Trends in Rice Yiel, Clustering and Convergence of Rice Productivity in the Mekong Delta (1995-2023)

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.906000436

Received: 17 June 2025; Accepted: 19 June 2025; Published: 22 July 2025

ABSTRACT

This study analyzes the rice yield trends in the Mekong Delta (MD) across the Winter-Spring, Summer-Autumn, and Autumn-Winter seasons using descriptive statistics, cluster analysis, and economic convergence techniques based on General Statistics Office data spanning 29 years (1995–2023). The results indicate a significant yield increase over time. For the Winter-Spring crop, yields increased from 3.5–4.0 tons/ha (1995) to 6.0–6.5 tons/ha (2023), with an average growth rate of 0.25 tons/ha/year during 2000–2010. Similarly, yields of the Summer-Autumn and Autumn-Winter crops rose from 3.0–4.0 to 5.5–6.5 tons/ha despite adverse impacts from saltwater intrusion and climate change in 2015–2016.

Cluster analysis shows distinct yield differences among provinces. Inland provinces like An Giang and Dong Thap achieved the highest yields (6.0–6.3 tons/ha), while coastal provinces like Bac Lieu and Ca Mau had lower yields (4.7–5.0 tons/ha). Rice yield clusters for the Winter-Spring crop split provinces into three groups, with average yields of 5.8, 6.2, and 6.5 tons/ha, respectively. Similar clustering patterns were found for Summer-Autumn and Autumn-Winter crops.

Beta and sigma convergence analyses further highlight trends in rice productivity development. Beta convergence reveals that provinces with initially lower yields experienced faster growth, but the estimated half-life is over 620 years, indicating slow convergence. Sigma convergence shows a decline in yield dispersion among provinces, though variation remains considerable.

Keywords: rice yield, Winter-Spring crop, Summer-Autumn and Autumn-Winter crops, clustering, convergence, Mekong Delta.

INTRODUCTION

The Role of the Mekong Delta in Rice Production

The Mekong Delta (MD) is regarded as Vietnam's leading rice production center, playing a crucial role in national food security and global rice exports. Although it covers only about 12% of the country's total area, the MD contributes more than 50% of Vietnam's rice output and 90% of its exported rice, making the country one of the world's top rice exporters (GSO, 2022). Benefiting from favorable natural conditions, the MD boasts fertile alluvial soil, a dense network of rivers and canals, and a tropical monsoon climate, creating ideal conditions for rice cultivation (Nguyen et al., 2021). The development of irrigation infrastructure and high-yield rice varieties has significantly improved production efficiency, meeting domestic consumption needs and boosting exports (Huynh, 2018).

However, the region faces serious challenges. Climate change has led to rising sea levels, saltwater intrusion, and prolonged droughts, all of which negatively impact rice yields (Tran et al., 2020). Additionally, population growth, labor shortages due to rural-to-urban migration, and freshwater resource depletion pose difficulties for the sustainable development of the MD (Le et al., 2019). Solutions such as crop restructuring, advanced technology application in farming, and water resource management are being recommended to improve rice production efficiency in the region (Nguyen et al., 2023).

Research Objectives

This study aims to evaluate the current status of rice productivity across crop seasons in the MD, a strategically important area for Vietnam's rice sector. Through analysis of statistical data and field surveys, the study identifies factors affecting rice yields, including natural factors (soil conditions, climate, and water availability), socio-economic factors (labor systems, production costs, and support policies), and technical factors (rice varieties, fertilizers, and cultivation technologies) (Nguyen et al., 2021; Le et al., 2019).

Moreover, the study proposes solutions to improve rice production efficiency in the face of major challenges such as climate change, salinity intrusion, and increasing competition for resources (Tran et al., 2020). These solutions aim to ensure sustainable development, improve farmers' income, and maintain the MD's competitive position in the global rice market (Huynh, 2018).

