Sustainable Production and Consumption 28 (2021) 1040–1049

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

"One must do, five reductions" technical practice and the economic performance of rice smallholders in the Vietnamese Mekong delta

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ARTICLE INFO

Article history:
Received 21 April 2021
Revised 14 July 2021
Accepted 15 July 2021
Available online 19 July 2021

Editor: Prof. Ming-Lang Tseng

Keywords:
Mekong Delta
"One Must Do
Five Reductions"
Economic performance
Rice smallholder
Propensity score matching

ABSTRACT

The "One Must Do, Five Reductions" (1M5R) program was certified in 2013, by Vietnam Ministry of Agriculture and Rural Development, as a national approach to promoting the best management practices in lowland rice cultivation. The main idea behind 1M5R is the use of good-quality/certified seeds (the One Must Do) as well as the reduction of seed rates, pesticide use, fertilizer inputs, water use, and postharvest losses (Five Reductions). However, the impact of these farming practices is not well understood. This study employs the propensity score matching (PSM) approach to investigate the factors that affect the adoption of the 1M5R practice and to estimate this technique's impact on the economic performance of rice cultivation. Primary data were collected through a household survey of 380 rice farms in four provinces in the Mekong Delta (MKD), Vietnam. The results indicate that adopting the 1M5R technique is significantly correlated with the educational level of household heads, their memberships in paddy cooperatives, and their attendance to previous training classes. Additionally, the 1M5R technical package helps farmers to reduce their production cost by 10%, increase a paddy's selling price by 4.5% per kg, and obtain 10% more profit, compared to traditional farming households. The return on investment for adopters increased by 22%. While the findings show that a sustainable farming technique is advantageous to local farmers, they fail to present any paddy yield increase in treatment fields. To scale up this program to other areas in the MKD, well-educated farmers who are still traditional producers/non-adopters should be positively invited for training classes of the program.

1. Introduction

The Mekong Delta (MKD), the world's third largest delta, comprises 54% of Vietnam's rice production areas and produces 55% of Vietnam's total rice output (General Statistics Office, 2018). Since the late 1990s, rice production in MKD has intensified rapidly, resulting in an overreliance on agrochemicals to achieve higher yields as well as rising production costs and environmental unsustainability (Tong, 2017; Tu, 2015). Compared to other agricultural countries in the region, Vietnam ranked second (430 kg/ha) after China (503 kg/ha), in terms of fertilizer consumption, while other countries, such as India (166 kg/ha), Thailand (162 kg/ha), and the Philippines (157 kg/ha), consume relatively low amounts of fertilizers per hectare of arable land (FAO, 2016). Each year, over 10 million tons of fertilizers are consumed in Vietnam, of which 80% are supplied by domestic factories. Approximately 60.6% of this amount is used to cultivate rice, and the rest is used to cultivate maize, coffee, sugarcane, fruits, and vegetables (International Fertilizer Association, 2017). Fertilizer is also the costliest item, compared to other crop production costs. In the period 2014–2015, Vietnam consumed 2.6 million tons of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), of which, 60% (1.6 million tons) was N fertilizer used for rice production. According to the Soil and Fertilizers Research Institute, the N use efficiency for rice plants in Vietnam is still low, at only 35–40%, and fertilization is imbalanced. Specifically, too much N is used, compared to P_2O_5 and K_2O. The calculated data across 5 years (2008–2012) indicate that the ratio of applied nutrients N: P_2O_5: K_2O is 3.3:1.5:1.[1] Thus, the excessive use of N not only generates waste and pollutes the environment,

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[1] Recommended fertilizer amounts, each season, for rice varieties with growth time between 85 and 100 days (kg/ha) are (i) Alluvial soil: winter–spring season (90–100 kg N; 30–40 kg P_2O_5; 30–40 kg K_2O); summer–autumn season (75–90 kg N; 30–40 kg P_2O_5; 30–40 kg K_2O). (ii) Light acid sulfate soil: winter–spring season

https://doi.org/10.1016/j.spc.2021.07.018
2352-5509/

but it also creates a suitable environment for pests and diseases to develop (Soil and Fertilizers Research Institute, 2016). This poses both economic and environmental risks and challenges in achieving sustainable agricultural development in the nation.

The Vietnamese agricultural sector also uses large amounts of pesticides, despite many integrated pest management programs having been implemented for many years. A recent report by the Vietnam Environment Administration (Ministry of Natural Resources and Environment) states that, on average, Vietnam uses 15,000–25,000 tons of pesticides each year. There is also proof that farmers and communities that use water sources with pesticide residues, in Vietnam and along the MKD, face serious health risks. Dasgupta (2007) showed that 35% of the MKD farmers who were medically tested showed signs of contamination by the organic phosphorus and carbamates in pesticides, of whom, 21% had symptoms of chronic poisoning. The household survey by Toan et al. (2013) found that household-level pesticide management remains suboptimal in the MKD, and a wide range of pesticide residues was found in the water, soil, and sediments throughout the monitoring period. Further, the human and environmental health awareness is limited, as evidenced by improper pesticide storage and waste disposal during pesticide handling and application (Chau et al., 2015). Owing to pesticide pollution, the authors failed to identify a clean water source in the MKD.

To reduce the excessive use of chemical fertilizers and pesticides, the Vietnam Ministry of Agricultural and Rural Development (MARD) has encouraged farmers to apply a farming technology known as climate smart agriculture (CSA),[2] which is aimed at promoting sustainability in rice cultivation. First, following the framework of a crop management technology designed by the International Rice Research Institute (IRRI), the “Three Reductions, Three Gains”[3] (3R3G) program was developed to reduce production costs, improve farmers’ health, and protect the environment when rice-production areas in the MKD are irrigated. This was achieved by reducing the use of seeds, nitrogen fertilizer, and pesticides. The campaign was piloted in Can Tho, Tien Giang, and Vinh Long provinces in 2003. Built on the success of the 3R3G campaign, the eco-friendly farming technique “One Must Do, Five Reductions” (1M5R) is a technological package that was developed during Phase IV of the IRRI’s Consortium and promoted by the World Bank’s Agricultural Competitiveness Project. More specifically, farmers who apply this technique are promoted to use certified seeds (One Must Do) and reduce the seed rate, use of fertilizers and pesticides, irrigation cost, and post-harvest losses (Five Reductions). In particular, this advanced technology is expected to be the best practice for intensive rice production in the MKD, and includes benefits, such as reducing production costs, increasing paddy yield, improving rice grain quality, enhancing farm profit, saving water and natural resources, reducing greenhouse gas emissions, and protecting the community’s health (Phung et al., 2014). 1M5R has been recognized by the Department of Crop Production as technical progress, according to Decision No. 532/QD-TT-CLT, dated November 7, 2012. In 2013, data collected from just eight provinces in the MKD indicated that 34,500 farmers participated in training, and that about 240,000 farmers were implementing 1M5R over 300,000 ha (IRRI, 2012). This recognition caused the wide deployment of 1M5R rice production areas in the MKD. In addition, the Decision No. 555/QD-BNN-TT dated January 26, 2021 about the “Re-structuring rice industry in Vietnam to 2025 and 2030” project also indicates about the percentage of climate smart farming techniques applied area should be over 60% of the total paddy planted area, equivalent to 4.2 million ha. Therefore, MKD’s agriculture sector urgently requires a formal assessment of the benefits of 1M5R application for rice producers. The most recent study by Connor et al. (2020) explores the factors that influence farmers’ decision to apply the 1M5R package in two MKD provinces: An Giang and Can Tho. It concluded that, while all farmers meticulously met the requirements for certified seeds, pesticides, and post-harvest loss reduction, they still had difficulties reducing their fertilizer use, water use, and seed rate. Other studies have measured the difference between farmers applying 1M5R and other groups of conventional farmers (Chi et al., 2013; Son et al., 2013; Tin et al., 2015). These studies compared descriptive statistics to draw conclusions regarding the higher profitability for households participating in 1M5R, compared to traditional households. However, deriving conclusions based on the differences in potential outcomes, without considering the observed sociological factors of the two household groups, may lead to self-selection bias. Therefore, using the propensity score matching (PSM) method, this study aims to i) identify the factors that influence farmers’ decision to join 1M5R and ii) assess the impact of the 1M5R technique on the economic performance of rice smallholders in the Vietnamese MKD. The empirical results of this study have implications for policymakers and local authorities, regarding the causal effects of 1M5R, which is an important rice farming technique. Some potential suggestions to improve the economic benefits of 1M5R for rice smallholders and, simultaneously, protect the surrounding natural environment in the region are suggested.

