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Adoption and Performance of Direct-seeded Rice (DSR) Technology in the Philippines

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Manual transplanting is the traditional rice crop establishment method in the Philippines. Consequently, crop establishment comprises over 25% of the total labor cost that drives up rice production costs in the country. The study, therefore, assessed the socioeconomic effect of direct-seeded rice (DSR) as an alternative to transplanted rice (TPR), determined the trends and patterns of adoption of DSR, examined the economic performance of DSR relative to TPR, and identified the factors that influence DSR adoption. The rice-based farm households survey data from 1996/1997 to 2016/2017 showed that the proportion of DSR farmer-adopters increased from 27% in 1996/1997 to 33–42% in 2016/2017. The adoption of DSR resulted in lower labor use and cost in crop establishment and higher labor productivity. However, lower yield and higher seed and herbicide costs relative to TPR were its major trade-offs. Despite this, the partial budget analysis showed that shifting to DSR posed incremental income, especially in rainfed areas and during the dry season, brought by labor savings that compensated for the higher seed and herbicide cost and yield penalty. Probit regression analysis revealed that area, use of seeds and pesticides, labor use, tenurial status, irrigation, and power cost significantly affected farmer adoption of DSR. Addressing the constraints, especially the yield gap between DSR and TPR, may enhance the adoption of DSR. The study suggests promoting DSR as a viable alternative to TPR in suitable areas through extension services and technology demonstrations; training and encouraging rice farmers to practice efficient weed control techniques including proper water management and land preparation, and to use technologies like drum seeder and similar technologies to save on seeds and labor; and developing rice varieties and technologies ideal for DSR.

Keywords: adoption rate, cost and returns, direct seeding, labor cost, productivity

INTRODUCTION

Rice is one of the major food cash crops in the Philippines, yet the cost of producing it in the country remains higher than the other top rice-producing countries in Southeast Asia. In 2013, rice farmers in the Philippines – as represented by Nueva Ecija – expended PHP 12.41 kg^{-1} to produce *palay* (unmilled rice), whereas their Thai (in Suphanburi) and Vietnamese (in Can Tho) counterparts spent only PHP 8.85 and 6.53 kg^{-1}, respectively (Moya *et al.* 2016). Data from the Philippine Statistics Authority (PSA) shows that the average cost of producing rice in the country was PHP 11.52 kg^{-1} in 2020, still relatively higher than other Southeast Asian countries.

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Labor cost is the top contributor to the rice production cost in the Philippines. Hired and operator, family, and exchange (OFE) labor comprised almost 53% (PHP 6.09 kg^{-1}) of the total production cost in 2020 due to the high-level labor requirements, and rising farm wage rates. Total labor use in the Philippines was around 69–71 labor-days (ld) ha^{-1} (1 ld = 8 h of work), substantially higher than that of Thailand with only 10–11 ld ha^{-1} and that of Vietnam with 20–22 ld ha^{-1} (Mataia *et al.* 2016). This difference is due to the varying degree of mechanization – as well as farm practices, particularly on crop establishment, in each country. Primarily owing to the dominant practice of manual transplanting, crop establishment accounts for 21–24 ld ha^{-1} or over 30% of the total labor use in rice production in the Philippines. On the other hand, rice farmers in Thailand and Vietnam extensively use direct seeding which uses about 1–2 ld ha^{-1} only (Mataia *et al.* 2016). DSR is easier to do as it only involves the sowing of dry or pre-germinated seeds into dry or puddled soils, whereas TPR requires the growing of seedlings in seedbeds and replanting them to the puddled field (Pandey and Velasco 2002). As such, DSR can reduce labor requirements by up to 50% depending on the production system (Pandey and Velasco 2002). Accordingly, Filipino farmers can reduce hired labor costs by PHP 1.14 kg^{-1} through DSR (Bordey *et al.* 2016).

The shift to DSR or alternate use of TPR and DSR has already spread among rice farmers in Asia, primarily due to rising wage rates. More farmers are likely to shift to DSR as labor becomes scarcer, irrigation water supply declines, and the need for crop intensification and diversification increases to attain food and nutrition security (Pandey and Velasco 2002). Other drivers for adoption include labor savings for more income, availability of high-yielding, short-duration rice varieties, and affordable chemical weed control measures. Kumar *et al.* (2015) and Choudhary *et al.* (2016) observed a corresponding 7–8 and 9–13% labor savings in DSR compared to manual TPR in Haryana, India. In Vietnam, the shorter growth duration of DSR enabled triple rice cropping in a year (Beltran *et al.* 2015), which improved the country's rice production.

This paper aimed to assess the socioeconomic effect of the rice farmers' adoption of DSR as an alternative to TPR. For this purpose, it determined the trends and patterns of adoption of DSR; examined the economic performance of DSR relative to TPR; identified the factors that influence DSR adoption, and provided policy recommendations to promote DSR. Doing so may provide the rationale to promote DSR technology to rice farmers in suitable areas in the country and may help identify the necessary support services to assist farmers who are willing or want to transition from TPR to DSR to deal with its constraints and trade-offs.

MATERIALS AND METHODS

Data and Sources

This paper focused on the 2016 wet season (WS) and 2017 dry season (DS) datasets from the rice-based farm households survey (RBFHS). The RBFHS is a regular survey carried out by the Socioeconomics Division of the Philippine Rice Research Institute (PhilRice) every five years since 1996–1997. It was designed to monitor the changes in the rice farming landscape in the Philippines and collects extensive information on farmers' crop management practices, production inputs and costs, harvest, farmgate price, and technology adoption, among others.

The 2016–2017 survey round of RBFHS covered 42 rice-producing provinces with 3,164 sample farmers for each season (Appendix Table I). The majority of these farmers plant rice for sale to traders as their main income source. Using the province as the domain, the survey used a two-stage sampling procedure, with the *barangay* as the first-stage sampling unit and the rice-based farm household as the second-stage sampling unit. Sample irrigated and rainfed *barangays* were randomly drawn from a list of irrigated and rainfed *barangays* in each identified province based on the classification from the BAS–Provincial Operation Center.

Similar respondents from previous survey rounds were re-interviewed to preserve the panel nature of the data except for the samples from Kalinga, Apayao, Negros Occidental, Nueva Vizcaya, Lanao del Sur, Western Samar, Capiz, Antique, and Palawan, which were newly included provinces during the 2016/2017 survey round. Respondents who have passed away, migrated, or have permanently stopped farming were replaced by the individual within the village to which the farm management was transferred. If the farm was subdivided into multiple recipients within the village, random selection among the recipients was done *via* draw lots. If the recipient could not be identified, the right coverage approach was employed to randomly select a replacement within the *barangay*. This approach requires a landmark within the *barangay* (*e.g.* school, *barangay* hall, church) as the data collector's starting point. From the landmark, the data collector moves along a path and chooses every third household from the landmark and the previous sample along the road or passageway moving in a serpentine manner. This method was also applied in randomly selecting new respondents from the added provinces.

For this study, the sample rice farmers in the dataset were stratified based on their reported crop establishment method. DSR farmers are those that used direct seeding, whereas TPR farmers are those that practiced transplanting as their crop establishment method during the reference period. Farmers with inconsistent or missing data were

excluded in the analysis.

The socioeconomic and farm characteristics of the farmers were derived from the RBFHS database. Data on the material and labor input use and cost, as well as yield and farmgate price, were likewise gathered from the 2016/2017 database as indicators of the economic performance of each crop establishment method. Meanwhile, the pattern of farmer adoption of DSR and TPR was determined using the data from 1996/1997, 2001/2002, 2006/2007, 2011/2012, and 2016/2017 survey rounds.

Methods of Analysis

Descriptive statistics through percentage distribution and means were used to describe the socioeconomic and farm characteristics of the rice farmers. Tabular analysis using percentage distribution was also employed to determine the trend and pattern of adoption of crop establishment methods by rice farmers over time. Means and costs and returns analysis were used to examine the economic performance of DSR *vis-à-vis* TPR. T-test analysis was also used to determine whether there is a significant difference in the input use and costs between DSR and TPR at a 95% confidence level. Additionally, the labor productivity of the two methods was compared by dividing their yield by their corresponding total labor use. A partial budget analysis was used to assess whether it is economically sound for farmers to shift to DSR from TPR.

To determine the factors affecting DSR adoption, a model with a binary outcome (whether the rice farmer is a DSR user or not) was estimated, but comparing outcomes from inherently dissimilar groups – especially in non-randomized experiments – may lead to bias and invalid results (Rosenbaum and Rubin 1983). Through matching, it is possible to reduce, if not totally remove, selection bias from having unbalanced groups. This bias came from the treatment and the control/counterfactual groups being systematically different from one another aside from the intervention itself (Binci *et al.* 2018).

This section starts with a discussion of propensity score matching used in creating the counterfactual group (non-DSR adopters) to be compared with the treatment group (DSR adopters). From this, the effect of DSR adoption on yield was estimated. This is followed by the description of the estimation implemented for the binary outcome model affecting DSR adoption. Separate models were estimated for WS and DS because the environment, farmers' behavior, and production are distinct between the two seasons.

Propensity score matching (PSM): forming a comparison group. PSM is one of the statistical techniques used to "construct" a counterfactual group (Gertler *et al.* 2016). This is implemented by estimating the probability of an observation (in this case, rice farmers) to enroll in a program (DSR adoption) based on the observed values of its characteristics. Rosenbaum and Rubin (1983) mathematically represented this as:

$$e(x) = pr(z = 1|x) \tag{1}$$

where $e(x)$, called the propensity score, is the probability of a treatment being exposed to the program ($z = 1$, where z is the dummy for the program) conditioned on the observed covariates x. From Jalan and Ravallion (2003), the impact estimator does not depend on the discrete response specification of the function $e(x)$. Hence, for this study, a probit specification is used to estimate Equation 1, as it would also be used to model the determinants of DSR adoption later. Equation 1, represented as a latent variable model, follows:

$$z_i = 1 \text{ iff } z_i^* > 0 \tag{2}$$

$$z_i = 0 \text{ iff } z_i^* \leq 0 \tag{3}$$

where:

$$z_i^* = x_i\beta + \mu_i \tag{4}$$

x_i is an exogenous vector of variables used for matching, β is a vector of parameters to be estimated, and μ_i is a normal random variable with variance 1 and correlation coefficient ρ. In choosing the explanatory variables for the computation of the said probabilities, a major consideration is using only characteristics that would not be affected by the program. Another is choosing a set of variables that balances the distribution between the statistically matched treatment and counterfactual groups. In finalizing the covariates used for matching and estimating the average treatment effect on the treated (ATT) of DSR adoption, this study mostly follows the algorithm of Binci *et al.* (2018). The following steps were undertaken:

