The Climatic Benefit of Perennial Rice Cropping System: A Case Study in West Java, Central Java, and East Java

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1 Introduction

There is an increasing awareness of the impacts of climate change on rice production, especially, in Asian countries. There are two main reasons for this trend. The first reason is the important contribution of Asian rice farming to employment and economic growth in Asia (Bandumula, 2018; Chauhan et al., 2017). The second one is Asia the world largest rice producer and rice consumer (Chauhan et al., 2017). In turn, possible threats to Asian rice production can affect a large fraction of the world population in terms of food security, livelihoods, and economic growth (Chauhan et al., 2017).

Among Asian countries, Indonesia is the third-largest rice producer and the third-largest rice consumer in the world (Setyanto et al., 2018). As such, Indonesia is an interesting place to understand the impacts of climate factors on Asian rice production. It is also acknowledged that Indonesian temperature, as well as Asian temperature, is relatively close to rice critical temperature, leaving Indonesia's rice production in danger under changing climate (Chauhan et al., 2017; Lobell & Gourdji, 2012; Lobell et al., 2008, 2011; Serraj & Pingali, 2018). Owing to this, some scholars have investigated several issues of Indonesian rice production. For instance, an existing study (Naylor et al., 2007) discussed the possible impacts of climate change on rice production in West Java and Bali. Other existing studies (Falcon et al., 2004; Naylor & Mastrandrea, 2009) estimated the impacts of El-Niño Southern Oscillation (ENSO) on rice production.

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Other studies also discussed significant issues such as the impacts of climate on Indonesian rice yield (Amalo et al., 2017; Kinose & Masutomi, 2019; Kuswanto et al., 2018; Yuliawan & Handoko, 2016), modeling the rice production (Karim et al., 2019; Utami et al., 2019), the impacts of land-use change on rice production (Makbul et al., 2019; WorldBank, 2008), and adaptation of the rice farming to climate or seawater intrusion (Bahri, 2017; Rondhi et al., 2019; Sembiring et al., 2020; Sutrisno & Setyono, 2017; Utami et al., 2018).

Existing studies arguably provide useful information to investigate possible threats to Indonesian rice production. However, existing studies that analyzed the impacts of climate on Indonesian rice yield are very limited and none of the existing studies have analyzed the impacts of climate factors on three main rice provinces including West Java, Central Java, and East Java. Since the three Java provinces are responsible for half of the Indonesian rice production (BPS, 2020), this study specifically aims to investigate the impacts of climate factors on rice yield in the three main rice provinces.

Besides the aforementioned issues, Indonesian rice studies also discussed the perennial rice cropping system, so-called the salibu. This is important as most rice farmers have suffered from high-production costs such as labor and pesticide expenses (Budianti, 2021; Fitri et al., 2019; Marpaung et al., 2022; Yamaoka et al., 2017). Those studies explained that the perennial rice cropping system (the salibu) can increase rice yield, decrease short-duration growth, and decrease production cost (Budianti, 2021; Fitri et al., 2019; Marpaung et al., 2022; Yamaoka et al., 2017).

While several studies (Bahri, 2017; Khairulbahri, 2021; Welch et al., 2010) claimed that high temperatures associated with climate change may decrease Indonesian rice yield, the salibu method leads to higher rice yield recently (Budianti, 2021; Marpaung et al., 2022; Paiman, 2021). So, this study also aims to assess whether the salibu method enables rice farmers to escape from the negative impacts of high temperatures. In doing so, after the impacts of climate factors in West Java, Central Java, and East Java are assessed, the climatic benefit of the salibu is examined. In this study, the climatic benefit occurs once the salibu method can negate the negative impacts of climate factors on rice yield.

In fulfilling the research aim, this study first introduces relevant studies and the research aim. Next, the types of collected data and used methods in this study are described. Following this, this study discusses the results and explains important findings. In the end, some concluding remarks are described accordingly.

2 Materials and Methods

2.1 Three Indonesian Provinces: West Java, Central Java, and East Java

These three provinces are situated in Java, the most populated island in Indonesia. Together, these provinces are the main buffer rice stock in Indonesia (BPS Jawa Tengah, 2021; BPS Jawa Timur, 2021). The main buffer stock means these provinces provide rice not only for their local population but also to export their rice to their neighboring provinces.

West Java lies between 5°50′–7°50′ South Latitude and 104°48′–108°48′ East longitude (BPS Jawa Barat, 2021) and its capital is Bandung, so-called Paris van Java. West Java consists of 18 regencies and 9 cities with a total area and population density of about 35,377 km^2 and 1,365 persons/km^2, respectively (BPS Jawa Barat, 2021).

West Java has average annual rainfall between 2,000–4,000 mm/year, making this province the highest annual rainfall compared to the other Java provinces. Agriculture contributes to about 20% and 9% of the total employment and the economic output, respectively (BPS Jawa Barat, 2021) (Fig. 1).

Central Java geographically stretches along the equator between 5°40’ to 8°30’ South Latitude and 108°30′ to 111°30′ East Longitude (BPS Jawa Tengah, 2021). Its capital is Semarang with a total area and population density of about 32,801 km^{2}and 1,113 person/km^2, respectively (BPS Jawa Tengah, 2021). Central Java has an annual rainfall of about 2,500 mm/year, leading to, at least, three rice growing seasons throughout the year. Agriculture contributes to 12.5 and 29% of the total economic output and the total employment, respectively (BPS Jawa Tengah, 2021).

Fig. 1 Indonesia and three main Java provinces (West Java, Central Java, and East Java). *Source* Google Maps (n.d.)

East Java is the easternmost Java province and lies between 7.12 ‘South Latitude—8.48’ South Latitude and between 111.0 ‘East Longitude—114.4’ East Longitude (BPS Jawa Timur, 2021). Its capital is Surabaya, the Indonesian second largest city after Jakarta. East Java has a total area and population density of about 47,800 km^2 and 851 persons/km^2, respectively (BPS Jawa Timur, 2021). The annual rainfall is about 2,800 mm/year, and the average temperature in 2020 was 27.3 °C. Moreover, agriculture contributes to 35% and 20% of the total employment and the total economic output, respectively (BPS Jawa Timur, 2021).

Based on previous paragraphs, it can be concluded that agriculture has an important contribution to employment and economic growth in given Java provinces. So, this study can give important insights for policymakers in supporting important agricultural contributions to employment and economic output.

