Estimating variability of growing season and drought occurrence for rainfed lowland rice area by simulation model

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ABSTRACT: A simulation model was used for estimating the start and end of growing period using rainfall data from 8 meteorological stations in the Northeast during 1951-2014. Three groups of rainfall based on mean across 64 years were separated to be high (1556 mm.), intermediate (1397 mm.) and low (1161 mm.) rainfall groups. To determine the difference in rainfall, start and end of growing periods (SGP and EGP) and opportunity of drought occurrence, the rainfall data were grouped into 5 periods, 1951-1979, 1980-1989, 1990-1999, 2000-2009 and 2010-2014 in comparison to means of 64 years. Amount of rainfall among the periods was not different, excepted 2000-2009 which was slightly increased. Start and end of growing period were determined at 80 percentage probability. Mean of SGP was not different between the high and intermediate rainfall groups (late May) but it was late under low rainfall group to mid-June to late July. Among the periods of years, there was no difference but it trended to be earlier for the last 5 years period. Mean of EGP across 64 years was earlier for the lower than higher rainfall groups. Among the periods, there was no difference, excepted during 2010-2014 which trended to be slightly delayed. Possibility of early season drought (ESD) was higher in low than high and intermediate rainfall groups. However, there was the increase during the last period in comparison to mean of 64 years for intermediate rainfall group. Late season drought (LSD) occurrence was the same as ESD which higher in lower than higher rainfall groups. The result suggested that there was not much change in SGP and EGP. However, there was increase in possibility of ESD under low and intermediate rainfall groups. In order to minimize risk to the change, planting date and rice varieties need to be considered.

Keywords: simulation model, growing period, drought occurrence, rainfed lowland rice

Introduction

More than 80% of rice growing areas in the Northeast, Thailand was occupied by rainfed lowland (Rice Department, 2016). Grain yield varied across years and locations depended on rainfall. Based on results from a project "strengthening farmers' adaptation to climate change in the rainfed lowland rice system in the northeast, Thailand" which conducted across northeastern region from Bung Kan (upper region) to Nakhon Ratchasima provinces (lower region), rainfall varied from sites to sites and years to years resulted in variation of grain yield which obtained from crop cutting (ARDA, 2016). Recent farmer survey suggested that present variable rainfall condition was unpredictable as

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former (ARDA, 2012) which caused difficulty in setting for start of planting and selecting of suitable rice varieties. Long dry-spell during early season was also observed in some locations in which extreme situation rice could be growth. This can be a reason for difficulty in predicting of planting times because this long dry-spell is rarely occurs. In contrast, occurrence of early season flood was observed in some sites, particularly in upper NE. The flood situation causes delay in transplanting with old seedling age or in some extreme case young seedling was completely damage. Re-transplanting or re-broadcasting has to be made. In order to understand the present climatic condition a simulation model was used to estimate whether there were changing in growing period, start, end and length of growing periods, drought occurrence and determined for suitable rice varieties.

Simulation model has been used for characterizing of growing environment in several purposes. The simulation model used in this paper was developed at the University of Queensland (Inthavong et al., 2011) which consists of crop growth model developed earlier (Fukai et al., 1995) and water balance model (Tsubo et al., 2007). The model had four modules including length of growing period, net biomass and yield potential, yield reduction by soil nutrient and water stress. Input to soil water balance model included temperature, radiation, photosynthesis active radiation (PAR), rainfall, potential evapotranspiration (PET), soil water characteristics, soil nutrient, lattitude and land slope. Output of soil water balance is length of growing period, while for combined model it is estimate attainable grain yield. The soil water balance model executed in a user-friendly spreadsheet (Microsoft® Excel using macro programing language (Inthavong, 2009). This model had been used for characterizing growing period in the Northeast Thailand using rainfall data during period 10 years period of 1999-2008 in project of breeding drought tolerance for rainfed lowland rice in the Mekong region.

