Planting time options to improve rice productivity based on the Integrated KATAM recommendations

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Abstract. The information system of integrated cropping calendar (KATAM) has been broadly applied in Indonesia and become a guideline for the users entering the next planting season, however, it allows limited options of planting time of one season. The aim of this study was to evaluate planting time scenarios to improve rice productivity using the crop simulation model Agricultural Production System Simulator (APSIM) in Bogor. Options evaluated considered three planting times, the growing season and water treatment. The simulated productivity values between 3 planting times were compared and analyzed. Result showed that APSIM could simulate productivity with a reasonably good accuracy (EF=0.74) across the different planting times following the season. For the irrigated rice, the late planting resulted similar productivity to the KATAM planting within the rainy (5.1 to 5.5 t ha\(^{-1}\)) and dry season (5.6 to 5.8 t ha\(^{-1}\)), whereas the early planting resulted the lowest productivity (3 to 5 t ha\(^{-1}\)). For the rainfed rice, the early planting presented the same productivity as the KATAM planting within the rainy (2.9 to 3.2 t ha\(^{-1}\)) and dry season (4.0 to 4.3 t ha\(^{-1}\)), respectively. This study confirmed simulation modeling is a useful tool in providing options for rice cropping systems and that a planting time based on the prevailing season conditions will ensure the acceptable rice productivity.

1. Introduction
Rice is a staple food for more than 250 million people in Indonesia. It is cultivated all over the area from the western to the eastern part of the country. According to the Statistic Indonesia [1], nearly 11 million ha were harvested in Indonesia and around 55 million tons of rice are produced. Like many countries, Indonesia faces challenges to increase food production, along with the increase of population growth, that is projected to exceed 305 million in 2035 [2]. Unfortunately, the increase conversion of rice fields cannot be offset by the expansion of new rice fields [3]. In addition, erratic climate conditions and increasing frequency of extreme climate events can cause the uncertainty of rice yield and further reduce the future rice productivity as well as bring instability in food production.

To maintain food production stability, the Indonesian Ministry of Agriculture has developed an atlas of cropping calendar to determine appropriate planting time of an area since 2007. As stated by Sacks et al. [4], planting calendar is a tool for farmers and extension workers to decide planting time and make decision within seed preparation, processing land, labor requirements, regulating use machine tools for land management, and harvesting. The method and substance of this atlas of cropping calendar continues updating. Since 2011 the atlas of integrated cropping calendar (kalender tanam/KATAM) has been evolved into a dynamic information system of integrated KATAM. This information available at sub-district level and includes of forecasted planting time, estimation of planting area, floods, droughts and pests’ prone area, recommendation of varieties, requirements of fertilizer dose [5,6]. Since 2014,
information on type and quantity of agricultural machinery have also been integrated to the information system of integrated KATAM.

The information system of integrated KATAM, furthermore, describes the potential pattern and planting time for food crops such as rice, maize and soybeans based on the potential and dynamics of climate and water resources. In addition, it is developed to support food security program and to respond to climate diversity and change. Starting in 2015, the information is updated two times a year that is growing season during dry season/MK and growing season during rainy season/MH following the season predictions issued by Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG). Subsequently, recommendations of this information system have been socialized via the web, android application, short message service center, or face to face with the extension workers. Nowadays, the implementation of the information system of integrated KATAM is widely used in many fields in Indonesia and as a guideline for the farmers in determining planting time. However, the information of forecasted planting time is limited to one planting period of each growing season.

Crop simulation model is an effective tool to quantify the response of crop yield and other crop variables to management options [7]. The simulation models have the ability to evaluate alternative strategies and to explore scenarios related to experimental sites and seasons as well as to provide information required to assess risk [8]. The Agricultural Production System Simulator (APSIM) model can simplify the interaction between soil, climate and crop on the growth and development of plant, the time range for harvesting in a long data period, so that the effect of climate variability on crop production can be notable [9]. Furthermore, it is able to evaluate the short-term and long-term impacts of agricultural system on crop that is strongly influenced by seasonal variations. Many studies show that APSIM has been used to simulate the production of many crops such as rice, wheat and legumes in Asia Pacific and South American countries [10 - 14]. In Indonesia, Boer et al. [15] has validated the APSIM result in the study of soybean in Bogor with the correlation results (r = 0.91). Meanwhile Gaydon et al. [12] reported that there was a insignificant bias of rice production in the West Nusa Tenggara (NTB) between the observed and the simulated measurement. The average of rice production in NTB province is around 6.1 t ha\(^{-1}\) over the last ten years.

