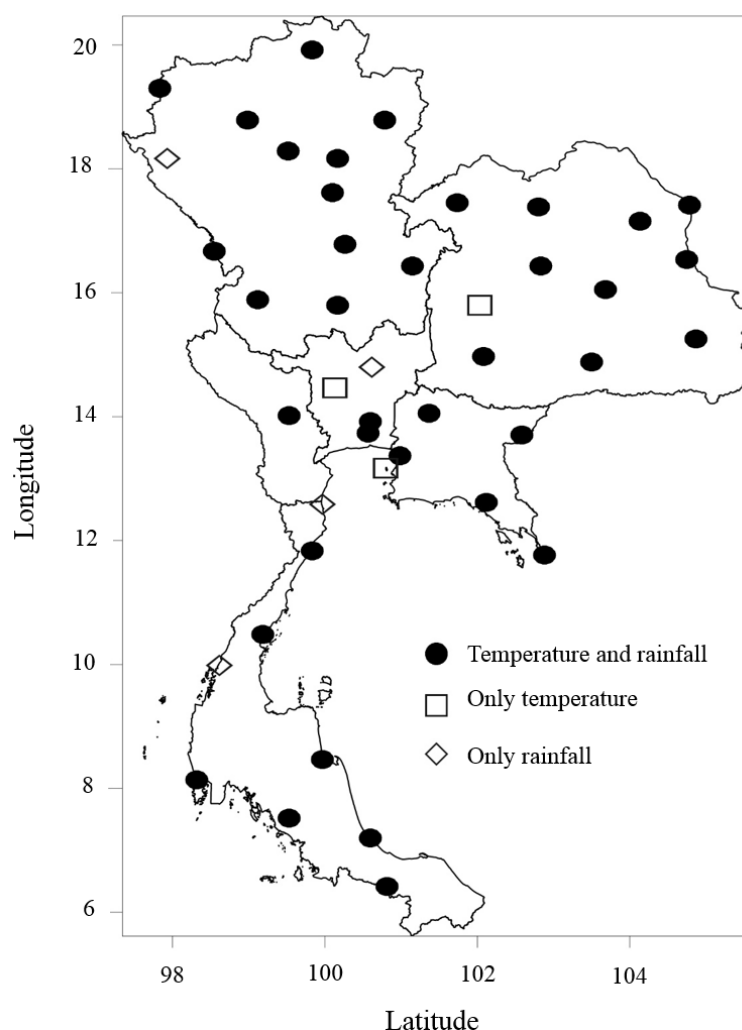


Figure 1. Geographical distribution of the TMD's surface weather stations with long-running quality controlled monthly mean surface air temperature and rainfall records during 1960-2016. Locations of the stations are basically divided into five topographic regions: 1) North, 2) Northeast, 3) Central, 4) East and 5) South, respectively.

2.2 Analysis methods

Long-term trends often present in the rice production, area harvested and yield data as a result of technological advances and additional farming techniques. The Ordinary Least Square (OLR) method (Tiamiyu et al., 2015; Pheakdey et al., 2017; Rahman et al., 2017) was then used to detrend for each of those time series. This method is robust to the effect of outliers in the series and is more suitable for estimating linear trend of non-normally distributed data. Anomaly time series, after linear trends had been removed, were then constructed as indices of short-term variations. Figure 2 shows actual data, trends and anomalies of the whole of Thailand's rice production, area harvested and yield.

Spearman's rank order correlation was employed to examine their degree of relationships among ENSO index, climate variables and rice data.

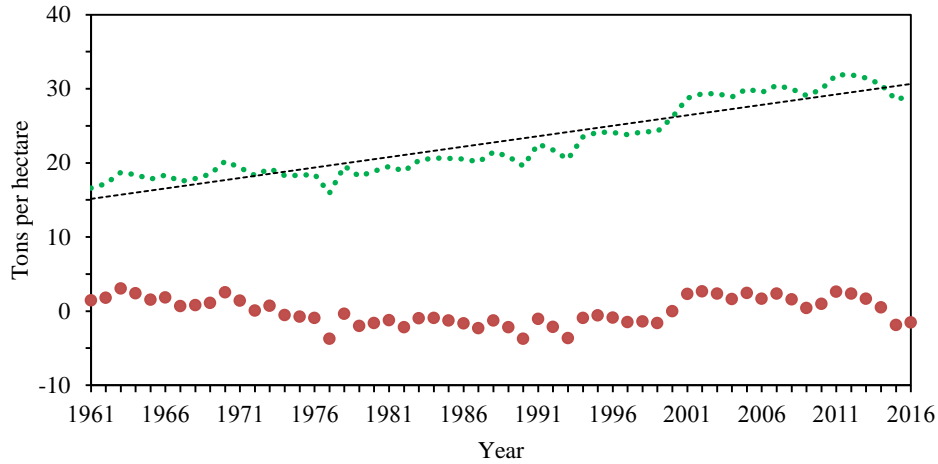
A correlation was taken to be significant when the no-correlation null hypothesis was exceeded with a probability of 95% and highly significant when the probability was 99% (Zubair, 2002; Asada and Matsumoto, 2009). A multiple linear regression was also analyzed to quantify the impact of ENSO and climate variability on rice production and yield where significant correlations had been found (Roberts et al., 2009; Tiamiyu et al., 2015; Rahman et al., 2017).