In order to understand present situation, rainfall of 64 years were analyzed to determine whether there was any change in rainfall among 10 years periods from 1951 to 2014 and effects of rainfall variability on growing periods, start and end of growing period and possibility of drought occurrence using water balance model. In addition, varieties suitable for each area were also demonstrated. Because of limitation in long term rainfall data, only 8 rainfall stations in 8 provinces were available for this work. The results from this work would be useful in minimizing risk due to rainfall variability.

Materials and Methods

Climatic data and soil condition

Input climatic data during 1951-2014 obtained from the Thai Meteorological Department included rainfall, temperature and potential evapotranspiration from meteorological stations in the Northeast, Thailand (Ubon Ratchathani, Sakon Nakhon, Mukdahan, Udon Thani, Surin, Roi et, Khon Kean and Nakhon Ratchasima) were used. Solar radiation was calculated from WeaData 2.0 program (Phakamas et al., 2013) and day length was calculated from number of possible sunshine duration (hr d^{-1}) as a function of latitude by van Keulen and Wolf (1986). The simulation was run under only loamy sand with 10% soil clay content which was the major soil type was used as an input. Soil water content at saturation, field capacity and permanent wilting point was estimated followed Saxton and Rawls (2006).

Simulation model

A simulation model consists of water balance and crop models which had been developed by Inthavong et al. (2011) were used. The model has been validated using soil water level under rainfed lowland condition of 9 farmer fields in Northeast, Thailand in 2013 which obtained from a project "strengthening farmers' adaptation to climate change in the rainfed lowland rice system in the northeast, Thailand conducted by Rice Department. The result was acceptable with correlation coefficient (r) of 0.69, Z-test 0.13 which was below the acceptable criteria of 1.96 and dr-stat of 0.54. By this model, start and end of growing periods (SGP and EGP), grain yield of 5 rice varieties and drought occurrence were estimated. Start growing period (SGP) was defined when soil moisture content was at field capacity for 3 weeks consecutively and end growing period (EGP) was taken when soil moisture was at permanent wilting point. Length of growing period (LGP) was the difference between start and end of growing periods. Start and end of growing period and LGP were determined at 80 percentage probability whereas drought occurrence was determined in percentage of each period. Time of drought occurrence divided into 4 periods i.e. first early season drought: ESD^{1st} (begin from SGP to week 24th or approximate Early April to middle June), second early season drought: ESD^{2nd} (begin from week $25^{th}$to 33^{rd} or middle June to August), mid-season drought: MSD (begin from week 34^{th} to 39^{th} or middle August to late September) and late season drought: LSD (begin fromweek 40^{th} to 45^{th} or early October to November). The ESD^{1st} and ESD^{2nd} coincide with seedling to beginning of tillering stage while MSD coincides with tillering stage and LSD is around 3 weeks before and after flowering. Drought occurrence was determined from simulated field water storage. The ESD^{1st}, ESD^{2nd} and MSD were defined when soil water content was lower than permanent wilting point at least for one week. Late season drought was defined when the soil water content was below saturation for three weeks before and after flowering time (Ouk et al., 2001). Number of years with drought occurrence was counted for each period of years and calculated to be probability. Grain yield of five rice varieties were estimated using mean weekly rainfall for each rainfall group. A crop model which was modified from the original developed by Inthavong et al. (2011) was used for estimating grain yield for five rice varieties. The original crop model was developed Inthavong et al. (2011) for TDK1 photoperiod insensitivity variety popular in Laos (Inthavong et al. 2011). In order to use for estimating for photoperiod sensitivity varieties, the original crop model was modified by incorporating flowering and harvesting equations. The modified model has been validated with result of acceptable (Sujariya, 2017).

Characteristic of 5 rice variety

Five recommended varieties included KDML 105 and RD6, RD15, RD12 and RD33. Two popular varieties in this NE region, KDML 105 and RD6 are photoperiod sensitivity flower around mid- October. RD15 and RD12 are early maturity photoperiod sensitive varieties flower around early October whereas RD 33 is photoperiod insensitivity which sowing to flowering of 100 days.

