Climate Change Impact on Paddy Yield in Indonesia: Farmers' Experience based on the 2021 Crop-Cutting Survey's Results

Prasetyo, Octavia Rizky and Kadir, Kadir

Statistics Indonesia, Statistics Indonesia

10 June 2023

Climate Change Impact on Paddy Yield in Indonesia: Farmers' Experience based on the 2021 Crop-Cutting Survey's Results

Octavia Rizky Prasetyo[1]
Statistics Indonesia (BPS), Jakarta, Indonesia – octavia.rizky@bps.go.id

Kadir
Statistics Indonesia (BPS), Jakarta, Indonesia – kadirsst@bps.go.id

Abstract: Climate change is a critical issue for food insecurity in many countries. It can disrupt food availability since it potentially results in the reduction of agricultural yield and eventually threatens smallholder farmers' livelihood and food security in the future. In the context of Indonesia, paddy cultivation, as one of the primary crop commodities, is also prone to climatic issues, such as floods and drought. However, to our knowledge, studies examining climate change's impact on the yield of paddy utilizing the nationwide survey in Indonesia are still limited. Hence, this study aims to assess the impact of climate change on the wetland and dryland paddy yield in Indonesia. In doing so, we applied a logistics regression to the 2021 Indonesian Crop-Cutting Survey results. The survey is conducted annually by Indonesian Statistical Agency (BPS) to obtain the yield data and information related to farmers' perceptions of climate change's impact on yield. After applying a logistics model to 50,619 wetland paddy crop samples and 1,081 dryland paddy crop samples, we found that paddy growers experiencing events resulting from climate change are more likely to have a higher probability of experiencing a decrease in their paddy yield than those who did not experience them, which is 2.23 times higher for wetland paddy and 1.77 times higher for dryland paddy. Besides, an incline in pest attack intensity and water insufficiency are also found to impact paddy yield reduction significantly. Further, based on kernel density distribution between groups of farmers, our finding pointed out that the yield of farmers affected by climatic issues, experiencing an increase in pest attacks, and facing water shortage, is slightly to the left of the opposite groups, which means that they are significantly lower than those unaffected. To conclude, this finding confirms that climate change, pest attacks, and insufficient avail water play a non-negligible role as yield-reducing factors in Indonesia's wetland and dryland paddy production. Thus, the mitigation of climate change impact, better strategy for pest control, and improved water management in paddy cultivation are essential to maintaining paddy production's sustainability.

Keywords: climate change; yield; crop-cutting; paddy; Indonesia

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1. Introduction

Since the era of the industrial revolution, human activities have extensively changed the composition of the global atmosphere resulting in climate change. It has produced substantial impacts on almost all aspects of human life, including agriculture production through agricultural productivity. Climate change is a critical issue for food insecurity in many countries. It can disrupt food availability since it potentially results in the reduction of agricultural productivity and eventually threatens smallholder farmers' livelihood and food security in the future. It happens because agricultural productivity is determined primarily by climate [1,2]. Indeed, agricultural productivity is strongly influenced by environmental factors affected by weather and climate, such as moisture and temperature [3,4].

As agriculture plays a pivotal role in human life, the impact of climate change on agricultural production should be taken into account seriously. It has motivated a substantial body of research on the aftermath of climate change on agricultural productivity, particularly crop yields. At least there are four ways through which climate would have an impact on crops physically [5], i.e. changes in temperatures and precipitation, carbon dioxide effects, water availability, climatic variability and the increase of extreme events such as droughts and floods.

Changes in climatic factors could possibly have either a positive or negative impact on crop yields. The rise in the concentration of carbon dioxide in the atmosphere, for example, can increase the photosynthesis rate and water usage efficiency [6]. Moreover, an increase in rainfall could also increase the yield [7]. However, in many places around the world, the extreme weather has caused droughts, floods, and the variability of rainfall patterns that reduced crop yields.

The negative impact of climate change on crop productivity and production has been confirmed by numerous studies. They found that drops in the yield are closely related to extreme events caused by climate change, such as extreme temperatures [8,9,10], droughts [11], and heavy rainfall and flooding [12].

In the Indonesian context, the negative impact of climate change on agricultural productivity is a serious problem. It is not only because the sector is the main source of livelihood for around one-third of the country's population but also because it provides food for all populations. In this regard, rice, as the primary food source for almost all Indonesians [13], is also prone to the threat of climate change-related events, such as floods and droughts.

Plenty of studies also confirmed the negative impact of extreme events related to climate change and other climate factors on paddy production through the yield in Indonesia [14,15,16,17,18]. However, almost all studies examining the effect of climate change on paddy yield in Indonesia are not based on a nationwide household survey. Instead, they use macro measurement approaches, mainly crop biophysical simulation and regression models, for a specific province in Indonesia.