Multivariate ENSO Index (MEI) was used to represent the state of ENSO. It is calculated from six different parameters, which are sea level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature and cloudiness in the tropic Pacific (Wolter and Timlin, 1998). Principal Component Analysis is used to determine MEI as the leading mode of those variables. MEI integrates more meteorological and

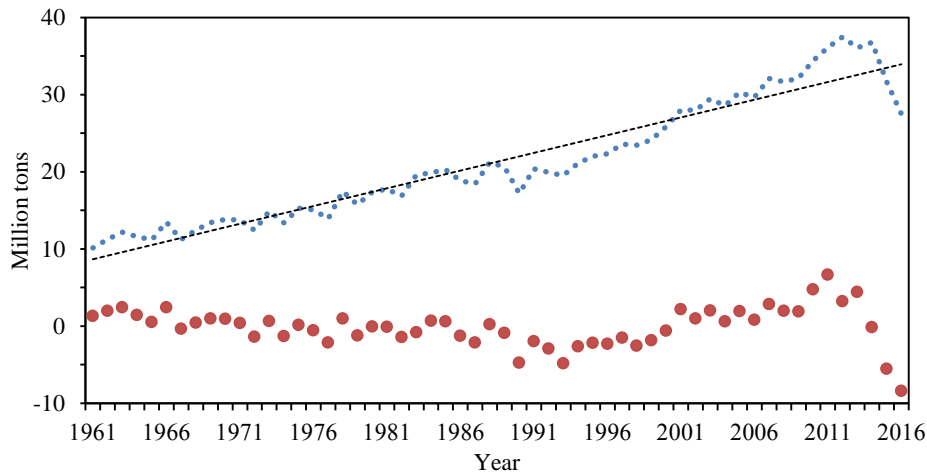
oceanographic information than other indices, and is more suitable for representing the nature of ENSO phenomenon than Southern Oscillation Index (SOI) or sea surface temperature (SST)-based indices (Wolter

and Timlin, 1998; Hanley et al., 2003). High negative values of MEI represent the cold ENSO phase (La Niña) while high positive MEI values represent the warm ENSO phase (El Niño).

a) Rice yield



b) Rice production



c) Rice area harvested

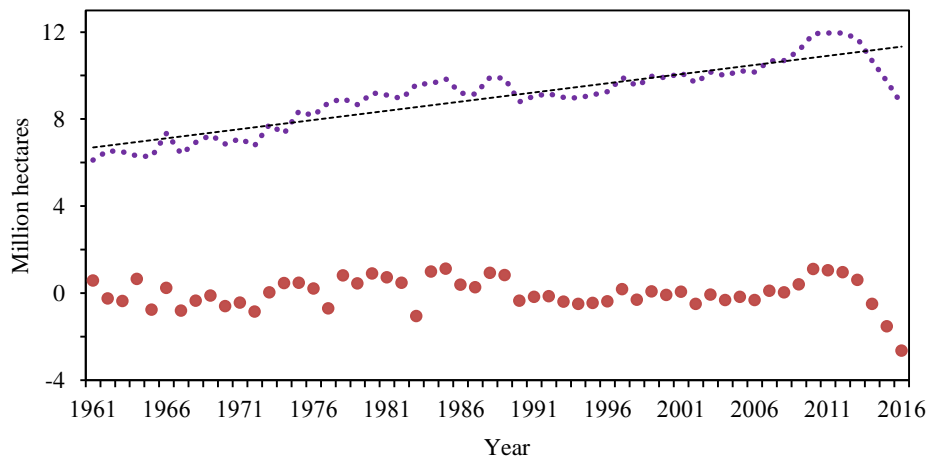


Figure 2. Annual time series of national-level rice production, area harvested and yield in Thailand during 1961-2016: general trends (solid line) and anomalies (points).

3. RESULTS AND DISCUSSION

3.1 Variability and trends in whole Thailand's rice production, area harvested and yield

Similar to other countries (Zubair, 2002; Selvaraju, 2003; Asada and Matsumoto, 2009; Roberts et al., 2009), annual time series of Thailand's rice production, area harvested and yield as a whole during 1961-2016 were dominated by technological trends due to notable improvement in farming technologies and techniques and land use change (Figure 2). Rice production aggregated for whole Thailand almost tripled over the past fifty-six years with a growth rate of 4.53% per year (Figure 2). Over this period, the area harvested also grew by 41.8%, expanding from 6.12 million hectares in 1960 to 8.68 million hectares in 2016 (Figure 2). As a result, the yield per hectare gained 75.6% from 16.59 tons in 1960 to 29.12 tons in 2016. It should be noted that most of the increased rice production was due to higher yields, which increased at an annual average rate of 1.70%, compared with an annual average growth rate of 1.38 for the area harvested. Sharp decline in rice production and area harvested was observed in the recent years corresponding to the period when Thailand has experienced the 2015/2016 severe drought (FAO, 2015; Naruchaikusol, 2016; World Bank Group, 2017).