1. From a pool of covariates, a stepwise (forward) regression was estimated through the ordinal generalized linear model to determine which variables are to be included. The level of significance was set at 5%. The set of variables are factors of production, farmer's characteristics, and other variables believed to affect the outcome variable (rice yield) but do not necessarily change as a result of DSR adoption;
2. Continuous variables selected in the first stepwise regression model were squared, and some interactions were added. All these variables were added to the initially chosen variables, and step 1 was repeated;
3. Since the study uses a cross-section data done in one period, the balancing properties of the matched treatment and counterfactual groups were determined. Methods used in the study include: [1] visually checking the graphs for the common support and the distribution of the propensity score estimates, [2]

t-tests for equality of means of matching variables used, and [3] statistic Rubin's B and Rubin's R. The value of B should be below 25 and R should lie between 0.5 and 2 for overall balance to be sufficient [Rubin (2001), as cited by Binci *et al.* (2018)]. If the two groups are said to be balanced, then the conditional independence assumption holds. This assumption stated that the outcome measure reflects the effect of the intervention since the observable characteristics were already accounted for;

4. Results from steps 1–3 determined the relevant variables for matching in a particular season. Once the covariates to include were finalized, a probit regression model was conducted to estimate the propensity scores (pscores). The final variables used in PSM are found in Table 1;

5. The outcome across units (*i.e.* farmers) was then matched through their respective estimated propensity scores using k-nearest neighbors matching (k = 1) and a caliper of 0.2. This is done to obtain the ATT estimate, the mean difference in outcomes over the common support (Caliendo and Kopeinig 2008). It should be noted that we "not only match the nearest neighbor but also other controls with identical (tied) pscores" (Leuven and Sianesi 2003).

Discrete choice model for the determinants of DSR adoption. To statistically ascertain the factors that significantly affect a farmer's likelihood to adopt direct seeding, a probit model was estimated. It is similar to Equation 1. But here, the covariates believed to influence DSR adoption, whether before or after, were all included (Table 2). The analysis is also restricted among observations part of the common support only, identified in PSM.

Equation 1 can also be expressed using Equations 2–4 as:

$$pr(z = 1|m) = pr(z_i^* > 0|M) \tag{5}$$

$$= pr(\mu_i > -M_i\beta|M) \tag{6}$$

$$= 1 - G(M_i\beta) = G(M_i\beta) \tag{7}$$

where $G(\cdot) = \phi(\cdot)$ is the cumulative distribution function of μ_i, a normally distributed variable with mean 0 and variance 1 (Wooldridge 2010). Instead of the notation x_i, the notation M_i was used to represent the exogenous vector of covariates explaining DSR adoption, which may (or may not) include those used in the PSM estimation. For both the WS and DS models, the covariate vector M_i is the same, which determined the statistically significant variables for DSR adoption in a particular season.

One of the assumptions in the probit model is the constant variance of the model's error. This is not a concern in PSM since it matches individuals from the control group to those with similar characteristics in the treatment group. However, for the purpose of determining the factors affecting DSR adoption, the model would have biased and inconsistent estimates when the homoscedastic distribution assumption of the model's error is violated. Freeman *et al.* (2018) explained that this happens when the level of information differs across observations.

To account for the presence of heteroscedasticity ($\delta > 0$), a heteroscedastic probit model whose variance is no longer equal to one but instead $\sigma_i^2 = \{\exp(N_i^- \delta)\}^2$ was estimated [Harvey (1976), as cited in StataCorp (2013)]. It should be noted that N_i^- is a vector of variable(s) that distinguishes the groups with different error variances and contains no intercept term. As such, the probability of a rice farmer to adopt DSR ($z_i = 1$) is now given as:

$$pr(z_i = 1) = G[M_i\beta / \exp(N_i^- \delta)] \tag{8}$$

"The chi-square (x^2) likelihood-ratio test of

Table 1. Description of the variables used in the PSM estimation.

Variable description	Remarks
Yield, rice production (in kg) over area harvested (in ha)	Outcome variable. Those with missing or inconsistent responses were dropped from the analysis
Treatment group = 1 if DSR farmer; zero if non-DSR farmer	Farmers who indicated that they used both DSR and transplanting were excluded from the analysis
Co-variates used in PSM where DSR adoption is the dependent variable	
Area harvested (in ha)	• Rice area harvested in the largest parcel (ha)
Dummy: tenure = 1 if land is owned; zero if otherwise	• Describes the right of a sample farmer to use a particular parcel
Dummy: rice organization = 1 if member; zero if otherwise	• Sample farmer's membership to a rice/rice-based farm organization
Number of farmer's household members	• Used only in the dry season model
Interaction variable: male x age	• This only considers the age (in yr) of male farmers. If the farmer is female, its value is zero. Used only in the wet season model.

Table 2. Description of the variables used in the discrete choice model affecting DSR adoption.

Variable description	Remarks
DSR adopter = 1 if farmer is using DSR; zero if non-DSR farmer	Dependent variable. Farmers who indicated that they are using both DSR and TPR were excluded from the analysis. Those with inconsistent/missing data were likewise excluded
Co-variates used in discrete choice model for DSR adoption	
Factors of production • area harvested (ha) • seeds used (kg ha^{-1}) • nitrogen used as fertilizer (kg ha^{-1}) • pesticide used (ai ha^{-1}) • hired labor (ld ha^{-1}) • operator, family and exchange (OFE) labor (ld ha^{-1})	Only factors of production with a statistically significant quadratic form were included in the final discrete choice model.
Other farming-related variables	
• dummy: tenure	• Tenure = 1 if land is owned; zero if otherwise
• dummy: irrigation •	• Irrigation = 1 if the water source comes from [1] gravity/pump; [2] STW, open/dug well, deepwell, SWIP/SFR; and [3] natural source (rivers, streams, free flowing). Otherwise, it is equal to zero.
• dummy: power	• Power = 1 if power cost (used for animal/machine rental and fuel and oil, except for irrigation) per hectare is greater than zero. Otherwise, the dummy for power is zero.
• dummy: capital used	• Capital = 1 if the only source of capital used for rice farming is own; otherwise, it is zero.
• dummy: rice organization	• Rice organization = 1 if farmer is a member; zero if otherwise
Farmer's characteristics	
• dummy: sex	• Sex = 1 if the farmer is male; zero otherwise
• age (in yr)	• A quadratic form of the variable *Age* was also included
• interaction: male x age	• This only considers the age (in yr) of male farmers. If the farmer is female, its value is zero. Used only in the wet season model.
• education (in yr)	• Highest educational level completed of sample rice farmer, computed in yr
• household size	• Total number of farmer's household members
• dummy: non-farm income	• Non-farm income = 1 if the farmer has other non-farm income sources; otherwise, it is zero.

[ai] active ingredient

heteroskedasticity [is used], which tests the full model with heteroskedasticity against the full model without" (StataCorp 2013).

LIMITATIONS OF THE STUDY

1. The study focuses on the economic performance of DSR adoption particularly on its effect on the net income of rice farmers should they opt to shift from TPR. It did not delve into the environmental effects of DSR;

2. The paper investigated the performance of DSR in general and not in terms of its specific methods (*i.e.* dry DSR, wet DSR);

3. The study also does not capture the effect of non-agricultural wage rate and non-agricultural employment status of the farmer's household on their planting mode given data limitations.

RESULTS AND DISCUSSION

Characteristics of Respondents

The socioeconomic characteristics of DSR farmers do not significantly differ from those of TPR farmers (Table 3). A larger portion of the respondents was male with an average household size of five. On average, they only had 8 years of formal education and have been in rice farming for 29 years. Their total household income commonly comes from different sources but more than half was from rice production, followed by non-farm income accounting for about a third of it.

Most of the rice farmers are smallholders with an average farm area smaller than 2 ha. DSR farmers had a slightly larger farm area with 1.83 ha, which may have been a factor in their selection of crop establishment method. Transplanting rice in a larger area is costly for farmers both in terms of money and time given the amount of labor, as well as the length of time required to perform the activity, especially if done manually. Irrigated areas account for around 69% of the total rice areas in the

Table 3. Socioeconomic and farm profile of sample rice farmers by crop establishment method, Philippines, 2016–2017.

Characteristic	DSR	TPR
n	2,027	3,646
Age	55	55
Sex (%)		
Male	81	84
Female	19	16
Household size	5	5
Educational attainment (no. of yr)	8	8
Farming experience (no. of yr)	29	29
Household income (PHP yr^{-1})	337,886	287,810
Rice income	196,039	153,318
Off-farm income	23,221	21,805
Non-farm income	98,912	93,060
Remittance	19,714	19,627
Ave. total farm area (ha)	1.83	1.43
Production ecosystem (%)		
Irrigated	63.5	76.18
Rainfed	36.5	23.82
Soil texture (%)		
Clayey	46.62	56.77
Loamy	24.61	21.69
Silty	3.98	4.36
Sandy	16.46	10.49
Clay loam	3.09	2.81
Sandy clay	1.61	1.16
Sandy loam	2.43	1.94
Silty clay	0.06	0.14
Others	0.11	0.17

[n] sample size
Source of basic data: PhilRice RBFHS 2016–2017

Philippines in 2016-2017, based on PSA data. Hence, the majority of the sample rice farmers operate in irrigated areas. More rice farmers used direct seeding in rainfed areas than in irrigated areas as transplanting becomes infeasible or inappropriate in areas with low or uncertain water availability (Pandey and Velasco 2002). Rice is mainly grown in clayey soils, which are more suitable for supporting the proper growth of the crop. Several studies (Grant 1964; Higgin 1964; Moormann and Dudal 1968), as cited by Moormann and Breemen (1978), have shown that rice yields are highest in soils with 25–50% clay in the surface and an equal or higher percentage in the subsoil.

Trends and Patterns of Adoption of DSR

Transplanting is the traditional crop establishment method used by rice farmers in the Philippines. From 1996/1997 to 2011/2012, over 69% of rice farmers used transplanting (Figure 1A). However, this declined in 2016/2017 with the increase in the proportion of DSR farmers. This was led by rice farmers in rainfed areas as over 42% of them used direct seeding during the period, a significant increase from the 27% adoption rate in 1996/1997. Likewise, DSR adoption in irrigated areas also grew to 33% in 2016/2017 from almost 27% in 1996/1997. This implies that some rice farmers may be starting to shift from transplanting to direct seeding in 2016/2017.

As a result of the replacement of quantitative restrictions with tariffs that liberalized rice importation in the country, farmers must be competitive amid an influx of low-cost rice from neighboring countries. The use of labor-saving technologies like DSR was one of Bordey *et al.*'s (2015) recommendations to help farmers become competitive by reducing labor costs.

