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Cumulative Effects of Intensified Cropping Cycles: Triple Rice Cropping in the Vietnamese Mekong Delta

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Abstract

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Keywords: Triple rice cropping, sustainability, Mekong Delta, Vietnam
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1. Introduction

Improving agricultural productivity is critical for food security and poverty reduction under land scarcity (Hayami and Ruttan, 1985; Gollin et al., 2007; Restuccia et al., 2008). The adoption of modern inputs, such as improved seeds and chemical fertilizers, and the intensification of cropping cycles enabled by irrigation were important drivers of the Green Revolution, the historical agricultural development under land pressure (Renkow and Byerlee, 2010; Pingali, 2010; Gollin et al., 2021). However, there are growing concerns about the negative impacts of over-intensification, such as land degradation and reduced profitability and sustainability of agriculture (Ali and Byerlee, 2002; FAO, 2011).

To assess these concerns, we examine the farm performance of triple rice cropping (hereafter, triple cropping), the use of which increased particularly in the Vietnamese Mekong Delta (VMD) in the 2000s and 2010s (Vu et al. 2022). Vietnam is one of the world's largest rice exporters, and its main production area is the VMD region. The government promoted intensive rice farming, and the effective area of rice production in the VMD increased by more than 34% from 1995 to 2015, largely due to the adoption of triple cropping (VCCI, 2022; GSO, 2022). During the same period, farmers also significantly increased their use of fertilizers, more than doubling their use of agricultural nitrogen (FAO, 2022). Excessive fertilizer use can degrade soils and, thus, threaten the profitability and sustainability of rice production. However, more rigorous empirical evidence is needed to confirm these concerns and draw policy implications.

This paper examines how triple cropping is associated with fertilizer use, rice yield, and rice income by analyzing a representative sample of rice farmers in the VMD. Because farmers may adopt triple cropping at the expense of other income opportunities, such as non-rice crops and off-farm wage employment, this paper also examines farm income and total household income. For these purposes, we analyze cross-sectional data on rice farmers in the VMD from four rounds of a nationally representative survey (Vietnam Household Living Standards Survey, VHLSS) conducted from 2006 to 2012. We construct an original dataset by combining these household data with a novel satellite imagery panel on commune-level rice cropping patterns from 2001 to 2012. We employ a two-way fixed effects model, exploiting the variation in consecutive years of triple cropping within each district by including district fixed effects, while controlling for temporal shocks within each province by including province-year fixed effects.

Our results show that fertilizer costs increase when triple cropping is continued for 4 years and beyond; pesticide and herbicide costs do not increase; yields increase, especially for the summer-autumn crop, which compensates for the increased fertilizer costs; and rice income per hectare per season does not decrease. In addition, the income of triple-cropping households increases by 32% in terms of annual agricultural income and by 16% in terms of total annual income. These results suggest that triple cropping is an economically rational option for farmers and does not worsen farm sustainability, at least during our study period.

Our study has implications for policies promoting farm intensification and its environmental and economic consequences in the VMD. Since the implementation of economic reforms in 1986, the Vietnamese government has promoted agricultural intensification in the VMD to improve food security, rural livelihoods, and flood control, which affects cropping patterns (Nguyen et al. 2019, Tran et al. 2019). Double and triple rice cropping in the VMD relies on two main types of dike systems. Low-dike systems allow double cropping by delaying flooding, with paddy fields eventually submerged during the flood season. High-dike systems, introduced after low-dike systems, allow triple cropping by preventing flooding. By the end of the 2000s, most of the fields in the delta were surrounded by dikes, allowing double and triple cropping.[1]

Although flood control in high-dike systems allows for an additional rice crop, there are disadvantages. Triple cropping can deplete long-term soil fertility because it uses consecutive cropping without fallow periods. This method can also interfere with the environmental benefits of flooding such as depositing fertile sediments, killing pests, and flushing out acidic soils (Manh et al., 2014; Manh et al., 2015; Chapman and Darby, 2016; Chapman et al., 2016). When the French colonial government developed the VMD and planned to control flooding through hydraulic interventions and canal networks, it overlooked the environmental benefits of seasonal flooding (van Staveren et al., 2018). Furthermore, it missed opportunities for farmers to diversify through flood-based production systems, such as freshwater aquaculture and floating crops. Thus, there are trade-offs between preventing and allowing flooding. Therefore, it is important to

[1] See Nguyen et al. (2019) and Tran et al. (2019) for a historical review of the changes in cropping patterns and land-use in the VMD.

examine whether promoting triple cropping is a reasonable strategy to balance agricultural development and its sustainability.

This paper draws on two strands of literature. The first, albeit small, strand of literature uses survey data from rice farmers in the VMD to examine the impact of triple cropping on farm sustainability. Tong (2017) argues that triple cropping provides only a marginal increase in net income to farmers due to the increase in agrochemical input costs and the decrease in output prices of the main rice varieties adopted in triple cropping.[2] Tran et al. (2018) compare rice farmers using different cropping patterns and show that in the years of triple cropping, their fertilizer and pesticide per hectare and production costs increase.[3] Notably, these results have limitations: they are unrepresentative and suffer from selection bias because the researchers only compare performance between triple cropping and double cropping in a few districts. We aim to overcome these limitations by using representative household data and conducting a formal regression analysis that controls for district and province-year fixed effects.

The second strand of literature uses satellite data and remote sensing methods to study land-use dynamics (Sakamoto et al., 2006; Sakamoto et al., 2009; Ngana et al., 2018; Han et al., 2022; Hui et al., 2022; Vu et al., 2022). The results show significant changes in land use during the 2000s and 2010s in the VMD, where rice cropping patterns have evolved from single to double and to triple cropping along with the construction of high-dike systems. Kontgis et al. (2019) and Jafino et al. (2021) conduct simulation analyses and argue that triple cropping potentially reduces farm profitability due to lower yields and higher input costs. Our study complements these studies by analyzing real-world data on the impact of increasing cropping intensity on agricultural sustainability.

The remainder of this paper is organized as follows. Section 2 describes the data, and Section 3 explains our empirical strategy. Section 4 presents the estimation results and discusses policy implications. The final section presents the conclusions.

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[2] Using observational data from 352 rice farmers in the VMD, Ho and Shimada (2021) report that implementing climate change responses (e.g., crop management practices that reduce fertilizer and chemical use) reduce the number of crops planted and that water management packages that change irrigation schedules are associated with increased rice yields, increased profitability, increased incomes, and decreased fertilizer use.

[3] See also Tran et al. (2023).

2. Data

Assessing intensive rice farming requires information on rice production, including agricultural inputs, output, and the number of rice plantings per year. Most of this information is available from the VHLSS, a nationally representative survey conducted by the government every two years since 2002.[4] We use data from four rounds of the VHLSS: 2006, 2008, 2010, and 2012. The 2002 and 2004 surveys are excluded because they do not provide the necessary information and we need some periods to examine the long-term effects of triple cropping.[5] The VHLSS has two main limitations: it is not a panel survey and it covers only the past 12 months.[6] Therefore, we cannot determine whether and for how long the sample households engaged in triple cropping in the periods prior to the survey year.

To overcome this limitation of the VHLSS data, we use novel land use estimates derived from satellite imagery provided by the Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization (NARO) in Japan. The data are based on algorithms developed by Sakamoto et al. (2007) and Sakamoto et al. (2009a) (2009b) and constructed using an integrated remote sensing approach with NASA's MODIS data (hereafter, NARO-MODIS data). The NARO-MODIS data classify agricultural land into different farming systems at a resolution of 250m based on spectral reflectance characteristics and systematic analysis of time-series satellite imagery. Examples of the farming systems are single, double, and triple rice farming, shrimp rice farming, and inland aquaculture. Importantly for our study, the NARO-MODIS data provide long-term information on the spatial and temporal variations of land use in the VMD from 2001 to 2012. We overlay the NARO-MODIS image with the commune boundaries and then calculate the proportion of the area by land-use classification within each commune. Next,

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4 Another possible source of information is the Vietnam Living Standards Survey (VLSS) conducted in 1992/1993 and 1997/1998 by the government with support from the World Bank. However, we use only the VHLSS because our empirical analysis focuses on the periods after 2001 due to the availability of land use information, as we explain in the paper.

5 Pesticides and herbicides costs are not available for the VHLSS 2002. In addition, the amount of fertilizer inputs, such as NPK, nitrogen, phosphorus, and potassium, are not available for the VHLSS 2002 and 2004.

6 The VHLSS has a rotating panel of households. However, the sample size is significantly reduced if the data are treated as a panel at the household level, and long-term panel data with more than two periods are rarely constructed.

we use the commune names to merge the VHLSS data with the NARO-MODIS data at the commune level.

We consider a commune to be a *triple cropping commune* if triple cropping predominates, defined by $area\_triple_{ct} > 0.5$, where $area\_triple_{ct}$ is the ratio of the triple cropped area to the total paddy area. We indicate triple cropping communes by using a dummy variable $triple_{ct} = 1$, if these conditions are fulfilled, and zero otherwise. These variables were obtained as commune-level panel data from 2001 to 2012. We restrict the samples to rice farming households in the Mekong River Delta region with positive rice production. The final sample consists of 1,815 households.

Figure 1 shows the rice cropping pattern in the VMD in 2001 and 2012. Although the area under rice cultivation (represented by light- and dark-shaded polygons) remained almost unchanged, the number of communes practicing triple cropping (dark-shaded polygons) increased between 2001 and 2012. The figure shows that intensified rice cultivation expanded mainly in the upper delta floodplains (i.e., the northeast), the Long Xuyen Quadrangle and the Plain of Reeds. In fact, high-dike systems were constructed in these wetlands in the 2000s, expanding the area of triple cropping (Vu et al., 2022). In addition, some communes in the coastal (i.e., southwestern) provinces, such as Soc Trang and Bac Lieu, also shifted from double to triple cropping. Thus, there is sufficient spatial and temporal variation in rice cropping patterns.

Figure 2 shows the histogram of the triple-cropping area ratio for each commune, $area\_triple_{ct}$. The figure suggests that cropping patterns are collective decisions by communes and broader geographic factors, such as agro-environmental conditions and high-dike systems.[7] Most farmers from the same commune adopt the same cropping practices, either triple or double cropping.[8] Triple cropping also increased from 2001 to 2012. The main variables of interest in this paper are the practice of triple cropping in the observation year and the consecutive years of triple cropping. We assume that a household in commune *c* practices triple cropping in period t if it is located in a triple-cropping commune, $triple_{ct} = 1$. Consecutive years of triple cropping, $years\_triple_{ct}$, are formally defined in the next section.

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[7] In general, irrigated rice farming involves many collective decisions and activities (e.g., irrigation timing); thus, cropping patterns are often determined at the commune level.

[8] For simplicity, this paper refers to cropping patterns with a lower intensity than that of triple cropping as "double cropping." The proportion of single cropping is small.

Our outcome variables are the (i) annual cost of chemical fertilizers, pesticides, and herbicides per hectare of the planted area; (ii) paddy yield per hectare; (iii) revenue, expenditure, and income from paddy production per hectare of the planted area; (iv) annual agricultural income from paddy, other crops, livestock, and fisheries; and (v) annual household income from agriculture, wages, and self-employment.[9] The regression analysis controls for the household size, age, sex, and education of the household head. For some outcomes, planted area and soil type are included.

Table 1 describes the sample households and their rice farming activities and performance, using the household in each year as the unit of observation. Summary statistics are presented using the triple cropping status, defined as whether a household is located in a commune that practiced triple cropping in the observation year. Table 1 shows that triple-cropping households tend to use more inputs and have higher yields, higher income from rice production, lower income from fishery, higher agricultural income, and higher total household income than double-cropping households.

3. Empirical strategies

This section presents our empirical model for estimating the effects of triple rice cropping. Let y_{icdpt} denote the outcome variable of farm household i in commune c in district d in province p in period t.[10] The main explanatory variables are the (i) triple cropping dummy ($triple_{ct}$) and (ii) number of consecutive years of triple cropping ($years\_triple_{ct}$) as of period t. For example, if $years\_triple_{ct} = k$, then commune c has practiced triple cropping without fallow for the previous k years up to period t. Conceptually, $years\_triple_{ct}$ is defined as follows:

$$years\_triple_{ct} = (years\_triple_{ct-1} + 1) \times triple_{ct}.$$

[9] The analysis in this study focuses on ordinary rice. Glutinous and specialty rice, which account for approximately 5% of the total planted paddy area, are excluded from our analysis because of their different production technologies.

[10] The administrative unit of Vietnam is divided into three levels: provinces, districts, and communes.

For given consecutive years of triple cropping up to period $t-1$, $years\_triple_{ct-1}$, consecutive years of triple cropping as of period t, $years\_triple_{ct}$, increases by 1 year as long as commune c practices triple cropping in period t, $triple_{ct} = 1$, and it is reset to zero when $triple_{ct} = 0$. For the first survey period, 2006, we construct $years\_triple_{c,2006}$ by evaluating the sequence of $triple_{ct}$ during the previous periods from 2001 to 2006. Since land use information before 2001 is not available, we cannot determine $years\_triple_{c,2006}$ for a period of 6 years or more. Therefore, the main analysis focuses on the cumulative effect of $years\_triple_{ct} = k$, where $k \in \{0,1,2,3,4,5\}$ or $k \geq 6$. We analyze the cumulative effect of consecutive triple cropping up to 11 years only using the subsample in the Appendix.

Table 2 summarizes the evolution of $years\_triple_{ct}$ for the sample households over four survey rounds. The proportion of households practicing double cropping ($years\_triple_{ct} = 0$) decreased over time, while the proportion of households practicing triple rice cropping for 6 or more years ($years\_triple_{ct} \geq 6$) increased from approximately 20% in the late 2000s to 30% in the early 2010s.[11]

We postulate the main estimating equations as follows:

Model 1:

$$\ln y_{icdpt} = \alpha + \beta triple_{ct} + X_{icdpt}\gamma + u_d + v_{pt} + \varepsilon_{icdpt}$$

Model 2:

$$\ln y_{icdpt} = \alpha + \sum_{k=1}^{K} \beta_k \, I(years\_triple_{ct} = k) + X_{icdpt}\gamma + u_d + v_{pt} + \varepsilon_{icdpt}$$

Model 1 estimates the effect of adoption of triple cropping on outcomes in the survey year. Model 2 decomposes this "treatment effect" by consecutive years of triple cropping and estimates potentially nonlinear long-term effects. The indicator variable $I(years\_triple_{ct} = k)$ equals 1 if $years\_triple_{ct} = k$ and 0 otherwise. Thus, the regression coefficient β_k represents the

[11] Here, we note that because we use repeated cross-sectional data, the evolution of $years\_triple_{ct}$ may be affected by the changes in cropping patterns over time in the same commune and the changes in the composition of the sample commune.

effect of triple cropping continued for k consecutive years. Since both models use the logarithm of the outcome variable, the effect is expressed as a percentage change. X_{icdpt} is the vector of covariates, including the paddy planted area, household size, age, sex, and education of the household head. District and province-year fixed effects are denoted by u_d and v_{pt} respectively. Finally, ε_{icdpt} is an error term clustered at the province level.

