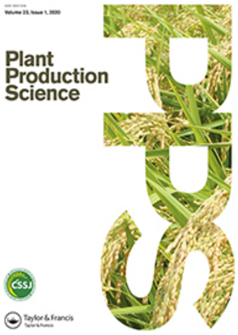

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Rainfall variability and its effects on growing period and grain yield for rainfed lowland rice under transplanting system in Northeast Thailand

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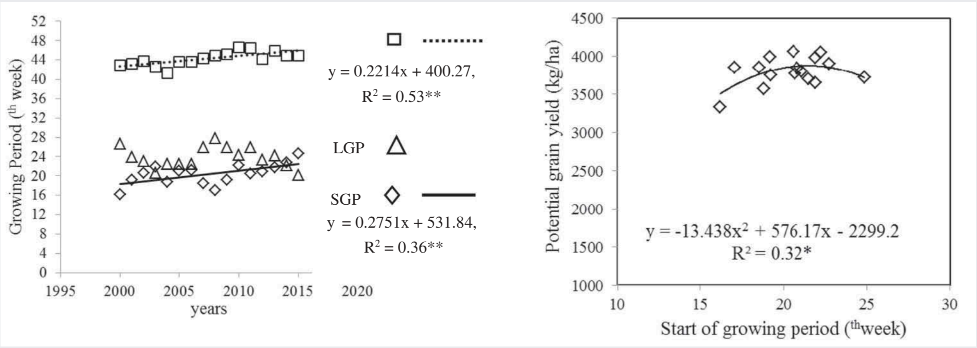
ABSTRACT

Rainfall variability in Northeast Thailand during 2000–2015 was examined with objectives to determine any changes in rainfall pattern with time, and to determine its effects on duration of rice growing period and grain yield using a simulation model. Variation in mean annual rainfall over 16 years in 93 locations in the region ranged from over 1,600 to less than 1,200 mm, and the locations were grouped into 4 based on the annual rainfall. The change in annual rainfall, and early, mid and late season rainfall was analysed for the rainfall groups. There was a significant reduction in the amount of early season rainfall during the 16-year period in all groups. However, there was no significant change for annual, and mid and late season rainfall. Simulation study showed that the start of rice growing period (SGP) was delayed with reduced early rainfall during the 16 year period and the end of rice growing period (EGP) was also delayed while there was no significant change for the length of rice growing period (LGP). Simulation results showed that grain yield of KDML105, leading variety in Thailand, tended to increase during the 16 year period, as delayed planting time was optimum for achieving maximum yield in all rainfall groups. With general delay in rainfall season, occurrence of late season drought was predicted to be reduced and this helped to increase simulated grain yield. However, adaptation to changing rainfall pattern needs to be planned in advance to maximize its effect.

In Northeast Thailand, changing in rainfall from 2000 to 2015 was investigated. The wet season tended to start later and end later, and this reflected in start (SGP) and end (EGP) of rice growing period (a). Delay in SGP under transplanting shifted the time of potential planting closer to optimum for KDML 105 variety (b) and also delay in EGP decreased severity of drought stress at the end of growing season thus reduced yield loss due to late season drought.



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1. Introduction

Rainfed lowland is a major rice production system in Northeast (NE) Thailand with areas of 5.4 million ha or 60% of country's total rice areas of 9 million ha (OAE, 2016). Crop yield depends on rainfall distribution during the growth, and lack of irrigation water in the region makes this production system highly vulnerable to changes in precipitation (Fukai, Chumphon & Hoshikawa, 2000). Early rain starts in March and rainfall increases to minor peak in May to June then decreases before the main wet season commences in July, with

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main peak in August and September, and then rainfall tapers off in October (Fukai, Sittisuang & Chanphengsay, 1998; Gympmamtasiri & Limniraunkol, 2001). Wet season in NE Thailand is commonly defined to start in May and end in October. In NE Thailand, mean annual rainfall is approximately 1,395 mm with annual amount declining from northeastern to southwestern part of the region (Nawata, Nagata, Sasaki, Iwama & Sakuratani, 2005). This pattern is related to humid southwest monsoon providing high rainfall in the downwind areas along the Mekong River facing the high mountains in Laos. In contrast, the southwestern part is rain shadowed by the mountains between Central and Northeast Thailand.

Drought develops at different times during the growing period of rainfed lowland rice in the Mekong region (Fukai & Ouk, 2012). In NE Thailand, most common type of drought is terminal drought that develops during reproductive phase and continues until maturity and in some cases the crops fails completely (Monkham et al., 2016). These authors also showed that intermittent drought that develops during growth and relieved by rainfall is also common. In order to avoid terminal drought, photoperiod sensitive varieties are commonly used in NE Thailand that matures before severe terminal drought develops. However in years of an early finish in rainfall, severe drought affects yield (Monkham et al., 2016). Sujariya, Jongdee, Inthavong, Budhaboon and Jongrungklang (2017) also showed yield loss due to late season drought during 2010–2014, and this was estimated by a simulation model to be about 12–39%, the estimated loss depending on the growth duration of rice varieties. Early planting would help avoid late season drought, but this commonly results in low harvest index, greater risk of crop lodging and consequently low yield (Sujariya, 2018). Sujariya et al. (2017) using transplanting method of crop establishment demonstrated that the optimum time of planting to produce the highest yield was in June under irrigated conditions. Climate change is taking place in the lower part of NE Thailand, and the maximum temperature has increased by 0.3–0.8°C per decade particularly in October-November (Prabnakorn, Maskey, Suryadi & Fraiture, 2018). These authors showed negative correlation between temperature and rice grain yield in the 30 years between 1984 and 2013. They also showed increasing trend of monthly rainfalls which resulted in some yield increase, but the overall effect of climate change has been a small yield reduction during the time period in the region. Climate change may also affect the availability of water resources. The extreme climate events that threaten rainfed lowland rice cultivation in some provinces in NE Thailand include prolonged dry-spells during vegetative stage (Chinvanno et al., 2006). This early season drought in turn could increase the cost of production with re-planting or supplying irrigation water to maintain rice growth. Rice yield in the region is considered to decrease in the future according to Babel, Agarwal, Swain and Herath (2011), and this may be due to the damaging effect of higher rainfall on the crop during harvesting time (Felkner, Tazhibayeva & Townsend, 2009).