A slightly higher proportion of rice farmers use DSR during the DS (Figure 1B). This is because the method is used by farmers to adapt to uncertain water availability with minimal and unpredictable rainfall to supplement the water requirements of rice, especially in rainfed areas during the DS. A stable supply of water is an important requisite for transplanting since the field must be puddled and completely wet for the seedling to be well established. Meanwhile, seeds can be direct-seeded onto dry soil by broadcasting, drilling, or dibbling as long as proper land preparation is performed.

Among provinces in the country, direct seeding was widely adopted by rice farmers in Aurora, Sultan Kudarat, Antique, Palawan, Capiz, and Iloilo (Figure 2). The history of direct seeding in Iloilo started in the late-1970s, which marked the start of double rice cropping in areas that used to be planted once a year with TPR (Pandey and Velasco 2002). This may be the reason why DSR is the prevalent method in the province, as well as in its neighboring provinces like Capiz and Antique. Meanwhile, the declining water availability due to less rainfall (Corales *et al.* 2015), and lack of irrigation may have provided the rationale for farmers in Aurora to shift to DSR. Likewise, local conditions may have stimulated the use of DSR among farmers in Palawan and in Sultan Kudarat.

Economic Performance of DSR

Yield. Yield from both DSR and TPR increased from 1996/1997 to 2016/2017 (Figure 3) probably owing to the development of modern rice varieties and improved crop management practices. However, the yield gap between TPR and DSR also widened. De Datta (1986) and Moody

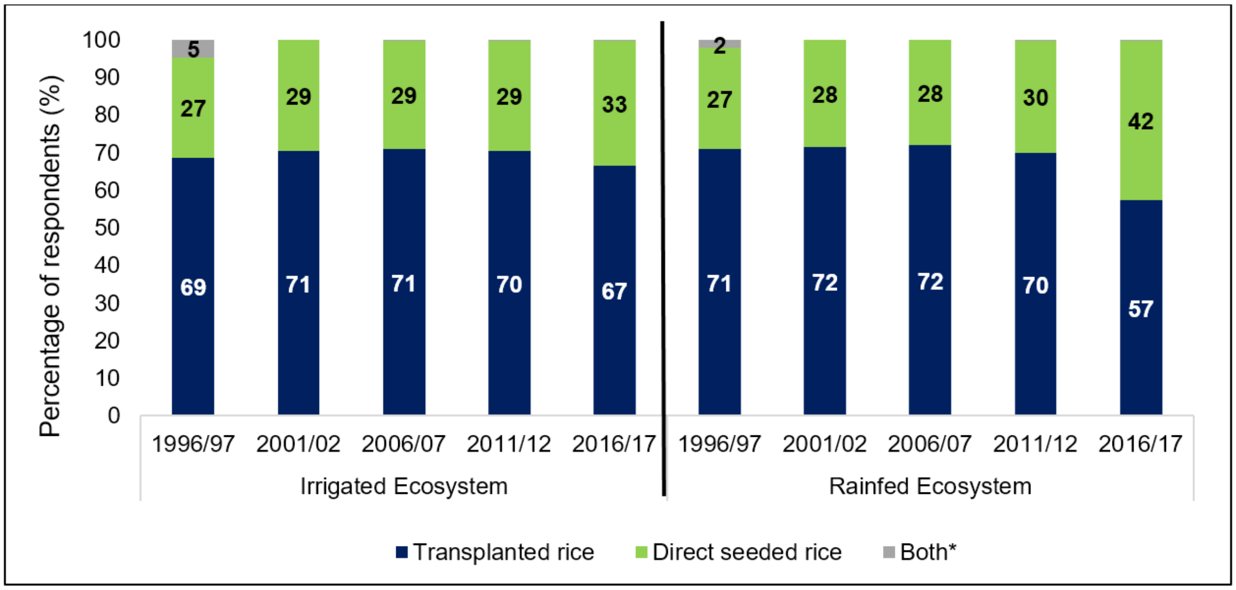

Figure 1A. Percentage distribution of rice farmers by method of crop establishment, and ecosystem, Philippines, 1996/1997–2016/2017. Source of basic data: PhilRice RBFHS 1996/1997-2016/2017; *Both direct seeding and transplanting

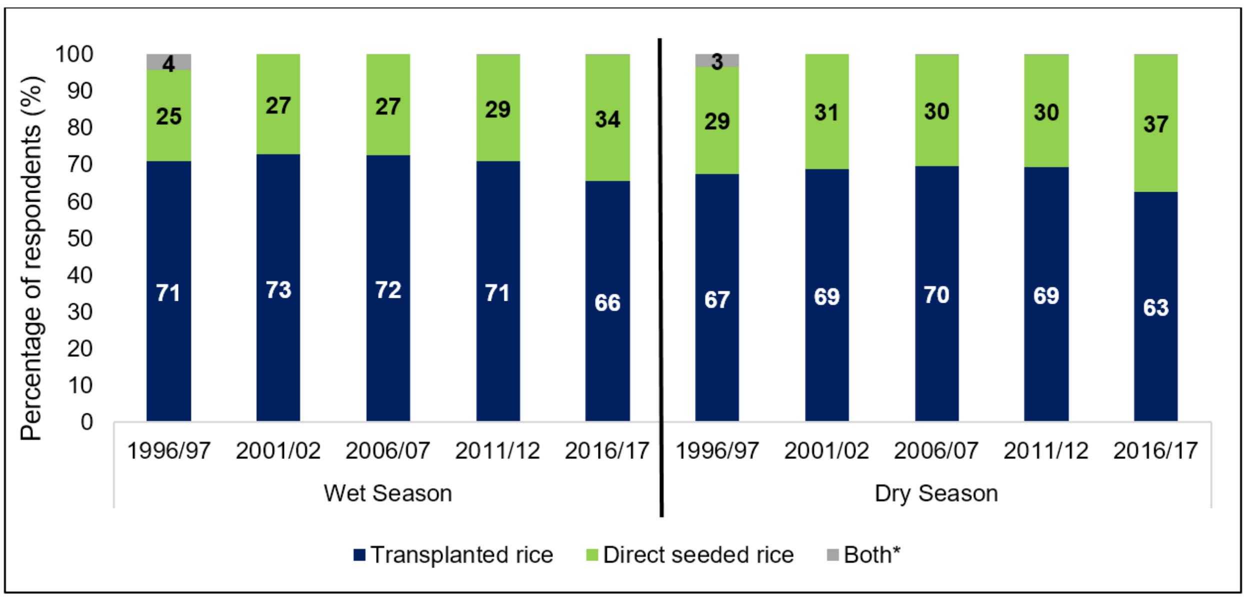

Figure 1B. Percentage distribution of rice farmers by method of crop establishment, and season, Philippines, 1996/1997–2016/2017 Source of basic data: PhilRice RBFHS 1996/1997-2016/2017; *Both direct seeding and transplanting

(1982), as cited by Pandey and Velasco (2002), identified the poor and uneven establishment of seedlings and weed infestation as major causes of the yield penalty in DSR. Since seeds are simply spread on the farm, root penetration and anchorage of DSR seedlings may not be as deep and as even as those of TPR, making them more prone to lodging. Manual broadcasting also causes uneven distribution of seeds that results in non-uniform planting densities per area and leads to uneven growth and crop stand.

Weeds also tend to grow simultaneously with DSR seedlings, thereby competing for essential soil nutrients. Additionally, most of the developed rice varieties are meant for transplanting, thus the lower yield performance if direct-seeded (Pandey and Velasco 2002). Most farmers usually procure seeds for their yield performance or grain quality without considering whether it is meant for direct seeding or not. This is probably brought by their lack of knowledge on such aspects of rice production.

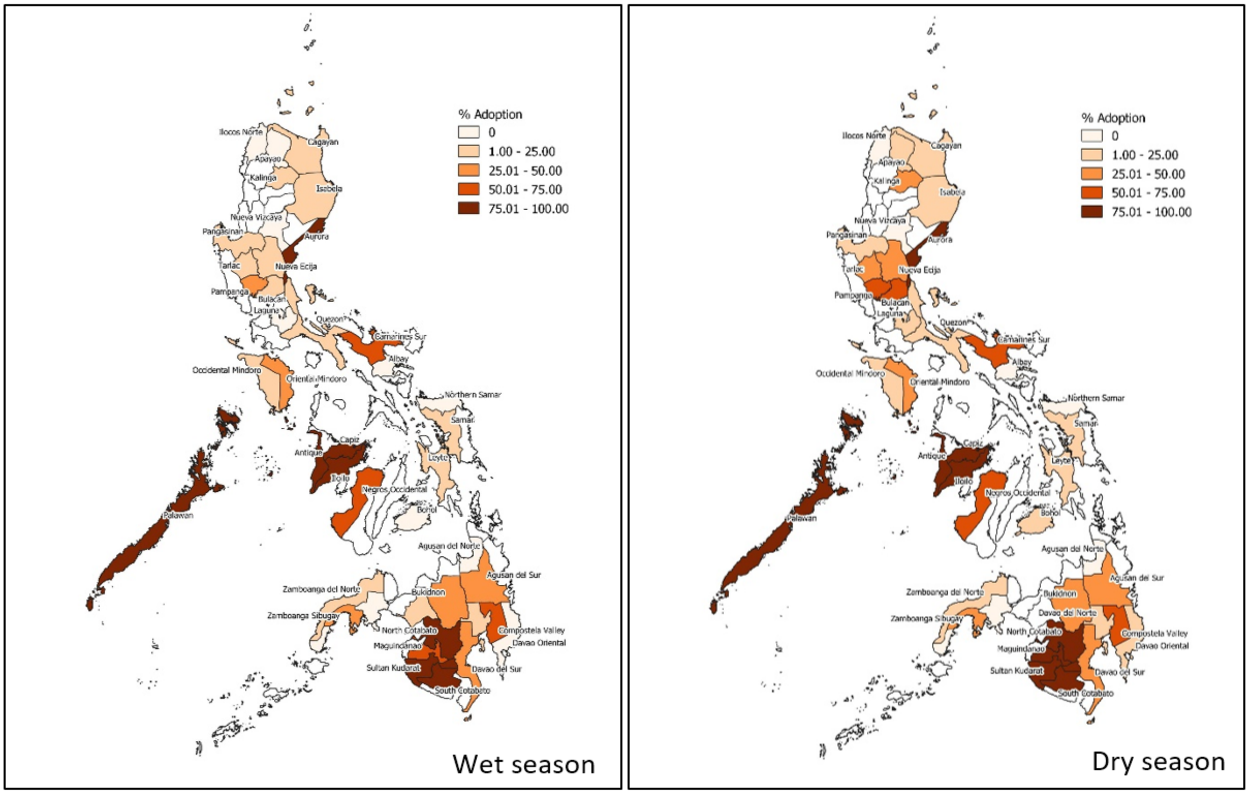

Figure 2. Percentage of DSR farmers by province and season, Philippines, 2016/2017.
Source of basic data: PhilRice RBFHS 2016-2017