2.2 The Salibu and Ratoon Methods

As seen in Table 1, rice growth can be categorized into three important stages including the vegetative, the reproductive, and the ripening stages (Yoshida, 1981).The length of different stages of rice growth is varied between long- and short-duration growth varieties. But the main difference is in the length of the vegetative stage (Moldenhauer & Slaton, 2001). While the length of the vegetative stage is about 30 days for short-duration rice varieties, long-duration rice varieties have about 60 days of the vegetative stage. So, in total, the medium duration growth of rice is 115–135 days, assuming farmers apply the transplantation method (Moldenhauer & Slaton, 2001; Yoshida, 1981).

The ratoon method has been known by rice farmers for a long time (Fitri et al., 2019; Juanda, 2016). In the transplantation method, farmers need land preparation and new seed for each new growing season. In contrast, the ratoon method aims to cultivate parent rice for new growing seasons without land preparation and without new seed. Although the ratoon method may save cost and farming time, this method has been neglected due to its low yield compared to its parent yield (Adji, 2022; Fitri et al., 2019; Pasaribu, 2016; Pasaribu & Anas, 2018).

The salibu method aims to improve the ratoon methods as it can sustain or increase rice yield compared to its parent yield. The salibu method is coined by other scholars (Erdiman & Misran, 2013) when they supervised farmers in North Sumatera. After successful harvesting seasons, the salibu method has been widely applied in other Indonesian provinces (Fitri et al., 2019).

The main difference between the two is in the ratoon method, farmers would not prune parent rice as new rice plants, whereas farmers in the salibu method would prune parent plants as new rice for the next growing seasons. Usually, after 5–15 days of the harvesting seasons, farmers would prune the parent rice (Pasaribu, 2016).

Because pruning the parent rice occurs after the rice has stems, roots, and tillers, salibu method combines the vegetative and reproductive phases. In turn, the total

Table 1 Three stages of rice growth

No	The stages of rice growth	
	The transplantation method	The ratoon and salibu methods
I	Vegetative (from seed germination to panicle initiation, 45–65 days) Rice biomass is converted into roots, tillers, and stems through respiration growth mechanisms	Please bear in mind that growth mechanisms in the transplantation and the salibu methods are similar such as panicle initiation, new root, and new tillers. The main differences are explained in this column
II	Reproductive (panicle initiation to flowering and heading, 35 days) Panicle which emergences in the reproductive stage is a critical because it will affect the number of panicles per farming area and grains per panicle. In the reproductive stage, photosynthesis is supported by the leaf	While the transplantation method needs land preparation, the ratoon and the salibu methods do not require land preparation Pruning parent rice after the harvesting seasons (the ratoon method does not need pruning) happens in the salibu method Since parent rice already has a root, stem, and leaf, rice in the earliest stage of the salibu method has been already in the vegetative and reproductive stages (Pasaribu, 2016; Pasaribu & Anas, 2018)
III	Ripening (flowering and heading to mature grain, 30 days) Rice grain is filled with milky materials into a soft dough. Afterward, panicles and leaves turn yellow with mature and hard grain	In principle, the salibu method has a similar length to the ripening stage (Pasaribu, 2016; Pasaribu & Anas, 2018)

Source Bahri (2017), Moldenhauer and Slaton (2001), and Yoshida (1978, 1981)

growing seasons of rice, after the salibu method, would be less than 90 days (Fitri et al., 2019; Marpaung et al., 2022; Paiman, 2021).

2.3 Data Collection

There are two types of collected data: climatic data and non-climatic data. Climatic data such as temperature and rainfall were collected from the Indonesian Bureau of Meteorological and Geophysics (BMKG). Non-climatic data such as rice yield were collected from the Indonesian Statistics Bureau (BPS).

Collected data are statistically analyzed to estimate relationships between rice yield and climate factors. Rice yield could be affected by climate factors including maximum temperature, minimum temperature, and rainfall (Khairulbahri, 2021; Lobell & Gourdji, 2012; Welch et al., 2010). So, this study applies linear regression models to relate rice yield to temperature, rainfall, and time trends (Lobell & Burke, 2010). High-yield rice varieties are based on technological progress that is encapsulated in improved rice varieties (Bahri, 2017; Gnanamanickam, 2009; Lobell & Burke, 2010). As another study (Khairulbahri, 2021; Lobell & Burke, 2010), this study uses time variables as a representation of the technological progress of improved rice varieties. Equation 1 shows a statistical model that estimates relationships between climate, time variables, and rice yield as follows:

$$\mathrm{Yi} = \mathrm{c}_1 + \alpha_1\mathrm{Ai} + \alpha_2\mathrm{Ai}^2 + \alpha_3\mathrm{Ti} + \alpha_4\mathrm{Ti}^2 + \alpha_5\mathrm{Ta} + \alpha_6\mathrm{Ta}^2 + \alpha_7\mathrm{Ri} + \alpha_8\mathrm{Ri}^2 + \varepsilon_1 \quad (1)$$

Yi = rice yield (tons/ha) in year t;
Ai = time variable as a representation of the technological change of rice (a year since 1993);
Ai^2 = squared time variable as a representation of the technological change of rice;
Ti = minimum temperature in Celsius in year t;
Ta = maximum temperature in Celsius in year t;
Ri = seasonal rainfall in mm/year in year t;
c_1 = constant;
ε_i = error.

For time variables, Ai and Ai^2, it was set as 1 starting since 1993 (in 1993 and 2019, Ai = 1 and Ai = 27 respectively). The statistical software Eviews© version 7 was used to conduct several statistical tests assessing the adequacy of a statistical model rice yield.

The performance of selected statistical models will be obtained and assessed by Ordinary Least Square (OLS) and *F*-tests, respectively. Owing to this, selected statistical models must conform to normality assumptions (Greene, 2003; Gujarati et al., 2012). Furthermore, reliable statistical models have to be fulfilled relevant assumptions such as homoscedasticity, uncorrelated predictors, and no serial correlations (Greene, 2003; Gujarati et al., 2012; Lobell & Burke, 2010).

To obtain the correct model specification, the general to simple approach is applied as it is a suitable practice in modern analysis (Greene, 2003; Quiroga & Iglesias, 2009). In principle, the general to simple approach asks scientists to collect all possible independent variables and regressed them with the dependent variable step by step to obtain the best statistical model(s). By applying the general to simple approach, we can prevent ourselves from abandoning possible significant independent variables, leading to the best statistical model (Greene, 2003; Quiroga & Iglesias, 2009).

3 Results and Discussion

3.1 Observed Data

Table 2 shows the total rice production in West, Central, and East Java, the three main rice provinces in Indonesia. In general, the three provinces have similar rice production, rice yield, and harvested areas. It is also shown in Table 2 that the total rice production of the three main rice provinces is about 50% of the Indonesian total rice production, showing the importance of the three provinces in Indonesia's rice production.