Results and Discussion

Rainfall characteristics

Means annual rainfall for period of 64 years (1951-2014), each 10 years period, (1951-1979, 1980-1989, 1990-1999, 2000-2009) and 5 years period (2010-2014) from 8 provinces, UBN, SKN, MDH, UDN, SRN, RET, KKN and NMA were shown table 1. Means across 64 years for each province varied from 1109 to 1599 mm. whereas period means of each province varied from 1001 to 1737 mm. There was consistent ranking of period means across provinces within each period. Therefore, rainfall were grouped based on ranking of period means to be 3 grouped, high, intermediate and low rainfall groups. The high rainfall group included UBN, SKN and MDH with mean range from 1525-1623 mm. intermediate UDN, SRN and RET with mean range from 1339 – 1552 mm. and low rainfall group included KKN and NMA with mean range from 1093-1239 mm. Standard deviation (SD) across periods for each province varied from 16 to 116 whereas mean SD for each group varied from 42 to 74. Across rainfall group, the intermediate group had highest SD while the lowest was high rainfall group. Variation among provinces was also observed for example in high rainfall group SD was highest

Table 1 Mean annual rainfall (mm.) for 64 years (1951-2014,BP) and each 10 years period, 1951-1979 (P1), 1980-1989 (P2), 1990-1999 (P3), 2000-2009 (P4) and 5 years period (2010-2014, P5) and standard deviation (SD) across 5 periods (P1 to P5) for 3 groups of rainfall from 8 provinces in Northeast, Thailand

Rainfall groups	Provinces	Main Annual Rainfall (mm.)						
		BP	P1	P2	P3	P4	P5	SD
High	UBN	1599	1582	1582	1609	1500	1652	55
	SKN	1572	1493	1493	1583	1634	1737	103
	MDH	1497	1502	1502	1504	1468	1480	16
	Mean	**1556**	**1525**	**1525**	**1565**	**1534**	**1623**	**42**
Intermediate	UDN	1442	1492	1492	1301	1439	1525	89
	SRN	1372	1294	1294	1353	1378	1575	116
	RET	1377	1410	1410	1363	1218	1464	94
	Mean	**1397**	**1399**	**1399**	**1339**	**1345**	**1522**	**74**
Low	KKN	1212	1192	1192	1212	1185	1353	71
	NMA	1109	1130	1130	1082	1001	1124	55
	Mean	**1161**	**1161**	**1147**	**1093**	**1239**	**1164**	**52**

Table 2 Means number days of consecutive wet days (CWD) for 64 years (1951-2014, BP) and each 10 years period, 1951-1979 (P1), 1980-1989 (P2), 1990-1999 (P3), 2000-2009 (P4) and 5 years period (2010-2014, P5) and standard deviation (SD) across periods for 3 groups of rainfall from 8 provinces in Northeast, Thailand

Rainfall groups	Provinces	Number days of consecutive wet days (CWD)						
		BP	P1	P2	P3	P4	P5	SD
High	UBN	121	123	120	118	117	118	2
	SKN	127	125	131	124	135	117	7
	MDH	117	118	115	117	118	111	3
	Mean	**121**	**122**	**122**	**120**	**123**	**115**	**3**
Intermediate	UDN	121	121	116	126	124	117	4
	SRN	119	120	117	120	119	115	2
	RET	108	107	108	109	108	111	2
	Mean	**116**	**116**	**114**	**119**	**117**	**114**	**2**
Low	KKN	107	107	107	108	107	111	2
	NMA	112	118	105	106	108	113	5
	Mean	**110**	**112**	**106**	**107**	**108**	**112**	**3**

in SKN (103) and lowest was in MDH (16). Similarly in intermediate group, the highest SD was found in SRN (116) and the lowest was in UDN (89). The consistent variation in annual rainfall ranking suggested that rainfall trend was unchanged across provinces. However, the variation across periods did not follow the amount of rainfall trend.