A most recent study in Indonesia has attempted to analyze climate change's impact on paddy yield utilizing a nationwide household survey, namely the 2018 crop-cutting survey (*Survey Ubinan*), and confirmed the negative consequence of climate change on paddy yield [19]. It tried to examine the impact of climate change through farmers' experience of climate change-related events in cultivating their paddy crops. However, it only focused on wetland paddy yield while leaving dryland paddy yield aside. Hence, we would like to give a broader analysis by examining the impact of climate change on both wetland and dryland paddy yield, given the substantial role of dryland paddy in total paddy production, particularly in the eastern part of Indonesia. Besides, since Java and outside Java differ in paddy cultivation characteristics [20], we also elaborate more on the difference in the yield distribution as the impact of climate change between the two regions. In doing so, we utilize the most recent data from the crop-cutting survey results in 2021. In particular, our study assesses the impacts of climate change experienced by farmers on the yield of wetland and dryland paddies cultivated. It aims to enrich the body of research on this area using a nationwide survey in Indonesia.

2. Methodology

This study made use of the data from the 2021 crop-cutting survey results carried out by the Indonesian Statistical Agency (BPS). The survey is a nationwide survey aiming primarily to obtain the yield data of crops, including wetland and dryland paddy crops, using the crop-cutting experiment. Additionally, the survey collects additional information regarding farmers' perceptions of climate change's impact experience on their yield by interviewing farmers. The survey is conducted annually in three periods, namely *subround* I (January-April), *subround* II (May-August), and *subround* III (September-December).

Since *subround* III in 2018, the crop-cutting survey for paddy commodities has made use of the subsegment samples database from the Area Sampling Frame (ASF) survey results for its sampling design [21]. In general, the ASF survey provides monthly information related to the state of the paddy growing phase that allows the prediction of the location (subsegment) of paddy that will be harvested in the upcoming three months. That information is then used as the basis for sample selection in the crop-cutting survey. The crop-cutting survey applies a stratified multi-stage sampling for its sample selection, including the subsegment samples selection for stage 1, paddy swath selection in each selected subsegment for stage 2, and 2.5 m x 2.5 m plot selection from each selected swath for the final stage. Thus, the unit of observation in this study is the crop-cutting plots. The climate change experience is subject to the declaration of the farmer on the selected plot in the survey.

This study focuses on wetland and dryland paddy since they are the main source of food in Indonesia. The total number of the sample is 50,619 for wetland paddy crops and 1,081 for dryland paddy crops. A logistic regression model was applied to assess the climate change impact on the yield state of wetland and dryland paddy in 2021 compared to the previous year. We decided to use the logistic regression model since our response variable is the binary variable [22]. To enrich the analysis, we also incorporate the intensity of pest attacks and water insufficiency in the model. Hence, we can also investigate the extent to which pest attack intensity and shortage in water supply affect the decrease in wetland and dryland paddy yield. The model specification in this study is denoted as follows:

$$y_\mathrm{i} = \alpha + \boldsymbol{x}_i'\beta + \varepsilon_\mathrm{i} \tag{1}$$

where y_i is the state of paddy yield, either wetland or dryland paddy, in comparison to the previous year, $\boldsymbol{x}_i'$ is a matrix covariate of independent variables, including the impact of climate change encountered by paddy growers, pest attack intensity, and water insufficiency, and ε_i is the component of error. A more detailed description of the variables included in the analysis is provided in Table 1. Additionally, we also apply logistic regression to equation (1) separately for Java and outside Java. The function of logistic distribution in our study can be expressed as the following equation [22]:

$$Prob(Y = 1|X) = \frac{e^{\alpha + x_i'\beta}}{1+e^{\alpha + x_i'\beta}} \tag{2}$$

To further analyze whether there is a significant difference in wetland and dryland paddy yield between paddy growers who encountered climate change-related events and not, we plot the distribution of the kernel density function of paddy yield for each paddy growers' group. Similar to the logistic regression estimate, we also provide the density of the wetland and dryland paddy yield based on the experience of farmers towards pest attacks and water insufficiency. Our study applies the Epanechnikov kernel function as the following equation [23]:

$$\hat{f}_k = \frac{1}{h}\sum_{i=1}^{n} K\left(\frac{x-X_i}{h}\right) \quad (3)$$

In Equation (3), h denotes the bandwidth determining the number of values required to estimate density at each point, x is the yield of wetland and dryland paddy in the natural logarithmic terms, and n is the sample size. This study set h = 0.1.

