Research article

Impact of Transplanting Date Shifts on Rice Production in Rain-fed Northeast Thailand

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Abstract Northeast Thailand, home to 60% of the nation's rice paddies, is a crucial rice-producing area. Over 90% of its fields are rain-fed, making them highly vulnerable to climate variability. Therefore, studying the impact of climate change on rice cultivation and proposing adaptation strategies is essential. One such strategy is shifting the transplanting date (TPD), which can help avoid extreme summer temperatures and increase water availability. Many studies have shown that shifting the TPD can improve rice yields, but in rain-fed systems, the harvest area is equally vital because of water limitations. Thus, this study examined the differences in the effects of TPD adjustments when evaluated using unit yield versus total rice production. A model was developed to estimate both crop growth and harvest area, with TPD determined by the condition that free water levels remained above a threshold for three consecutive weeks. The threshold was set at 12.9 mm based on a previous study. The model was calibrated using data from 2007 to 2016 and validated using data from 1997 to 2006. The model accuracy during both periods, evaluated using RMSE, demonstrated good agreement with the observed data for all provinces except Loei. To identify the optimal TPD for maximizing unit yield and total production, the threshold was adjusted in 5 mm increments, ranging from 12.8mm to 32.8mm. In 1991, the results showed that 10 out of 16 provinces had different optimal TPDs depending on whether the objective was to maximize unit yield or total production. Specifically, in seven provinces, the optimal TPD for total production occurred later than that for unit yield, likely due to heterogeneous rainfall patterns. These findings suggest that climate change adaptation strategies should prioritize total rice production over unit yield when assessing their impacts.

Keywords climate change adaptation, rain-fed rice cultivation, production model

INTRODUCTION

The global hunger assessment for 2023, measured by the prevalence of undernourishment (PoU), indicates a lack of progress toward achieving Zero Hunger. Hunger rates surged from 2019 to 2021 and have since stagnated, with a global PoU of 9.1% in 2023 (FAO et al., 2024). Rice, which contributes 23% of cereal-derived calories in Low-Income Food-Deficit Countries (FAO, 2022), plays an important role in global food security.

Within Thailand, where rice cultivation is widespread, Northeast Thailand stands out as it is home to 60% of the nation's paddies. However, over 90% of these fields are rain-fed, making them highly vulnerable to climatic variability. Limited water availability causes significant fluctuations in transplanting dates and planted areas. Sawano et al. (2008) reported over a month's variation in transplanting dates and substantial area reductions in drought years (e.g., a 20% reduction of planted area in 2005 compared to 2004). Given that precipitation patterns are expected to become more extreme due to climate change, studying its impacts on rice cultivation and proposing adaptation strategies is essential.

Optimizing transplanting dates (TPD) offers a cost-effective adaptation strategy by avoiding high temperatures and enhancing water availability. Abbadi et al. (2015) found that increased precipitation in May shifted the optimal TPD from June to May. Sujariya et al. (2020) identified late May to early June as ideal for maximizing yields. Using CERES-Rice, Babel et al. (2011) projected a 10% yield increase by shifting TPD 30 days earlier, and 34% or 23% increases by delaying it 20 days under future scenarios. Boonwichai et al. (2019) suggested that advancing TPD by a week under RCP4.5 was effective, and the study implied that differences in findings arise from model assumptions and climate scenarios.

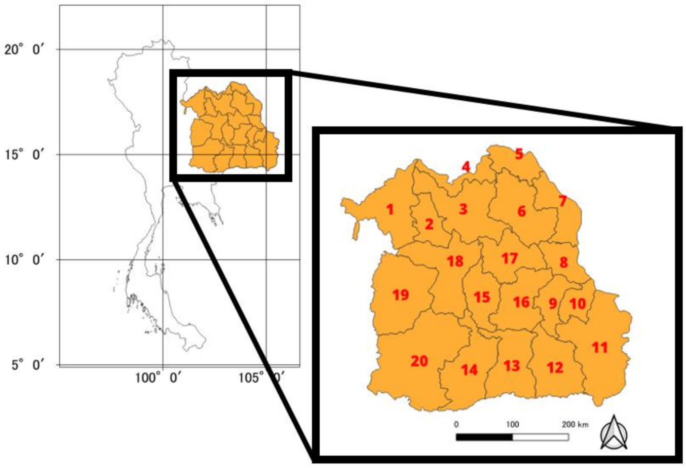
While these studies have proposed an optimal TPD, two factors must be refined for effective TPD optimization. First, rice in Northeast Thailand is photoperiod-sensitive, with heading triggered as the day length shortens. Late-season TPDs conflict with this trait, limiting their feasibility despite increased late-season water. Studies proposing delayed TPD often overlook these factors. Second, few studies have considered fluctuations in planted areas. Prior research focused on yield per unit area (ton/ha), but addressing hunger requires maximizing total production (tons), a product of yield and planted area. Optimal TPD must prioritize total production to enhance food security.