The consecutive wet days (CWD) was difference among rainfall groups but the difference was small among periods of year, similar to the difference in amount of rainfall **(Table 2)**. Within a group of rainfall the difference was smaller than between groups. Among period, the large difference was found only 2010-2014 which CWD decreased in high rainfall group but increased in low rainfall group.

Growing period

Start, end and length of growing periods were presented as mean of each rainfall group. The differences in SGP, EGP and LGP were observed across rainfall groups particularly SGP and LGP but the difference was small for EGP. Start of growing period for high and intermediate with range from week 20^{th} to 22^{nd} whereas low rainfall group range from week 24^{th} – 29^{th}. End of growing period was similar for all rainfall groups with range from week 44^{th} – 48^{th}. For length of growing period, high and intermediate rainfall group had longer of 23- 27 weeks than low rainfall group 17-21 weeks. Small variation in SD across periods suggested that the difference in growing period, SGP, EGP and LGP was small (Table 3).

Table 3 Start of growing period (SGP) , end of growing period (EGP) and length of growing period (LGP) for 6 periods of years 1951-2014 (BP), 1951-1979 (P1), 1980-1989 (P2), 1990-1999 (P3), 2000-2009 (P4) and 2010-2014 (P5) and standard deviation (SD) across periods under high, intermediate and low rainfall groups.

Rainfall groups	Period						
	BP	P1	P2	P3	P4	P5	SD
				Start of growing season (week)			
High	21	21	21	20	20	21	1
Intermediate	22	22	21	22	21	20	1
Low	28	28	25	29	24	27	2
				End of growing season (week)			
High	46	46	47	46	47	48	1
Intermediate	46	46	46	46	48	47	1
Low	45	45	46	45	44	45	1
				Number of weeks of length growth period			
High	25	25	27	26	27	27	1
Intermediate	24	25	25	23	26	27	1
Low	17	18	21	17	20	18	2

Table 4 Probability of occurrence for early, middle and late season drought (%) during 6 periods of years. 1951-2014 (BP), 1951-1979 (P1), 1980-1989 (P2), 1990-1999 (P3), 2000-2009 (P4) and 2010-2014 (P5) and standard deviation (SD) across periods for high, intermediate and low rainfall groups.

Rainfall groups	Period						
	BP	P1	P2	P3	P4	P5	SD
				Early season drought (%)			
High	16	21	17	10	13	7	5
Intermediate	25	28	17	20	13	60	17
Low	53	52	60	50	55	50	4
Mean	**31**	**34**	**31**	**27**	**27**	**39**	**5**
				Mid-season drought (%)			
High	6	5	3	7	7	7	2
Intermediate	17	19	23	13	10	7	6
Low	56	60	70	60	45	20	18
Mean	**26**	**28**	**32**	**27**	**21**	**11**	8
				Late season drought (%)			
High	43	47	30	50	47	27	10
Intermediate	44	48	37	53	33	40	7
Low	62	59	65	75	55	60	7
Mean	**50**	**51**	**44**	**59**	**45**	**42**	7

Probability of drought occurrence

Variation in probability of drought occurrence was observed among times of occurrence and periods of years (Table 4). Based on means across 64 years (1951-2014), the possibility of drought occurrence in late season (LSD) was more frequent than early season (ESD) and mid-season (MSD), 50, 31and 26%, respectively. Among rainfall groups, there was a higher chance in occurrence in low than intermediate and high rainfall groups. Across periods of years, ESD trended to increase in P5 in intermediate (60%) and low (50%) rainfall groups in comparison with mean across 64 years (BP) but there was decrease in high rainfall group (7%). For MSD and LSD, probability in P5 was lower than mean across 64 years. The results indicated that the frequency of drought occurrence treaded to be increased for ESD but decreased for LSD.