Climate and non-climate-related anomalies which explain the variability around the trend are the other important component presented in the annual time series of Thailand's rice production, area harvested and yield (Figure 2). Anomaly time series after the technological trends had been removed showed substantial year-to-year variations which rice production and area harvested deviated around the long-term trends ranging from -6.52 to 5.37 million tons and -2.65 to 1.11 million hectares, respectively (Figure 2). Rice production, area harvested and yield had more than twenty years when anomalies exceeding one standard deviation which correspond to 36.7%, 17.1% and 21.6% of the long-term means, respectively. A closer observation revealed that anomalies in rice production were relatively larger than those in yield, perhaps implying that the effects of climate variability are compounded through changes in both yields and area harvested. To further examine the relationships between ENSO index, climate variables and rice data, only the anomaly time series were used in the following section.

3.2 Relationships between Thailand's rice production, area harvested and yield and ENSO index and climate variables

From the correlation analysis, it was clear that Thailand's rice production, area harvested and yield aggregated and/or averaged at a country level negatively correlated with ENSO index (Figure 3). The inverse relationships between MEI and the anomalies of rice production ($r=-0.49$), area harvested ($r=-0.40$) and yield ($r=0.39$) were significant at the 1% level, and account for 24.2%, 19% and 17% of total variability, respectively (Figure 3). Similar significant relationships have been detected in many regions of the world (Iizumi et al., 2014) including Indonesia (Naylor et al., 2007), Sri Lanka (Zubair, 2002), India (Selvaraju, 2003), Philippines (Roberts et al., 2009; Stuecker et al., 2018) and China (Zhang et al., 2008; Shuai et al., 2013). It was also evident that rice production showed a highest correlation with MEI, consistent with the study of Yahya et al. (2010) illustrating that rice production in Sri Lanka had a higher correlation with ENSO events than rice yield for both "Maha" (October to March) and "Yala" (April to September) cultivation seasons. Moreover, Roberts et al. (2009) reported that ENSO events exerted greater impact on rice production than area harvested and yield for the rain-fed systems in Luzon, the Philippines.

The relationships observed from this analysis suggest that year-to-year weather-related anomalies of Thailand's rice production, area harvested and yield at a country level tended to vary in response to the phase reversals of ENSO events. This is particularly true for the negative anomalies of Thailand's rice production, area harvested and yield which corresponded well to the warm phase of ENSO (positive MEI). During the 5 strongest historic El Niño events (1982/83, 1987, 1992/93, 1997 and 2015/16), for example, rice production and yield declined on an average by 16% and 8.8% from the long-term means, respectively. It was reported that rice production especially the second dry season decreased about 10 million tons as a result of the 2015/2016 severe drought driven by recent El Niño events (Thaiturapaian, 2016; World Bank Group, 2017). Slightly higher than normal of rice production and yield could be seen during the La Niña years such as those observed in 1971, 1974/75, 1999 and 2011.