The remainder of this paper is organized as follows. Section 2 is the literature review. Section 3 introduces the methodology and data used in this study. Section 4 presents the results and discussions. The last section concludes the study and presents policy recommendations for enhancing the economic welfare of 1M5R rice farming in MKD.

2. Literature review

Household sampling for climate smart farming techniques, such as 1M5R, cannot be random. The survey and interviews of rural households must be based on the geographical location, ecological region, rice cultivation characteristics, and consultation with local authorities. As such, this causes, first, “selection bias,” when sampling participants for analysis. Second, bias may arise from the unobserved characteristics in rice households. For example, these households may participate in the 1M5R technique because of their personal preferences, abundant capital resources, and motivation to experience new technology, among other reasons. In such cases, controlling for these types of biases requires an instrument that can explain the participation of farmers in 1M5R, based on their observable socioeconomic characteristics, before subsequently explaining the difference in rice production outcomes.

To date, many studies have used PSM to eliminate non-randomization bias and, simultaneously, calculate the causal effects of a program or project on smallholders in the agriculture sector. Recently, PSM was used to calculate the impact of CSA and climate change adaptation on smallholder rice farmers’ technical efficiency (TE) (Ho and Shimada, 2019). The results indicate that both climate change adaptation and CSA application affect the rice growers’ TE score. More specifically, climate change adaptation increases the TE scores for rice-producing households by 13–14% compared to conventional households. CSA also helps households increase TE by about 5–6%, compared to households that do

(80–100 kg N; 40–50 kg P_2O_5; 25–30 kg K_2O); summer–autumn season (70–80 kg N; 40–50 kg P_2O5; 25–30 kg K_2O) (Phung et al., 2014).

[2] The most commonly-used definition of CSA is that provided by FAO (2010), which defines CSA as a form of agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes greenhouse gases (GHGs) (mitigation) where possible, and enhances achievement of national food security and development goals.

[3] The three reductions reflect the reduction of seed rate, fertilizer use and insecticide spraying. The three gains are an increase in net-farm profit, better health for farmers and an improved environment (Huan et. al, 2005).

not apply it. Duong and Thanh (2019) also use the PSM–DID approach to examine the economic impact of adopting modern rice varieties in Vietnam, using a dataset derived from the Vietnam Access to Resources Household Survey in 2012 and 2014. The empirical results reveal that only large farms can improve their productivity by adopting modern varieties, and the impact of the adoption on the value-added, in terms of profit and based on different farm sizes, is insignificant. Concerning the Pakistan agricultural sector, Ali et al. (2014) used PSM to establish the impact of a direct sowing technology on rice production. This technique, with the essence of a water-saving technology, saves a considerable amount of irrigation water, compared to the traditional transplanting method, thereby helping adopters to reduce production and labor costs, and simultaneously increase rice and corn yields in the same cultivated area, compared with conventional households. Wu et al. (2010) also used PSM to conclude that adopting the improved upland rice technology has had a significant positive effect on farmers' well-being in rural China, which is measured by increased household income and reduced poverty incidences. The incomes for households that apply science and technology to production are expected to be approximately 1.53, 1.32, and 1.26 times higher in 2000, 2002, and 2004, respectively, compared to those of households that do not apply science and technology. With increased income and reduced poverty incidences considered as possible outcomes, PSM was used effectively by Mendola (2007) to estimate the impact of adopting agricultural technology on households in rural Bangladesh. Adopting a high-yielding variety (HYV) was found to have a robust and positive impact on household income, which in turn contributes to poverty alleviation in rural Bangladesh.

The most recent study on the determinants of 1M5R adoption in the MKD indicates that all farmers met the requirements, which include the use of certified seeds, pesticide reduction, and post-harvest loss reduction. However, farmers found it difficult to reduce their fertilizer use, irrigation water, and especially the seed sown density. All six elements of the technical package are adopted owing to the ease of implementation, education, satisfaction, and non-rice income (Connor et al., 2020). In existing studies, household demographic factors, such as gender, age (Tran et al., 2020), education level (Abegunde et al., 2020; Dung, 2020), farming experience (Abegunde et al., 2020), cultivated area (Abegunde et al., 2020; Dung, 2020; Ho and Shimada, 2019), formal credit access (Dung, 2020; Mwungu, 2019); technologies and the cost of implementation (Khatri-Chhetri et al., 2017), and membership in agricultural organizations (Abegunde et al., 2020; Tran et al., 2020) were found to have significant impacts on farmers' decision to join CSA in developing countries, including Vietnam.

3. Methods

3.1. Methodology

PSM was first defined by Rosenbaum and Rubin (1983) and supplemented by Khandker et al., (2010). PSM constructs a statistical comparison group, which is based on a model of the probability of participating in treatment T and is conditional on observed characteristics X or the propensity score, $P(X) = Pr\ (T = 1|X)$. Two important assumptions need to be followed to estimate the causal effects of a program. These include (i) the conditional independence assumption (CIA) and (ii) the presence of common support or overlap condition. Under these two assumptions, matching on $P(X)$ is as good as matching on X, according to Rosenbaum and Rubin (1983).

The CIA posits that given a set of observable covariates X, which are not affected by treatment, potential outcomes Y are independent of treatment assignment T (Khandker et al., 2010). Hence, in the first PSM step, a probit model is used to identify the determinants of farmers' decisions to participate in the 1M5R package (T) and to calculate the propensity scores, using a set of covariates (X_i). The main purpose of the propensity score estimation is not to predict selection into treatment but to balance all covariates (Caliendo and Kopeinig, 2008). The probit model is specified as

$$y(0,1) = \beta_0 + \beta_1 X_1 + \ldots + \beta_{11} X_{11} \tag{1}$$

where $y\ (0,1)$ is the status of farmers' participation in 1M5R ($y = 1$ participating in 1M5R; $y = 0$ not participating in 1M5R/conventional farmers), and β_0 to β_9 are the regression coefficients. The covariates are chosen following the assumption that only variables that are unaffected by participation (or related anticipation) should be included in the model. If these variables are measured before participation, it must be guaranteed that they are not influenced by the anticipation of participation (Caliendo and Kopeinig, 2008). The data for participants and non-participants should also be obtained from the same sources (same questionnaires). As such, the independent variables in equation (1) are as follows: X_1 is the age of household head, X_2 is the gender, X_3 is education level, X_4 is the years of experience, and X_5 is the family members. Further, X_6 is the paddy land size, X_7 is the number of land plots, X_8 is the credit status of households, X_9 is the prior participation in training classes, X_{10} is the off-farm (non-agricultural activities), X_{11} is the cooperative membership, and X_{12} is the membership of Farmers' Association. The details for these covariates are described in detail in Table 1.

