Combining simulation model and field observation in understanding crop productivity to climate variation

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Abstract. Changes in climate characteristics affect the growth and development of paddy and therefore affect rice productivity. Simulation model can be used to study the effect of climate change on rice productivity. In this study, combination of crop simulation model and field observation are used to comprehend the effect of climate change on rice productivity. The study uses field observation data. Climate, soil, and crop management input variable are similar to observation conditions. This research used default Aquacrop to estimate rice productivity in response to climate changes in Subang and also used DSSAT to estimate rice productivity and biomass components. The observation results showed that rice productivity in Pamanukan, Binong, Pagaden, Purwadadi, and Cijambe are about 6, 9, 7, 7, and 4 ton/ha. The output of the crop simulation model shows that rice productivity estimation based on the model have similar amount to rice productivity based on the field observation. Productivity estimation of simulation models is based on climate variations distinguished by temperature and rainfall accumulation. In the applications, it can be used to prepare mitigation and adaptation actions

Keywords: climate change, rice productivity, model simulation

1. Introduction
Rice (Oryza sativa L.) is the main food crop cultivated in Indonesia. The need for rice increases every year in line with the rate of population growth [1]. This causes an increase in rice crop productivity to be the main focus of Indonesian agriculture. Rice farming provides employment for 21 million agricultural households in Indonesia [2]

Increasing the productivity of rice plants has various challenges. Challenges such as increasing the productivity of rice plants and the conversion of land degradation, agricultural infrastructure, availability of production facilities, the adoption of appropriate technology, extensive land ownership, agricultural institutions, farmers’ access to capital, guarantee crop prices, and global climate change [3]. In addition to agricultural management, challenges to climate change in the form of shifting rain patterns, changes in temperature and humidity directly affect the productivity of rice plants [4,5,6,7]. Climate change increases the vulnerability of pests to plant diseases, increases water stress, and decreases rice productivity [8,9]

Planning and management of rice is done as a form of adaptation to the challenges of rice plants. Planning and management of rice plants is carried out with the irrigation planning cropping system, fertilizer, pest control systems and plant season planning [10]. Post harvest management is also carried out to stabilize food prices, especially rice

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The result of crop simulation model can be used as an alternative solution for food crop planning [9,10]. Food crop simulation models are used to assess the impacts of climate change and analyze adaptation strategies [9]. In this study, the Aquacrop model is used to simulate land water balance and the DSSAT (Decision Support System for Agrotechnology Transfer) model is used to estimate the productivity of rice crop yield components in one planting season.

A combination of a food plant simulation model with field observations was conducted to validate the results of a food crop simulation model, evaluate various agricultural management, and predict rice productivity based on climate change. This study provides the view that the food crop simulation model can be used to develop agricultural planning and management strategies, the food crop simulation model can be used as a basis for adaptation and mitigation actions related to food security, and be an option for estimating crop productivity and in areas with limited access.

This research aims to estimate rice productivity in response to climate changes using Aquacrop and estimate rice productivity and biomass components using DSSAT in Subang.

2. Materials and Methods

This research was conducted with a general approach to the method as shown in figure 1.

![Research general approach diagram](image)

Figure. 1 Research general approach diagram.

2.1 Literature Review

Literature review is conducted from January 1, 2019 to January 15, 2019 using the Google Scholar search engine (scholar.google.com). The keywords used are agricultural management, crop model simulation, paddy phenology field observation, rice productivity on climate change scenario.

2.2 Practical Agricultural Management

Practical agricultural management in the form of determination of planting time, land processing technology, selection of cultivars, the time and amount of irrigation, the time and amount of fertilizer application, and the time of pest control of rice plants. Practical agricultural management refers to the Integrated KATAM of the Ministry of Agriculture and is verified by field observations.

2.3 Crop Model Simulation

2.3.1 DSSAT 4.7. The DSSAT 4.7 simulation model was carried out in the demoplot of Pamanukan and Cijambe Districts with the location of the area in figure 2. The method uses the default simulation option DSSAT 4.7. The data used the DSSAT 4.7 simulation model in table 1.
Figure. 2 Demoplot location.