Table 1. Variables Description

Response variables: It is a binary response variable of the yield state of wetland and dryland paddy in comparison to the year before based on paddy growers' perceptions. It is coded 1 if "decreased" and 0 "otherwise". The reference category is code 0.	
Independent variables:	
Climate change experience	It is a binary variable of climate change impact, such as drought and flood, experienced by farmers based on their declaration. It is coded 1 if "not experiencing climate change impact" and 2 if "experiencing climate change impact". The reference category is code 1.
Pest attack intensity	It is a categorical variable of pest attacks encountered by paddy growers in comparison to the year before based on their declaration, which is coded 1 if "decreased", 2 if "no difference", and 3 if "increased". The reference category is code 1.
Water insufficiency	It is a binary variable of water insufficiency for irrigation based on paddy growers' declaration, which is coded 1 if "sufficient" and 2 if "not sufficient". The reference category is code 1.

Source: authors' elaboration.

3. Results and Discussion

The estimation results in Table 2 corroborate the negative impact of climate change, pest attacks, and water insufficiency on the wetland and dryland paddy yield in Indonesia. However, the pseudo R^2 is only 0.1346 for wetland paddy estimates and 0.1875 for dryland paddy estimates, indicating that variables included in the model simultaneously can only explain a small part of the variation in our dependent variables. It could be explained since the paddy yield variation might be determined by some other factors outside variables in the model specification, such as farmers' characteristics. Nevertheless, since we rely on crop-cutting survey results that focus on estimating yield using the crop-cutting experiment with limited information on farmers' characteristics, we consider this as one of the limitations in our study.

Our finding in Table 2 demonstrates, at a 1 per cent level of significance, that farmers who have experienced climate change-related events are more likely to have a higher probability of seeing a decrease in their paddy yield than those without experience in climate change-related events. This finding is partially supported by some studies that pointed out a reduction in yield or production as one of the results of climatic shocks, such as prolonged droughts, dry seasons, and heat waves [1,14,15,24]. Our results reveal a significant impact of climate change on the yield of both types of paddy crops, wetland paddy and dryland paddy, which indicates that paddy cultivation in Indonesia is generally vulnerable to climatic shocks. The probability of wetland paddy growers experiencing events related to climate change to experience a decrease in their paddy yield was 2.23 times higher than those who did not experience climate change-related events, while it was 1.77 times higher for dryland paddy yield.

Likewise, a more intense pest attack is also found to impact paddy yield reduction significantly. Our finding reveals that paddy growers experiencing an increase in the intensity of pest attacks have a higher likelihood of experiencing a decrease in wetland and dryland paddy yield. In more detail, wetland paddy farmers experiencing an increase in pest attacks are 9.43 times more likely to have a higher likelihood of seeing a decline in their wetland paddy yield than those farmers experiencing a decrease in pest attacks. Even for dryland paddy yield, the impact is more substantial, as shown by a higher coefficient magnitude. Dryland paddy growers experiencing an increase in pest attacks are 14.18 times more likely to see a significant drop in their yield than those with a decrease in pest attacks.

Furthermore, as expected, the water scarcity for paddy cultivation also significantly explains the likelihood of paddy yield reduction. Based on farmers' experience, those with water shortage for their wetland paddy crops are 2.35 times more likely to experience a decline in their yield than farmers with sufficient water for irrigation. The likelihood is similar for dryland paddy yield, where farmers experiencing a lack of water supply for their dryland paddy cultivation are 2.24 more likely to experience a significant drop in their yield than those without any issue in water supply for their paddy cultivation. It confirms the critical role of effective water management in cultivating wetland paddy and dryland paddy.

Table 2. Logistic Regression Estimation Results on the State of the 2021 Paddy Yield in Comparison to the Previous Year

