© 2019 IJSRSET | Volume 6 | Issue 2 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology
DOI : https://doi.org/10.32628/IJSRSET196297

Web-Based Decision Support System for Japonica Rice Cultivation in West Java Province, Indonesia

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ABSTRACT

Indonesia has a potency for planting Nikomaru, a japonica rice cultivar that has a capability for tolerating a high air temperature due to a chance for international trading, mainly to Japan. Developing a crop model to know the potency of Nikomaru in Indonesia based on the climate condition is an easier step than doing direct planting. A Decision Support System (DSS) was expected to help Indonesian farmers to decide their plantation. A field experiment was needed to develop and evaluate a crop model for predicting rice production. A web-based DSS developed for simulating some scenarios to know the potency of Nikomaru in West Java Province, Indonesia. Bogor Regency and Bandung Regency were selected area due to a higher rice production than the other places. Both of them would face dry periods. Bandung Regency will face the worst dry period in the first scenario.

Keywords: Decission Support System, Crop Modelling, Yield Prediction, Japonica Rice

I. INTRODUCTION

As a primary commodity in the world, rice consumption reached more than 450 billion ton during 2016 and 2017. In Asia, rice consumption was almost 90% of total rice consumption in the world. The top 3 of rice consumers are China, India, and Indonesia. Asian countries dominated the top 10 of rice consumers, and it influences the global rice consumption and stock [1].

Indonesia has a high potency as a big rice producer in the world. It has high rice productivity and harvested area, and their production increases every year (PSD Online Database 2013-2017). To maximise that potency, one of the ideas is planting rice by using a cultivar which has a high economic value. Japonica rice cultivar is one of the rice cultivars which has a high economic value due to a chance for international trading, mainly to Japan. Japan rice production is always lower than its consumption. There is a deficit on rice stock more than 1000 Million Ton (PSD Online Database 2010-2017).

Another advantage of Japonica rice is about their effect on human health, especially on their Glycemic Index (GI). The GI is a number to represent the rise of a person's glucose level caused by their consumed food. A food with a high level of GI can increase glucose level quickly, and it will increase the risk of diabetes mellitus disease. The GI value of Koshihikari variety, one of the popular Japonica rice varieties is 48.00 [2][3]. It is lower than the GI value of IR 64 variety, one of the famous rice cultivars in Indonesia. The GI value of IR 64 is 73.20 [4] and 69.96 [5]. Generally, The GI values of Japonica rice varieties are around 47.00 to 76.00 [6]. Some rice varieties used in Indonesia also have a high GI value. These were around 54.43 to 97.29 [5] and 63.00 to 77.00 [7].

Planting Japonica rice in Indonesia is a challenge for Indonesian farmers, and it needs support from the government by providing some planting recommendations or planning. Making a plan for suitable paddy field area of Japonica rice cultivar is a critical plan. We need direct planting for knowing the suitability of Japonica rice cultivar in Indonesia. However, it will take time and a high effort. One of the ideas is making a suitable area based on the climate condition. The climate parameters (temperature, solar radiation, and rainfall) are important factors which have to be considered due to their influence on the rice yield [8]. An analysis of suitable rice cultivar based on the climate condition in Indonesia is needed to decide the chosen Japonica rice cultivar. One of the possible Japonica rice cultivars is Nikomaru. It has a capability for tolerating a high air temperature [9][10][11][12].

A model of rice yield based on the climate condition is needed for predicting the potency of Japonica rice cultivar in Indonesia. One example of the models to predict rice yield is Shierary Rice has been developed, calibrated and validated by Handoko in 1994 [13]. This model can estimate rice yield by using climate data in a daily temporal resolution. This model was also implemented by some researchers for knowing rice growth with remote sensing [14], monitoring of rice [15], and estimating climate change effect for rice yield[16]. Besides that, this model also was implemented to the other plant such as sugarcane [17], and potato [18].

Shierary rice model is powerful to explain the development and growth process in daily temporal resolution. Researchers can understand their relationship and trend. The decision maker also can simulate this model to reach its expectation on rice yield. Previously, this model has been used for predicting Indica rice cultivars. Rice yield of Japonica rice cultivar can be predicted by using that model concept but, some crops parameters are needed.