OBJECTIVE

The objective of this study was to develop a production estimation model for rain-fed rice that accounts for fluctuations in the planted area and to verify whether the optimal TPD based on yield differs from that based on total production.

METHODOLOGY

As of 2024, the study area in northeastern Thailand consisted of 20 provinces. However, the provinces of Nong Bua Lamphu, Bung Kan, and Amnat Charoen were excluded from the analysis during the calculation period (1997-2016), due to changes in their administrative status, which could affect data consistency and availability.



ID	Provinces
1	Loei
2	Nong Bua Lamphu
3	Udon Thani
4	Nong Khai
5	Bung Kan
6	Sakon Nakhon
7	Nakhon Phanom
8	Mukdahan
9	Yasothon
10	Amnat Charoen
11	Ubon Ratchathani
12	Sisaket
13	Surin
14	Burirum
15	Mahasarakham
16	Roi Et
17	Kalasin
18	Khon Kaen
19	Chaiyaphum
20	Nakhon Ratchasima

Fig. 1 Study area and provincial boundaries

This study developed a production estimation model for rain-fed rice, consisting of three sub-models: 1) planted area, 2) harvest rate, and 3) yield.

The planted area sub-model estimates the areas where rice is planted using a one-dimensional water-balance model. Each 1 km^2 paddy pixel retrieved from the 2015 land use map of the Land Development Department Thailand was treated as a single bucket, with changes in the free water level calculated as follows:

$$H_i = H_{i-1} + R_i - (ET_i + P_i) \tag{1}$$

Where, H is free water level in a paddy pixel [mm], R is precipitation, retrieved from Thai Meteorological Department [mm], ET is evapotranspiration [mm], P is percolation [mm] and i is the time step [day].

The transplanting date (TPD) was defined according to Inthavong et al. (2011), when H in equation (1) exceeded 12.8 mm for three consecutive weeks. The planted area was determined as the number of planted pixels within the planting season (1st July–31st August, Sawano et al., 2008).

The harvest rate sub-model estimates the ratio of the harvested area to the planted area. The harvest rate was calculated using the equation from FAO (1979).

$$Hr_i = \frac{\sum ETa_i + a}{\sum ETp_i + a} \tag{2}$$

Where, Hr is harvest rate [-], ETa is actual evapotranspiration [mm], ETp is potential evapotranspiration [mm], a is initial water depth [mm], and i is the time step [day].

The yield sub-model estimates rice yield using the approach of Monteith (1977), taking into account photoperiod sensitivity (Hasegawa et al., 2008). Crop phenology was modeled using the Heat Unit Index (HUI):

$$HUI_i = \frac{\sum (Ti - Tb) * PE_i}{PHU} \tag{3}$$

$$PE_i = 1 - \exp\left(Min(DL_i - DL_c), 0\right) \tag{4}$$

Where, HUI is a Heat Unit Index [-], T is daily mean temperature, retrieved from National Oceanic and Atmospheric Administration [°C], Tb is the crop-specific base temperature, below which no growth occurs [°C], PHU is the Potential Heat Units required for crop maturity [°C], PE is the photoperiod effect, ranging from 0 to 1 [-], DL is the day length [hour], and DLc is the critical day length above which no growth occurs [hour]. In this study, the calculation of the HUI began when a pixel was planted, and the pixel was considered harvested when the HUI exceeded 1. From the TPD to harvest date, yield is calculated using the following equations.

$$Yield = HI * Bm \tag{5}$$

$$Bm = \sum \Delta B_i \tag{6}$$

$$\Delta B_i = BE * PAR_i * \min(TS_i, WS_i) \tag{7}$$

Where Yield [g m^{-2}] is the economic yield, HI is the harvest index [-], Bm is the total biomass [g m^{-2}], ΔB is the biomass increment [g m^{-2}], BE is the radiation-to-biomass conversion coefficient [g MJ^{-1}], PAR is the intercepted solar radiation [MJ m^{-2}], TS is the temperature stress [-], and WS is the water stress [-].