RESEARCH METHODOLOGY

Data

The study uses both secondary and primary data related to rice yield across Winter-Spring and Summer-Autumn–Autumn-Winter crops from 1995 to 2023. The data spans 13 provinces in the MD and is sourced from the General Statistics Office's official dataset published over the 29-year period (1995–2023).

Analytical Methods

The study employs quantitative analysis and descriptive statistics to assess rice yield trends by season in the Mekong Delta and to identify productivity differences and convergence patterns among provinces during 1995–2023. Specifically, the following methods are applied:

Descriptive statistical analysis of yield trends: Rice yield data is analyzed over time using box plots and line charts. Box plots are used to illustrate yield dispersion and differences across seasons and provinces, while line charts help identify temporal yield trends. This method provides an overview of yield changes and highlights periods of growth or decline (Nguyen et al., 2021).

Clustering provinces based on yield and production conditions: The K-means method is applied to group provinces based on indicators such as rice yield, cultivated land area, irrigation levels, and socio-economic indicators (MacQueen, 1967). This clustering helps identify provinces with similar production conditions, enabling tailored solutions for each group. The clustering result is validated using the Silhouette index to assess clustering quality (Rousseeuw, 1987).

Beta and sigma convergence testing: The study uses beta (β) and sigma (σ) convergence tests to assess the narrowing of yield disparities among provinces over time. Beta convergence is tested using a regression model in which rice yield is the dependent variable, and initial yield and socio-economic factors are independent variables. Beta convergence occurs when provinces with initially low yields grow faster than those with higher initial yields, reducing yield disparities (Barro & Sala-i-Martin, 1992). Sigma convergence is assessed through the declining standard deviation of rice yields across provinces over time, reflecting the reduction of yield inequality (Nguyen et al., 2023).

Tools and software: Data analysis is conducted using statistical software such as R and Python, with specialized libraries including ggplot2, scikit-learn, and statsmodels.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

RESULTS AND DISCUSSION

Rice Yield Trends Over the Years

Winter-Spring Crop

Rice yield for the Winter-Spring crop increased from an average of 3.5–4.0 tons/ha in 1995 to 6.0–6.5 tons/ha in 2023 (Figure 3.1). This crop season recorded the highest yield due to favorable weather conditions and advanced farming techniques. During 2000–2010, the average yield growth rate was 0.25 tons/ha/year, but this growth slowed after 2010. From 1995 to around 2010, yields increased steadily. A drop in productivity was observed between 2010 and 2012. However, after 2012, yields recovered rapidly and continued to rise steadily until 2023. The chart shows a positive trend in Winter-Spring rice yield improvement in the Mekong Delta over nearly 30 years.

