Evaluating the Potential Impacts of High Temperature on Rice Production in Northeast Thailand

Danai Pornamnuaylap[1,2,4], Atsamon Limsakul[3], Pitayakon Limtong[4], and Amnat Chidthaisong[1,2,*]

[1]The Joint Graduate School of Energy and Environment and, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand
[2]Center for Energy Technology and Environment, Ministry of Education, Thailand
[3]Environmental Research and Training Center, Technopolis, Klong 5, Klong Luang, Pathumthani 12120, Thailand
[4]Land Development Department, Phahonyothin Rd., Chatuchak, Bangkok 10900, Thailand.
*Corresponding authors: amnat_c@jgsee.kmutt.ac.th

Abstract: We analyzed the 30-years trends of temperatures during 1983-2012 and evaluated the potential impacts of daily maximum temperature on rainfed rice production in northeast Thailand. The temperatures records at 19 meteorological stations of the Thai Meteorological Department in the region were used for this purpose. We found that the average daily maximum, mean, and minimum temperatures had significant increased with increasing rate per decade of 0.16°C ($p \leq 0.01$), 0.11°C ($p \leq 0.05$), and 0.28°C ($p \leq 0.01$), respectively. Using the temperature indices derived from daily maximum temperature of ≥35°C, at which adverse effects on rice production have been suggested, it was revealed that rice cultivation in northeast Thailand would have experienced high temperature stress. However, the overall impacts were considered as low for all stations except at Kosum Phisai station where the impact level was moderate. On the monthly basis it was found that the potential impacts of high temperature on rice production were especially high during February-May (vegetative growth state of rice), and in November (reproductive stage). In most cases the impacts for these months were moderate, except in Kosum Phisai where this was high. Our analysis indicates that daily maximum temperature both in terms of magnitude and frequency may have exerted the adverse impacts on rice production in northeast Thailand. Further in-depth analysis with sufficient observation data will further improve our understanding of potential impacts as well as provide guidance for counter measures in the future.

Keywords: northeast Thailand, rainfed rice, impacts of high temperature.

1. Introduction

Rice is the world's most important food crop, and it serves as a staple food for about half of the world's population. The demand for rice is expected to increase as the rice consuming population grows [1]. It is projected that climate change will result in more extreme climatic conditions and rice production are more likely subject to the events of high temperature during its growing period [5] . Vulnerability of the rice production system to the change in climate will have severe impacts on the world rice market and food supply.

Thailand is the sixth largest rice producer and the main exporter in the world [2]. Based on water management schemes, rice cultivation in Thailand can be divided into irrigated and rainfed rice ecosystems. Irrigated rice (most of area in the central Thailand) is usually cultivated year round while rainfed rice is cultivated during rainy season (late April-December). Currently, More than 60% of the rice-growing areas and more than 50% of rice production are in the northeastern part of the country [3]. More than 70% of these growing areas are under rainfed conditions [4]. The dependence of rainfed rice on climatic conditions such as timing, duration and intensity of rainfall and variations in temperature makes it very vulnerable to climate change and variability.

Global mean surface air temperature has increased by approximately 0.85°C in the 20th century and is projected to further increase by 0.3-4.8°C [5]. In Thailand, the averaged maximum temperature has increased by 0.57°C during the 56-years period from 1965-2006 and the averaged mean temperature has increased more than the global mean temperature by 0.016°C per decade [6]. Rising temperature and its extremes are expected to become a major detrimental factor to rice production in most rice growing regions. Extreme temperature, for example, if taking place at the stages when rice plants are most vulnerable such as during heading stage would potentially affect rice yields. Exposing rice during this stage to high temperature stress, it was found that pollen formation and development, insemination and spikelet fertility were severely damaged [7-8]. In addition, grain-filling process was also affected, resulting in reduction of single-grain weight [8].

The threshold of high temperature that exerts damages to rice production has been suggested as maximum daily temperature of ≥35°C [7-8]. Exposing rice plant to this temperature for one hour was sufficient to induce sterility in rice (both indica and japonica genotypes). Kim et al. [9] also found that during heading stage this high temperature stress can significantly reduce grain yield, spikelet fertility, and grain weight by accelerating the panicle senescence.

As mentioned above, Thailand is the main rice exporting country. However, investigation on potential impacts of climate change and variability on rice production is rare. In this study, we analyzed the past temperature records during 1983-2012 in northeast Thailand where majority of rice is cultivated under rainfed conditions. Our main objectives are; 1) to investigate the temperature trends and its spatial variations, and 2) to use these temperature records to evaluate whether potential stresses to high temperature have been occurred. The results will be useful for improving our understanding of the impacts of climate change and variability on rice production, so that appropriate measures to cope with this issue and to reduce the potential impacts would be formulated.

2. Experimental

2.1 Data set and data quality control

The 30-years temperature records (1983-2012) for northeast Thailand were obtained from the Thai Meteorological Department (TMD). These records comprised of temperature data from all 19 meteorological stations in the region (Table 1 and Fig. 1). The temperature data were subject to quality control and correlation as described below. Only those stations with at least 90% in terms of record length and data completeness were included in the current analysis. In this study, tests of spatial and temporal outliers, data missing interpolation and homogeneity were applied. Temporal checks for outlier were performed utilizing the sample distribution of each calendar month separately for each station. Extreme temperature values were flagged based on limits determined from ±5 × IQR (Inter-Quartile Range; 75th percentile minus 25th percentile). For spatial outlier checks, a nearly-station technique was operated. This method detects the outliers by comparing the candidate data with neighboring stations by mean of linear regression for each calendar month. Temperature value was flagged as potential outliers if they felt outside ±5×RMSE (Root-Mean-Square-Error) of linear regression for all pairs of stations. The missing data were estimated using the method described by Limjirakan et al. [6, 10], and Feng et al. [11].

Homogeneity was evaluated using an R-Base Language program, RHtestsV2 software package, developed at the Climate Research Division of Atmospheric Science and Technology Branch of Canada [12]. This program is competent of identifying multiple step changes based on the penalized maximal *t* test and the penalized maximal *F* test. The nonhomogeneous data were removed from further analysis [6, 13].