Another similarity between the three provinces is the dominance of irrigated farming areas (95%) instead of non-irrigated areas (5%) (BPS Jawa Barat, 2021; BPS Jawa Tengah, 2021; BPS Jawa Timur, 2021). As consequence, farmers in the three provinces harvest their rice almost throughout the year. Of climate, West Java is relatively cooler than the other provinces but West Java has higher rainfall than the other provinces.

The highest maximum temperature (33.98 °C) and the highest minimum temperature (24.9 °C) are lower than rice's temperature threshold of maximum temperature (35 °C) and minimum temperature (22 °C), respectively (Table 3). However, the impacts of temperature on rice yield are not always statistically significant as described in the following paragraphs.

As seen in Table 4, for all rice in the three provinces, technological progress such as better rice varieties have an important role in increasing rice yield. This premise is in line with existing studies (Bahri, 2017; Gnanamanickam, 2009; Lobell & Burke, 2010), confirming the importance of technological progress in supporting rice yield. However, the impacts of high temperatures are different in the three Indonesian provinces. The following paragraphs explain the different impacts of high temperatures on rice yield.

3.1.1 West Java

As 95% of total farming areas are irrigated rice areas, it is not surprising that the effects of rainfall are not statistically significant on rice yield in West Java. Likewise, the impacts of minimum temperature are not statistically significant, as the highest observed minimum temperature was 21.7 °C, lower than the threshold of minimum temperature (22 °C) (Peng et al., 2004). In another hand, a time variable, as a representation of technological progress such as better rice varieties, significantly can increase rice yield in West Java ($p < 0.01$). Likewise, maximum temperature has a significant impact on rice yield. Every 1 °C increase in maximum temperature tends to increase rice yield by about 3.387 tons/ha ($p < 0.01$).However, the maximum temperature tends to negatively decrease rice yield once the observed maximum temperature surpasses 33 °C. This is in line with other studies (Bahri, 2017; Jagadish et al., 2010; Khairulbahri, 2021), stating that maximum temperature tends to decrease rice yield by over 33 °C.

3.1.2 East Java

Farmers in East Java have experienced the negative impacts of high minimum temperature. The impacts of minimum temperature are statistically significant as

Table 2 Rice production, rice yield, and harvested areas in West Java, Central Java, and East Java

Province	Rice production (tons)			Rice yield (tons/ha)			Harvested areas (ha)			Fractions of rice production		
	2020	2019	2018	2020	2019	2018	2020	2019	2018	2020 (%)	2019 (%)	2018 (%)
West Java	9,016,772	9,084,957	9,647,359	5.7	5.75	5.7	1,586,889	1,578,836	1,707,254	16	17	16
Central Java	9,489,164	9,655,654	10,499,588	57	5.75	5.8	1,666,931	1,678,479	1,821,983	17	18	18
East Java	9,944,538	9,580,934	10,203,213	5.7	5.63	5.8	1,754,380	1,702,426	1,751,192	18	18	17
Indonesia	54,649,202	54,604,033	59,200,534	5.1	5.11	5.2	10,657,275	10,677,887	11,377,934	52	52	51

Source BPS Jawa Barat (2021), BPS Jawa Tengah (2021), BPS Jawa Timur (2021), and BPS Indonesia (2022)

Table 3 A summary of climatic data (1993–2019). Bracketed values show minimum and maximum values

Provinces	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)
West Java	28.93 (26.1–31.83)	19.21 (16.2–21.7)	2,241 (1,046–4,453)
Central Java	32.28 (31.4–33.98)	24.17 (23–24.9)	3,227 (3,140–3,398)
East Java	33.43 (32–34.35)	22.48 (20.7–24.68)	2,025 (1,218–3,464)

Table 4 Statistical models for each province

Variables	West Java	East Java	Central Java
Time variable	0.052**	0.037**	0.022**
Minimum temperature	–	−0.09*	0.149*
Maximum temperature	3.387**	5.78*	0.118*
Squared Maximum temperature	−0.058**	−0.087*	–
C	−44.38*	−88.7*	−2.36
Adjusted R^2	79%	63%	77%
F-tests	<0.01	<0.01	<0.01

* = significant at α = 5%, ** = significant at α = 1%

the observed minimum temperature is higher than 22 °C, the threshold of minimum temperature (Peng et al., 2004). Table 4 shows that rice yield will be decreased by about 0.09 tons/ha for a 1 °C increase in minimum temperature ($p < 0.05$).

In contrast, farmers have experienced the positive impacts of maximum temperature as 1 °C increase in maximum temperature tends to increase rice yield by about 5.87 tons/ha ($p < 0.05$). However, similar to rice yield in West Java, the maximum temperature tends to decrease rice yield once the maximum temperature surpasses about 33 °C. Rainfall, conversely, has no significant impact as 95% of the total rice farming is supported by irrigation facilities (BPS Jawa Timur, 2021).

3.1.3 Central Java

Surprisingly, observed minimum temperature and observed maximum temperature tend to increase rice yield in Central Java. For every 1 °C increase in the minimum and maximum temperature, rice yield is projected to increase by about 0.149 and 0.118 tons/ha, respectively ($p < 0.05$). The impacts of rainfall on rice yield are not statistically significant ($p > 0.1$), due to a large fraction of irrigated rice land (95%) in Central Java (BPS Jawa Tengah, 1993).

The positive impacts of high temperatures are due to important reasons. The main reason is rice farmers in Central Java have applied the salibu method (Nugroho et al., 2018; Pemerintah Jateng, 2021; Sulistyono, 2019). The salibu method is local wisdom that shortens the growth duration of rice significantly without sacrificing rice

Table 5 Comparisons between the salibu and non-salibu methods

No	Descriptions	Salibu	Non-salibu (ratoon)
1	Fertilizer	Organic	Organic/non-organic
2	Seed	No new seed each season	New seed each season
3	Land cultivation	No	Yes
4	Growth duration	<90 days	>90 days
5	Yield	Relatively higher	Relatively lower
6	Farming cost	Relatively lower	Relatively higher
7	Water consumption	Relatively lower	Relatively higher

Source Budiant (2021), DodiCandra (2020), Fitri et al. (2019), Krisnaputri (2020), Marpaung et al. (2022), Paiman (2021), and Yamaoka et al. (2017)

yield (Jahari & Sinaga, 2019; Nugroho et al., 2018; Wahyuni et al., 2019). The salibu method can shorten rice duration growth, to less than 90 days, enabling farmers to harvest their rice for about 2–3 months (Agustina et al., 2021; Muzabi, 2021). Short growth-duration (SDG) rice varieties after the salibu method also enable rice to escape from climate extremes such as heat stress and droughts (Abdullah et al., 2008; Bouman, 2007; Yoshida, 1981). SDG rice varieties also enable farmers to escape heat stress during the night through transpiration cooling as most farming areas have sufficient irrigated water during the night (Jagadish et al., 2010; Wassmann et al., 2009).