Table 1. Data input simulation model DSSAT 4.7.

| Data          | Parameter                                      | Description                                                                 |
|---------------|-----------------------------------------------|----------------------------------------------------------------------------|
| Climate       | Daily rainfall, maximum air temperature, minimum air temperature | Pamanukan Demoplot of 1 January 2018 - 6 June 2019                             |
|               |                                               | Cijambe Demoplot of 1 January 2018 - 24 May 2019                            |
| Soil          | Physical/chemical properties                  | Soil Laboratory test of Pamanukan and Cijambe demoplot                       |
| Farming       |                                               |                                                                            |
| management    |                                               |                                                                            |
| parameters    |                                               |                                                                            |
|               | Parameter                                     | Pamanukan                                                                 |
|               |                                               | Cijambe                                                                    |
| Planting date | December 31, 2018                            | January 9, 2019                                                             |
| Planting method| Dry seed                                     | Dry seed                                                                   |
| Planting      | Rows                                          | Rows                                                                       |
| distribution  |                                               |                                                                            |
| Plant population at seeding/m² | 250                                    | 100                                                                        |
| Row spacing   | 20 cm                                         | 30 cm                                                                      |
| Planting depth| 5 cm                                          | 10 cm                                                                      |
| Row direction, Degree from North | 0                                             | 0                                                                          |
| Irrigation    |                                               |                                                                            |
|               | 200 mm at 2,9,15, and 20 DAP; 150 mm at 25 DAP; 100 mm at 30 DAP; 70 mm at 41,51,62,65,68,74 and 77 DAP | 90 mm at 9 and 17 DAP; 150 mm at 27 DAP                                     |
| Urea          | 220 kg / ha at 10 DAP                        | 310 kg/ha at 17 DAP                                                        |
|               |                                               | 95 kg/ha at 41 DAP                                                         |
|               |                                               | 95 kg/ha at 47 DAP                                                         |
| Genetic       |                                               |                                                                            |
| coefficients  |                                               |                                                                            |
|               | coefficient                                  | IR42 Value | IR64 Value |
|               | Unit                                          | Value     | Value     |
| P1            | °C day                                        | 651       | 500       |
| P2R           | °C day                                        | 120       | 160       |
| P5            | °C day                                        | 580       | 450       |
|               |                                               |            |            |
P2O Hour The length of the critical day when developments are at their maximum rate 10.5 12

G1 (gram) Potential grain coefficient as an estimate of the number of grains per gram at flowering 65 60

G2 Gram Unit grain weight under ideal development conditions (light, water, and nutrients are met, while pests and diseases are absent) 0.028 0.025

G3 Koesfisien anakan 1 1

G4 Temperature coefficient of tolerance (usually a value of 1 for varieties that grow in a normal environment) 1 1

Note: DAP= Days after planting

2.3.2 Aquacrop. Aquacrop simulation models carried out in 2 out of 5 clusters of Subang Regency [11]. Data used in the DSSAT 4.7 simulation model in table 2.

Table 2. Aquacrop simulation model input data.

| No. | Data       | Parameter                                                                 | Description                                                                                     |
|-----|------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| 1   | Iklim      | Daily rainfall, daily maximum air temperature, daily minimum air temperature | Field observation data for Binong, Pagaden and Purwadadi areas                               |
| 2   | Soil Profile| Physical properties of soil                                               | Test results of the Environmental Biotechnology Laboratory at the Indonesian Center for Biodiversity and Biotechnology |
| 3   | Irrigation Management | High irrigation | The water level is 20 mm to 5 DAP and 50 mm / 10 days to 70 DAP |
| 4   | Rice plants | Plant Characteristics                                                    | Results of Aquacrop simulation model calibration                                                |

2.4 Field Observation. Data and methods for collecting field observations are shown in table 3. Field observations were carried out in the demonstration plots of Pamanukan, Binong, Pagaden, Purwadadi and Cijambe Districts.