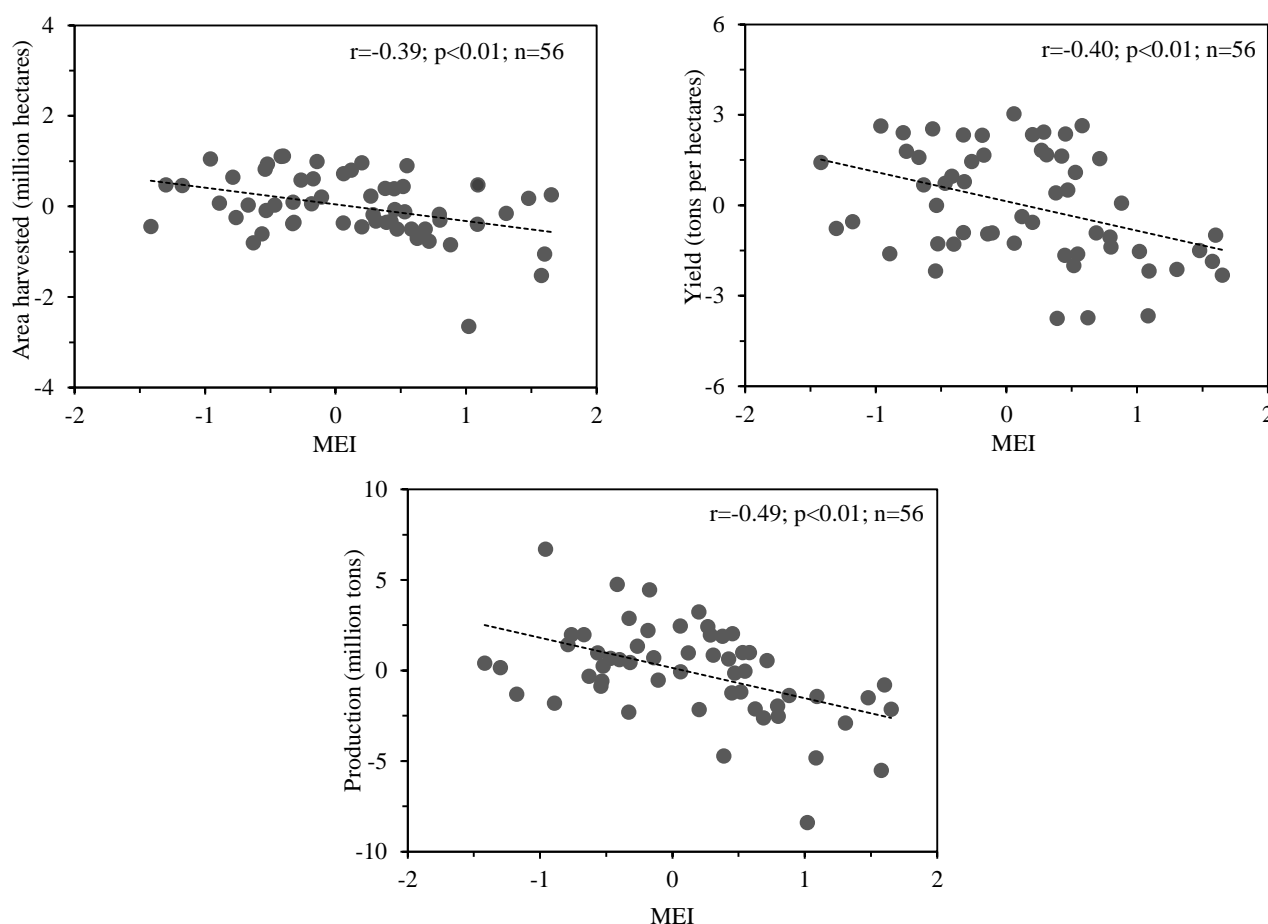


Figure 3. Correlations between annual values of MEI and anomalies of Thailand's rice production, area harvested and yield for the period 1961-2016.

Correlation analysis further disclosed that, in addition to MEI, the country-scale anomalies of rice production, area harvested and yield exhibited significant positive correlations with interannual variations in annual rainfall total and annual number of rainy days averaged over Thailand as a whole (Figure 4 and Figure 5). Such observed relationships indicate that rice production, area harvested and yield tended to be lower (higher) than normal during the years when Thailand experienced deficit (excess) rainfall and lower (greater) number of rainy days. Similar to the relationship with MEI, higher correlation coefficients were in general found for rice production and yield which percentages of variability explained by each of these climate variables were, on an average, 23% (Figure 3, Figure 4, and Figure 5). Strong relationships between rainfall variability and rice production and yield were previously reported in the Ganges-Brahmaputra Basin (Asada and Matsumoto, 2009), Vietnam (Chung et al., 2015), Nigeria (Tiarniyu et al., 2015)

and Cambodia (Pheakdey et al., 2017). In addition, Thailand's rice production, area harvested and yield showed negative correlations with annual mean surface air temperature but only the correlation coefficient of production was significant at the 95 confidence level (Figure 6). These results are in line with the recent findings of Pheakdey et al. (2017) showing that difference between maximum and minimum temperatures rather than variability in mean air temperature exerted significant effect on rice yield in Cambodia. Previous studies have been documented that ENSO phenomenon is an important remote driver of Thailand's climate variability (Limsakul and Goes, 2008; Wikarnpapraharn and Kositsakulchai, 2010; Limsakul and Singhruck, 2016; Limsakul et al., 2007; Limsakul et al., 2017). These results in combination with the above-mentioned previous findings suggest that ENSO exerts its influence on rice production and yield in Thailand via inducing anomalies in rainfall and temperature.

