APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM WITH FIELD EXPERIMENT TO ASSESS SUITABLE ZONATION MAPPING FOR RICE CULTIVARS UNDER PROJECTED GLOBAL WARMING IN LOWER NORTHERN THAILAND

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ABSTRACT

The aims of this research were to assess the effects of increased temperature on total chlorophyll and grain yield of 5 commercial Thai rice cultivars (Chinat1, Pathumthani1, Phitsanulok2, KorKhor29, and Riceberry) in lower northern Thailand. Nine field-open top chambers (OTCs) with electric systems were applied from 2018 to 2020 in Phitsanulok to simulate projected 2 future temperature situations in 2100 which consistent with RCP4.5 and RCP8.5 scenarios (higher than ambient level by 2.6℃ and 4.5℃, respectively). The results under field experiment revealed that the negative significant impacts on total chlorophyll were obvious appeared in KorKhor29 under RCP8.5 scenarios. In addition, results in grain yield indicated that decreases in yield were correlated with increased temperature under both of 2 situations. The high reduction in total grain yield (ton per ha) were also found in Riceberry and Phitsanulok 2 under RCP8.5 scenario by 88-95%. However, it seems that Chainat1 was heat-tolerant cultivars under both of 2 warming situations, by the way in which the property of increases in total chlorophyll and grain yield. Then all results were combined with the spatial temperature model and analyzed by the GIS to assess suitable zonation mapping for rice cultivars under projected global warming in lower northern area. As a result, we also found the positive effects of temperature rise on grain yields in Chainat1. These results are parallel to findings from the field experiment. The data indicated that under projected future temperature levels, it seemed that Tak province, Phitsanulok and Uttaradit provinces were suitable areas for rice cultivation. Chainat1 cultivar should be selected for cultivation in this area, especially in Tak province.

1. BACKGROUND

The Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report (AR5) revealed that as global mean temperatures increase, there will be more frequent hot temperature extremes in the tropics regions. In the RCP8.5 scenario, which projects the most rapid global warming when emitting GHGs at their current level (with more than double emissions), projects 2.6-4.8ºC temperature increase. In the RCP 4.5 scenario, where most GHG emissions are almost eliminated after the 21st century, the projected temperature range increase is 1.1-2.6ºC (IPCC, 2013).

Rice is a staple food for approximately half of the world's population, however there is plenty of research evidence that rice yield will be influenced negatively by temperature increases in many parts of the world because physiological processes of crops are largely affected by high temperature stress (Thanacharoenchanaphas and Rugchati, 2018). IPCC has also reported that heat stress is projected to increasingly responsible for rice yield reduction in tropical regions without adaption (Shi et al., 2016). In Thailand, rice is the important economic crop. Meanwhile, the status of current mean temperature during the rice planting season has been changed at meteorological observatories in the northern regions of Thailand (Limsakul *et al*., 2011). Hence, Thailand might affected on the food security under climate change.

Thus, it is necessary to analyze suitable zonation mapping for rice cultivars under projected global warming. The temperature dataset widely used for spatialization called interpolation techniques including Inverse Distance Weighting (IDW) Ordinary kriging (OK), temperature lapse rate (TLR), and Multiple linear regression (MLR). Chai et al. (2011) was compared the technique for temperature interpolation in Xinjiang Uygur, China. The result showed the performance of IDW technique while using the directly interpolating observed temperature. The IDW shows the strengths including rapid, accurate and easy to applied while using the non-complex method. Moreover, Jiang et al. (2021) was developed the adaptation modeling of maize under climate change situation. The temperature data set was interpolated using IDW technique with agrotechnology transfer (DSSAT) model. The result showed slightly relative error (<5%) and high index of agreement (0.8).

Estimating the impact of climate change on yield of rice cultivars and the evaluation of appropriate adaptation and mitigation strategies are of extreme concern to development of new agricultural areas and use of heat resistant varieties to stabilize the rice yield in Thailand in future.