The model was calibrated using statistical production data from 2007 to 2016 retrieved from the OAE and validated using data from 1997 to 2006.

RESULTS AND DISCUSSION

For model validation, statistical data on provincial wet-season rice production published by the Office of Agricultural Economics, Thailand (OAE) were used to evaluate the accuracy using RMSE. Because a 1 km^2 pixel is unlikely to be fully covered by paddy fields, the estimated planted area used for production estimation was adjusted using the ratio of the statistical paddy field area in 2015, retrieved from the OAE, to the area derived from the land use map, referred to as the paddy ratio.

Table 1 shows the RMSE of the estimated production and yield in each province during the validation period. The units are ton and ton ha^{-1} for production and yield, respectively, and the numbers in parentheses indicate values expressed as percentages. Figure 3 shows the changes in production and yield in Loei, which had a maximum RMSE of more than 30% for both production and yield. Loei is located in a mountainous area with high forest cover (approximately 57%) and fragmented paddy fields, which pose challenges for accurate land classification at a 1 km resolution. In such regions, contiguous paddy areas are often underrepresented on land use maps, resulting in an underestimation of the actual paddy field extent per pixel. Consequently, Loei was the only province where the paddy ratio exceeded one. This likely led to an overestimation of the planted area, which in turn caused an overestimation of the production. Additionally, Loei has a high forest cover of 57%, and because the model does not account for the fertility of soil and groundwater supply provided by forests, it is believed that this resulted in an underestimation of yield. Therefore, the analysis was conducted without Loei. To improve the model accuracy for that area, considering groundwater movement and soil fertility maps would be beneficial.

Table 1 RMSE of estimated production and yield in each province during validation period

Province	RMSE of production (%)	RMSE of yield (%)
Nong Khai	40358 (13.7)	0.20 (10.5)
Loei	57931 (35.8)	0.79 (31.1)
Sakon Nakhon	151268 (31.2)	0.20 (10.6)
Udon Thani	176588 (22.2)	0.17 (9.1)
Nakhon Phanom	44320 (16.9)	0.17 (9.1)
Kalasin	66340 (17.1)	0.36 (16.9)
Khon Kaen	144751 (23.1)	0.37 (19.1)
Mukdahan	15815 (14.6)	0.26 (13.8)
Chaiyaphum	102532 (30.7)	0.25 (12.9)
Maha Sarakham	116042 (22.2)	0.42 (20.5)
Roi Et	109276 (14.0)	0.36 (18.1)
Yasothon	71734 (24.5)	0.19 (10.2)
Ubon Ratchathani	99171 (8.7)	0.16 (9.2)
Nakhon Ratchasima	251218 (28.6)	0.28 (15.3)
Buri Ram	99122 (11.8)	0.29 (14.8)
Si Sa Ket	150082 (21.0)	0.32 (15.5)
Surin	137792 (15.9)	0.38 (18.8)
Average	525550 (20.2)	0.29 (14.6)

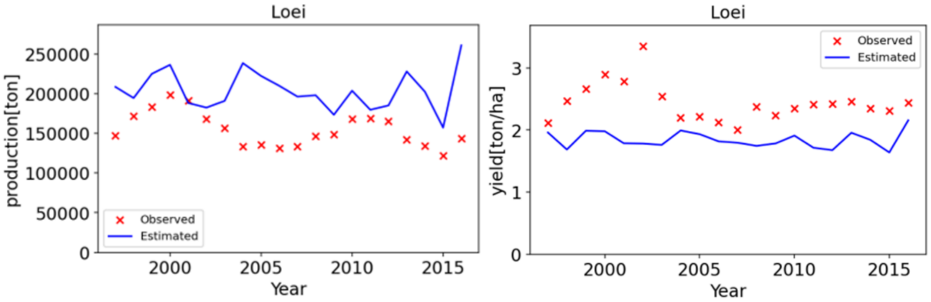


Fig. 3 Changes in production and yield in Loei (left: production, right: yield)

