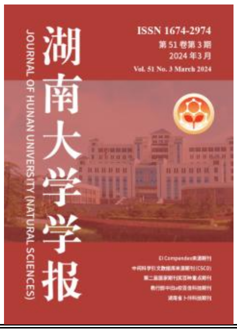

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Does Climate Change Affect Rice Yield? Evidence from the Mekong River Delta, Vietnam

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Abstract: This study investigates the effects of climate change on rice yield in Vietnam's Mekong River Delta. Using provincial-level data spanning 2010-2019, the research employs feasible generalized least squares to address heteroskedasticity. Findings reveal distinct impacts of climate change on rice yield between the winter-spring and summer-autumn crops. While sunshine hours and land area positively influence yield in both seasons, the highest water level affects only the summer-autumn crop. Conversely, average salinity negatively affects both crops, with a 1-g/liter increase reducing yields by 0.535 quintals/ha in winter-spring and 0.101 quintals/ha in summer-autumn. Although rising humidity diminishes winter-spring crop yield, it does not affect the summer-autumn crop. Moreover, scaling up leads to increased rice productivity in both seasons. These insights underscore the importance of climate-resilient agricultural strategies in the Mekong River Delta. The findings can help local governments and policymakers concretely quantify the impact of climate change on rice productivity. Therefore, appropriate policies can be developed to address climate change to improve rice productivity and increase farmers' incomes.

Keywords: climate change, rice yield, sustainability, Mekong River Delta.

气候变化会影响水稻产量吗？来自越南湄公河三角洲的证据

摘要：本研究调查了气候变化对越南湄公河三角洲水稻产量的影响。该研究利用2010-2019年的省级数据，采用可行的广义最小二乘法来解决异方差问题。研究结果揭示了气候变化对冬春作物和夏秋作物水稻产量的不同影响。虽然日照时数和土地面积对两个季节的产量都有积极影响，但最高水位仅影响夏秋作物。相反，平均盐度对这两种作物都有负面影响，冬春季每增加1克/升，产量就会减少0.535公担/公顷，夏秋季会减少0.101公担/公顷。虽然湿度上升会降低冬春季作物的产量，但不会影响夏秋季作物。此外，扩大规模可以提高两个季节的水稻产量。这些见解强调了湄公河三角洲气候适应型农业战略的重要性。研究结果可以帮助地方政府和政策制定者具体量化气候变化对水稻生产力的影响。因此，可以制定适当的政策来应对气候变化，以提高水稻生产力并增加农民收入。

关键词：气候变化、水稻产量、可持续性、湄公河三角洲。

1. Introduction

The intricate relationship between climate change and agriculture underscores a pressing concern for global sustainability. Climate variations, including shifts in temperature, precipitation patterns, and extreme weather events, pose significant threats to agricultural productivity and food security worldwide [1]. While certain regions may experience minor benefits from moderate temperature increases, others face profound challenges, particularly in low latitudes, where even slight alterations in climate can detrimentally impact productivity [2].

Vietnam stands as a poignant example of the complex interplay between climate change and agricultural sustainability, with rice cultivation serving as a cornerstone of its economy and food security. As the most vital food crop in the country, rice sustains over 97 million people and serves as the primary income source for rural households [3]. Vietnam's status as the third-largest exporter and fifth-largest producer of rice underscores the critical role this crop plays in its agricultural landscape [4].

The Mekong River Delta (MRD) is the epicenter of rice cultivation in Vietnam, producing the nation's most rice output. Covering a vast cultivated area of 7,279 thousand hectares, the MRD not only supports agriculture and aquaculture but also serves as a vital source of livelihood for its inhabitants [3]. However, this region's dependency on its hydrometeorological regime renders it highly susceptible to the adverse impacts of climate change and socioeconomic development [5].

Despite being a critical hub for agricultural production, the MRD is plagued by significant vulnerabilities, including flooding, sea-level rise, storm surges, and saltwater intrusion, worsened by its low-lying coastal terrain [6]. Changes in rice production patterns brought about by climate change further intensify these issues and pose a serious threat to regional sustainability and food security [7, 8].

This study explores the intricate dynamics between climate change and rice production in the MRD, employing modeling techniques and geographic information systems (GIS) to assess the impact of climate variables on rice yield. By delving into the nuanced relationship between climate change and agricultural productivity at a regional level, this research aims to provide valuable insights for policymakers and local authorities to develop targeted interventions and support mechanisms for farmers in the MRD. Through a comprehensive understanding of these challenges, stakeholders can work collaboratively to enhance the resilience and sustainability of rice production despite climate change-induced uncertainties.

2. Materials and Methods

2.1. Study Region

Situated in the southern region of Vietnam, the MRD encompasses a coastal lowland terrain characterized by its flat topography, with an average altitude ranging from 1.2 to 1.5 m above sea level. Covering a natural expanse of 40,816.40 km2, the MRD constitutes approximately 12.3% of the nation's total area. The delta's coastline stretches over 700 km, representing nearly 22% of Vietnam's coastal perimeter and encompassing seven of the thirteen coastal provinces [9]. Notably, the MRD is one of Vietnam's most significant regions impacted by global climate change, evident in its erratic weather patterns. During the dry season, the MRD experiences sweltering temperatures coupled with the infiltration of saltwater inland. Conversely, the rainy season brings prolonged floods, leading to the inundation of low-lying areas and adversely affecting both economic activities and the livelihoods of residents within the region [3].

2.2. Empirical Model Specification

To evaluate the influence of climate variables (including temperature, rainfall, sunshine hours, humidity, and water level) on rice yield, the feasible generalized least squares (FGLS) method was employed. This method was chosen because of its capability to address heteroskedasticity within panel data. Notably, FGLS regression exhibits greater efficiency than ordinary least squares, particularly in scenarios with heteroskedasticity and cross-sectional correlations [10]. Moreover, FGLS is adept at determining optimal weights to rectify heteroskedasticity [11, 12].