APSIM allows an effective way to help agricultural practitioners to create planting calendar and manage crop management strategies. Moreover, the impact of environmental changes such as climate change on crop yields and how the changes in cropping patterns can affect the environment over time can be identified. However, information on the ability of the model to predict the performance of rice crop, particularly concerning planting time based on the integrated KATAM recommendations has never been evaluated. This study therefore aimed to evaluate options of planting time to improve rice productivity in accordance with the integrated KATAM recommendations.

2. Materials and methods

2.1. Site description

Data from field experiments conducted at the Muara Experimental Site from January to November 2017 in Bogor were used to calibrate and evaluate the model. The Muara Experimental Site (6°36’ S, 106°47’ E) is an experimental site under Indonesian Center for Rice Research. During the experiment period, it receives an average rainfall of 2954 mm, and experiences an average minimum temperature range of 21.0 to 22.8°C with the lowest values in May (table 1). Furthermore, this experimental site has 35 ha of rice fields with its unique characteristics as a miniature urban agriculture.
Table 1. Average monthly radiation and rainfall, and monthly maximum and minimum daily temperatures based on daily weather records from January to November 2017 at the Muara Experimental Site weather station.

|                | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Year |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Radiation (MJ m\(^{-2}\)) | 367.8 | 274.7 | 376.3 | 540.2 | 178.0 | 351.5 | 362.4 | 418.1 | 402.7 | 389.8 | 345.9 | 4007 |
| Rainfall (mm)  | 182.6 | 632.8 | 397.6 | 568.0 | 593.2 | 525.4 | 222.0 | 125.8 | 280.8 | 379.6 | 143.8 | 2954 |
| Max average daily temperature (°C) | 30.2 | 29.2 | 30.1 | 31.4 | 31.6 | 30.7 | 31.3 | 32.5 | 32.9 | 32.5 | 31.9 | 31.4 |
| Min average daily temperature (°C) | 22.4 | 21.9 | 21.9 | 21.5 | 21.0 | 22.2 | 21.1 | 21.9 | 22.3 | 22.8 | 22.5 | 21.9 |

2.2. Description of measured field data set

The field experiments were conducted in the rice field with an area of 3000 m\(^2\) from January to November 2017 at the Muara Experimental Site, in Bogor. The soil texture is a clay soil containing 66.4% clay, 9.50% sand, and 24.1% silt, with a pH (in water) of 4.8.

The treatments were set out in a randomized complete block design consisting of two water treatments (irrigated (i.e. continuous flooding) and rainfed rice cropping system) by three planting times (early, late and compatible planting time based on the integrated KATAM recommendations), with three replications. The planting of rice was carried out two times, in rainy season/MH (March to April 2017) and in dry season/MK (June to July 2017).

The fertilizer was applied and broadcasted to the soil three times at 7 days after planting (200 kg ha\(^{-1}\) of Ponska), 21 days after planting (125 kg ha\(^{-1}\) of Urea), and 35 days after planting (125 kg ha\(^{-1}\) of Urea). The dose of fertilizer was based on the KATAM recommendations. Rice (cv. Inpari 32) was transplanted and then broadcasted onto cultivated moist soil in irrigated and rainfed rice cropping system. The rice crops were later harvested at maturity and crop samples were weighed for the dry weight. Soil sampling was taken from the layer 0 to 90 cm prior to the cultivation of the rice crop. Soil samples were then dried at 40°C and ground for analysis.

2.3. Parameterisation of the APSIM model

The APSIM version 7.9 was set up with the rice module, the soil water module (SOILWAT), the soil N module (SOILN), the residue module (Surface OM), and the Manager [8]. These modules are integrated to the central engine of APSIM to simulate rice productivity based on the integrated KATAM recommendations at the Muara Experimental Site in Bogor, West Java.