II. METHODS AND MATERIAL

This research was divided into three parts which are model development and testing, system development, and system implementation. Model development and testing were conducted at The Laboratory of Environmental Hydrology and The Experimental Field of Crop Science Laboratory, Faculty of Agriculture, Ehime University, Japan, while the others research sections were conducted at The GIS Laboratory, MIT IPB, Indonesia.

A. Field Research and Calculation of Model Variables and Parameters

Field research was conducted to gather information of rice crop growth process, crop parameters, meteorological parameters which will be used for model development and testing. Field research was conducted from Mei 2017 to October 2017 by planting Nikomaru, a Japonica rice cultivar on an experimental field which has an area 78.5 m^2 and surrounded by upland fields, greenhouses, and rice fields. Rice was planted on June 18th by using 20x25 plant spacing and three seedlings in every hole, and it harvested on October 20^{th}.

Meteorological parameters measurement was done by installing some meteorological instruments at the field. The global solar radiations (*St* and *aSt*) were measured by using CNR-4 net radiometer (Kipp & Zonen, Netherland) at 2.5 m height. Two sensors of HMP-155

(Vaisala Inc., Finland) was used to observe air temperature (*T*). Solar radiation within the rice canopy was also measured by CM-3 pyranometer (Kipp & Zonen, Netherland) on 20 cm height. It was installed on August 18th. Meteorological parameters were sampled every 10 seconds, averaged and recorded every 1 minute by CR1000 data logger (Campbell Scientific Inc., USA).

Daily averages of *T* and sunshine hours (*n*) on Matsuyama Weather Station measured by Japan Meteorological Agency (http://www.data.jma.go.jp) were collected for completing data before instrument installation on the experimental field. *St* was calculated from *n* using a linear model for daily global solar radiation estimation [19]. The equation is shown on Eq.1 and *St* is assumed equal to be *Q*.

$$\frac{Q}{Q_0} = a + b \left(\frac{n}{N}\right) \text{ ………..…… (1)}$$

Where Q is the daily total amount of solar radiation falling on a horizontal surface of the earth (MJ/m^2), Q_0 is the daily total amount of solar radiation on the extraterrestrial (MJ/m^2), n is observed daily sunshine hours (hour), N is the maximum possible amount of the daily total sunshine hours (hour). a and b are coefficients of linear regression. In Japan area, a equals 0.22, and b equals 0.57 [20].

Dry weight of each rice organs (stem, leaf, and panicle), and leaf area index (*LAI*) were observed by measuring two destructive samples selected based on the average height, average tiller number, and plant diameter on the soil surface of 10 undestructive samples. The destructive sample of rice organs were dried on an oven for 48 hours on 80^{0}C. Destructive sampling was started on July 11th and it was conducted every week. Radiation Use Efficiency (*RUE*), *k*, specific leaf area (*sla*), and biomass proportion of each organ was calculated from those destructive samples. On the harvesting day, dry weight of each organ was measured from 1 m^2 paddy field area with two replications.

RUE is the relationship between accumulated crop dry matter and intercepted solar radiation [21]. *RUE* can be estimated by many methods. One of the popular methods used by many crop researcher is representing RUE as the slope of the linear relationship between plant productivity and incident radiation [22].

The parameter k, a coefficient of canopy light extinction indicates the amount of solar radiation transmitted to the field surface, and it represents the efficiency of plant canopy for intercepting the light. A small k means solar radiation reached soil surface in a high amount [23][24]. It can be calculated with a simplified of the Beer Lambert Law [25][26][27] (Eq. 2).

$$k = -\ln\left(\frac{Stc_m}{St_m}\right) / LAI_m \text{ ………..…… (2)}$$

Where Stc_m is measured solar radiation beneath the canopy (MJ/m^2), St_m is measured solar radiation above the canopy (MJ/m^2), LAI_m is measured leaf area index. *sla* is a ratio between LAI_m and dry weight of leaf. It represents the leaf thickness. The biomass proportion of each organ was calculated by comparing dry weight change of each organ to dry weight change of total.