Subsequently, the common support region, where the propensity score distributions for the treatment and comparison groups overlap, $0 < P\ (T_i = 1|X_i) < 1$, need to be defined. Therefore, treatment units have to be similar to non-treatment units, in terms of observed characteristics that are unaffected by participation. The common support region was assessed by examining a graph of propensity scores across the treatment and comparison groups (Fig. 1). Some of the non-participant observations, which fall outside the common support region, are excluded at this stage. In addition to overlapping, there should be a similar distribution ("balance") in the treatment and comparison groups within each of the five quintiles to ensure that the mean propensity score is equivalent (Imbens, 2004). Therefore, a balancing test should be performed on individual covariates (Dehejia and Wahba, 2002), to check if $\hat{P}(X|T = 1) = \hat{P}(X|T = 0)$ (Khandker et al., 2010). No rule states the extent to which imbalance is acceptable in a propensity score, and the proposed maximum standardized differences for specific covariates range from 10% to 25% (Garrido et al., 2014; Stuart et al., 2013).

On account of the overlap of propensity scores between treatment and comparison groups, due to CIA, the average treatment effect on the treated (ATT) can be written as

$$ATT_{PSM} = E_{P(X)|T=1}\{E[Y_1|T = 1, P(X)] - E[Y_0|T = 0, P(X)]\} \tag{2}$$

where T refers to the treatment and is equal to 1 if the farmer is a 1M5R participant, Y_1 is the participant's outcome, Y_0 is the non-participants' outcome, and X is a vector of the control variables. The ATT in this study represents the average difference between the observed outcomes of the two groups of farmers: participants and non-participants, in the 1M5R technical package. The outcome variables used in this study are paddy yield, output price, production cost, gross income, and return on investment (ROI) ratio. Description of these outcome variables is displayed in Section 3.4.

After the propensity scores were generated, and the balancing test passed, participants and non-participants with similar propensity scores were matched using various matching algorithms, including nearest neighbor matching (NNM), caliper or radius, stratification or interval, kernel matching (KM), and local linear matching (Becker, 2002). Without a clearly superior propensity score

Table 1
Covariates used in the probit model to generate the propensity scores.

Variable	Description	Mean	S.D.
T: 1M5R participation	Treatment-Dummy, receives 1 value if households practice 1M5R package on its farms, 0 otherwise.	0.37	0.48
Age	Age of the household heads (year)	49.46	10.64
Gender	Dummy, receives 1 value if the household heads are male, 0 otherwise.	0.94	0.23
Educational level	Number of years of schooling of the household heads	6.97	3.53
Farming experience	Number of years of rice farming experience	26.17	19.14
Household size	Number of family members	4.46	1.43
Rice land	Total area of rice farmland, measured in hectare	2.77	3.35
No. of rice plots	Number of plots in that rice farmland	2.10	1.80
Credit	Dummy, receives 1 value if the households had a loan for agricultural production from banks, 0 otherwise.	0.19	0.40
Training	Dummy, receives 1 value if the households did participate in training classes for 1M5R, 0 otherwise	0.71	0.46
Off-farm	Dummy, receives 1 value if the households had non-agricultural job that can create income, 0 otherwise	0.14	0.35
Cooperative membership	Dummy, receives 1 value if the household heads are rice cooperative members, 0 otherwise	0.69	0.46
Farmer's Association	Dummy, receives 1 value if the household heads are members of farmer associations, 0 otherwise	0.26	0.44

Source: Authors' calculation based on household survey

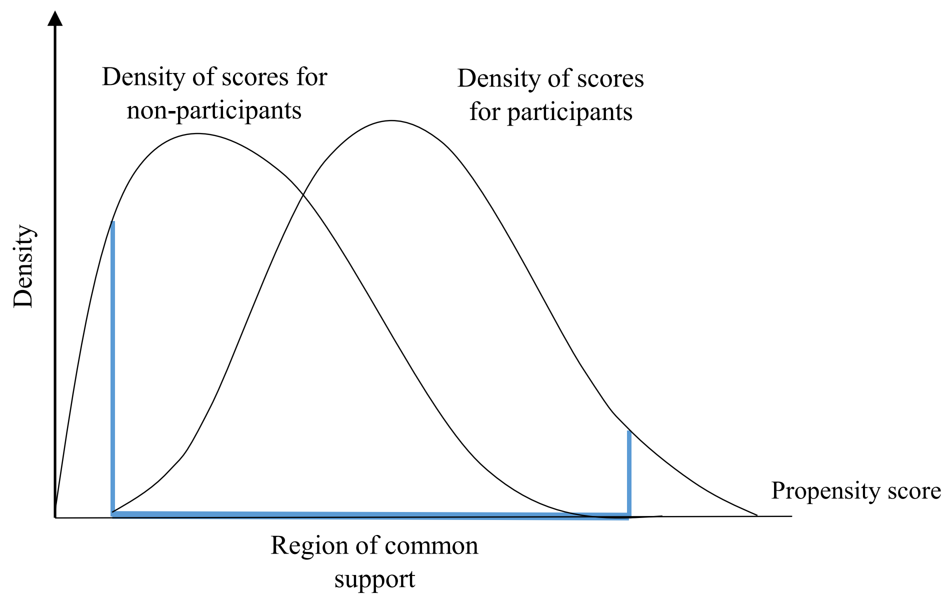

Fig. 1. Example of common support (Khandker et al., 2010).

weighting or matching method (Garrido et al., 2014), we used two extensively applied methods: NNM and KM. NNM is one of the most popular techniques, in which each treatment unit is matched to the comparison unit with the closest propensity score. One can also choose the number of nearest neighbors n (usually $n = 5$) and match it, with or without replacement (Khandker et al., 2010). KM and local linear matching are nonparametric matching estimators that use the weighted averages of (nearly) all individuals in the control group, depending on the choice of the kernel function, to construct the counterfactual outcome (Caliendo and Kopeinig, 2008). In addition, KM maximizes precision (by retaining sample size) without worsening bias (by placing greater weight on better matches) (Garrido et al., 2014); therefore, it is more favorable than NNM (Powell-Jackson and Hanson, 2012).

3.2. Study site

This study uses data from the household survey in Can Tho, An Giang, Dong Thap, and Bac Lieu provinces, from the "Market Oriented Smallholder Value Chains" (MSVC) project in 2018. The MSVC project is a public–private partnership (PPP) between the Federal Ministry for Economic Cooperation and Development (BMZ) through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and Olam International Limited. The study site chosen by stratification sampling technique represents four out of six agro-ecological sub-regions of the MKD, including An Giang province (Long Xuyen Quadrangle), Dong Thap province (Dong Thap Muoi area), Can Tho city (the riverside of Tien and Hau rivers), and Bac Lieu province (coastal area) (Fig. 2). The paddy area and production for these four provinces accounted for 38.11% and 39.98% of the entire MKD region and production in 2018, respectively.