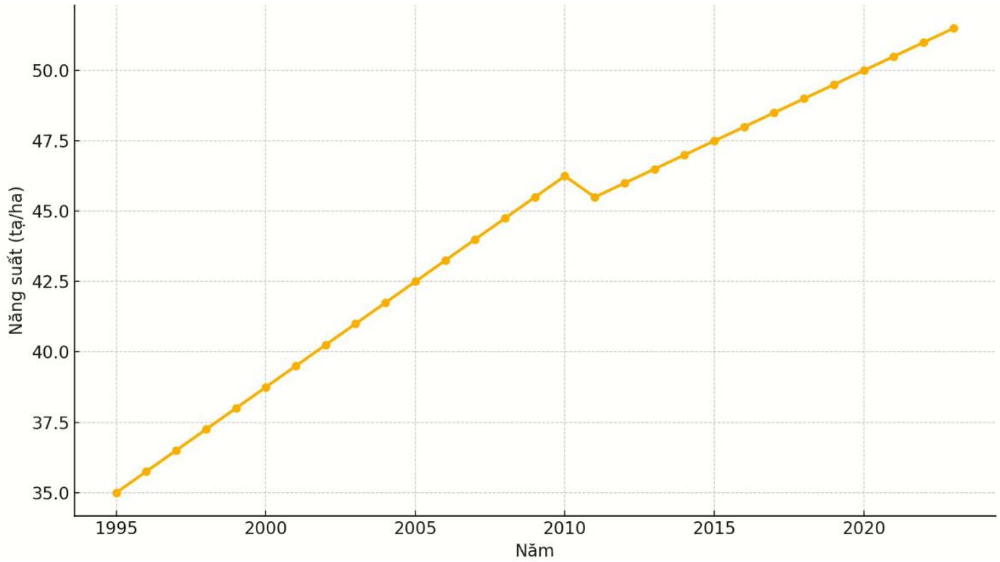

Figure 3.1: Rice yield trends for the Winter-Spring crop in the Mekong Delta (1995–2023).

Provincial-level analysis (Figure 3.2) shows that rice yields in all provinces have generally increased over time. Provinces such as Dong Thap, An Giang, Can Tho, and Kien Giang experienced strong growth, reaching 6.0–6.5 tons/ha during 2020–2023. Long An and Vinh Long showed steady increases, with average yields of about 5.5–6.0 tons/ha by 2023. Provinces like Ben Tre, Bac Lieu, and Ca Mau had lower yields, around 4.0–5.0 tons/ha in recent years. Since 2010, most provinces have seen stable yield growth, indicating technological and production condition improvements.

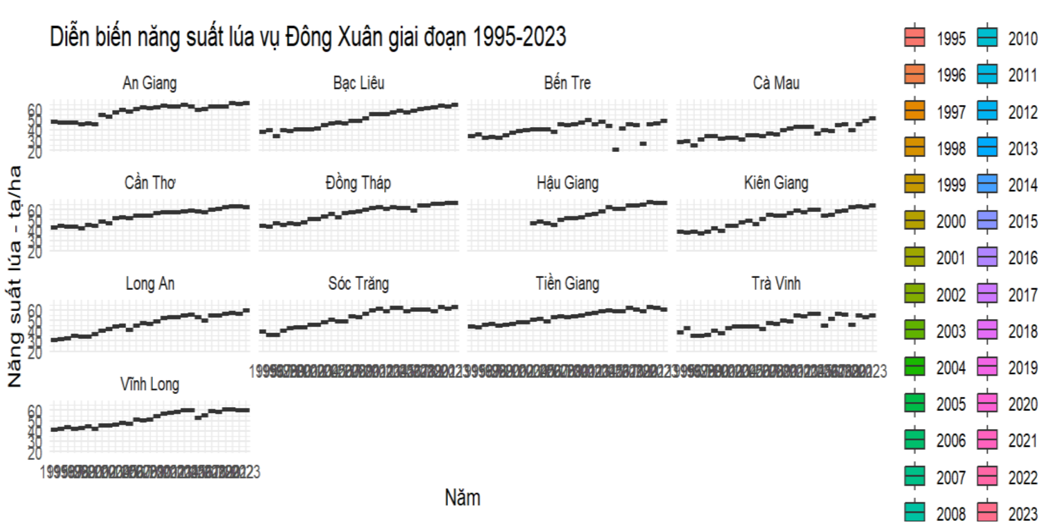

Figure 3.2: Rice yield trends by province for the Winter-Spring crop in the Mekong Delta (1995–2023).

Summer-Autumn and Autumn-Winter Crops

Rice yields for the Summer-Autumn and Autumn-Winter crops also showed significant growth, from 3.0–4.0 tons/ha in 1995 to 5.5–6.5 tons/ha in 2023 (Figure 3.3). However, yields were lower than the Winter-Spring crop due to climate conditions and saltwater intrusion. Significant fluctuations were observed in 2015–2016 during severe saltwater intrusion events.

