Rice plantation projection based on scenario representative concentration pathways (RCP) 4.5 in West Java Province

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Abstract. Climate change is characterized by the changing of weather and climate elements in the earth, such as temperature and precipitation over a long period. The changing of these climate elements will affect the water balance then affect the agricultural management system, especially in timing and cropping patterns. This study aims to explain the projection of climate change result in the future and its relation with the changing of planting time and crop patterns of rice in West Java Province based on Representative Concentration Pathways (RCP) 4.5 scenario from 2006 until 2040. The data used in this study were observation data of temperature and rainfall in period of 2006-2015 from 39 rainfall posts with the height data of each rainfall post. The analysis conducted in this study was based on Thorntwaite and Matter water balance models by using observation data (2006-2015) as the baseline and future periods (2021-2030 and 2031-2040). Air temperature and rainfall data in period of 2006-2015 were used to correct the model data. Calculation of groundwater availability was calculated for each representative of Oldeman climate type. Furthermore, the rice planting schedule can be known when the condition of the level of groundwater availability reaches field capacity. The results of the analysis show changes in the Oldeman climate type and the level of groundwater availability due to changes in air temperature and rainfall parameters resulting from projections on current conditions. This caused a change in the planting schedule. The planting schedule will start early when the climate type turns wet, so the condition of the level of groundwater availability increases. The planting schedule in September was seen more broadly in the East and West parts of West Java in the period of 2021-2030 compared to the period of 2006-2015 and 2031-2040.

Keywords : plantation, climate change, temperature, precipitation

1. Introduction
The evaluation results by the Ministry of Agriculture in 2015 showed that the fundamental problems predicted to still be faced by the food crop sub-sector in the period of 2015-2019, covering aspects such as environmental damage, climate change, infrastructure, facilities, land, and water. Plants will produce high production if given enough water at the right time [1].

West Java Province is geographically located in 5°-50'-7°50' south latitude and 104°-48'-108°48' east longitude. This province is a center of rice production that has the highest rice production rates compared to other provinces [2]. Based on data from Jawa Barat Pertanian (2011), several regions in West Java experienced a shift in rice planting periods such as in Indramayu. Information on planting calendars in this region is divided into three growing seasons, namely the first planting period (November), the second planting period (April), and the third planting period (August).
Suriadi [3] said that the rainfall pattern of West Java during the last two decades (1991-2007) had significant changes. Therefore, adaptation and mitigation efforts are needed. One effort is to establish information about the groundwater availability for plants and provide an overview of planting schedules that are suitable for future climate conditions.

The view on future climate change can be obtained with Representative Concentration Pathways (RCP). RCP has four scenarios, namely RCP 2.5, RCP 4.5, RCP 6.0 and RCP 8.5. The use of scenarios is not aimed at predicting the future, but to get a better understanding of the uncertainties and alternatives of the future [4]. The results of climate projections provide information about the projectional changes in groundwater availability, in order to determine the planting schedule especially for rice in West Java.

This study aimed to determine the pattern of rice planting schedules by comparing the current period (2006-2015) with future periods (2021-2030 and 2031-2040) using projection data. The parameters used were temperature and rainfall. Both were used for the analysis of future groundwater availability so that the projected planting schedule can be determined. The results of the climate projection provided an overview of climate conditions until 2040. This can be one step to deal with climate change, by establishing planting patterns and planting calendars based on climatic conditions, especially for rice in West Java Province so as to minimize crop failure due to climate change and to obtain maximum production.

2. Data and Method
The research data was based on the monthly rainfall observation data from 2006 to 2015 in 39 observation points consisted of operating rainfall posts and BMKG stations in West Java Province. The air temperature was obtained based on the height of the place using the Braak formula [5]:

\[ T_h = T_{h_0} - \left( \frac{0.6}{100} h \right) \]  

with:

- \( T_h \) = temperature at the rainfall post (°C)
- \( T_{h_0} \) = temperature at the reference station (°C)
- \( h \) = height difference of rainfall posts asl (meter)

Numerous GCMs simulation runs have been implemented by various countries as part of the WCRP's Fifth Coupled Models Inter-comparison Project (CMIP5) in which the simulation outputs can be downloaded from its web portal. For SEACLID/CORDEX SEA, member countries within the Southeast Asia region use GCM model simulation outputs archived at the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy. Model data for RCP4.5 scenario projection get from the center of climate change in BMKG. The data projection RCP4.5 needs correction to be equalized with observational data. The correction was calculated based on the difference between observation data and model data. Model and observation data must have the same period. Corrected rainfall can be calculated using the following equation [6]:

\[ CH_{\text{model,kor}} = CH_{\text{mod}} \times \frac{CH_{\text{obs}}}{CH_{\text{mod}}} \]  

where,

- \( CH_{\text{model,kor}} \) = model monthly rainfall after correction
- \( CH_{\text{mod}} \) = model rainfall before correction
- \( CH_{\text{obs}} \) = observed average rainfall in baseline period
- \( CH_{\text{mod}} \) = model average rainfall in baseline period
Whereas for corrected air temperature can be calculated by the following formula (Weiland et al., 2010):

\[ T_{\text{mod.kor}} = T_{\text{mod}} + (\bar{T}_{\text{obs}} - \bar{T}_{\text{mod}}) \]  