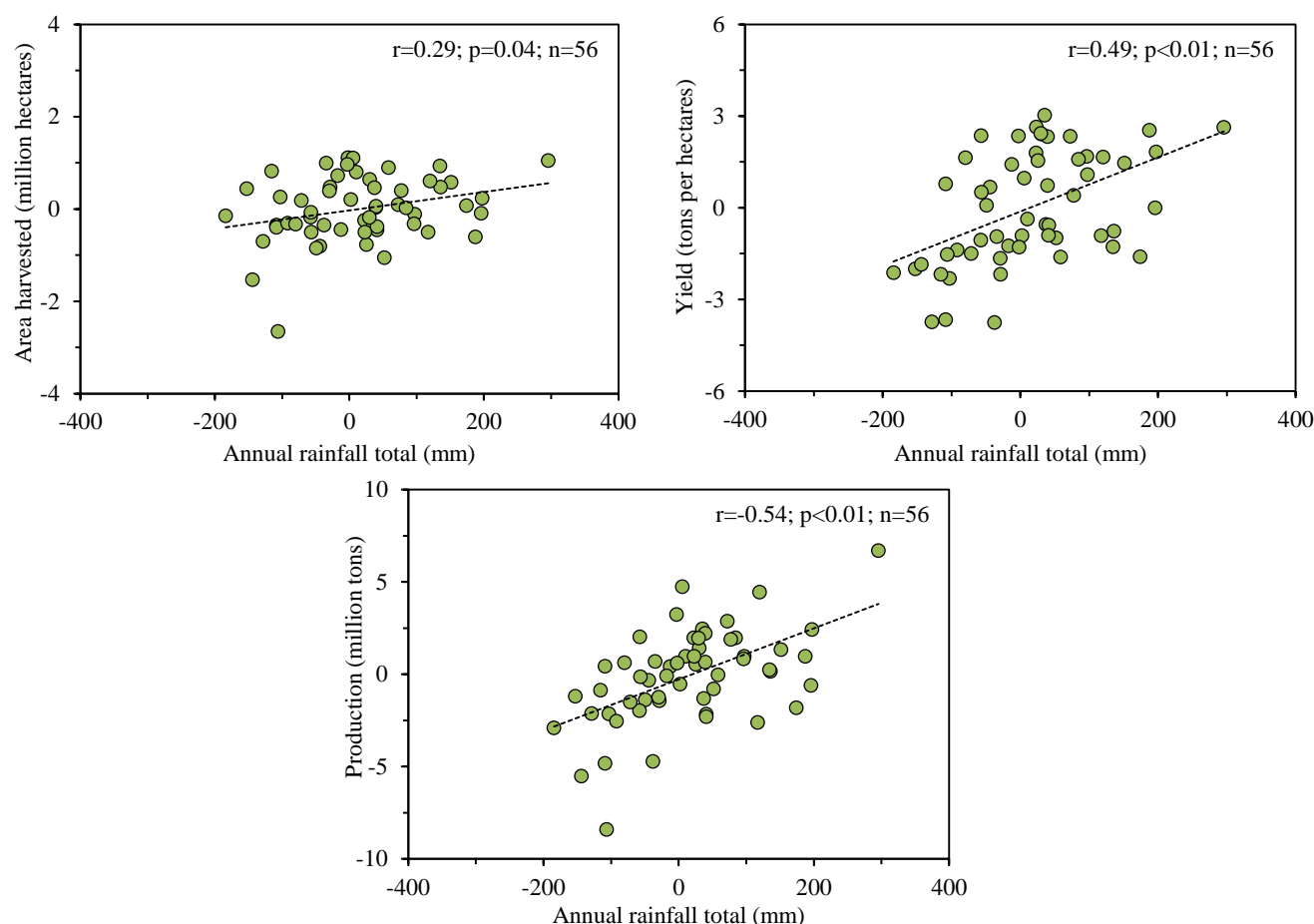


Figure 4. Correlations of the anomaly values between annual rainfall total and Thailand's rice production, area harvested and yield for the period 1961-2016.

3.3 Asymmetrical relationships between ENSO index and Thailand's rice production, area harvested and yield

It is well known that the asymmetry is an intrinsic nonlinear characteristic of ENSO phenomenon which makes El Niño events often stronger than La Niña events (An and Jin, 2004; Sarachik and Cane, 2010; Trenberth, 2013; Kohyama et al., 2018). Thus, symmetry and asymmetry in relationships between anomalies of Thailand's rice production, area harvested and yield and MEI were examined. The relationships were determined separately for MEI-positive and MEI-negative years. As shown in Figure 7, the asymmetrical ENSO-Thailand's rice production relationship did exist. That is to say, significant decline in Thailand's rice production, area harvested and yield occurred only during the warm phase of ENSO corresponding to the El Niño events (positive MEI) (Figure 7). Stronger El Niño events were usually associated with large decrease in Thailand's

rice production, area harvested and yield such as in 1982/1983, 1992/1993 and 2015/2016. Such asymmetrical relationships highlight that the strength of El Niño years exerts a much greater influence on Thailand's rice production, area harvested and yield than the magnitude of La Niña years does. The results from this analysis are in line with the studies of Ubilawa (2012) and Ubilawa and Holt (2013) demonstrating that El Niño and La Niña events exerted asymmetric effects on wheat yields, prices, stock-to-use ratios and exports for all export countries. Gutierrez (2017) also showed that La Niña exerted, on average, a stronger and negative impact on wheat yield anomalies, exports and stock-to-use ratios than El Niño. Moreover, similar asymmetry in relationship could be seen between the MEI and country-level anomalies of annual total rainfall in Thailand. It was evident that the magnitude of El Niño events had significant influence on annual total rainfall, while the strength of La Niña events had no significant effect. This observation shows that the

previously reported asymmetry in the ENSO-rainfall relationship in Thailand (Limsakul and Singhruck,

2016) can be extended to rice production and yield as well.

