Quantification the Impact of Climate Change on Paddy Field Yield Production in Subang, Indonesia

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Abstract. Paddy field production is impacted by the climate and water resources, which is driven by environmental condition and also water management. It is required to evaluate the impact of climate change and water management to plan the future management strategies as the adaptation of climate change. This paper evaluate the potential impact of climate change on paddy field production and water resources using Aquacrop crop simulation model for Subang District in Indonesia. The crop phenology information was obtained from the field survey and applied to set up and validate the Aquacrop model. The historical paddy field production and irrigation water requirement was calculated based on history data and the future paddy field production and irrigation water management was calculated based on future climatic condition. The future climate projection under RCP 8.5 climate scenario was applied to investigate the impact of future changing climate on crop production. The simulation outputs show the increasing of the rainfall by average of 27% and impact to the increasing of the paddy field productivity by 19% in the period of 2021 – 2050. The result also indicates the increasing of the flood and plant diseases and influence to the paddy production in the future. These findings suggest that the good water management on flood impact is required to mitigate the negative impact of the future climate and secure the future paddy field production.

Keywords: Climate change, Crop modelling, Rice production, Aquacrop

1. Introduction

Global carbon dioxide (CO2) emissions impacts to the increasing of temperature by 0.74 ± 0.18 °C due to climate change. CO2 has high correlation with the anthropogenic greenhouse gases (GHGs). It was reported that the GHGs increase by 80 % from 1970 to 2004 and its projected to increase about 40 – 110 % between year 2000 and 2030 due to energy consumption [1]. The IPCC estimates the temperature is expected to increase by 0.2 °C per decade in the next two decades. Long et al., [2] mentioned that the increasing of CO2 associated to the increasing temperature and can further impact to the agricultural production due to changes in evapotranspiration, plant growth rates, plant litter composition, and the nitrogen-carbon cycle. However, changing on agricultural yield varies between location, management and also crop, therefore, to understand the impacts of climate change on crop production, it is required to evaluate the projected increases in anthropogenic GHGs on the crops production.

There are several approaches were applied to evaluate the impact of climate change on crop production. Field experiment mostly applied to evaluate the potential effect of various environmental conditions, such as temperature, CO2, nutrients, water, and agronomic management to the eco-
physiological processes as well as crop production. However, it is impossible to accurately account for all these variables and their interactions in a field experiment. Thus, development of an effective calibrated and validated agri-cultural system model is essential for investigating the integrated effects of various chemical, physical, and biological processes [3]. The uses of crop simulation model are suggested [4,5] by combining the field experiment [6] and crop simulation approaches [7]. Crop simulation model models have become a key tool in extrapolating the impact of climate change from limited experimental evidence to broader climatic zones, soil types, crop management regimens, crops and climate change scenarios. While these models are a simplification of the reality, they allow a first assessment of the complexity of climate change impact in agriculture. They are playing an increasingly important role in assisting agriculture to adapt to climate change [8]. The objectives of this study were: (1) to utilize the Aquacrop simulation model to gain a better understanding of the response of paddy rice production to air temperature and rainfall and; (2) to apply the model to predict the impacts of temperature and rainfall changes on rice crop production in the future period in Subang District, West Java Indonesia.

2. Material and Methods

2.1. Material

The climate of Subang district classified as monsoon, tropical. It receive annual rainfall range from 1500 – 3000 mm based on the location with an occurrence of 70-80% of the total rainfall in the monsoon during November to April. The average temperature varies between 23 °C and 34 °C. Climatic data used for this study was climate data including maximum temperature, minimum temperature, evapotranspiration and rainfall for the period of 1971 – 2000 from worldclim (www.worldclim.org) [9] and CHIRPS (http://chg.geog.ucsb.edu/data/chirps ) [10]. The spatial resolution on WorldClim data is quite detailed and subtle so that it can be used to produce climate classification while CHIRPS has greater resolution but more detailed data because it is available up to daily data.

2.2. Material

Cluster analysis is the method for climate regionalization. On this study, the area was divide into six region (cluster) based on rainfall data aimed to understand the climate characteristics of the study area. The analysis of the impact of changing climate is evaluated on each cluster using Aquacrop 3.1. The Aquacrop 3.1 used on this study simulates crop yield components and also phonological stages. Aquacrop obtains the atmospheric CO2 concentration for a particular year. The daily maximum temperature, minimum temperature and rainfall was analyzed during the study period. The crop data included days from sowing to emergence, full cover date, maturity date, and harvest date, start of senescence date, maximum rooting date, and maximum root depth. The data on grain yield was recorded at different stages of crop growth during each crop experiment. Soil water which is a soil water balance as well as crop growth simulation model was evaluated and calibrated by trial and error approaches.