The modified Wald test was applied to both the fixed effect model (FEM) and random effect model (REM) in this study. The findings reveal heteroskedasticity in both models. The reduced form of the regression equation is expressed as follows:

The model of rice yield in the winter-spring season:

$$\text{Yield\_WS}_{it} = \alpha + \sum_{j=1}^{n} \beta_j X_{jit} + \varepsilon_{it} \qquad (1)$$

Rice yield model for the summer-autumn season:

$$\text{Yield\_SA}_{it} = \gamma + \sum_{j=1}^{n} \beta_j X_{jit} + \vartheta_{it} \qquad (2)$$

The dependent variables, $Yield\_WS_{it}$ and $Yield\_SA_{it}$, represent rice yield during the winter-spring and summer-autumn seasons, respectively. The explanatory variables, denoted by X, encompass temperature, rainfall, sunshine hours, humidity, highest water level, lowest water level, salinity, winter-spring rice area, and summer-autumn rice area. Here, j signifies the explanatory variable, n denotes the total number of explanatory variables, i signifies the province within the MRD (including Long An, Dong Thap, Tien Giang, Ben Tre, Vinh Long, Tra Vinh, Can Tho City, Hau Giang, Soc Trang, An Giang, Bac Lieu, Kien Giang, and Ca Mau), and t denotes the year (ranging from 2010 to 2019). The dataset is compiled from the statistical yearbooks of the 13 provinces within the MRD spanning 2010–2019. ε_{it} and ϑ_{it} are the errors of the regression models.

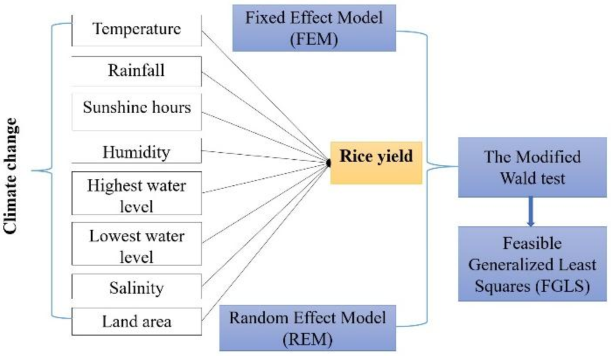

Fig. 1 The research methodology diagram (The authors)

3. Results and Discussion

3.1. Climate Change Trends in the MRD

In recent years, there has been a notable decline in the total annual rainfall across the MRD, as depicted in Fig. 2. For instance, in 2017, half of the provinces within this region experienced total rainfall exceeding 2000 mm. However, by 2019, there was a significant reduction, with total rainfall ranging from 1000 to 1600 mm. Particularly noteworthy is Bac Lieu province, which recorded the lowest rainfall at just over 700 mm. This decline in rainfall has had a profound impact on livelihood activities throughout the MRD.

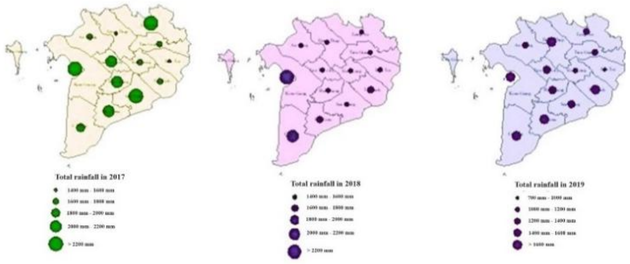

Fig. 2 Change in total rainfall in the MRD from 2017 to 2019 [13]

Fig. 3 depicts the prevalence of saline intrusion across most provinces of the MRD in 2020, with a notable concentration along the East Coast, encompassing Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau, Kien Giang, Vinh Long, Hau Giang, and Long An. Particularly elevated salinity levels ranging from 20 to 35 g/L are observed primarily in Ca Mau and parts of Kien Giang province. Moreover, the figure illustrates a trend of increasing extreme salinity amplitudes, reaching 4 g/L in 2016 and 2020, indicative of a deepening saline intrusion. The compounded effects of saltwater intrusion, drought, and the heightened intensity and frequency of other natural disasters during 2016-2020 have led to a scarcity of fresh water, profoundly impacting the livelihoods of communities in the MRD.

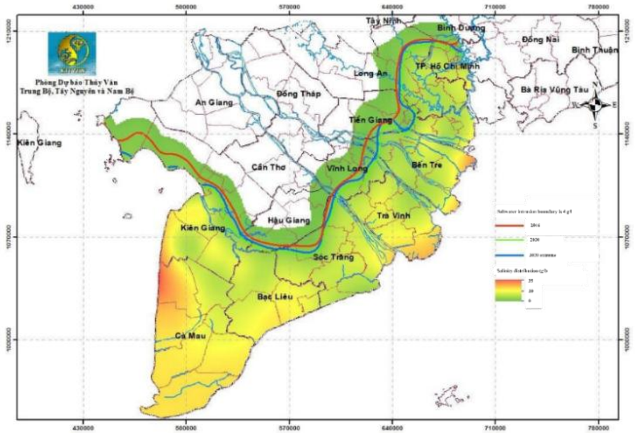

Fig. 3 Map of salinity distribution in the MRD [14]

The MRD region has suffered extensive damage from natural disasters, which has significantly affected the population and agricultural productivity. Specifically, the total estimated damage from natural calamities in Ca Mau and Bac Lieu provinces ranked highest and second highest, respectively, within the MRD, amounting to 44,823 billion VND and 18,699 billion VND, as outlined in Table 1. Due to its unique geographic location, which borders the sea on three sides, Ca Mau province suffers severe ramifications from saline intrusion and the effects of climate change coming from the East Sea, causing damage to approximately 20,167 hectares of rice fields and approximately 340 hectares of crops. Similarly, Bac Lieu province witnessed damage to approximately 1,245 hectares of rice fields and nearly 12,636 hectares of crops due to natural disasters. Ben Tre province also suffered considerable losses, estimated at approximately 5,868 billion VND, primarily attributed to saline intrusion and prolonged drought, which have had severe repercussions on agricultural production and household livelihoods.