\( T_{\text{mod.kor}} \) = monthly air temperature after correction
\( T_{\text{mod}} \) = monthly air temperature before correction
\( \bar{T}_{\text{obs}} \) = observed average of monthly air temperature in baseline period
\( \bar{T}_{\text{mod}} \) = model average of monthly air temperature in baseline period

Determination of Oldeman climate types for each period was done using corrected model data [7]. This was based on the number of wet months and dry months respectively with the following criterias:

| Main types | Respective wet month | Sub Division | Respective dry month |
|------------|----------------------|--------------|---------------------|
| A          | >9                   | 1            | <2                  |
| B          | 7-9                  | 2            | 2-3                 |
| C          | 5-6                  | 3            | 4-6                 |
| D          | 3-4                  | 4            | >6                  |
| E          | <3                   |              |                     |

Reference: (Oldeman, 1982)

The next step was to determine the planting schedule based on the level of groundwater availability. This was to find out the favorable planting period. To find out the water availability for plants, it was necessary to know evapotranspiration values calculated by the method of Thronthwaite and Matter [8] as follows:

a. Calculating monthly heat index \((i)\):

\[ i = \left(\frac{t}{6} \right)^{1.514} \]  

\( t \) = monthly average temperature

b. Calculating total monthly heat index \((I)\):

\[ I = \sum_{Jan}^{Dec} i \]  

(5)

c. Calculating standard ETP :

\[ ETP = 16 \left(\frac{18t}{i} \right)^a \]  

\( ETP \) = monthly average standard ETP (mm)

\( A = 675 \times 10^{-9}t^3 - 771 \times 10^{-7}t^2 + 1792 \times 10^{-5}t + 0.49239 \)

d. Correction of standard ETP uses day length (for latitude 0, 1 day = 12.1 hours) and the number of days per month = 30 days, thus:

\[ ETP = \left(\frac{X}{30}\right) \left(\frac{Y}{12}\right) ETP_{\text{standard}} \]  

(7)
X = number of days in a month  
Y = day length in hours  
The day length table was obtained from secondary data in "Crop Evaporation" [9].

e. The column for air temperature was filled according to the results of average temperature estimation in each rainfall station using the Braak formula that has been done before. 

Furthermore, the evapotranspiration value was used to determine the value of groundwater availability for plants. Groundwater availability was calculated using the method of Thorntwaite and Matter land water balance on a monthly basis. Data used were rainfall, water content at field capacity level (KL) and water content at permanent wilting point (TLP). Steps in water balance calculation were as follows:

1. The column for rainfall (CH) was filled with CH data on a monthly average or CH with certain probability.
2. The column for potential evapotranspiration (ETP) was filled with the results of the ETP estimation using the equation by Thorntwaite & Matter (1957)
3. The column for CH-ETP was filled with the difference between rainfall and plant evapotranspiration.
4. The column for accumulation potential of water loss (APWL) was filled with negative results in step 3, accumulated month by month as Accumulation Potential of Water Loss (APWL) value and then filled in the corresponding column.
5. The column for groundwater content (KAT). First, field capacity (KL) was determined. The filling of the KAT column began at the first month of APWL based on the formula calculation as follows:

\[ KAT = KL \times k^{|APWL|} \]  

where:
\[ k = p_0 + p_1/KL \]
\[ p_0 = 1.000412351 \]
\[ p_1 = -1.073807306 \]
KL = field capacity  
|APWL| = absolute value of APWL

The column for KAT at the first month, where CH-ETP is positive, was filled with (KAT = last KAT + CH-ETP), so on until the KAT = KL value is reached. Since that month, during the excessive raining, the KAT value was constant, equal with KL. From the results of KAT, the index value or water requirement criteria for plants can be found as follows:

\[ ATS = \frac{KAT - TLP}{KL - TLP} \times 100\% \]  

Where:
ATS : percentage of available groundwater  
TLP : permanent wilting point  
KAT : groundwater content  
KL : field capacity

Table 2 describes the percentage of ATS by the level of groundwater availability. ATS results are divided into 3 classes, as follows:
Table 2. Percent of water available (% ATS)

| Percentage of ATS | Level of groundwater availability |
|-------------------|-----------------------------------|
| <40               | Low                               |
| 40-60             | Medium                            |
| >60               | Sufficient                        |

3. Results and Discussion

3.1 Correction results of RCP 4.5 scenario model data

RCP 4.5 scenario data consisted of air temperature and rainfall data which still have significant errors. To minimize this error, the RMSE statistical test was performed. The smaller the RMSE value, the better the performance and accuracy of this model data, thus made it proper for research use. The correction results showed that the model data has lower RMSE value compared to the model data before correction. This can be seen in table 3 and table 4.