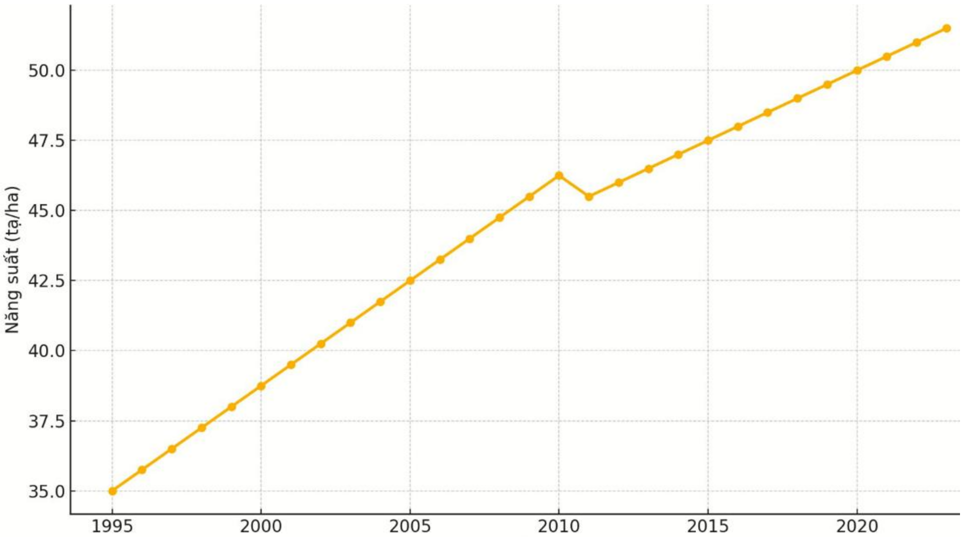

Figure 3.3: Rice yield trends for the Summer-Autumn and Autumn-Winter crops in the Mekong Delta (1995–2023).

Provincial breakdowns of Summer-Autumn–Autumn-Winter yield trends in the Mekong Delta for 1995–2023 are illustrated in Figure 3.4. All provinces experienced upward yield trends. Provinces such as An Giang, Dong Thap, Can Tho, and Long An had the highest yields, approaching 6.5 tons/ha by the end of the period. Coastal provinces like Bac Lieu, Ca Mau, and Soc Trang had lower yields, ranging from 5.0–5.5 tons/ha. The chart highlights the strong development of agriculture, particularly Summer-Autumn rice production, in the region over the past 30 years.

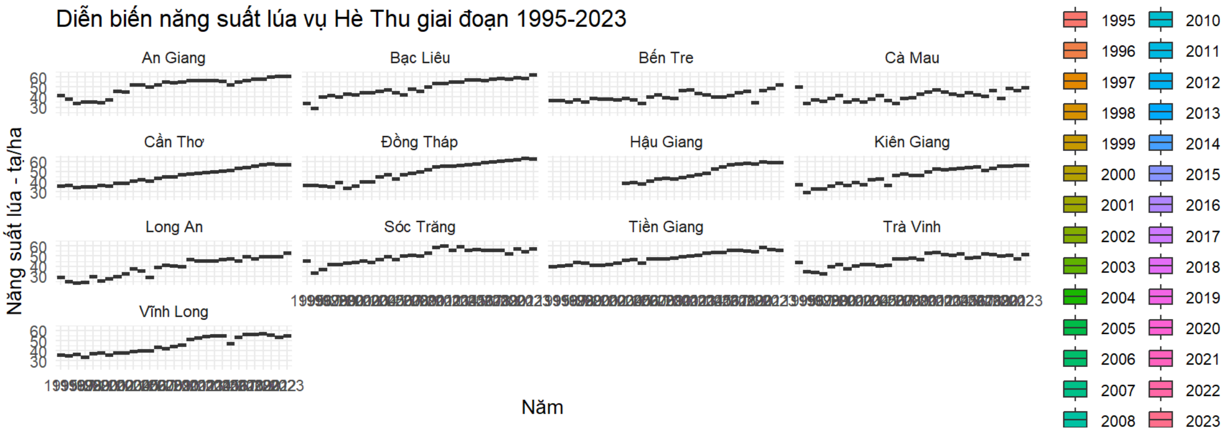

Figure 3.4: Rice yield trends by province for the Summer-Autumn and Autumn-Winter crops in the Mekong Delta (1995–2023).