Table 1 Damage caused by natural disasters in 2019 in the MRD [9]

Province	Dead and missing people	Injured people	Damaged house	Damaged rice area (Ha)	Damaged crop area (Ha)	Total damaged value (billion VND)
Long An	2	8	722	250	1.9	26.15
Tien Giang	-	5	483	-	-	69.40
Ben Tre	-	1	262	-	-	5,868
Tra Vinh	-	-	60	163	-	1.71
Vinh Long	-	3	237	445	151	37
Đong Thap	10	5	947	1413	21,4	39.8
An Giang	-	-	-	1580	99	91.07
Kien Giang	1	1	13,045	-	-	126.68
Can Tho	1	2	345	-	-	8.397

Province	Dead and missing people	Injured people	Damaged house	Damaged rice area (Ha)	Damaged crop area (Ha)	Total damaged value (billion VND)
Hau Giang	1		265	-	-	5.4
Soc Trang	1	5	487	15,485	2,20719	22.74
Bac Lieu	1	-	263	1,245	12,636	18,699
Ca Mau	29	4	4,118	20,167	340	44,823

3.2. Rice Production in the MRD

Fig. 4 illustrates a trend of contraction in the rice production scale, with a slight decrease observed in the area of rice cultivation from 2018 to 2022. Despite this decline, the MRD remains the foremost region for rice cultivation in the country, encompassing nearly 54% of the total rice cultivation area. Consequently, there has been a marginal decrease in rice production from 24,507 thousand tons to 23,536 thousand tons during the period spanning 2018 to 2022. Nevertheless, rice production in the MRD region still contributes to over 55% of the country's total output.

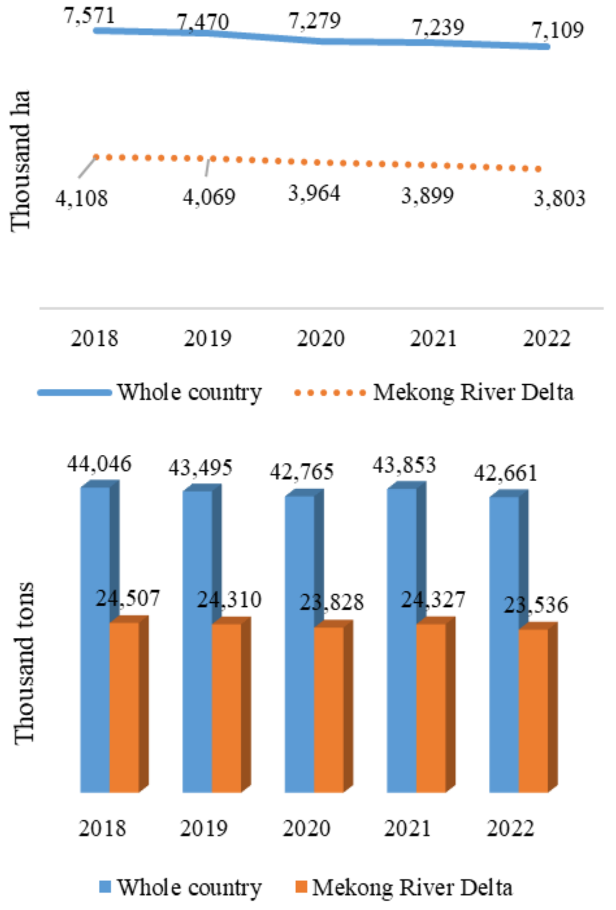

Fig. 4 Rice cultivation area and rice yield in Vietnam and the MRD [9]

Fig. 5 illustrates that the rice yield during the winter-spring crop averaged about 64.32 quintals per hectare, surpassing the yield during the summer-autumn crop, which averaged 52.41 quintals per hectare. Typically, summer-autumn rice crops face considerable challenges from monsoon rains or even storms during the rainy season, leading to potential decreases in crop yields and adverse impacts on vegetation greenness [15]. Furthermore, drought and saltwater intrusion exert significant pressure on rice yield. There is notable variation in rice yield during the summer-autumn season among provinces compared with the winter-spring season. Provinces like An Giang and Dong Thap consistently exhibit higher yields in both crops, while provinces like Ca Mau and Ben Tre experience lower yields, largely attributed to the severe impacts of drought and saltwater intrusion.

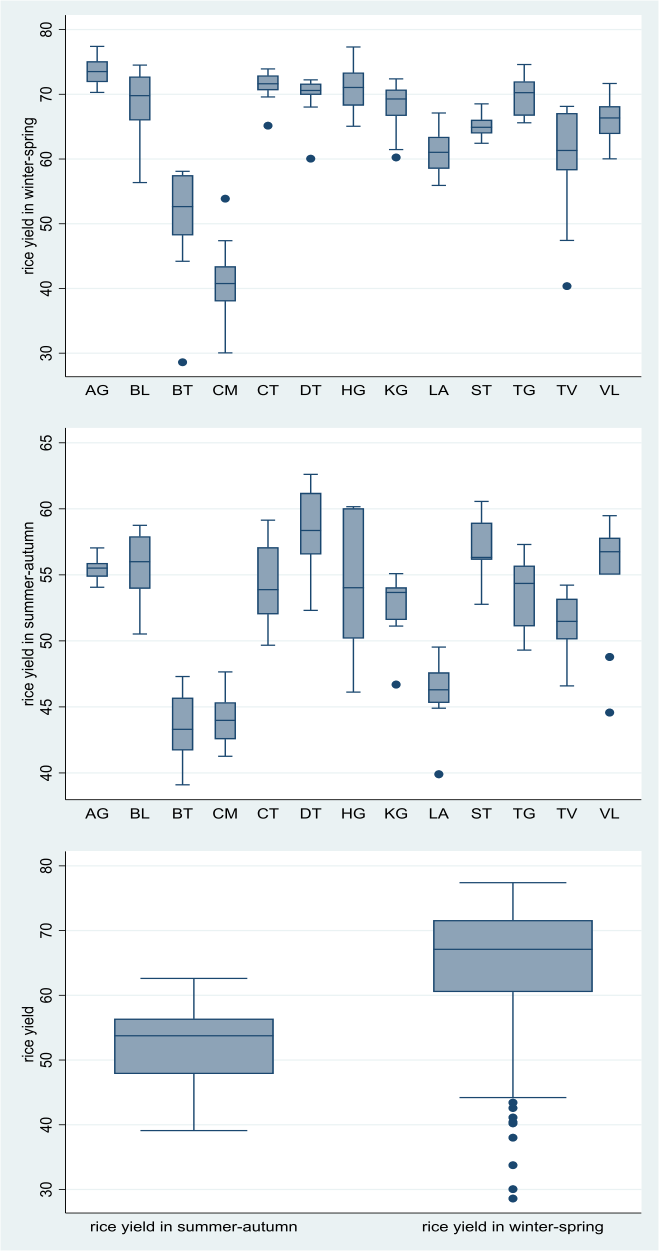

Fig. 5 Rice yield of the winter-spring and summer-autumn crops in provinces of the MRD region [3]