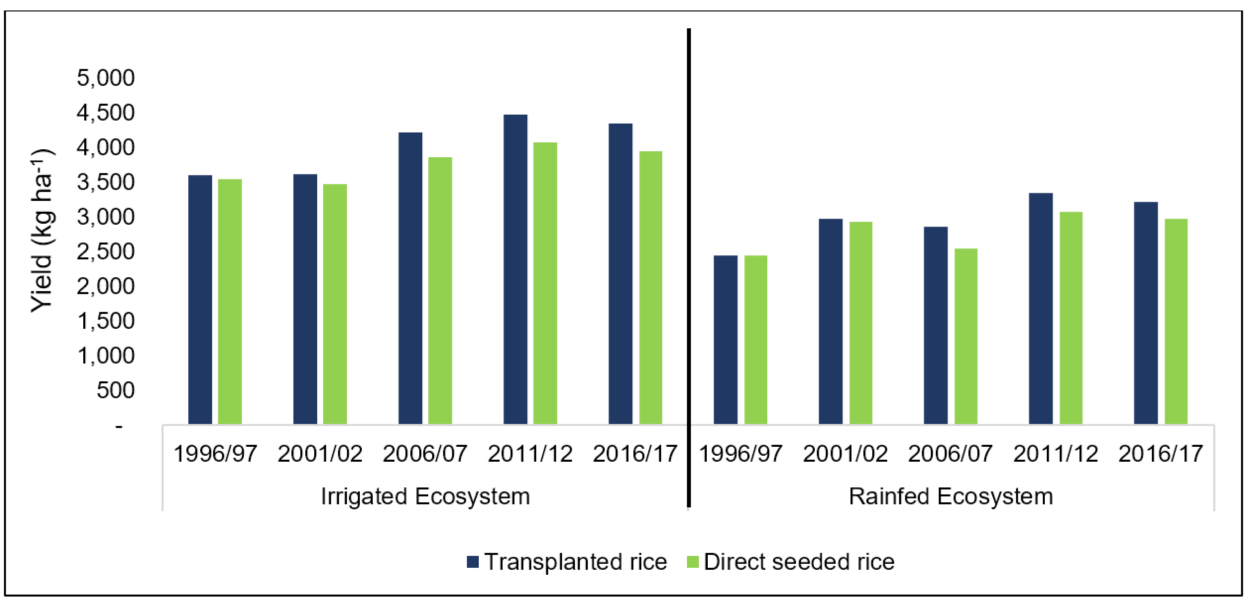

Figure 3. Average yield by method of crop establishment and ecosystem, Philippines, 1996/1997 to 2016/2017.
Source of basic data: PhilRice RBFHS 1996/1997-2016/2017

In 2016/2017, the TPR yield was 4,342 and 3,215 kg ha^{-1} in irrigated and rainfed areas, respectively. Meanwhile, the DSR yield was 3,943 kg ha^{-1} in irrigated areas and 2,977 kg ha^{-1} in rainfed areas (Figure 3). T-test results, however, showed the insignificant difference between TPR and DSR yield in most conditions, except in 2016WS in irrigated areas. In general, yield in irrigated areas was higher than in rainfed areas emphasizing the importance of adequate irrigation water to productivity. Adverse climate, poor soils, and lack of appropriate modern technologies are also constraints to productivity in rainfed areas (Mariano *et al.* 2010).

Studies around Asia also commonly observed lower yield in DSR compared with TPR. Xu *et al.*'s (2019) meta-analysis showed a 12% yield penalty in DSR compared with TPR with weed and water management and climatic stress as the most influential factors. Bhullar *et al.* (2018) also observed a 5% yield penalty in DSR in Punjab, although this was eventually overcome by the farmers by being more adept at sowing and weed control techniques relevant to DSR. This is evidence that the yield disparity between DSR and TPR can be overcome by farmers with the right practices. Accordingly, there are several studies (Bhushan *et al.* 2007; Sudhir-Yadav *et al.* 2014; Laing *et al.* 2018) that found comparable or higher yields from DSR relative to TPR.

Material input use: seed use rate. In the 2016/2017 cropping seasons, the seed use rate in DSR was consistently higher than in TPR in both ecosystems (Table 4). On average, DSR farmers used 58% more rice seeds in the WS and 65% more rice seeds in the DS than TPR farmers. This may be to account for seeds that fail to germinate or get damaged by biotic and abiotic factors. Meanwhile, seed use is lower in TPR as farmers can manage the number of seedlings that they transplant per hill unlike in DSR, wherein seeds are simply scattered in the field.

The data also showed that the seeding rate of the rice farmers was greatly above the recommended seeding rate of 20–40 kg ha^{-1} when transplanting and 40–80 kg ha^{-1} when direct seeding *via* row seeding or broadcasting (PhilRice 2020). This inefficiency in the seed use of rice farmers results in higher production costs. DSR farmers in India were able to use 15–40 kg of seeds per ha depending on the type of seed drill used and agroecological conditions (Mahajan *et al.* 2013) demonstrating the possibility of lowering farmers' seed use to the recommended rates in the Philippines. Accordingly, training and information drives are needed to educate farmers and to correct the idea that using more seeds guarantees higher output. More seeds were also generally used during the WS than the DS as replacements for DSR seeds that get carried over by floods or rainwater and TPR seedlings that get damaged by heavy rainfall.

Material input use: fertilizer application rate. Slightly less fertilizer was generally applied on DSR than on TPR (Table 4). This difference was most apparent in terms of potassium (K), in which the application rate in DSR was 19 and 21% less than in TPR during the WS and DS, respectively. Nitrogen (N) was the most applied element, as it is the most limiting nutrient in the soil and is essential in enhancing crop growth, grain yield, and quality (Rice Knowledge Bank n.d.). Significant differences in fertilizer use were observed in the irrigated ecosystem during the WS with 14, 16, and 13% less N, phosphorus (P), and K applied on DSR relative to TPR, respectively. Fertilizer use was generally lower in rainfed areas given limited water that facilitates nutrient uptake of crops.

The generally recommended amount of nutrient application to achieve a 2-ton/ha yield level is 20 kg ha^{-1} N and 5 kg ha^{-1} P in clay loam soils and an additional 10–15 kg ha^{-1} K in sandy soils (IRRI 2015). This amount should be doubled to expect a higher 3-ton ha^{-1} yield (IRRI 2015). In 2016/2017, rice farmers' P and K applications ranged around this recommended level, whereas their N application seems to be a bit excessive. Nonetheless, farmers produced around 3 to more than 4 tons ha^{-1} rice yield. However, properly determining the right element, amount, and timing of fertilizer application is crucial to maximize the yield potential of rice crops (PhilRice 2020) and to avoid the wastage of these costly inputs. This may be done through visual diagnosis partnered with diagnostic tools like leaf color chart and minus-one-element technique (PhilRice 2020) or digital tools like the Rice Crop Manager (Buresh *et al.* 2019), among others.

Material input use: pesticide application rate. Herbicides and insecticide use were higher in DSR than in TPR (Table 4). This is because weeds tend to grow simultaneously with DSR seedlings with no water to control them during seedling emergence, and due to the alternate drying and wetting cycles that accelerate the growth of weeds (Kumar *et al.* 2015; Raj and Syriac 2017). The higher plant density of DSR also makes for a suitable environment for insect pests and diseases with a cooler, more humid, and shadier microenvironment (Balasubramanian and Hill 2002). Because of these, yields from DSR become lower than TPR without proper and effective pest control measures. On average, herbicide use in DSR was 37% higher than in TPR in the WS and 25% higher in the DS, whereas insecticide use in DSR was 38 and 21% higher than in TPR in the WS and DS 2016/2017, respectively.

Weeds seem to be the most prevalent problem with DSR. Younas *et al.* (2015) and Ahmed *et al.* (2020) have both associated lower grain yield in DSR in Pakistan and in Bangladesh, respectively, primarily to weed infestation. Mahajan *et al.* (2013) and Matloob *et al.* (2014) even asserted that weeds are the main biological constraint

Table 4. Material input use by method of crop establishment, ecosystem, and season, Philippines, 2016–2017.

Item	Wet season			Dry season		
	DSR	TPR	% diff.	DSR	TPR	% diff.
All ecosystem						
Seeds (kg ha^{-1})	139	75	60*	134	67	67*
Fertilizer (kg ha^{-1})						
N	86	98	–13*	90	90	0
P	8	9	–9*	8	9	–12*
K	13	16	–21*	13	16	–21*
Pesticides (ai ha^{-1})						
Herbicide	0.53	0.36	38*	0.42	0.33	27*
Insecticide	0.37	0.25	40*	0.29	0.24	20*
Fungicide	0.08	0.05	32	0.06	0.07	–27
Other chemicals	0.18	0.26	–37*	0.16	0.21	–24*
Irrigated ecosystem						
Seeds (kg ha^{-1})	140	73	63*	134	65	69*
Fertilizer (kg ha^{-1})						
N	90	103	–14*	95	98	–3
P	8	10	–16*	9	9	–8
K	15	17	–13*	16	17	–6
Pesticides (ai ha^{-1})						
Herbicide	0.54	0.36	40*	0.45	0.33	29*
Insecticide	0.38	0.25	41*	0.30	0.25	20*
Fungicide	0.07	0.06	28	0.05	0.08	–39*
Other chemicals	0.18	0.27	–39*	0.19	0.23	–20*
Rainfed ecosystem						
Seeds (kg ha^{-1})	137	79	53*	134	72	61*
Fertilizer (kg ha^{-1})						
N	80	85	–6	76	61	23*
P	7	7	-1	5	6	–14
K	9	12	–28*	7	12	–47*
Pesticides (ai ha^{-1})						
Herbicide	0.53	0.37	34*	0.40	0.33	20*
Insecticide	0.36	0.25	36*	0.27	0.22	21
Fungicide	0.08	0.05	37	0.07	0.06	15
Other chemicals	0.17	0.21	–21	0.14	0.19	–31*

*Significant at α = 5%
[ai] active ingredient
Source of basic data: PhilRice RBFHS 2016–2017

to the successful adoption of DSR technology in Asia. This is supported by Farooq *et al.* (2011), who stated that poor weed management may result in partial to complete failure of DSR crops. With this, Younas *et al.* (2015) suggested the need to integrate herbicide application with other cultural practices like the use of weed-competitive cultivars, optimum sowing time, appropriate fertilizer and water application, and narrow crop row spacing for effective and sustainable weed control for DSR.