Notably, a concern is that the continuation of triple cropping may degrade soil fertility and reduce rice yields and incomes, undermining the sustainability of intensified rice farming. In response, farmers may increase fertilizer use to partially compensate for reduced soil nutrients. Based on these considerations, we postulate the following hypothesis:

With the continuation of triple cropping,
(Hypothesis i) fertilizer use in triple cropping increases with its continuation ($\beta_k \leq \beta_{k'}$ for $k \leq k'$) and exceeds that in double cropping ($\beta > 0$), and
(Hypothesis ii) rice yields and net incomes per hectare in triple cropping decrease with its continuation ($\beta_k > \beta_{k'}$ for $k \leq k'$) and may be lower than those for double cropping ($\beta < 0$).

In addition, triple cropping may require year-round family labor at the expense of income opportunities in non-rice agriculture and the non-farm sector. To capture the overall impact, we also examine the impact on farm and household incomes.

If the following identification assumption holds, our estimated coefficients have a causal interpretation: the main explanatory variables $triple_{ct}$ or $years\_triple_{ct}$ are not correlated with ε_{icdpt} after controlling for district and province-year fixed effects and other covariates. This assumption is plausible if the choice of rice cropping pattern is exogenous to individual farm households. Figure 2 shows that the cropping pattern is almost uniform within each commune. This finding suggests that the choice of triple cropping is most likely exogenous at the household level, as agro-environmental conditions and the availability of high-dike systems play a critical role in the choice of cropping practices.

However, if the adoption of triple cropping at the commune level within the same district is not randomly conditional on our covariates, our estimated coefficients on the triple-cropping indicators may be biased. For example, communes with more favorable agronomic conditions may adopt triple cropping more promptly. We examine this possibility by comparing household characteristics and agricultural outcomes in 2002, using the 2002 VHLSS, among "early adopters" who adopted triple cropping in or before 2002, "late adopters" who adopted triple cropping after 2002, and "never adopters" who never started triple cropping during our 2001-2012 observation period.[12] While late adopters have slightly higher potential yield (GAEZ)[13] than never adopters after controlling for district fixed effects and other factors, early adopters have significantly higher rice area planted, potential rice yield (GAEZ), and value of rice produced (Table A1 and Figure A1 in the Appendix). To address this potential selection problem, we also analyze a subsample that excludes the early adopters. In other words, this subsample consists of (i) communes that adopted triple cropping after 2002 and (ii) communes that continued with double cropping throughout, both of which were similar in 2002.

4. Results

4.1. Input costs

First, we consider the relationship between triple cropping and input costs. The critical question is whether triple cropping is associated with higher chemical inputs, possibly in response to reduced fertility or increased pests and diseases due to intensive cropping.

Table 3 (a) presents the estimated annual cost of chemical fertilizer per hectare (1000 VND/ha).[14] Columns 1-3 report estimates for the triple-cropping dummy (model 1), and columns 4-6 use the dummies for consecutive years of triple cropping (model 2). All specifications control for covariates (i.e., log of planted area, household size, age, sex, and

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[12] We did not use the 2002 data for the main analysis because some outcome variables are not available. See footnote 6.

[13] Geographical variation in potential rice yield was obtained from the FAO-GAEZ v4 database, which estimates the agroecologically achievable yields of 53 crops based on soil/terrain assessments and weather characteristics of a given region. To assess the suitability for rice production, we used the potential rice yield values for rainfed, low-input production.

[14] Ideally, we would like to break down the annual costs by crop season (winter-spring, summer-autumn) and compare the common crop for double and triple cropping because triple cropping adds an additional crop that may differ from the tradition double cropping (winter-summer, summer-autumn). Unfortunately, we cannot realize the objective because data are not available for inputs by cropping season.

education of household head) and province-year fixed effects. Columns 2, 3, 5, and 6 include district fixed effects, and columns 3 and 6 use the subsample without early adopters.

Figure 3 visually presents the estimated coefficients with a 95% confidence interval. The vertical axis represents the proportional change in input costs. The estimates of the triple-cropping dummy (columns 1-3) and the consecutive years of triple cropping (columns 4-6) are shown to the left and right of the dashed vertical line, respectively.

Our preferred specifications are those that include district fixed effects (columns 2, 3, 5, and 6), using only variations in treatment status (triple cropping) or consecutive years of triple cropping over time within districts. In general, the estimates decrease after including district fixed effects. This finding suggests that triple-cropping communes tend to use higher inputs than double-cropping communes do, even before adopting triple cropping.

Table 3 and Figure 3 reveal several important results. First, the estimated coefficients of the triple-cropping dummies are small in magnitude and not significantly different from zero, suggesting that there is no overall difference in fertilizer use between triple-cropping households and double-cropping households. Second, the estimates for consecutive years of triple cropping show no immediate effect of adopting triple cropping, as suggested by the coefficient on the first year of triple cropping ($years\_triple_{ct} = 1$), which is negative and insignificant when district fixed effects are included. This result implies that the mere adoption of triple cropping does not immediately affect fertilizer use.

Third, the fertilizer costs increase after $k = 3$. The point estimates in column 6 of Table 3 indicate that the fourth year of triple cropping is associated with a 15.3% increase in fertilizer costs. Although the estimates are noisy, there is an increasing trend in fertilizer use with the continuation of triple cropping. This result is consistent with our first hypothesis, suggesting that farmers increase fertilizer application as intensive cropping continues. We observe a similar pattern for the annual amount of NPK fertilizer used per planted area (kg/ha) (Appendix).

We also examine the effect of triple rice cropping on the use of pesticides and herbicides (Table 3 (b, c) and Figure 3 (b, c)). The estimated coefficients are mostly nonsignificant and sometimes negative after controlling for district fixed effects. The point estimates in column 6 of Table 3 (b) are imprecise, but suggest that pesticide costs decrease by 23%-46% after 2-5 consecutive years of triple cropping. The point estimates for herbicides are also negative or small (0.098), except for a 36% increase in cost in the second year of triple cropping. These results suggest that triple cropping is not associated with increased pesticide or herbicide costs.

4.2. Yield

A major concern with triple cropping is that continued intensification reduces soil fertility and paddy yield. Table 4 and Figure 4 present the estimation results of paddy yield per planted area (kg/ha) for the annual average, winter-spring crop (dry season, the main crop), and summer-autumn crop (wet season).[15] In addition to the usual set of covariates (household size, age, sex, and education of the household head), we include the GAEZ soil type, aggregated at the commune level to control for soil fertility.[16] Most of the estimated coefficients are positive but not significant. For the summer-autumn crop, households in triple-cropping communes have an average yield increase of 3.8% (Table 4, column 5). There is no evidence suggesting that paddy yield decreases in consecutive years of triple cropping (Table 4, column 6).

Because the diminishing effect of triple cropping on yields may be offset by increased inputs, the results of a mediation-type analysis with an additional control for inputs (log of fertilizer, pesticide, and herbicide costs per hectare (1000 VND/ha)) are presented in the Appendix. The pattern is similar to that in Table 4 and Figure 4; we find no negative and significant coefficients. This finding suggests that the direct effect of triple cropping remains non-negative even after controlling for inputs.

4.3. Agricultural income

Table 5 and Figure 5 present the results of the revenue, expenditure, and income per hectare of rice production.[17] Most of the estimated coefficients are not significant. Rice income is not lower than that of double cropping, and rice income does not decrease in consecutive years of triple cropping.

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[15] The third crop, introduced by triple cropping, is grown mainly in autumn-winter.

[16] The results controlling for the annual cost of fertilizer, pesticide, and herbicide per area planted are presented in the Appendix.

[17] Rice income is defined as the rice yield multiplied by the price of rice, less the total cost of rice production per hectare. The latter includes the cost of agricultural inputs, wages for hired labor, and rents for land and capital, but excludes family labor costs and imputed rent for own land and capital. Thus, farm income consists of implicit costs of own resources and farm profits.

Table 6 and Figure 6 present the estimation results from the models of annual agricultural income, separately for income from rice, other crops, livestock, fisheries, and total agriculture. In general, households in triple cropping communes earn on average 49% more from rice (column 1) and 88% more from other crops (column 3) than households in double-cropping communes do. Although not statistically significant, triple cropping is associated with 100% less income from fishery (column 7). This result suggests that the third crop substitutes for fishery.[18] Overall, the farmers who adopted triple cropping earned 32% more in total agricultural income (column 9). There is no clear pattern of increase or decrease in income with consecutive years of triple cropping.

4.4. Household income

Finally, because the cultivation of the third crop may require family labor, we examine whether farmers adopt triple cropping at the expense of non-rice farming or off-farm activities. The estimation results in Table 7 and Figure 7 suggest that this trade-off does not occur. In general, the incomes of triple-cropping households from all sources do not decrease in the consecutive years of triple cropping. Households in triple-cropping communes had a 32% higher agricultural income and a 16% higher total income.[19] The increasing availability of agricultural mechanization services may have helped farmers continue triple cropping without losing other income opportunities (Takeshima et al., 2020).

5. Discussion

In the VMD, from 2001 to 2012, the area of triple cropping increased (Figure 1). Studies have argued that triple cropping with high dikes prevents the influx of nutrient-rich flood sediments and fisheries, which reduces farmers' income in the long run (Tong, 2017; Tran et al., 2018).

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[18] Notably, although the total farm income of triple-cropping rice is higher than that of double cropping, double-cropping farmers are likely to combine rice production with other crops, freshwater aquaculture, or off-farm employment during the flood season.

[19] In the Appendix, we also report estimates using the interaction of the triple cropping dummy and the year dummies because the level of non-agricultural income is unlikely to be affected by the continuation of triple cropping. The results indicate that incomes are higher for triple cropping households, with some exceptions by source and year.

However, these analyses rely on cross-sectional comparisons of selected cases (three districts in Tong, 2017, and four districts in Tran et al., 2018), which may suffer from selection bias because these triple-cropping districts may have been less fertile than other districts before adopting this practice.

We analyzed the consequences of triple cropping using representative data from the VMD and attempted to overcome selection bias by controlling for district and province-year fixed effects. After 3 consecutive years of triple cropping, farmers' fertilizer use increased, consistent with the hypothesis that they compensate for reduced soil nutrients by increasing fertilizer use. Notably, farmers' pesticide and herbicide costs per hectare decreased after switching from double cropping to triple cropping. In addition, their rice yields did not decrease, and their rice income, farm income, and total household income were significantly higher than under double cropping. These results are also robust to subsample analysis, which excludes communes that started triple cropping in or before 2002. Our results are consistent with the long-term trends reported by Vu et al. (2022), where the average rice yield increased from 4.4 t/ha in 2000 to 6.0 t/ha in 2020, and triple cropping expanded and remained dominant in the VMD until 2015.

Importantly, we found no evidence suggesting that the continuation of triple cropping reduces rice yields, contrary to what has been argued in case studies in the literature. Several interpretations of our results are possible. First, triple cropping may not significantly degrade soil fertility, at least for up to 6 consecutive years (or even up to 11 consecutive years).[20] Livsey et al. (2021) compare soil properties between samples from farmland with and without high-dike systems, and find that nutrients do not systematically decrease in the triple-cropped area.

Second, triple cropping may reduce soil fertility, but intensive fertilizer application offsets for the negative effect. However, this scenario is unlikely to occur because our mediation-type analysis suggests that the direct effect of triple cropping remains non-negative when controlling for fertilizer use.

Third, the triple-cropping communes were initially more fertile than the double-cropping communes. We have seen that the rice yield in the triple-cropping communes tends to be higher

[20] We do not find a decreasing trend in yield even after 6-12 years of triple cropping when we regress the dummies of consecutive years of triple-cropping without top-coding at 6 years (Appendix). The estimates of the dummies for $years\_triple_{ct} > 6$ are generally positive but highly variable with large margins of error due to the small number of observations.

than that in the double-cropping communes before the start of triple cropping. This phenomenon may mask the negative effect of triple cropping on yield because the initial high yield may offset the decline in soil fertility. However, our results from the fixed effects analysis show that yield does not decline over time with the adoption or consecutive years of triple cropping.

Fourth, triple-cropping farmers may have adopted different rice varieties that differ from those adopted by double-cropping farmers, which may have resulted in the former having higher yields than the latter. This suggestion is supported by the reports that the rice variety structure and production methods in triple-cropping regions have been renovated toward intensive farming (VCCI, 2022).

In summary, triple cropping did not reduce rice productivity or degraded soil fertility during our study period. Our analysis also shows that triple-cropping farmers had higher rice, farm, and household incomes than double-cropping farmers in the late 2000s and the early 2010s. During this period, rice prices were relatively high, in part due to the 2007-2008 global food price crisis, and the fertilizer supply was abundant because of the increased domestic production (Kojin et al., 2022).

However, since the 2010s, the situation of rice cultivation and farmers has been gradually deteriorating due to declining world rice prices (Fig. 1 in Kikuchi et al., 2021) and climate change, especially in the VMD (e.g., erratic rainfall, water scarcity, increased frequency and severity of floods and droughts, riverbank erosion, rising sea levels, and shrinking arable land) (VCCI, 2022). These problems threaten the sustainability of rice production, both environmentally and economically. Under these circumstances, the government has renewed its emphasis on improving rice cultivation practices to be less intensive and more environmentally friendly than those currently used (e.g., reducing the use of agrochemicals and using organic fertilizers instead of chemical fertilizers, by implementing plans such as the "*three reductions, three increases" model*).[21] To reduce the use of fresh water, the government is placing more emphasis on reducing rice production and converting paddy fields to aquaculture, fruit trees, or industrial and service

[21] "Three reductions, three increases" is the rice production model first presented by Vietnamese scientists at an international conference in 2005, and officially recognized as an advanced technology by the Ministry of Agriculture and Rural Development in 2006 under the Direction of the Ministry of Agriculture and Rural Development 24/CT-BNN. "Three reductions" refers to reducing the use of seed, fertilizer, and pesticide, and "three increases" refers to increasing productivity, quality and efficiency (Nguyen and Hoang, 2012).

land in the long term (Government Resolution 120/NQ-CP in 2017, The Political Report at the 13th National Congress of the Communist Party of Vietnam).

Local governments, sometimes in collaboration with foreign aid, are implementing two methods to increase the sustainability of rice farming. First, they are promoting the adoption of technologies to make triple-cropping sustainable. Literature has explored technologies to conserve water and fertilizer and reduce methane gas emissions (e.g., alternate wetting and drying irrigation) to complement triple cropping in suitable rice-growing areas (Nhan et al., 2016; Arai, 2022). In addition, since 2010, local governments and agronomists have been recommending a new cropping method called *three years, eight crops*. In this method, 2 consecutive years of triple cropping should be followed by double cropping in the third year (Binh et al., 2022), and the land should be left fallow during the flood season. Recently, even the *two-year, five-crop* model has started to be applied.