Notes: AG - An Giang province; BL - Bac Lieu province; BT - Ben Tre province; CM - Ca Mau province; CT - Can Tho city; DT - Dong Thap province; HG - Hau Giang province; KG - Kien Giang province; LA - Long An province; ST - Soc Trang province; TG - Tien Giang province; TV - Tra Vinh province; VL - Vinh Long province

3.3. Impact of Climate Change on Rice Yield in the MRD

Climatic data on the 13 provinces within the MRD, covering 2010-2019, were utilized to develop models for the winter-spring and summer-autumn crops. Consequently, variables such as annual average temperature, total annual rainfall, total of sunshine hours per year, average annual humidity, highest river water level, lowest river water level, and mean salinity exhibited consistent statistical values for both seasons (Table 2). Despite the summer-autumn crop having a larger cultivated land area than the winter-spring crop, the rice yield was notably lower, primarily attributed to the impacts of climate change. Specifically, the average rice yield variable stood at 52.4 quintals per hectare, with variations ranging from 39.1 to 62.6 quintals per hectare.

Table 2 Descriptive statistics of the variables (The authors)

Variable	**Unit**	**Max**	**Min**	**Mean**	**SD**
Rice yield in winter-spring	Quintals/ha	77.4	28.6	64.3	10.18
Rice yield in summer-autumn	Quintals/ha	62.6	39.1	52.4	5.50
Temperature	^{0}C	28.4	26.8	27.5	0.30
Ln(rainfall)	mm	8.3	6.6	7.4	0.26
Ln(hours_sunshine)	Hours	8.2	7.6	7.8	0.10
Humidity	%	89.0	77.4	82.2	1.82
Highest water level	cm	500.0	70.0	185.0	76.09
Lowest water level	cm	45.5	-222.0	-110.5	66.12
Salinity	g/L	35.0	0.0	10.4	8.97
Ln(land area_WS)	Ha	12.6	5.7	11.4	1.03
Ln(land area_SA)	Ha	12.6	9.5	11.5	0.79

Hausman's test yields a probability greater than the significance level (Prob > chi2 = 0.2110 > α), indicating insufficient statistical evidence to reject the null hypothesis (H0). In simpler terms, while separate effects are present, they are not correlated with the independent variable, suggesting that the REM is more suitable than the FEM (Table 3).

Table 3 Impact of climate change on rice yield of the winter-spring crop (The authors)

Variable	**OLS**	**FEM**	**REM**	**FGLS**	**VIF**
Temperature	0.298 (0.13)	-0.367 (-0.19)	-0.396 (-0.21)	-0.312 (-0.19)	1.66
Ln(rainfall)	1.474 (0.58)	-2.987 (-1.51)	-1.978 (-1.00)	1.295 (0.74)	1.62
Ln(hours_sunshine)	34.247*** (5.16)	11.155* (1.94)	14.267** (2.51)	22.264*** (3.51)	1.50
Humidity	-1.042*** (-3.01)	-0.196 (-0.62)	-0.418 (-1.35)	-1.000*** (-3.96)	1.41
Highest water level	0.009 (1.07)	0.020 (1.28)	0.011 (1.05)	-0.002 (-0.26)	1.37
Lowest water level	-0.028*** (-2.73)	-0.020 (-0.96)	-0.025* (-1.86)	-0.031*** (-3.92)	1.58
Salinity	-0.388*** (-4.44)	-0.422*** (-3.08)	-0.396*** (-3.64)	-0.535*** (-7.05)	2.05
Ln(land area_WS)	4.074*** (5.68)	4.812*** (5.76)	4.787*** (6.34)	4.002*** (6.06)	1.94
_cons	-183.649 (-1.90)	-30.658 (-0.38)	-42.402 (-0.55)	-71.147 (-0.94)	
Prob > F	0.0000	0.0000	0.0000		
R-squared	0.6677	0.5861	0.6207		
F-test	0.0000				
Hausman's test		0.2110			
Modified Wald			0.0000		
Wooldridge			0.3396		

* p < 0.1; ** p < 0.05; *** p < 0.01

However, the modified Wald test is statistically significant (Prob > chi2 = 0.0000 < 5%), providing ample statistical evidence to reject the null hypothesis (H0). There is a problem with the estimates that were made using the REM regression method on panel data because of this significance. This means that regression coefficient tests cannot be trusted regarding statistical significance. Consequently, the model results may lack reliability. To address this issue, the FGLS regression method is employed [12].

The analysis revealed five significant factors influencing rice yield in the winter-spring season within the MRD. These factors include sunshine hours, humidity, the lowest water level, salinity, and the land area dedicated to winter-spring cultivation, all of which have a statistical significance of 1%. However, variables such as temperature, rainfall, and the highest water level had no discernible impact on winter-spring rice yield (Table 3).

Sunshine hours exhibit a positive correlation with winter-spring crop yield. A 1% increase in total sunshine hours per year results in an approximate increase of 0.223 quintals per hectare in rice yield. This finding aligns with the pivotal role of sunshine hours in enhancing photosynthesis and rice plant growth, particularly during the flowering stage, which promotes pollination and improves seed firmness. Consequently, higher sunshine hours contribute to increased rice yield, a phenomenon observed in previous studies [16, 17].

Humidity, which represents atmospheric water vapor, negatively affects winter-spring crop yield. A 1% increase in average humidity decreases rice yield by 1.0 quintals per hectare. Elevated humidity levels during rice cultivation hinder flower blooming and seed development, diverting plant energy toward stem and leaf growth and making rice plants susceptible to pests. These findings corroborate previous research highlighting the adverse impact of high humidity on rice yield [18–20].

The lowest river water level, indicative of low flood years and drought, significantly diminishes winter-spring rice yield. For every 1 cm increase in the lowest river water level, there is a decrease of 0.031 quintals per hectare in rice yield. Insufficient river water levels result in inadequate irrigation water, worsening soil acidification and salinity due to drought conditions and increased exposure to the sun. Drought-induced stress negatively affects rice plants at various levels, impairing flowering, dry matter accumulation, and photosynthetic capacity, thus leading to substantial yield losses [17, 21].

Increased average salinity is inversely associated with winter-spring rice yield. A rise of 1 g/L in average salinity translates to a decrease of 0.535 quintals/hectare in rice yield. Prolonged hot weather and reduced rainfall intensify drought conditions, leading to saline intrusion, which hampers irrigation water quality and increases soil salinity levels. Soil salinity adversely affects rice productivity by impeding root shoot dry weight, yield, fecundity percentage, chlorophyll concentration, and other key growth parameters [22–27].