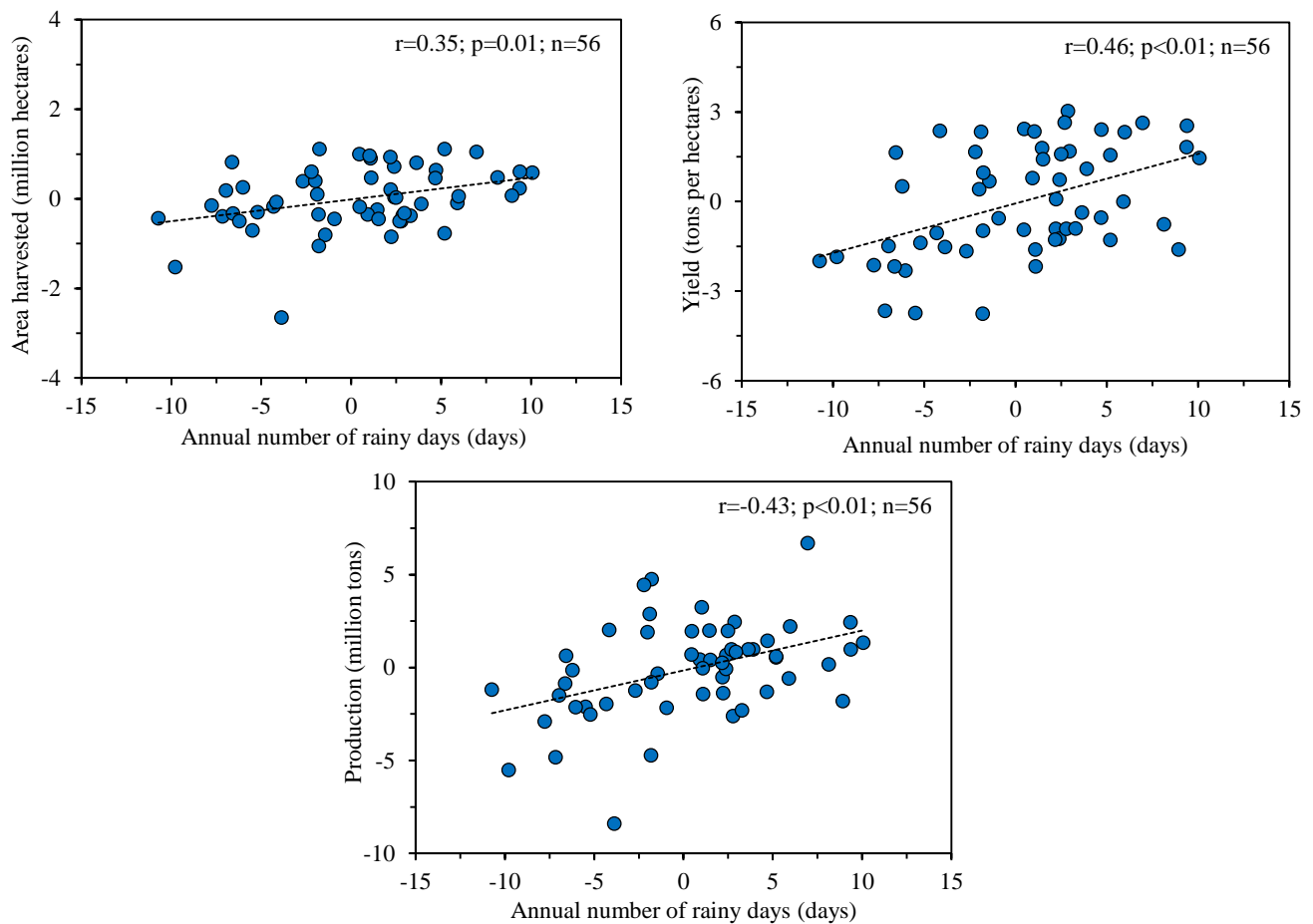


Figure 5. Correlations of the anomaly values between annual number of rainy days and Thailand's rice production, area harvested and yield for the period 1961-2016.

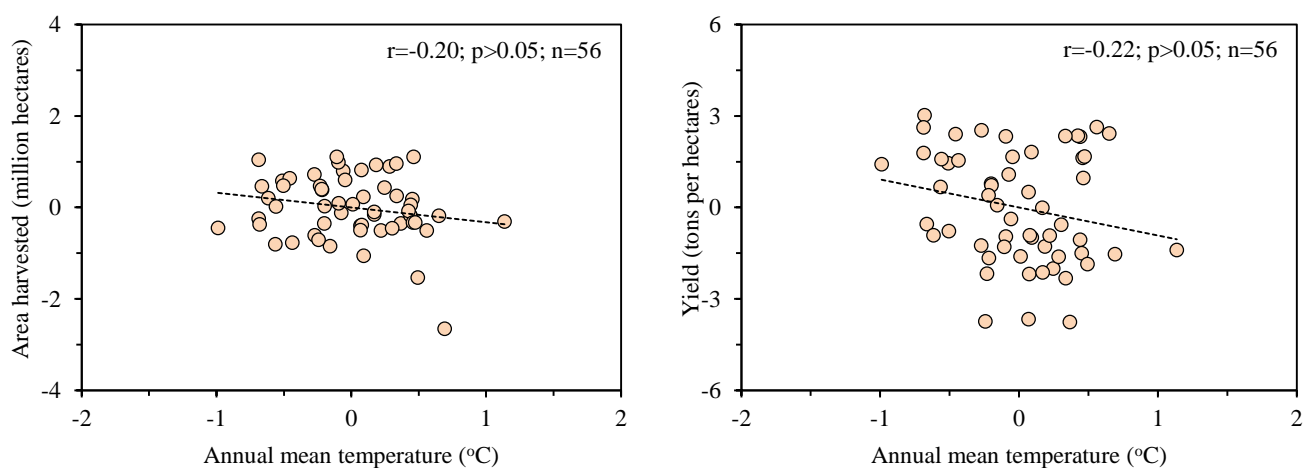


Figure 6. Correlations of the anomaly values between annual mean surface air temperature and Thailand's rice production, area harvested and yield for the period 1961-2016.

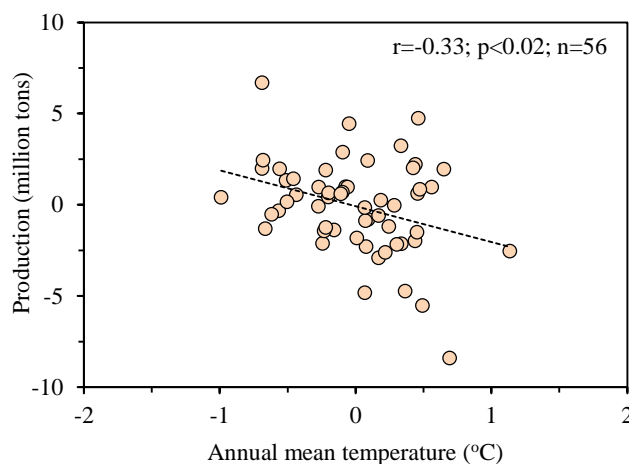


Figure 6. Correlations of the anomaly values between annual mean surface air temperature and Thailand's rice production, area harvested and yield for the period 1961-2016 (cont.).