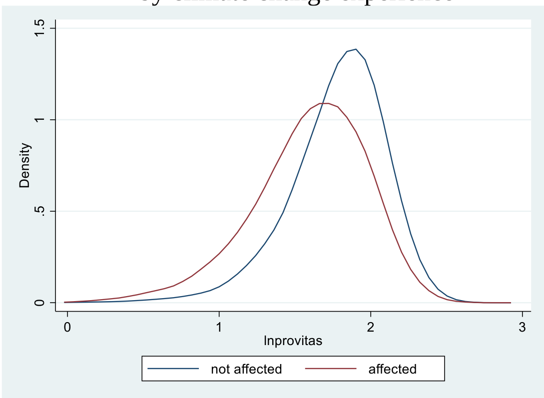
Variables	Wetland Rice		Dryland Rice	
	Coefficient	**Odds Ratio**	**Coefficient**	**Odds Ratio**
Climate change experience	0.8028***	2.2318***	0.5751***	1.7773***
	(0.0288)	(0.0643)	(0.2039)	(0.3624)
Pest attack intensity				
No difference	0.5547***	1.7415***	0.5943**	1.7938**
	(0.0350)	(0.0609)	(0.2390)	(0.4289)
Increased	2.2448***	9.4384***	2.6520***	14.1820***
	(0.0388)	(0.3664)	(0.2587)	(3.6695)
Water insufficiency	0.8530***	2.3468***	0.8066***	2.2402***
	(0.0377)	(0.0884)	(0.2263)	(0.5070)
Constant	-0.3094***	0.0453***	-3.1606***	0.0424***
	(0.0516)	(0.0023)	(0.3354)	(0.0142)
Probability > χ^2	0.0000	0.0000	0.0000	0.0000
Pseudo R^2	0.1346	0.1346	0.1875	0.1875

Notes: Number of observations is 50,619 for wetland paddy and 1,081 for dryland paddy; *** statistically significant at α=1%, ** statistically significant at α=5%; standard error is in parentheses.
Source: authors' calculation.

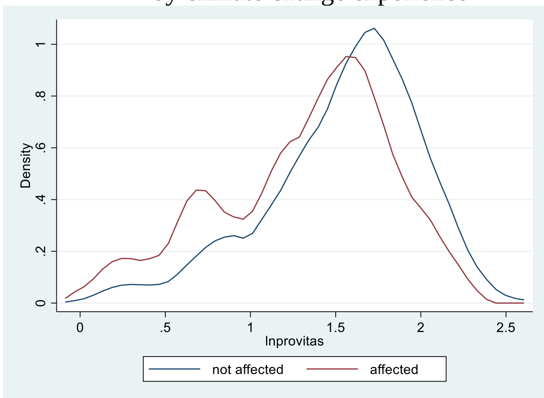
Further analysis of the kernel density function of wetland and dryland paddy yield between different groups of farmers shows consistent results with the logistic regression estimates. As shown in Figure 1, our study highlights that the distribution in the yield of paddy growers suffering the impact of climate change issue-related events, the incline in pest attacks intensity, and water insufficiency is slight to the left of the opposite groups. It means that farmers affected by those three issues are more likely to have a significantly lower yield than those unaffected. It again insists on the adverse impact of climatic issues, pest attacks, and the scarcity of water on wetland and dryland paddy yield, which may eventually threaten the sustainability of national paddy production.

Figure 1. Kernel density for wetland and dryland paddy yield by the experience in climate change, pest attacks, and water insufficiency

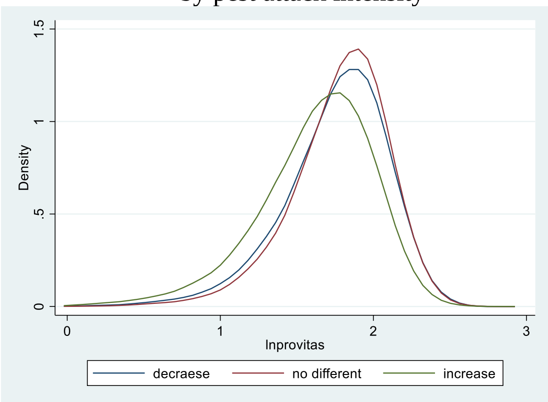
(i) Wetland paddy yield distribution by climate change experience



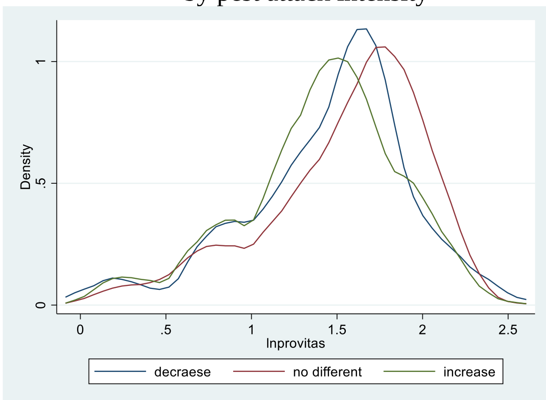
(ii) Dryland paddy yield distribution by climate change experience