Table 1. Lists of meteorological stations in northeast Thailand from which the temperature records were used in this study.

Station No.	Station Name	Latitude	Longitude	TMD station code	WMO station code
1	Nong Khai	17.8667	102.7167	352201	48352
2	Loei	17.4500	101.7333	353201	48353
3	Udon Thani	17.3833	102.8000	354201	48354
4	Sakon Nakhon Agromet	17.1167	104.0500	356301	48355
5	Nakhon Phanom	17.4167	104.7833	357201	48357
6	Khon Kaen	16.4633	102.7867	381201	48381
7	Mukdahan	16.5333	104.7167	383201	48383
8	Kosum Phisai	16.2472	103.0681	387401	48382
9	Chaiyaphum	15.8000	102.0333	403201	48403
10	Roi Et Agromet	16.0667	103.6167	405301	48404
11	Ubon Ratchathani Agromet	15.3925	105.0592	407301	48408
12	Ubon Ratchathani	15.2500	104.8667	407501	48407
13	Si Sa Ket Agromet	15.0333	104.2500	409301	48409
14	Nakhon Ratchasima	14.9628	102.0767	431201	48431
15	Pak Chong Agromet	14.6439	101.3208	431301	48435
16	Chok Chai	14.7189	102.1686	431401	48434
17	Surin Agromet	14.8833	103.4500	432301	48433
18	Tha Tum	15.3167	103.6833	432401	48416
19	Nang Rong	14.5833	102.8000	436401	48436

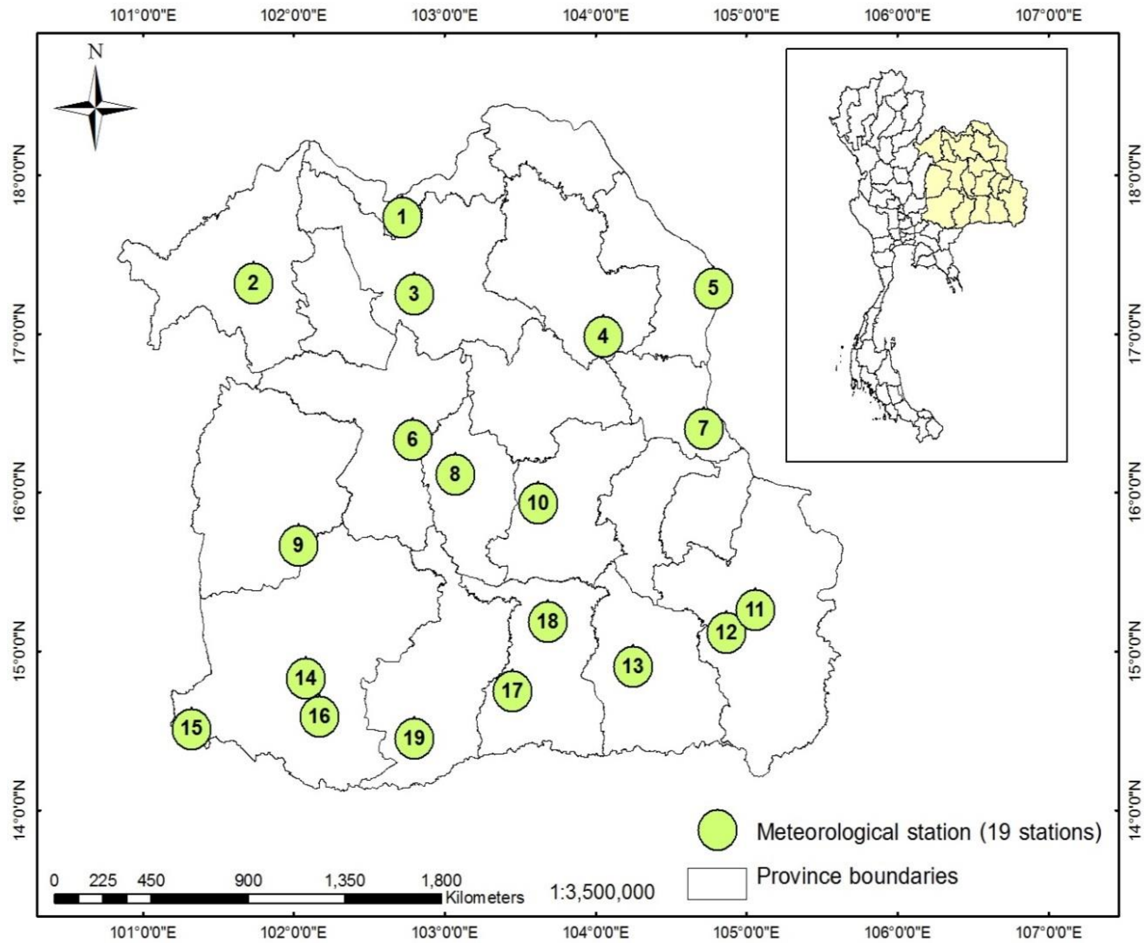

Figure 1. Location of Thai Department of Meteorology's station in northeast Thailand, from which temperature records during 1983-2012 were used in this study.

Table 2. Temperature criteria applied for developing high temperature indices in this study.

Score level	High temperature index		
	Rate of change in number of day with ≥35°C (day/30years)	Number of times with 3 consecutive days (Times)	Total number of days with ≥35°C (day/30 years)
1	0.1 – 3.7	1	1 – 235
2	3.8 – 7.4	2	236- 470
3	≥7.5	≥3	471 – 706

2.2 Trend computation of climate data

Trends in daily maximum temperature was determined using the ordinary least square (OLS) method, which is widely used and accepted non-parametric trend estimator in hydro-meteorological series. This estimator is resistant to the effect of outliers and robust to non-normal data distribution. Statistical significance of the trends was tested by using the non-parametric two-tailed Kendall's tau test [6].