3.3. Data collection

After the study site was identified, primary data were collected using the convenience sampling method in the two seasons Summer-Autumn and Autumn-Winter in the crop year 2018. One hundred paddy producers were interviewed from each province regarding the following: households demographic information (age, gender, farming experience, family members, number of family members involved in labor, cultivated land size, number of plots, credit status, training class attendance, memberships of cooperatives and farmer associations); information regarding production activities (production cost items, paddy yield, selling price, gross income, and net profit); and the experience and application of smart rice cultivation techniques (1M5R, 3R3G, integrated pest management – IPM, alternative wet and drying – AWD). Specifically, households that practice 1M5R must follow the six elements

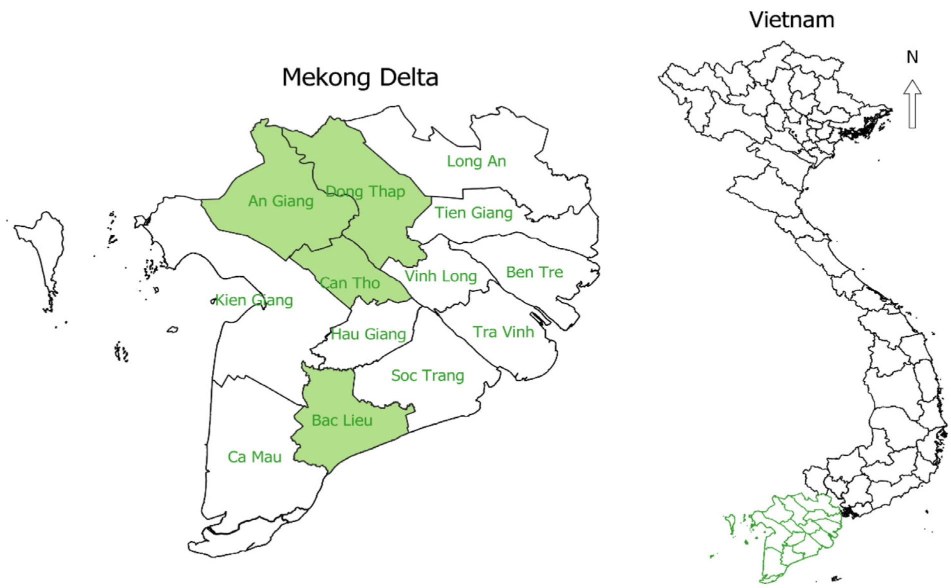

Fig. 2. Map of Mekong Delta and study site.

of the technical package: households must use certified seeds,[4] reduce the seed sown density to the range 80–100 kg/ha, reduce the amount of nitrogen fertilizer applied to less than 130 kg/ha, reduce the amount and frequency of pesticide use, reduce the amount of irrigation water, and finally reduce the post-harvest loss by using combine harvesting machines. To meet the study objectives, the authors conducted PMS analysis on extracted data from the 380 households, which included 140 1M5R adopters 240 non-adopters/individual rice producers. These two groups of farmers had similar farming areas, weather conditions, and climate conditions for comparison.

3.4. Explanation of variables used in the model

The treatment variable represents participation of households in the 1M5R farming technique for the four provinces. The treated group (participants) comprises farmers who practiced 1M5R on their farms for at least three seasons. The untreated group (non-adopters, non-participants, and control group) include those who use their own traditional techniques to cultivate paddies (conventional farmers).

The independent variables used in the probit model to compute trend scores are shown in Table 1. Based on previous studies mentioned in the literature review, the authors included variables, such as participation in agricultural training and membership of local farmer's associations (FAs). Among these variables, farmer characteristics, such as education level, production experience, membership of cooperatives or FAs, and training participation are expected to have positive impacts on the decision to adopt the 1M5R package. Farmers with higher education levels and much more experience could achieve better understanding when trained on, or consulted about, the technical requirements. FA membership and production groups could also help farmers obtain incentives for input materials and agricultural mechanization to apply modern farming technology. The statistical information and mean difference of these covariates between participants and non-participants are presented in Table 2.

Regarding the outcome variables, some studies have used economic indicators to estimate the causal effect of a program or agricultural technology on smallholders. Bidzakin et al. (2019) used yield and gross margins as outcomes to investigate the importance of contract farming in rice production. Ma and Abdulai (2017) examined the impact of agricultural cooperative membership on output price, gross income, farm profit, and ROI. Ali et al. (2015) estimated the impact of direct seeding, using the rice sowing technology, on rice and wheat crop yields and farmers' incomes. Wu et al. (2010) utilized households' incomes and poverty gap as outcome variables to assess the impact of improved upland rice technology on farmers' well-being. Based on the advantages of adopting the 1M5R package, indicated in the guidebook of MARD (Phung et al., 2014), this study uses production cost, paddy yield, output price (per kg), farm's income, and the ROI ratio as the outcome variables for comparison. The input data mentioned in this study is the average values of the two seasons. Farm's net profit was calculated by deducting total production cost from the gross income. The gross income was computed by fresh paddy (wet paddy) yield multiplying with farm-gate selling price reported by each household. Total production cost included all the costs for seeds, fertilizers, pesticides, herbicides, fungicides, hired labor and machinery for all steps including land preparation, irrigation, seeding, fertilizing, pesticides spraying and harvesting. The return on investment ROI was calculated by (Returns – Investment/Investment). ROI is a preferred indicator to measure farm performance is preferred because it not only introduces the farm's income from rice production, but it also considers the profitability of agricultural investments (Böhme, 2015; Kleemann et al., 2014; Ma and Abdulai, 2017).

4. Results and discussion

4.1. Descriptive statistics

General information regarding the two groups of rice farmers is presented in Table 2. Compared to conventional farmers, farmers who participate in 1M5R are younger and more educated house-

[4] Certified seed varieties are defined according to the national technical standards on the quality of rice seeds QCVN 01-54: 2011/BNNPTNT, issued by the Ministry of Agriculture and Rural Development. The following is observed: (i) The seeds must be bright with little or no streaks, few discolored and deformed grains, homogeneous in size; (ii) The seeds origins must be pure (not mixed with other varieties), have low impurity and the germination rate > 80%; (iii) The seeds must be free from insects, sclerotia, or dangerous pathogens.

Table 2
Main characteristics of rice farms by 1M5R participation status.

Characteristics	Adopters (1) (140)	Non-adopters (2) (240)	Diff. (1)–(2)	
Age	49.40	49.50	0.10	
Gender	0.94	0.94	0.00	
Educational level	7.73	6.51	1.22	***
Farming experience	28.22	24.96	3.26	
Household size	4.55	4.41	0.14	
Rice farmland	2.94	2.68	0.26	
Rice plots	2.07	2.11	− 0.04	
Credit	0.21	0.18	0.03	
Training	0.87	0.60	0.27	***
Off-farm activities	0.14	0.13	0.01	
Cooperative membership	0.85	0.60	0.25	***
Farmer's association	0.23	0.27	− 0.04	

Source: Authors' calculations, based on household surveys.
*** indicates 1% significant level.

Table 3
Mean difference in rice production cost and outcome variables between 1M5R adopters and non-adopters in MKD.