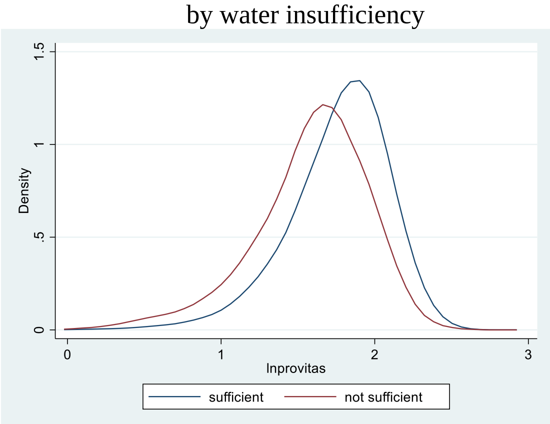
(iii) Wetland paddy yield distribution by pest attack intensity



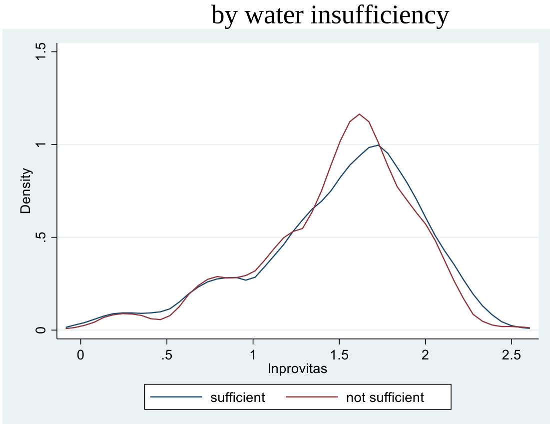
(iv) Dryland paddy yield distribution by pest attack intensity



(v) Wetland paddy yield distribution by water insufficiency



(vi) Dryland paddy yield distribution by water insufficiency



Source: authors' calculation.

Table 2 and Figure 1 allow us to investigate the association of events resulting from climate change, the intensity of pest attacks, and water insufficiency with paddy yield. However, they cannot specifically assess whether the impacts of those experiences in different regions with different paddy cultivation characteristics affect yield differently. To obtain more perspective on this issue, we also estimate the impact of our three regressors on the state of the yield of wetland paddy and dryland paddy in two different regions, namely Java and outside Java, as shown in Tables 3 and 4.

Table 3. Logistic Regression Estimation Results on the State of the 2021 Wetland Paddy Yield in Comparison to the Previous Year in Java and Outside Java

Variables	Java		Outside Java	
	Coefficient	Odds Ratio	Coefficient	Odds Ratio
Climate change experience	0.9035***	2.4681***	0.7569***	2.1317***
	(0.0505)	(0.1247)	(0.0356)	(0.0758)
Pest attack intensity				
No difference	0.4998***	1.6483***	0.5891***	1.8024***
	(0.0553)	(0.0912)	(0.0453)	(0.0816)
Increased	2.2607***	9.5898***	2.2289***	9.2899***
	(0.0618)	(0.5927)	(0.0499)	(0.4633)
Water insufficiency	0.8775***	2.4048***	0.8183***	2.2667***
	(0.0587)	(0.1411)	(0.0495)	(0.1122)
Constant	-3.0965***	0.0452***	-3.0653***	0.0466***
	(0.0807)	(0.0036)	(0.0677)	(0.0032)
Probability > χ^2	0.0000	0.0000	0.0000	0.0000
Pseudo R^2	0.1333	0.1333	0.1352	0.1352

Notes: Number of observations is 22,849 for Java and 22,770 for outside Java; *** statistically significant at α=1%, ** statistically significant at α=5%; standard error is in parentheses.
Source: authors' calculation.

Table 4. Logistic Regression Estimation Results on the State of the 2021 Dryland Paddy Yield in Comparison to the Previous Year in Java and Outside Java

Variables	Java		Outside Java	
	Coefficient	Odds Ratio	Coefficient	Odds Ratio
Climate change experience	1.1523***	3.1656***	0.1620	1.1758
	(0.3753)	(1.1880)	(0.2519)	(0.2962)
Pest attack intensity				
No difference	0.4804	1.6168	0.6594**	1.9336**
	(0.4658)	(0.7532)	(0.2866)	(0.5541)
Increased	2.8401***	17.1177***	2.4917***	12.0820***
	(0.4846)	(8.2961)	(0.3174)	(3.8351)
Water insufficiency	0.8971**	2.4526**	0.5461	1.7266
	(0.3566)	(0.8745)	(0.3492)	(0.6030)
Constant	-3.5480***	0.0288***	-2.6384***	0.0715***
	(0.5795)	(0.0167)	(0.4807)	(0.0343)
Probability > χ^2	0.0000	0.0000	0.0000	0.0000
Pseudo R^2	0.2730	0.2730	0.1348	0.1348