2.3 Rice production and cultivation calendar in northeast Thailand

In northeast Thailand, there were three major rice varieties that accounted for almost 90% of cultivation areas [2]. These were Khao Dawk Mali 105 (KDML105, accounted for 48%), RD6 (34%) and RD15 (7%). KDML105 is an aromatic and nonglutinous variety released in 1926, whereas RD6 and RD15 are KDML105 mutants, produced by the gamma ray treatment, and were released in 1977 and 1978, respectively [14]. These are photoperiod-sensitive varieties and usually planted at beginning of raining season (around June-early July). However, the timing of planting and subsequently harvesting varied from year to year depending on rainfall. Generally, the duration from transplanting to harvest averaged 127 days for KDML105, 139 days for RD6, and 124 days for RD15, respectively.

The earliest sowing date usually occurred in mid-April and the last sowing date was in late August. The sowing date averaged was early June. Transplanting started in the middle to end of May and lasted until early to middle of September. The averaged transplanting date was early of July. Heading started in middle to end of August and lasted until middle to late of November. The heading date averaged over all varieties was early to middle of October. Harvesting started at the end of October and lasted until middle to the end of December. The average time for harvesting was the end of November [15].

2.4 Temperature threshold and high temperature stress severity indices

In this study, the high temperature threshold considered to induce stress and therefore potentially damage rice production was determined as the daily maximum temperature of equal or exceeding 35°C. This criterion is based on the previous study results of Yoshida [7] and later applied by various researchers to evaluate the impacts of high temperature on rice production [16-17]. In the current study, high temperature records in the northeast Thailand were analyzed and reported station-wise. To be as much as possible consistent with rice calendar, the temperature data over 30 years were analyzed on a monthly basis. The monthly simple potential impact scores at each meteorological station were calculated from a summation product of three indices. The first index is the numbers of day having maximum temperature ≥35°C (accumulative numbers of day during 30 years). The second index is the rate of change (increasing/ decreasing) in numbers of day at given station having maximum temperature ≥35°C over 30 years (number of day/30 years). The third index is the numbers of events (i.e. for each month how many times during 30 years the records at particular station consecutively experienced daily maximum temperature exceeding 35°C and lasted for ≥3 days or more). We selected the duration of ≥3 days or more because there have been numerous studies suggesting that exposing rice plant to such temperature and extending duration can induce significant damages to rice growth and productivity [7-8]. Each index was divided into four levels (levels 0-3) based on magnitude and frequency of occurrence (on another word, its severity). From the combinations of three indices and four levels of severity, potential impact scores were calculated resulting in totally ten impact levels (score 0 to 9). These were then grouped into 4 levels of impact indication; no impact (score 0); low impacts (score between 1 and 3), moderate impacts (between 4 and 6), and high impacts (between 4 and 9) as shown in Table 1 and Table 2.

3. Results and Discussion

3.1 Overall trends of annual temperature during 1983-2012

The analysis of temperature data was firstly performed on the overall changes in temperatures (Fig. 2). During 30 years of measurements at all 19 meteorological stations, the daily mean, maximum and minimum temperature has statistically increased. During 1983-2012 the mean temperature in northeast Thailand was 26.8°C, and this has increased at the rate of 0.11°C/decade ($p \leq 0.05$). For daily maximum and minimum temperatures, the increase rates were 0.16°C/decade and 0.28°C/decade ($p<0.01$), respectively. This analysis results agreed well with the trends over the whole Thailand during 1955-2009, where the increasing rate of minimum (0.27°C/decade) temperature has been found to be much faster than the mean temperature (0.18°C/decade) and the maximum (0.16°C/decade) [6, 10].

Both frequency and magnitude of high temperatures are important for evaluating the potential impacts of high temperature on rice production. In this study we therefore emphasized on the daily maximum temperature. Overall, the annual average, minimum and maximum values of daily maximum temperatures during this 30 years period were 32.5, 15 and 43.3°C, respectively. The average daily maximum temperature in northeast Thailand is therefore below the critical temperature potentially affecting rice production (≥35°C). About 60% of total daily maximum temperature data fell with the ranges of 31-35°C. However, the maximum ones clearly exceeded the threshold temperature for rice production. This study was then focused on analysis of timing and spatial distribution of those days with ≥35°C, which made up about 40% of all maximum temperature records.

The temperature trends in most part have been in good corresponding to the El Niño Southern Oscillation (ENSO) phenomena. During the El Niño periods, the warmer than usual years were usually observed, especially during the strong El Niño periods of 1986-88, 1997-98 and 2009-10. The cooler than usual, on the other hand, were usually observed during La Niña events (for example in 1984-85, 1988-89, 1995-96, 1998-2000 and 2005-06 [18]. The warmest (1.0°C above the average of 1983-2012) and coolest years were 1998 and 2011 (0.7°C below the average), respectively

Although warming in the Northeast was common, large temporal and spatial variations were observed. Spatially, there were several stations that have experienced relatively warming with varying degree of changes in individual temperature components (maximum, mean and minimum temperatures). For example, station no. 7 (Mukdahan) showed the highest increase in maximum and mean temperature (0.5, 0.37°C/decade, respectively), while station no. 15 showed the highest increase in minimum temperature (0.73 °C/decade, Fig. 3). Thus, while general warming trends were observed, this warming also to certain degree was probably modified by local conditions and characteristics of the meteorological stations.