Second, the local governments are promoting the reduction of rice cultivation. The reason for this initiative is that climate change is disrupting rice cultivation and increasing the vulnerability of rice farmers' livelihoods (Tran et al., 2022). Farmers in the VMD are responding by reducing their dependence on rice cultivation and diversifying their livelihoods into non-rice agriculture and off-farm activities. Non-rice agriculture and off-farm activities are expanding due to economic development and increased demand overseas, particularly in China. Another factor is that the decline in the international price of rice is reducing the incentives for farmers to grow rice.

6. Conclusion

To assess the sustainability of intensified rice farming, we examine the cumulative effects of triple rice cropping on fertilizer use, rice yield, and income in VMD. We construct a new dataset that integrates regionally representative household data and commune-level satellite imagery panel data on rice cropping patterns. Our empirical results indicate that continuous triple rice cropping is associated with a slight increase in chemical fertilizer costs. However, our results do not show any reduction in yield, rice income per hectare, farm income, or total household income. Rather, triple cropping tends to be associated with increases in yield and income.

Our results do not support the view that triple cropping practices reduce soil quality and farm incomes, thereby undermining the sustainability of rice production, both economically and environmentally. This perspective contrasts with that reflected in the recent policy trend to reduce the cropping intensity in the VMD. Several socio-economic factors that emerged after our study period (i.e., 2006-2012), such as the decline in paddy prices, the expansion of off-farm employment opportunities, and the increasing concern about climate changes, are possible reasons for the policy shift. However, it should be noted that the farmers have largely maintained the area share of triple cropping by increasing the use of agricultural mechanization service providers. Therefore, despite economic and environmental concerns, the preference for triple cropping over double cropping has not decreased.

Our study has several limitations. First, due to data availability, the cumulative effects of triple cropping are aggregated when the consecutive years of triple cropping exceed 6 years (we report results using longer consecutive years in the Appendix). A more accurate discussion would be possible if further research analyzes the long-term effects over a longer period than in this paper. Second, we do not consider the externalities of triple cropping that may have affected our policy recommendations. Thus, further research should pay attention to the estimation of externalities. Third, we do not investigate whether flooding has a positive environmental impact on paddy fields. A possible research strategy to obtain this information is to compare the outcomes of double-cropping households in flooded and non-flooded communes, which we leave for further research.

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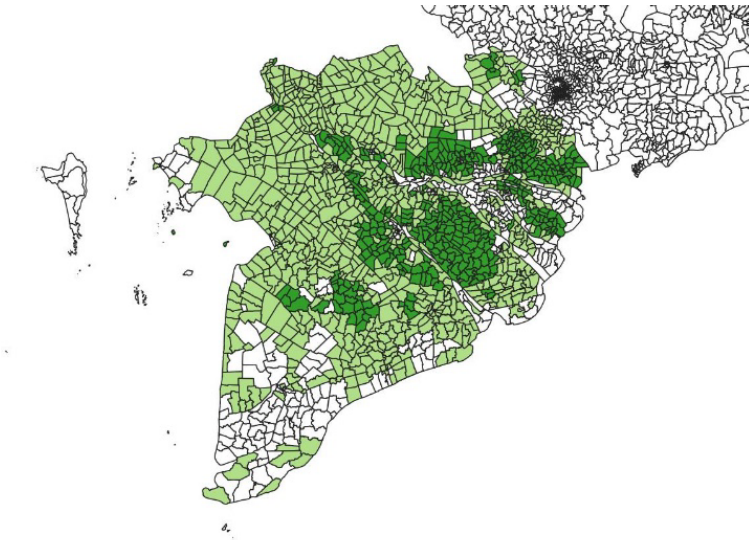
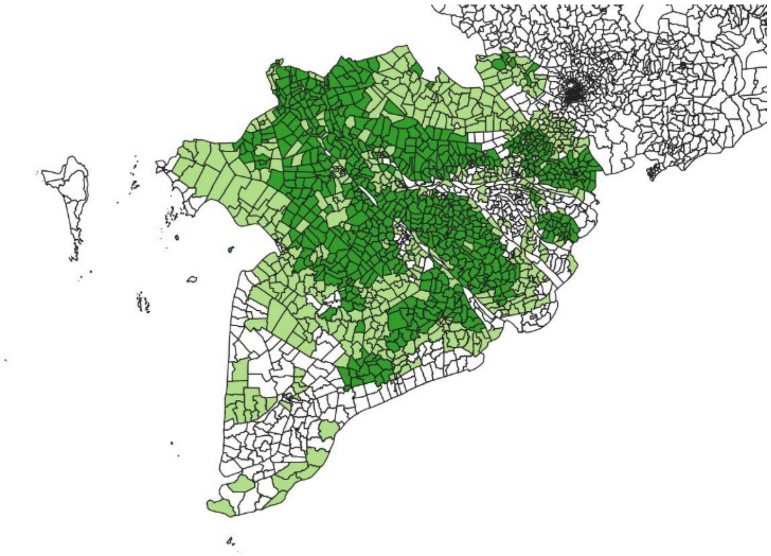


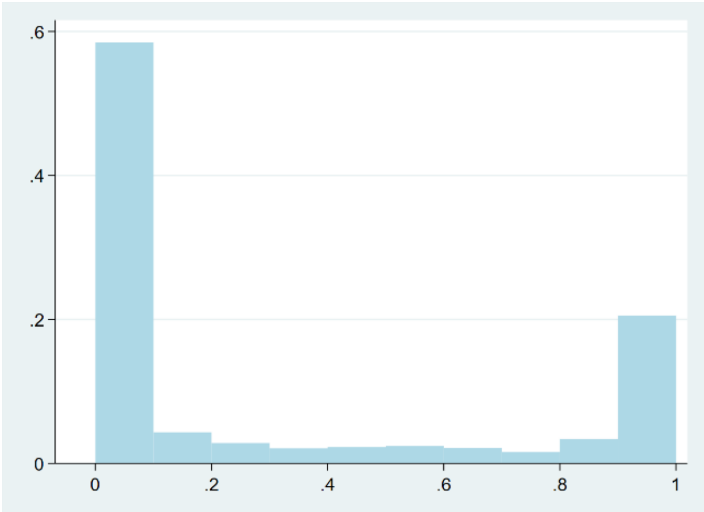
(a) 2001



(b) 2012

Figure 1: Rice cropping pattern in the Vietnamese Mekong Delta

Notes: Shaded polygons represent communes with paddy fields covering more than 10% of the total commune area. In the darker-shaded communes, the area under triple-cropping is more than 50% of the area under paddy ($area\_triple_{ct} > 0.5$); in the lighter-shaded communes, it is less than or equal to 50%.



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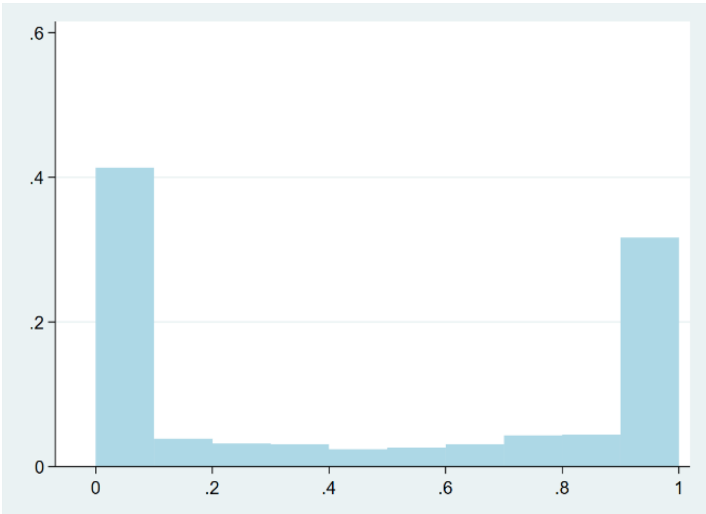

(b) 2012

Figure 2: Change in triple cropping ratio

Notes: The horizontal axis represents the ratio of the triple cropping area to the total paddy area in each commune. The vertical axis represents the relative frequency of communes being in each bin of the triple cropping ratio. The number of bins is 10.

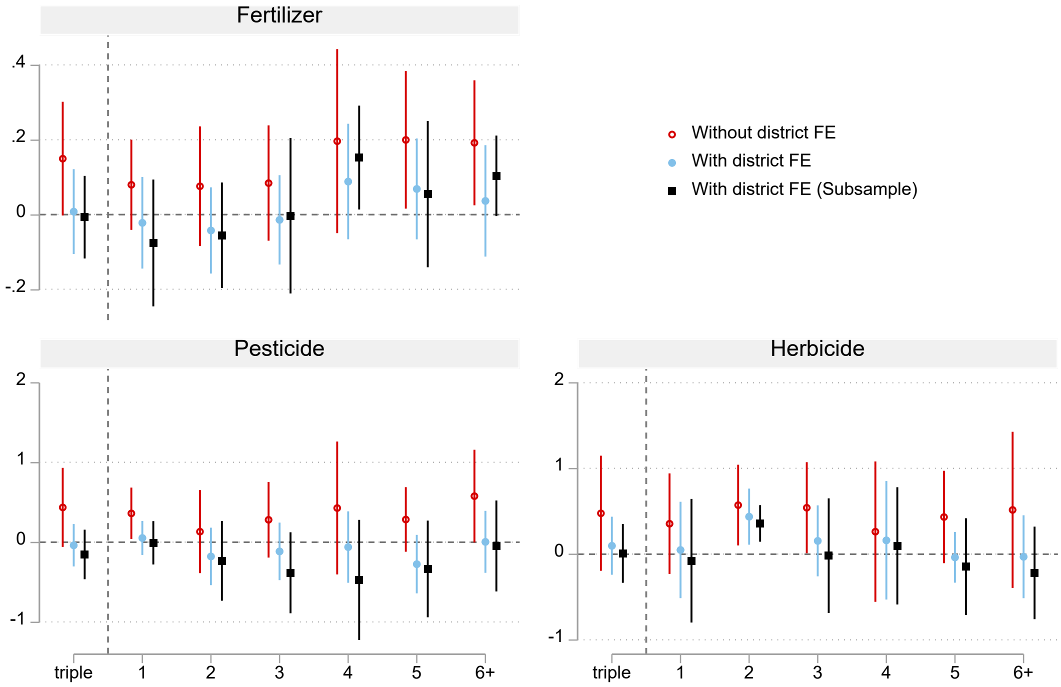

Figure 3. Triple cropping and input costs

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are the logs of the cost of fertilizer, pesticide, and herbicide per hectare (1000 VND/ha). Estimates are reported in Table 3. Covariates include GAEZ soil type, log of area planted, household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

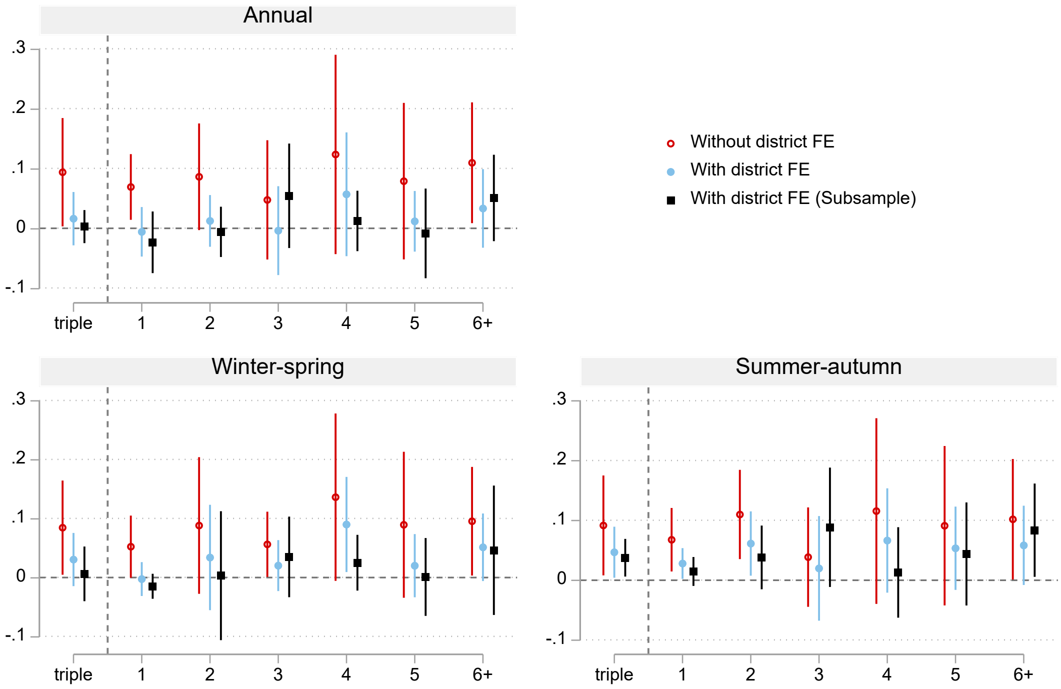

Figure 4. Triple cropping and yield

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are the log of rice yields. Estimates are reported in Table 4. Covariates include GAEZ soil type, log of area planted, household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

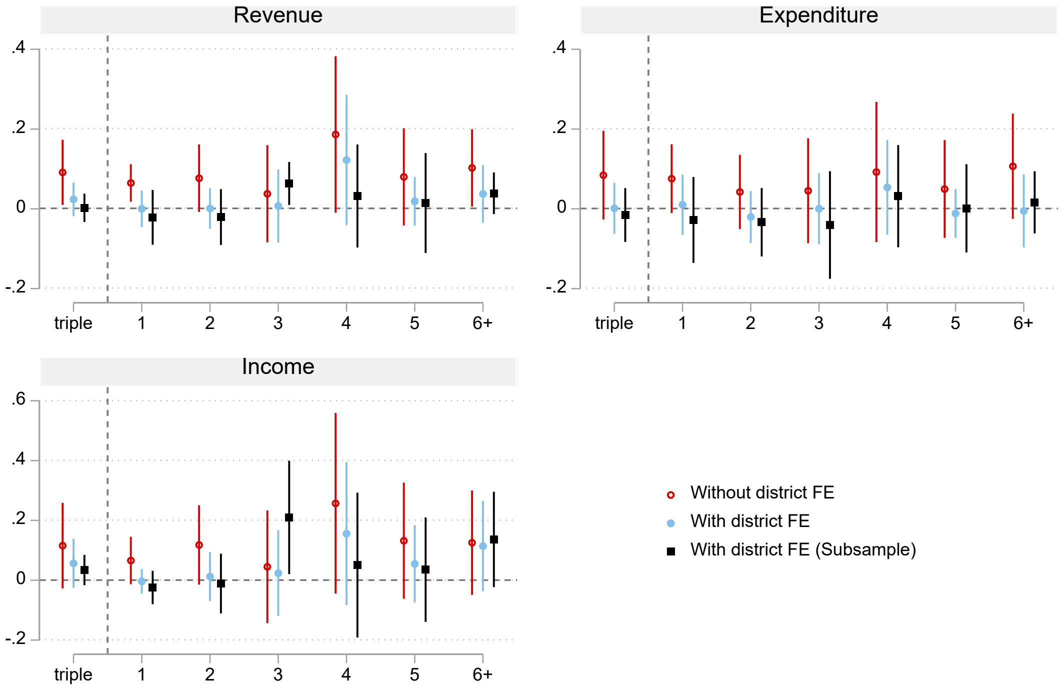

Figure 5. Continuation of triple rice cropping and income from rice production

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are the logs of revenue, expenditure, and income per planted area for paddy production. Estimates are reported in Table 5. Covariates include log of area planted, household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