Effect of changes in rainfall distribution pattern within rice growth period can be estimated using a simulation model. The model developed by Inthavong, Tsubo and Fukai (2011) uses the combination of soil, climatic characteristics, and plant parameters, and estimates soil water availability and then determines the start of growing period (SGP) and end of growing period (EGP) and hence length of growing period (LGP). This model was calibrated with standing water level determined across Savannakhet Province in Central Laos and has demonstrated LGP to be good indicator of crop suitability under various water limiting conditions.

In this study, rainfall data obtained from Thai Meteorological Department (TMD) across NE Thailand from 2000 to 2015 were used to determine whether rainfall pattern changed with time during the period, and using the model of Inthavong et al. (2011) we evaluated whether this rainfall pattern change had any effect on the duration of rice growing period and grain yield.

2. Materials and methods

2.1. Study area

The study area covered NE Thailand (14° 8′ N to 18° 20′ N, 100° 52′ E to 105° 38′ E) with 20 provinces, and their agricultural and rice paddy areas in 2015 are shown in Table 1. The large rice paddy areas were found in provinces of Ubon Ratchathani (UBN), Nakhon Ratchasima (NMA), Surin (SRN) and Sisaket (SSK). Soil clay content in each province ranged from 3 to 34%, but was mostly less than 10% (GCP, 2013). Variation in provincial grain yield varied from 1,919 kg/ha in Bueng Kan (BBN) to 2,413 kg/ha in SRN while variation in annual rainfall varied from 832 in Maha Sarakham (MKM) to 2,079 mm in Nakhon Phanom (NPM).

2.2. Rainfall groups

Rainfall data from 93 rainfall stations from 2000 to 2015 were obtained from Thai Meteorological Department in NE Thailand. Mean annual rainfall in the region over 16 years varied from maximum of 2,131 mm to minimum of 823 mm. All stations were grouped into four based on their mean annual rainfall; group 1 with 15 rainfall stations with rainfall exceeding 1,600 mm, group 2 with 24 stations with rainfall between 1,401 and 1,600 mm, group 3 with 34

Table 1. Agricultural and rice paddy area (ha), grain yield (OAE, 2016), soil clay content (%), annual rainfall for each province in 2015 (Thai Meteorological Department website), and rainfall groups (1 the highest and 4 the lowest) in Northeast Thailand.

	Agricultural area		Rice paddy area					
Province	(ha)	(%)	(ha)	(%)	Grain yield (kg/ha)	Soil clay content (%)	Annual rainfall (mm)	Rainfall group
BBN	201,368	1.97	69,535	0.68	1,919	7–24	1,505	1
SNK	495,929	4.85	303,397	2.97	1,994	4–25	1,524	1 and 2
UBN	858,357	8.4	600,809	5.88	2,063	4–24	1,259	1 and 2
NPM	304,298	2.98	203,072	1.99	2,194	5–15	2,079	1 and 2
NKI	246,814	2.42	71,885	0.7	2,313	5–34	1,524	1and 2
UDN	618,993	6.06	262,332	2.57	2,338	5–30	1,129	2
MDH	206,090	2.02	198,522	0.74	2,213	4–5	1,014	2
ACR	232,459	2.28	148,406	1.45	2,138	7–25	1,032	2
YST	274,834	2.69	198,522	1.94	2,213	5–34	1,005	2
SSK	651,047	6.37	461,773	4.52	2,256	5–25	1,383	2
KSN	453,269	4.44	227,303	2.22	2,300	4–34	909	2 and 3
NBP	269,949	2.64	106,809	1.05	1,981	6–20	1,101	2 and 3
SRN	673,182	6.59	474,612	4.65	2,413	4–20	1,259	2 and 3
RET	594,692	5.82	454,621	4.45	2,375	3–24	1,052	3
MKM	450,972	4.41	314,040	3.07	2,281	4–30	832	3
LEI	434,125	4.25	52,733	0.52	2,313	4–15	895	3
BRM	701,884	6.87	425,767	4.17	2,381	3–11	1,029	3
KKN	675,176	6.61	310,883	3.04	2,113	5–30	999	3 and 4
CPM	532,548	5.21	224,125	2.19	2,194	4–23	913	3 and 4
NMA	1,341,676	13.13	481,489	4.71	2,256	4–10	1,171	4
Total	10,217,663	100	5,467,680	53.5				

BBN, Bueng Kan; NKI, Nong Khai; NPM, Nakhon Phanom; SNK, Sakon Nakhon; UDN, Udon Thani; MDH, Mukdahan; ACR, Amnat Charoen; UBN, Ubon Ratchathani; YST, Yasothon; KSN, Kalasin; NBP, Nong Bua Lam Phu; SSK, Sisaket; RET, Roi Et; KKN, Khon Kaen, MKM, Maha Sarakham; LEI, Loei; SRN, Surin; BRM, Buriram; CPM, Chaiyaphum; NMA, Nakhon Ratchasima

stations with rainfall between 1,201 and 1,400 mm, and group 4 with 20 stations with rainfall less than 1,200 mm. The major rainfall groups for each province are also shown in Table 1.

In addition to annual rainfall, the amount of early, mid and late season rainfall was also calculated and examined for the rainfall change in the 16 years period. The early season, week 14 to week 24 (early April to mid-June) coincided with rice's planting time. Mid-season was from week 25 to week 39 (mid-June to late September) coinciding with tillering to early panicle development stages while late season was from week 40 to week 45 (early October to early November) coinciding with late panicle development to maturity. These crop development stages were for Khao Dawk Mali 105 (KDML 105), the most popular photoperiod sensitive variety for rainfed lowland rice in NE Thailand which occupied for more than 50% of total rice growing areas in the region (Office of Agricultural Economics [OAE], 2016). Under common planting time (April to June), this variety flowers in mid-October and can be harvested about 30 days after flowering in the middle to late November. However, planting time can be varied due to the onset of rainy season, and this affects flowering time slightly.