Simulated grain yield

Grain yield for 5 varieties were estimated by a modified crop model for photoperiod sensitivity rice varieties under rainfed condition. The estimation was based on rainfall data of each rainfall group to determine whether which type of variety would be suitable for each rainfall group (Table 5). There was variation in means grain yield across rainfall groups among 5 varieties. The highest grain yield was observed in RD33 of 3,304 kg/ha whereas the lowest was observed in RD6 of 3,029 kg/ha. Variation within each variety was also observes across rainfall groups. It was observed that RD6 had the largest variation with SD across rainfall groups of 713 and the lowest variation was found in RD12 with SD of 193. The difference in SD showed that the lowest was found under high rainfall group but the highest was observed under low rainfall group. This suggested that all five varieties are suitable under high and intermediate rainfall groups but only RD12 and RD15 were suitable for low rainfall group.

Table 5 Grain yield (kg/ha) obtained from simulation crop model for 5 varieties, KDML 105, RD6, RD15, RD12 and RD33 under high, intermediate and low rainfall groups during 2010-2014 and standard deviation (SD) across varieties and rainfall groups.

Rainfall groups	Grain yield (kg/ha)					
	KDML 105	RD6	RD15	RD12	RD33	SD
High	3452	3478	3249	3223	3570	151
Intermediate	3517	3472	3204	3203	3572	177
Low	2381	2137	2836	2880	2769	326
Mean	**3117**	**3029**	**3096**	**3102**	**3304**	**119**
SD	**638**	**713**	**227**	**193**	**463**	

This paper, a simulation model was used to estimate growing period (SGP, EGP and LGP) and seasonal drought occurrence, ESD^{1st} (during SGP to week 24th or approximate Early April to middle June), ESD^{2nd} (during week 25thto 33rd or middle June to August), MSD (during week 34th to 39th or middle August to late September) and LSD for 64 years period (1951- 2014) and each 10 years period (1951-1979, 1980-1989, 1990-1999, 2000-2009) and 5 years period (2010-2014). Rainfall data of 8 provinces, UBN, SKN, MDH, UDN, SRN, RET, KKN and NMA, were used to run the model. Because there was consistence difference in amount of annual rainfall among province, thus they were grouped into three groups, high, intermediate and low. There was variation in SGP and EGP among rainfall group but variation among periods of years was small within each group of rainfall. This could be because within each group the amount and number of CWD across periods of year was not much changed. Possibility of drought occurrence was estimated based on growing duration of KDML 105 which flowered around mid-October. It was found that LSD was a major drought problem. However, it trended to decrease in the last period (2010-2014) but ESD trended to increase. The water balance model used for this work had been used for characterization of growing period for Savannakhet province in Laos (Inthavong et al. (2011). This water balance model had been validated for Thai soil using standing water data from project Strengthening Farmers' Adaptation to Climate Change in Rainfed Lowland Rice System in Northeast, Thailand. The modified crop model was also used for estimating grain yield of 5 recommended rice varieties in NE Thailand. The results showed that there was variation in grain yield among varieties under different rainfall group. Under high and intermediate rainfall groups, variation in grain yield among varieties was small suggested that all five varieties adapted well under these conditions. Under low rainfall group, variation among varieties was large and photoperiod sensitivity with short duration varieties (RD12 and RD15) obtained high grain yield. This was because there was high chance of drought occurrence in late season which caused large yield reduction for long duration varieties. Fukai (1999) suggested that flowering time was the most important factor for rainfed lowland rice which flowering has to fit to rainfall pattern. In case of RD33, photoperiod insensitivity, grain yield was the highest but might not appropriate for variable rainfall condition such rainfed lowland rice. Ouk et al. (2001) used 10 lines with different level of photoperiod sensitivity for determining the effect of late seeding and transplanting with old seedling. They concluded that under variable rainfall conditions, photoperiod sensitivity variety was more suitable and flexible than that photoperiod insensitivity variety.

Conclusion and Suggestions

Characterization for understanding of target areas is an important issue for planning of crop production. In this paper modeling approach was used to estimate growing season and possibility of drought occurrence. Rice variety suitable for rainfall groups was indentified. However, this work was only some parts of northeastern region. Presently, characterization of rainfed lowland rice areas for whole NE region is being conducted using the same model and the results will be presented later.

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