Table 5 highlights comparisons between the salibu and non-salibu (ratoon) methods. Rice farmers who apply the salibu method tend to enjoy some benefits such as fewer farming costs (less labor cost and less seed cost), shorter duration growth, and relatively higher yield. Two advantages of the salibu method such as shorter growth duration and less water consumption are important in coping with the negative impacts of climate change (Lobell & Burke, 2010; Rosenzweig et al., 2020).

Moreover, in the salibu method, rice farmers prune parentrice which leads to new shoots or tillers, leading to new roots (Fitri et al., 2019; Isnawan et al., 2022; Pasaribu & Anas, 2018). More roots and more tillers mean that rice has a higher coverage to capture important nutrients and higher rice yields, respectively. As parent rice is still in the farming field, parent rice and new fertilizer can be a better combination of nutrient sources for rice growth.

Differing farmers in Central Java, several studies showed that farmers in East Java (Afiani, 2018; Sayaka & Hidayat, 2015) and West Java (Dianawati & Sujitno, 2015; Rasmikayati et al., 2020; Rochdiani et al., 2017; Rohaeni & Ishaq, 2015) have sown rice varieties with relatively long growth duration (115–125 days) with limited farmers having applied the salibu method in East (Budianti, 2021) and West Java (Effendy et al., 2021). These are possible explanations for why farmers in West Java and East Java have experienced the negative impacts of high temperatures.

In tackling the negative impacts of high temperatures, rice scientists have developed heat-tolerant rice varieties (Yang et al., 2017; Ye et al., 2015; Zhang et al., 2013).

However, the application of heat-tolerant rice varieties may be lagged due to costs, different rice tastes, and policymakers' involvement (Kondamudi et al., 2012). As shown in this study, sowing SDG varieties after the salibu method should be seen as an alternative to cope with the negative impacts of high temperatures.

Existing studies (Boonwichai et al., 2019; Lobell & Burke, 2010) suggested that shifting crop seasons is one solution for minimizing the negative impacts of high temperatures. The salibu method, due to its shorter-duration growth, enables farmers to apply shifting crop seasons, preventing the rice from heat stress.

Likewise, since the rising temperature is associated with climate change, the positive impacts of the salibu method should be investigated further in higher temperatures, anticipating the negative impacts of higher temperatures beyond the observed temperatures.

4 Conclusion

This study discusses the impacts of climate factors on rice yield in the three Indonesian main provinces including West Java, Central Java, and East Java. This is important as recent temperatures in these main rice producers have reached the temperature threshold for rice growth. The importance of this study is also supported as these three regions capture about half of the Indonesian total rice production. This means that any possible threat to rice production in given provinces is likely to influence the Indonesian rice supply significantly.

In near future, the maximum temperature tends negatively affect rice yield in West Java and East Java if the maximum temperature is higher than 33 °C. Similarly, as the observed minimum temperature has surpassed the threshold of minimum temperature, farmers in East Java have experienced the negative impacts of minimum temperature on their rice. Again, since the recent minimum temperature in these three main regions has been close to the threshold of minimum temperature, changing climate is a big threat to the Indonesian rice supply.

By contrast, farmers in Central Java have experienced the positive impacts of minimum temperature and maximum temperature although both types of observed temperatures have surpassed their temperature thresholds. It appears that salibu method enables farmers to escape heat stress during rice growth, shorten duration growth, and accumulate more grain weight. Thus, this study offers a promising finding that the salibu method can minimize the negative impacts of high temperatures associated with climate change.

One of the possible mechanisms to cope with high temperatures associated with climate change is short-duration growth rice which enables rice to escape from climate extremes (Abdullah et al., 2008; Bouman, 2007; Yoshida, 1981). As the salibu method can shorten rice duration growth, rice farmers in Central Java can escape from the negative effects of high temperatures.

Another study explained other benefits of the salibu such as time saving and less production cost (Fitri et al., 2019). Owing to this, stakeholders such as policymakers/the government and rice scientists should disseminate the benefit of the salibu method as a promising farming method to get a higher profit and to cope with the negative impacts of high temperatures associated with climate change.

As precautionary measures, please bear in mind that the climatic benefit of the salibu method stated in this study is valid within observed temperatures. When the temperature rises significantly, for instance, due to climate change, the climatic benefit of the salibu method should be investigated further.

Last but not the least, the projections of the negative impacts of climate change and simulating possible options to minimize the negative impacts of climate change in the three main provinces will be the next avenue. This is important as IPCC (2013) projects that southern Indonesia will experience an increase in maximum temperature and minimum temperature by about 0.5 °C and 3 °C by 2100, respectively, depending on Radiative Concentration Pathways (RCP) scenarios.

Declarations **Competing Interest Statement**
The author declares no conflict of interest.

Code Availability
Not applicable.

Authors' Contributions Not applicable.

Funding Statements Not applicable.

Availability of Data and Supporting Material Data used in this study are available on request. Appendix A provides a summary of statistical test results.

Appendix A: Results of Statistical Tests

Statistical tests	West Java	Central Java	East Java
Jarque–Bera test	$p > 1\%$ Accept the null hypothesis: residuals are normally distributed	$p > 1\%$ Accept the null hypothesis: residuals are normally distributed	$p > 1\%$ Accept the null hypothesis: residuals are normally distributed
Breusch-Godfrey Serial Correlation LM Test	$p > 5\%$ Accept the null hypothesis: data are NOT serial correlated	$p > 1\%$ Accept the null hypothesis: data are NOT serial correlated	$p > 1\%$ Accept the null hypothesis: data are NOT serial correlated