B. Model Structure

The model adopted the concept of Sheirary Rice model [13] by using the development growth sub-model only. It can be used for predicting rice yield based on a daily average of climate parameters by assuming the water condition was not be a limiting factor. This model predicting rice growth duration, intercepted solar radiation, dry matter production, and dry weight of each organ.

Rice growth duration was predicted by using thermal heat unit (Eq. 3) [28]. During growth duration, rice needs a specific amount of heat. It can be predicted by using air temperature and base temperature (T_0) which is a lower threshold temperature for the development process. It was assumed to be 10^{0}C [29].

Biomass production was predicted as dry matter production (gram in 1 m^2 of paddy field area) calculated by using conversion of solar radiation intercepted by rice canopy (Eq. 3 – 13).

$$GDD_i = \sum_i^n (T_i - T_0) \quad (3)$$
$$St_{int,i} = St_i\left(1 - e^{-k \cdot LAI_i}\right) \quad (4)$$
$$DMP_i = RUE * St_{int,i} \quad (5)$$
$$\Delta WL_i = nL_i * DMP_i \quad (6)$$
$$\Delta WS_i = nS_i * DMP_i \quad (7)$$
$$\Delta WP_i = nP_i * DMP_i \quad (8)$$
$$WL_i = \Delta WL_i + WL_{i-1} - SL_i \quad (9)$$
$$WS_i = \Delta WS_i + WS_{i-1} - SS_i \quad (10)$$
$$WP_i = \Delta WP_i + WP_{i-1} \quad (11)$$
$$WG_i = 0.95 * WP_i \quad (12)$$
$$LAI_i = sla_i * WL_i \quad (13)$$

Where GDD_i is growing degree days on day-i (^{0} days), i is days after transplanting (day), T_i is air temperature on day-i (^{0}C), T_0 is the lower threshold for the development process (^{0}C), *Stint* is intercepted solar radiation by the rice canopy (MJ/m^2), k is a coefficient of canopy extinction, *LAI* is predicted leaf area index calculated by Eq. 6, *DMP* is dry matter production (g/m^2), *RUE* is radiation use efficiency (g/MJ).

C. Model Evaluation

Model calibration was done by comparing the model prediction results and weekly dry weight samples. For reaching the optimum model, every prediction of dry weight was evaluated by Normalized Root Mean Square Error (NRMSE) and considering the pattern of data on a comparison chart. NRMSE can be calculated as shown in eq.14, while the model validation was done by comparing the prediction model and the measured dry weight on harvesting day. It was evaluated by the percent error method.

$$RMSE = \sqrt{\frac{\left(\sum_{i=1}^n (W_p - W_m)^2\right)}{n}} \quad (14)$$
$$NRMSE = \frac{RMSE}{W_m} * 100\% \quad (15)$$

Where *NRMSE* in %, W_p is predicted dry weight (g/m^2), Wm is measured dry weight (g/m^2), n is data count.

D. System Design

Expert knowledge in this DSS was gathered by literature reviews about research results on crop modelling. The knowledge also was gathered from the field research results. Data used on this DSS consist of the location of weather stations, climate data and crop parameters. This DSS developed on a Web-GIS based system by using an Apache Server as the web server, Google Map API as the map visualizer, MySQL as the database management system, Amchart3 for plotting the data on a chart, and DataTables for displaying the data on a table. The web system was developed by using Hypertext Markup Language (HTML), PHP Hypertext Preprocessor (PHP 5), JavaScript, and Bootstrap 4 used for the user interface components.

This DSS works with user input by selecting their paddy field location. The system will find some weather station close to the user's location based on a radius given by the user. Climate data will be retrieved from the selected weather stations. Inverse Distance Weighted (IDW) will be applied when more than one selected weather stations. IDW can be calculated as Eq.16.

$$\bar{\upsilon}(x) = \sum_i^n \upsilon_i w_{i(x_i)} \,/\, \sum_i^n w_i(x_i) \quad (16)$$
$$w_i = 1 / d(x, x_i)^2 \quad (17)$$

Where x is the selected paddy field location, $\bar{\upsilon}$ is the average of the climate parameter value, υ_i is the value of weather parameter on weather station i, w_i is the weight, d(x,xi) is the distance between x location and location of weather station i. The climate data used in the model were air temperature, solar radiation. Rainfall also was used for providing an annotation for dry period.

