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Rice yield in response to climate trends and drought index in the Mun River Basin, Thailand

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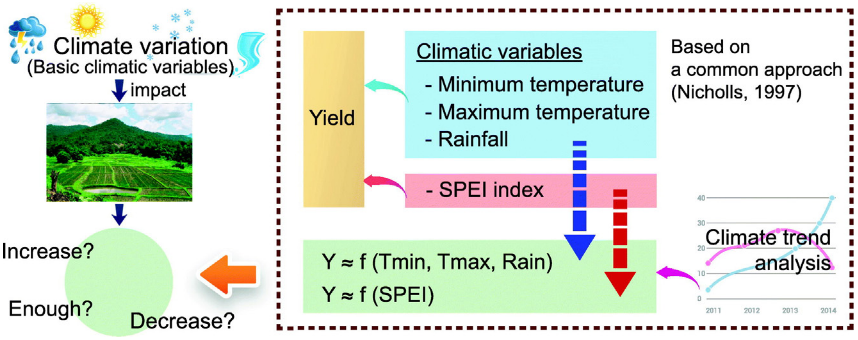
HIGHLIGHTS

- Analysis of impacts of past climate trends on rice yield in the Mun River Basin.
- The analysis also includes relationships between rice yield and SPEI.
- Increasing Tmax and Tmin cause damage to rice production in the area.
- 1-month SPEI has stronger relationship with rice yield than other timescales and rainfall.
- The rice yield impacts due to climate trends in the basin were rather low.

GRAPHICAL ABSTRACT



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ABSTRACT

Rice yields in Thailand are among the lowest in Asia. In northeast Thailand where about 90% of rice cultivation is rain-fed, climate variability and change affect rice yields. Understanding climate characteristics and their impacts on the rice yield is important for establishing proper adaptation and mitigation measures to enhance productivity. In this paper, we investigate climatic conditions of the past 30 years (1984–2013) and assess the impacts of the recent climate trends on rice yields in the Mun River Basin in northeast Thailand. We also analyze the relationship between rice yield and a drought indicator (Standardized Precipitation and Evapotranspiration Index, SPEI), and the impact of SPEI trends on the yield. Our results indicate that the total yield losses due to past climate trends are rather low, in the range of <50 kg/ha per decade (3% of actual average yields). In general, increasing trends in minimum and maximum temperatures lead to modest yield losses. In contrast, precipitation and SPEI-1, i.e. SPEI based on one monthly data, show positive correlations with yields in all months, except in the wettest month (September). If increasing trends of temperatures during the growing season persist, a likely climate change scenario, there is high possibility that the yield losses will become more serious in future. In this paper, we show that the drought index SPEI-1 detects soil moisture deficiency and crop stress in rice better than precipitation or precipitation based indicators. Further, our results emphasize the importance of spatial and temporal resolutions in detecting climate trends and impacts on yields.

1. Introduction

Temperature and precipitation are the two fundamental variables commonly used as indicators for changes in climate. The impacts of climate variability and change on crop yields have been studies by

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numerous researchers worldwide; both for historical and future climates and for various crops (Adams et al., 1998; Babel et al., 2011; Bhatt et al., 2014; Challinor et al., 2014 etc.; Erda et al., 2005; Fischer et al., 2005; Fuhrer et al., 2006; Hekstra, 1986; Nicholls, 1997). Studies on the impacts of past climate trends on crop yields using empirical models have come to different conclusions depending on crop types and their locations. For example, some studies reported reductions in wheat yields in Russia and France, and maize yields in China as a result of increased temperature (Brisson et al., 2010; Lobell et al., 2011; Tao et al., 2008; Wei et al., 2014). Others report increases in wheat yields in Mexico due to decreased nighttime temperature (Lobell et al., 2005), whereas an increase in minimum temperature is the dominant factor attributed to increases Australian wheat yields (Nicholls, 1997). Furthermore, rice yields in China have increased due to significant warming trend (Tao et al., 2008). In the United States, the yield impacts on wheat, maize and soybean are not obvious because of less significant climate trends (Lobell et al., 2011). In a study in the Koshi basin (Nepal) Bhatt et al. (2014) pointed out that crop yield impacts differ even in the same basin depending on altitudes.

These findings have resulted in an improved understanding of the links between climate and crop yields and the extent to which climate impacts productivity. However, these studies used basic climatic variables such as minimum, maximum and mean temperatures and precipitation at a rather coarse temporal (annual or by growing season) and spatial scale, such as global (Lobell and Field, 2007; Lobell et al., 2011), regional (Lobell et al., 2007; Schlenker and Lobell, 2010), and national scale (Nicholls, 1997; Rowhani et al., 2011; Wei et al., 2014).

Drought indices relate to cumulative effects of a prolonged and abnormal moisture deficiency (World Meteorological Organization, 1992), thus they have a strong connection to agriculture. There are a number of drought indices commonly used such as Standardized Precipitation Index (SPI) (McKee et al., 1993), Standardized Precipitation and Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010), Palmer Drought Severity Index (PDSI) (Palmer, 1965), Normalized Difference Vegetation Index (NDVI) (Tucker, 1979).