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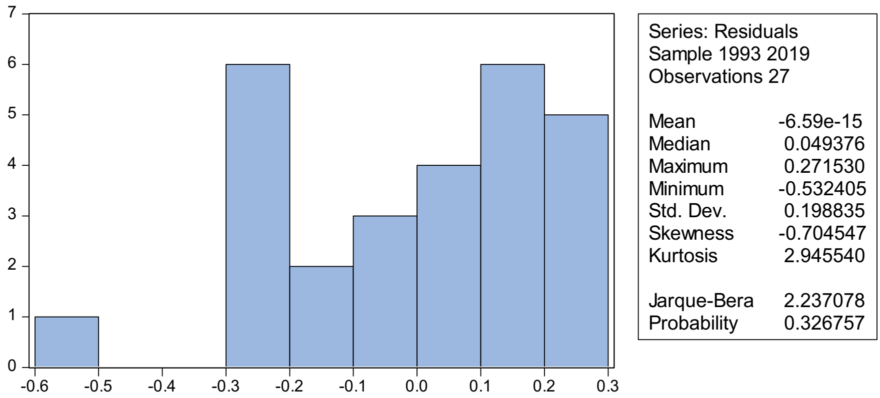
Statistical tests	West Java	Central Java	East Java
Variance Inflation Factors	<5 There is no any multicollinearity among independent variables	<5 There is no any multicollinearity among independent variables	<5 There is no any multicollinearity among independent variables
Heteroskedasticity Test: White	$p > 1\%$ Accept the null hypothesis: independent variables have homogeneous variances (homoscedasticity)	$p > 1\%$ Accept the null hypothesis: independent variables have homogeneous variances (homoscedasticity)	$p > 1\%$ Accept the null hypothesis: independent variables have homogeneous variances (homoscedasticity)
F-tests	$p < 1\%$ The statistical model can represent relationships between predictors and a predictand properly	$p < 1\%$ The statistical model can represent relationships between predictors and a predictand properly	$p < 1\%$ The statistical model can represent relationships between predictors and a predictand properly

Appendix B: The Results of Statistical Tests

West Java

Dependent Variable: RICEYIELD (Quintal)
Method: Least Squares
Date: 08/17/21 Time: 17:38
Sample: 1993 2019
Included observations: 27

Variable	Coefficient	Std. Error	*t*-Statistic	Prob
TIMEVARIABLE	0.052330	0.006218	8.415719	0.0000
MAXTEMP	3.387128	1.123246	3.015482	0.0062
MAXTEMP*MAXTEMP	−0.058426	0.019429	−3.007206	0.0063
C	−44.37824	16.26699	−2.728116	0.0120
R^2	0.815006	Mean dependent var		5.398741
Adjusted R^2	0.790876	S.D. dependent var		0.462289
S.E. of regression	0.211405	Akaike info criterion		−0.134125
Sum squared resid	1.027921	Schwarz criterion		0.057851
Log likelihood	5.810685	Hannan-Quinn criter		−0.077040
F-statistic	33.77601	Durbin-Watson stat		1.118468
Prob (*F*-statistic)	0.000000			



Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	2.282795	Prob. *F*(3,20)	0.1102
Obs*R^2	6.887058	Prob. Chi-Square(3)	0.0756

Variance Inflation Factors
Date: 08/17/21 Time: 17:41
Sample: 1993 2019
Included observations: 27

Variable	Coefficient variance	Uncentered VIF	Centered VIF
TIMEVARIABLE	3.87E-05	5.995509	1.417120
MAXTEMP	1.261682	642,551.5	595.8193
MAXTEMP*MAXTEMP	0.000377	162,660.7	600.2958
C	264.6151	159,862.4	NA

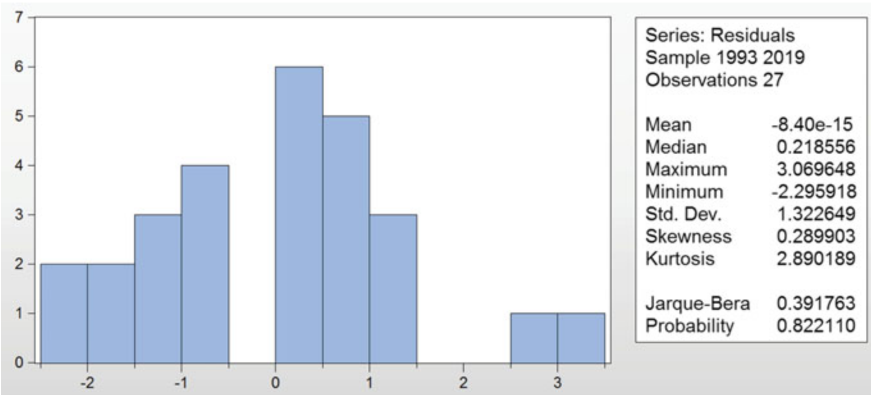
Note Maxtemp and its square are a self-multiplication so their high VIFs are an indication that they have multicollinearity issue(s)

Heteroskedasticity Test: White			
F-statistic	0.715020	Prob. *F*(6,20)	0.6419
Obs*R^2	4.768739	Prob. Chi-Square(6)	0.5738
Scaled explained SS	3.366215	Prob. Chi-Square(6)	0.7617

East Java

Dependent Variable: RICEYIELD
Method: Least Squares
Date: 06/19/21 Time: 22:25
Sample: 1993 2019
Included observations: 27

Variable	Coefficient	Std. Error	*t*-Statistic	Prob
TIMEVARIABLE	0.0371019	0.0066341	5.592580	0.0000
MINTEMP	−0.0909193	0.0527742	−1.722798	0.0990
MAXTEMP	5.777870	3.035728	1.903290	0.0702
MAXTEMP^2	−0.0870791	0.0452201	−1.925673	0.0672
C	−88.74630	51.17422	−1.734200	0.0969
R^2	0.691236	Mean dependent var		55.16333
Adjusted R^2	0.635097	S.D. dependent var		3.627105
S.E. of regression	2.191033	Akaike info criterion		4.572200
Sum squared resid	105.6138	Schwarz criterion		4.812169
Log likelihood	−56.72469	Hannan-Quinn criter		4.643555
F-statistic	12.31294	Durbin-Watson stat		1.545657
Prob(*F*-statistic)	0.000021			



Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	1.085246	Prob. *F*(1,21)	0.3094
Obs*R^2	1.326752	Prob. Chi-Square(1)	0.2494