Rice Yield Clustering

Winter-Spring Crop Clustering

The clustering analysis showed that when the number of clusters (k) increased from 1 to 3, the within-cluster sum of squares (WSS) dropped significantly. This indicates that partitioning the data into 3 clusters captures distinct yield differences across groups. Beyond k = 3, WSS decreased more slowly, implying that additional

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

clusters did not significantly improve yield group separation. For the Winter-Spring crop (Figure 3.5), three optimal clusters were identified, representing groups of provinces with different rice yields. These clusters reflect provinces with possibly different production conditions (e.g., soil quality, weather, farming practices) but similar Winter-Spring yields, allowing for shared categorization.

Cluster 1 includes Ben Tre and Vinh Long.

Cluster 2 includes An Giang, Tra Vinh, and Ca Mau.

Cluster 3 includes Bac Lieu, Can Tho, Dong Thap, Hau Giang, Kien Giang, Long An, Soc Trang, and Tien Giang.

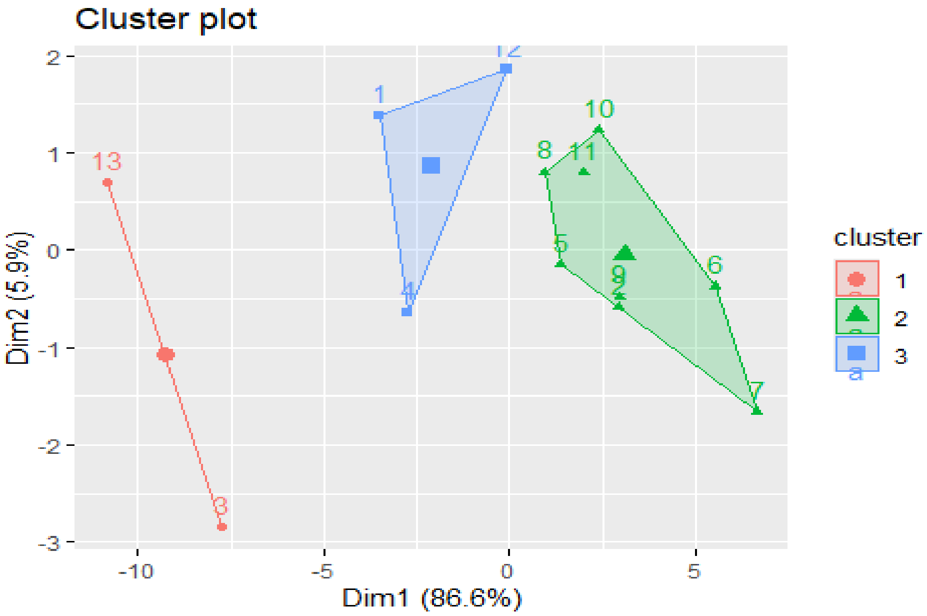

Figure 3.5: Clustering of provinces based on Winter-Spring crop yields.

Figure 3.6 illustrates each cluster with a distinct color and lists provinces along with their average yield: Cluster 1 (red): average yield of 6.2 tons/ha. Cluster 2 (blue): average yield of 5.8 tons/ha. Cluster 3 (green): average yield of 6.5 tons/ha

These findings reveal significant differences in rice productivity across the clusters.