2. METHODS

2.1 Field Warming Experiment and Rice Planting Management

The experiment was conducted at Phitsanulok province (16°799790′, 100°225468′E) in lower northern Thailand during 2018 to 2020. Nine field-open top chambers (OTCs) with electric systems were applied to simulate projected future temperature situations which consistent with RCP scenarios. Three controlled temperature levels with three replications were set up by black infrared bulbs and air conditioners that linked to the automatic controlling system to maintain at ambient level (32.55±1.48°C ; Control treatment) including two elevated air temperature by 2.6°C (HT4.5 treatment) and 4.5°C (HT8.5 treatment) under RCP4.5 and RCP8.5 scenarios, respectively. At seedling growth stage, all five cultivars were exposed to three different temperature situations for 10 hr. day^{-1} exposure (7.00 am – 5.00 pm) in open top chambers until harvest.

2.3 Chlorophyll Analysis

At the flowering stage, rice fresh leaves were sampled and cut into pieces for determining total chlorophyll. They were extracted by 80 percent acetone. Then green pigment extract solutions of leaves samples were passed through a UV-VIS spectrophotometer at 2 wavelengths :663 nm and 645 nm. Total Chlorophyll content for each sample was calculated according to Arnon (1949) as follows (equation 1):

$$\textit{Total Chlorophyll (mg/g. fw)} = (20.2 \times \lambda_{645}) + (8.02 \times \lambda_{663}) \qquad (1)$$

2.4 Yield Component Analysis

At the maturity stage, 12 plants per cultivar were harvested from each treatment. Total number of grains, filled grains (complete grains) and unfilled grains (incomplete grains) per panicle were counted manually from the panicles which were selected randomly. Total filled grains and unfilled grains per panicle was used to calculate percentage of filled grains. panicle^{-1}.

The 1000 grain weight was determined by digital balance at about 14% moisture content. The thousand grains weight was expressed in gram (gm). The 1000 grains weight of grain from each cultivar was recorded. The data was converted and reported as grain yield as ton. ha^{-1} by following equation 2 (Yoshida, 1981).

Grain yield (t/Ha)=no. of panicles per m^2 *x %filled grains per panicle x 1000 grain weight(g) x* 10^{-5} *(2)*

2.5 Modeling and Zonation Mapping

Daily temperature dataset was obtained from Meteorological Department of Thailand. The data was collected from weather station from 1950 to 2019. Pycharm 2021.1.1 (Python) was applied for the data screening and preparation. The prepared temperature data was interpolated using IDW by QGIS 3.14. The province boundary data was obtained from Royal Thai survey department. The rice paddy area data was obtained from Land development department.

2.6 Statistical Analysis

The total chlorophyll and yield component value data were analyzed statistically with analysis of variance (ANOVA). Significant difference of parameters were reported at p<0.05 by DMRT.

3. RESULTS

3.1 Total chlorophyll content

Results in total chlorophyll content showed the obvious positive by elevated temperature under HT4.5 situation. The significant increases (p<0.05) were shown in both Chinat1 and KorKhor29 cultivars. We found that, elevated air temperature by 2.6°C induced increase by 21.3% and 3.2% in Chinat1 and KorKhor29, respectively. However, the significant increase was not found under HT8.5 situation (p>0.05) (Table 1.).

3.2 Yield component

Grain yields under field experiment were harvested at maturing stage to assess grain quantity (Table1). The results showed the obvious negative significant impacts (p<0.05) on percentage of filled grains per panicle in Pathumthani1, Pitsanulok2 and Riceberry under both of 2 situations (HT4.5 and HT8.5). The percentage of filled grains.panicle^{-1} of Pathumthani1, Phitsanulok2 and Riceberry fell 24-28% under the HT4.5 situation, respectively. The dramatic significant decrease higher than 50% under the HT8.5 situation were appeared in Phitsanulok2 and Rice berry. However, the positive statistically significant results were shown in Chainat1 and KorKhor by 13.6% under RCP4.5 scenario.