Labor use. Total labor use in DSR was lower by around 50% compared with that of TPR in 2016/2017 (Table 5) primarily

due to lower labor requirements in crop establishment. Crop establishment constituted the bulk of the preharvest labor in TPR with over 20 ld ha^{-1}, whereas DSR used a maximum of nearly 3 ld ha^{-1} only. TPR involves several activities such as seedbed preparation, seed sowing, seedling management, and pulling and hauling of seedlings, whereas seeds are directly sown in the field in DSR. Significant differences were observed between the labor use in the crop establishment of DSR and TPR in all ecosystems and seasons. On average, labor in crop establishment in DSR was lower than TPR by 157% in WS to 162% in DS.

Additionally, total labor use for pest management, including weeding, was significantly lower in DSR than in TPR by an average of 38–48%. This may be because pest management in TPR is also performed in the seedbed during seedbed preparation and as part of seedling management. This may mean that TPR spends more days on pest management, whereas DSR uses more input per application for pest management given the higher pesticide usage, as shown in Table 4. Labor for pest management was higher in rainfed ecosystems due to inadequate water to help control weed growth and pest infestation.

DSR also used less labor in harvesting and threshing compared with TPR given the lower yield from DSR. From Table 3, a significant difference in labor use in harvesting and threshing between DSR and TPR was consistently observed across ecosystems and seasons. Specifically, labor use in harvesting and threshing in DSR was lower by 21–31% on average.

Consistently, less labor use in DSR was also very pronounced in several Asian countries. Bhullar *et al.* (2018) observed that farmers in Punjab were able to save 14 ld ha^{-1} with DSR. Likewise, Yamano *et al.* (2013) and Kumar *et al.* (2015) estimated a 40% and 7–8% reduction in labor use with DSR in the Indo-Gangetic Plains and in India, respectively.

Costs and returns of DSR vs. TPR. Despite the lower yield performance of DSR, its net income was usually higher than TPR (Table 6). This can be mainly attributed to the savings in labor costs that compensated for the lower yield from DSR (Pandey and Velasco 2002). Total labor cost in DSR was a significant 36–39% lower than in TPR in 2016/2017. Accordingly, the average rice production cost in DSR was nearly PHP 11.00 kg^{-1} only, whereas the production cost in TPR was more than PHP 12.00 kg^{-1}.

Labor cost accounted for the largest share of rice production cost: 53–55% in TPR and only 45–48% in DSR. Labor cost is the combined value of the costs of hired and OFE labor. OFE or family labor cost was valued using the prevailing farm wage rate for each farm activity in the sample area during the reference period and the time spent by the household working on the farm. Meanwhile, hired labor costs may be computed using the prevailing farm wage rate and the time used by the farm worker to finish each operation or based on the agreed amount between the farmer and farm worker to perform one or several operations on the farm.

Total hired and OFE labor cost in TPR was PHP 25,135–27,030 ha^{-1} on average and only PHP 16,960–18,806 ha^{-1} in DSR. This disparity in labor cost was mainly caused by the higher amount that TPR farmers spent on crop establishment. While DSR farmers spent only PHP 707–798 ha^{-1} for crop establishment, TPR farmers spent PHP 6,895–8,001 ha^{-1}, higher by 159–168% (Appendix Table III). On the other hand, the material cost in DSR was higher than in TPR. This is due to more procured and used seeds, as well as herbicides and insecticides (as shown in Table 4). Seed cost in DSR was 30% higher than in TPR. Likewise, herbicide and insecticide costs in DSR were higher by 49–81 and 13–39% relative to TPR, respectively (Appendix Table II).

Aside from these, rice farmers also pay for additional items or other costs, which comprise 19–20% of the total production cost. These costs include land rent, food, transportation, land tax, and interest in capital, among others (Appendix Table IV). Total other cost was also contributory to the higher production cost in TPR by 23–32% than in DSR. This can be attributed to land rent that accounts for over 70% of the total other costs, and that registered a significant difference between TPR and DSR. Food cost spent on TPR was also significantly higher than on DSR. Food cost refers to the value of food provided by the farmer to its hired farm workers. The significantly higher amount of labor use in terms of the number of workers or days meant significantly higher food costs in TPR compared with DSR.

The profit advantage of DSR over TPR was most pronounced in rainfed areas during the DS with a difference of 108%. The net profit-cost ratios of DSR also indicate that it is generally more profitable than TPR. Unit cost is correspondingly lower in DSR compared with TPR. These bolster Bordey *et al.*'s (2015) recommendation to encourage farmers to use direct seeding as the benefit is greater than its trade-offs. Still, farmers must consider the local conditions, soil type, and ecosystem in selecting the appropriate crop establishment method to adopt. Specifically, TPR is ideal in areas with low wage rates, adequate water supply, and abundant labor (Pandey and Velasco 2002). Otherwise, DSR might be more suitable given the available cheap weed control measures (Pandey and Velasco 2002).

Effect of DSR on labor productivity. Labor productivity is the ratio of yield to total labor use as a measure of the efficiency of the individuals that worked on the farm. Table 7 shows that labor productivity is consistently higher in DSR than in TPR mainly owing to less labor used particularly

Table 5. Total labor use by method of crop establishment, ecosystem, and season, Philippines, 2016–2017.

Item	Wet season			Dry season		
	DSR	TPR	% diff.	DSR	TPR	% diff.
	(ld ha^{-1})					
All ecosystem						
Preharvest labor	24.27	52.41	–73*	22.34	51.03	–78*
Land preparation	12.20	11.55	6	11.18	11.43	–2
Crop establishment	3.05	25.54	–157*	2.68	25.85	–162*
Crop care and maintenance	9.02	12.43	–32 *	8.44	10.66	–23*
Irrigation and drainage	3.92	5.83	–39*	4.36	4.72	–8
Nutrient management	1.36	1.65	–20*	1.21	1.43	–17*
Pest management	3.25	4.78	–38*	2.66	4.35	–48*
Roguing	0.48	0.17	94*	0.21	0.15	34
Harvesting and threshing	15.45	19.15	–21*	12.80	17.49	–31*
Post-harvest labor	2.89	3.31	–13 *	2.62	3.57	–31*
Permanent hired labor	5.21	5.73	–9	4.99	4.62	8
Total labor	**47.82**	**80.60**	**–51***	**42.75**	**76.71**	**–57***
Irrigated ecosystem						
Preharvest labor	24.46	51.15	–71*	22.88	47.85	–71*
Land preparation	11.70	11.11	5	11.28	10.11	11
Crop establishment	3.09	27.71	–160*	2.79	26.88	–162*
Crop care and maintenance	9.68	12.33	–24*	8.81	10.86	–21*
Irrigation and drainage	4.58	6.34	–32*	4.88	5.45	–11
Nutrient management	1.35	1.61	–18*	1.20	1.44	–18*
Pest management	3.17	4.23	–29*	2.52	3.87	–42*
Roguing	0.57	0.16	111*	0.21	0.10	72
Harvesting and threshing	14.93	19.23	–25*	11.40	16.25	–35*
Post-harvest labor	3.04	3.41	–11	2.43	3.45	–35*
Permanent hired labor	5.61	6.50	–15	5	5	4
Total labor	**48.05**	**80.29**	**–50***	**42.14**	**72.79**	**–53***
Rainfed ecosystem						
Preharvest labor	23.92	55.96	–80*	20.89	62.62	–100*
Land preparation	13.08	12.79	2	10.91	16.26	–39*
Crop establishment	2.97	30.45	–164*	2.55	36.43	–174*
Crop care and maintenance	7.86	12.72	–47*	7.43	9.93	–29*
Irrigation and drainage	2.76	4.40	–46	2.98	2.08	36*
Nutrient management	1.37	1.78	–26*	1.22	1.41	–15
Pest management	3.40	6.34	–60*	3.03	6.12	–68*
Roguing	0.33	0.20	45	0.20	0.33	–48
Harvesting and threshing	16.36	18.92	–14*	16.56	22.01	–28*
Post-harvest labor	2.63	3.03	–14	3.15	4.03	–25
Permanent hired labor	4.51	3.57	23	3.79	2.35	47
Total labor	**47.42**	**81.47**	**–53***	**44.39**	**91.01**	**–69***

*Significant at α=5%
Source of basic data: PhilRice RBFHS 2016–2017

Table 6. Costs and returns by method of crop establishment, ecosystem, and season, Philippines, 2016–2017.

Item	Wet season			Dry season		
	DSR	TPR	% diff.	DSR	TPR	% Diff.
All ecosystems						
Gross returns (PHP ha^{-1})	**49,809**	**57,233**	**–14***	**57,393**	**63,079**	**–9**
Yield (kg ha^{-1})	3,337	3,719	–11*	3,586	3,839	–7
Price (PHP kg^{-1})	14.93	15.39		16.00	16.43	
Production cost (PHP ha^{-1})	**37,406**	**47,290**	**–23***	**39,452**	**48,731**	**–21***
Material cost	12,423	11,643	6*	12,506	11,297	10*
Labor cost	16,960	25,135	–39*	18,806	27,030	–36*
Power cost	1,095	969	12	529	807	–42*
Other costs	6,929	9,543	–32*	7,611	9,597	–23*
Net returns (PHP ha^{-1})	12,402	9,943	22	17,941	14,439	22
Net profit-cost ratio	0.33	0.21	45	0.45	0.29	43
Cost (PHP kg^{-1})	11.21	12.72	–13	11.00	12.69	–14*
Irrigated ecosystem						
Gross returns (PHP ha^{-1})	**57,180**	**62,974**	**–10***	**68,102**	**76,738**	**–12***
Yield (kg ha^{-1})	3,710	4,076	–9*	4,176	4,609	–10*
Price (PHP kg^{-1})	15.41	15.45		16.31	16.65	
Production cost (PHP ha^{-1})	**38,919**	**48,471**	**–22***	**41,736**	**49,569**	**–17***
Material cost	12,954	12,049	7*	13,170	11,871	10*
Labor cost	17,652	25,475	–36*	19,772	26,976	–31*
Power cost	784	934	–17	493	835	–51*
Other costs	7,529	10,013	–28*	8,301	9,887	–17*
Net returns (PHP ha^{-1})	18,261	14,504	23*	26,366	27,170	–3
Net profit-cost ratio	0.47	0.30	44	0.63	0.55	14
Cost (PHP kg^{-1})	10.49	11.89	–13*	9.99	10.76	–7
Rainfed ecosystem						
Gross returns (PHP ha^{-1})	**42,800**	**51,533**	**–19***	**47,043**	**49,756**	**–6**
Yield (kg ha^{-1})	2,964	3,361	–13*	2,997	3,069	–2
Price (PHP kg^{-1})	14.44	15.33		15.70	16.21	
Production cost (PHP ha^{-1})	**34,758**	**43,946**	**–23***	**33,329**	**45,679**	**–31***
Material cost	11,493	10,491	9*	10,728	9,207	15*
Labor cost	15,749	24,174	–42*	16,216	27,226	–51*
Power cost	1,639	1,069	42	624	706	–12
Other costs	5,877	8,212	–33*	5,761	8,541	–39*
Net returns (PHP ha^{-1})	8,041	7,587	6	13,714	4,077	108*
Net profit-cost ratio	0.23	0.17	29	0.41	0.09	129
Cost (PHP kg^{-1})	11.73	13.08	–11	11.12	14.89	–29*

*Significant at α=5%
Source of basic data: PhilRice RBFHS 2016–2017

during crop establishment. Additionally, labor use for harvesting and threshing is lower in DSR given less yield to harvest than in TPR. This means that DSR technology is generally more labor efficient compared to TPR. This also suggests that the use of DSR as a labor-saving technology can stimulate labor productivity in rice production.