Figure 4 compares provincial production and yield under various planting thresholds in 1991. In this study, the planting threshold is defined as the free water level [mm] that H in equation (1)must exceed for consecutive 3 weeks. This threshold was incrementally increased by 5 mm up to 32.8 mm from a baseline of 12.8. In 1991, most provinces exhibited different optimal transplanting dates (TPD) when assessed based on yield versus production during the calculation period. Three provinces were excluded because they were not established by 1991. Among the 16 remaining provinces, 10 Bung Kan, Udon Thani, Chaiyaphum, Roi Et, Yasothon, Amnat Charoen, Ubon Ratchathani, Nakhon Ratchasima, Buri Ram, and Si Sa Ket showed different optimal TPDs for yield and production. These findings highlight that the optimal TPD for yield does not necessarily maximize production. Furthermore, Udon Thani, Roi Et, Yasothon, Ubon Ratchathani, Nakhon Ratchasima, Buri Ram, and Si Sa Ket (Group A) indicated later TPD for maximizing production compared to yield. These results suggest that transplanting date recommendations based solely on yield optimization, as proposed in previous studies by Abbadi et al. (2015) and Sujariya et al. (2020), may not be suitable when the goal is to maximize total production. Since production depends not only on yield but also on planted area, models that incorporate planting area estimation such as the one used in this study are essential for identifying transplanting date that better reflect the actual conditions and decision-making processes faced by farmers.