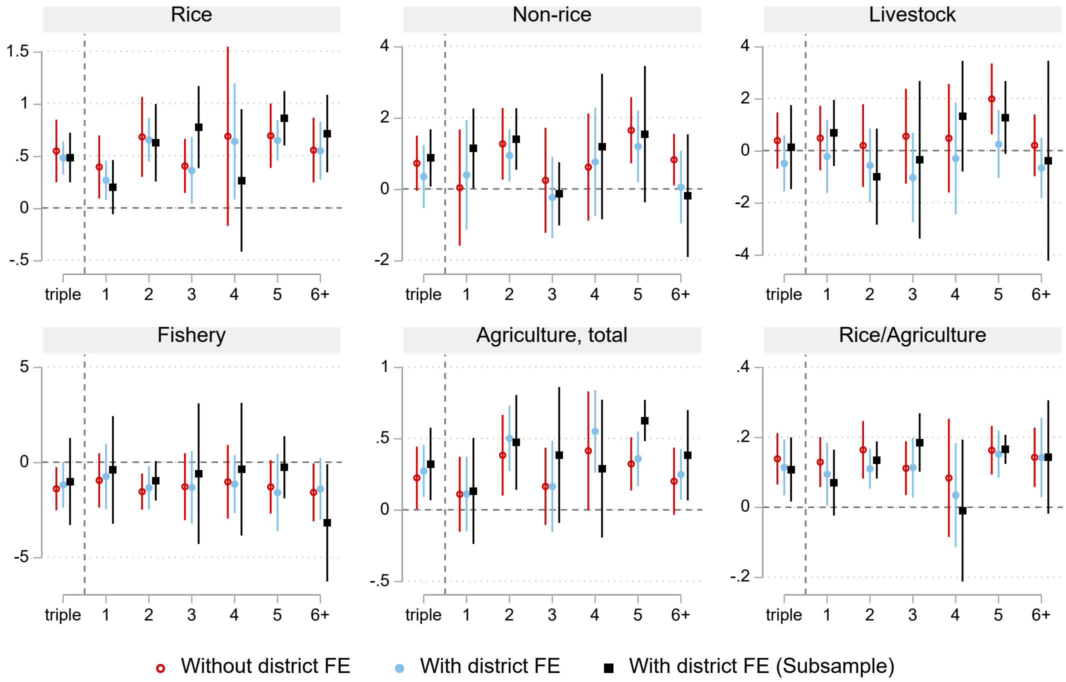

Figure 6. Triple cropping continuation and agricultural income

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are the logs of income from rice, other crops, livestock, fishery, and total agricultural income (1000 VND). Estimates are reported in Table 6. Covariates include household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

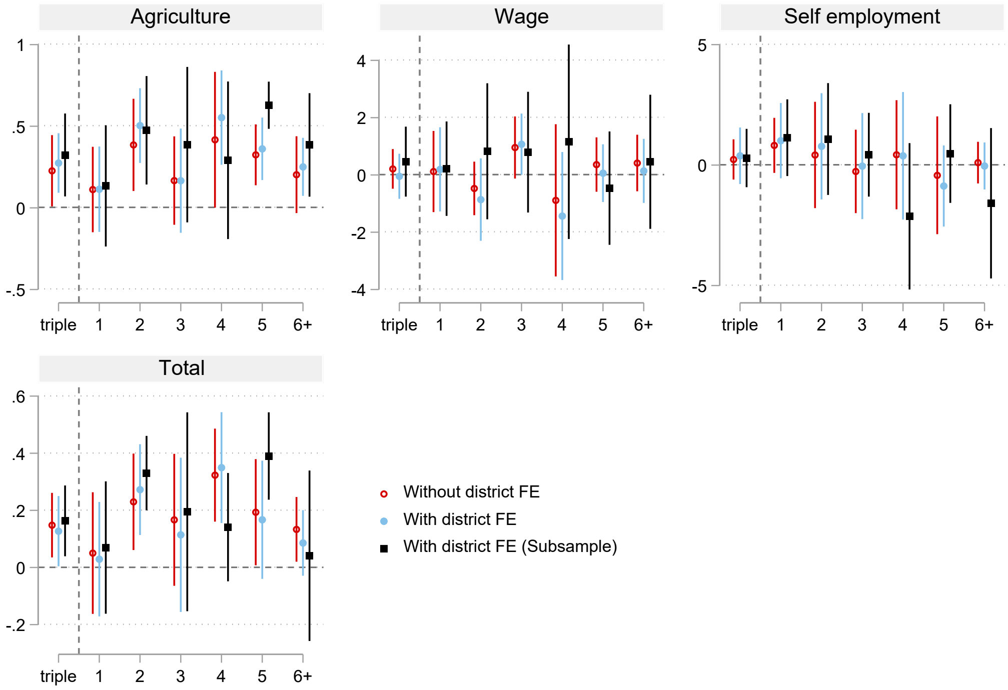

Figure 7. Triple cropping continuation and household income

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are the logs of income from agriculture, wage, self-employment, and total income (1000 VND). Estimates are reported in Table 7. Covariates include household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

Table 1. Basic characteristics of sample households and their rice farming

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
	Double cropping households			Triple cropping households			Difference	
	Obs.	Mean	S.D.	Obs.	Mean	S.D.	Diff.	s.e.
Inputs for rice farming								
Chemical fertilizer costs per planted area (1,000VND/ha)	539	3316.2	2115.5	1276	4153.6	1972.6	837.4 ***	-103.6
Pesticide costs per planted area (1,000VND/ha)	539	951.5	1143.4	1276	1445.1	1344.0	493.6 ***	-66.2
Herbicide costs per planted area (1,000VND/ha)	539	280.00	353.1	1276	401.6	312.6	121.6 ***	-16.7
Paddy yield								
Yield, total (kg/ha)	539	4387.5	1536	1276	5450.3	1035.0	1062.8 ***	-61.9
Yield, winter-spring (kg/ha)	302	5489.6	1627.4	1230	6435.7	1185.5	946.2 ***	-82.5
Yield, summer-autumn (kg/ha)	380	4163.8	1423.3	1208	4883.2	1082.8	719.3 ***	-69.0
Planted area for rice farming								
Planted area, total (ha)	539	2.123	2.954	1276	2.472	2.641	0.349 *	-0.141
Planted area, winter-spring (ha)	539	0.809	1.534	1276	0.963	1.084	0.154 *	-0.063
Planted area, summer-autumn (ha)	539	0.906	1.522	1276	0.973	1.183	0.068	-0.066
Rice farming (per planted area)								
Revenue per planted area (1,000VND/ha)	539	17807.9	9149.4	1276	21838.2	8590.8	4030.3 ***	-450.0
Expenditure per planted area (1,000VND/ha)	539	9322.7	5252.1	1276	11407.1	5167.8	2084.5 ***	-266.8
Net paddy income per planted area (1,000VND/ha	539	8485.2	5665.1	1276	10431.0	5495.2	1945.8 ***	-284.9
Agricultural income (annual household-level)								
log (income from rice farming)	525	9.030	1.390	1264	9.592	1.158	0.563 ***	-0.064
log (income from other crops)	461	5.108	4.357	1109	5.733	4.085	0.625 **	-0.231
log (income from livestock)	533	2.744	4.952	1266	3.378	5.065	0.634 *	-0.260
log (income from fishery)	532	4.608	4.980	1275	2.964	4.733	-1.643 ***	-0.248
log (agricultural income)	536	9.792	1.154	1274	10.010	1.010	0.216 ***	-0.054
Share of rice income among agricultural income	485	0.558	0.309	1152	0.699	0.257	0.142 ***	-0.015
Household income (annual household-level)								
log (agricultural income)	536	9.792	1.154	1274	10.010	1.010	0.216 ***	-0.054
log (wage income)	539	3.959	5.891	1276	4.246	5.843	0.287	-0.301
log (self-employment)	539	1.074	5.285	1275	1.207	5.408	0.133	-0.276
log (total household income)	538	10.440	0.882	1275	10.570	0.813	0.130 **	-0.043
Household characteristics								
Household size	539	4.419	1.530	1276	4.420	1.586	0.001	-0.081
Sex of household head (1 if male)	539	0.796	0.403	1276	0.815	0.388	0.019	-0.020
Age of household head	539	50.730	13.750	1276	50.330	13.610	-0.399	-0.701
Completed grade of household head	539	4.896	3.233	1276	5.230	3.344	0.334 *	-0.170
Observations		539			1,276		1,815	

Note. The unit of observation is household-year. Triple-cropping status is defined as whether a household is in a commune that practiced triple cropping in the observed year. We added 0.01 to the variables before taking the logarithm. When taking the logarithm, observations with negative values (especially for income) are dropped. We leave them dropped because such observations are small, except for 245 samples dropped for income from other crops (for other incomes, rice income drops 26 observations). We report estimation results using levels and all the observations in the Appendix.

Table 2. Number of sample households by consecutive years of triple cropping

Year	Consecutive years of triple cropping							
	0	1	2	3	4	5	6+	Total
2006	304	8	46	11	6	8	108	491
2008	250	30	17	4	30	6	73	410
2010	251	28	9	20	10	8	141	467
2012	169	55	36	26	8	23	130	447
Total	974	121	108	61	54	45	452	1,815

Note: This table shows number of observations by survey round and by consecutive years of triple cropping.

Table 3. Triple cropping and input use

(a) Fertilizer

	(1)	(2)	(3)	(4)	(5)	(6)
triple cropping in year t	0.151	0.009	-0.006			
	(0.070)	(0.052)	(0.051)			
Years of triple cropping = 1				0.081	-0.021	-0.075
				(0.055)	(0.056)	(0.0778)
Years of triple cropping = 2				0.077	-0.041	-0.054
				(0.073)	(0.053)	(0.065)
Years of triple cropping = 3				0.085	-0.013	-0.002
				(0.071)	(0.055)	(0.095)
Years of triple cropping = 4				0.197	0.089	0.153
				(0.113)	(0.071)	(0.064)
Years of triple cropping = 5				0.201	0.070	0.056
				(0.084)	(0.062)	(0.090)
Years of triple cropping = 6+				0.193	0.038	0.105
				(0.077)	(0.068)	(0.049)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	No	Yes	Yes	No	Yes	Yes
Subsample	No	No	Yes	No	No	Yes
Observations	1,815	1,815	1,152	1,815	1,815	1,152
Within-R2	0.029	0.199	0.190	0.032	0.200	0.193

(b) Pesticide

	(1)	(2)	(3)	(4)	(5)	(6)
triple cropping in year t	0.439	-0.035	-0.150			
	(0.227)	(0.122)	(0.142)			
Years of triple cropping = 1				0.365	0.056	-0.004
				(0.148)	(0.098)	(0.125)
Years of triple cropping = 2				0.136	-0.175	-0.230
				(0.239)	(0.165)	(0.229)
Years of triple cropping = 3				0.284	-0.112	-0.379
				(0.217)	(0.165)	(0.233)
Years of triple cropping = 4				0.432	-0.058	-0.469
				(0.382)	(0.205)	(0.345)
Years of triple cropping = 5				0.288	-0.271	-0.331
				(0.186)	(0.168)	(0.278)
Years of triple cropping = 6+				0.581	0.008	-0.044
				(0.266)	(0.178)	(0.261)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	No	Yes	Yes	No	Yes	Yes
Subsample	No	No	Yes	No	No	Yes
Observations	1,815	1,815	1,152	1,815	1,815	1,152
Within-R2	0.063	0.314	0.301	0.068	0.315	0.302

(c) Herbicide

	(1)	(2)	(3)	(4)	(5)	(6)
triple cropping in year t	0.479	0.100	0.010			
	(0.308)	(0.155)	(0.157)			
Years of triple cropping = 1				0.357	0.051	-0.075
				(0.269)	(0.258)	(0.331)
Years of triple cropping = 2				0.574	0.439	0.360
				(0.216)	(0.150)	(0.098)
Years of triple cropping = 3				0.544	0.157	-0.016
				(0.244)	(0.190)	(0.307)
Years of triple cropping = 4				0.264	0.163	0.099
				(0.376)	(0.317)	(0.314)
Years of triple cropping = 5				0.435	-0.035	-0.144
				(0.247)	(0.136)	(0.259)
Years of triple cropping = 6+				0.518	-0.028	-0.217
				(0.418)	(0.222)	(0.248)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	No	Yes	Yes	No	Yes	Yes
Subsample	No	No	Yes	No	No	Yes
Observations	1,815	1,815	1,152	1,815	1,815	1,152
Within-R2	0.049	0.270	0.252	0.049	0.272	0.254

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure 3 provides a visual representation of the estimation results.

Table 4. Triple cropping continuation and yield

	(1) Annual	(2) Annual	(3) Win.-sum.	(4) Win.-sum.	(5) Sum.-aut.	(6) Sum.-aut.
triple cropping in year t	0.0037		0.0067		0.0378	
	(0.0127)		(0.0210)		(0.0144)	
Years of triple cropping = 1		-0.0225		-0.0143		0.0149
		(0.0236)		(0.0096)		(0.0111)
Years of triple cropping = 2		-0.0051		0.00363		0.0383
		(0.0193)		(0.0496)		(0.0244)
Years of triple cropping = 3		0.0552		0.0355		0.0887
		(0.0401)		(0.031)		(0.0458)
Years of triple cropping = 4		0.0131		0.0256		0.0132
		(0.0232)		(0.0215)		(0.0347)
Years of triple cropping = 5		-0.0076		0.0015		0.0441
		(0.0344)		(0.0300)		(0.0395)
Years of triple cropping = 6+		0.0516		0.0467		0.0838
		(0.0331)		(0.0498)		(0.0358)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Subsamples	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,152	1,152	892	892	969	969
Within-R2	0.421	0.422	0.418	0.421	0.227	0.229

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure 4 provides a visual representation of the estimation results.