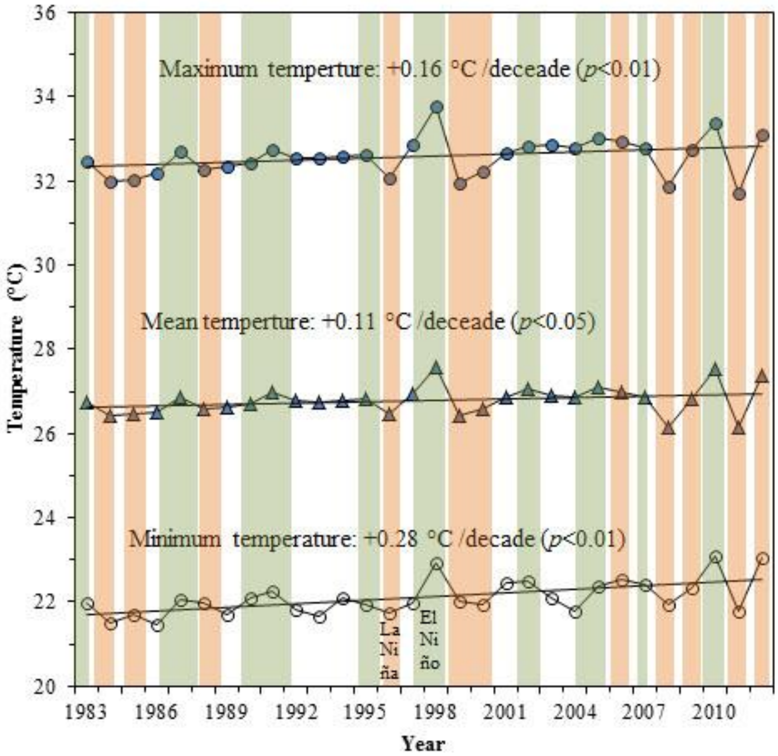

Figure 2. Overall trends during 1983-2012 of annual maximum, mean and minimum temperature. The shading areas indicate the duration of La Nina and El Nino.

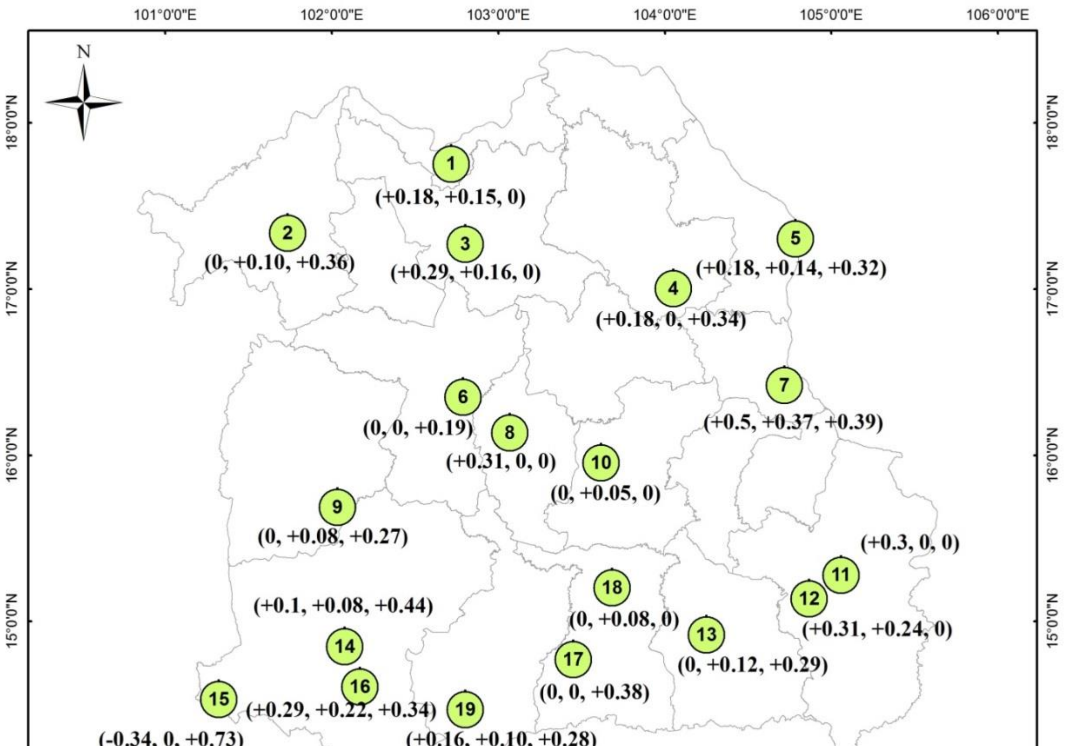

Figure 3. Spatial variations and trends of temperature change during 1983-2012 among all meteorological stations in northeast Thailand. The three values associated with each station location indicate annual maximum, mean and minimum temperatures, respectively. When zero (0) is used, it indicates that change of that temperature component is not statistically significant at p≤0.05 by Kendall'tau non-parametric test.

3.2 Changes in monthly maximum temperature indices

3.2.1 Cumulative numbers of days with temperature ≥35°C

The numbers of days with temperature ≥35°C for each month during the study period were counted and reported. This count included any single day with temperature ≥35°C and any continuous warming days that lasted more than one day. Except the Station No. 15 (Pak Chong located in mountainous area), 17-30% of days (2,000-3,000 days of total daily records during 30 years) were found to experience the maximum temperature ≥35°C (Fig. 4A). Station No. 8 (Kosum Phisai) stood out with the highest warming numbers. The average value per station was 2,290 days (20% of total). These high temperature days usually concentrated during the hottest months (February-May, Fig. 4B). These are during the dry season when cultivation of rice and other crops do not usually occur.

3.2.2 Rate of changes in numbers of days with temperature ≥35°C

When evaluating the impacts of past or future climate change, the rate of change is one of the important aspects. Knowing this will be very helpful for considering how urgent the adaptation measures would be needed. In this study, we analyzed the changing rate of day with temperature ≥35°C during the last 30 years. Table 3 shows these analysis results. It is obvious that variations among stations as well as among months in a given year were common. Changes can be found in both positive (increase) and negative directions. In this study, we focused on only those changes in trends with statistically significant. Interestingly, during the hottest period of the year (Feb-May), most of the stations show the decreasing trends in number of days with temperature ≥35°C (though in many cases not statistically significant). However, during other months these showed the increasing trend. Worth mentioning is a significant decrease at Station No. 15 (Pak Chong) in March and April of 15.2 and 14.2 days/30 years, respectively, and the significant increases during June-December at Stations No. 7 (Mukdahan) and 8 (Kosum Phisai). In addition, it is apparent for all stations except Station No. 15 that the numbers of days with temperature ≥35° C in November have also increased.

Table 3. Impact levels derived from high temperature indices that are used to descript the potential impacts of daily maximum temperature on rice production.