E. System Implementation

The DSS of this research was published on an online website (http://bit.ly/japonriceAPP). This website used climate data observed by BMKG on 2012 to 2013 (http://dataonline.bmkg.go.id, downloaded on May 2018). It provides weather station data on Java Island. For this research, the processed data were on West

Java province. The selected automatic weather stations (AWS) are shown in Table 1. Those station selected based on their climate data availability in 2012 to 2013.

TABLE I
THE SELECTED AUTOMATIC WEATHER STATION (AWS) IN WEST JAVA PROVINCE, INDONESIA

AWS	District	Altitude (m)
Stamet Citeko	Bogor	978
Staklim Bogor	Bogor City	250
Stamet Jatiwangi	Majalengka	50
Stasiun Geofisika Bandung	Bandung	791

Data Source: http://dataonline.bmkg.go.id.

For this paper, the model was simulated by predicting rice yield planted on every ten days to know the optimum planting date in a year. At this step, the user was able to select a planting date based on their decision after knowing the dry weight prediction of grain through a year. Continuously, it was simulated by setting the selected planting date by the user for knowing the daily dry weight, the growing pattern, and the dry period warnings. The paddy field area was assumed to be 1 ha, and the seedling weight was 1.5 g/m^2.

III.RESULTS AND DISCUSSION

A. Crop Parameters based on The Field Research

The calculated *RUE* values for Nikomaru rice cultivar on this research were different on each stage (Table II). The growing stage after the early stage to flowering had the highest *RUE* and it each the lowest value on the last stage (after flowering to harvesting). This *RUE* values used for model input based on daily *GDD* value. Parameter *RUE* is needed for calculating biomass production by converting the solar energy intercepted by leaf canopy (Eq. 4). For this equation, parameter k is assumed to be 0.45 as an average calculate *k* value from the field experiment result.

TABLE III
ESTIMATED RUE DURING RICE GROWTH STAGE BASED ON FIELD REASEACH RESULT

Stage	GDD (^{0}days)	RUE (g/MJ)	R^2
1	< 499.479	1.155	0.956
2	499.479-1255.500	1.810	0.965
3	≥ 1255.500	0.721	0.941

Note: R^2 is coefficient of Determination.
1 (Early stage), 2 (after early stage to flowering), 3 (after flowering to harvesting).

Biomass proportion of each rice organ was needed for distributing the biomass production converted by RUE from intercepted solar radiation. It was expressed as a constant value on the first growing stage and as an equation of linear regression (Table III). On the early stage, biomass proportion was assumed to be a constant value from the calibration result. The stem had the highest proportion on the second stage (after the early stage to panicle initiation) due to stem elongation and tiller development [30]. The biomass proportion for panicle was allocated from the second stage. It increased and reached 100% on the last stage. The other organs (stem and leaf) decreased on the third and the last stage. the grain dry weight is 95% of pannicle dry weight.

TABLE IIIII
THE EQUATION OF BIOMASS PROPORTION OF EACH RICE ORGAN DURING RICE GROWTH STAGE BASED ON FIELD REASEACH RESULT

Stage	GDD (^{0}days)	Rice Organ	Biomass Proportion (%)	R^2
1	< 499.48	Stem	nS=45	-
		Panicle	nP=0	-
		Leaf	nL=55	-
2	499.479-993.04	Stem	nS=0.067*GDD + 11.743	0.918
		Panicle	nP = 0	0.967
		Leaf	nL = 100–nS–nP	-

Stage	GDD (^{0}days)	Rice Organ	Biomass Proportion (%)	R^2
3	993.043 – 1456.24	Stem	nS=-0.155*GDD +227.2	0.918
		Panicle	nP=0.176*GDD -159.45	0.967
		Leaf	nL=100–nS–nP	-
4	≥ 1456.24	Stem	nS=0	-
		Panicle	nP=100	-
		Leaf	nL=100	-

Notes: 1 (Early Stage), 2 (after early stage to panicle initiation), 3 (after panicle initiation to flowering), 4 (after flowering to harvesting).