Table 3. RMSE value of rainfall model data

| No  | Rain Post | RMSE Before Correction | RMSE After Correction |
|-----|-----------|------------------------|-----------------------|
| 1   | Darmaga   | 206.74                 | 159.32                |
| 2   | Depok     | 199.55                 | 180.57                |
| 3   | Gunung mas| 262.83                 | 190.31                |
| 4   | Montaya   | 144.44                 | 138.1                 |
| 5   | Cibeet    | 189.5                  | 149.15                |
| 6   | Cibereum  | 123.6                  | 121.66                |
| 7   | Empagra   | 161.73                 | 147.5                 |
| 8   | Jatiseeng | 185.05                 | 106.27                |
| 9   | Batujaya  | 266.89                 | 151.57                |
| 10  | Krangkeng | 202.24                 | 76.63                 |

Table 4. RMSE value of air temperature model data

| No  | Rain Post | RMSE Before Correction | RMSE After Correction |
|-----|-----------|------------------------|-----------------------|
| 1   | Darmaga   | 1.15                   | 0.25                  |
| 2   | Depok     | 0.53                   | 0.38                  |
| 3   | Gunung mas| 0.48                   | 0.35                  |
| 4   | Montaya   | 3.05                   | 0.4                   |
| 5   | Cibeet    | 1.81                   | 0.39                  |
| 6   | Cibereum  | 0.59                   | 0.4                   |
| 7   | Empagra   | 1.37                   | 0.38                  |
| 8   | Jatiseeng | 0.65                   | 0.25                  |
| 9   | Batujaya  | 0.65                   | 0.36                  |
| 10  | Krangkeng | 0.63                   | 0.32                  |
3.2 Changes in Oldeman climate types
Spatially, the regions with B2 and B3 climate types extended in the central part during the period of 2021-2030 compared to 2006-2015 and 2031-2040. B2 and B3 climate types have sufficient amount of rainfall for the needs of rice plants up to two planting times and one planting times of secondary crops. This was because monthly average rainfall in the central part of West Java Province was higher in that period. Meanwhile, during 2031-2040 the regions with D3 and E climate types in the northern coast were more extended than in the period of 2006-2015. This condition was expected because in that period, monthly average rainfall in the rainfall posts located in the northern coast had fewer wet months and more dry months. The distribution of Oldeman climate types in West Java Province in each period can be seen in figure 1, figure 2, and figure 3.

3.3 Groundwater availability
In each Oldeman climate type in West Java Province, one representative rainfall post was chosen and its groundwater availability was calculated. Air temperature and rainfall data from direct observation and model data projection were used as input in the calculation of groundwater availability, thus the condition of groundwater availability in normal period (2006-2015) and projection period (2021-2030 and 2031-2040) were obtained.

Figure 1. Oldeman climate types in West Java Province in the period of 2006-2015.

Figure 2. Oldeman climate types in West Java Province in the period of 2021-2030.

Figure 3. Oldeman climate types in West Java Province in the period of 2031-2040.
In the period of 2006-2015 (figure 4), the A1 and B1 climate types almost reached field capacity in all months. However, there was a decline in B2 climate type in August, although insignificant, because in the next month it was above the permanent wilting point and rose progressively to be able to fulfill the need for rice plantings. As for D4 and E climate types, the groundwater availability levels decreased from May to November. For this reason, the regions with D4 and E climate types could not be planted with rice.

The value of groundwater availability during 2021-2030 in A1, B1, and B3 climate types (figure 5) reached field capacity in most months, but in B1 climate type began to decline in July and August. The decline was still above the optimum KAT; thus, it was still sufficient for rice planting throughout the year. As for E climate type, the value of groundwater availability was very low so it was not sufficient for rice planting.

The value of groundwater availability in the period of 2031-2040 (figure 6) in A1, B1, and B2 climate types reached field capacity in most months. When compared with the previous period, the period of 2031-2040 showed a significant decline in June to September. Whereas in D4 and E climate types, the value of the groundwater availability were very low, thus insufficient for rice planting.