Impact level	Description
0	No impact
1-3	Low impact
4-6	Moderate impact
7-9	High impact

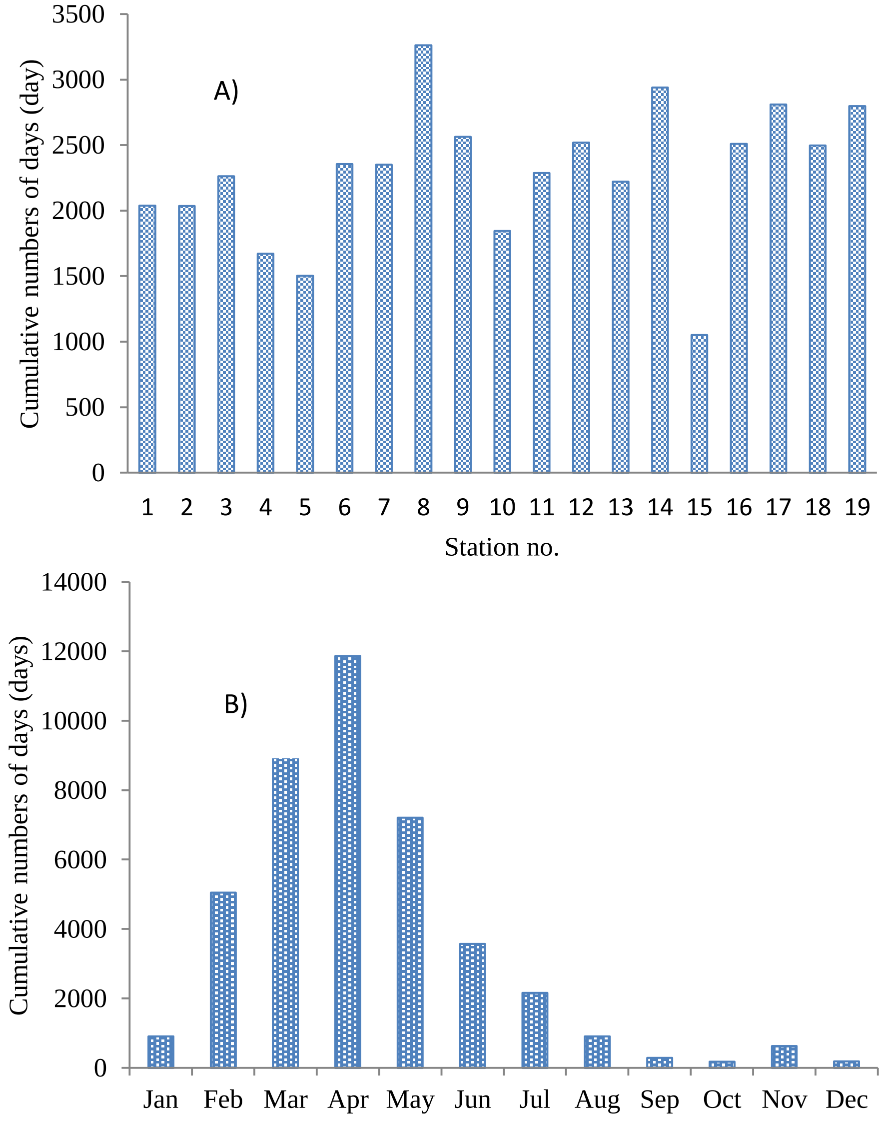

Figure 4. Distribution in cumulative numbers of days with daily maximum temperature ≥35° in northeast Thailand during 1983-2012, A) spatial distribution among all meteorological stations and B) temporal variations among months in a year.

3.2.3 Numbers of ≥ 3 consecutive days with temperature ≥35°C

Apart from the cumulative numbers and rate of change, the duration over which the temperature ≥35°C persist can have significant impacts on rice yield [29]. In northeast Thailand, although there were high numbers of days with temperature ≥35°C but these did not continued consecutively for more than 2 days. The numbers of high temperature events generally fell between 2 and 6-8 times during 1983-2012. This seems to be found more at the stations located in the southern part (station no. 12-19). However, at station No. 8, this event was more frequent (13 times) than other stations (Fig. 5A). Similar to other temperature indices, the occurrence of this event was concentrated in the hottest months (February-May) of each year (Fig 5B).

3.3 Potential impacts of high temperature on rice production in northeast Thailand

Rice, like other cultivated crops, has variable temperature optimal more or less specific for each growth stage. Deviation from the stage-dependent optimum temperature will alter the physiological activities or lead to a different developmental pathway [16]. In addition, the response of rice to temperature stress depends on duration, intensity, period of its occurrence (day or night), and rate of temperature change [29].

Combining the temperature indices mentioned above into the potential impacts indicator, we found that in general the potential impacts were low, except at station no. 8 (Kosum Phisai) where the moderate impact level was found (Fig. 6). This station was where the occurrence of all three aspects of daily maximum temperature indices were concurrently observed. For all other stations, usually not all of these temperature indices concurrently observed and this was the main reason why the estimated impact level was indicated as low. On the monthly basis, the results indicate that potential effects of high temperature were found at all stations and throughout the year. However, the levels of impacts varied. Low impacts were identified for January, September, October and December for majority of stations. During February-June and in November the impacts were moderate. The high impacts were found at station no. 8 in March, June and July, Station no. 13 in March and station no. 18 in April. In addition, there was a general trend that for all stations the levels of impacts usually increased from January and peaked around March-April (Fig. 7).