Effect of DSR adoption on income. Partial budget analysis showed that shifting to DSR would mean higher net income for rice farmers in most conditions (Table 8). This is due to the reduced costs of crop establishment, crop care and maintenance, and harvesting and threshing. Reduced costs due to direct seeding were estimated to range from PHP 7,790–9,518 ha^{-1}. However, the trade-off with DSR is the additional costs on seeds, herbicides and insecticides, and the yield penalty, which is projected to amount to PHP 2,880–8,874 ha^{-1}. Despite this, the increment in income due to labor savings from DSR is more than enough to compensate for its yield penalty and added material costs. In China, farmers experienced a 66% increment in income after shifting from TPR to DSR (Sha *et al.* 2019). Younas *et al.* (2015) and Sarangi *et al.* (2020) both estimated higher net economic benefits per ha and benefit-cost ratio in DSR in Pakistan and Eastern India.

The positive effect of DSR adoption on income was highest in rainfed areas and during the DS amounting to PHP 6,638, a 48% increase from the current income level of farmers in these conditions. This may be because of the lack of water that limits the yield advantage of TPR over DSR in the DS. It may also be drawn from the analysis that direct seeding is not a one-size-fits-all method of crop establishment that all rice farmers could shift to. Agro-climatic conditions and cropping season are still important factors that farmers must consider before shifting to DSR given the varying changes that it can cause to the income of farmers in terms of effect and magnitude.

Effect of DSR adoption on rice production. This subsection presents the impact of DSR adoption among rice farmers and the determinants of the technology's adoption after subjecting the data to PSM. The analysis is restricted to observations as part of the common support. As mentioned, separate models for the WS and DS were estimated.

From a set of covariates thought to affect the outcome variable (rice yield) but not necessarily change because of DSR adoption, five variables were used in the PSM WS and DS models that balance the treatment and the control groups (Table 9). As pointed out earlier, the objective here is to find covariates that would make both groups relatively alike to reduce, if not eliminate, the bias in estimating its effect on the outcome variable.

Common in both models, area harvested and land ownership increase the predicted probability that a farmer adopted DSR, whereas membership in a rice organization decreases it (Table 9). DSR is relatively a more practical option in larger farm areas as it is less money- and time-consuming relative to TPR. Larger household size also seems to positively affect farmers' adoption of DSR technology possibly due to their need to generate higher income to meet their family's needs. Meanwhile, farmers who are members of farmers' associations and cooperatives (FACs) are perceived to stick to TPR. This is possibly brought by the influence of other farmers within FACs who may also be used to transplant rice. During WS, older farmers appear less likely to adopt DSR possibly because the seeds may get washed away by rain or flood.

Table 7. Labor productivity by method of crop establishment, ecosystem, and season, Philippines, 2016–2017.

Item	Wet season			Dry season		
	DSR	TPR	% diff.	DSR	TPR	% diff.
All ecosystems						
Yield (kg ha^{-1})	3,337	3,719	–11	3,586	3,839	–7
Labor use (ld ha^{-1})	48.15	81.88	–52	43.61	82.75	–62
Labor productivity (kg ld^{-1})	69.30	45.41	42	82.23	46.39	56
Irrigated ecosystem						
Yield (kg ha^{-1})	3,710	4,076	–9	4,176	4,609	–10
Labor use (ld ha^{-1})	47.95	80.29	–50	42.16	72.79	–53
Labor productivity (kg ld^{-1})	77.37	50.77	42	99.04	63.32	44
Rainfed ecosystem						
Yield (kg ha^{-1})	2,964	3,361	–13	2,997	3,069	–2
Labor use (ld ha^{-1})	48.35	83.48	–53	45.06	92.71	–69
Labor productivity (kg ld^{-1})	61.30	40.26	41	66.50	33.10	67

Source of basic data: PhilRice RBFHS 2016–2017

Table 8. Partial budget analysis on rice farmers' shift from TPR to DSR by ecosystem, and season, Philippines

Item	Wet season	Dry season
<u>**Irrigated ecosystem**</u>		
Added income due to change:		
None		
Reduced costs due to change (PHP ha^{-1}):		
Crop establishment cost	5,967.63	6,544.34
Crop care and maintenance cost	913.44	812.15
Harvesting and threshing cost	908.66	1,509.38
Subtotal	7,789.73	8,865.87
Added costs due to change (PHP ha^{-1}):		
Seed cost	1,106.00	1,061.00
Herbicide cost	294.00	647.00
Insecticide cost	644.00	144.00
Reduced income due to change:		
Yield reduction (kg ha^{-1})	366.00	433.00
Farmgate price (PHP kg^{-1})	15.16	16.22
Value of yield reduction (PHP ha^{-1})	5,548.17	7,022.39
Subtotal	7,592.17	8,874.39
Net change	**197.56**	**–8.52**
<u>**Rainfed ecosystem**</u>		
Added income due to change:		
None		
Reduced costs due to change (PHP ha^{-1}):		
Crop establishment cost	6,226.00	8,043.75
Crop care and maintenance cost	1,143.06	675.58
Harvesting and threshing cost	850.86	799.16
Subtotal	8,219.92	9,518.49
Added costs due to change (PHP ha^{-1}):		
Seed cost	860.00	919.00
Herbicide cost	707.00	668.00
Insecticide cost	79.00	125.00
Reduced income due to change:		
Yield reduction (kg ha^{-1})	397.00	72.00
Farmgate price (PHP kg^{-1})	15.16	16.22
Value of yield reduction (PHP ha^{-1})	6,018.10	1,167.69
Subtotal	7,664.10	2,879.69
Net change	**555.82**	**6,638.80**

Source of basic data: PhilRice RBFHS 2016–2017

Table 9. Probit regression to estimate propensity scores for the WS and DS models.

Dependent variable: DSR adopter = 1; 0 if otherwise				
Independent variables	**Coefficient**	**Std. error**	**Coefficient**	**Std. error**
	Wet season		Dry season	
Area harvested (ha)	0.1209***	0.0247	0.1188***	0.0255
Interaction: male x age	–0.0025**	0.0010		
Household size			0.0287**	0.0115
Dummy: tenure	0.2360***	0.0508	0.1257**	0.0515
Dummy: rice organization	–0.1051**	0.0480	–0.2219***	0.0502
Constant	–0.5280***	0.0702	–0.5458***	0.0785
Number of observations	2,960.0000		2,705.0000	
LR chi square (4)	59.3700		53.0400	
prob > chi square	0.0000		0.0000	
Log likelihood	–1,871.4710		–1,759.1980	

*** $p < 0.01$, ** $p < 0.05$. Authors' own computation.
Source of basic data: PhilRice RBFHS 2016–2017

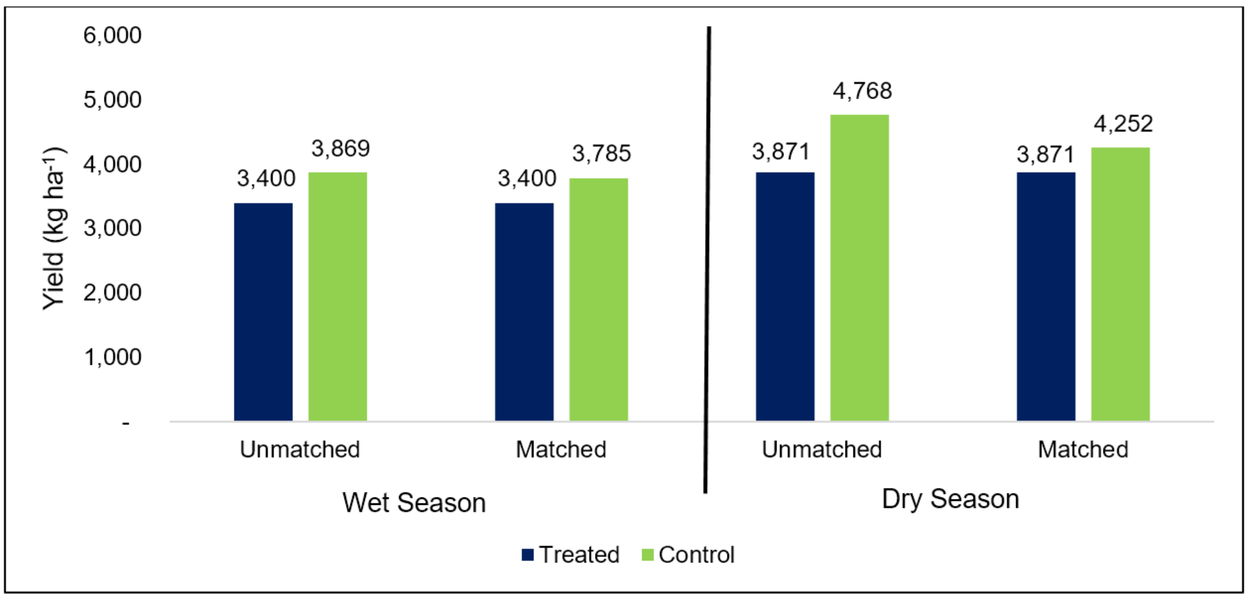

Figure 4. Average yield of rice farmers adopting DSR and TPR before and after matching, by season.
Note: farmers using DSR in crop establishment are considered part of the treatment group.
Source of basic data: PhilRice RBFHS 2016–2017

Farmers who own their land seem to be more inclined to adopt DSR as they have the liberty to decide on their own.