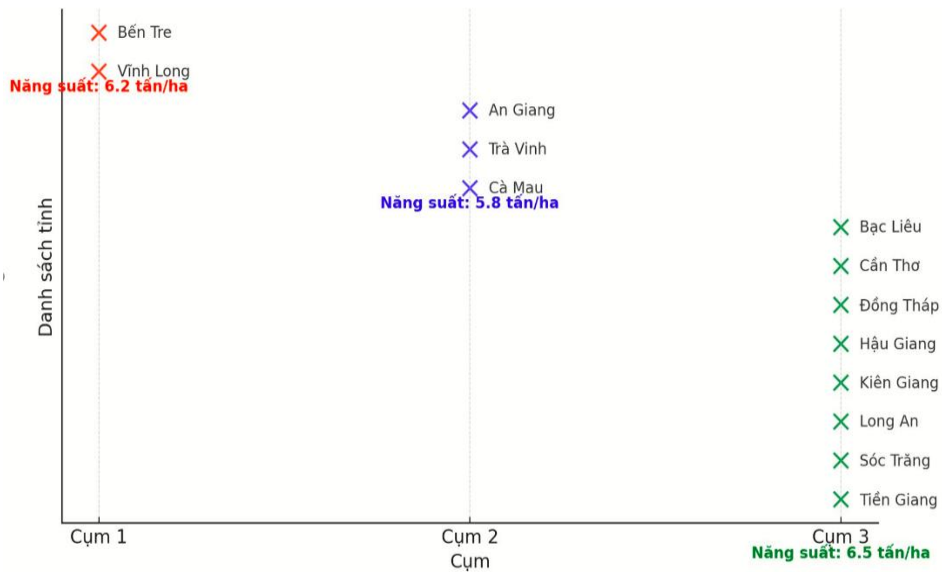

Figure 3.6: Clustered provinces for the Winter-Spring crop with average yields.

Summer-Autumn and Autumn-Winter Crop Clustering

The clustering results in Figure 3.7 identify three groups of provinces with distinct yield characteristics. These clusters reflect commonalities in production conditions, weather, or farming techniques that lead to similar Summer-Autumn and Autumn-Winter rice yields among provinces within each group.

Cluster 1 includes An Giang, Ben Tre, and Vinh Long.

Cluster 2 includes Bac Lieu, Dong Thap, Hau Giang, Tien Giang, and Tra Vinh.

Cluster 3 includes Can Tho, Ca Mau, Kien Giang, Long An, and Soc Trang.

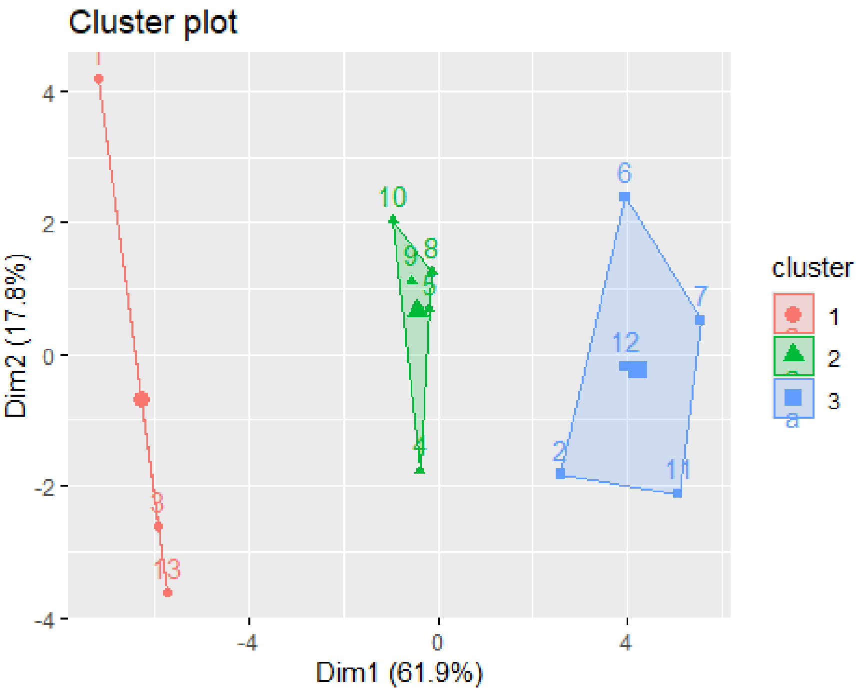

Figure 3.7: Clustering of provinces for the Summer-Autumn and Autumn-Winter crops.