Table 5. Continuation of triple rice cropping and income from rice production

	(1) Revenue	(2) Revenue	(3) Expenditure	(4) Expenditure	(5) Income	(6) Income
triple cropping in year t	0.0022		-0.0156		0.0339	
	(0.0163)		(0.0310)		(0.0232)	
Years of triple cropping = 1		-0.0215		-0.0281		-0.0244
		(0.0315)		(0.0494)		(0.0256)
Years of triple cropping = 2		-0.0208		-0.0336		-0.0111
		(0.0321)		(0.0394)		(0.0458)
Years of triple cropping = 3		0.0634		-0.0407		0.2100
		(0.0248)		(0.0619)		(0.0869)
Years of triple cropping = 4		0.0320		0.0316		0.0505
		(0.0593)		(0.0588)		(0.111)
Years of triple cropping = 5		0.0143		0.0012		0.0354
		(0.0575)		(0.0508)		(0.0801)
Years of triple cropping = 6+		0.0388		0.0162		0.1360
		(0.0239)		(0.0357)		(0.0731)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Subsamples	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,152	1,152	1,152	1,152	1,136	1,136
Within-R2	0.378	0.38	0.386	0.387	0.198	0.202

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure 5 provides a visual representation of the estimation results.

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Table 6. Triple cropping continuation and agricultural income

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Rice	Rice	Non-rice	Non-rice	Livestock	Livestock	Fishery	Fishery	Total	Total	%Rice	%Rice
triple cropping in year t	0.489		0.883		0.149		-0.998		0.323		0.109	
	(0.109)		(0.368)		(0.740)		(1.051)		(0.117)		(0.042)	
Years of triple cropping = 1		0.205		1.153		0.694		-0.386		0.134		0.071
		(0.119)		(0.513)		(0.583)		(1.298)		(0.170)		(0.043)
Years of triple cropping = 2		0.630		1.414		-0.983		-0.959		0.475		0.136
		(0.170)		(0.396)		(0.846)		(0.477)		(0.152)		(0.024)
Years of triple cropping = 3		0.780		-0.122		-0.336		-0.585		0.387		0.186
		(0.181)		(0.407)		(1.390)		(1.697)		(0.218)		(0.038)
Years of triple cropping = 4		0.269		1.204		1.339		-0.349		0.291		-0.009
		(0.313)		(0.936)		(0.975)		(1.601)		(0.221)		(0.093)
Years of triple cropping = 5		0.865		1.551		1.288		-0.246		0.628		0.166
		(0.120)		(0.878)		(0.643)		(0.750)		(0.066)		(0.019)
Years of triple cropping = 6+		0.719		-0.174		-0.376		-3.167		0.385		0.144
		(0.171)		(0.789)		(1.762)		(1.414)		(0.145)		(0.074)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subsamples	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,136	1,136	966	966	1,145	1,145	1,144	1,144	1,149	1,149	1,029	1,029
Within-R2	0.298	0.306	0.257	0.262	0.176	0.182	0.2	0.209	0.217	0.221	0.248	0.256

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure 6 provides a visual representation of the estimation results.

Table 7. Household income

	(1) Agriculture	(2) Agriculture	(3) Wage	(4) Wage	(5) Self	(6) Self	(7) Total	(8) Total
triple cropping in year t	0.323		0.461		0.290		0.163	
	(0.117)		(0.561)		(0.556)		(0.057)	
Years of triple cropping = 1		0.134		0.216		1.135		0.070
		(0.170)		(0.757)		(0.731)		(0.106)
Years of triple cropping = 2		0.475		0.824		1.080		0.330
		(0.152)		(1.090)		(1.065)		(0.060)
Years of triple cropping = 3		0.387		0.793		0.429		0.195
		(0.218)		(0.967)		(0.798)		(0.160)
Years of triple cropping = 4		0.291		1.155		-2.128		0.141
		(0.221)		(1.558)		(1.394)		(0.087)
Years of triple cropping = 5		0.628		-0.463		0.476		0.390
		(0.066)		(0.908)		(0.939)		(0.070)
Years of triple cropping = 6+		0.385		0.457		-1.586		0.041
		(0.145)		(1.074)		(1.432)		(0.137)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subsamples	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,149	1,149	1,152	1,152	1,152	1,152	1,151	1,151
Within-R2	0.217	0.221	0.144	0.145	0.135	0.145	0.324	0.329

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure 7 provides a visual representation of the estimation results.

Appendix

A. Selection at the commune level

To examine whether communes that adopted triple cropping earlier have different characteristics than others, we use the 2002 VHLSS data and compare the outcomes of (i) *early adopters* who started triple cropping in or before 2002, (ii) *late adopters* who started triple cropping after 2002, and (iii) *never adopters* who remained with double cropping throughout our observation period (2001-2012). Note that because we are comparing the outcomes in 2002, the outcomes for early adopters are affected by triple cropping. The specification is,

$$y_{ic,2002} = \alpha + \beta_1 early_{ic,2002} + \beta_2 late_{ic,2002} + X_{ic,2002}\gamma + u_d + v_{pt} + \varepsilon_{ic,200w}.$$

Table A1 shows the estimates and Figure A1 provides a graphical representation. Triple cropping households tend to have higher log yields, higher GAEZ predicted yields, and higher total value per area planted. Early adopters tend to have higher estimated coefficients than the late adopters. There is no clear evidence that triple-cropping households spent more on fertilizer, but they do seem to have spent more on pesticides and herbicides.

The continuation of triple-cropping may be detrimental to rice farming and eventually force farmers out of the business. If this is the case, such communes will be dropped from our sample. This will underestimate the negative impact of triple cropping. It is not possible to examine this possibility of this attrition with the VHLSS data, but we can examine whether the area of paddy fields decreased for communes with longer consecutive years of triple cropping. To do this, we use the satellite imagery data and construct a commune-level balanced panel data at the commune level for 2001 to 2012, with variables for area, paddy area, dummy for triple cropping, and consecutive years of triple cropping.

We then regress the variables capturing the status of rice production on the triple-cropping dummy or consecutive years of a triple cropping (continuous), with commune and year fixed effects. The outcome variables are the area share of paddy fields (out of total area) and an indicator for "rice-producing commune", such that the area of paddy fields exceeds 10% of the area of the commune. The results in Table A2 show that the area share of paddy area decreased by less than 0.4 percentage points when triple cropping was practiced (columns 1 to 3). Columns 4 to 6 show that triple cropping is not correlated with the commune's rice production status. Taken together, we find no evidence suggesting that triple cropping reduces rice area.

B. Fertilizer inputs in quantity

We report the correlation between triple-cropping and the logarithm of the annual amount of fertilizer used per hectare (kg/ha) in Figure A2 and Table A3. We observe that NPK use increases after 3 consecutive years of triple-cropping. This is similar to the pattern of annual fertilizer cost (1000 VND/ha) reported in the main text.

C. Yield with control for inputs

Figure A3 and Table A4 report the estimates of triple-cropping dummies and consecutive years of triple-cropping on the logarithms of yield (kg/ha), controlling for the annual input costs (1000 VND/ha) in addition to the usual covariates. The estimates can be interpreted as a direct effect of triple-cropping on yield, after controlling for input use. Note, however, that input costs are not available by crop season. Therefore, the results by crop season are for reference only.

D. Estimations using levels of costs and earnings

In the main text, we estimated the correlation between triple-cropping and outcomes by taking the logarithms of the outcomes. However, taking logarithms drops observations with negative values. Although the number of dropped observations is small, we report the estimation results here using the levels of costs and incomes, rather than the logarithms in the main text (Figure A4-A7 and Table A5-A8). The patterns are similar.

E. Longer consecutive years of triple cropping

Because we top-coded the consecutive years of triple cropping ($years\_triple_{ct}$) to six years, we cannot examine the longer correlation of triple-cropping with the outcomes. The main reason for top-coding is that there are only few observations with $years\_triple_{ct}$ above six (Table A9).

Nevertheless, to examine longer correlations, we report the results without top-coding, at the risk of introducing variations and noise in the estimates due to the small number of observations (Figures A8–A12 and Tables A10-A14). Note that the analysis is restricted to subsample that excludes "early adopters" in order to identify $years\_triple_{ct}$ above six.

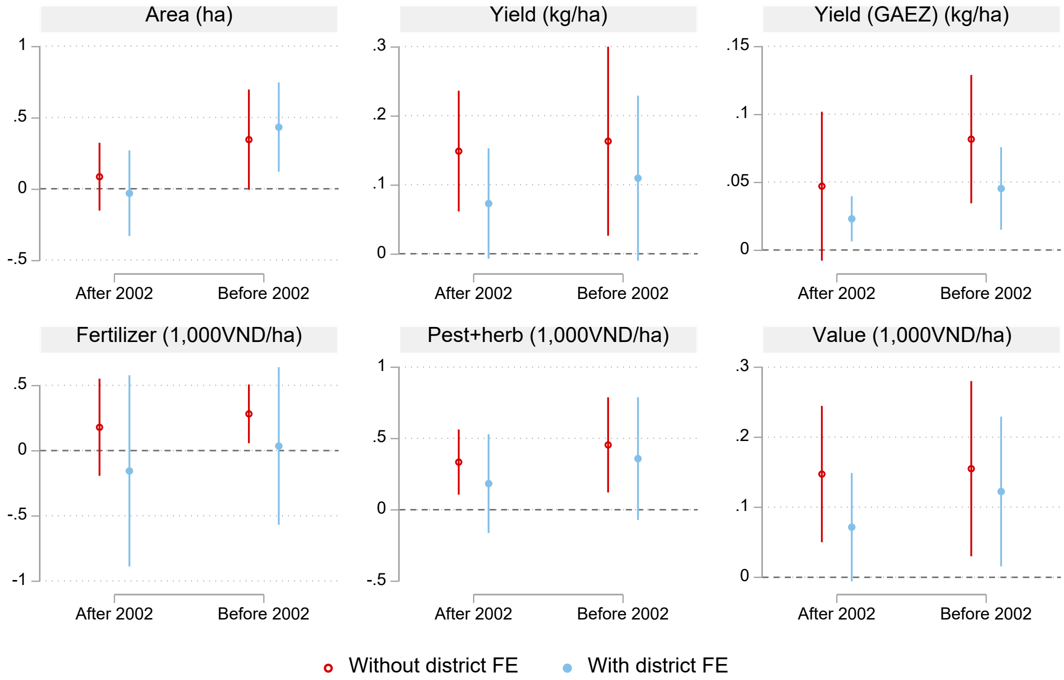

Figure A1. Selection

Note: This figure shows the estimated coefficients of the dummies for "early adopters" (started triple cropping in or before 2002) and "late adopters" (started triple cropping after 2002). The reference group is the "never adopters" (households in communes that did not adopt triple cropping between 2001 and 2012). Estimates are reported in Table A1. Covariates include household size, age, sex, and educational attainment of the household head. For yield, the log of the planted area is also included. The dot represents the point estimate; the bar represents the 95% confidence interval.

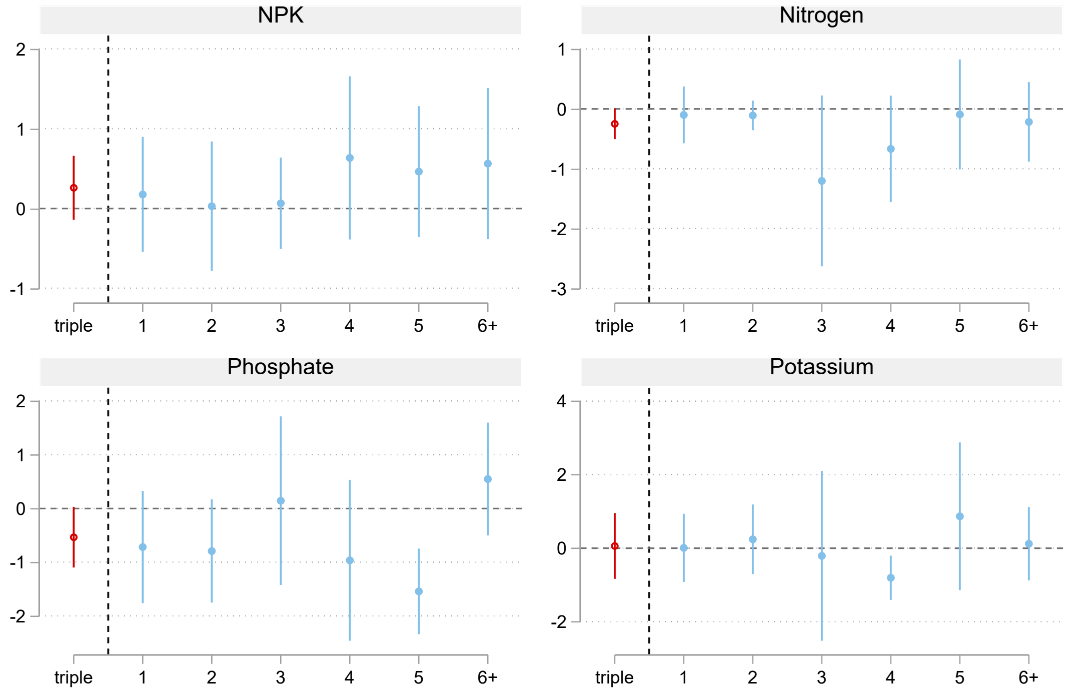

Figure A2. Triple-cropping and the quantity of fertilizer

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are the annual amounts of fertilizer used per hectare (kg/ha). Estimates are reported in Table A3. Covariates include household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

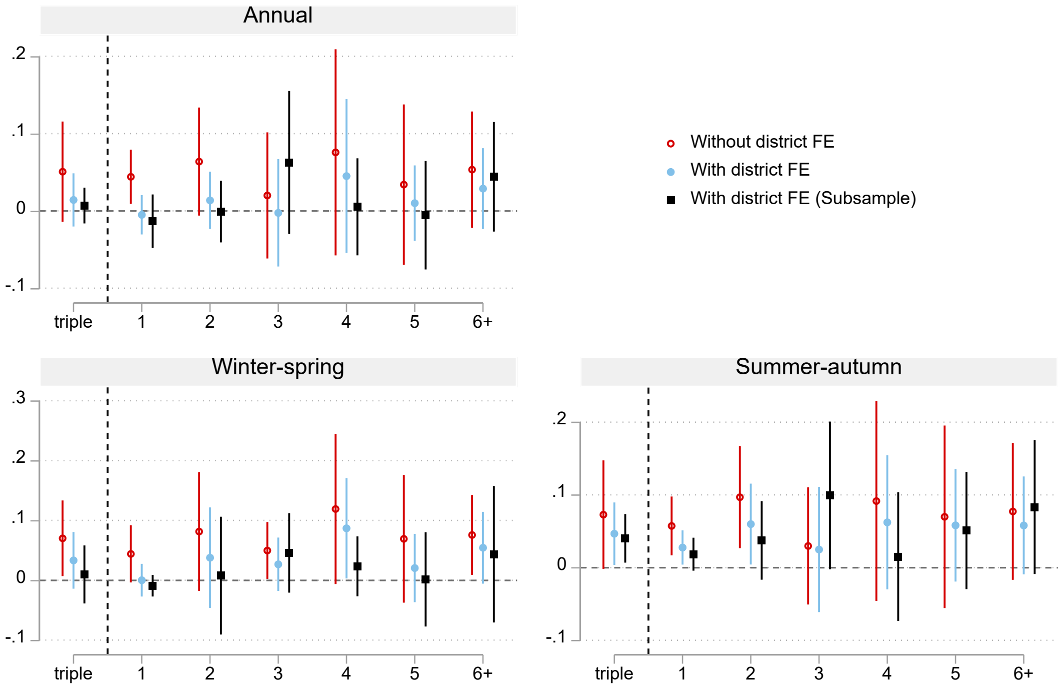

Figure A3. Triple-cropping and yield with control for inputs

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are the log of rice yields. Estimates are reported in Table A4. Covariates include GAEZ soil type, log of area planted, log of costs for fertilizer, pesticide, and herbicide per hectare (1000 VND/ha), household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