Figure 4 shows the relative yields of matched and unmatched DSR and TPR. Consistent with some studies (Bhullar *et al.* 2018; Xu *et al.* 2019), DSR (treated) yield is consistently lower than TPR (control) yield, which appears to be statistically significant (Appendix Table VI). However, it can also be noted that the yield gap between DSR and TPR slightly narrowed after matching. This demonstrates the potential of DSR yield to become at par with TPR yield. Joshi *et al.*'s (2013) study covering the Philippines, India, Cambodia, Thailand, and Nepal showed that DSR yield can potentially match TPR yield with proper management and that DSR can be a viable practice to adapt to labor and water shortages. Accordingly, Abrogena *et al.* (2012) asserted the importance of appropriate practices to improve DSR yield, as it observed some farmers who were able to produce more than 5 tons ha^{-1} using the establishment method. Farooq *et al.* (2011) called for the breeding of special varieties and formulation of suitable management strategies to close the gap between TPR and DSR yield.

Determinants of DSR adoption. In both WS and DS models, area, use of seeds and pesticides, labor use, tenurial status, irrigation, and power cost appear to significantly affect farmer adoption of DSR (Table 10). As mentioned, larger farm areas may encourage farmers to use DSR to save money and time instead of TPR. Higher seed and pesticide use may also mean a higher probability that a farmer adopted DSR. Although the negative coefficient of the (seed and pesticide) squared variables indicates that the farmer will only adopt DSR up to a certain threshold of seed and pesticide use. Beyond this lessens the likelihood that the farmer will continue or decide to adopt DSR. Meanwhile, lower labor use suggests more likelihood that a farmer adopted DSR. Farmers in irrigated areas also appear to be less likely to adopt DSR since irrigation allows for transplanting, which most of them prefer given higher yield. Likewise, lower power cost also shows that a farmer is likely to use DSR. Also, farmer-owners of land have the authority to make decisions regarding their farm. In this case, they appear to be more inclined to adopt DSR probably to save on labor costs.

Table 10. Factors affecting farmer-adoption of direct seeding (DSR) using heteroscedastic probit model, by season.

Dependent variable: DSR adopter = 1; 0 if otherwise				
Independent variables	**Coeff**	**Std. error**	**Coeff**	**Std. error**
	Wet season		Dry season	
Area harvested (ha)	0.37876***	0.08170	0.47423***	0.07913
Area harvested squared	–0.03997***	0.01109	–0.02523***	0.00817
Seeds (kg ha^{-1})	0.02529***	0.00190	0.03651***	0.00267
Seeds squared	–0.00003***	0.00001	–0.00006***	0.00001
Fertilizer (kg ha^{-1})	–0.00335***	0.00064	–0.00072	0.00079
Pesticide (kg ha^{-1})	0.41069***	0.07431	0.45362***	0.12838
Pesticide squared	–0.04484***	0.01345	–0.08791**	0.03520
Hired labor (ld ha^{-1})	–0.01848***	0.00166	–0.03270***	0.00277
Hired labor squared	0.00002***	0.00000	0.00006***	0.00001
OFE labor (ld ha^{-1})	–0.00332***	0.00103	–0.00099***	0.00033
Dummy: tenure = own	0.26272***	0.07287	0.15553*	0.08870
Dummy: irrigation	–0.34079***	0.07432	–0.35830***	0.10418
Dummy: power	–0.35244***	0.07372	–0.29118***	0.08904
Dummy: capital used = own	0.01566	0.06968	0.20348**	0.08942
Dummy: rice organization	0.15546**	0.06798	–0.04336	0.08631
Dummy: sex = male	0.06462	0.40569	0.35378	0.51609
Age (in yr)	0.00694	0.02123	0.06187**	0.02930
Age squared	–0.00003	0.00018	–0.00049**	0.00025
Interaction: male x age	–0.00280	0.00686	–0.00785	0.00876
Education (in yr)	0.00385	0.01076	–0.00278	0.01425
Household size	0.02738*	0.01495	0.02210	0.01936
Dummy: non-farm income	1.10E–08	1.31E–07	9.30E–08	9.95E–08
Constant	–2.31023***	0.70467	–4.33714***	0.94901
lnsigma2 (dummy: area harvested at most 1 ha)	0.16868**	0.07538	0.39362***	0.07756
LR test of lnsigma2: chi square	4.89000		24.79000	
prob > chi square	0.02710		0.00000	
Number of observations	2947.00000		2,699.00000	
Zero outcomes	1938.00000		1,693.00000	
Nonzero outcomes	1009.00000		1,006.00000	
LR chi square	287.00000		274.84000	
prob > chi square	0.00000		0.00000	
Log likelihood	–1189.62600		–1,009.31300	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Note: Farmers with inconsistent or missing information were removed from the analysis. Authors' own computation.
Source of basic data: PhilRice RBFHS 2016-2017

CONCLUSION AND RECOMMENDATIONS

Results showed that the proportion of DSR farmers increased from 27% in 1996/1997 to 33-42% in 2016/2017, with a higher percentage observed in rainfed areas. The economic advantage of DSR over TPR lies in its lower labor requirement and cost of crop establishment. However, higher seed, insecticide, and herbicide costs are the major trade-offs when shifting to DSR. Yield from DSR is also generally lower than that of TPR due to greater weed and pest pressure. Despite this, labor productivity is higher in DSR compared with TPR. Accordingly, the labor savings in DSR is large enough to offset these trade-offs, which translate to a higher net income than in TPR. Partial budget analysis showed that shifting to DSR is most profitable for farmers in rainfed areas and during the DS. Still, minimizing the trade-offs and addressing the constraints to adoption such as narrowing the yield gap between DSR and TPR may accelerate the adoption of DSR technology in suitable areas.

Promoting direct seeding as a viable alternative to transplanting to rice farmers in suitable areas must be intensified to encourage adoption. Expanding farm irrigation and drainage may be instrumental for this (Pandey and Velasco 2002). From Alam *et al.* (2018), DSR can produce comparable yields with TPR by optimizing management practices. For this, training on efficient weed control techniques including proper land preparation and water management as preventive measures is critical to minimize the yield gap between DSR and TPR, which is the primary concern of farmers. The PalayCheck platform may be a good reference material at least for farmers in irrigated lowland areas for this. Varieties specifically meant for the direct seeding method (*e.g.* with early seedling vigor, high resistance to lodging, tolerance of low oxygen level, drought-resistance, and weed competitiveness) should also be developed (Pandey and Velasco 2002). Moreover, drum seeders and similar technologies must be simultaneously promoted to enhance the efficiency of farmers in terms of seed use. In line with this, educating farmers through technology demonstrations is imperative to make them more receptive to these technologies. Providing such technologies may also facilitate the adoption of DSR.

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APPENDICES

Table I. Distribution of respondents by province, RBFHS, 2016–2017.

Province	Total sample
Aurora	60
Bulacan	86
Nueva Ecija	151
Pampanga	60
Tarlac	86
Leyte	86
Iloilo	116
Zamboanga del Norte	60
Zamboanga del Sur	60
Zamboanga Sibugay	60
Davao del Norte	60
Davao del Sur	60
Davao Oriental	60
South Cotabato	60
Palawan	60
Nueva Vizcaya	60
Ilocos Norte	60
Pangasinan	151
Apayao	60
Cagayan	116
Isabela	116
Kalinga	60
Laguna	60
Quezon	60
Occidental Mindoro	60
Oriental Mindoro	86
Albay	60
Camarines Sur	116
Northern Samar	60
Western Samar	60
Negros Occidental	90
Bohol	86
Antique	60
Capiz	60
Agusan del Norte	60
Agusan del Sur	60
Bukidnon	86
Compostella Valley	60
North Cotabato	86
Sultan Kudarat	60
Maguindanao	86
Lanao del Sur	60
Total	**3,164**

Table II. Material cost by method of crop establishment, ecosystem, and season, Philippines, 2016–2017.

Item	Wet season			Dry season		
	DSR	TPR	% diff.	DSR	TPR	% diff.
	(PHP ha^{-1})					
All ecosystems						
Seeds	3,737	2,754	30*	3,810	2,820	30*
Fertilizer	5,571	6,313	–12*	5,330	5,536	–4*
Herbicides	1,269	768	49*	1,143	486	81*
Insecticides	1,112	750	39*	1,098	963	13*
Fungicides	157	120	27	123	117	5
Other pesticides	449	573	–24*	455	619	–31*
Total material costs	**12,296**	**11,278**	**9**	**11,960**	**10,541**	**13***
Irrigated ecosystem						
Seeds	3,892	2,786	33*	4,085	3,024	30*
Fertilizer	6,045	7,029	-15*	6,197	6,563	–6*
Herbicides	1,243	949	27*	1,170	522	77*
Insecticides	1,174	530	76*	1,101	957	14*
Fungicides	146	132	9	104	146	–34*
Other pesticides	465	630	–30*	491	663	–30*
Total material costs	**12,964**	**12,055**	**7***	**13,148**	**11,876**	**10***
Rainfed ecosystem						
Seeds	3,583	2,722	27*	3,535	2,616	30*
Fertilizer	5,098	5,596	–9	4,463	4,509	–1
Herbicides	1,296	588	75*	1,117	449	85*
Insecticides	1,050	971	8	1,095	970	12
Fungicides	169	107	45	143	87	48
Other pesticides	433	517	–18	419	575	–31*
Total material costs	**11,628**	**10,502**	**10***	**10,771**	**9,207**	**16***

*Significant at $\alpha = 5\%$
Source of basic data: PhilRice RBFHS 2016–2017

Table III. Labor cost by method of crop establishment, ecosystem, and season, Philippines, 2016–2017.