Table 3. Data and field observation data collection methods.

| No. | Data       | Parameter                          | Observation Method                                                                 |
|-----|------------|------------------------------------|-----------------------------------------------------------------------------------|
| 1   | Climate    | 1. Rainfall 2. Air temperature 3. air humidity 4. evapotranspiration | 1. Rainfall data is taken with a simple rain gauge measured 2 days 2. Measured using a thermometer every day 3. Measured with a wet ball and dry ball thermometer then a calculation is made 4. Plant samples are taken on paint cans and weighed 2 days |
| 2   | Phenology  | Plant height and tillers           | Measured using tape measurement and counters once a week in the vegetative phase and 4 days in the generative phase |
| 3   | Irrigation | Soil water level                   | Measured by tape measurement following phenological measurements                   |

DSSAT requires daily precipitation, maximum and minimum air temperature, and solar radiation as standard weather inputs. Daily precipitation, maximum and minimum air temperature data are from observational climate data (Table 3) in five demplots in Pamanukan, Pagaden, Purwadari, Binong, and Cijambe, combined with corrected nasapower data. The solar radiation data is obtained from nasapower. The irrigation and phenology data are from observational data. Soil properties vary with depth. The soil samples are taken from five demplots and the information of soil properties are tested in ICBB (Indonesian Center for Biodiversity and Biotechnology).
Aquacrop requires daily precipitation, maximum and minimum air temperature, reference evapotranspiration, and the mean annual carbon dioxide (CO₂) concentration as standard weather inputs. Daily precipitation, maximum and minimum air temperature data were obtained from global climate model of MIROC and CSIRO for baseline period (1986-2015) and future period (2021-2050). The reference evapotranspiration (Eto) data was derived from weather station data using Penman-Monteith equation (Allen et al. 1998) and Eto calculator (FAO 2009) available in Aquacrop. The past and current mean annual carbon dioxide (CO₂) concentration values are measured by the Mauna Loa Observatory in Hawaii and can be chosen by the user (Steduto et al. 2009). Soil properties for Aquacrop simulation are obtained from Subang Regency.

3. Result and Discussion

3.1. Field Observation Result
The characteristics of the study locations are shown in table 4. Variations in climatic characteristics can be seen from the high rainfall [11]. Variations in the phenological characteristics of plants can be seen from differences in rice varieties [12]. Climate characteristics and characteristics of rice varieties determine the needs of rice water plants and rice productivity in each region [12]. Cijambe demoplots have the lowest productivity because the growth and development of plant phenology is not optimum at low temperatures.

| Demoplot (Varietas) | Variabel               |  Productivity (ton/ha) |
|---------------------|------------------------|------------------------|
|                     | T Average (°C)         | Rainfall (mm/plant season) | RH (%) | Tillers (stem) | Plant Height (cm) | Water Requirement (mm/plant season) |
| Binong (Ketan)      | 29                     | 600                     | 86      | 38             | 123.88            | 1134                               |
| Purwadadi (Inpari 32)| 28                     | 536                     | 88      | 29             | 112.84            | 897                                |
| Pamanukan (IR42)    | 29                     | 1033                    | 87      | 49             | 140.20            | 1242                               |
| Pagaden (Tarabas)   | 31                     | 542                     | 84      | 24             | 134.84            | 1216                               |
| Cijambe (IR64 Jumbo)| 25                     | 2471                    | 85      | 30             | 104.63            | 690                                |

3.2. Crop Model Simulation

3.2.1 Crop Water Requirement. A comparison of the water needs of the Aquacrop simulation model results with the observations is shown in figure 3. The daily water requirement trend of the simulation model with field observation results is negatively related but simulation model result have a fluctuation pattern following field observation results. Field observation results have a value of 10-12 higher than crop simulation model results. High water requirement influenced by differences in the phase of rice plants [13]. This is caused by Aquacrop not taking into account agricultural management.
3.2.2 Biomass productivity. Growth conditions of rice plants can be seen from the growth of leaf biomass, stems, roots and grains of rice. The biomass of leaves, stems, and roots of rice tends to increase and reach a maximum point at 100 HST. Stem and leaf biomass growth is a reference for rice plant growth conditions in the vegetative phase and initial indicator of rice crop productivity estimation. Rice biomass growth can be the basis for estimating rice productivity. The biomass growth of leaves, stems, roots and ears can be seen in figure 4. The pattern of height and number of observed tillers was positively related to the growth of biomass from the simulation model. Plant height and number of tillers observed in figure 5. Illustrates the growth of rice plant biomass in the field.
3.2.3 Rice Productivity. Rice productivity comparison from DSSAT simulation results with field observations is shown in table 5. DSSAT simulation results with irrigation and fertilizer inputs based on field conditions show values that are comparable to the results of field observations. DSSAT simulation results without irrigation and fertilizer show productivity results that are only influenced by regional climatic conditions. DSSAT simulation results without irrigation and fertilizer have a very low productivity value compared to the results of field observations. The application of fertilizer and irrigation is an act of adaptation and mitigation of agricultural management for climate change [9]