2.3. Estimation of growing period

A water balance model that incorporates deep percolation rate as a function of soil clay content was utilized for determination of start and end of growing period (Inthavong et al., 2011). The model calculates field water loss due to evapotranspiration, deep percolation and seepage, and is capable of quantifying field water availability weekly and identifying the time of water stress. In this study, the growing period was estimated for flat or almost flat land areas with slope of 0 to 2%. Start of growing period (SGP) was defined as the time when field water storage within the surface soil layer was greater than field capacity for three continuous weeks, while end of growing period (EGP) was defined as the time when the amount of water storage within the surface layer was lower than wilting point. The length of growing period (LGP) was determined as the difference between SGP and EGP.

The mean weekly climatic data such as rainfall, minimum and maximum temperature, solar radiation, and potential evapotranspiration for 2000 to 2015 were used to run the model. Rainfall and temperature data were obtained from the Thai Meteorological Department (TMD). Solar radiation was calculated from WeaData 2.0 program (Phakamas, Jintrawet, Patanothai, Sringam & Hoogenboom, 2013) and daylength data were modified from van Keulen and Wolf (1986). Soils information was extracted for 169 locations where rainfall data were available from Thailand Land Development Department (GCP, 2013) using their digital soil map database. Within this soil data, soil clay content varied from 3 to 34% and most locations were sandy soil (69%) whereas loamy sand was 12%, sandy clay loam 12% and sandy loam 8% (Table 2). The estimation of volumetric soil moisture contents at various thresholds i.e. soil moisture content at saturation

Table 2. Soil texture and soil clay content (%) of major paddy soils in Northeast Thailand.

Soil texture	Soil clay content (%)	Number of site	%
Sand	0–10	116	69
Loamy sand	10–15	20	12
Sandy loam	15–20	13	8
Sandy clay loam	20–35	20	12
Total		169	100

(SAT), field capacity (FC) and permanent wilting point (PWP) were estimated according to Saxton and Rawls (2006). The water balance model was run for each of 93 rainfall sites for each of 16 years and SGP and EGP were determined.

2.4. *Estimation of grain yield*

In this study, grain yield was estimated under transplanting system. Start of growing period estimated from the water balance model was used as sowing date in the nursery for running the crop growth model of FAO/IIASA (2000) and Kam, Tuong, Bouman, Fajardo and Reyes (2000), and net biomass production and maximum potential grain yield was estimated (Inthavong, Fukai & Tsubo, 2014). However, the original crop growth model was modified for estimation of flowering date and harvest index for photoperiod sensitive variety KDML105. Equation for flowering time is:

$$Y_{KDML105} = 0.0026x^2 - 1.5805x + 312.47 \qquad (1)$$

where $Y_{KDML105}$ is days to flowering, and x is a sowing date (Julian date), and equation for

harvest index is:

$$Y_{KDML105} = -0.0017x + 0.6025 \qquad (2)$$

where $Y_{KDML105}$ is harvest index and x is days to flowering. Equations developed by Sujariya (2018) were used for estimation of biomass and potential grain yield for KDML105. Yield limitation due to water deficit was estimated by a linear equation developed by Ouk et al. (2006):

$$YR = -1.68WL_{REL} \qquad (3)$$

where YR is yield reduction (%), and WL_{REL} is the relative water level (cm). In this model free water level (FWL) around flowering (3 weeks before and after flowering date) is used as an index of the severity of the water deficit to estimate yield reduction. WL_{REL} is zero when FWL is equal to or higher than the soil surface, while WL_{REL} is FWL when FWL is lower than the soil surface.

The output of the simulation included potential grain yield and water- limited grain yield. Mean grain yield for the whole region was estimated across 93 rainfall stations and group mean grain yield was estimated based on the number of rainfall stations in each rainfall group.

3. Results

3.1. *Annual and seasonal rainfall*

Annual rainfall map shows that the highest annual rainfall areas were found in northeastern corner (NKI, BBN and NPM) with the amount exceeding 1,600 mm and declined downward towards southwestern corner (CPM and NMA) with the amount being less than 1,200 mm (Figure 1(a)).

The rainfall pattern for early (weeks 14 to week 24) and mid-season (week 25 to week 39) was similar to that for total annual rainfall (Figure 1(b,c)). The late season (week 40 to week 45) rainfall pattern was different as the highest rainfall areas were found in southwestern corner

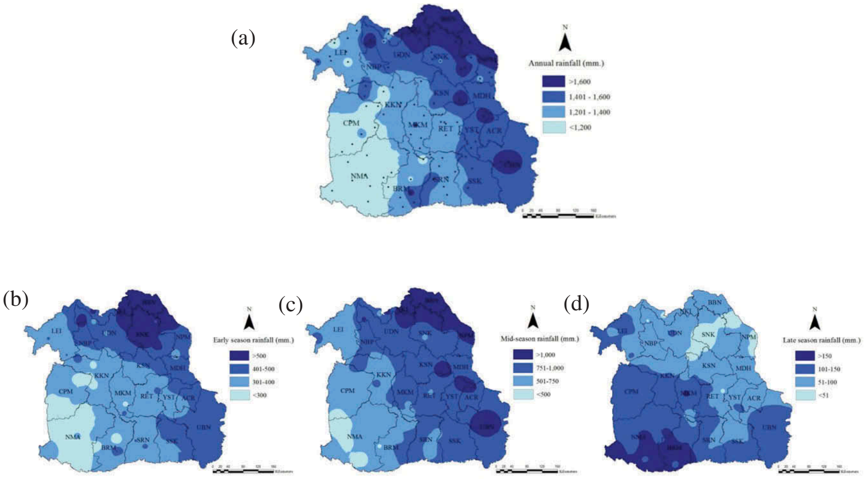

Figure 1. Spatial maps for annual rainfall (a), and seasonal rainfall for early (b), middle (c) and late season (d) in Northeast Thailand.