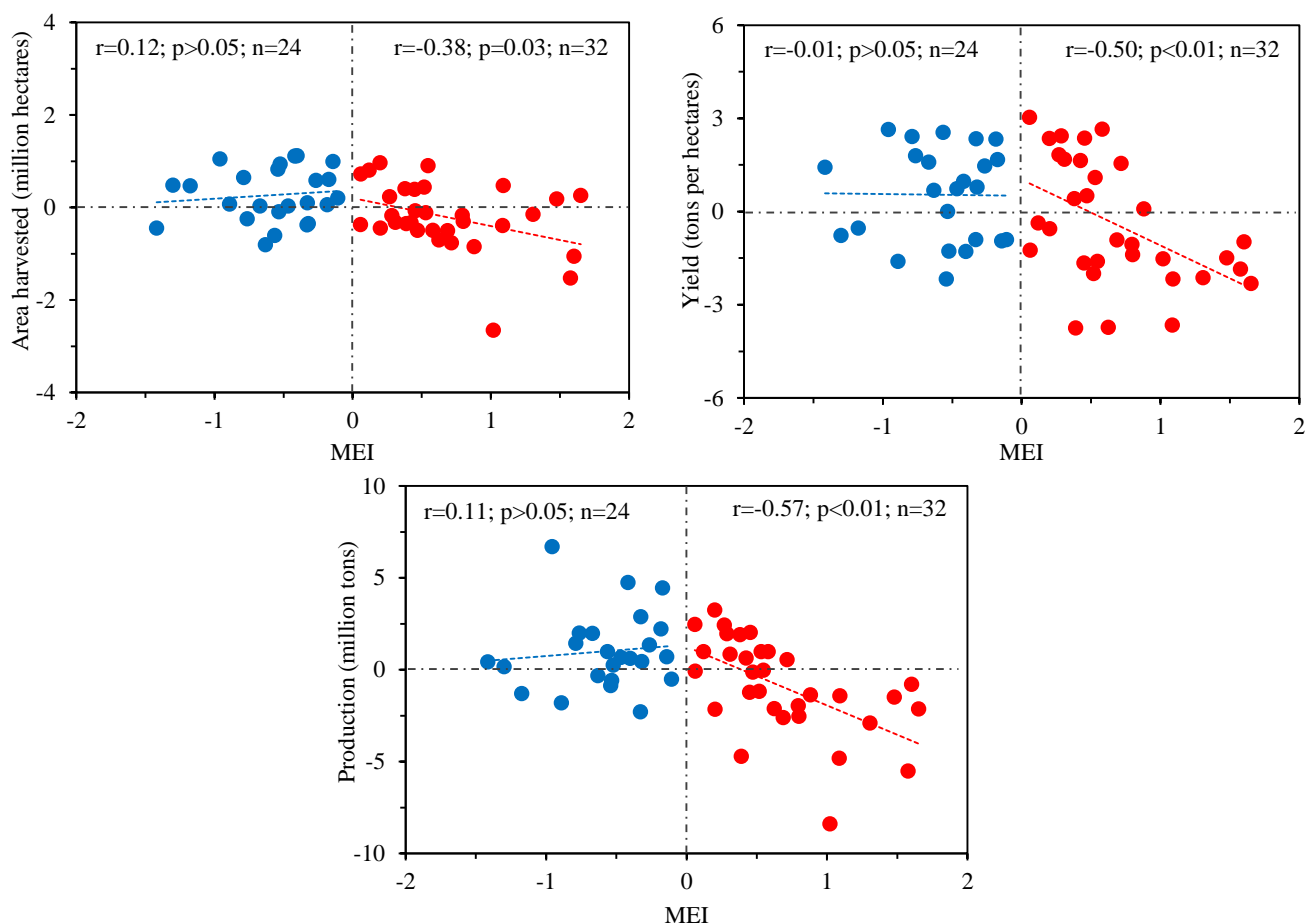


Figure 7. Correlations between annual values of MEI and anomalies of Thailand's rice production, area harvested and yield for the period 1961-2016. The correlations were determined separately for MEI-positive and MEI-negative values.

3.4 Regression analysis

A multiple least-squares linear regression was further analyzed to estimate the effect of ENSO and its associated climate variability on Thailand's rice production and yield. The MEI and annual rainfall total which had been correlated well with Thailand's

rice production and yield were chosen as the independent variables. When the MEI and annual rainfall total were regressed against Thailand's rice production and yield, coefficients of determination (R^2) were significant at the 1% level, although the models only explained 36% and 27%, respectively

(Table 1 and Table 2). There was evidence that the models built on two independent variables could provide better determination of variability in rice production and yield than just considering either the MEI or annual rainfall total (Table 1 and Table 2). However, the inclusion of annual number of wet days and annual mean surface air temperature as the independent variables did not improve the model performance. The asymmetrical relationships between MEI and annual rainfall total and Thailand's rice production and yield as shown in the previous section

appear to reduce predictive skill of the models developed based on a linear combination of independent variables for the entire data series. When the multiple linear regression was developed only for the El Niño phase (positive MEI values), however, the model could explain up to 45% and 39% for rice production and yield, respectively (Table 3 and Table 4). These results provide better understanding that predictability of ENSO impact on rice production in Thailand depends much on its phase.