Figure 3.8 depicts each cluster with a specific color and lists provinces with their average yield: Cluster 1 (red): average yield of 5.7 tons/ha. Cluster 2 (blue): average yield of 6.2 tons/ha. Cluster 3 (green): average yield of 6.0 tons/ha.

Provinces are grouped based on factors such as production conditions, climate, and farming practices, with relatively homogeneous yields within each cluster.

Figure 3.8: Clustered provinces for the Summer-Autumn and Autumn-Winter crops with average yields.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VI June 2025

Rice Yield Convergence

Winter-Spring Crop

The regression results of the absolute beta convergence model for the Winter-Spring crop, estimated using the OLS method, are shown in Table 3.1. The estimated beta coefficient is -0.0210. A negative beta indicates absolute convergence in rice yield among Mekong Delta provinces during the Winter-Spring season. In other words, provinces with initially lower yields tended to grow faster than those with higher initial yields.

The estimated half-life is 619.47, meaning it would take approximately 620 years for the yield gap between provinces to halve. The R^2 value is 0.4404, indicating that about 44% of the variation in the data is explained by the model. Overall, the results support the hypothesis of absolute beta convergence in Winter-Spring rice yields in the Mekong Delta-under normal conditions, lower-yield provinces tend to grow faster than higher-yielding ones, reducing disparities in the long run.

Table 3.1: Regression Results of the Unconditional (Beta) Convergence Model – Winter-Spring Crop

Variable	**Coefficient**
Intercept	0.093904*** (3.423)
Beta	-0.021035** (-2.942)
Lambda	0.001119ns
Half-life	619.472260
R^2	0.4404
F-value	8.655***

Note: *, **, *** indicate significance at the 10%, 5%, and 1% levels respectively; ns = not statistically significant; t-values in parentheses.

For conditional convergence, the regression results of the sigma convergence model based on trend regression are shown in Table 3.2. The intercept is -1.923280 and statistically insignificant, indicating it does not significantly influence the model. The coefficient of the Time variable is 0.001024 with a t-ratio of 0.5604, also statistically insignificant. The R^2 value of 0.01715 suggests the model has low explanatory power. Additionally, the F-value of 0.3141 confirms that the overall model lacks statistical significance. This reinforces the conclusion that there is insufficient evidence of dispersion reduction in Winter-Spring yields across provinces.

Table 3.2: Regression Results of the Conditional (Sigma) Convergence Model - Winter-Spring Crop

Variable	**Coefficient**
Intercept	-1.923280ns (-0.5227)
Time	0.001024ns (0.5604)
R^2	0.01715
F-value	0.3141ns

Figure 3.9 illustrates the inverse relationship between rice yield and yield growth in the Winter-Spring crop. As yields rise, their growth rate tends to decline, suggesting an optimal yield threshold may be approaching. This may be due to saturation of input factors like land, technology, and production intensity, making further yield improvements more difficult.

Summer-Autumn and Autumn-Winter Crops

The regression results of the absolute beta convergence model for the Summer-Autumn and Autumn-Winter crops, estimated by OLS, are shown in Table 3.3. The alpha coefficient is 0.092068, marginally significant at the 10% level. The beta coefficient is -0.021039, statistically significant at 5%, suggesting beta convergence: provinces with higher initial yields grew more slowly than those with lower yields.

The half-life is estimated at 619.36 years, indicating a very slow convergence process in rice yield among provinces. The R^2 value of 0.2117 shows that 21.17% of yield variation is explained by the model. The F-value of 2.954 confirms the model's statistical significance.