The variable representing rice cultivation area exhibits a positive influence on winter-spring rice yield. A 1% increase in winter-spring crop area corresponds to a rise of 0.040 quintals per hectare in rice yield. Expanding cultivable land enables farmers to increase production, thereby enhancing productivity. On the other hand, conditions like saline intrusion, which are a result of extended drought and heat, reduce the amount of arable land and reduce rice yield. Large-scale rice farming has been demonstrated to improve ecological and energy efficiency, contributing to enhanced productivity [28–30].

Table 4 reveals significant factors influencing rice yield in the winter-spring season within the MRD. Sunshine hours, the highest water level, and the land area dedicated to the summer-autumn crop exhibit a positive impact on winter-spring rice yield at a significance level of 1%. Conversely, salinity exerts a negative influence on rice yield.

Table 4 Impact of climate change on rice yield of the summer-autumn crop (The authors)

Variable	**OLS**	**FEM**	**REM**	**FGLS**	**VIF**
Temperature	0.898 (0.58)	1.120 (0.83)	1.147 (0.91)	0.319 (0.37)	1.66
Ln(rainfall)	2.373 (1.32)	-0.291 (-0.21)	-0.062 (-0.05)	-0.247 (-0.29)	1.62
Ln(hours_sunshine)	18.204^{***} (3.89)	3,144 (0.78)	4.267 (1.10)	7.337^{***} (2.64)	1.50
Humidity	-0.573^{**} (-2.40)	-0.339 (-1.55)	-0.366^{*} (-1.74)	-0.225 (-1.55)	1.41
Highest water level	0.023^{***} (4.12)	0.018 (1.64)	0.018^{**} (2.16)	0.014^{***} (3.39)	1.37
Lowest water level	-0.013^{*} (-1.82)	-0.020 (-1.25)	-0.015 (-1.43)	-0.008 (-1.42)	1.58
Salinity	-0.108^{*} (-1.85)	-0.228^{**} (-2.41)	-0.202^{**} (-2.49)	-0.101^{**} (-2.13)	2.05
Ln(land area_SA)	1.488^{**} (2.32)	0.849 (0.35)	1.742 (1.37)	2.111^{***} (3.08)	1.94
_cons	-106.673 (-1.61)	14.222 (0.23)	-4.982 (-0.09)	-20.249 (-0.55)	
Prob > F	0.0000	0.0092	0.0001		
R-squared	0.4664	0.3570	0.4085		
F-test	0.0000				
Hausman test		0.9579			
Modified Wald			0.0049		
Wooldridge			0.0000		

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

During the summer-autumn crop, a 1% increase in sunshine hours corresponds to a growth of 0.073 quintals per hectare in rice yield. This increase is comparable to the effect observed during the winter-spring crop, where the yield increases by 0.223 quintals per hectare. Increased sunshine hours from mid-May to early June create favorable conditions for pollination and fertilization, enhancing seed firmness and ultimately boosting rice yield [25].

In the dry season, elevated temperatures lead to drought, resulting in reduced river water levels. Addressing this issue, higher river water levels aid in providing irrigation water and mitigating soil salinity, thereby enhancing rice crop yield. For every 1 cm increase in the highest river water level, the yield of the summer-autumn crop increases by 0.014 quintals per hectare. Drought's adverse effects on rice are most pronounced during reproductive stages, threatening yield sustainability [31, 32].

Average annual salinity negatively affects rice yield. A 1-g/L increase in average salinity decreases summer-autumn rice yield by 0.101 quintals per hectare. Elevated temperatures and minimal rainfall from late March to early May intensify drought and saltwater intrusion, significantly affecting rice yield in both seasons [26, 27, 33].

Expansion of land area positively influences rice yield. A 1% increase in rice area results in a rise of 0.021 quintals per hectare in summer-autumn crop yield. The impact of land area expansion is more pronounced in the winter-spring crop, suggesting that increasing arable land in the winter-spring crop contributes more significantly to rice yield enhancement. The summer-autumn crop is generally more vulnerable to the effects of climate change, resulting in lower yields than those of the winter-spring crop [34, 35].

4. Conclusion

Research results show that climate change has a negative impact on rice productivity in the MRD. Average salinity has a negative impact on both the winter-spring and summer-autumn rice crops. It is worth noting that the increase in salinity has a greater impact on the winter-spring rice yield than the summer-autumn crop. In fact, an increase of 1 g/L reduces productivity by 0.535 quintals/ha in the winter-spring crop and by 0.101 quintals/ha in the summer-autumn crop. Moreover, for the winter-spring crops, variables such as humidity, lowest water level, and salinity exert negative impacts, whereas sunshine hours and land area contribute positively to rice yield. Conversely, in summer-autumn crops, an increase in water level emerges as a potential solution to provide irrigation water and mitigate soil salinity, thereby enhancing rice yield. In addition, expanding land area also increases rice productivity in both crops, so local authorities need to have appropriate agricultural strategies to improve rice productivity and increase income for farmers in MRD. Hence, to cope with climate change, farmers should use new crops (such as salt-tolerant rice varieties and drought-resistant rice varieties) and change crop varieties and seasons. Moreover, for the winter-spring crop, local authorities should strengthen the system of dykes and dams to prevent floods and limit damage to rice productivity.

Moving forward, to ensure sustainable development in rice production within the MRD, several recommendations can be proposed:

1. Climate-resilient farming practices: Encourage the adoption of climate-resilient agricultural practices such as crop diversification, water management strategies, and the use of salt-tolerant rice varieties to mitigate the adverse effects of climate change on rice yield.

2. Investment in irrigation infrastructure: Prioritize investment in irrigation infrastructure and water management systems to ensure adequate water supply during dry periods and mitigate the impacts of saltwater intrusion on agricultural land.

3. Research and development (R&D): Support R&D initiatives aimed at developing drought- and salt-tolerant rice varieties tailored to the unique environmental conditions of the MRD, thereby enhancing resilience to climate change.

4. Capacity building and education: Provide training and capacity-building programs for farmers on climate-smart agricultural practices, sustainable water management, and soil conservation techniques to improve productivity while minimizing environmental degradation.

5. Policy support: Implement policies that incentivize sustainable agricultural practices, promote ecosystem-based adaptation strategies, and provide financial support for farmers to adopt climate-resilient technologies.