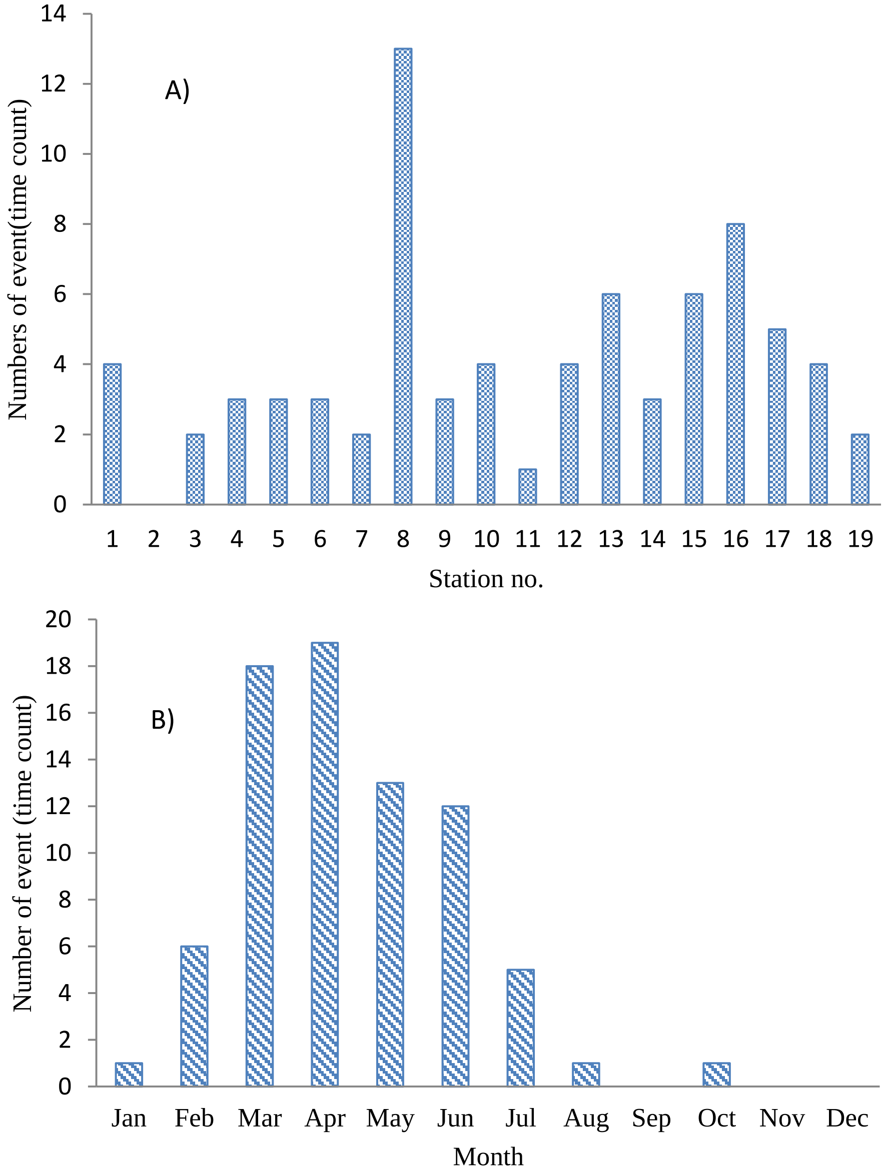

Figure 5. Distribution of numbers of ≥ 3 consecutive days with temperature ≥35° in northeast Thailand during 1983-2012, A) spatial distribution among all meteorological stations and B) temporal variations among months in a year.

Table 4. Monthly rate of change for numbers of days with daily maximum temperature ≥ 35ºC during 1983-2012. Bold values indicate the rates of change that are statistically significant at p≤0.05 by Kendall'tau non-parametric test.

Station	Number of days with daily maximum temperature ≥ 35ºC (days)											
No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.3	4.8	-3.4	-4.0	-2.0	2.2	-12.6	0.3	**2.1**	0.4	**3.1**	0.2
2	0.9	3.5	-3.3	-6.1	-0.6	1.6	-0.7	-0.8	-0.4	0.4	**2.0**	0.0
3	1.1	**7.7**	-0.4	-2.9	2.2	2.4	2.5	0.2	**1.6**	0.7	**4.0**	0.3
4	0.9	4.5	-3.4	-1.3	1.9	3.3	2.0	-0.3	0.6	0.5	**3.3**	1.4
5	0.9	4.9	-0.3	-4.3	0.4	0.2	-0.6	0.3	0.4	0.4	**1.7**	0.0
6	0.8	-1.7	-3.5	-4.2	-1.2	3.3	-0.1	-0.5	0.8	0.4	**3.3**	0.0
7	3.1	**11.0**	2.6	0.5	4.5	**8.2**	**5.5**	**2.8**	**2.4**	**1.9**	**5.2**	1.4
8	3.0	1.9	-0.8	-4.1	3.7	**8.8**	**9.2**	**4.4**	**3.3**	**3.0**	**7.0**	**2.9**
9	2.0	2.9	-3.4	-4.2	-4.5	2.1	-0.8	-0.9	-0.5	0.4	**3.6**	0.2
10	0.5	2.6	-3.0	-5.6	-1.5	3.7	1.1	-0.2	0.1	0.0	**2.5**	0.4
11	2.2	4.2	1.4	0.6	2.4	2.7	2.6	0.5	0.1	0.5	**4.7**	**2.9**
12	1.2	5.1	0.6	-1.4	1.8	4.8	1.9	**1.1**	0.1	0.8	**5.1**	**2.3**
13	-0.5	5.5	-2.6	-0.9	-0.4	2.6	1.5	0.3	-0.3	0.2	**2.3**	**0.5**
14	1.3	-0.1	-5.1	-4.8	-2.9	3.4	0.5	3.1	-0.2	0.3	**2.4**	0.0
15	-0.5	-3.7	**-15.2**	**-14.2**	-4.7	0.4	-0.5	0.0	0.0	0.0	0.3	0.0
16	1.6	4.6	-3.0	-2.3	2.5	6.2	0.6	**4.4**	0.2	0.6	**2.2**	**1.0**
17	0.5	2.5	-4.3	-3.5	-1.5	3.7	-0.6	0.2	0.8	0.9	**3.8**	**0.9**
18	0.2	-0.1	-4.9	-5.1	-2.2	2.4	0.4	0.1	0.1	0.2	**3.0**	0.6
19	2.5	0.7	-3.8	-2.8	1.2	1.0	-1.1	1.7	0.0	0.2	**2.4**	0.8