2.3.1. Soil setup. The SOILWAT and SOILN modules were parameterized following standard practices using APSIM. The parameters for the SOILWAT module include soil bulk density, saturated soil water content, drained upper limit water content at field capacity (DUL), crop lower limit, and soil texture. The parameters for the SOILN module include organic carbon (OC), pH, Finert (inert fraction C) and Fbiom (microbial biomass fraction) (table 2). Finert and Fbiom, a collection of different organic materials based on specific default values, represent a portion of the total organic carbon in a particular site [10, 16]. The content of initial nitrogen in the soil was adjusted to 6 and 4 kg ha\(^{-1}\) of NO\(_3\), and 4 and 1 kg ha\(^{-1}\) of NH\(_4\) at 0 to 20 and 20 to 200 cm respectively. The content of initial water at planting was adjusted to 100 % evenly distributed.
Table 2. Bulk density Soil (BD), saturation (SAT), lower limit of plant-available water (LL15), drained upper limit of water (DUL), organic carbon (OC), fraction of active soil organic material as microbial biomass (Fbiom) and fraction of inert organic matter (Finert) at various soil depths for the initiation of the APSIM model.

| Depth (cm) | BD (g cm$^{-3}$) | SAT (mm mm$^{-1}$) | DUL (mm mm$^{-1}$) | LL15 (mm mm$^{-1}$) | OC (%) | Fbiom | Finert |
|-----------|------------------|-------------------|-------------------|-------------------|-------|-------|-------|
| 0-15      | 0.85             | 0.50              | 0.46              | 0.27              | 0.53  | 0.07  | 0.20  |
| 15-30     | 1.03             | 0.45              | 0.41              | 0.30              | 0.52  | 0.05  | 0.40  |
| 30-60     | 0.84             | 0.49              | 0.45              | 0.30              | 0.51  | 0.02  | 0.55  |
| 60-90     | 0.78             | 0.54              | 0.49              | 0.29              | 0.50  | 0.02  | 0.85  |

2.3.2. Plant module calibration. For rice crop, Inpari 32 variety was parameterized using standard crop parameters of IR72 variety [17] according to the procedure described by Bouman and Van Laar [18]. Data of rice crop planted during the rainy season (MH) on 13th of March 2017, and during the dry season (MK) on 5th of July 2017 were used to parameterize the rice module. Phenological parameters include the juvenile phase, the photoperiod-sensitive phase, the panicle development phase, and the reproductive phase. Details of the phenological parameters are given in Table 3. Furthermore, the parameter values for each phase of phenology development were adjusted until the value of the simulation phase best fit with the values of the observation phase.

Table 3. Phenological parameters and values for the Inpari 32 variety.

| Parameters                              | IR72 (default values) | Inpari 32 values | Units |
|-----------------------------------------|-----------------------|-----------------|-------|
| Development rate in juvenile phase      | 0.000773              | 0.000793        | ^Cd$^{-1}$ |
| Development rate in photoperiod-sensitive phase | 0.000758              | 0.000788        | ^Cd$^{-1}$ |
| Development rate in panicle development phase | 0.000784              | 0.000794        | ^Cd$^{-1}$ |
| Development rate in reproductive phase  | 0.001784              | 0.001894        | ^Cd$^{-1}$ |

2.4. Model performance analysis

This study is a preliminary study, a limited number of samples was then used for statistical analysis. The efficiency of forecasting (EF) was used to evaluate the performance of the model [19]. The equation of EF as follows:

$$EF = 1 - \left[ \frac{\sum (O - P)^2}{\sum (O - \bar{O})^2} \right]$$

Where O and P are the paired observed and simulated values, $\bar{O}$ is the mean of all observed values. The EF values explains the overall goodness-of-fit of the data with values close to one showing high performance of the model, whereas the negative values showing low performance [20].

2.5. Scenario analysis

Crop model simulations were developed to evaluate rice productivity based on integrated KATAM recommendations. Scenarios simulations were carried out to assess different planting times following the growing season to define their productivity. These simulations were examined using climate data from January to November 2017. Details of scenarios are describes as follows:

i. Planting time:
   a. Based on integrated KATAM recommendations (3rd of March 2017 for MH and 5th of July 2017 for MK).
   b. Early planting; 20 days before planting time of KATAM.
c. Late planting; 20 days after planting time of KATAM.

ii. Water treatment:
   a. Irrigated rice; water supply was applied in accordance with the integrated KATAM recommendations.
   b. Rainfed rice; water supply depend on natural rainfall.

Fertilizer application was set similar to the field experiments for each system. The type, dose, and time of application based on KATAM recommendations i.e. three times at 7 days after planting (200 kg ha\(^{-1}\) of Ponska), 21 days after planting (125 kg ha\(^{-1}\) of Urea) and 35 days after planting (125 kg ha\(^{-1}\) of Urea).