Table 3.3: Regression Results of the Unconditional (Beta) Convergence Model – Summer-Autumn and Autumn-Winter Crops

Variable	Coefficient
Intercept	0.092068* (2.006)
Beta	-0.021039** (-1.719)
Lambda	0.001119
Half-life	619.356437
R^2	0.2117
F-value	2.954***

The sigma convergence model results (Table 3.4), based on trend regression, show an intercept of 0.1641008 and a Time coefficient of -0.0000683, both statistically insignificant. This indicates no strong statistical evidence of sigma convergence over time. The R^2 value is only 0.006352, meaning the model explains less than 1% of the variance in yield dispersion, and the F-value of 0.1151 confirms the model's lack of significance.

Table 3.4: Regression Results of the Conditional (Sigma) Convergence Model – Summer-Autumn and Autumn-Winter Crops

Variable	Coefficient
Intercept	0.1641008ns (0.4048)
Time	-0.0000683ns (-0.3392)
R^2	0.006352
F-value	0.1151ns

Figure 3.10 shows an inverse relationship between average yield and yield growth rate for the Summer-Autumn crop from 1995 to 2023. Higher-yield provinces experienced slower growth, while lower-yield provinces grew faster—evidence of beta convergence across regions over time.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study reveals that rice yields in the Mekong Delta have significantly increased over nearly three decades. Winter-Spring yields rose from 3.5–4.0 tons/ha in 1995 to 6.0–6.5 tons/ha in 2023, with an average growth rate of 0.25 tons/ha/year during 2000–2010, which slowed after 2010. A brief yield decline occurred from 2010–2012, followed by a steady recovery and increase up to 2023. Yields of the Summer-Autumn and Autumn-Winter crops also increased from 3.0–4.0 to 5.5–6.5 tons/ha over the same period.

Provincial-level analysis reveals stark yield differences. Leading provinces such as An Giang, Dong Thap, and Can Tho reached 6.0–6.3 tons/ha in 2023, while coastal provinces like Bac Lieu and Ca Mau remained at 4.7–5.0 tons/ha. Cluster analysis confirms these disparities, with three provincial groups: high-yield (6.5 tons/ha), medium-yield (5.8 tons/ha), and low-yield (5.7 tons/ha), with the latter mainly comprising coastal provinces.

Beta and sigma convergence analyses show signs of convergence. Provinces with low initial yields, like Ca Mau (3.5 tons/ha in 1995), grew at an average of 3%/year, compared to 1%/year in leading provinces like An Giang. The estimated half-life of 620 years suggests very slow convergence. Sigma convergence results show a significant reduction in yield inequality, with variance dropping from 24 in 1995 to 10 in 2023—mostly during 1995–2005.

In summary, although significant progress has been made, yield disparities among provinces remain. Leading provinces average 6.0–6.3 tons/ha, while coastal provinces trail by 20–25%, largely due to severe salinity and poor soil quality. If well-coordinated policies are implemented, coastal provinces could reach 5.5–6.0 tons/ha by 2030, aligning with current inland province averages.

Recommendations

Based on the findings, the following measures are proposed to improve rice yields and reduce regional disparities in the Mekong Delta:

Irrigation infrastructure investment: Coastal provinces like Bac Lieu and Ca Mau (4.7–5.0 tons/ha in 2023) should prioritize irrigation systems to mitigate salinity impacts, potentially increasing yields by 0.5–1.0 tons/ha.

Advanced farming technologies: In An Giang and Dong Thap (6.0–6.3 tons/ha), using high-quality rice varieties and water-saving techniques could help lower-yield provinces improve yields by 8–12%.

Research and technology transfer: Developing salt-tolerant rice varieties could raise productivity by 10–15% in saline areas.

Training and extension programs: Effective practices from Can Tho (yield increase from 5.0 tons/ha in 2005 to 6.3 tons/ha in 2023) should be expanded to improve resource use efficiency.

Financial support: Provide preferential credit to farmers in low-yield areas to boost yields by 5–8%.

Monitoring and evaluation: Establish yield monitoring systems to enable timely policy adjustments, as seen in Dong Thap where yields increased 3%/year.

These recommendations aim not only to improve rice productivity but also to foster sustainable development, with projected regional yield increases of 10–15% over the next decade.

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