The parameter *sla* was assumed to be a constant value on the early stage, and it was expressed as a polynomial regression function on the second growing stage, and it predicted by using a logistic regression function on the last stage (Table IV). The *sla* value declined throughout the growing stage period following a non-linear curve [29].

TABLE IVV
THE EQUATION OF SLA DURING RICE GROWTH STAGE BASED ON FIELD REASEACH RESULT

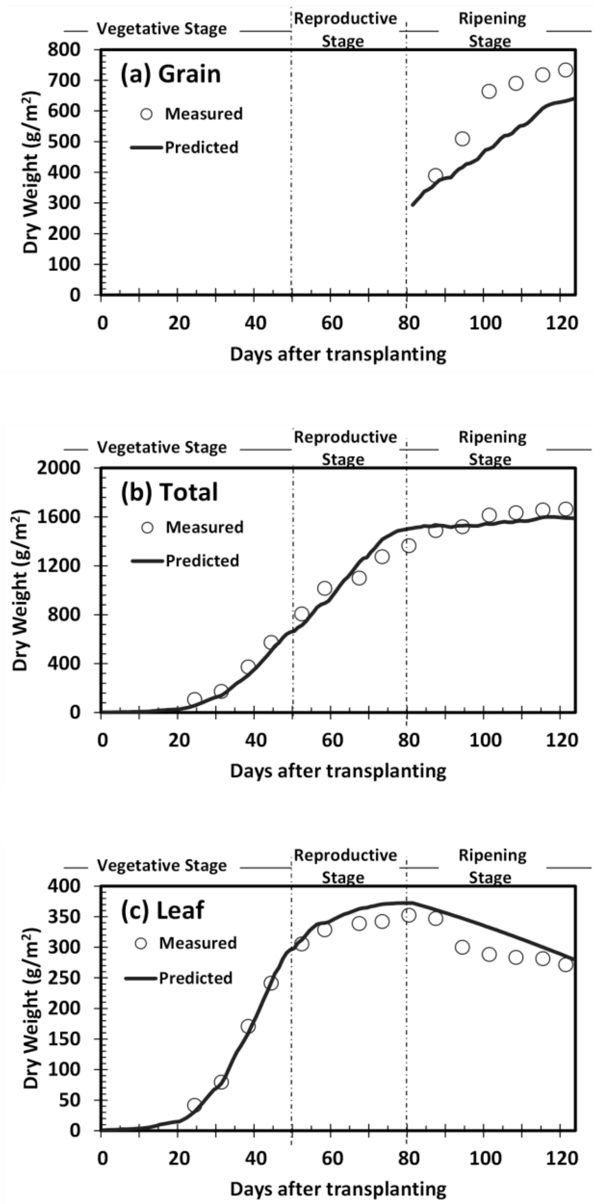
Stage	GDD (^{0}days)	SLA (g/m^2)
1	< 499.479	0.041
2	499.479-1255.500	0.149–0.0000000002854 ∗ GDD3+0.00000066∗GDD^2 +0.0005098∗GDD
3	≥ 1255.500	0.0178407 + 0.01826/GDD

Notes: 1 (Early Stage), 2 (after early stage to panicle initiation), 3 (after panicle initiation to flowering).

B. Model Evaluation

Model calibration was done by tuning some parameters of models such as biomass proportion and specific leaf area. The comparison results between predicted and measured dry weight of each rice organ are shown in Fig. 2. The pattern of predicted dry weight was similar to the measured one. However, the pattern of predicted grain dry weight was lower than the measured one.

The NRMSE (Table V) also shown that the predicted grain dry weight had a higher gap compare to prediction results of the other organ. However, the pattern of the grain weight was overestimated than the measured one. The last result of grain (on the harvesting day) was close to the harvested dry weight. Table VI show that the prediction or grain yield was lower than the measured one. The average prediction was 7% lower compared to the measured one.