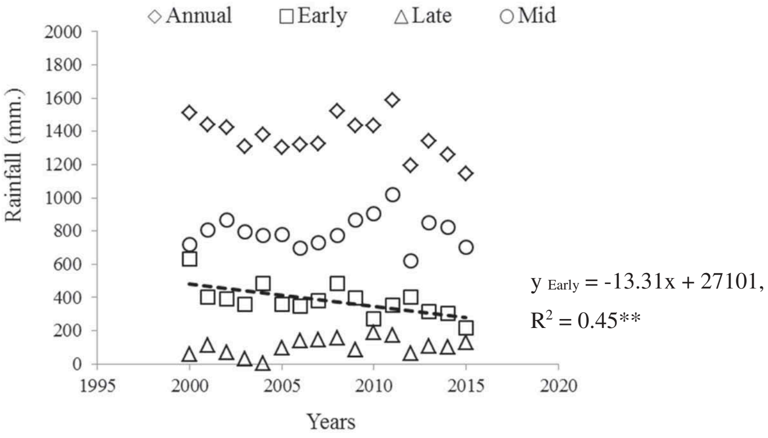

Figure 2. Change in the amount of rainfall (annual, and early, middle and late season) in 2000–2015.

and declined upward towards the northeastern corner (Figure 1(d)).

3.2. *Changes in rainfall in 16 years*

Mean annual rainfall for the period of 2000–2015 across 93 rainfall stations in NE Thailand varied from 1,589 mm in 2011 to 1,147 mm in 2015 with the mean of 1,371 mm across 16 years. Among seasonal rainfalls, mid-season had the highest amount of 795 mm followed by early and late seasons of 380 and 103 mm, respectively. The changes in mean annual and seasonal rainfall across 93 stations in the period from 2000 to 2015 are shown in Figure 2. The amount of early season rainfall significantly decreased with time during 2000 to 2015 ($R^2 = 0.45$). The other relationships for annual, mid and late season rainfall were not significant.

Significant decrease in early season rainfall during the time period was observed in 3 of the 4 rainfall groups and in total annual rainfall in 1 rainfall group (Table 3). Late season rainfall tended to increase within the 16-year period, but the relationship was not significant in any rainfall group.

Table 3. Change in the amount of annual, and early, middle and late season rainfall with time (mm/year) during 2000–2015 for each rainfall group.

Rainfall groups	Annual	Early	Middle	Late
Gr1	−1.77	−14.71*	10.07	4.89
Gr2	−17.54*	−15.60**	−1.61	3.63
Gr3	−11.15	−13.49**	1.24	4.53
Gr4	−1.36	−6.83	2.92	5.22
Whole NE Thailand	−10.42	−13.31**	1.54	4.57

Note: * Significant at probability of 0.05 and ** significant at probability of 0.01.

3.3. *Effect of rainfall on growing period*

Within the 16-year period, variation in SGP, EGP and LGP in each rainfall group was significantly related to the variation in the amount of annual and seasonal rainfall. For SGP, significant negative relationship was observed with early season rainfall for all rainfall groups with R^2 ranging from 0.57 to 0.87 indicating that higher amount of early season rainfall in a year resulted in earlier SGP (Figure 3). The slope of regression was larger in lower than higher rainfall groups indicating that the effect of rainfall would be larger in the lower rainfall groups. On the other hand, significant positive relationships were found between EGP and the amount of late season rainfall in all rainfall groups with R^2 ranging from 0.49 to 0.74 suggesting that increased amount of late rainfall would delay the EGP with similar slopes in all rainfall groups. For LGP, significant positive relationships with annual rainfall were found in all rainfall groups with R^2 ranging from 0.34 to 0.76.

3.4. *Changes in growing period in the 16-year period*

Changes in SGP, EGP and LGP during the 16-year period for all the rainfall groups together and also for each rainfall group are shown in Figure 4. There were significant positive relationships for SGP (R^2 = 0.36) and EGP (R^2 = 0.53) when all stations were considered together, but there was no significant relationship for LGP. The results suggested that growing period started later from 2000 to 2015, but the growing duration was unchanged. Relationship for SGP was significant in all rainfall groups except group 1. In group 4, with the lowest rainfall, SGP occurred later than in any other groups. For EGP, significant positive relationship was found in all rainfall groups