Implementing these recommendations and fostering collaboration among stakeholders, policymakers, researchers, and local communities are crucial. Together, we can build a more resilient and sustainable agricultural sector in the MRD. This sector will withstand the challenges posed by climate change while ensuring food security and livelihoods for future generations.

References

[1] REYNOLDS M. P. (ed.) *Climate change and crop production*. CABI, Wallingford, 2010. https://books.google.ru/books?hl=ru&lr=&id=wjLdXPCyqSMC&oi=fnd&pg=PR5&dq=Climate+change+and+crop+production&ots=6NAwjebuo2&sig=DTEXxTFHkLOv6e1DCXpQKB9db0o&redir_esc=y#v=onepage&q=Climate%20change%20and%20crop%20production&f=false

[2] JIANG Z., RAGHAVAN S. V., and HUR J. Future changes in rice yields over the Mekong River Delta due to climate change—Alarming or alerting? *Theoretical and Applied Climatology*, 2019, 137(1-2): 545-555. https://doi.org/10.1007/s00704-018-2617-z

[3] GENERAL STATISTICS OFFICE. *Statistical yearbook of 2020*. Statistical Publishing House, Hanoi, 2021. https://www.gso.gov.vn/en/data-and-statistics/2021/07/statistical-yearbook-of-2020/

[4] CLAUSS K., OTTINGER M., and LEINENKUGEL P. Estimating rice production in the Mekong Delta, Vietnam, utilizing time series of Sentinel-1 SAR data. *International Journal of Applied Earth Observation and Geoinformation*, 2018, 73: 574-585. https://doi.org/10.1016/j.jag.2018.07.022

[5] TUAN L. A., & CHINVANNO S. Climate Change in the Mekong River Delta and Key Concerns on Future Climate Threats. In: STEWART M., & COCLANIS P. (eds.) *Environmental Change and Agricultural Sustainability in the Mekong Delta. Advances in Global Change Research*, Vol. 45. Springer, Dordrecht, 2011: 207-217. https://doi.org/10.1007/978-94-007-0934-8_12

[6] CHAUDHRY P, RUYSSCHAERT G. *Climate change and human development in Viet Nam: A case study*, 2008. https://oxfamilibrary.openrepository.com/bitstream/handle/10546/111979/climate-change-human-development-vietnam-010108-en.pdf?sequence=1

[7] WASSMANN R., JAGADISH S. V. K., and SUMFLETH K. Chapter 3 Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for Adaptation. *Advances in Agronomy*, 2009, 102: 91-133. https://doi.org/10.1016/S0065-2113(09)01003-7

[8] WASSMANN R., HIEN N. X., and HOANH C. T. Sea Level Rise Affecting the Vietnamese Mekong Delta: Water Elevation in the Flood Season and Implications for Rice Production. *Climatic Change*, 2004, 66(1/2): 89-107. https://doi.org/10.1023/B:CLIM.0000043144.69736.b7

[9] GENERAL STATISTICS OFFICE OF VIETNAM.

Statistical yearbook of Vietnam 2022. Statistical Publishing House, Hanoi, 2023. https://www.gso.gov.vn/wp-content/uploads/2023/06/Sach-Nien-giam-TK-2022-final.pdf

[10] BAI J., CHOI S. H., and LIAO Y. *Feasible Generalized Least Squares for Panel Data with Cross-Sectional and Serial Correlations*, 2019. https://doi.org/10.48550/arXiv.1910.09004

[11] STRUTZ T. *Data fitting and uncertainty: A practical introduction to weighted least squares and beyond*. Springer, 2011.

[12] LEE C. Y., HUANG T. S., and LIU M. K. Data Science for Vibration Heteroscedasticity and Predictive Maintenance of Rotary Bearings. *Energies*, 2019, 12(5): 801. https://doi.org/10.3390/en12050801

[13] NATIONAL HYDROMETEOROLOGICAL FORECASTING CENTER. *The change of total rainfall in Mekong River Delta from 2017-2019*. Hanoi, 2020.

[14] NATIONAL HYDROMETEOROLOGICAL FORECASTING CENTER. *Map of salinity distribution in the Mekong River Delta*. Hanoi, 2020.

[15] SON N. T., CHEN C. F., and CHEN C. R. Prediction of rice crop yield using MODIS EVI−LAI data in the Mekong Delta, Vietnam. *International Journal of Remote Sensing*, 2013, 34(20): 7275-7292. https://doi.org/10.1080/01431161.2013.818258

[16] CHEN H., WU W., and LIU H. B. Assessing the relative importance of climate variables to rice yield variation using support vector machines. *Theoretical and Applied Climatology*, 2016, 126(1-2): 105-111. https://doi.org/10.1007/s00704-015-1559-y

[17] SANDHU N., & KUMAR A. Bridging the Rice Yield Gaps under Drought: QTLs, Genes, and Their Use in Breeding Programs. *Agronomy*, 2017, 7(2): 27. https://doi.org/10.3390/agronomy7020027

[18] AYINDE O., OJEHOMON V., and DARAMOLA F. Evaluation of the Effects of Climate Change on Rice Production in Niger State, Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 2013, 6(6): 763-773. https://doi.org/10.4314/ejesm.v6i6.7S

[19] PANDEY K. K., RAI V. N., and SISODIA B. V. S. Effect of weather variables on rice crop in Eastern Uttar Pradesh, India. *Plant Archives*, 2015, 15(1): 575-579. https://plantarchives.org/PDF%2015%20-%201/575-579%20(2948).pdf

[20] MATSUI T., NAMUCO O. S., and ZISKA L. H. Effects of high temperature and CO_2 concentration on spikelet sterility in indica rice. *Field Crops Research*, 1997, 51(3): 213-219. https://doi.org/10.1016/S0378-4290(96)03451-X

[21] FAROOQ M., WAHID A., and LEE D. J. Advances in Drought Resistance of Rice. *Critical Reviews in Plant Sciences*, 2009, 28(4): 199-217. https://doi.org/10.1080/07352680902952173

[22] HAKIM M. A., JURAIMI A. S., and HANAFI M. M. The effect of salinity on growth, ion accumulation and yield of rice varieties. *Journal of Animal and Plant Sciences*, 2014, 24(3): 874-885. https://thejaps.org.pk/docs/v-24-3/30.pdf