Results in total grain yield (ton. ha^{-1}) indicated that there were significant trends (p<0.05) of decreases in grain yield under increased temperature trend. The significant effects of the increase temperature at 2.6°C (under HT4.5) caused grain yield loss by 48% in riceberry. The results also showed that the cumulative effects of the elevated temperature at 4.5°C (HT8.5) obviously reduced grain yield by 94.9% and 88.1% in Phitsanulok2 and Riceberry, respectively. In contrast, the great significant increase of grain yield by 60.8% under increase temperature at 2.6°C was shown in Chainat1. Overall results in this part suggest that Phitsanulok2 and Riceberry are susceptible to heat stress during grain filling stage. In contrast, Chainat1 is highly tolerant to heat stress. Because, results under field experiment revealed that increasing temperature under RCP4.5 and RCP8.5 induced the positive responses in total chlorophyll content and grain yield.

It is possible that, a defense mechanisms might occurs in Chainat1 cultivar under increasing temperature. It is possible that they have the potential controlling heat tolerance genes during reproductive stage or grain filling stage (Ye et al., 2015; Wu et al., 2021).

3.3 Suitable Zonation Mapping for Rice Cultivars

Daily temperature dataset was collected form 118 weather stations but 16 stations were located in the lower northern part of Thailand. Then, the data was analyzed and calculated the function of temperature increasing rate using linear regression. The differential of the linear function was determined as daily temperatures and calculated as the temperature over the next 100 years. The result is shown in Table 2.

The temperature dynamic data indicated that the highest increasing trend was found on the northern Tak, southern Nakhonsawan including southern and northern Phetchabun. These area trended to increasing the temperature approximately 2.5-3.7°C which related with the RCP4.5. On the other hand, the south of Tak was showed the surprised result which its temperature decreasing trend. The temperature level in this area trends to decrease by 3.65°C over the next 100 years. This might be the effect of western forest complex of Thailand. For the insanely results were the data from central of Sukhothai and central of Pichit, they were removed from our experiment due to its discrepancy.

Table 1. Mean values (±SD) of total chlorophyll, percentage of filled seed. ear^{-1}, and grain yield observed from samples of 3 treatments and exposed to elevated air temperature levels in 5 rice cultivars.

Rice Cultivars	Treat ment	total chlorophyll (mg. g fw^{-1})			filled seed. ear-1 (%)			grain yield (t/ha)		
		x̄	Change**	Sig.	x̄	Change**	Sig.	x̄	Change**	Sig.
Chainat1	CT	39.97±5.49^{a}			64.4±14.2^{a}			1.81±0.63^{a}		
	HT4.5	48.47±3.88^{b}	+21.27	p<0.05*	73.2±14.1^{b}	+13.62	p<0.05*	2.91±0.57^{b}	+60.77	p<0.05*
	HT8.5	47.73±0.98^{ab}	+19.41		55.7±10.5^{a}	-13.44		1.93±0.36^{a}	+6.62	
Pathum thani1	CT	35.51±5.25^{a}			63.7±16.4^{b}			1.55±0.73^{a}		
	HT4.5	36.35±6.99^{a}	+2.36	p>0.05	47.7±22.0^{a}	-25.08	p<0.05*	2.13±1.36^{a}	+37.42	p>0.05
	HT8.5	43.47±0.07^{a}	+22.43		49.1±15.2^{a}	-22.91		0.9±0.44^{a}	-41.94	
Phitsa nulok2	CT	39.81±3.52^{a}			85.05±6.01^{c}			2.36±0.91^{b}		
	HT4.5	42.78±6.48^{a}	+17.31	p >0.05	64.43±4.56^{b}	-24.24%	p<0.05*	2.09±0.77^{b}	-11.44	p<0.05*
	HT8.5	41.44±4.88^{a}	+13.95		3.81±0.26^{a}	-95.52%		0.12±0.05^{a}	-94.92	
KorKhor 29	CT	44.06±0.76^{ab}			74.8±12.1^{a}			1.65±0.56^{a}		
	HT4.5	45.47±4.32^{b}	+3.19	p<0.05*	84.8±01.0^{a}	+13.36	p>0.05	1.94±0.35^{a}	+17.58	p>0.05
	HT8.5	39.10±0.57^{a}	-11.26		66.9±12.7^{a}	-10.55		1.18±0.25^{a}	-28.48	
Riceberry	CT	42.21±7.04^{a}			71.46±0.35^{c}			1.60±0.22^{c}		
	HT4.5	43.63±0.29^{a}	+3.36	p>0.05	51.77±10.59^{b}	-27.55	p<0.05*	0.83±0.21^{b}	-48	p<0.05*
	HT8.5	50.07±0.11^{a}	+18.63		12.06±2.48^{a}	-83.12		0.19±0.06^{a}	-88.13	

Note: The different letters for each treatment indicate a significant difference at $\rho<0.05$.