Item	Wet season			Dry season		
	DSR	TPR	% diff.	DSR	TPR	% diff.
	(PHP ha^{-1})					
All ecosystems						
Preharvest labor	7,126	14,477	–68*	7,376	15,952	–74*
Land preparation	4,287	4,513	–5	4,490	5,028	–11
Crop establishment	798	6,895	–159*	707	8,001	–168*
Crop care and maintenance	2,041	3,070	–40*	2,179	2,922	–29*
Irrigation and drainage	777	1,234	–45*	1,011	935	8
Nutrient management	238	344	–36*	231	257	–11*
Pest management	936	1,447	–43*	881	1,668	–62*
Roguing	90	45	67*	56	63	–12
Harvesting and threshing	7,557	8,437	–11*	8,044	9,199	–13*
Post-harvest labor	800	834	–4*	1,020	1,304	–24*
Permanent hired labor	1,271	1,231	3	1,645	1,150	35
Total labor	**16,754**	**24,979**	**–39***	**18,086**	**27,605**	**–42***
Irrigated ecosystem						
Preharvest labor	7,196	14,193	–65*	7,874	14,582	–60*
Land preparation	4,191	4,307	–3	4,762	4,114	15
Crop establishment	795	6,763	–158*	752	7,296	–163*
Crop care and maintenance	2,210	3,124	–34*	2,360	3,172	–29*
Irrigation and drainage	995	1,439	–36*	1,254	1,339	–7
Nutrient management	134	242	–58*	136	122	11*
Pest management	979	1,397	–35*	912	1,648	–58*
Roguing	102	46	76*	58	62	–7
Harvesting and threshing	8,088	8,997	–11*	8,771	10,280	–16*
Post-harvest labor	872	947	–8	1,212	1,388	–14*
Permanent hired labor	1,529	1,646	–7	2,025	1,734	16
Total labor	**17,686**	**25,784**	**–37***	**19,881**	**27,984**	**–34***
Rainfed ecosystem						
Preharvest labor	7,056	14,761	–71*	6,879	17,322	–86*
Land preparation	4,384	4,719	–7	4,219	5,943	–34*
Crop establishment	800	7,026	–159*	662	8,706	–172*
Crop care and maintenance	1,872	3,015	–47*	1,998	2,673	–29*
Irrigation and drainage	559	1,028	–59	768	530	37*
Nutrient management	342	447	–26*	325	392	–18
Pest management	893	1,497	–51*	851	1,688	–66*
Roguing	77	44	56	53	63	–18
Harvesting and threshing	7,026	7,876	–11*	7,318	8,117	–10*
Post-harvest labor	727	721	1	828	1,220	–38
Permanent hired labor	1,013	815	22	1,266	566	76
Total labor	**15,822**	**24,174**	**–42***	**16,291**	**27,226**	**–50***

*Significant at $\alpha = 5\%$
Source of basic data: PhilRice RBFHS 2016–2017

Table IV. Other cost items by method of crop establishment, ecosystem, and season, Philippines, 2016–2017.

Item	Wet season			Dry season		
	DSR	TPR	% diff.	DSR	TPR	% diff.
	(PHP ha^{-1})					
All ecosystems						
Food	1,439	1,790	–22*	1,227	1,733	–34*
Irrigation	370	382	–3	291	236	21
Transportation	106	114	–7	179	221	–21
Amortization fee and/or land tax	71	303	–124*	145	86	51
Land rent	9,561	11,432	–18*	11,092	13,646	–21*
Other inputs	833	880	–5*	1,021	963	6
Interest on capital	494	779	–45*	260	348	–29*
Total other costs	**12,875**	**15,679**	**–208***	**14,216**	**17,234**	**–19***
Irrigated ecosystem						
Food	1,277	1,648	–25*	1,083	1,574	–37*
Irrigation	713	743	–4	568	429	28*
Transportation	105	118	–12	183	187	–2
Amortization fee and/or land tax	111	345	–103*	154	125	21
Land rent	10,563	12,412	–16*	12,795	14,401	–12*
Other inputs	886	947	–7*	1,121	1,091	3
Interest on capital	656	903	–32*	284	482	–52*
Total other costs	**14,311**	**17,116**	**–18***	**16,187**	**18,288**	**–12***
Rainfed ecosystem						
Food	1,601	1,932	–19*	1,372	1,893	–32*
Irrigation	27	20	30	15	44	–99
Transportation	107	110	–2	175	256	–38
Amortization fee and/or land tax	31	260	–157*	136	46	98
Land rent	8,559	10,453	–20*	9,390	12,891	–31*
Other inputs	780	812	–4	922	836	10
Interest on capital	333	655	–65*	236	214	10
Total other costs	**11,439**	**14,242**	**–22***	**12,245**	**16,179**	**–28***

*Significant at $\alpha = 5\%$
Source of basic data: PhilRice RBFHS 2016–2017

Table V. Balance testing among variables used in PSM, before and after matching

Variables used for matching	Sample	Mean		% bias[a]	% reduct |bias|[b]	t statistic[c]	p > |t|
		Treated	Control				
Wet season							
Area harvested	Unmatched	1.2060	1.0183	19.1000		5.0900	0.0000
	Matched	1.2060	1.1496	5.8000	69.9000	1.1600	0.2460
Interaction: male x age	Unmatched	43.6430	45.9650	–9.8000		–2.5500	0.0110
	Matched	43.6430	42.5580	4.6000	53.3000	1.0100	0.3120
Dummy: tenure	Unmatched	0.7085	0.6162	19.6000		5.0100	0.0000
	Matched	0.7085	0.7302	–4.6000	76.4000	–1.0900	0.2770
Dummy: rice organization	Unmatched	0.5020	0.5467	–9.0000		–2.3200	0.0210
	Matched	0.5020	0.5138	–2.4000	73.5000	–0.5300	0.5940
Dry season							
Area harvested	Unmatched	1.1965	1.0177	17.9000		4.6300	0.0000
	Matched	1.1952	1.2030	–0.8000	95.6000	–0.1600	0.8760
Household size	Unmatched	4.9376	4.7131	10.5000		2.6500	0.0080
	Matched	4.9414	4.8858	2.6000	75.2000	0.5700	0.5680
Dummy: tenure	Unmatched	0.6647	0.6114	11.1000		2.7800	0.0050
	Matched	0.6644	0.6693	–1.0000	90.7000	–0.2400	0.8130
Dummy: rice organization	Unmatched	0.5387	0.6190	–16.3000		–4.1100	0.0000
	Matched	0.5382	0.5372	0.2000	98.8000	0.0400	0.9640

[a] "The standardized % bias is the [percentage] difference of the sample means in the treated and [control] (unmatched or matched) sub-samples as a percentage of the square root of the average of the sample variances in the treated and [control] groups" [formulae from Rosenbaum and Rubin (1985), as cited by Leuven and Sianesi (2003)].
[b] Percentage change in the absolute value of the bias between % bias in the unmatched and the matched samples.
[c] "t-tests for equality of means in the two samples… are based on a regression of the variable on a treatment indicator" (Leuven and Sianesi 2003).
Authors' own computation.
Source of basic data: PhilRice RBFHS 2016–2017

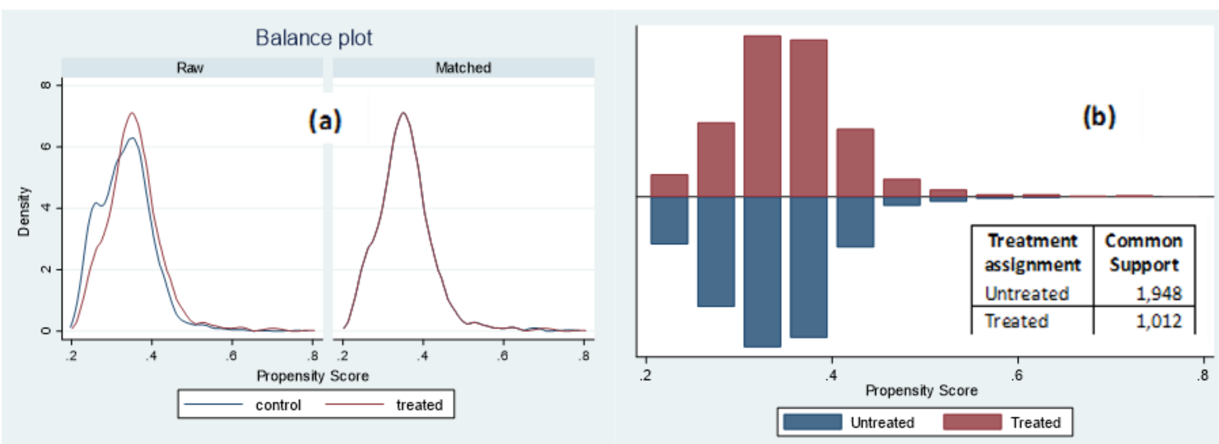

Figure I. Graphical representation of balanced DSR and non-DSR groups, and common support for the wet season PSM model. Note: [a] kernel density plots before and after matching, and [b] propensity score histogram after matching, by treatment status. Farmers using DSR in crop establishment are considered part of the treatment group. Authors' own computation. Source of basic data: PhilRice RBFHS 2016–2017

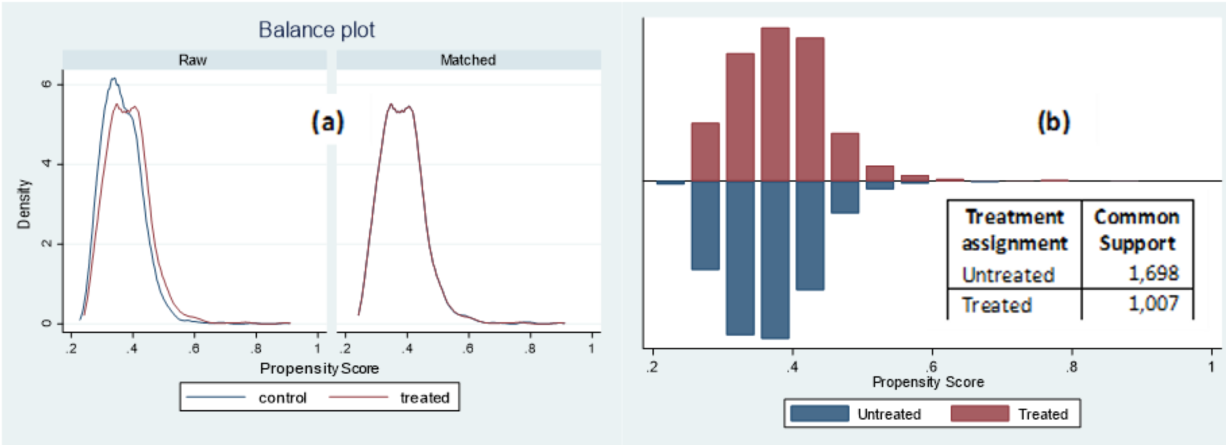

Figure II. Graphical representation of balanced DSR and non-DSR groups, and common support for the dry season PSM model. Note: (a) kernel density plots before and after matching, and [b] propensity score histogram after matching, by treatment status. Farmers using DSR in crop establishment are considered part of the treatment group. Authors' own computation. Source of basic data: PhilRice RBFHS 2016–2017

Table VI. Difference in rice yield (kg/ha) between DSR and TPR for the wet and dry season models using PSM.

Sample	Difference	Standard Error	Rubin's B	Rubin's R
Wet season				
Unmatched	–469.3688***	74.3009	29.90‡	1.08
Matched (ATT)	**–385.6593*****	94.1942	9.00	1.03
Dry season				
Unmatched	–897.4545	586.4280	29.00‡	1.18
Matched (ATT)	**–381.4981*****	102.9701	2.90	1.02

*** $p < 0.01$. ‡ The two groups (treatment and control groups) are unbalanced if B > 25%, R outside [0.5; 2]. Authors' own computation.
Source of basic data: PhilRice RBFHS 2016–2017