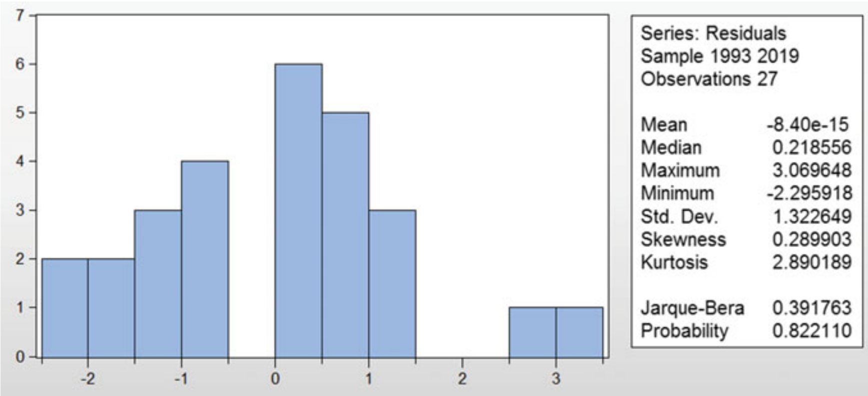
Variance Inflation Factors Date: 06/19/21 Time: 22:25 Sample: 1993 2019 Included observations: 27			
Variable	Coefficient variance	Uncentered VIF	Centered VIF
TIMEVARIABLE	0.004401	6.353340	1.501699
MINTEMP0301	0.278512	783.8395	1.427394
MAXTEMP	921.5646	5,831,862	3391.381
MAXTEMP^2	0.204485	1,459,367	3373.374
C	261,880.0	1,472,883	NA

Heteroskedasticity Test: White			
F-statistic	0.892452	Prob. *F*(11,15)	0.5671
Obs*R^2	10.68052	Prob. Chi-Square(11)	0.4704
Scaled explained SS	2.670528	Prob. Chi-Square(11)	0.9944

Central Java

Dependent Variable: RICEYIELD Method: Least Squares Date: 06/19/21 Time: 18:04 Sample: 1993 2019 Included observations: 27				
Variable	Coefficient	Std. Error	*t*-Statistic	Prob
C	−2.360660	2.604512	−0.906373	0.3741
MINTEMP	0.1491781	0.0811496	1.838309	0.0790
MAXTEMP	0.1181910	0.0641578	1.842192	0.0784
TIMEVARIABLE	0.0222607	0.0047817	4.655391	0.0001
R^2	0.795775	Mean dependent var		53.83148
Adjusted R^2	0.769137	S.D. dependent var		2.926784
S.E. of regression	1.406266	Akaike info criterion		3.655707
Sum squared resid	45.48444	Schwarz criterion		3.847683
Log likelihood	−45.35204	Hannan-Quinn criter		3.712791
F-statistic	29.87370	Durbin-Watson stat		1.729870
Prob (*F*-statistic)	0.000000			

Variance Inflation Factors Date: 06/19/21 Time: 21:22 Sample: 1993 2019 Included observations: 27			
Variable	Coefficient variance	Uncentered VIF	Centered
C	678.3484	9261.505	NA
TIMEVARIABLE	0.002286	8.012450	1.893852
MINTEMP0101	0.658526	5287.336	1.432334
MAXTEMP1	0.411622	5857.022	1.643119



Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	0.162849	Prob. *F*(1,22)	0.6904
Obs*R^2	0.198392	Prob. Chi-Square(1)	0.6560

Heteroskedasticity Test: White			
F-statistic	1.215024	Prob. *F*(9,17)	0.3479
Obs*R^2	10.56913	Prob. Chi-Square(9)	0.3064
Scaled explained SS	7.248406	Prob. Chi-Square(9)	0.6113

References

Abdullah, B., Tjokrowidjojo, S., & Sularjo, S. (2008). *Perkembangan dan prospek perakitan padi tipe baru di Indonesia.*

Adji, R. (2022). Pendampingan Teknologi Budidaya Salibu Pasca Pandemi Covid 19 Di Desa Cimekar, Cileunyi, Bandung. *ACADEMICS IN ACTION Journal of Community Empowerment, 4*(1), 27–39.

Afiani, F. R. K. (2018). Penerapan K-MEANS Clustering Untuk Mengetahui Varietas Padi Unggul Produksi Balai Pengkajian Teknologi Pertanian Jawa Timur. *JATI (jurnal Mahasiswa Teknik Informatika), 2*(1), 336–343.

Agustina, H., Setiawan, B. I., & Sugiyanta, S. (2021). *Manajemen Air Sistem Irigasi Evapotranspirasi Aliran Bawah Permukaan (Sistem Irigasi Evapotranspirasi) Pada Budidaya Padi Sistem of Rice Intensification (SRI) Salibu.*

Amalo, L. F., Hidayat, R., & Sulma, S. (2017). Analysis of agricultural drought in east Java using vegetation health index. *AGRIVITA, Journal of Agricultural Science, 40*(1), 63–73.

Bahri, M. (2017). *Integrating statistical and system dynamics modelling to analyse the impacts of climate change on rice production in West Nusa Tenggara, Indonesia.*

Bandumula, N. (2018). Rice production in Asia: Key to global food security. *Proceedings of the National Academy of Sciences, India Section b: Biological Sciences, 88*(4), 1323–1328.

Boonwichai, S., Shrestha, S., Babel, M. S., Weesakul, S., & Datta, A. (2019). Evaluation of climate change impacts and adaptation strategies on rainfed rice production in Songkhram River Basin, Thailand. *Science of the Total Environment, 652*, 189–201.

Bouman, B. (2007). *Water management in irrigated rice: Coping with water scarcity.* Int. Rice Res. Inst.

BPS. (2020). *Produksi padi Indonesia.* BPS.

BPS Indonesia. (2022). *Tabel Dinamis Produksi Padi Indonesa.*

BPS Jawa Barat. (2021). Jawa Barat dalam Angka 2020. *Badan Pusat Statistik Provinsi Jawa Barat*.

BPS Jawa Tengah. (1993). *Jawa Tengah dalam Angka.* BPS.

BPS Jawa Tengah. (2021). Jawa Tengah dalam Angka 2020. *Badan Pusat Statistik Provinsi Jawa Barat*.

BPS Jawa Timur. (2021). Jawa Timur dalam Angka 2020. *Badan Pusat Statistik Provinsi Jawa Barat*.

Budianti, Y. A. B. Y. A. (2021). Analisis Faktor Produksi Usahatani Padi Dengan Metode Salibu Di Kecamatan Madiun Kabupaten Madiun Jawa Timur. *Jurnal Agribisnis, 23*(2), 274–283.

Chauhan, B. S., Jabran, K., & Mahajan, G. (2017). *Rice production worldwide* (Vol. 247). Springer.

Dianawati, M., & Sujitno, E. (2015, July). *Kajian berbagai varietas unggul terhadap serangan wereng batang cokelat dan produksi padi di lahan sawah kabupaten Garut, Jawa Barat*. In Prosiding Seminar Nasional Masyarakat Biodiversity Indonesia (Vol. 1, No. 14, pp. 868–873).