All scenarios above were set using the language of APSIM’s Manager and the SoilWat module. Simulations began on the 1\(^{st}\) of January 2017 and ran until the 30\(^{th}\) of November 2017. Soil water, soil mineral N and soil organic matter were reset to initial conditions.

3. Results and discussion

3.1. Parameterization of APSIM for the Inpari 32 variety

The APSIM model was parameterized for the Inpari 32 rice variety using parameterized soil from the Muara Experimental Site. These parameters are based on the phenology of the Inpari 32 variety for each growth phase as shown in table 3.

The performance of the APSIM model in simulating rice productivity can be seen in figure 1 and 2. The simulated values were then compared to the observed values. The simulated value of rice productivity (5.4 t ha\(^{-1}\)) during the rainy season with irrigation application showed a value that was comparable to the observed one (5.2 t ha\(^{-1}\)), whereas the simulated value of rice productivity (3.2 t ha\(^{-1}\)) under rainfed condition was lower than the observed value (4.9 t ha\(^{-1}\)) (figure 1). Entering the dry season (figure 2), the simulated value of rice productivity (5.6 t ha\(^{-1}\)) applied with water irrigation was lower than the observed value (6.1 t ha\(^{-1}\)). For the rainfed rice system, the simulated value of rice productivity (4.3 t ha\(^{-1}\)) was also lower than the observed one (4.9 t ha\(^{-1}\)).

The simulation results showed that the APSIM model can estimate rice productivity quite well in accordance with the given water application and following the growing season. However, in general the simulated values were much lower than estimated, particularly for the rainfed rice system due to limited water supply. Rainfed rice relied only on rainfall flooding the rice field trials, whereas irrigated rice were flooded continuously from the water source.

There was a large gap between the simulated and observed value of rice productivity under rainfed condition during the rainy season. It was quite challenging to set fully rainfed condition in the field since the water flow from the adjacent field trials treated with irrigation treatment was difficult to avoid. Therefore, the requirement of water was fulfilled not only from rainfall, but also from the irrigation treatment.

According to Mackill et al. [21], rainfed rice system normally has high inconstancy at the beginning and end of the rainy season, the amount of rainfall and its duration. During the growth period, the chance of abiotic pressures such as drought is high, particularly at the critical growth stage. This can cause substantial damage to the growth and nutritional use of the rice crop. To avoid adverse effects, determining the optimal time for planting is very crucial so that rice growth turns out under favorable flowering [22].
3.2. Evaluation of the model

The model was evaluated for rice productivity. The RMSEn in % of the observed mean was 16 for rice productivity with a good EF (table 4). This indicated that the APSIM model was able to predict rice productivity based on model efficiency.
Table 4. Statistical criteria (root mean square error, RMSE and model efficiency, EF) as well as observed range and mean for evaluating productivity of rice.

| Parameters         | N  | Observed range (kg ha\(^{-1}\)) | Observed mean (kg ha\(^{-1}\)) | RMSE | RMSEn (%) | EF  |
|--------------------|----|----------------------------------|---------------------------------|------|-----------|-----|
| Rice productivity  | 4  | 4900 to 6100                     | 5275                            | 0.84 | 16        | 0.74|

3.3. Scenario analysis

Scenario analysis identifies the accurate planting time in obtaining high rice productivity. Selection of planting time for the early planting was set 20 days before 3\(^{rd}\) of March 2017 for MH and 5\(^{th}\) of July 2017 for MK, whereas for the late planting was set 20 days after 3\(^{rd}\) of March 2017 for MH and 5\(^{th}\) of July 2017 for MK. The periods of 20 days before and after planting time of KATAM recommendations was considered as a period that allows rice crop to grow and develop properly so that rice productivity can be obtained (results from the field observations and validations of KATAM recommendation).

The scenario analysis showed the effect of planting time on rice productivity. For irrigated rice, the KATAM planting and the late planting were favorable when compared to the early planting in rainy season. Rice productivity for the KATAM and late planting were much higher (5.1 to 5.5 t ha\(^{-1}\)) than the early planting (3.0 t ha\(^{-1}\)) (figure 3). Whereas, for rainfed rice, the KATAM planting and the early planting produced higher rice productivity (2.9 to 3.2 t ha\(^{-1}\)) compared to the late planting (0.4 t ha\(^{-1}\)). The in-season rainfall for the irrigated rice was almost entirely able to meet the water requirement of crop (1000 to 1600 mm), allowing a more effective use of in-season rainfall during the period of rice growth. On the other hand, for the rainfed rice, its water requirements cannot be fulfilled by in-season rainfall, causing low performance of rice growth and productivity.