	Adopters (140) (1)	Non-adopters (240) (2)	Diff. (1)–(2)
Inputs quantity (kg/ha)			
Seeds	121 (25.86)	187 (34.40)	− 66***
N	95 (30.27)	117 (46.16)	− 22***
P_2O_5	64 (30.67)	79 (38.63)	− 15***
K_2O	50 (32.80)	58 (37.01)	− 8*
Cost items (USD/ha)			
Seeds	69.60 (19.66)	93.19 (21.67)	− 23.59***
Fertilizer	167.69 (55.48)	205.70 (81.15)	− 38.01***
Pesticides, herbicides, insecticides,	152.14 (79.29)	183.08 (79.34)	− 30.94***
Land preparation	58.12 (23.32)	72.20 (34.18)	− 14.07***
Irrigation	37.03 (23.43)	43.47 (28.73)	− 6.44**
Fertilizing, spraying	67.26 (79.79)	57.13 (56.49)	10.13
Harvesting	80.03 (19.92)	85.78 (21.31)	− 5.75***
Others	3.51 (5.39)	5.27 (10.13)	− 1.76*
Total cost	687.56 (156.34)	798.11 (185.10)	− 110.55***
Cost per kg	0.12 (0.29)	0.13 (0.28)	− 0.01***
Outcome variables			
Rice output (ton/ha)	5.90	6.24	− 0.34***
Output price (USD/kg)	0.25 (0.02)	0.23 (0.01)	0.01***
Revenue (USD/ha /ha)	1,537.39 (269.88)	1,545.82 (239.56)	− 8.42
Profit (USD/ha /ha)	849.84 (269.18)	747.71 (247.80)	102.13***
ROI	1.32	1.01	0.31***

Source: Authors' calculation based on household survey
Standard deviation in the parentheses.
1 US Dollar in Vietnamese Dong is 23,288.98 for 11/11/2018.
***, **, and * *significant at 1, 5, and 10% probability level, respectively*.

hold heads. Specifically, there is a significant difference between the household heads in the treated and control farms, in terms of their participation in previous agricultural technical training and their agricultural cooperatives' memberships. In addition, farmers who choose to apply the 1M5R technique also have more experience in paddy cultivation; however, this difference is not statistically significant. The difference in other characteristics, such as household size, rice land area, number of plots, credit status, and non-agricultural activities, is not significant. This indicates similarities in the sociological characteristics of the interviewees.

Regarding the inputs required for the cultivation steps, Table 3 shows the difference in physical materials used by the two groups of rice households. It is clear that households that practice 1M5R use significantly fewer seeds, which are sown at 121 kg/ha, compared to households that do not practice 1M5R. While this amount is still high, compared to the technical recommendation (seed density should be from 80 to 100 kg/ha regarding to the broadcasting technique using a manually-pulled drum seeder) (Phung et al., 2014), it still indicates the farmers' effort in seed reduction compliance. Seed rate reduction is the first important step in the 1M5R technical package. Reducing the amount of seeds to 80–100 kg/ha reduces the pest infestation, compared to a strong seeding density. For this reason, farmers can reduce the amount of pesticides and nitrogen fertilizers and save irrigation water. As described in Table 3, households participating in 1M5R used nitrogenous fertilizers N, P_2O_5, and K_2O[5] at 95, 64, and 50 kg/ha, respectively, while ordinary households with larger amounts of seeds used more fertilizer at 117, 79, and 58 kg/ha, respectively.

A significant difference is noted in almost all types of costs between 1M5R participants and non-participants. Following the instructions of the technical package, participants can reduce their seed cost by an average of 23.59 USD/ha. Consequently, this group could also reduce their fertilizer and pesticide expenses by 38.01 and 30.99 USD/ha, respectively. Using tractors combined with laser technology for land leveling[6] before each season helps farmers to

[5] Farmers in this study used inorganic Urea (contains 60% N), DAP (18% N and 46% P_2O_5), NPK_1 (20% N, 20% P_2O_5 and 15% K_2O) and NPK_2 (16% N, 16% P_2O_5 and 8% K_2O), KCL (60% K_2O) commercial fertilizers.

[6] Laser land leveling (LLL) is a laser-guided technology used to level fields by removing soil from their high points and depositing it in their low points. LLL reduces greenhouse gas emissions by saving on energy, reducing cultivation time, and improving input-use efficiency. In a level field, water is distributed evenly, thus, reducing the amount of time and volume of water needed for irrigation (Mitigation technologies, IRRI).

Table 4
Determinants of farmers' participation in 1M5R package.

	Coef.	Std. error
Age	− 0.013	0.010
Gender	0.286	0.314
Educational level	0.036*	0.022
Farming experience	0.011	0.010
Household size	0.041	0.052
Rice land	0.022	0.022
No. of rice plots	− 0.010	0.043
Credit	0.127	0.182
Training	0.768***	0.177
Off-farm	0.091	0.213
Coop. membership	0.532***	0.171
Farmers Assoc.	− 0.148	0.165
_cons.	− 1.692	0.608
Number of observations		364
Log-likelihood		− 212.724
Prob > chi^2		0.000
Pseudo R^2		0.116

***,* *significant at 1 and 10% probability level, respectively.*
Source: Authors' calculation based on household survey.

not only reduce the amount of seeds but also to reduce the water pumping cost[7] (Aryal et al., 2015; Phung et al., 2014). Moreover, applying the AWD technique mentioned in the guidebook can effectively help 1M5R adopters to reduce irrigation costs by 6.44 USD/ha. Regarding the harvesting step, the 1M5R group was promoted to harvest paddy using a combine harvesting machine. This sharing activity in renting machinery helps 1M5R farmers to lower their harvesting costs by 5.75 USD/ha, compared to individuals who hire labor to complete their harvests. The data also show that the total production cost and the cost per kg of 1M5R fields are lower by 110.55 USD/ha and 0.01 USD/kg, respectively, compared to those of ordinary households. Except for spraying pesticides, fertilizing, and hired labor costs, all 1M5R fields' cost items are significantly lower than those for traditional fields are. The rice yield of the treated fields (5.90 ton/ha) was lower than that of the control fields (6.24 ton/ha) by 340 kg/ha. However, with a significantly higher output price, at 0.25 USD/kg, 1M5R households achieve much better profitability at 849.84 USD/ha. Therefore, the calculated profitability ROI ratio of participants in CSA was 31% higher than that of regular households in MKD provinces. Generally, it is shown that the values of the four, out of the five, outcome variables are higher for 1M5R adopters than they are for non-adopters, and the mean differences are statistically significant at the 1% level. However, this comparison, based on the t-test, is only descriptive; to obtain the true effects of the 1M5R technical package on farms' economic outcomes, a potential selection bias needs to be considered.

4.2. The effect of 1M5R package on the economics performance of rice smallholders

The result of the probit model, presented in Table 4, indicates the correlation between participation in 1M5R and households' demographic characteristics. More specifically, the decision to adopt this CSA is positively correlated with the education of household heads, their 1M5R training class attendance, and cooperative membership. Household heads with higher education are more likely to participate in the 1M5R. It is understandable that farmers with better education will understand cultivation techniques, and they can benefit in their production and natural environments if the amount of seeds and chemical fertilizer are reduced. This result supports the findings of previous studies on households' decisions to engage in CSA (Abegunde et al., 2020; Connor et al., 2020; Dung, 2020). Farmers who had previously participated in 1M5R technical training prefer to join 1M5R, as they were officially and technically aware of the importance of this farming technique and its benefits to production and to the environment. Finally, for cooperatives memberships, the institutional factor has a significantly positive impact on the implementation of the 1M5R technique, at the 1% significance level. Similar conclusions are also indicated by Abegunde et al. (2020) and Tran et al. (2020). These results emphasize the importance of information distribution to farmers through training classes and the support of cooperatives/farming groups in providing seed supply, fertilizer, agricultural machinery, and irrigation systems during dry seasons.