3.4 Changes in planting schedules
Based on the calculation of groundwater availability in the baseline period, the first, second and third rice planting schedule for each period were obtained.
3.4.1 Changes in the first rice planting schedule

![Figure 7](image1.png) **Figure 7.** The first rice planting schedule in the period of 2006-2015.

![Figure 8](image2.png) **Figure 8.** The first rice planting schedule in the period of 2021-2030.

Based on figure 7, it can be seen that during the period of 2006-2015, in the central part of West Java, most began to plant rice in October, while small portions in the Bekasi, Indramayu, and Karanganyar planted rice in November. Whereas, the northern coastal region had a planting schedule in December.

Figure 8 showed a change in the first planting schedule in the central part of West Java. In the period of 2021-2030, the first rice planting schedule in central West Java tended to begin in September, earlier than in the baseline period (2006-2015). The western part of West Java generally had a planting schedule in September that extended to Bandung Regency. In the northern coastal region of West Java, the planting schedule was later, which was in January.

![Figure 9](image3.png) **Figure 9.** The first rice planting schedule in the period of 2031-2040.

The period of 2031-2040 (figure 9) had a similar pattern to the baseline period (2006-2015). It is shown in the spatial illustration where in most parts of the central West Java, the first rice planting occurred in October. However, the western part of West Java experienced a narrowing areas.
3.4.2 Changes in the second rice planting schedule
Changes in the second planting schedule were seen in the central part of West Java. In the period of 2006-2015, the central part of West Java began the second rice planting in February and a small part began in January. During the baseline period (2006-2015) and near period (2021-2030) it was divided into 4 areas, namely areas with planting schedules in January, February, March, and areas with no planting schedule. The difference was seen in the middle period (2031-2040) that only has three areas, namely the areas with planting schedules in January, February, and areas with no planting schedule. Spatially, the second rice planting schedule can be seen in figures 10, 11 and 12.

3.4.3 Changes in the third rice planting schedule
In general, during the third planting season of the baseline period (figure 1) the entire region of West Java Province had two planting areas, namely the area with planting schedules in May and June. This was due to the deficient value of groundwater availability, so that it could not reach three planting seasons. In the baseline period (2006-2015) the regions with planting schedule in May were almost the same in each period, covering a small part of Bogor, Sukabumi, and a small part of Tasikmalaya Regency.
In the period of 2021-2030 (figure 14) the region with the start of planting in May extended to the central and eastern parts, which was different from the previous period. There also several areas that did not have planting schedules, namely in parts of Indramayu, Bekasi, Sumedang, and the eastern part of Bandung. Figure 15 showed the third planting schedule in the middle period. It can be seen clearly that the northern coastal region did not have planting schedule. Whereas the western part of West Java such as Bogor, Cianjur, and parts of Sukabumi Regency still had planting schedules which fell in May. Spatially, the area that did not have planting schedule extended to the middle part.

4. Conclusion

Based on the results of this research, it can be concluded that the projection of Oldeman climate types had insignificant changes compared to the baseline period (2006-2015). In the period of 2006-2015 to 2031-2040, the Oldeman climate types consisted of 9 types. Regions with B2 and B3 climate types were more extended in the central part during the period of 2021-2030 than in the period of 2006-2015 and 2031-2040. Meanwhile, in the period of 2031-2040, there was an extension of regions with D3 and E climate types in the north coast.

The groundwater availability in the central part of West Java Province was generally categorized as "sufficient" in all periods. Meanwhile, regions with “low” to “medium” level of groundwater availability were more spread in the northern coast. Of the three periods that have been analysed, the largest region with “low” groundwater availability occurred in September during 2006-2015, since September is the peak of dry season.

The change in air temperature parameters and the projected rainfall to the baseline period (2006-2015) caused changes in the rice planting schedule. Changes in the first planting schedule were evident in the central part and the north coastal region of West Java. During the planting season of the 2006-2015 period, generally the rice planting began in October in the western part and November in the north coast. In the period of 2021-2030, the start of planting was the same as in the period of 2006-2015, which was in October. Meanwhile, in some parts of the northern coastal region, the start of planting in November changed to January. In the period of 2031-2040, the first planting in the central part of West Java began in October while in the north coastal region began in January. The second planting in the central part of West Java during the period of 2006-2015 generally began in February, during 2021-2030 generally began in January and during 2031-2040 began in the same month as in 2006-2015 (February). The start of the third planting schedule only existed in some parts of Bogor, Sukabumi, Cianjur, Garut, Bandung, Tasikmalaya, Ciamis, some parts of Subang, Banjar, and Pangandaran, which was in May.
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