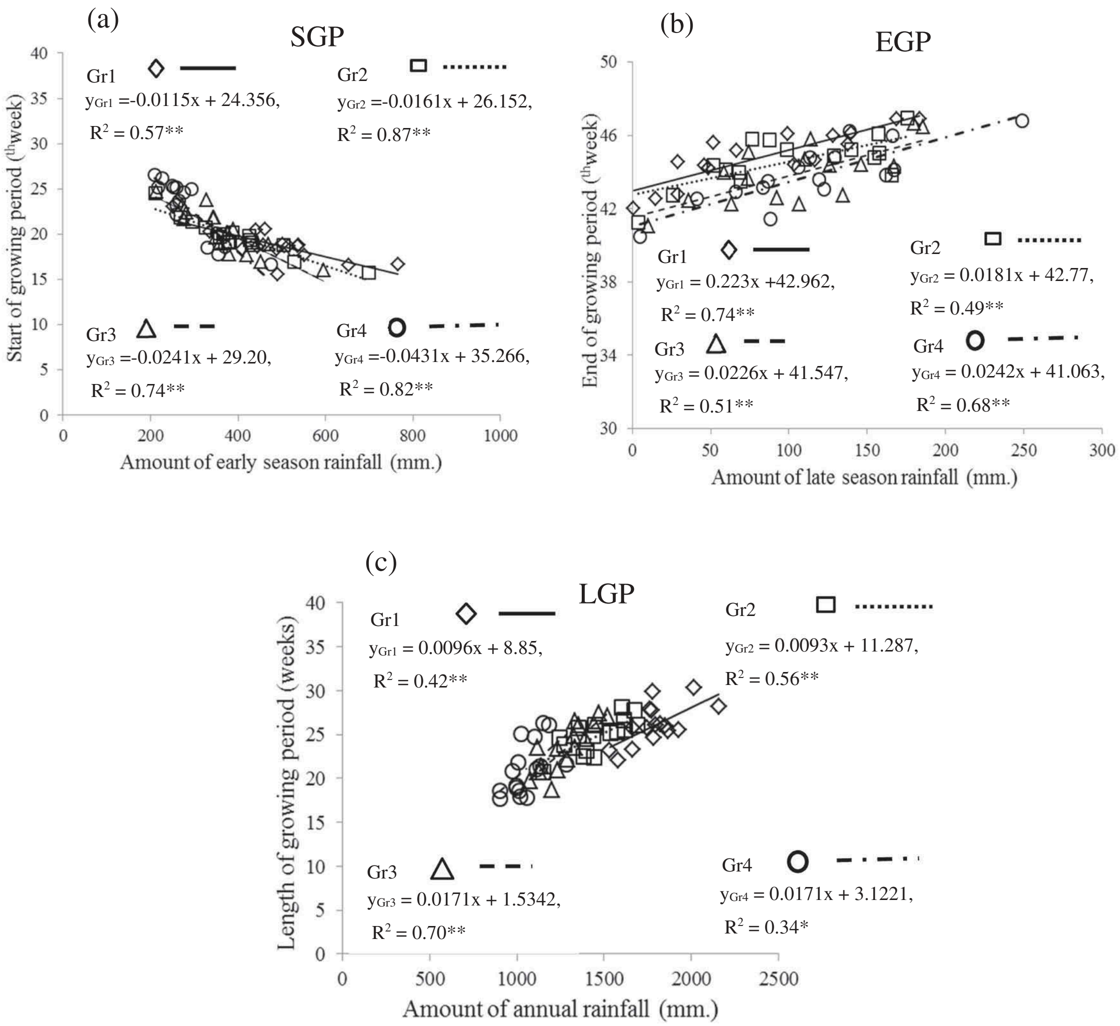

Figure 3. Relationship between amount of early rainfall and SGP (a), amount of late season rainfall and EGP (b), and amount of annual rainfall and LGP (c), for four rainfall groups.

while there was no significant relationship for LGP in all groups. LGP tended to be the longest in group 1 and shortest in group 4; mean LGP was 26, 25, 24, and 21 weeks for group 1, 2, 3 and 4, respectively.

Year 2001 was taken as a typical year at the beginning of the 16 year period, and 2014 as a typical year towards the end of the period. In year 2000 and 2015 the amounts of annual rainfall were too extreme, and thus year 2001 and 2014 were chosen for comparison. Annual, early and late seasonal rainfalls in 2001 (1,442, 403 and 110 mm respectively) were higher than in 2014 (1,261, 302 and 100 mm respectively). However, mid-seasonal rainfall was slightly higher in 2014 (824 mm) than in 2001 (806 mm). Among rainfall groups, annual rainfall was higher in 2001 than 2014 in all groups except group 4. For seasonal rainfall, early rainfall was higher in all the 4 groups, mid-season rainfall was higher in groups 2 and 3 and late season rainfall was higher in group 1 and 2 in 2001 than in 2014. Differences in the spatial variation maps between 2001 and 2014 for SGP, EGP and LGP (Figure 5) indicate the changes over time. The SGP was earlier than week 21 in most areas in 2001 (Figure 5(a)) while in 2014 SGP occurred later throughout the region, and most areas had SGP in week 21–24 (Figure 5(b)). In 2001, EGP of most areas took place in week 40–45 (Figure 5(c)) while in 2014 the areas with EGP of week 43–45 and week 46–48 expanded and covered almost the whole region (Figure 5(d)). As the results of longer delay in SGP than EGP, LGP became shorter in 2014 than in 2001. In 2001, LGP in most areas was in 21–24 and 25–28 weeks (Figure 5(e)). For 2014, LGP for most areas was in 21–24 weeks, and areas with LGP of 25–28 weeks and more than 28 weeks became smaller while areas with LGP of less than 17 weeks became larger (Figure 5(f)).

3.5. Variation in simulated grain yield

Changes in simulated potential grain yield, water-limited grain yield and their difference in the 16 year period were