* A p-value less than 0.05 ($p\leq 0.05$) is statistically significant. ** Percentage change compared to control (CT)

Table 2. The dynamic temperature model of the lower northern part of Thailand

Station	Temperature change function	Differential	Temperature dynamic over the next 100 years (°C)
Tak (west)	6E-06x + 32.015	6.00E-06	0.22
Tak (south west)	-0.0001x + 32.446	-0.0001	-3.65
Tak (central)	3E-05x + 26.201	3.00E-05	1.10
Tak (north)	0.0001x + 31.97	0.0001	3.65
Tak (east)	3E-05x + 33.018	3.00E-05	1.10
Kamphaengphet (north)	7E-05x + 32.507	7.00E-05	2.56
Sukhothai (central)	-0.0004x + 39.868	-0.0004	-14.6*
Sukhothai (east)	4E-05x + 32.594	4.00E-05	1.46
Uttaradit (west)	-1E-05x + 33.994	-1.00E-05	-0.37
Nakhonsawan (central)	4E-05x + 33.583	4.00E-05	1.46
Pitsanulok (central)	9E-06x + 33.329	9.00E-06	0.33
Pichit (central)	-0.0004x + 38.638	-0.0004	-14.6*
Nakhonsawan (south)	0.0001x + 31.651	0.0001	3.65
Phetchabun (south)	8E-05x + 32.502	8.00E-05	2.92
Phetchabun (central)	2E-05x + 33.145	2.00E-05	0.73
Phetchabun (north)	7E-05x + 32.067	7.00E-05	2.56

*Outliner data was removed in next section.

Figure 1. was interpolated to the 350m grid of temperature increasing over the next 100 years using IDW. The four red area which represents the high increasing temperature trend including northern of Tak, central of Kamphaengphet, southern of Nakhonsawan, and northern of Phetchabun. The western of Tak was showed the decreasing trend which related to Table 2. Then, Figure 1 was overlayed with the paddy field data and showed in Figure 2. It shows the dynamic of

rice yield under global warming situation model was estimated the yield over the next 100 years based on our temperature dynamic. The results showed that Chainat 1 showed the increasing yield trend through the increasing temperature. This might be appropriate for high increasing temperature area like northern of Tak, central of Kamphaengphet, and Southern of Nakhonsawan which might be maximum increased more than 50-60 %yield from the present.

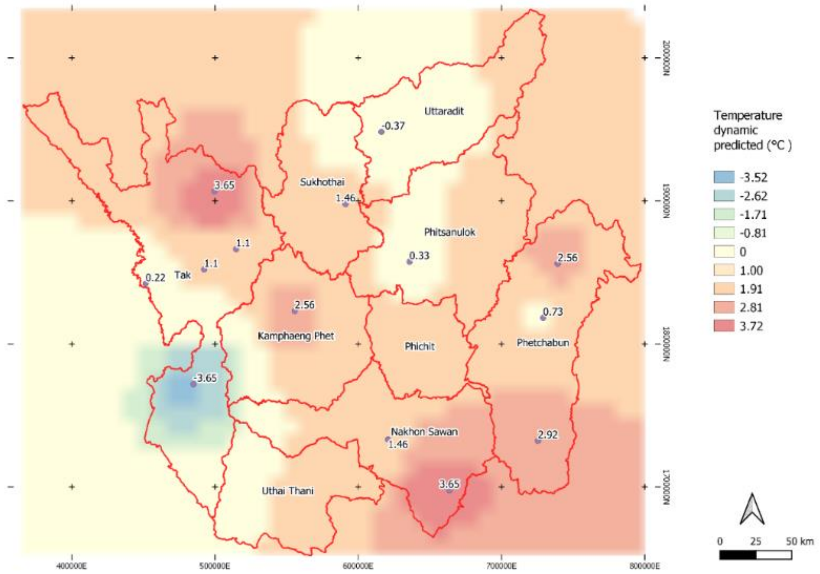

Figure 1. Temperature dynamic predicted over the next 100 years using linear regression and IDW.