The propensity score distributions of the two groups are shown in Fig. 3. The estimated propensity scores for the entire sample range between 0.035 and 0.999, with a mean score of 0.374 (SD = 0.178). The propensity scores for members vary between 0.058 and 0.999 and have a mean score of 0.462 (SD = 0.150). The propensity scores for non-members vary between 0.035 and 0.717, with a mean score of 0.321 (SD = 0.171). Thus, the common support region for the distribution of the estimated propensity scores of members and non-members would range between 0.058 and 0.717. The households with propensity scores outside this range are excluded from the sample. The final number of households in the common support region is 364, including 136 participants and 228 non-participants in the 1M5R package.

The next important step is checking for selection bias and the quality of the matching algorithm used in this study. The results of the balancing test for all covariates between the 1M5R participants and non-participants are presented in Table 5. Before matching, the mean standardized bias for all variables used in the probit model was 17.8%. After matching, using NNM (n = 5) and kernel algorithms, the mean bias between these covariates was significantly reduced to 4.3% and 2.2%, respectively. After matching, the large bias values of educational level and training activity between the two groups were greatly reduced to values smaller than 10%. The balancing test's result, through KM and NNM, presents a good matching quality, which can be used to draw conclusions regarding the treatment effect and to provide further implications of the 1M5R package.

Finally, the economic impact of 1M5R on household performance is presented in Table 6. Overall, applying 1M5R can help reduce the total production cost by more than 80 USD/ha. For adopters, the cost per kg is lower by 0.007 USD/kg through KM, compared to that for ordinary farmers, which is still a very modest figure. Regarding the outcome variables, households following 1M5R package have lower rice yields, compared to households using normal amount of inputs, which are equivalent to 0.37 tons/ha and 0.28 tons/ha with NNM and KM, respectively. Households that practice 1M5R grow aromatic and high quality rice to provide for both export and domestic markets. During the Summer-Autumn season, the weather was very humid with rainfall and there was high risks of pests and disease. Meanwhile, 1M5R adopters had to reduce seed sowing density, fertilizers and pesticides spraying. Therefore, the yield of 1M5R participants was lower which might be caused by the reduction of inputs. It would be ideal that paddy yield could maintain or slightly increase as mentioned in previous studies when Vietnamese farmers practiced the reductions in seeds, fertilizers and pesticides application (Huan et. al, 2005; Tin et. al, 2008). However our empirical results shows that higher yield has not yet realized and lower yield may be inevitable in the short-run. Paddy products from 1M5R households are purchased

[7] The empirical results from the study by Aryal (2015) indicated that laser leveling in rice fields reduced irrigation time by 47–69 h/ha/season and improved yield by approximately 7 %, compared with traditionally leveled fields.

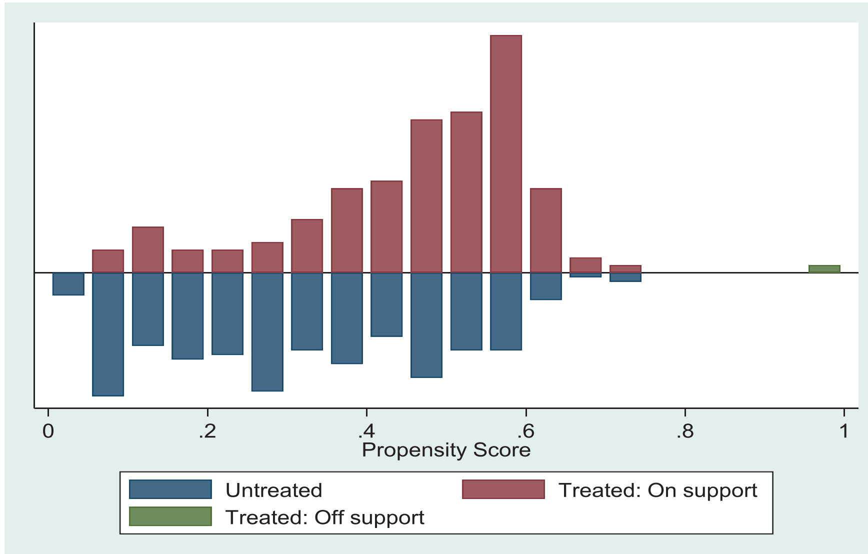

Fig. 3. Distribution of the propensity score for 1M5R participants (treated group) and non-participants (untreated group)
Source: Authors' compilation, using GIS mapping.

Table 5
Balancing test with unmatched and matched samples.

Variable	Unmatched				NNM (n = 5)				Kernel			
	Treated	Control	% bias	T	Treated	Control	% bias	T	Treated	Control	% bias	T
Age	49.40	49.45	− 3.9	− 0.36	48.99	48.41	5.4	0.46	48.99	48.83	1.5	0.13
Gender	0.95	0.94	2.4	0.22	0.96	0.96	0	0	0.96	0.95	1.6	0.14
Educational level	7.63	6.52	33.1***	3.01	7.61	7.35	7.8	0.67	7.61	7.43	5.5	0.47
Farming experience	28.22	25.10	14.6	1.50	25.99	26.08	− 0.5	− 0.08	25.99	26.35	− 1.7	− 0.28
Household size	4.56	4.44	8.2	0.75	4.57	4.69	− 8.5	− 0.72	4.57	4.57	− 0.1	− 0.01
Rice land	2.95	2.61	9.9	0.96	2.96	2.68	8	0.7	2.96	2.77	5.5	0.46
No. of rice plots	2.09	2.12	− 1.7	− 0.15	2.09	2.19	− 5.8	− 0.54	2.09	2.16	− 3.7	− 0.34
Credit	0.21	0.18	7.7	0.72	0.21	0.18	6.4	0.52	0.21	0.19	3.4	0.28
Training	0.85	0.62	52***	5.77	0.87	0.88	− 1.4	− 0.15	0.84	0.84	0	0.02
Off-farm	0.88	0.60	65.4	0.34	0.14	0.13	2.6	0.21	0.87	0.87	0.2	− 0.13
Cooperative memberships	0.14	0.13	3.7***	4.63	0.84	0.84	1	0.1	0.14	0.15	− 1.6	0
Farmers Assoc.	0.24	0.29	− 11.3	− 1.04	0.24	0.22	4.7	0.41	0.24	0.24	− 1.8	− 0.15
Mean standardized bias (%)			17.8				4.3				2.2	

Note: *** significant at the 1% probability level; NNM = nearest neighbor matching.

by traders at a higher average price of 0.011 and 0.010 USD/kg, respectively, thanks to the operation of cooperatives as agencies in selling products and making contracts with traders. The total revenue of the 1M5R household group decreases slightly due to lower paddy output; however, owing to the relative cost reduction, the net profit is higher by 62.277 USD/ha and 77.628 USD/ha with NNM and KM, respectively. This result is in line with the findings from other studies (Huan et. al, 2005; Stuart et. al, 2018; Tin et. al, 2008) that the improved farming technique (mainly cutting down excessive input items activities) significantly helped applicants to reduce production cost and increase their net income. Finally, the technical package 1M5R proves to be effective in helping participants improve economic performance when their ROI is higher by 0.24, which is statistically significant at the 1% level. In conclusion, the technical package 1M5R does not ensure paddy yield, but achieves its primary objective of reducing the production costs and improving households' earnings in treatment fields. Hence, the advantageous ROI ratio not only presents the 1M5R adopters' benefits from rice production but also introduces their effective investments into agricultural activity by following the reduction strategies. The practical results of this study could encourage farmers in other areas to join in and be convinced about both the economics and environmental impacts of 1M5R technical package to paddy smallholders. Through the benefits brought to rural life, scaling up the 1M5R in every province of the MKD is very promising.