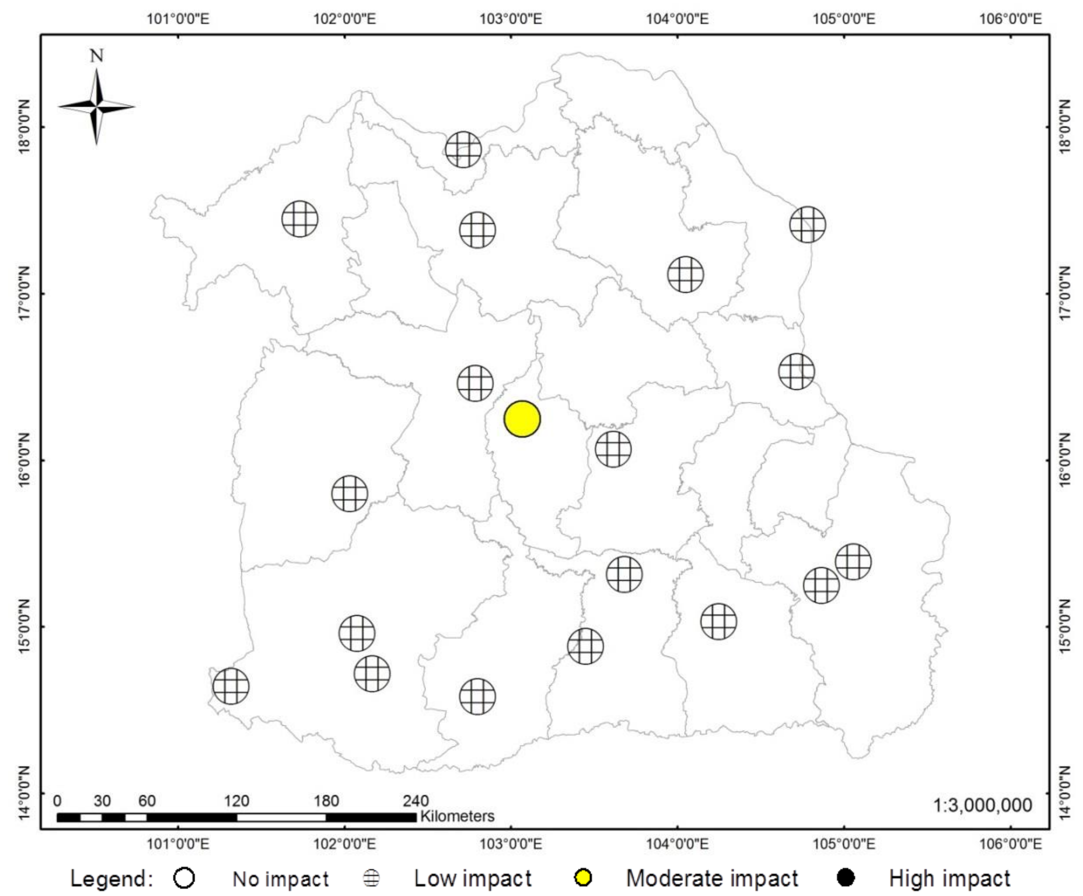

Figure 6. Potential impacts of daily maximum temperature (≥35°C) on rice production in northeast Thailand, calculated from temperature records during 1983-2012.

According to Satake and Yoshida [19], the most sensitive stages to high temperature stress are flowering (anthesis and fertilization) and booting (microsporogenesis). Temperatures ≥ 35˚C at anthesis and lasting for more than1 h were reported to be the cause for high sterility in rice [20]. Spikelets that were exposed to temperatures >35°C for about 5 d during flowering became completely sterile [21]. In northern Thailand, on average rice cultivation is usually started around early June. Majority of stations during this time appeared to suffer a low potential impact from high temperature, except at station no. 8 where high potential impacts still persisted. Yoshida [7] reported that during this stage the germination percentage decreased when exposed to the temperatures between 15-37°C for 2 days. The consistent results were also reported by Ali et al. [22] who found that high temperature reduced the overall germination about 40%. However, after germination the high temperature (≤40°C) could promote seedling growth, increase the rate of leaf emergence and could provide more tiller buds [7]. Elongation of the radicle also stops at the temperature above 40°C. Therefore, high temperature stress has an influence in both the development and damage to early-rice growing. In order to lessen or avoid these impacts, Babel et al. [23] suggested that adjusting the sowing dates and determining the optimal dates will be helpful in declining the effect of high temperature.