The SPEI, a meteorological drought index, is more relevant to agriculture than precipitation or precipitation-based indices such as SPI, because it is based on both precipitation and temperature. It can be computed at any preferable timescales and the values represent both wet and dry conditions (Guttman, 1999; Zargar et al., 2011). which both can affect crop yields when threshold values are exceeded. In addition, the meteorological drought index can detect the onset of drought sooner than agricultural and hydrological drought indices. However, even though SPEI has been widely used for monitoring and forecasting climate variations and conditions, it is rarely used to evaluate the link between crop yields and climate.

The objectives of this paper are to examine climate variability and trends, and the relationships between rice yields and basic climatic parameters such as minimum (Tmin), average (Tave), maximum (Tmax) temperatures, precipitation (Prec), and the drought index SPEI. This study is implemented for the Mun River Basin, Thailand, where no such study has been executed before. The study advances previous work by assessing yield changes at monthly time step rather than using averages or summations over the growing season. A shorter time step is important because of the varying degree of crop sensitivity to climate at each growth stage. In addition, this study takes a finer spatial scale than earlier studies, using basin and sub-basin scales as opposed to national level and global assessments. Because the climate - yield relationship is scale dependent and empirical models at global scale cannot reliably be used to anticipate the outcomes at finer scales (Lobell and Field, 2007; Tao et al., 2008), assessments on a smaller spatial scale (such as basin level) deepens the understanding of crop-climate links.

2. Study area

Thailand is among top ten largest rice-producing countries in the world (FAO, 2013), but its annual average rice yield of 3.1 ton/ha is only half of rice yields in South Korea and Japan and ranks almost at the bottom among the Southeast Asian countries (Food and Agriculture Organization of the United Nations, 2016). The lowest average yield in Thailand, 2.3 ton/ha, is found in the northeastern region where approximately 60% of rice is cultivated (Office of Agricultural Economics, 2016).

The Mun River Basin, the largest river basin in Thailand with a total area of 71,060 km^2 is located in the northeast of the country, covering 10 provinces (Fig. 1). It has a tropical savannah climate (Peel et al., 2007), with an annual precipitation between 800 mm and 1800 mm concentrated in the rainy season from mid-May to mid-October, with maxima in August or September. The monthly mean temperature ranges from 25 °C to 30 °C. In the cool season, i.e., mid-October to mid-February, not only the temperature but also the precipitation is lowest. The hot period is from mid-February to mid-May, with the highest temperature in April.

Approximately 75% of total agricultural land in the Mun River Basin (5.2 million ha) is devoted to paddy fields of which about 90% is rain-fed (Table 1). The total rice cultivation and irrigated areas were derived from the land use map of 2013 obtained from the Land Development, Thailand and the map of irrigated area 2012–2013 obtained from the Royal Irrigation Department, Thailand. The KDML105 (Khao Dok Mali 105) and RD6 (Rice Department 6) are the two main varieties of Jasmine rice in the area with a potential yield of 2.3 t/ha and 4.2 t/ha respectively. They are medium-maturing types with a life cycle of 120–140 days, roughly from July to November (Bureau of Rice Research and Development (BRRD), n.d.). The common technique for rice cultivation in Thailand nowadays is direct seeding. The three development stages (Brouwer et al., 1989) are the vegetative stage (July–September), reproductive stage (October) and ripening stage (November).

Rainfed rice yields in the Mun River basin are generally below potential due to water shortages. The average total precipitation over rice-growing season varies between 600 and 1100 mm (average 821 mm) with considerable spatial and temporal variations from province to province as shown in Fig. 1. The eastern provinces receive more precipitation than the west because of the influence of tropical depressions (The Meteorological Department of Thailand, n.d.). The amount of precipitation decreases considerably after the rainy season. The precipitation concentrates in the months July to September (200 mm per month or more). The last two months of the growing season (October and November) are relatively dry. The effective precipitation is approximately 550 mm (Table 2). This amount is not sufficient for rice cultivation, which requires roughly 1300–1600 mm (including the amount of water needed for soil saturation, percolation, seepage losses and water layer establishment). The predominant soil types consist of coarse-loamy, fine-silty, fine-loamy, clayey-skeletal soils with average percolation and seepage losses up to 5 mm/day.

3. Data and methods

3.1. Data collection

Time series data of monthly precipitation, Tmin and Tmax from 1984 to 2013 were obtained from the Royal Irrigation Department and the Meteorological Department of Thailand. Of the total 196 precipitation stations in the basin, only 53 have continuous time-series records for the specified period. Among them, only 10 stations also have adequate temperature data. Therefore, data from several adjacent stations outside the basin were included. Annual rice production data of the 10 provinces were acquired from the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives. The length of the yield records