Table 1. Multiple regression results for whole data series between MEI and annual total rainfall as independent variables and rice production as dependent variable.

Independent variables	Coefficient (standard errors)	t-Statistic	p-value	
Constant	-0.0890 (0.2944)	-0.30	0.76	
MEI	-0.9752 (0.4373)	-2.23	0.03	
Annual total rainfall	0.01005 (0.00328)	3.06	0.01	
Analysis of variance				
Source	DF	SS	F	p>F
Regression	2	127.837	14.65	0.001
Residual error	53	231.257	-	-
Total	55	359.094	-	-
Rice production = 0.089 - 0.975* MEI + 0.01005* Annual total rainfall; R ² =0.36				

Table 2. Multiple regression results for whole data series between MEI and annual total rainfall as independent variables and rice yield as dependent variable.

Independent variables	Coefficient (standard errors)	t-Statistic	p-value	
Constant	-0.0325 (0.2260)	-0.14	0.890	
MEI	-0.4922 (0.3357)	-1.47	0.149	
Annual total rainfall	0.00697 (0.00252)	2.77	0.001	
Analysis of variance				
Source	DF	SS	F	p>F
Regression	2	49.263	9.58	0.001
Residual error	53	136.269	-	-
Total	55	185.532	-	-
Rice yield = -0.032 - 0.492* MEI + 0.00697* Annual total rainfall; R ² =0.27				

Table 3. Multiple regression results between MEI and annual total rainfall as independent variables and rice production as dependent variable. Analysis was done only for the El Niño phase (positive MEI values).

Independent variables	Coefficient (standard errors)		t-Statistic	p-value
Constant	0.8104 (0.6582)		1.23	0.228
MEI	-2.1894 (0.8800)		-2.49	0.02
Annual total rainfall	0.01128 (0.00463)		2.44	0.02
Analysis of variance				
Source	DF	SS	F	p>F
Regression	2	91.366	11.43	0.001
Residual error	29	115.913	-	-
Total	31	207.279	-	-
Rice production = 0.810 - 2.19* MEI + 0.0113* Annual total rainfall; R ² =0.45				

Table 4. Multiple regression results between MEI and annual total rainfall as independent variables and rice yield as dependent variable. Analysis was done only for the El Niño phase (positive MEI values).

Independent variables	Coefficient (standard errors)		t-Statistic	p-value
Constant	0.6720 (0.5351)		1.26	0.219
MEI	-1.3274 (0.7153)		-1.86	0.074
Annual total rainfall	0.00888 (0.00376)		2.36	0.03
Analysis of variance				
Source	DF	SS	F	p>F
Regression	2	44.444	8.41	0.001
Residual error	29	76.599	-	-
Total	31	121.043	-	-
Rice production = 0.672 - 1.33* MEI + 0.0887* Annual total rainfall; R ² =0.39				

4. CONCLUSIONS

Analysis of the impacts of ENSO and its associated climate variability on Thailand's rice production, area harvested and yield can disclose some interesting findings. Annual time series of Thailand's rice production, area harvested and yield aggregated and/or averaged for whole Thailand during 1961-2016 exhibited substantial year-to-year variations with large deviations from the long-term means. The results showed that the non-climate-related component including Thai rice policy and governmental interventions which have been changed over the course of time since the Second World War accounted for large variations in Thailand's rice production, area harvested and yield. However, it was evident that weather-related anomalies of Thailand's rice production, area harvested and yield, which explained about one third of total interannual variance, significantly correlated with ENSO events and its associated climate variability. The observed relationships suggest that year-to-year weather-related variations of Thailand's rice production, area harvested and yield at a country level tended to vary in response to the phase reversals of ENSO events. For example, large decrease in Thailand's rice production, area harvested and yield occurred during El Niño events. Moreover, there was an indication that rice production, area harvested and yield tended to be lower (higher) than normal during the years when Thailand experienced deficit (excess) rainfall and lower (greater) number of rainy days. These results in combination with the previous studies suggest that ENSO exerts its influence on rice production and yield in Thailand via inducing anomalies in rainfall and temperature.

The asymmetrical ENSO-Thailand's rice production relationship is another noteworthy finding of weather-related anomalies. Significant declines occurred only during El Niño events, highlighting a much greater influence of El Niño events on Thailand's rice production, area harvested and yield than La Niña events. This analysis provides additional evidence extending the previously reported asymmetry in the ENSO-rainfall relationship in Thailand to rice production and yield as well. Moreover, the results shed more light on that predictability of ENSO impact on rice production in Thailand depends much on its phases, and the asymmetrical ENSO-rice relationship should be taken into account when developing linearly predictive model. This study focused only on national-level analysis, due to lack of long-term high-quality digitized rice data at sub-national and provincial scales. Compilation of those data from related governmental agencies is therefore needed for further study to fully address the effect of ENSO and its associated climate variability on Thailand's rice production, area harvested and yield at sub-national, provincial and local scales.

ACKNOWLEDGEMENTS

Author would like to thank Thai Meteorological Department for kindly providing valuable monthly rainfall and temperature data. Special thanks are also extended to the editor and the anonymous reviewers for their insightful critiques and constructive comments to substantially improve the quality of the earlier version of the manuscript.

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