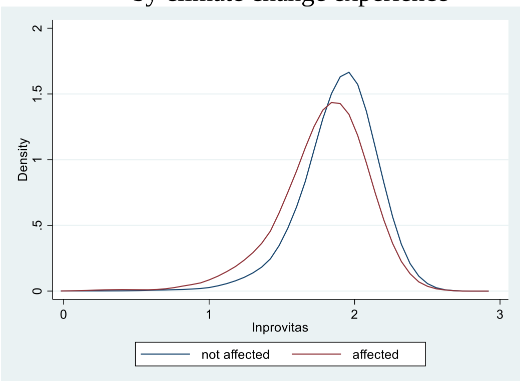
Notes: Number of observations is 503 for Java and 578 for outside Java; *** statistically significant at α=1%, ** statistically significant at α=5%; standard error is in parentheses.
Source: authors' calculation.

Table 3 affirms that the negative impact of climate change on wetland paddy yield is an issue in both regions. Farmers experiencing climate change-related events are more likely to experience a higher decline in their yield than the reference groups either in Java or outside Java. However, the likelihood of experiencing a decrease in wetland paddy yield is slightly higher in Java than outside Java. Interestingly, in the case of dryland paddy yield, the results in Table 4 demonstrate a significant impact of climate change on yield reduction only in Java. It insists that despite the climate change has a bad effect on the wetland and dryland paddy yield in both regions, paddy cultivation by farmers in Java is more likely to be vulnerable to the adverse impact of climatic change.

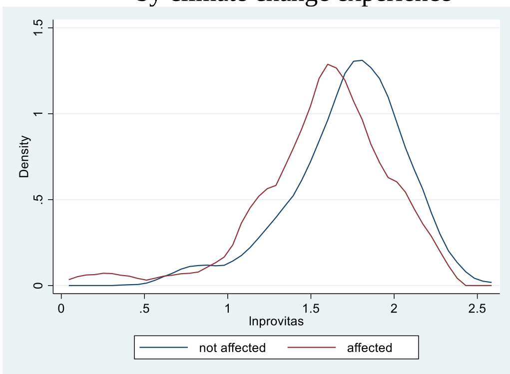
Climate change-related events nowadays are not only the result of natural events but rather the disruption consequence of human activities [25]. Hence, Java, as one of the islands with the largest population in Indonesia and being employed with massive economic development, is prone to the detrimental effect of climate change, which can then lead to a substantial drop in agricultural production. Likewise, the impact of the rise in the intensity of pest attacks and water shortage is more likely to affect a significant drop in yield in Java. Further investigation on the kernel density function in Figures 2 and 3 shows consistent results, demonstrating a lower yield of wetland and dryland paddy affected by climatic issues, pest attacks, and water insufficiency in both regions.

Figure 2. Kernel density for wetland and dryland paddy yield by the experience in climate change, pest attacks, and water insufficiency in Java

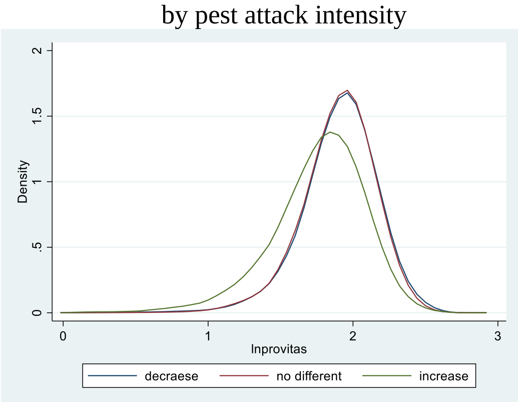
(i) Wetland paddy yield distribution by climate change experience



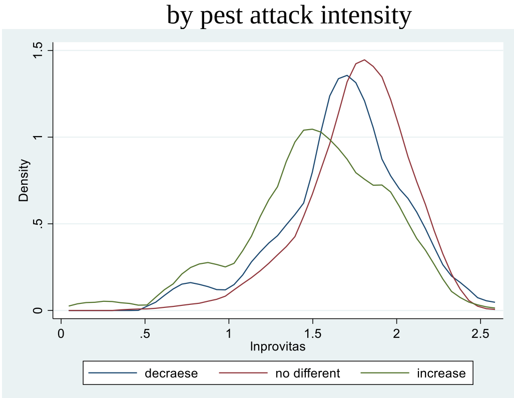
(ii) Dryland paddy yield distribution by climate change experience