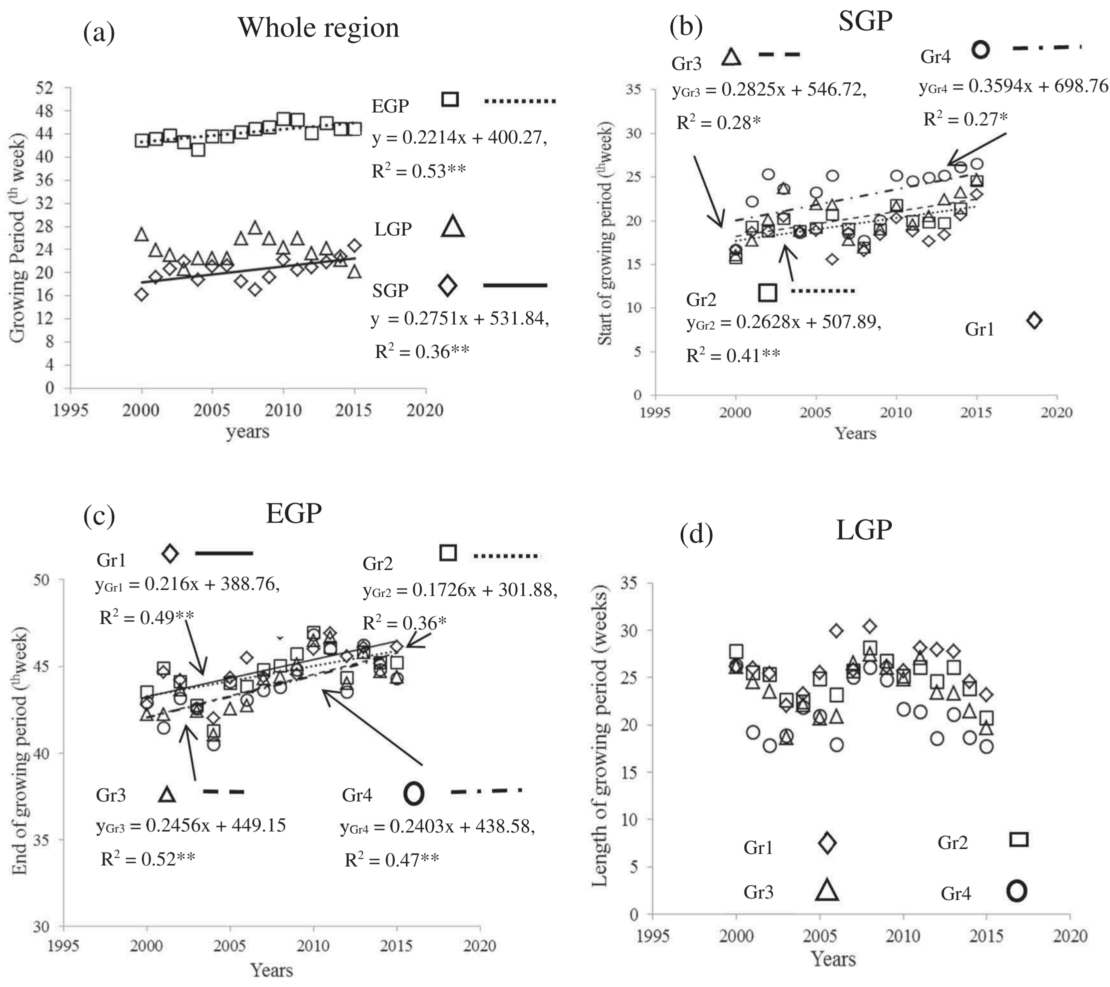

Figure 4. Changes with time during 2000 to 2015 in mean start (SGP), end (EGP) and length (LGP) of growing periods across 93 rainfall stations throughout the whole NE Thailand region (a), and SGP (b), EGP (c) and LGP (d) among four rainfall groups.

investigated for each rainfall group and also across 93 rainfall stations together for the whole NE Thailand. Based on the slope of each regression, potential grain yield increased with time at the rate from 22 to 29 kg/ha/year among groups and water-limited grain yield increased at even higher rate from 51 to 68 kg/ha/year among rainfall groups because of the reduced effect of drought during this 16 year period (Table 4).

Sowing date is assumed to be the same as SGP, and with earlier sowing estimated flowering dates were earlier in 2001 than in 2014 for each rainfall group and the whole region (Table 5). The lowest rainfall group (group 4) had later sowing and later flowering dates than other groups in both years. However, both potential grain yield and water-limited grain yield in 2014 was higher than in 2001 in all rainfall groups and the whole region. For the whole region, yield reduction declined from 32% in 2001 to 27% in 2014, and the largest reduction was found in group 4.

When 2001 rainfall data are used, the delay in sowing in 2014 as compared with 2001 resulted in increase in potential grain yield in all rainfall groups (Table 5). Flowering date delayed and became similar to those in 2014 sowing results. On the contrary, there was a decrease in water-limited grain yield in all rainfall groups.

Significant relationship was observed for SGP and potential grain yield with R^2 of 0.32 and the result indicated that the optimum SGP would be in week 21 to 22. (Figure 6(a)). The relationship between the simulated and observed was highly significant with R^2 of 0.46 although the simulated yield was much greater than observed in high yielding years (Figure 6(b)).

4. Discussion

The present work showed that rainfall distribution within a wet season has changed over the 16 years (2000 to 2015), and particularly the amount of early wet season rainfall declined which delayed SGP and EGP, and slightly shorten LGP. This change in rainfall pattern