DodiCandra, Y. T. (Director). (2020). *Tahapan Dan Proses Penerapan Teknologi Padi Salibu Tahap Awal Sampai Tahap Akhir*. https://www.youtube.com/watch?v=cYGszc9rI5Q

Effendy, L., Hanan, A., Haryanto, Y., & Putri, K. (2021). Farmers' preference for innovation of Salibu rice technology in Garut Regency, West Java-Indonesia. *Education, 5*(65), 13.

Erdiman, N., & Misran, M. Y. (2013). Peningkatan produksi padi dengan teknologi spesifik lokasi Sumatera Barat (teknologi salibu). *Laporan Hasil Pengkajian Tahun.*

Falcon, W. P., Naylor, R. L., Smith, W. L., Burke, M. B., & McCullough, E. B. (2004). Using climate models to improve Indonesian food security. *Bulletin of Indonesian Economic Studies, 40*(3), 355–377.

Fitri, R., Kusnadi, N., & Yamaoka, K. (2019). SALIBU technology in Indonesia: An alternative for efficient use of agricultural resources to achieve sustainable food security. *Paddy and Water Environment, 17*(3), 403–410.

Gnanamanickam, S. (2009). Rice and its importance to human life. In *Biological control of rice diseases, progress in biological control* (pp. 1–11). Springer.

Google Maps. (n.d.). *Indonesia and three main Java provinces* [Map]. https://www.google.com/maps

Greene, W. H. (2003). *Econometric analysis*. Pearson Education India.

Gujarati, D. N., Porter, D. C., & Gunasekar, S. (2012). *Basic econometrics*. Tata McGraw-Hill Education.

Isnawan, B. H., Aziez, A. F., & Salisu, M. A. (2022). The role of agronomic factors in Salibu rice cultivation. *The Open Agriculture Journal*, *16*(1).

Jagadish, S., Sumfleth, K., Howell, G., Redoña, E., Wassmann, R., & Heuer, S. (2010). Temperature effects on rice: Significance and possible adaptation. *Advanced Technologies of Rice Production for Coping with Climate Change: 'No Regret' Options for Adaptation and Mitigation and Their Potential Uptake* (pp. 19–25).

Jahari, M., & Sinaga, P. H. (2019). Menyiasati penyempitan musim tanam padi dengan budidaya ratun dan salibu. *Dinamika Pertanian, 35*(3), 65–72.

Juanda, B. R. (2016). Potensi Peningkatan Produksi Padi Dengan Meningkatkan IP (Indek Panen) Melalui Penerapan Teknologi Padi Salibu. *Jurnal Penelitian Agrosamudra, 3*(1), 75–81.

Karim, A., Sarra, D., Wasono, R., & Utami, T. (2019). Spatial Modelling for rice production analysis in Central Java Province Indonesia. *Journal of Physics: Conference Series, 1217*(1), 012113.

Khairulbahri, M. (2021). Analyzing the impacts of climate change on rice supply in West Nusa Tenggara, Indonesia. *Heliyon, 7*, e08515.

Kinose, Y., & Masutomi, Y. (2019). Impact assessment of climate change on rice yield using a crop growth model and activities toward adaptation: Targeting three provinces in Indonesia. In *Adaptation to climate change in agriculture* (pp. 67–80). Springer.

Kondamudi, R., Swamy, K. N., Chakravarthy, D. V. N., Vishnuprasanth, V., Rao, Y. V., Rao, P. R., Sarla, N., Subrahmanyam, D., & Voleti, S. R. (2012). Heat stress in rice–physiological mechanisms and adaptation strategies. *Crop stress and its management: Perspectives and strategies* (pp. 193–224). Springer.

Krisnaputri, D. (Director). (2020). *7 Prinsip Teknologi Padi Salibu.* https://www.youtube.com/watch?v=uhZaaEqyYjk

Kuswanto, H., Salamah, M., Retnaningsih, S. M., & Prastyo, D. D. (2018). On the Impact of Climate Change to Agricultural Productivity in East Java. *Journal of Physics: Conference Series, 979*(1), 012092.

Lobell, D. B., & Burke, M. (2010). *Climate change and food security: Adapting agriculture to a warmer world* (Vol. 37). Springer Science & Business Media.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science, 319*(5863), 607–610.

Lobell, D. B., & Gourdji, S. M. (2012). The influence of climate change on global crop productivity. *Plant Physiology, 160*(4), 1686–1697.

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science, 333*(6042), 616–620.

Makbul, Y., Faoziyah, U., Ratnaningtyas, S., & Kombaitan, B. (2019). Infrastructure development and food security in Indonesia: The impact of the trans-java toll road on rice paddy farmer's desire to sell farmland. *Journal of Regional and City Planning, 30*(2), 140–156.

Marpaung, D. S. S., Anika, N., & Bindar, Y. (2022). Strategi Peningkatan Produktivitas Padi Melalui Sistem Salibu Padi. *Jurnal Sumberdaya Lahan, 16*(1), 1–7.

Moldenhauer, K., & Slaton, N. (2001). Rice growth and development. *Rice Production Handbook, 192*, 7–14.

Muzabi, A. K. F. (2021). *Efektivitas Penambahan Pupuk Superfosfat dan Biofertilizer Terhadap Pertumbuhan dan Produksi adi Ratun (Oryza sativa L).*

Naylor, R. L., Battisti, D. S., Vimont, D. J., Falcon, W. P., & Burke, M. B. (2007). Assessing risks of climate variability and climate change for Indonesian rice agriculture. *Proceedings of the National Academy of Sciences, 104*(19), 7752–7757.

Naylor, R. L., & Mastrandrea, M. D. (2009). Coping with climate risks in Indonesian rice agriculture: A policy perspective. In *Uncertainty and environmental decision making* (pp. 127–153). Springer.

Nugroho, A. D., Fadlilah, C. U., Astuti, R. P., Irmania, L. V., Lestari, C., Pinardi, S. T., Anjarwati, N., Anjarwati, A., Bahtiar, E. W., & Pratama, D. A. (2018). Pelaksanaan Program Upaya Khusus (UPSUS) Swasembada Pangan Berkelanjutan di Kabupaten Kendal Provinsi Jawa Tengah. *JPPM (jurnal Pengabdian Dan Pemberdayaan Masyarakat), 2*(2), 287–296.

Paiman, P. Y. (Director). (2021). *Budidaya padi Salibu Part 2*. https://www.youtube.com/watch?v=DhR1Sxo1NtI

Pasaribu, P. O. (2016). *Sifat Fisiologi Dan Agronomi Padi Ratun Dengan Sistem Salibu Pada Budidaya System of Rice Intensification (SRI).*

Pasaribu, P. O., & Anas, I. (2018). Rice ratooning using the salibu system and the system of rice intensification method influenced by physiological traits. *Pertanika Journal of Tropical Agricultural Science*, *41*(2), 637–654.