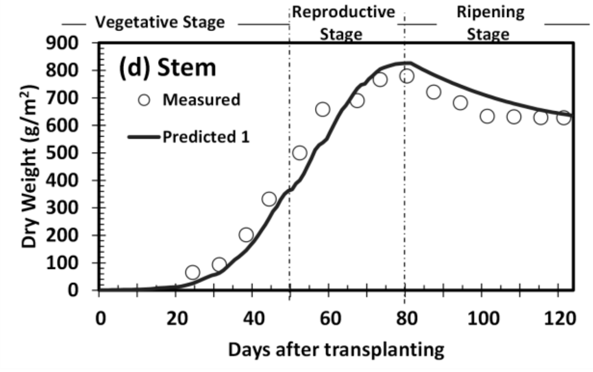


Figure 1 : Comparison of dry weight of each rice organ after calibration process

TABLE V

NRMSE OF EACH COMPARISON BEETWEEN MEASURED AND PREDICTED DRY WEIGHT

Stage	RMSE (g/m²)	NRMSE (%)
Grain	121.5	19.7
Total	8.6	7.9
Leaf	23.4	8.8
Stem	61.5	11.5

TABLE VI

VALIDATION RESULT OF PREDICTED RICE YIELD

Sample	Measured Dry Weight of Grain (g)	Gap Between The Predicted and The Measured (g)	Percent Error (%)
1	693.2	-53.8	-7.8
2	694.0	-54.6	-7.9
3	676.9	-37.5	-5.5

C. Rice Yield Prediction in West Java Province, Indonesia

Fig. 3 show the predicted dry weight of grain on each selected AWS. As a DSS, this chart gave two information for the user as considered parameters for deciding for their rice plantation. The user can choose the planting date based on the grain dry weight representing rice production and accumulated rainfall representing water availability. Based on Fig. 3, the chosen places were Stamet Citeko and Stasiun Geofisika Bandung due to the higher grain weight than the other places. By combining the prediction of grain weight and water availability, the user can decide the planting dates. For this paper, on Stamet Citeko was decided to plant rice at May 29th and Oct 16th, and on Stasiun Geofisika Bandung was Apr 29th and Oct 6th.

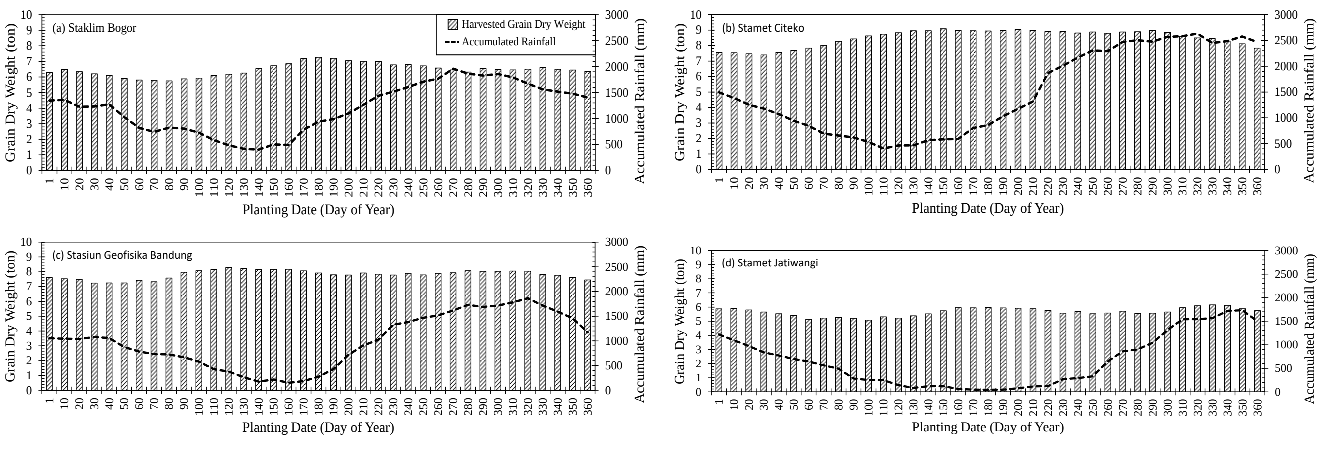


Figure 2 : Predicted rice yield through a year on the selected weather station in Wes Java, Indonesia

The second step of this DSS is considering the selected planting date based on the dry period. On this step, the user got information about a daily prediction of grain weight and annotations of dry periods planted on the user selected planting date. The second planting date was assumed 14 days after the harvesting date of the first growing period so the user would also know their rice production when they apply a continuous planting in a year by taking 14 days between each period for preparing the rice field for the second period. By considering that information, the farmer can decide theirs prefer planting date based on their ability to provide water for irrigating their rice field.