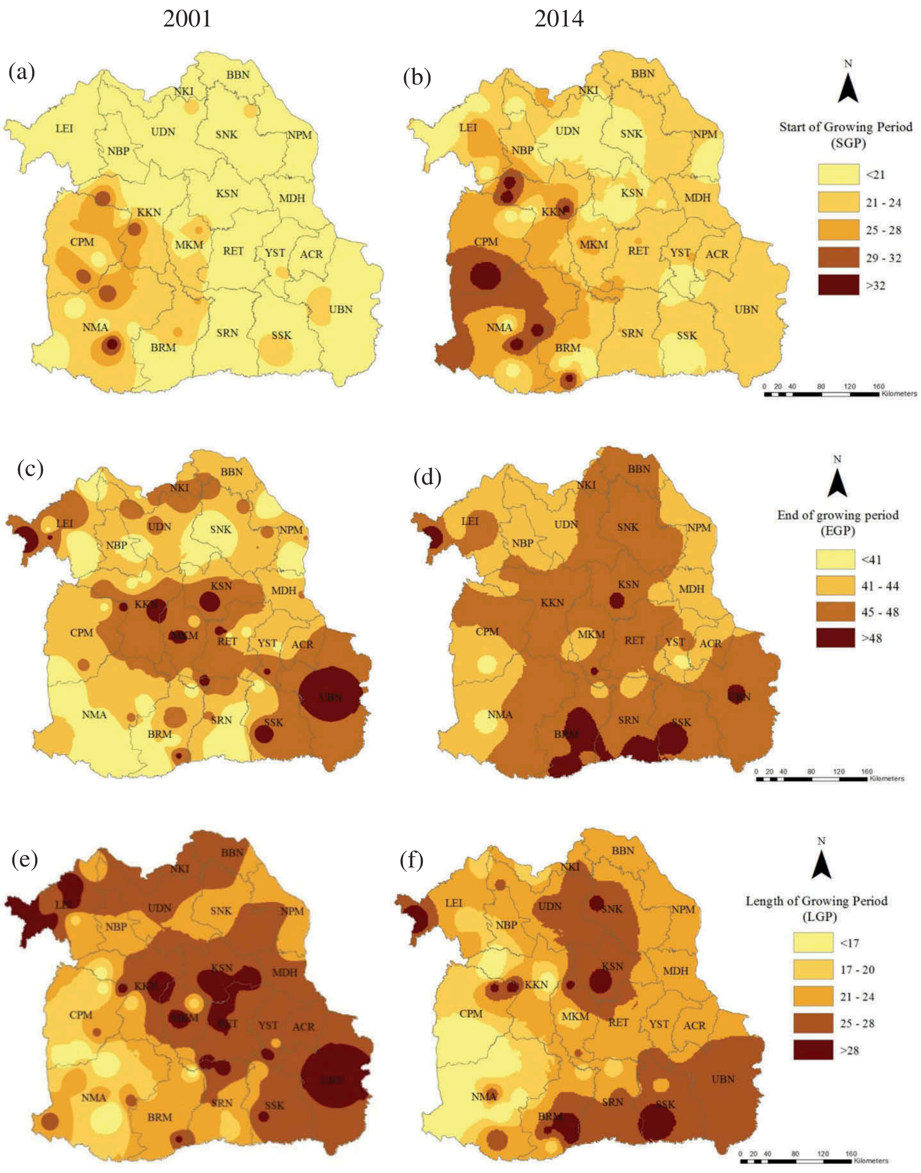

Figure 5. Spatial variation maps for comparison of start of growing period (a and b), end of growing period (c and d), and length of growing period (e and f) between 2001 (a, c and e) and 2014 (b, d and f).

could have large effects on reducing the effect of late season drought on grain yield of rainfed lowland rice production system in NE Thailand and elsewhere. In addition, the effect depends on the amount of rainfall in different areas, as shown in different responses among 4 rainfall groups of rice areas. Inthavong, Tsubo and Fukai (2012) classified lowland rice areas in Savannakhet in Central Laos according to LGP; less than 21 weeks as drought susceptible and more than 25 weeks as favourable. Using their criteria, LGP determined over Thailand, Laos and Cambodia shows southwestern part of NE Thailand, southern part of Cambodia and Savannakhet in Laos have shorter LGP which are considered to be drought prone, while northeastern part of NE Thailand towards the Mekong River is considered to be favourable (GCP, 2013). Soil types shown in NE

Table 4. Regression coefficient (slope) for the relationship between simulated potential grain yield, water-limited grain yield and yield reduction percentage during 2000–2015 for each rainfall group and whole NE Thailand.

Rainfall group	Potential grain yield (kg/ha/year)	Water-limited grain yield (kg/ha/year)	Yield reduction (%/year)
Gr1	23.56**	55.10**	−0.96**
Gr2	22.20*	50.76*	−0.90**
Gr3	29.13**	67.87**	−1.28**
Gr4	26.42**	63.55**	−1.28**
Whole NE Thailand	25.67**	59.48**	−1.09**

Note:* Significant at probability of 0.05 and ** significant at probability of 0.01

Table 5. Comparison of sowing and flowering dates, simulated potential grain yield, water-limited grain yield and yield reduction (%) due to drought for each rainfall group and whole region in 2001 and 2014 and also using 2001 rainfall data and 2014 sowing date (2001*).

	Sowing date		Flowering date		EGP		Potential grain yield			Water-limited grain yield			Yield reduction		
	2001	2014	2001	2014	2001	2014	2001	2014	2001*	2001	2014	2001*	2001	2014	2001*
Rainfall group	(week)	(week)	(day)	(day)	(week)	(week)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(%)	(%)	(%)
Gr1	19	21	6-Oct	8-Oct	45	46	3936	3979	4165	3118	3279	3104	21	18	25
Gr2	20	21	8-Oct	10-Oct	45	45	3919	3943	4011	2832	3011	2759	28	24	31
Gr3	18	23	7-Oct	14-Oct	43	45	3660	3907	4047	2415	2761	2276	34	29	44
Gr4	23	27	15-Oct	24-Oct	42	45	3691	3786	3783	1900	2513	1591	49	33	58
Whole NE Thailand	20	23	9-Oct	14-Oct	44	45	3792	3923	4005	2563	2876	2433	32	27	39

Note: 2001 = simulated data from amount of 2001 rainfall and sowing date
2014 = simulated data from amount of 2014 rainfall and sowing date
2001* = simulated data from amount of 2001 rainfall and 2014 sowing date

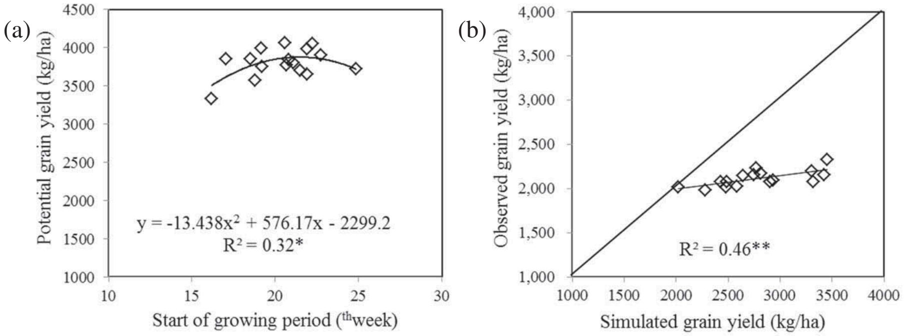

Figure 6. Relationship between yearly mean start of growing period (SGP) and simulated potential grain yield across 93 rainfall stations (a), and between simulated and observed grain yield of rainfed lowland rice in NE Thailand (b), for the period 2000–2015.

Thailand here are similar to those in Savannakhet, Laos and most of the area has low clay content of less than 7%, which makes rice susceptible to intermission of rainfall (Inthavong et al., 2011).