Figure 3. APSIM simulation for rice productivity (t ha\(^{-1}\)) in the rainy season based on the KATAM, early and late planting time across the 2017 climate record for the Muara Experimental Site.

Entering the dry season, for irrigated rice, the KATAM, late and early planting showed relatively the same level of rice productivity (5.6 to 5.8 t ha\(^{-1}\)), whereas for rainfed rice, the KATAM and late...
planting produced higher rice productivity (4.0 to 4.3 t ha\(^{-1}\)) compared to the early planting (2.8 t ha\(^{-1}\)) (figure 4). The irrigated rice was highly responsive to water supply. Water availability was sufficient to drive the grain yield. Conversely, as the rainfed rice crop received a relatively low amount of water, the response of crop to water supply amount can be limited. The rainfed rice may use the soil moisture much better than the irrigated rice.

![Figure 4](image)

**Figure 4.** APSIM simulation for rice productivity (t ha\(^{-1}\)) in the dry season based on the KATAM, early and late planting time across the 2107 climate record for the Muara Experimental Site.

The purpose of the scenario analysis was to appraise the performance of irrigated and rainfed rice at different planting time (the KATAM, late and early planting) in Muara, Bogor using the APSIM model. The model demonstrated that mean rice productivity differed with planting time and rice cropping systems. Planting irrigated rice during the rainy season based on KATAM planting is likely allowing more grain yields as a result of rainfall which was higher in February than in March and April (table 1). For the late planting time, the rainfall during the period of crop grow provides low water supply that may cause low soil water content. This condition, however, can be optimally resolved by irrigation water. The early planting time scenario indicated that the rainfall was already high enough in February and additional water from irrigation system created waterlogged condition that can restrict crop growth and development. As a result rice productivity in this scenario was the lowest. On the other hand, planting rainfed rice during this season based on the KATAM and early planting resulted higher rice productivity compared to the late planting. Under rainfed condition, the crop water requirement rely only on rainfall. The KATAM and early planting time scenario showed that the rainfall was sufficient for the growth and development of rice. This provides slightly higher soil water content close to the soil surface that maintains soil moisture at the deeper levels, resulting high rice productivity. The late planting time pointed out that the rainfall was insufficient to support crop growth and development, causing crop to use more stored soil water and consequently reducing rice productivity.

Planting irrigated rice during the dry season resulting the same level of rice productivity as the rainy season. Although the amount of rainfall was much lower during the dry season, the water requirement of crop was fulfilled by the system of irrigation. The KATAM, late and early planting scenarios resulting the same rice productivity, showing that the time period (20 days before and after the KATAM planting...
time) allows the rice growth and development. However, it is not the case for the rainfed rice, the KATAM and late planting time led to a smaller susceptibility of drought compared to the early planting time. The sufficient water supply during the late planting time provides more soil conditions, causing good germination and crop establishment, showing in relatively high crop productivity.

Determination of suitable planting time is challenging due to the soil water content is effected by planting time and rainfall. The probability of rainfall before and after planting rice crop should be obviously appraised so that farmers can decide compatible times for planting and avoid considerably high soil strength. Moreover, they may look at the comparison of simulated rice productivity of the three planting times in deciding time to start planting. The simulation model is able to pick the performance complexity of rice crops up in irrigation and rainfed systems. Further study is required to evaluate the performance of the model across agroclimatic conditions with different rice varieties.

4. Conclusions

The APSIM model is comparatively able to capture the impact of management practices based on KATAM recommendations in irrigated and rainfed rice cropping systems. However, since this study was a preliminary research, adequate and good quality of experimental data set would be required for further evaluation of the model.

The model allows continuous simulation of soil, water and crop variables in rice cropping system over a range of planting times in the tropical climate of Muara Experimental Site in Bogor, West Java. The best planting time during the rainy and dry season for irrigated and rainfed rice cropping system is in accordance with the KATAM and late planting. To achieve high rice productivity in both irrigated and rainfed rice cropping system, farmers should take planting time and prevailing climate condition into account.

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