At the first place (Fig. 3) by planting Nikomaru rice on May 29th, they will face some dry periods on the first planting period for some couples days. On the other way, the farmers will face some dry periods on the second planting period when they planted their rice on Oct 16th. The second scenario was better due to their dry period amount.

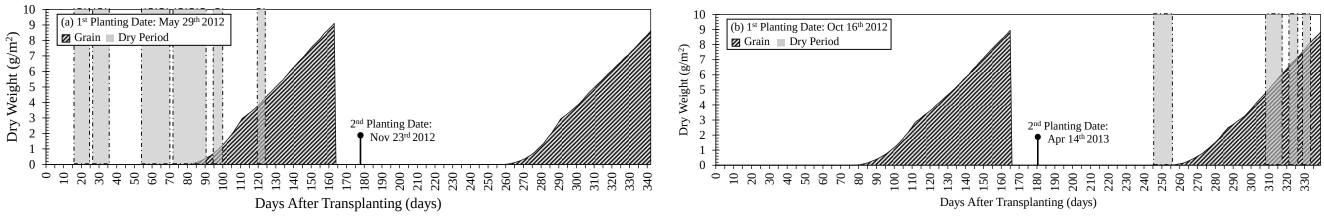


Figure 3 : Predicted rice yield in the selected planting date on Stamet Citeko

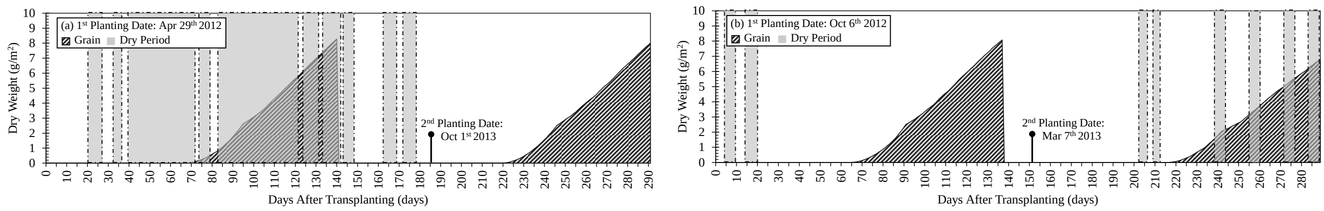


Figure 4 : Predicted rice yield in the selected planting date on Stasiun Geofisika Bandung

At Bandung District (Fig. 4), the farmer would face dry periods on almost the whole first planting period. It would be a problem when the farmer did not have enough water source for their field, but it would be a big chance for the farmer when they have enough water source. However, if the farmer does not have enough water source, it would be better to select the second scenario (planted on Oct 16th).

This DSS can be used for considering the best planting date based on the predicted grain weight and dry periods. The grain weight was predicted only from the climate condition. For making greater DSS, involving other factors such as water needed, planting space, fertilizer is required.

IV.CONCLUSION

The model developed in this research can predict the dry weight of rice grain successfully. The average prediction was 7% lower compared to the measured one. The implementation of this model by developing a web-based DSS can help farmers to decide the best planting date based on the predicted grain weight and the dry periods warning. On Wes Java province, the better places for planting Nikomaru based on the climate condition are Bogor District and Bandung District. Those regencies have higher grain weight than the other regencies both of them will face dry period. In the other hand, Bandung regency will face the worst dry periods in the first scenario.

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Cite this article as :

Taufiq Yuliawan, Handoko, Impron, Hiroki Oue, "Web-Based Decision Support System for Japonica Rice Cultivation in West Java Province, Indonesia", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 6 Issue 2, pp. 363-372, March-April 2019. Available at doi : https://doi.org/10.32628/IJSRSET196297
Journal URL : http://ijsrset.com/IJSRSET196297