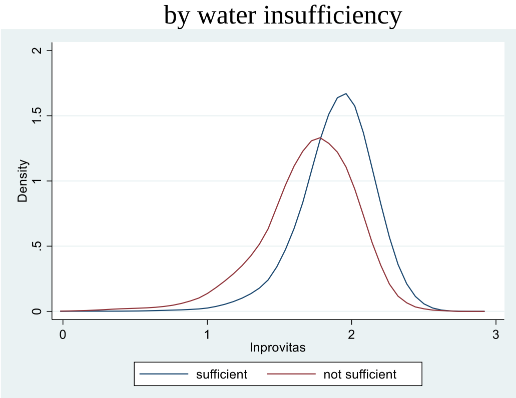
(iii) Wetland paddy yield distribution by pest attack intensity



(iv) Dryland paddy yield distribution by pest attack intensity



(v) Wetland paddy yield distribution by water insufficiency



(vi) Dryland paddy yield distribution by water insufficiency

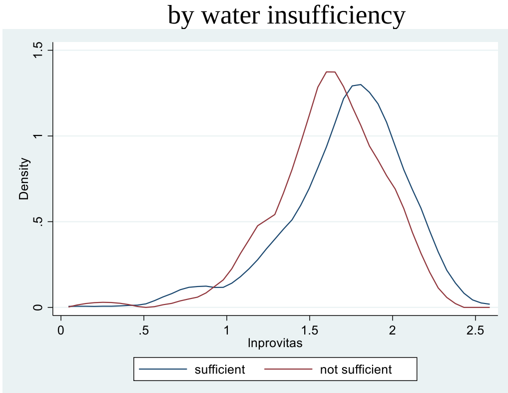
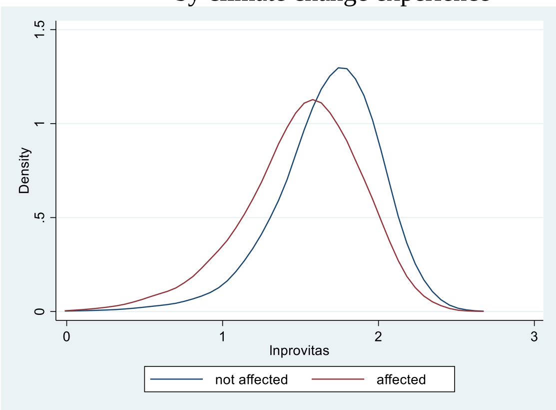
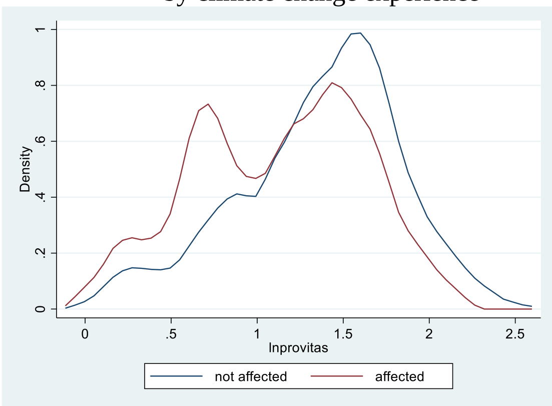


Figure 3. Kernel density for wetland and dryland paddy yield by the experience in climate change, pest attacks, and water insufficiency experience outside Java

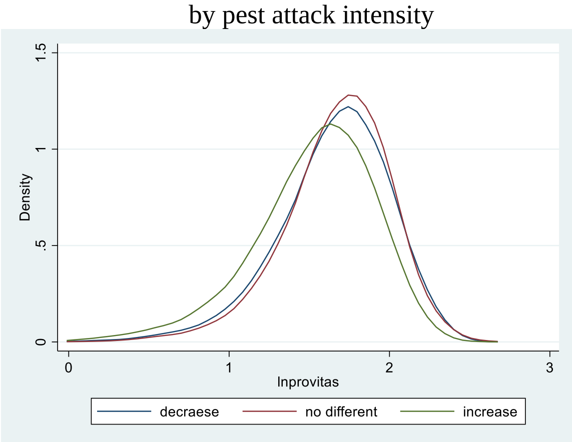
(i) Wetland paddy yield distribution by climate change experience



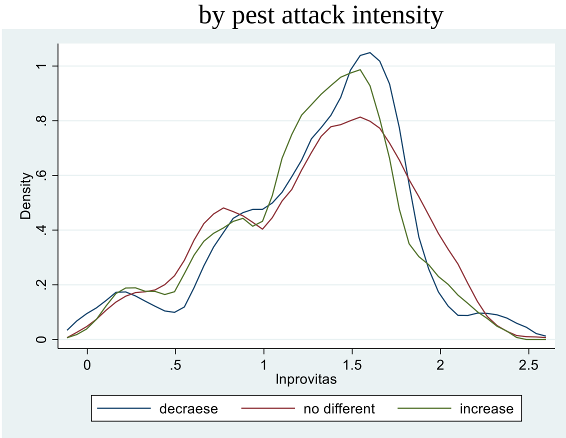
(ii) Dryland paddy yield distribution by climate change experience