3. Result and Discussion

Subang district is located at eastern part of Java with altitude varies from 0 to 1500 meter above sea level. Subang district has an average annual of rainfall about 3000 mm with monsoonal rainfall pattern with average temperature range from 24 – 25 °C. The rainfall and temperature pattern are shown in Figure 1.
3.1. Model Calibration
Simulated yield were in reasonable agreement with the observed yields in calibration for all temperatures, rainfall and cultivar using the 2000 - 2010 data, with the correlation coefficient (r) of 0.80, Root Mean Square Error (RMSE) of 0.53 and Mean Square Error (MSE) of 9%. Paired t-tests demonstrated no statistically significant difference between the simulated and observed yields in various temperature, rainfall and cultivar groups. Table1 shows the initial and calibrated value of Aquacrop parameters.

Moreover, the crop simulation model Aquacrop is able to simulate the crop production closely with the observed data showing that there are no statistically significant difference between the simulation model output and observed yield under selected agriculture management practices (Figure 2). The year by year comparison of both crop yield production generate similar result with no significant differences.

| Aquacrop parameter                        | Initial | Calibrated |
|-------------------------------------------|---------|------------|
| Sowing rate (kg h⁻¹)                      | 80      | 120        |
| Maximum canopy cover                      | 120     | 75         |
| Initial Canopy cover (%)                  | 3       | 4.52       |
| Crop coefficient                          | 4       | 1.10       |
| Base temperature (°C)                     | 10      | 10         |
| Upper temperature (°C)                    | 40      | 30         |
| Maximum effective rooting depth           | 1       | 0.60       |
| Water productivity (gm⁻²)                 | 20      | 40         |
| Reference harvest index (m)               |         |            |
Yield response to changes in temperature and rainfall

Yield response to changes in temperature and was evaluated by applied the calibrated Aquacrop to the climate variability condition. The El Nino Southern Oscillation (ENSO) is the main sources of the global climate variability as well as in the study area. ENSO influences the rainfall pattern especially in the tropical Pacific region [11]. In this study, the time periods are grouped into three condition namely normal, El Nino and La Nina in which is characterized based on Ocean El Nino Index (ONI) on each period (Figure 3).

To assess the impact of climate variability on crop production, the model was applied on the different climatic condition. Paddy field are high susceptible to drought during El Nino condition, because it required more water than other crops. Therefore, the decreasing of water availability during El Nino condition affects to the crop production in study area. During El Nino condition, the rainfall is expected to decrease about 7% compared to the normal condition and its impact to the decreasing of the crop production by about 6% or decrease from 6.7 to 6.3 ton/ha during normal to El Nino period. Decreasing of the crop production during El Nino condition because of the changing of the climatic condition such as warmer than average temperature and drier than normal condition. Both condition impact on the water availability and also phonological processes of the crop as well as crop production. However, the El Nino condition has no significant impact on the irrigated paddy field. Based on the analysis, there are no significant different crop production on irrigated paddy filed area during normal and El Nino condition (Figure 4)
Similarly, during La Nina, the crop production is expected to decrease by 5% or decreasing from 6.7 to 6.4 ton/ha during normal to La Nina condition. Decreasing of the crop production during La Nina because of several area experienced flood due to increasing of rainfall during La Nina period. Flood on the paddy field impact on the failure harvesting stages.

3.3. Effect of climate change on irrigation water requirement and crop production

To apply the model for future environments as well as climatic change, the model was applied on Normal condition for the period of 2010 – 2015 as the baseline period and 2021 -2050 as the future period. The future climate condition was generated based on the RCP 8.5 scenario. The crop simulation shows the decreasing of crop production on the future compared with the baseline period. With decreasing water availability due to decreasing of rainfall, crop production decreased about 23% in the future compared with the baseline period (Figure 5). The decreasing of the future crop production was investigated because of decreasing water availability due to decrease rainfall. Based on IPCC projection and GCM model output, Subang area is expected to experience decreasing rainfall about 15% on the future period. Furthermore the temperature is expected to increase by 2°C under RCP 8.5 scenario.

Figure 4. Paddy field production during Normal, El Nino and La Nina climate variability under irrigated (left) and non-irrigated (right) area

Figure 5. Irrigation water requirement (IWR) during the baseline and future (2021 – 2050) period
Moreover, the irrigation water requirement was investigated for the future period. It was found that increasing of irrigation water requirement to keep the yield production similar as baseline period. The IWR is expected to increase about 26% compared with IWR on the baseline period. The increasing of the IWR due to increasing of water requirement for the Evapotranspiration in the future period.

The result is in line with the previous research with is result that increasing of minimum temperature by 1\degree C will decrease the yield of paddy field by 10\% [12] and increasing of average temperature by 1\degree C will reduce the crop production by 5-7\%. Decreasing crop production due to reduced sink formation, shorter period of growth, and increased respiration [13].

4. Conclusion

The simulations results suggest that maximum and minimum temperatures could significant effect on rice yield, and this effect could become more pronounced if temperatures rise in 40\degree C. Sensitivity analysis indicates that crop model is sensitive to changing of rainfall and temperature . The simulation outputs show the increasing of the rainfall by average of 27\% and impact to the increasing of the paddy filed productivity by 19\% in the period of 2021 – 2050. The result also indicates the increasing of the flood and plant diseases and influence to the paddy production in the future. These findings suggest that the good water management on flood impact is required to mitigate the negative impact of the future climate and secure the future paddy field production.

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