[23] ALI Y., ASLAM Z., and ASHRAF M. Y. Effect of salinity on chlorophyll concentration, leaf area, yield and yield components of rice genotypes grown under saline environment. *International Journal of Environmental Science & Technology*, 2004, 1(3): 221-225. https://doi.org/10.1007/BF03325836

[24] SELAMAT A., & ISMAIL M. R. Deterministic model approaches in identifying and quantifying technological challenges in rice production and research and in predicting population, rice production and consumption in Malaysia. *Pertanika Journal of Tropical Agricultural Science*, 2009, 32(2): 267-291. http://www.pertanika.upm.edu.my/pjtas/browse/regular-issue?article=JTAS-0178-2009

[25] THUY N. N., & ANH H. H. Vulnerability of rice production in Mekong River Delta under impacts from floods, salinity and climate change. *International Journal on Advanced Science, Engineering and Information Technology*, 2015, 5(4): 272-279. https://dx.doi.org/10.18517/ijaseit.5.4.545

[26] TRI N. H., CHOOWAEW S., VAN NI D., and KANSANTISUKMONGKOL K. Impact of saline intrusion and adaptation options on rice- and fish-farming households in the Mekong Delta of Vietnam. *Kasetsart Journal of Social Sciences*, 2019, 40(2): 427-433. https://doi.org/10.34044/j.kjss.2019.40.2.10

[27] SAH S. S., MAULUD K. N. A., and SHARIL S. Impact of saltwater intrusion on paddy growth in Kuala Kedah, Malaysia. *Journal of Sustainability Science and Management*, 2021, 16(6): 15-30. https://doi.org/10.46754/jssm.2021.08.004

[28] MASUDA K. Eco-Efficiency Assessment of Intensive Rice Production in Japan: Joint Application of Life Cycle Assessment and Data Envelopment Analysis. *Sustainability*, 2019, 11(19): 5368. https://doi.org/10.3390/su11195368

[29] ARUNRAT N., PUMIJUMNONG N., and SEREENONCHAI S. Assessment of climate change impact on rice yield and water footprint of large-scale and individual farming in Thailand. *Science of the Total Environment*, 2020, 726: 137864. https://doi.org/10.1016/j.scitotenv.2020.137864

[30] MASUDA K. Energy Efficiency of Intensive Rice Production in Japan: An Application of Data Envelopment Analysis. *Sustainability*, 2018, 10(2): 120. https://doi.org/10.3390/su10010120

[31] JEONG J. S., KIM Y. S., and BAEK K. H. Root-Specific Expression of *OsNAC10* Improves Drought Tolerance and Grain Yield in Rice under Field Drought Conditions. *Plant Physiology*, 2010, 153(1): 185-197. https://doi.org/10.1104/pp.110.154773

[32] ZHANG J., ZHANG S., and CHENG M. Effect of Drought on Agronomic Traits of Rice and Wheat: A Meta-Analysis. *International Journal of Environmental Research and Public Health*, 2018, 15(5): 839. https://doi.org/10.3390/ijerph15050839

[33] TRAN D. D., QUANG C. N. X., and TIEN P. D. Livelihood Vulnerability and Adaptation Capacity of Rice Farmers under Climate Change and Environmental Pressure on the Vietnam Mekong Delta Floodplains. *Water*, 2020, 12(11): 3282. https://doi.org/10.3390/w12113282

[34] KOIRALA K. H., MISHRA A., and MOHANTY S. Impact of land ownership on productivity and efficiency of rice farmers: The case of the Philippines. *Land Use Policy*, 2016, 50: 371-378. https://doi.org/10.1016/j.landusepol.2015.10.001

[35] UNGGUL HERIQBALDI D., PURWONO R., and HARYANTO T. An analysis of technical efficiency of rice production in Indonesia. *Asian Social Science*, 2015, 11(3): 91-102. https://doi.org/10.5539/ass.v11n3p91

参考文:

[1] REYNOLDS M. P.（编辑）气候变化和作物生产。CABI，沃林福德，2010。https://books.google.ru/books?hl=ru&lr=&id=wjLdXPCyqSMC&oi=fnd&pg=PR5&dq=Climate+change+and+crop+product&ots=6NAwjebuo2&sig=DTEXxTFHkLOv6e1DCXpQKB9db0o&redir_esc=y#v=onepage&q=气候%20change%20和%20crop%20产量&f=false

[2] JIANG Z.、RAGHAVAN S.V. 和 HUR J. 气候变化导致湄公河三角洲稻米产量的未来变化——令人震惊还是警报？理论与应用气候学，2019，137(1-2): 545-555. https://doi.org/10.1007/s00704-018-2617-z

[3]统计总局。2020年统计年鉴。统计出版社，河内，2021年。https://www.gso.gov.vn/en/data-and-statistics/2021/07/statistical-yearbook-of-2020/

[4] CLAUSS K.、OTTINGER M. 和 LEINENKUGEL P. 利用哨兵-1 SAR数据的时间序列估算越南湄公河三角洲的稻米产量。国际应用地球观测与地理信息杂志，2018，73：574-585。https://doi.org/10.1016/j.jag.2018.07.022

[5] TUAN L. A., & CHINVANNO S. 湄公河三角洲的气候变化和对未来气候威胁的主要关注。见：STEWART M. 和 COCLANIS P.（编辑）湄公河三角洲的环境变化和农业可持续性。全球变化研究进展，卷。45.施普林格，多德雷赫特，2011：207-217。https://doi.org/10.1007/978-94-007-0934-8_12

[6] CHAUDHRY P, RUYSSCHAERT G. 越南气候变化与人类发展：案例研究，2008年。https://oxfamilibrary.openrepository.com/bitstream/handle/10546/111979/climate-change-human-development-vietnam-010108-en.pdf?sequence=1

[7] WASSMANN R.、JAGADISH S.V.K. 和 SUMFLETH K. 第3章气候变化对亚洲水稻生产影响的区域脆弱性和适应范围。农学进展，2009，102：91-133。https://doi.org/10.1016/S0065-2113(09)01003-7

[8] WASSMANN R.、HIEN N. X. 和 HOANH C. T. 海平面上升影响越南湄公河三角洲：洪水季节水位上升及其对水稻生产的影响。气候变化，2004，66(1/2)：89-107。https://doi.org/10.1023/B:CLIM.0000043144.69736.b7

[9]越南统计总局。2022年越南统计年鉴。统计出版社，河内，2023年。https://www.gso.gov.vn/wp-content/uploads/2023/06/Sach-Nien-giam-TK-2022-final.pdf