However, other rice cultivars in ours experiment including Pathumthani 1, Phitsanulok 1, KorKhor 29, and Riceberry were showed the decreasing yield trend. Especially, Riceberry was showed the most sensitive on decressing yield. In our assumption, high temperature increasing area might reduce the Ricebery yield about 70%yield from the present.

The zonation mapping related with the temperature dynamic over the next 100 year showed the suitable rice cultivar that might be advantage on Chainat 1 yield. Northern of Tak and southern of Nakhonsawan showed its efficiency to increasing the yield approximately 70% yield under global warming situation. Pathumthani 1 showed the slightly effect on temperature (-10 to 10%yield) which depended on the area, excepting the western of Tak might incressing yield to 50%yield. This was found similarly result with the Korkhor 29. For the both of Phitsanulok 1 and Riceberry, the yield might reduce approximately 50-70%yield while planting in Northern of Tak, southern of Nakhonsawan, northern and southern of Phetchabun, and central of Kamphaengphet. We advised that they should be promoted to central of Phitsanulok, Uttaradit, and the western of Tak. Data revealed the evident increasing yield under the increasing temperature in Chainat1 cultivar. These results are parallel to results from the chamber experiment. Hence, Chainat1 cultivar should be selected for cultivation in this area.

5. CONCLUSIONS

The results from experiment with GIS showed that under projected future temperature levels based on RCP4.5 and RCP8.5 scenarios around the next 100 years, it seemed that Chainat1 is the tolerant cultivar, whereas Phitsanulok2 and Riceberry are susceptible cultivars. Finally, Tak province was the suitable areas for rice cultivation. Hence, Chainat1 cultivar should be selected for cultivation in this area, especially in Tak province.

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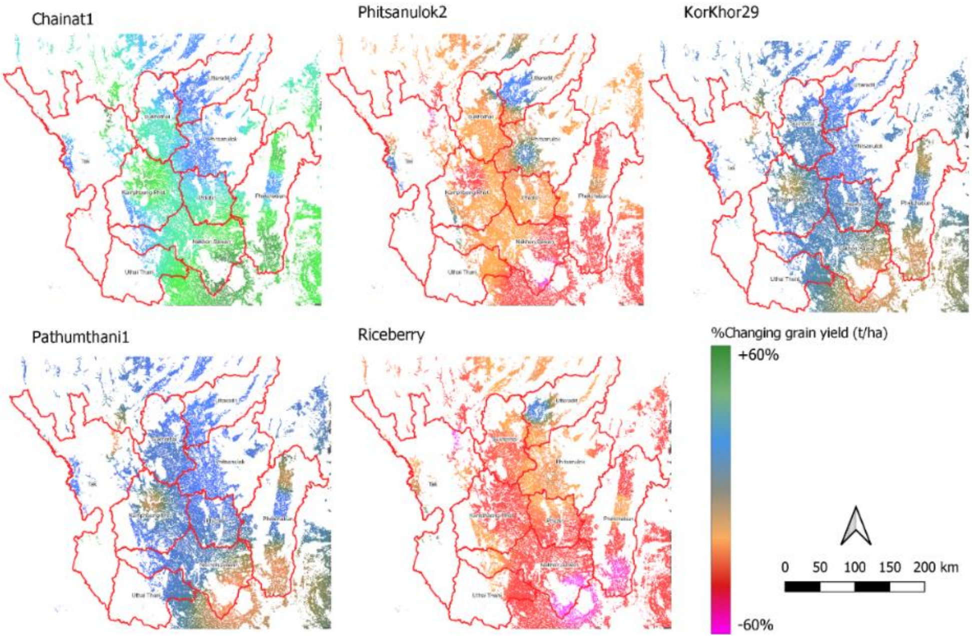

Figure 2. Rice cultivar zonation mapping under projected global warming

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