Table 5. Productivity estimation comparison using the DSSAT model and field observation productivity

| Demoplot     | DSSAT (with irrigation + fertilizer) | DSSAT (without irrigation + fertilizer) | Field Observation |
|--------------|------------------------------------|----------------------------------------|-------------------|
| Cijambe      | 4.5 ton/ha                         | 1 ton/ha                               | 4 ton/ha          |
| Pamanukan    | 6.5 ton/ha                         | 0.8 ton/ha                             | 6 ton/ha          |

Table 5 shows the comparison of rice productivity between Cijambe and Pamanukan with 2 different treatments (with irrigation and fertilizer treatment and without irrigation and fertilizer treatment) for 1 cultivating season based on the output of DSSAT. Based on the table 5, the crop area where irrigation and fertilizer are provided for the crop tend to have higher amount of rice productivity than the area where irrigation and fertilizer aren’t provided for the crop. Pamanukan has higher rice productivity when irrigation and fertilizer are provided for the crop, meanwhile Cijambe has higher rice productivity in the area where irrigation and fertilizer aren’t provided. According to Suprihatno et al. [14], IR64 and IR42 produced the average rice productivity of 5 tons/ha, so the simulation results using DSSAT model in Cijambe and Pamanukan could represent the actual rice productivity in the area where irrigation and fertilizer are provided for the crop.

Demonstration plot in Cijambe is located in the altitude of 648 meters above sea level which tends to have low rice productivity. The altitude of the location is one of the climate control factors that has a strong influence on air temperature. The air temperature affect the speed of metabolism, especially photosynthesis and respiration. The demonstration plot in Pamanukan is located in the altitude under 100 meters above sea level. The rice productivity in Pamanukan based on the field observation is 6 tons/ha, higher than Cijambe which only has 4 tons/ha. The rice productivity in Pamanukan is higher
because the intensive maintenance by the farmers in the demonstration plots, giving adequate fertilizer and irrigation despite the low rainfall during the simulation. In addition to the altitude and air temperature factor, the differences in cultivars between IR64 and IR42 also contributed to the amount of rice productivity. The age of IR64 according to Suprihatno et al. [14] is 110-120, while the IR42 is 135-145 days. This results in the difference in plant biomasses where the biomass of IR42 is higher along with the longer age of the plant, so the rice productivity in Pamanukan is also higher than the biomasses of IR64 rice plant in Cijambe.

4. Conclusion
Archiving observation data for plant growth and development has not well recorded in Indonesia. The statistical data are usually reported only crop production and/or productivity. On the other hand, devising tactical management strategy for farming in anticipating climate variation or extremes requires understanding on contributing factors to crop growth and development such as climate, soils and applied farming practices. This study shows a plant simulation model as an alternative solution for planning and management of food crops. We utilized agricultural simulation models, i.e., Aquacrop and DSSAT, in combination with field observations to study plant growth and development as well as the effects farming practices to paddy production at the study sites.

The results of the simulation of crop models have a value not far different from the results of field observations. Plant simulation models can be an evaluation instrument for agricultural management. Crop biomass productivity simulation model have a similar trend to field observation phenology. Water requirement result between model simulation and field observation have a similar fluctuation pattern. Simulation models can be used as an alternative to study crop growth and development. The models also offer an opportunity to predict crop response to different climate characteristics, soil properties, and the amount of irrigation and fertilizers.

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