Similar to the results of this study in NE Thailand, the effect of climate change in adjacent Northwest Cambodia has delayed beginning and ending of rainy season by approximately 1 month causing extremely drought and flood events during growing season (Martin, 2017). The onset of rainfall in wet season is an important factor determining SGP (Inthavong et al., 2011; Oladipo & Kyari, 1993). In this study, change in SGP was associated with early rainfall in week 14 to 24 (early April to mid-June) while Inthavong et al. (2011) found SGP to be related to amount of rainfall in April in Savannakhet. Among four rainfall groups, SGP varied between late April to late May in 2001, but this was delayed to late May to late June in 2014. Based on farmer survey, farmers observed that rainfall pattern has changed and this made it difficult for them to determine the optimum planting date. However, they could not adapt their crop management to the changing rainfall pattern, and planting date remained about the same late April to May, according to the final report of a project 'Strengthening farmers' adaptation to climate change in rainfed lowland rice system in Northeast Thailand' (ARDA, 2013). Under farmer practice, drought occurrence was frequently observed after sowing in the seedling nursery or broadcasting in the main paddy. Transplanting time was delayed due to lack of rainfall and farmers used old seedlings while early direct seeding date would result in poor plant establishment and require re-broadcasting. Dalgliesh, Charlesworth, Lonh and Poulton (2016) reported that competition between weed and rice plant would be high under dry conditions causing additional weed control measures.

Yearly variation in EGP was significantly correlated with rainfall during the late season, and this is similar to the work in Savannakhet that EGP was associated with rainfall pattern in October (Inthavong et al., 2011). The main varieties grown in NE Thailand are strongly photoperiod sensitive and flower in October as shown in KDML105 in the present simulation work. Thus 4 weeks delay in planting from year 2001 to year 2014 would result in delay in flowering of only 5 days in October. The effect of delayed planting on flowering time for KDML105 and some other major varieties is well known in NE Thailand (Rajatasereekul et al., 1997), and the present work simulated well the effect on flowering time for KDML105. Maintaining standing water at flowering is important for high yield in rainfed lowland rice in Thailand (Jearakongman et al., 1995), and hence delay in EGP to week 45 (early November) in 2014 would help minimize the effect of terminal drought that is very common in NE Thailand (Monkham et al., 2016). Thus the present study has shown the effect of drought which would be most severe in low rainfall areas of Group 4 could be reduced substantially with the delay in EGP. Comparison between 2001 and 2014 showed that both potential grain yield and water-limited grain yield were higher in 2014 than 2001 in all four rainfall groups. The planting and flowering times and EGP were later in 2014 than 2001 which resulted in high potential grain yield but yield reduction percentage was lower, contributing to higher water-limited grain yield. During the study period LGP tended to become shorter in most areas, as delay in SGP trended to be longer than delay in EGP. However, for KDML105 the simulation suggested yield to increase with the change in rainfall pattern, which is in agreement with the work of Prabnakorn et al. (2018).

Relationship between simulated and observed grain yield obtained from OAE (2016) during 2000 to 2015 was significant although observed grain did not respond much to favourable seasonal conditions compared to the simulated grain yield. It is possible that some limiting factors are not incorporated in the model. In NE Thailand, paddy condition is diverse which can be classified as upper, intermediate and lower paddy positions (Gympmamtasiri & Limniraunkol, 2001) with difference in soil fertility and texture and soil water conditions (Boling et al., 2008; Homma, Horie, Shiraiwa & Supapoj, 2007). However, in this study only the difference in soil texture among the 93 rainfall stations was used for estimating grain yield. In addition, KDML105 used in this simulation work is known as very susceptible to leaf and neck blast, which is a major disease for rainfed lowland rice in NE Thailand. In the model, insect, disease and flood problems that affect grain yield are not incorporated. These could be the reasons for overestimation of grain yield under rainfed conditions.

The relationship between SGP (sowing date) and grain yield showed that optimum SGP under transplanting to achieve highest grain yield was in week 21 to 22 (in late May to early June) as found in monthly planting throughout a year in Sujariya (2018). Kerdsuk (2002) and Praiwan (2008) report different optimum planting date for KDML105 of early April and May under irrigated condition. In comparison for potential grain yield in 2001 and 2014, planting time in 2001 might be too early for maximum yield and then delay in planting in 2014 resulted in planting time approaching to optimum time after change in rainfall pattern.

It is assumed that sowing takes place at SGP and the simulation conducted for water balance and crop growth. In general, farmers do not necessarily sow the seeds in nursery at the same time as SGP. Farmers sow the seeds when they assure that there is continuous rainfall, and transplanting will take place about one month later or when there is sufficient standing water. The results of the present study indicate likely advantages of such later planting of KDML105. This finding can be applicable to other variety such as RD6 which flowering time is about one week later than KDML105 but cannot be applied to shorter duration varieties such as RD12 and RD15. However, there has been a major change from transplanting to direct seeding in NE Thailand, and this can add further flexibility in the time of planting. In case of Cambodia and Laos, rice can be direct seeded earlier than transplanting without waiting for standing water in paddy (Dalgliesh et al., 2016; Laing et al., 2018). Direct-seeded rice can likewise be planted earlier in Northeast Thailand to increase planting window for farmers, but it should be noted that there is yield penalty of direct seeding over transplanting under unfavourable growing conditions (Hayashi, Kamoshita, Yamagishi, Kotchasatit & Jongdee, 2010). Early planting of direct seeding may cause serious weed problems while early standing water is more likely with late planting and this may aid weed control. However, the change in establishment method requires more adapted varieties (Fukai, Xangsayasane, Manikham & Mitchell, 2019), particularly a variety that can compete with weeds in early planting. Implication of such changes on the start and end of growing period and the length of growing period requires further research.

5. Conclusion

Changes in rainfall pattern during 2000–2015 in NE Thailand were investigated and a simulation model was used to quantify the effects of such changes on growing period, SGP, EGP and LGP, and also grain yield of KDML105. The rainfall tended to start and end later at the end of the 16 years period, and this reflected in delayed SGP and EGP. Delay in SGP and EGP provided more suitable growing condition for production of KDML105. At the end of the 16 year period the water-limited yield of KDML105 was greater. Delay in SGP under transplanting shifted the time of planting closer to the optimum, and also delay in EGP decreased severity of drought stress at the end of growing season, thus resulting in increased potential yield and also reduced yield loss due to late season drought.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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