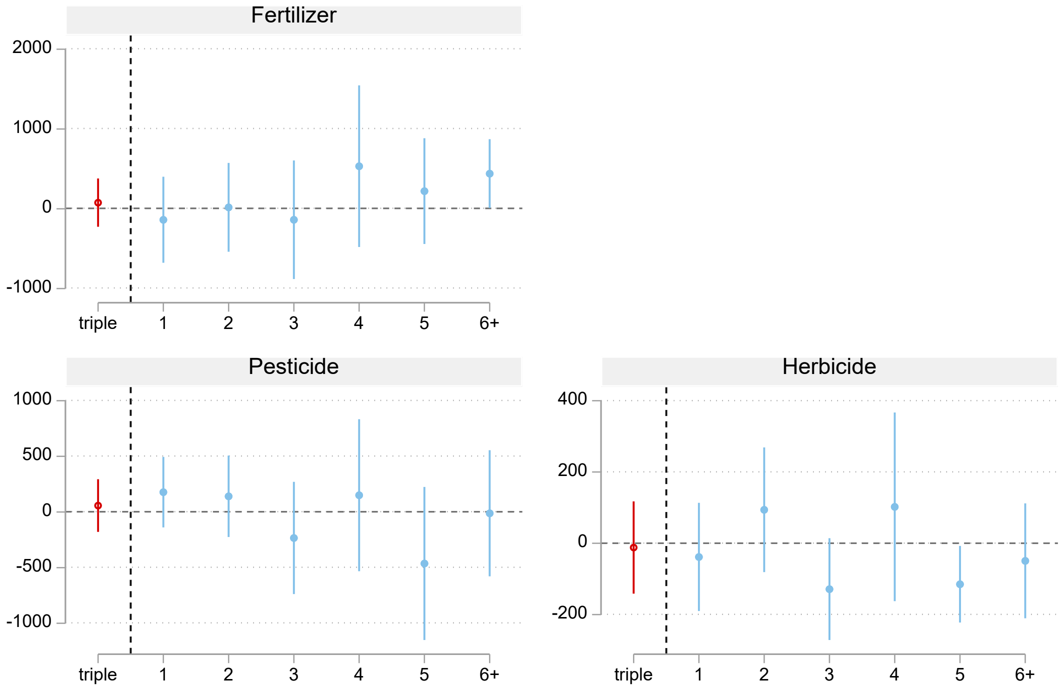

Figure A4. Triple-cropping and input costs (in levels)

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are the cost of fertilizer, pesticide, and herbicide per hectare (1000 VND/ha) (in levels). Estimates are reported in Table A5. Covariates include GAEZ soil type, log of area planted, household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

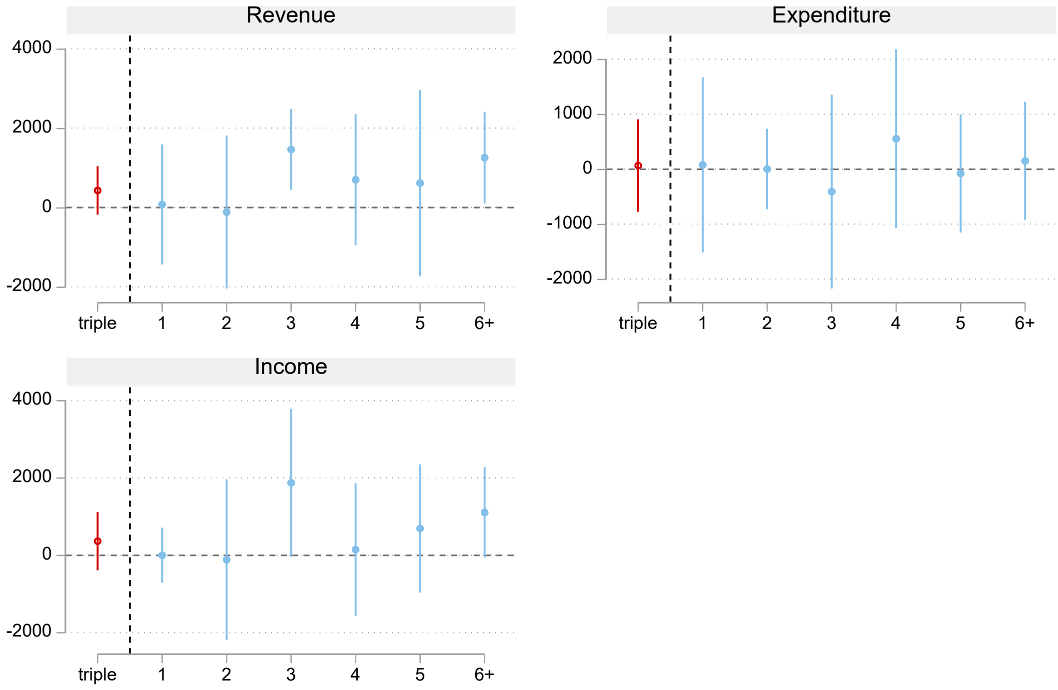

Figure A5. Triple-cropping and income from rice production (in levels)

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are revenue, expenditure, and income per planted area for paddy production (in levels). Estimates are reported in Table A6. Covariates include GAEZ soil type, log of area planted, household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

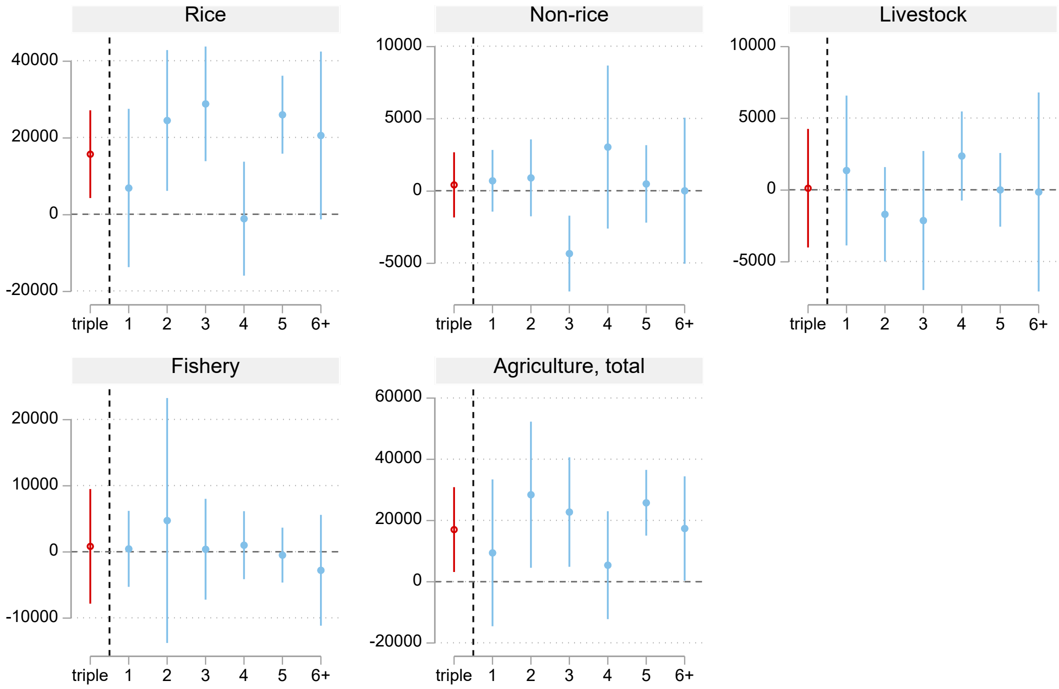

Figure A6. Triple-cropping and agricultural income (in levels)

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are income from rice, other crops, livestock, fishery, and total agricultural income (1000 VND) (in levels). Estimates are reported in Table A7. Covariates include household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

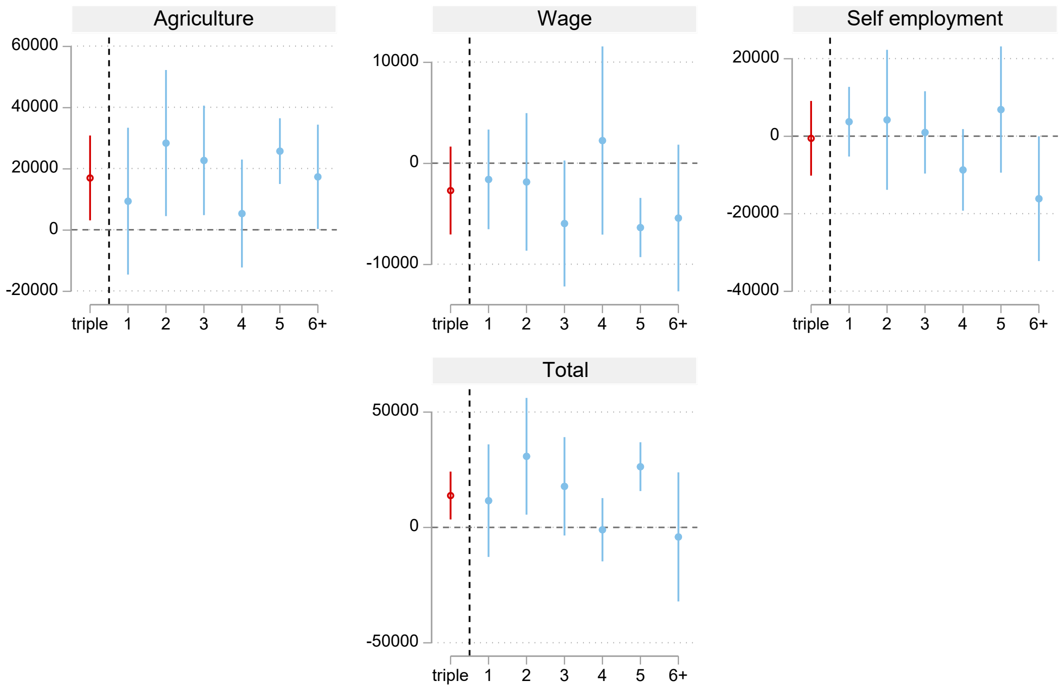

Figure A7. Triple-cropping and household income (in levels)

Note: This figure shows the estimated coefficients from the two regression models. The coefficients of the triple-cropping dummy are to the left of the dashed vertical line. The coefficients of the consecutive years of the triple-cropping dummies are to the right of the dashed vertical line. The outcome variables are income from rice, other crops, livestock, fishery, and total agricultural income (1000 VND) (in levels). Estimates are reported in Table A8. Covariates include household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

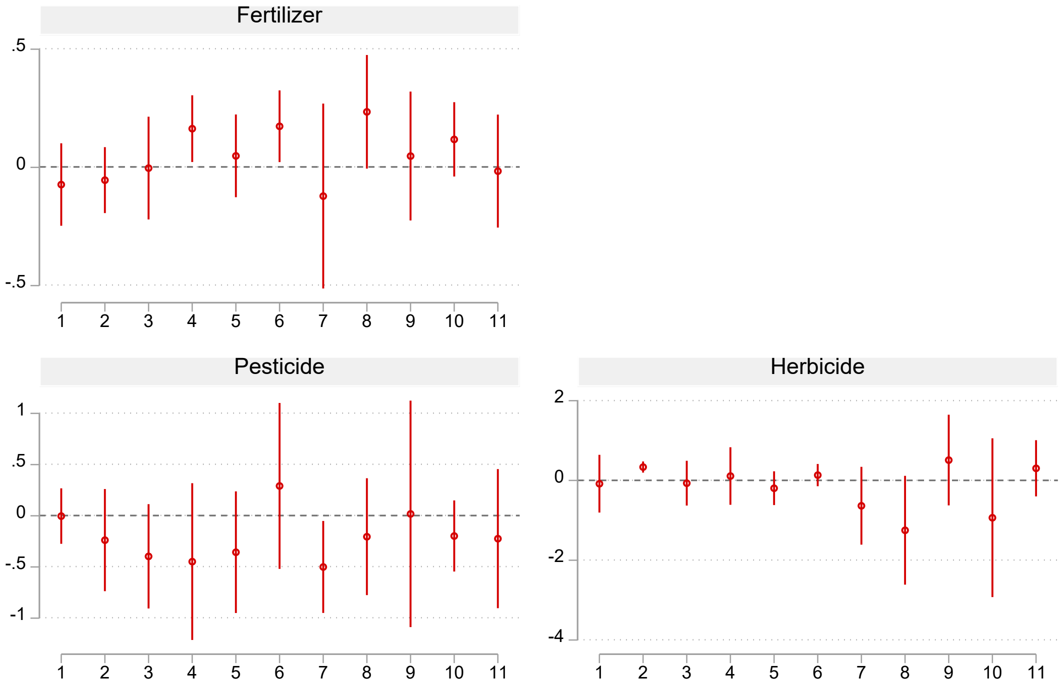

Figure A8. Consecutive years of triple cropping and input costs

Note: This figure shows the estimated coefficients of the consecutive years of the triple-cropping dummies. The outcome variables are the logs of the cost of fertilizer, pesticide, and herbicide per hectare (1000 VND/ha). Estimates are reported in Table A10. Covariates include GAEZ soil type, log of area planted, household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