5. Conclusion

The 1M5R package has become one of the most important techniques for paddy producers to adopt in Vietnam and the MKD, since 2011. The empirical results from this study indicate that educational level, training class attendance, and cooperative membership are the key factors driving households' decision to practice the 1M5R technique in their fields. The PSM results are also consistent with the objectives of the 1M5R application, which helps farmers to reduce production costs, obtain better output prices, and enhance profit per hectare. However, the rice yield was not maintained, but was slightly lower in the treatment fields due to the decrease in seed density and chemical fertilizer usage. PSM is found to be effective in estimating the treatment effects of the important 1M5R technique on the economic performance of smallholders, after eliminating the selection bias problem. With the significant reduction in seed sown density and chemical input, it is possible to conclude that 1M5R is a climate-smart practice that contributes not only to rice producers' economic performance but also to the sustainable environment of the MKD region.

Table 6
Treatment effect of 1M5R on farm's performance with Nearest Neighbor Matching and Kernel algorithms.

	Variables	Sample	Adopters	Non-adopters	Diff.		T-stat
NNM (n = 5)	Cost/kg (USD/kg)	Unmatched	0.119	0.128	−0.010		−3.21
		ATT	0.118	0.124	−0.006		−1.54
	Total cost	Unmatched	691.398	793.353	−101.955	***	−5.51
	(USD/ha)	ATT	692.243	773.071	−80.828	***	−3.63
	Yield	Unmatched	5.91	6.24	−0.33	***	−3.39
	(ton/ha)	ATT	5.92	6.29	−0.37	***	−3.11
	Output price/kg	Unmatched	0.247	0.237	0.011	***	5.43
	(USD/kg)	ATT	0.247	0.237	0.011	***	4.38
	Revenue	Unmatched	1,537.369	1,546.782	−9.412		−0.35
	(USD/ha)	ATT	1,540.742	1,559.292	−18.550		−0.56
	Farm's profit	Unmatched	845.971	753.428	92.543	***	3.37
	(USD/ha)	ATT	848.498	786.221	62.277	***	1.82
	ROI	Unmatched	1.31	1.03	0.28	***	4.97
		ATT	1.32	1.08	0.24	***	3.48
Kernel	Cost/kg (USD/kg)	Unmatched	0.119	0.128	−0.010	***	−3.21
		ATT	0.118	0.126	−0.007	**	−2.09
	Total cost	Unmatched	691.398	793.353	−101.955	***	−5.51
	(USD/ha)	ATT	692.243	772.363	−80.120	***	−3.83
	Yield	Unmatched	5.91	6.24	−0.33	***	−3.39
	(ton/ha)	ATT	5.92	6.20	−0.28	***	−2.57
	Output price/kg	Unmatched	0.247	0.237	0.011	***	5.43
	(USD/kg)	ATT	0.247	0.237	0.010	***	4.4
	Revenue	Unmatched	1,537.369	1,546.782	−9.412		−0.35
	(USD/ha)	ATT	1,540.742	1,543.233	−2.491		−0.08
	Farm's profit	Unmatched	845.971	753.428	92.543	***	3.37
	(USD/ha)	ATT	848.498	770.870	77.628	***	2.45
	ROI	Unmatched	1.31	1.03	0.28	***	4.97
		ATT	1.32	1.08	0.24	***	3.64

Source: calculated from household survey
1 US Dollar in Vietnamese Dong is 23,288.98 for 11/11/2018.
***.
***significant at 1 and 5 probability level, respectively.*

Some policy implications are suggested through the main findings of this study. First, participating in cooperatives and farming groups could provide better access to irrigation, mechanization, and after-harvest storage for farmers because of the available input supply and output contracts associated with rice enterprises. Second, agricultural training courses should emphasize and encourage paddy producers to continue reducing the seeds sown, to meet the recommended amount, which is 80–100 kg/ha. By visiting fields that implement 1M5R in local areas successfully, traditional producers could understand and practice input reduction on their own farms. In addition, the government could encourage rice enterprises to expand their paddy areas, and grant certificates to 1M5R products for both domestic and export demands.

The limitation of this study is the absence of post-harvest loss indicator on fields for comparison. Finally, some suggestions for future research topics include examining the difference in TE between 1M5R adopters and traditional fields and estimating the impact of climate smart technologies, such as Laser Land Leveling or AWD, on rice production systems in the Mekong Delta region.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests

Acknowledgements

We would like to express our appreciation to the Mekong Delta Development Research Institute's director and the leader of the MSVC project for their consent to acquire and use the dataset for analysis.

Funding

This study was financially supported by the Federal Ministry for Economic Cooperation and Development, Germany in household survey's design and primary data collection. In addition, this study also received partial funding, for the proof reading and language editing step from SPIRITS, Kyoto University.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2021.07.018.

References

Abegunde, V.O., Sibanda, M., Obi, A., 2020. Determinants of the adoption of climate-smart agriculture practices by small-scale farming households in King Cetshwayo District Municipality. South Africa. Sustain. 12 (195), 1–27. doi:10.3390/su12010195.
Ali, A., Erenstein, O., Rahut, D.B., 2014. Impact of direct rice-sowing technology on rice producers' earnings: Empirical evidence from Pakistan. J. Dev. Stud. 1, 244–254. doi:10.1080/21665095.2014.943777.
Aryal, J.P., Mehrotra, M.B., Jat, M.L., Sidhu, H.S., 2015. Impacts of laser land leveling in rice–wheat systems of the north-western Indo-Gangetic Plains of India. Food Secur 7, 725–738. doi:10.1007/s12571-015-0460-y.
Becker, S.O., Ichino, A., 2002. Estimation of average treatment effects based on propensity score. Stata J 2 (4), 358–377 https://doi.org/10.1177%2F1536867X0200200403.
Bidzakin, J.K., Fialor, S.C., Awunyo-Vitor, D., Yahaya, I., 2019. Impact of contract farming on rice farm performance: Endogenous switching regression. Cogent. Econ. Finance. 7, 1–20. doi:10.1080/23322039.2019.1618229.
Böhme, M.H., 2015. Does migration raise agricultural investment? An empirical analysis for rural Mexico. Agric. Econ. 46 (2), 211–225. doi:10.1111/agec.12152.
Caliendo, M., Kopeinig, S., 2008. Some practical guidance for the implementation of propensity score matching. J. Econ. Surv. 22, 31–72. doi:10.1111/j.1467-6419.2007.00527.x.
Chau, N.D.G., Sebesvari, Z., Amelung, W., Renaud, F.G., 2015. Pesticide pollution of multiple drinking water sources in the Mekong delta, Vietnam: evidence from two provinces. Environ. Sci. Pollut. Res. 22, 9042–9058. doi:10.1007/s11356-014-4034-x.