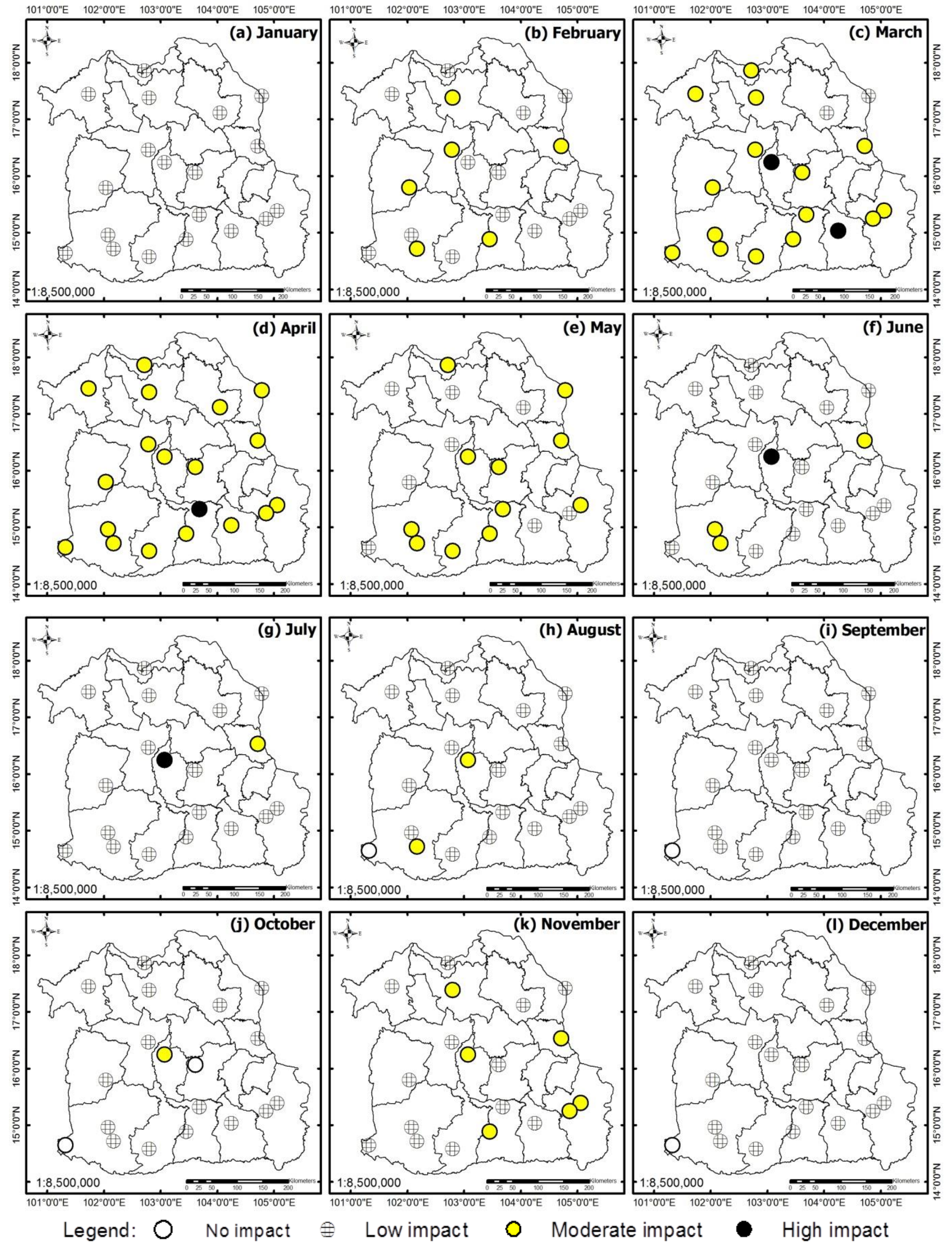

Figure 7. Distribution of monthly potential impacts of daily maximum temperature among all meteorological stations, calculated using 30 years temperature records from each station.

The main rice variety grown in the northeast was KDML105 with flowering date on average falling around the second week of October (RD, 2014) but this may extend until middle to late of November. The months of August, October and November appeared to experience both a moderate and low impacts. In November, 32% of stations show a moderate impact. Studies in past indicate that one or two hours of high temperature exposure at anthesis has a decisive effect on the incidence of sterility [7, 16]. In addition, these studies indicate that high temperature (35°C) during microsporogenesis and anthesis resulted in 34% and 80% decline in spikelet fertility, respectively. Anthesis in rice is extremely sensitive to high temperature and spikelets opening on any flowering day during the flowering period (5-7 days) could be affected differently depending on the duration of exposure [7, 16].

The harvesting stage of main rice-growing season in northeast Thailand was on average during late October to December. During this period majority of station appeared to have a moderate impacts from high temperature. For this stage of rice growth, high temperature affects cellular and developmental processes leading to reduced fertility and grain quality [24, 16]. Decreased grain weight, reduced grain filling, higher percentage of milky white rice are common effects of high temperature exposure during ripening stage [7, 16]. Studies on the effects of future climate change with 5°C increase in temperature resulted in a decline in rice yield of 33.89% for KDML105 and 19.83% for RD6 [23]. This yield loss may be caused by heat-induced spikelet sterility or increased crop respiration loss during grain filling, which reduces the grain-filling capacity and thus reduces the grain yield [25].

Another important aspect of temperature effects on rice quality is the occurrence of chalky grain resulted from high temperature. Chalky rice occurs frequently when the average temperature during the 20 day period after heading is above 26–27°C [26]. Since the heading date in northeast region averaged over all varieties was around early to middle of October and the averaged mean temperature during this period over 30 years was 25-27°C, it is likely that rice quality has been also affected by such high temperature episodes.

Despite the potential impacts of high temperature as mentioned above, it is still difficult to draw a general relationship between temperature and past yield records. This is because there are many other factors that could affect rice yield during growing season. These include, for example, water availability and management, pest and diseases, fertilizer application and others. However, our study results do suggest that high temperature associated with climate variability in Northeast Thailand may potentially dampen rice production.

In view that climate change will likely result in more extreme climatic conditions in rice growing regions [5] and that rice cultivation are likely subject to high temperature stress, more details investigation on the potential impacts should be investigated. Since this study can be considered as only overview/speculation from temperature records, other supportive analysis should be further carried out. For example, high night temperature is often found to be more damaging than high day temperature [27]. Wide diurnal temperature variation can make plants more stressed with hot days and cold nights while narrow variation can lead to more respiration with large outflow of photosynthetes. According to Ziska and Bunce [28], the ratio of respiration to photosynthesis increases with increasing temperatures. In addition, the key physiological processes such as anthesis respond to temperature change at minute to hour time scale, detailed temperature measurements at sufficiently high time resolution are needed to improve our understanding of responses and process mechanisms that lead to accurate evaluation of impacts of temperature on rice growth and yields.

4. Conclusions

Temperature records during 1983-2012 in northeast Thailand from 19 meteorological station showed that overall daily maximum, mean and minimum temperatures have been increased. However, the rates of increase were different among meteorological stations. Analyzing three aspects of daily maximum temperature; numbers of days with temperature ≥35°C, cumulative numbers of days with temperature ≥35°C, and Numbers of ≥3 consecutive days with temperature ≥35°C revealed that all stations were subject to potential impacts from high temperatures. Overall index show that the station no. 8 (Kosum Phisai) ranked highest and thus has subject to impacts of high temperature during the 30 years period. With a year and for all stations, the months of February-May appeared to be most vulnerable to high temperature, while the months of November was also moderately vulnerable. Given that rice cultivation in northeast Thailand is usually started in April-June, and rice plant heading around October-November, we concluded that high temperature may potentially cause stresses to rice growth during its vegetative period and to yield and its component during its reproductive period. It is therefore suggested that detailed study with comprehensive temperature measurements and growth records be needed to improve our understanding of the impacts of climate change and variability on rice production in northeast Thailand.

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