Pemerintah Jateng. (2021). *Petani Padi Purbalingga Terapkan Teknologi 'Salibu Jarwo SuPER'*. https://jatengprov.go.id/beritadaerah/petani-padi-purbalingga-terapkan-teknologi-salibu-jarwo-super/

Peng, S., Huang, J., Sheehy, J. E., Laza, R. C., Visperas, R. M., Zhong, X., Centeno, G. S., Khush, G. S., & Cassman, K. G. (2004). Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences, 101*(27), 9971–9975.

Quiroga, S., & Iglesias, A. (2009). A comparison of the climate risks of cereal, citrus, grapevine and olive production in Spain. *Agricultural Systems, 101*(1–2), 91–100.

Rasmikayati, E., Saefudin, B. R., Rochdiani, D., & Natawidjaja, R. S. (2020). Dinamika Respon Mitigasi Petani Padi di Jawa Barat dalam Menghadapi Dampak Perubahan Iklim serta Kaitannya dengan Pendapatan Usaha Tani. *Jurnal Wilayah dan Lingkungan, 8*(3), 247–260.

Rochdiani, D., Kuswarini, K., & Bobby, R. S. (2017). *Risiko Perubahan Iklim Serta Pengaruhnya Terhadap Pendapatan Petani Usahatani Padi di Jawa Barat*. In Prosiding Seminar Nasional Mitigasi dan Strategi Adaptasi Dampak Perubahan Iklim di Indonesia. Pekanbaru (ID): Universitas Islam Riau.

Rohaeni, W. R., & Ishaq, M. I. (2015). Evaluasi Varietas Padi Sawah pada Display Varietas Unggul Baru (VUB) di Kabupaten Karawang, Jawa Barat. *Agric, 27*(1), 1–7.

Rondhi, M., Fatikhul Khasan, A., Mori, Y., & Kondo, T. (2019). Assessing the role of the perceived impact of climate change on national adaptation policy: The case of rice farming in Indonesia. *Land, 8*(5), 81.

Rosenzweig, C., Mbow, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Liwenga, E. T., Pradhan, P., Rivera-Ferre, M. G., & Sapkota, T. (2020). Climate change responses benefit from a global food system approach. *Nature Food, 1*(2), 94–97.

Sayaka, B., & Hidayat, D. (2015). Sistem perbenihan padi dan karakteristik produsen benih padi di Jawa Timur. *Analisis Kebijakan Pertanian, 13*(2), 185–202.

Sembiring, H., A Subekti, N., Nugraha, D., Priatmojo, B., & Stuart, A. M. (2020). Yield gap management under seawater intrusion areas of Indonesia to improve rice productivity and resilience to climate change. *Agriculture*, *10*(1), 1.

Serraj, R., & Pingali, P. (2018). *Agriculture & food systems to 2050: Global trends, challenges and opportunities* (Vol. 2). World Scientific.

Setyanto, P., Pramono, A., Adriany, T. A., Susilawati, H. L., Tokida, T., Padre, A. T., & Minamikawa, K. (2018). Alternate wetting and drying reduces methane emission from a rice paddy in Central Java, Indonesia without yield loss. *Soil Science and Plant Nutrition, 64*(1), 23–30.

Sulistyono, A. (2019). *Adaptasi Perubahan Iklim Ala Petani Pulokulon*. http://dispertan.grobogan.go.id/artikel/adaptasi_perubahan_iklim_ala_petani_pulokulon

Sutrisno, J., & Setyono, P. (2017). The effect of adaptation to climate change on rice production in the watershed region of Cemoro, Central Java, Indonesia. *International Journal of Applied Environmental Sciences, 12*(1), 211–220.

Utami, A. W., Cramer, L. A., & Rosenberger, N. (2018). Staple food diversification versus Raskin: Developing climate change resilience in rural Indonesia. *Human Organization, 77*(4), 359–370.

Utami, T., Prahutama, A., Karim, A., & Achmad, A. R. (2019). Modelling rice production in Central Java using semiparametric regression of local polynomial kernel approach. *Journal of Physics: Conference Series, 1217*(1), 012108.

Wahyuni, S., Zulvera, Z., Tanjung, H. B., & Arif, E. (2019). Hubungan Karakteristik Inovasi dan Kearifan Lokal Terhadap Keberlanjutan Penerapan Teknologi Padi Salibu di Kabupaten Tanah Datar, Sumatera Barat. *Jurnal Penyuluhan*, *15*(1).

Wassmann, R., Jagadish, S., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R., & Heuer, S. (2009). Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. *Advances in Agronomy, 102*, 91–133.

Welch, J. R., Vincent, J. R., Auffhammer, M., Moya, P. F., Dobermann, A., & Dawe, D. (2010). Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. *Proceedings of the National Academy of Sciences, 107*(33), 14562–14567.

WorldBank, T. (2008). *Adapting to Climate change: The case of rice in Indonesia*. The World Bank.

Yamaoka, K., Htay, K. M., Erdiman, E., & Fitri, R. (2017). *Increasing water productivity through applying tropical perennial rice cropping system (Salibu Technology) In CDZ, Myanmar*.

Yang, Z., Zhang, Z., Zhang, T., Fahad, S., Cui, K., Nie, L., Peng, S., & Huang, J. (2017). The effect of season-long temperature increases on rice cultivars grown in the central and southern regions of China. *Frontiers in Plant Science, 8*, 1908.

Ye, C., Tenorio, F. A., Argayoso, M. A., Laza, M. A., Koh, H.-J., Redoña, E. D., Jagadish, K. S., & Gregorio, G. B. (2015). Identifying and confirming quantitative trait loci associated with heat tolerance at flowering stage in different rice populations. *BMC Genetics, 16*(1), 1–10.

Yoshida, S. (1978). *Tropical climate and its influence on rice [periodicity, productivity and stability]*. (IRRI Research Paper Series [Philippines]).

Yoshida, S. (1981). *Fundamentals of rice crop science*. International Rice Research Institute.

Yuliawan, T., & Handoko, I. (2016). The effect of temperature rise to rice crop yield in Indonesia uses Shierary Rice Model with Geographical Information System (GIS) feature. *Procedia Environmental Sciences, 33*, 214–220.

Zhang, Y., Tang, Q., Peng, S., Zou, Y., Chen, S., Shi, W., Qin, J., & Laza, M. R. C. (2013). Effects of high night temperature on yield and agronomic traits of irrigated rice under field chamber system condition. *Australian Journal of Crop Science, 7*(1), 7–13.