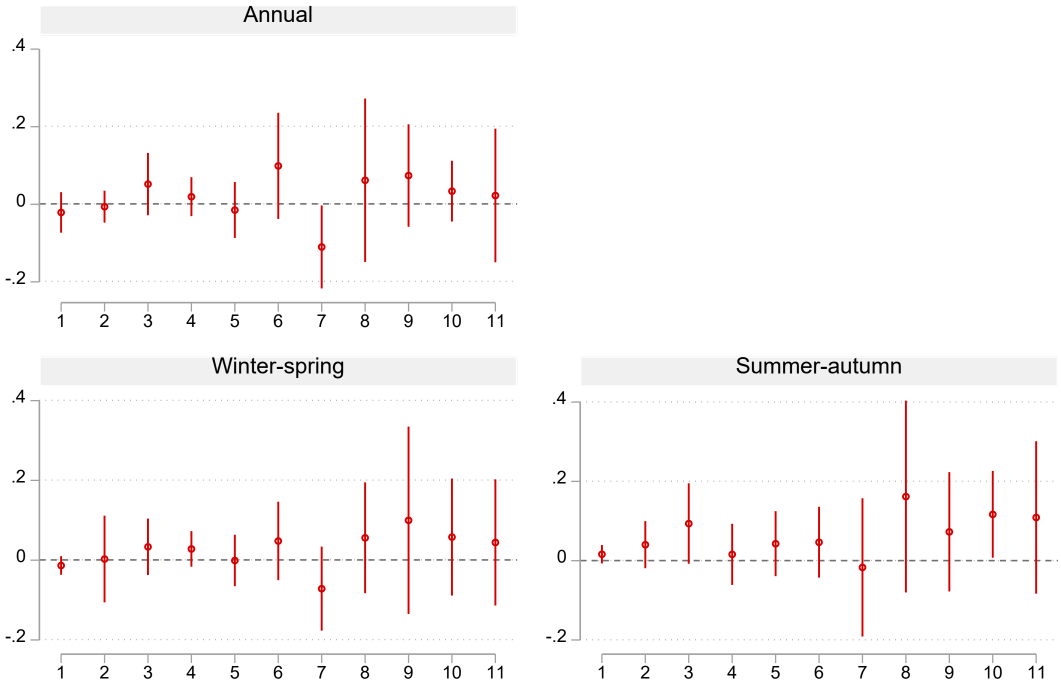

Figure A9. Consecutive years of triple cropping and yield (controlling input costs)

Note: This figure shows the estimated coefficients of the consecutive years of the triple-cropping dummies. The outcome variables are the log of rice yields. Estimates are reported in Table A11. Covariates include GAEZ soil type, log of area planted, household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

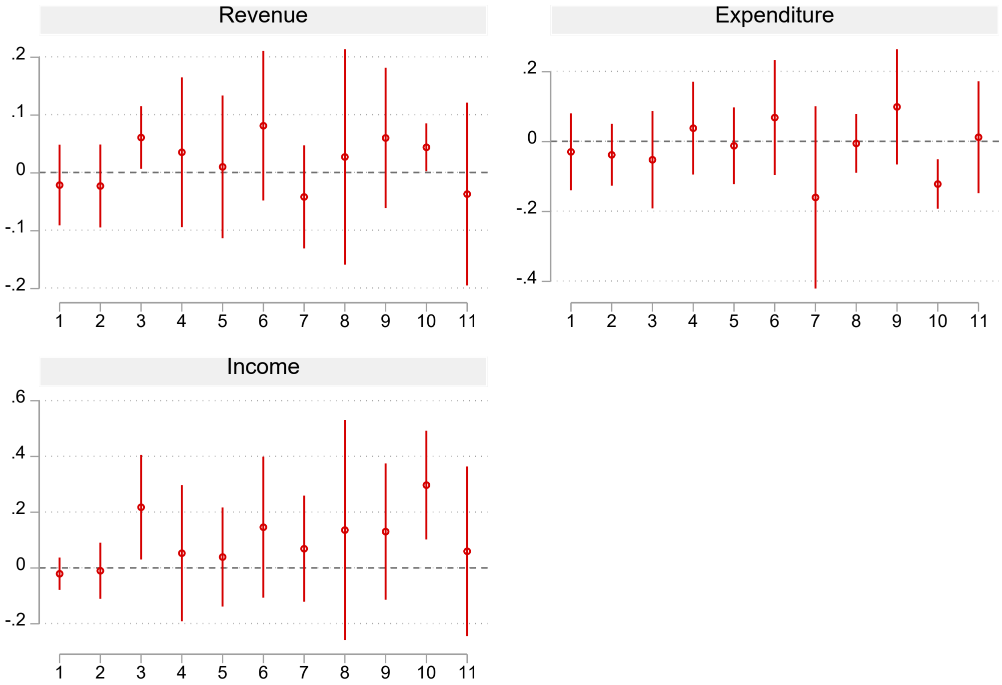

Figure A10. Consecutive years of triple cropping and income from rice farming

Note: This figure shows the estimated coefficients of the consecutive years of the triple-cropping dummies. The outcome variables are the logs of revenue, expenditure, and income per planted area for paddy production. Estimates are reported in Table A12. Covariates include the log of area planted, household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

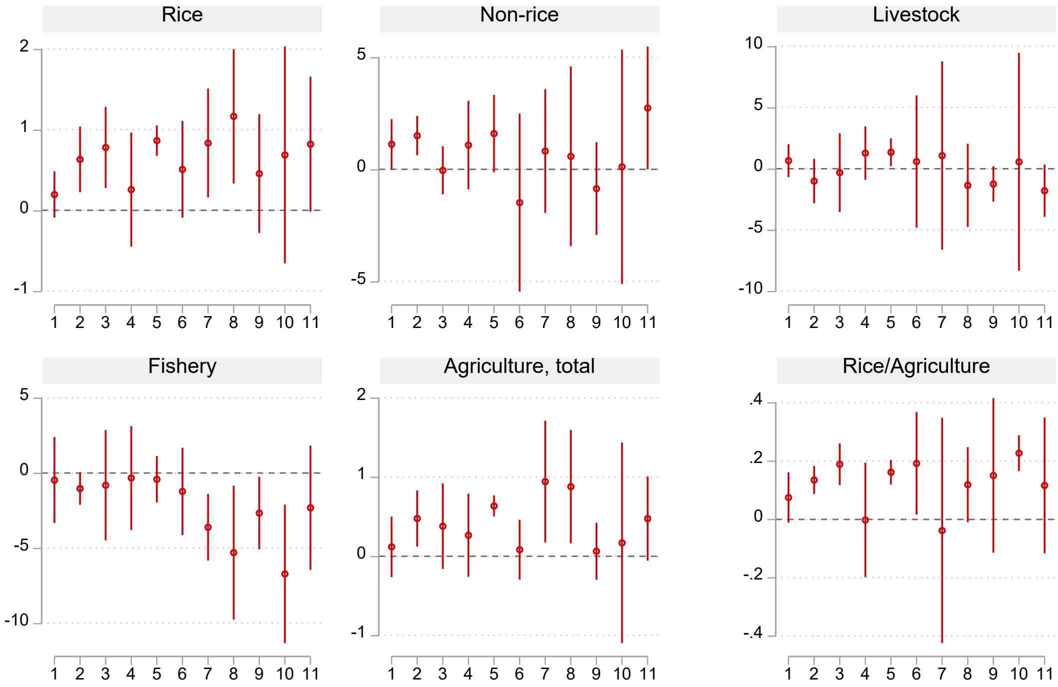

Figure A11. Consecutive years of triple cropping and agricultural income

Note: This figure shows the estimated coefficients of the consecutive years of the triple-cropping dummies. The outcome variables are the logs of income from rice, other crops, livestock, fishery, and total agricultural income (1000 VND). Estimates are reported in Table A13. Covariates include household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

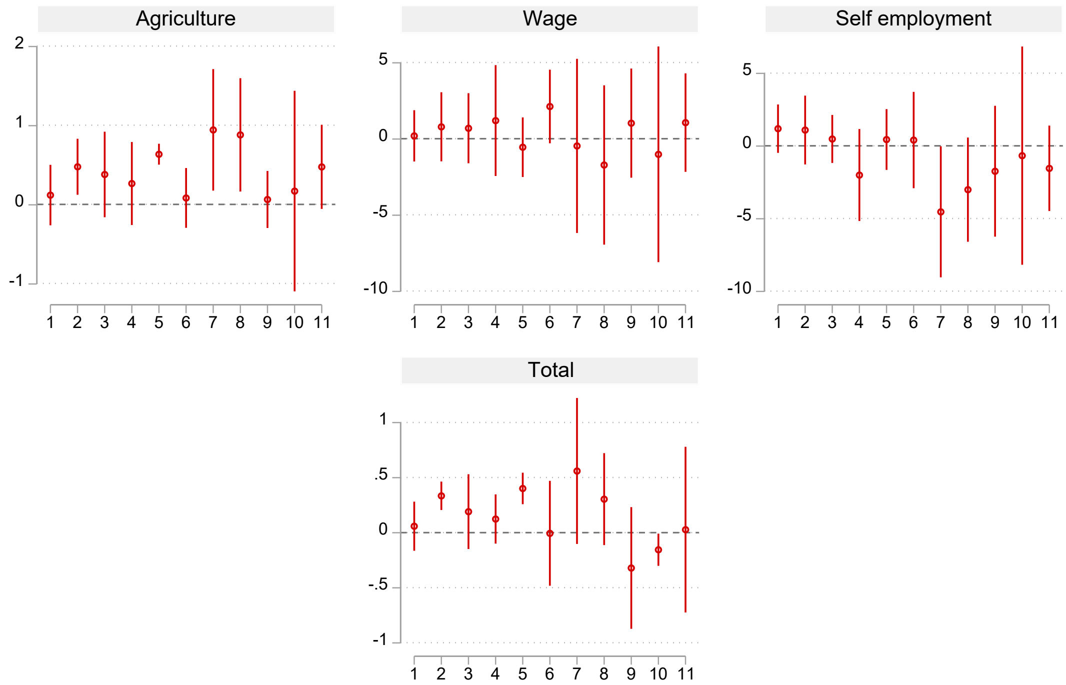

Figure A12. Consecutive years of triple cropping and household income

Note: This figure shows the estimated coefficients of the consecutive years of the triple-cropping dummies. The outcome variables are the logs of income from agriculture, wage, self-employment, and total income (1000 VND). Estimates are reported in Table A14. Covariates include household size, age, sex, and educational attainment of the household head. The dot represents the point estimate; the bar represents the 95% confidence interval.

Table A1. Comparison of farm characteristics between early, late, and never adopters

	(1)	(2)	(3)	(4)	(5)	(6)
	Area	Area	Yield	Yield	GAEZ	GAEZ
Triple cropping after 2002	0.0883	-0.0272	0.149	0.0734	0.0472	0.0232
	(0.109)	(0.138)	(0.0401)	(0.0367)	(0.0252)	(0.00762)
Triple cropping before 2002	0.348	0.436	0.164	0.11	0.0819	0.0456
	(0.161)	(0.144)	(0.0628)	(0.0548)	(0.0217)	(0.014)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	No	Yes	No	Yes	No	Yes
Observations	2,021	2,021	2,020	2,020	2,021	2,021
Within-R2	0.0595	0.272	0.0632	0.312	0.129	0.798

	(7)	(8)	(9)	(10)	(11)	(12)
	Fertilizer	Fertlizer	Pest+herb	Pest+herb	Value	Value
Triple cropping after 2002	0.181	-0.154	0.335	0.185	0.147	0.0717
	(0.171)	(0.337)	(0.105)	(0.159)	(0.0446)	(0.0355)
Triple cropping before 2002	0.283	0.0366	0.456	0.360	0.155	0.123
	(0.103)	(0.277)	(0.153)	(0.197)	(0.0574)	(0.0490)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	No	Yes	No	Yes	No	Yes
Observations	2,020	2,020	2,020	2,020	2,020	2,020
Within-R2	0.0197	0.274	0.0342	0.149	0.0478	0.299

Note: Outcome variables are logs of total area planted(ha), yield (kg/ha), predicted yield (GAEZ) (kg/ha), fertilizer cost (1000 VND/ha), pesticide and herbicide cost (1000 VND/ha), total output (kg/ha), and total output value (1000VND/ha) per area planted for rice production. We added 0.01 to the variables before taking the logarithm. The covariates include the log of the planted area (except for columns 1 and 2), household size, age, sex, and education of the household head. Standard errors in parentheses are clustered at the province level. Figure A1 provides a visual representation of the estimation results.

Table A2. Triple cropping and area of paddy fields

	(1)	(2)	(3)	(4)	(5)	(6)
	%field	%field	%field	Producing	Producing	Producing
c_triple > 0.5	-0.00199		-0.00377	0.00139		-0.00140
	(0.00164)		(0.00171)	(0.00394)		(0.00380)
Years of triple cropping		0.000308	0.000875		0.00116	0.00137
		(0.000439)	(0.000453)		(0.00100)	(0.000935)
Commune fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	22,200	22,200	22,200	22,200	22,200	22,200
Within-R2	0.0150	0.0149	0.0151	0.00534	0.00539	0.00539

Note: The unit of observation is commune-year. The data use a balanced panel of communes. Area is defined in pixels of satellite imagery. Standard errors are in parentheses.

Table A3. Triple-cropping and the quantity of fertilizer

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	NPK	NPK	Nitrogen	Nitrogen	Phosphate	Phosphate	Potassium	Potassium
triple cropping	0.268		-0.241		-0.529		0.0637	
	(0.184)		(0.118)		(0.259)		(0.410)	
Years of triple cropping = 1		0.184		-0.0920		-0.712		0.0125
		(0.330)		(0.218)		(0.479)		(0.426)
Years of triple cropping = 2		0.0377		-0.101		-0.786		0.245
		(0.372)		(0.114)		(0.441)		(0.434)
Years of triple cropping = 3		0.0733		-1.194		0.150		-0.206
		(0.263)		(0.655)		(0.719)		(1.060)
Years of triple cropping = 4		0.642		-0.659		-0.958		-0.801
		(0.469)		(0.408)		(0.687)		(0.276)
Years of triple cropping = 5		0.471		-0.0845		-1.536		0.871
		(0.376)		(0.421)		(0.365)		(0.922)
Years of triple cropping = 6+		0.571		-0.208		0.553		0.124
		(0.435)		(0.305)		(0.482)		(0.458)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects								
Mean of Dep. Variable								
Observations	1141	1141	1141	1141	1141	1141	1141	1141
Within-R2	0.210	0.212	0.235	0.243	0.205	0.212	0.204	0.207

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A2 provides a visual representation of the estimation results.

Table A4. Triple cropping and yield with control for inputs

	(1)	(2)	(3)	(4)	(5)	(6)
	Annual	Annual	Win.-sum.	Win.-sum.	Sum.-aut.	Sum.-aut.
triple cropping	0.00764		0.0104		0.0405	
	(0.0106)		(0.0220)		(0.0153)	
Years of triple cropping = 1		-0.0126		-0.00850		0.0187
		(0.0159)		(0.00817)		(0.0104)
Years of triple cropping = 2		-0.000181		0.00844		0.0376
		(0.0183)		(0.0447)		(0.0247)
Years of triple cropping = 3		0.0634		0.0463		0.0995
		(0.0424)		(0.0301)		(0.0466)
Years of triple cropping = 4		0.00601		0.0240		0.0154
		(0.0288)		(0.0227)		(0.0406)
Years of triple cropping = 5		-0.00484		0.00215		0.0513
		(0.0322)		(0.0357)		(0.0370)
Years of triple cropping = 6+		0.0449		0.0441		0.0835
		(0.0325)		(0.0518)		(0.0423)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,152	1,152	892	892	969	969
Within-R2	0.499	0.500	0.474	0.476	0.252	0.254

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A3 provides a visual representation of the estimation results.