[10] BAI J.、CHOI S. H. 和 LIAO Y. 具有横截面和序列相关性的面板数据的可行广义最小二乘法，2019。https://doi.org/10.48550/arXiv.1910.09004

[11] STRUTZ T. 数据拟合和不确定性：加权最小二乘法及其他方法的实用介绍。施普林格，2011。

[12] LEE C. Y., HUANG T. S., 和 LIU M.K. 旋转轴承振动异方差和预测维护的数据科学。能源，2019，12(5)：801。https://doi.org/10.3390/en12050801

[13] 国家水文气象预报中心。2017-2019年湄公河三角洲总降雨量变化 河内，2020年。

[14]国家水文气象预报中心。湄公河三角洲盐度分布图。河内，2020年。

[15] SON N. T.，CHEN C. F.，和 CHEN C. R. 利用越南湄公河三角洲莫迪斯埃维–莱伊数据预测水稻作物产量。国际遥感杂志, 2013, 34(20): 7275-7292. https://doi.org/10.1080/01431161.2013.818258

[16] CHEN H.，WU W.，和 LIU H.B. 利用支持向量机评估气候变量对水稻产量变化的相对重要性。理论与应用气候学, 2016, 126(1-2): 105-111. https://doi.org/10.1007/s00704-015-1559-y

[17] SANDHU N., & KUMAR A. 弥合干旱条件下的水稻产量差距：QTL、基因及其在育种计划中的应用。农学，2017，7(2)：27。https://doi.org/10.3390/agronomy7020027

[18] AYINDE O.、OJEHOMON V. 和 DARAMOLA F. 气候变化对尼日利亚尼日尔州水稻生产影响的评估。埃塞俄比亚环境研究与管理杂志，2013，6(6)：763-773。https://doi.org/10.4314/ejesm.v6i6.7S

[19] PANDEY K. K.、RAI V. N. 和 SISODIA B. V. S. 天气变量对印度北方邦东部水稻作物的影响。植物档案馆, 2015, 15(1): 575-579。https://plantarchives.org/PDF%2015%20-%201/575-579%20(2948).pdf

[20] MATSUI T.，NAMUCO O.S.，和 ZISKA L.H. 高温和二氧化碳浓度对籼稻小穗不育的影响。大田作物研究，1997，51(3)：213-219。https://doi.org/10.1016/S0378-4290(96)03451-X

[21] FAROOQ M.、WAHID A. 和 LEE D. J. 水稻抗旱性进展。植物科学评论，2009，28（4）：199-217。https://doi.org/10.1080/07352680902952173

[22] HAKIM M.A.、JURAIMI A.S. 和 HANAFI M.M. 盐度对水稻品种生长、离子积累和产量的影响。动植物科学学报, 2014, 24(3): 874-885. https://thejaps.org.pk/docs/v-24-3/30.pdf

[23] ALI Y.，ASLAM Z.，和 ASHRAF M. Y. 盐度对盐环境下水稻基因型的叶绿素浓度、叶面积、产

量和产量构成的影响。国际环境科学与技术杂志，2004，1(3)：221-225。https://doi.org/10.1007/BF03325836

[24] SELAMAT A., & ISMAIL M. R. 确定性模型方法，用于识别和量化稻米生产和研究中的技术挑战，以及预测马来西亚的人口、稻米生产和消费。佩塔尼卡热带农业科学杂志，2009，32(2)：267-291。http://www.pertanika.upm.edu.my/pjtas/browse/regular-issue?article=JTAS-0178-2009

[25] THUY N. N., & ANH H. H. 湄公河三角洲水稻生产在洪水、盐度和气候变化影响下的脆弱性。国际先进科学、工程与信息技术杂志，2015，5(4)：272-279。https://dx.doi.org/10.18517/ijaseit.5.4.545

[26] TRI N. H.、CHOOWAEW S.、VAN NI D. 和 KANSANTISUKMONGKOL K. 盐分入侵和适应方案对越南湄公河三角洲稻米和养鱼家庭的影响。农业社会科学学报, 2019, 40(2): 427-433。https://doi.org/10.34044/j.kjss.2019.40.2.10

[27] SAH S. S.、MAULUD K. N. A. 和 SHARIL S. 咸水入侵对马来西亚瓜拉吉打稻田生长的影响。可持续科学与管理学报, 2021, 16(6): 15-30. https://doi.org/10.46754/jssm.2021.08.004

[28] MASUDA K. 日本集约化水稻生产的生态效率评估：生命周期评估和数据包络分析的联合应用。可持续发展，2019，11(19)：5368。https://doi.org/10.3390/su11195368

[29] ARUNRAT N.、PUMIJUMNONG N. 和 SEREENONCHAI S. 气候变化对泰国大规模和个体农业的水稻产量和水足迹影响的评估。总体环境科学，2020年，726：137864。https://doi.org/10.1016/j.scitotenv.2020.137864

[30] MASUDA K. 日本集约化水稻生产的能源效率：数据包络分析的应用。可持续发展，2018，10(2)：120。https://doi.org/10.3390/su10010120

[31] JEONG J. S.，KIM Y. S.，和 BAEK K. H. 奥斯纳克10的根特异性表达提高了水稻在田间干旱条件下的耐旱性和谷物产量。植物生理学, 2010, 153(1): 185-197. https://doi.org/10.1104/pp.110.154773

[32]张健，张书，程明。干旱对水稻和小麦农艺性状的影响：荟萃分析。国际环境研究与公共卫生杂志，2018，15(5)：839。https://doi.org/10.3390/ijerph15050839

[33] TRAN D. D.，QUANG C. N. X.，TIEN P. D. 越南湄公河三角洲洪泛区气候变化和环境压力下稻农的生计脆弱性和适应能力。水，2020年，12(11)：3282。https://doi.org/10.3390/w12113282

[34] KOIRALA K. H.、MISHRA A. 和 MOHANTY S. 土地所有权对稻农生产力和效率的影响：菲律宾案例。土地利用政策，2016，50：371-378。https://doi.org/10.1016/j.landusepol.2015.10.001

[35] UNGGUL HERIQBALDI D.、PURWONO R. 和 HARYANTO T. 印度尼西亚稻米生产技术效率分析。亚洲社会科学，2015，11(3)：91-102。https://doi.org/10.5539/ass.v11n3p91