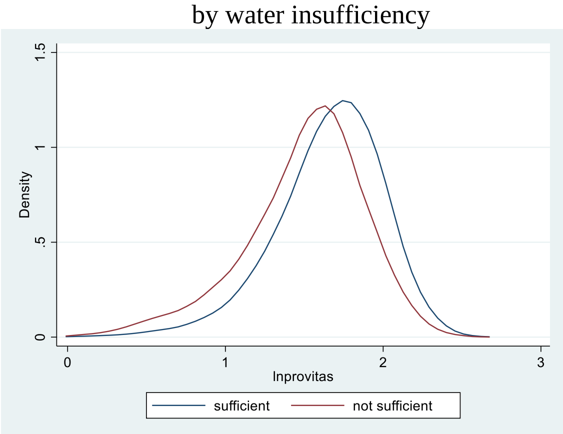
(iii) Wetland paddy yield distribution by pest attack intensity



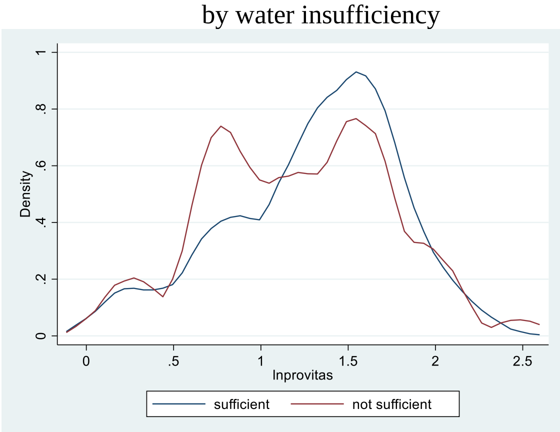
(iv) Dryland paddy yield distribution by pest attack intensity



(v) Wetland paddy yield distribution by water insufficiency



(vi) Dryland paddy yield distribution by water insufficiency



It is worth noting that the climate change experience information used in this study relies on the farmers' perceptions, which may not always coincide with the empirical climatology data [26]. However, our results demonstrate relatively consistent results with existing relevant studies. It suggests that farmers' perceptions could be useful information in examining the impact of climate change on wetland and dryland paddy yield. Based on the experience of farmers, our results pointed out the negative consequence of climate change, pest attacks, and water insufficiency on wetland and dryland paddy yield in Indonesia. Climate change might lead to an increase in temperature, which may also provoke invasive pest attacks and reduce the water supply. Hence, to deal with the negative impact of climatic shocks-related events on wetland and dryland paddy yield, our study insists on the importance of mitigation strategies for climate change, such as increasing the climate change mitigation-related knowledge and skill of farmers as well as providing and promoting the use of climate-resilient technological innovation and infrastructure, both for wetland and dryland paddy cultivation, along with better pest control and water management.

4. Conclusion

Climate change has led to an increase in extreme events such as droughts and floods, which potentially reduce crop yields. In Indonesia, paddy is one of the primary commodities prone to the threat of climate change impact. Our study aims to assess the impact of climate change on the reduction of wetland and dryland paddy yield in Indonesia. In doing so, we utilized a nationwide households survey, namely the 2021 crop-cutting survey. We tried to assess the impact of climate change through farmers' experience towards climate change-related events in cultivating their wetland and dryland paddy crops.

By applying a logistic regression model, we found that climate change significantly affects a decrease in wetland and dryland paddy yield. Paddy growers experiencing climate change-related events are more likely to have a higher probability of experiencing a decrease in their yield than those unaffected. In line with the regression result, the kernel density distribution function also pointed out that the wetland and dryland paddy yield distribution of farmers experiencing climate change-related events is slight to the left of the opposite groups. It means that they are significantly lower than those who are unaffected. Additionally, we also found that an incline in pest attack intensity and water shortage also negatively affect paddy yield, both for wetland and dryland paddy. Moreover, our finding suggests that the climate change impact on wetland paddy yield is a country's issue since it significantly reduces the wetland paddy yield in Java and outside Java with a more substantial impact on paddy yield in Java Island. Hence, our study suggests the importance of climate change mitigation strategies, better pest control, and water management in paddy cultivation throughout the country to maintain sustainable national paddy production.

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