Table A5. Triple-cropping and input costs (in levels)

	(1) Fertilizer	(2) Fertilizer	(3) Pesticide	(4) Pesticide	(5) Herbicide	(6) Herbicide
triple cropping	76.68		57.59		-11.92	
	(138.9)		(108.6)		(59.40)	
Years of triple cropping = 1		-137.9		178.0		-38.42
		(247.4)		(145.4)		(69.67)
Years of triple cropping = 2		17.84		140.8		93.94
		(255.5)		(167.9)		(80.27)
Years of triple cropping = 3		-137.6		-233.5		-128.7
		(341.1)		(231.4)		(65.57)
Years of triple cropping = 4		533.5		150.7		102.2
		(464.9)		(313.4)		(121.5)
Years of triple cropping = 5		221.2		-462.9		-114.9
		(304.1)		(315.6)		(49.33)
Years of triple cropping = 6+		440.5		-11.71		-49.30
		(198.0)		(260.0)		(73.98)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,152	1,152	1,152	1,152	1,152	1,152
Within-R2	0.202	0.207	0.343	0.348	0.220	0.231

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A4 provides a visual representation of the estimation results.

Table A6. Triple-cropping and income from rice production (in levels)

	(1) Revenue	(2) Revenue	(3) Expenditure	(4) Expenditure	(5) Income	(6) Income
triple cropping	440.8		71.66		369.2	
	(280.3)		(385.6)		(345.6)	
Years of triple cropping = 1		88.12		84.15		3.969
		(694.5)		(731.0)		(327.1)
Years of triple cropping = 2		-103.5		8.515		-112.0
		(884.4)		(335.9)		(952.8)
Years of triple cropping = 3		1474.3		-402.4		1876.7
		(467.4)		(809.2)		(878.6)
Years of triple cropping = 4		712.0		560.6		151.4
		(757.1)		(746.9)		(788.2)
Years of triple cropping = 5		626.1		-70.38		696.5
		(1077.5)		(493.2)		(760.6)
Years of triple cropping = 6+		1269.1		157.6		1111.5
		(529.1)		(492.2)		(537.0)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,152	1,152	1,152	1,152	1,152	1,152
Within-R2	0.314	0.316	0.307	0.307	0.191	0.195

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A5 provides a visual representation of the estimation results.

Table A7. Triple-cropping and agricultural income (in levels)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Rice	Rice	Non-rice	Non-rice	Livestock	Livestock	Fishery	Fishery	Total	Total
triple cropping	15767.3		430.2		131.5		841.0		17040.0	
	(5247.7)		(1034.6)		(1895.7)		(3974.6)		(6357.5)	
Years of triple cropping = 1		6956.1		712.9		1364.4		464.2		9443.4
		(9465.8)		(979.8)		(2395.6)		(2635.7)		(11008.2)
Years of triple cropping = 2		24548.2		915.7		-1685.2		4750.6		28428.4
		(8416.5)		(1221.3)		(1508.8)		(8496.4)		(10954.4)
Years of triple cropping = 3		28876.5		-4324.6		-2120.9		405.2		22768.5
		(6851.1)		(1203.3)		(2223.9)		(3498.1)		(8208.4)
Years of triple cropping = 4		-1042.9		3046.5		2375.3		1019.8		5416.0
		(6814.7)		(2588.5)		(1425.0)		(2358.4)		(8087.6)
Years of triple cropping = 5		26046.6		497.5		15.38		-479.2		25799.6
		(4661.1)		(1230.5)		(1178.4)		(1903.7)		(4927.9)
Years of triple cropping = 6+		20642.8		23.64		-132.5		-2773.4		17402.2
		(10031.0)		(2318.8)		(3182.1)		(3844.8)		(7817.8)
Province-Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152
Within-R2	0.201	0.214	0.212	0.215	0.121	0.127	0.108	0.112	0.164	0.172

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A6 provides a visual representation of the estimation results.

Table A8. Triple-cropping and household income (in levels)

	(1) Agriculture	(2) Agriculture	(3) Wage	(4) Wage	(5) Self	(6) Self	(7) Total	(8) Total
triple cropping	17040.0		-2684.0		-526.5		13829.5	
	(6357.5)		(1994.4)		(4421.2)		(4757.5)	
Years of triple cropping = 1		9443.4		-1580.9		3754.4		11616.9
		(11008.2)		(2262.5)		(4123.3)		(11193.5)
Years of triple cropping = 2		28428.4		-1832.3		4240.3		30836.4
		(10954.4)		(3123.4)		(8287.9)		(11609.8)
Years of triple cropping = 3		22768.5		-5941.8		994.7		17821.4
		(8208.4)		(2860.0)		(4872.0)		(9782.0)
Years of triple cropping = 4		5416.0		2264.3		-8674.4		-994.1
		(8087.6)		(4272.6)		(4832.1)		(6291.7)
Years of triple cropping = 5		25799.6		-6343.1		6887.7		26344.2
		(4927.9)		(1343.8)		(7472.6)		(4857.0)
Years of triple cropping = 6+		17402.2		-5401.6		-16095.9		-4095.3
		(7817.8)		(3328.6)		(7387.0)		(12835.9)
Province-Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152
Within-R2	0.164	0.172	0.230	0.233	0.103	0.117	0.184	0.195

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A7 provides a visual representation of the estimation results.

Table A9. Number of observations by consecutive years of triple cropping

Years of triple cropping	Freq.	Percent	Cum.
0	873	75.78	75.78
1	87	7.55	83.33
2	63	5.47	88.80
3	30	2.60	91.41
4	21	1.82	93.23
5	16	1.39	94.62
6	15	1.30	95.92
7	6	0.52	96.44
8	13	1.13	97.57
9	15	1.30	98.87
10	6	0.52	99.39
11	7	0.61	100.00
Total	1,152	100.00	

Note: This table shows the number of observations by consecutive years of triple cropping in the subsample.

Table A10. Consecutive years of triple-cropping and input costs

	(1) Fertilizer	(2) Pesicide	(3) Herbicide
Years of triple cropping=1	-0.0727	-0.00322	-0.0820
	(0.0800)	(0.124)	(0.332)
Years of triple cropping=2	-0.0541	-0.238	0.336
	(0.0640)	(0.229)	(0.0641)
Years of triple cropping=3	-0.00310	-0.396	-0.0687
	(0.0997)	(0.234)	(0.258)
Years of triple cropping=4	0.164	-0.448	0.111
	(0.0648)	(0.351)	(0.331)
Years of triple cropping=5	0.0486	-0.356	-0.194
	(0.0803)	(0.273)	(0.194)
Years of triple cropping=6	0.174	0.291	0.134
	(0.0696)	(0.372)	(0.128)
Years of triple cropping=7	-0.121	-0.500*	-0.635
	(0.179)	(0.206)	(0.448)
Years of triple cropping=8	0.235	-0.204	-1.249
	(0.110)	(0.262)	(0.626)
Years of triple cropping=9	0.0479	0.0185	0.511
	(0.125)	(0.508)	(0.521)
Years of triple cropping=10	0.118	-0.198	-0.935
	(0.0722)	(0.159)	(0.913)
Years of triple cropping=11	-0.0158	-0.224	0.304
	(0.110)	(0.312)	(0.323)
Province-year fixed effects	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes
Observations	1,152	1,152	1,152
Within-R2	0.194	0.303	0.258

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A8 provides a visual representation of the estimation results.

Table A11. Consecutive years of triple-cropping and yield (controlling input costs)

	(1) Total	(2) Win-spri	(3) Sum-aut
Years of triple cropping=1	-0.0211	-0.0133	0.0163
	(0.0240)	(0.0106)	(0.0107)
Years of triple cropping=2	-0.00630	0.00290	0.0403
	(0.0189)	(0.0494)	(0.0272)
Years of triple cropping=3	0.0520	0.0335	0.0937
	(0.0369)	(0.0321)	(0.0466)
Years of triple cropping=4	0.0195	0.0282	0.0159
	(0.0231)	(0.0203)	(0.0354)
Years of triple cropping=5	-0.0149	-0.000766	0.0429
	(0.0331)	(0.0293)	(0.0376)
Years of triple cropping=6	0.0989	0.0481	0.0466
	(0.0628)	(0.0447)	(0.0410)
Years of triple cropping=7	-0.110	-0.0714	-0.0170
	(0.0491)	(0.0479)	(0.0801)
Years of triple cropping=8	0.0619	0.0560	0.162
	(0.0967)	(0.0631)	(0.111)
Years of triple cropping=9	0.0740	0.1000	0.0728
	(0.0607)	(0.107)	(0.0691)
Years of triple cropping=10	0.0338	0.0579	0.117
	(0.0360)	(0.0667)	(0.0503)
Years of triple cropping=11	0.0226	0.0445	0.109
	(0.0790)	(0.0718)	(0.0882)
Province-year fixed effects	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes
Observations	1152	892	969
Within-R2	0.424	0.423	0.231

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A9 provides a visual representation of the estimation results.

Table A12. Consecutive years of triple-cropping and income from rice farming

	(1)	(2)	(3)
	Revenue	Expenditure	Income
Years of triple cropping=1	-0.0210	-0.0292	-0.0206
	(0.0320)	(0.0505)	(0.0266)
Years of triple cropping=2	-0.0226	-0.0378	-0.0100
	(0.0329)	(0.0406)	(0.0462)
Years of triple cropping=3	0.0612	-0.0519	0.218
	(0.0249)	(0.0639)	(0.0861)
Years of triple cropping=4	0.0357	0.0384	0.0531
	(0.0595)	(0.0609)	(0.112)
Years of triple cropping=5	0.0105	-0.0119	0.0393
	(0.0566)	(0.0504)	(0.0816)
Years of triple cropping=6	0.0816	0.0688	0.146
	(0.0594)	(0.0755)	(0.116)
Years of triple cropping=7	-0.0415	-0.160	0.0692
	(0.0409)	(0.120)	(0.0874)
Years of triple cropping=8	0.0276	-0.00522	0.136
	(0.0855)	(0.0386)	(0.181)
Years of triple cropping=9	0.0605	0.0994	0.131
	(0.0557)	(0.0757)	(0.112)
Years of triple cropping=10	0.0443	-0.121	0.297
	(0.0190)	(0.0325)	(0.0895)
Years of triple cropping=11	-0.0366	0.0126	0.0599
	(0.0725)	(0.0735)	(0.140)
Province-year fixed effects	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes
Observations	1,152	1,152	1,136
Within-R2	0.380	0.390	0.203

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A10 provides a visual representation of the estimation results.

Table A13. Consecutive years of triple-cropping and agricultural income

	(1) Rice	(2) Non-rice	(3) Livestock	(4) Fishery	(5) Total	(6) %Rice
Years of triple cropping=1	0.203	1.143	0.695	-0.446	0.122	0.0754
	(0.131)	(0.512)	(0.617)	(1.313)	(0.175)	(0.0395)
Years of triple cropping=2	0.637	1.524	-0.975	-1.011	0.480	0.136
	(0.186)	(0.402)	(0.832)	(0.495)	(0.162)	(0.0220)
Years of triple cropping=3	0.786	-0.0236	-0.281	-0.792	0.383	0.189
	(0.231)	(0.491)	(1.478)	(1.684)	(0.248)	(0.0327)
Years of triple cropping=4	0.263	1.104	1.308	-0.308	0.269	-0.00158
	(0.324)	(0.906)	(1.001)	(1.587)	(0.241)	(0.0899)
Years of triple cropping=5	0.870	1.617	1.380	-0.395	0.639	0.162
	(0.0861)	(0.792)	(0.522)	(0.708)	(0.0606)	(0.0194)
Years of triple cropping=6	0.514	-1.462	0.621	-1.203	0.0863	0.193
	(0.275)	(1.821)	(2.478)	(1.332)	(0.173)	(0.0807)
Years of triple cropping=7	0.841	0.837	1.107	-3.584	0.946	-0.0375
	(0.310)	(1.266)	(3.526)	(1.018)	(0.352)	(0.177)
Years of triple cropping=8	1.172	0.602	-1.323	-5.275	0.883	0.119
	(0.382)	(1.840)	(1.558)	(2.043)	(0.329)	(0.0591)
Years of triple cropping=9	0.462	-0.838	-1.212	-2.640	0.0669	0.151
	(0.338)	(0.949)	(0.665)	(1.107)	(0.165)	(0.122)
Years of triple cropping=10	0.693	0.136	0.597	-6.692	0.173	0.228
	(0.616)	(2.399)	(4.083)	(2.112)	(0.582)	(0.0280)
Years of triple cropping=11	0.826	2.757	-1.766	-2.287	0.479	0.117
	(0.384)	(1.255)	(0.978)	(1.897)	(0.244)	(0.107)
Province-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,136	966	1,145	1,144	1,149	1,029
Within-R2	0.308	0.268	0.184	0.216	0.227	0.258

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A11 provides a visual representation of the estimation results.

Table A14. Consecutive years of triple-cropping and household income

	(1) Agriculture	(2) Wage	(3) Self	(4) Total
Years of triple cropping=1	0.122	0.206	1.195	0.0591
	(0.175)	(0.772)	(0.764)	(0.102)
Years of triple cropping=2	0.480*	0.799	1.100	0.335
	(0.162)	(1.041)	(1.086)	(0.0592)
Years of triple cropping=3	0.383	0.706	0.487	0.191
	(0.248)	(1.054)	(0.758)	(0.156)
Years of triple cropping=4	0.269	1.207	-1.996	0.125
	(0.241)	(1.670)	(1.452)	(0.103)
Years of triple cropping=5	0.639	-0.539	0.448	0.402
	(0.0606)	(0.897)	(0.959)	(0.0656)
Years of triple cropping=6	0.0863	2.133	0.411	-0.00532
	(0.173)	(1.108)	(1.520)	(0.218)
Years of triple cropping=7	0.946	-0.454	-4.526	0.560
	(0.352)	(2.622)	(2.069)	(0.304)
Years of triple cropping=8	0.883	-1.707	-3.000	0.305
	(0.329)	(2.399)	(1.645)	(0.192)
Years of triple cropping=9	0.0669	1.040	-1.734	-0.320
	(0.165)	(1.644)	(2.066)	(0.253)
Years of triple cropping=10	0.173	-1.007	-0.660	-0.154
	(0.582)	(3.247)	(3.445)	(0.0670)
Years of triple cropping=11	0.479	1.074	-1.533	0.0280
	(0.244)	(1.483)	(1.348)	(0.345)
Province-Year fixed effects	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes
Observations	1,149	1,152	1,152	1,151
Within-R2	0.227	0.148	0.149	0.335

Note: All specifications include covariates. Standard errors in parentheses are clustered at the province level. Figure A12 provides a visual representation of the estimation results.