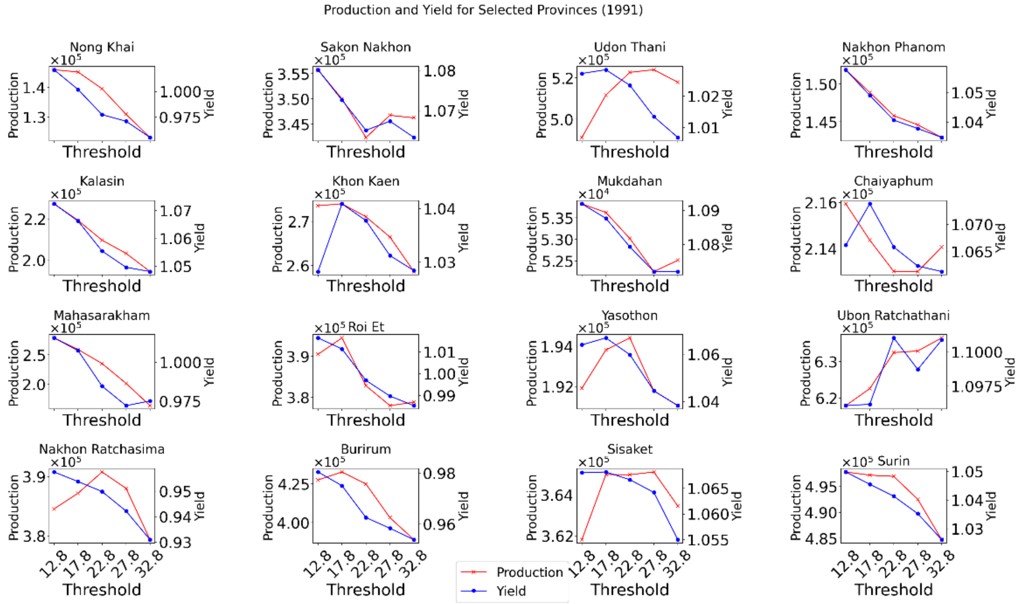


Fig. 4 Provincial yield and production for each planting threshold in 1991

Figure 5 shows the daily average rainfall of Group A and other provinces during the simulation period, from 1st May to 31st October 1991. The arrows in the figure indicate the cumulative rainfall from May 1 to July 31 (first half of the simulation period) and from August 1 to October 31 (second half of the simulation period). In 1991, provinces in Group A experienced 36 mm less rainfall in the first half of the rainy season and 95 mm more rainfall in the second half compared to other provinces. Typically, a higher yield leads to higher production; therefore, the optimal transplanting date (TPD) for yield was obtained in a previous study. However, in rainfall patterns like that observed for Group A in 1991, accepting a shorter growing period and reduced yield to avoid a decrease in the harvest area ratio caused by water deficits could lead to higher total production. In the future, research aimed at optimizing farmers' crop calendars will be needed through analyses that quantitatively demonstrate rainfall patterns in which the production-based optimal TPD is later than the yield-based optimal TPD for such reasons.

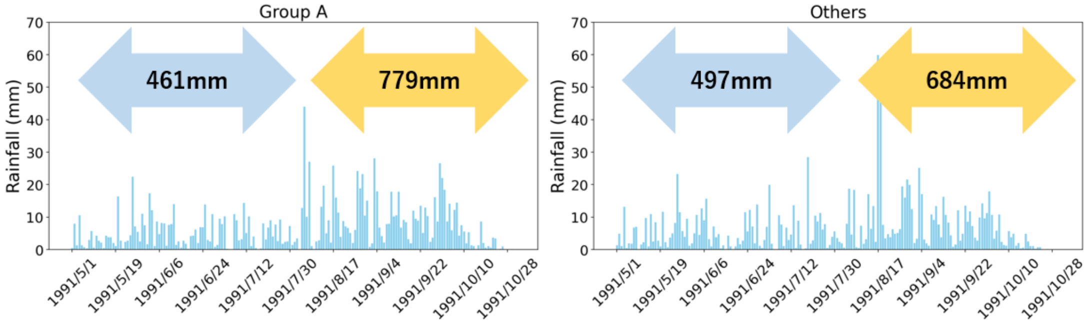


Fig. 5 Daily average rainfall of Group A and other provinces in 1991

CONCLUSION

This study developed a production estimation model for rain-fed rice, accounting for fluctuations in the planted area and yield. These findings highlight that the optimal TPD for maximizing production often differs from that for maximizing yield, emphasizing the importance of prioritizing total production over unit yield in climate change adaptation strategies. The model integrates rainfall patterns, water availability, and planting area dynamics, offering a framework to understand their impact on rice production and optimize crop calendars to mitigate water deficits sustainably.

Model validation using statistical data confirmed its ability to estimate production and yield in northeastern Thailand. However, the accuracy was lower in Loei, with the highest RMSE for both metrics. This is likely due to Loei's mountainous terrain, fragmented paddy fields, and high forest cover (57%), which the model did not account for, leading to an overestimation of the planted area and production and an underestimation of the yield. Loei was excluded from the analyses to ensure consistency. In addition, recent climate variability, including the increased frequency of floods and droughts, may influence model accuracy. While drought-related damage can be represented in the model through decreases in the water stress index (WSi) and harvest rate (Hri), the impact of flooding is not incorporated. Therefore, if flood events have become more frequent since 2016, the model's accuracy may have declined in more recent years. Moreover, the model defined paddy fields based on the 2015 land use map. Although significant changes in the paddy area could reduce estimation accuracy, statistical data from the Office of Agricultural Economics indicate that the planted area in Northeast Thailand has fluctuated within ±5% between 2015 and 2024. This suggests that the impact of land-use change on model performance remains limited.

In 1991, the largest number of provinces exhibited differences between the optimal TPDs based on production and those based on the unit yield. This discrepancy was mainly due to the different rainfall patterns. Provinces with lower rainfall during May–July and higher rainfall during August–October tended to adopt TPDs later. Although delaying TPD shortens the growing period due to photoperiod sensitivity, leading to reduced unit yields, it mitigates water deficits, prevents reductions in harvest area, and maximizes total production. These findings indicate that the optimal TPD based on production often differs from that based on the yield. This implies that the optimal transplanting date proposed by previous studies based on yield may differ from that based on production. Furthermore, if future advancements allow for approximate predictions of rainfall patterns within the growing period, it may become possible to propose TPDs that depend on regional rainfall patterns, thereby maximizing the production.

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