Chi, T.T.N., Anh, T.T.T., Tuyen, T.Q., Palis, F., Singleton, G., Toan, N.V., 2013. Implementation of one must and five reductions in rice production in An Giang Province. Omon Rice J 19, 237–249.
Connor, M., Tuan, L.A., DeGuia, A.H., Wehmeyer, H., 2020. Sustainable rice production in the Mekong River Delta: Factors influencing farmers' adoption of the integrated technology package "one must do, five reductions" (1M5R). Outlook Agric 1–15 https://doi.org/10.1177%2F0030727020960165.
Dasgupta, S., Meisner, C., Wheeler, D., Xuyen, K., Lam, N.T., 2007. Pesticide poisoning of farm workers–implications of blood test results from Vietnam. Int. J. Hyg. Environ. Health. 210, 121–132. doi:10.1016/j.ijheh.2006.08.006.
Dehejia, R.H., Wahba, S., 2002. Propensity score-matching methods for non-experimental causal studies. Rev. Econ. Stat. 84, 151–161. doi:10.1162/003465302317331982.
Duong, P.B., Thanh, P.T., 2019. Adoption and effects of modern rice varieties in Vietnam: Micro-econometric analysis of household surveys. Econ. Anal. Policy. 64, 282–292. doi:10.1016/j.eap.2019.09.006.
Dung, L.T., 2020. Factors influencing farmers' adoption of climate-smart agriculture in rice production in Vietnam's Mekong Delta. Asian J. Agric. Dev. 17 (1), 109–124. doi:10.37801/ajad2020.17.1.7.
Garrido, M.M., Kelley, A.S., Paris, J., Roza, K., Meier, D.E., Morrison, R.S., Aldridge, M.D., 2014. Methods for constructing and assessing propensity score. Health Res. Educ. Trust 49, 1701–1720. doi:10.1111/1475-6773.12182.
Ho, T.T., Shimada, K., 2019. The effects of climate smart agriculture and climate change adaptation on the technical efficiency of rice farming—an empirical study in the Mekong Delta of Vietnam. Agric 9 (99), 1–20. doi:10.3390/agriculture9050099.
Huan, N.V, Thiet, L.V., Chien, L.V., Heong, K.L., 2005. Farmers' participatory evaluation of reducing pesticides, fertilizers and seed rates in rice farming in the Mekong Delta. Vietnam. Crop Prot. 24, 457–464. doi:10.1016/j.cropro.2004.09.013.
Imbens, G., 2004. Nonparametric estimation of average treatment effects under exogeneity: A review. Rev. Econ. Stat. 86, 4–29. doi:10.1162/003465304323023651.
Khandker, S.R., Koolwal, G.B., Samad, H.A., 2010. Handbook on Impact Evaluation: Quantitative Methods and Practices. World Bank, Washington, D.C.
Khatri-Chhetri, A., Aggarwal, P.K., Joshi, P.K., Vyas, S., 2017. Farmers' prioritization of climate-smart agriculture (CSA) technologies. Agric. Syst. 151, 184–191. doi:10.1016/j.agsy.2016.10.005.
Kleemann, L., Abdulai, A., Buss, M., 2014. Certification and access to export markets: Adoption and return on investment of organic-certified pineapple farming in Ghana. World Dev 64, 79–92. doi:10.1016/j.worlddev.2014.05.005.
Ma, W., Abdulai, A., 2017. The economic impacts of agricultural cooperatives on smallholder farmers in rural China. Agribusiness 33, 537–551. doi:10.1002/agr.21522.
Mendola, M., 2007. Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. Food Policy 32, 372–393. doi:10.1016/j.foodpol.2006.07.003.
Mwungu, C.M., et al., 2019. Household welfare effects of stress-tolerant varieties in Northern Uganda. The Climate-Smart Agriculture Papers In: Rosenstock T., Nowak A., Girvetz E. (eds). Springer, Cham doi:10.1007/978-3-319-92798-5_15.
Powell-Jackson, T., Hanson, K., 2012. Financial incentives for maternal health: Impact of a national programme in Nepal. J. Health Econ. 31, 271–284. doi:10.1016/j.jhealeco.2011.10.010.
Rosenbaum, P.R., Rubin, D.B., 1983. The central role of the propensity score in observational studies for causal effects. Biometrica 70, 41–50. doi:10.1093/biomet/70.1.41.
Stuart, A.M., Devkota, K.P., Sato, T., Pame, A.R.P., Balingbing, C., Phung, N.T.M., Kieu, N.T., Hieu, P.T.M., Long, T.H., Beebout, S., Singleton, G.R., 2018. On-farm assessment of different rice crop management practices in the Mekong Delta, Vietnam, using sustainability performance indicators. Field Crops Res 229, 103–114. doi:10.1016/j.fcr.2018.10.001.
Stuart, E.A., Lee, B.K., Leacy, F.P., 2013. Prognostic score-based balance measures can be a useful diagnostic for propensity scores in comparative effectiveness research. J. Clin. Epidemiol. 66, 84–90. doi:10.1016/j.jclinepi.2013.01.013.
Tin, H.Q., Struik, P.C., Price, L.L., Be, T.T., 2008. Comparative analysis of local and improved practices used by farmer seed production schools in Vietnam. Field Crops Res 108, 212–221. doi:10.1016/j.fcr.2008.05.005.
Toan, P.V., Sebesvari, Z., Bläsing, M., Rosendahl, I., Renaud, F.G., 2013. Pesticide management and their residues in sediments and surface and drinking water in the Mekong Delta. Vietnam. Sci. Total Environ. 452–453, 28–39. doi:10.1016/j.scitotenv.2013.02.026.
Tong, Y., 2017. Rice intensive cropping and balanced cropping in the Mekong Delta, Vietnam — economic and ecological considerations. Ecol. Econom. 132, 205–212. doi:10.1016/j.ecolecon.2016.10.013.
Tran, N.L.D., Rañola, R.F., Jr., Sander, B.O., Reiner, W., Nguyen, D.T., Nong, N.K.N., 2020. Determinants of adoption of climate-smart agriculture technologies in rice production in Vietnam Int. J. Clim. Chang. Strateg. Manag. 12, 238–256. doi:10.1108/IJCCSM-01-2019-0003.
Tu, V., 2015. Resource use efficiency and economic losses: implications for sustainable rice production in Vietnam. Environ. Dev. Sustain. 19, 285–300. doi:10.1007/s10668-015-9724-0.
Wu, H., Ding, S., Pandey, S., Tao, D., 2010. Assessing the impact of agricultural technology adoption on farmers' well-being using propensity-score matching analysis in rural China. Asian Econ. J. 24 (2), 141–160. doi:10.1111/j.1467-8381.2010.02033.x.
Phung, N.T.M., Du, P.V., Singleton, G., 2014. One Must DoOne Must Do, Five Reductions (1M5R): Best Management Practices for Lowland Irrigated Rice in the Mekong Delta. Ministry of Agricultural and Rural Development: Vietnam and International Rice Research Institute, Philippines.
Son, N.N., Tin, N.H., Sanh, N.V., 2013. 2013. Intensive paddy rice & 1 Must Five Reductions applied: The constraint of farmers and improvements at household level. Can Tho Univ. J. Sci. 26, 66–74.
Tin, N.H., Huong, L.T.C., Son, N.N., Sanh, N.V., Duyen, C.M., 2015. 2015. The economic efficiency of "One Must Do, Five Reductions" (1M5R) technique applied in rice production between cooperative and non-cooperative farmer groups in Kien Giang and An Giang Provinces. Can Tho Univ. J. Sci. 37 (2), 76–85.