Sugar Tech (July-Aug 2020) 22(4):574–582
https://doi.org/10.1007/s12355-020-00821-2

RESEARCH ARTICLE

The Impacts of Certified Seed Plant Adoption on the Productivity and Efficiency of Smallholder Sugarcane Farmers in Indonesia

Anik Suwandari[1,2] · Yuli Hariyati[1,2] · Titin Agustina[1,2] · Ati Kusmiati[1,2] · Triana Dewi Hapsari[1,2] · Ahmad Fatikhul Khasan[1] · Mohammad Rondhi[1,2]

Received: 28 July 2019 / Accepted: 27 March 2020 / Published online: 8 April 2020

Abstract The development of a certified seed plant (CSP) to increase the production of sugarcane cultivation is one of the primary efforts of the Indonesian government. The purpose of this study was to evaluate the impact of CSP adoption on the productivity and efficiency of smallholder sugarcane farmers in Indonesia. This study used data from the 2014 Indonesian Plantation Farm Household Survey consisting of 3849 farmers. We used propensity score matching to evaluate the impact of CSP adoption on the productivity and technical efficiency of sugarcane farming. We found that the adoption of CSPs increases the productivity of sugarcane farming. The average yield of the farmers who adopt CSPs is 88.24 tons/ha while the average yield of those who do not adopt CSPs is 82.94 tons/ha. Additionally, the adoption of CSPs increases the technical efficiency of sugarcane farming. The average efficiency of the farmers who adopt CSPs is 78.31%, while the non-adopting farmers have a technical efficiency of 76.44%. These results suggest that the current policy regarding CSP adoption has been on the right track. However, the government should encourage farmers to exercise good farming practices since the technical efficiency is low. Additionally, since the current rate of adoption is only 18.13%, the government should prioritize policies encouraging the adoption of CSPs.

✉ Yuli Hariyati
yuli.faperta@unej.ac.id

1 Department of Agribusiness, University of Jember, Jember 68121, Indonesia

2 Institutional Economic for Agribusiness Reforms and Development (INFRARED) Research Group, University of Jember, Jember 68121, Indonesia

Keywords Smallholder sugarcane farmer · Certified seed plant · Farm productivity · Farm efficiency · Propensity score matching

Introduction

Certified seed plants (CSPs) are one of the proposed means to increase the productivity of sugarcane farming since the total lack of plantation renewal due to the absence of high-quality seed plants causes low productivity in sugarcane cultivation in many countries (Bello-Bello et al. 2018). In Indonesia, the necessity to increase sugarcane productivity is of the highest priority since the national sugar industry cannot produce adequate sugar to meet local demand. Currently, the Indonesian sugar industry can only supply 48% of the local demand, and the smallholder sugarcane farmers supply 56% of the raw sugarcane material (Toharisman and Triantarti 2016). The lack of high-quality seeds and inefficient farms are among the primary challenges of Indonesian sugarcane farming that caused low sugarcane productivity (Toharisman et al. 2013). Thus, the Indonesian government, through the Ministry of Agriculture, is aiming to increase the productivity and quality of sugarcane farming through plantation renewal with certified seed plants (Directorate General of Plantations 2013). Thus, it is crucial to assess whether this policy increases the productivity and farm efficiency of Indonesian smallholder sugarcane farmers.

The availability of high-yield and high-quality sugarcane varieties is crucial to the efficiency of the sugarcane industry and is a primary factor in the effort to increase farm productivity and farmers' incomes (Singh et al. 2019). The use of appropriate sugarcane varieties was found to increase the sugar recovery rate to approximately 12% in

Shahjahanpur, India (Singh et al. 2017). Additionally, in Indonesia, sugarcane cultivation under PT Perkebunan Nusantara X (PTPN X), which uses high-quality plant cane, was found to be more technically efficient than cultivation of ratoon cane (Setyawati and Wibowo 2019). Economically, the use of high-quality bud chip technology for planting sugarcane is better than conventional sugarcane planting; the former results in 13.86% higher productivity, and the cost is 10.24% less than that of the latter (Patnaik et al. 2017). Generally, the adoption of certified seeds has significantly increased agricultural production. Evidence has been found in various types of crops, such as rice (Arouna et al. 2017; Chandio and Yuansheng 2018), wheat (Abdelmageed et al. 2019), and maize (Yadav et al. 2018). Thus, a comprehensive evaluation of the benefit of certified seeds in improving both farm performance and farmer welfare is essential to policymakers.

The present study aims to evaluate the impact of CSP adoption on the productivity and efficiency of Indonesian sugarcane farmers. Sugarcane farmers are vital to the Indonesian sugar industry because they supply a significant proportion of raw material. However, the farmers also have to compete with the abundant stock of imported sugar, which decreases the price received at harvest and directly affects their income. In response to this, the Indonesian government aimed to increase sugarcane productivity by developing and introducing a highly productive variety of sugarcane and distributing it to the farmers as a CSP. The effectiveness of this policy needs to be rigorously evaluated with comprehensive data and analyses. Thus, utilizing a nationally representative survey of smallholder sugarcane farmers in Indonesia included 3849 farmers, and this study will assess the productivity and technical efficiency of sugarcane cultivation in Indonesia. Numerous studies have assessed the productivity and technical efficiency of sugarcane cultivation in Indonesia (Kurniawan 2012; Susilowati and Tinaprilla 2012; Fahriyah et al. 2018; Setyawati and Wibowo 2019), but these studies were unable to capture the spatial heterogeneity of the impact of certified seed adoption and are unsuitable for policy evaluation at the national level. Additionally, the present study will contribute to the farm efficiency literature by expanding the sample selection to include nationally representative data, in contrast to the usual case studies (Koirala et al. 2016; Abdul-Rahaman and Abdulai 2018; Chaovanapoonphol and Somyana 2018; Nguyen et al. 2018; Huy and Nguyen 2019).

Methods

Data

This study used data from the 2014 Indonesian Plantation Farm Household Survey (IPFHS) created by the BPS (the Indonesian Statistical Agency). The IPFHS was a part of the 2013 Agricultural Census, which is conducted every 10 years. The IPFHS provides nationally representative data for Indonesian plantation and farm households and covers several plantation crops, such as sugarcane, cocoa, oil palm, rubber, tobacco, coffee, and other crops. The crops are categorized into two groups: national plantation commodities and provincial plantation commodities. Sugarcane was categorized as a provincial plantation commodity. The survey was conducted from May 27 to July 7, 2014 (Sub-Directorate of Plantation Crop Statistics 2016). Figure 1 provides the sample distribution of the 2014 IPFHS.

The figure shows that the majority of the sugarcane farmers are located on Java Island, especially in East and Central Java, with 95% of the total farmers. The rest of the farmers are located in North Sumatra, Lampung, Gorontalo, South Sulawesi, Yogyakarta, and West Java. In total, 8831 farmers were sampled for the IPFHS. However, we removed the data for the farmers who sold their sugarcane before harvest (*ijon*) and those who sold their sugarcane with an approximation method (*tebasan*) and obtained 5037 farmers. In preharvest selling, the farmers sell the sugarcane before it reaches maturity. The local term for this system is *ijon* (a Javanese word meaning green, as green is used to describe the young plants). Furthermore, some farmers sell their sugarcane without weighing the product. In this case, the trader (i.e., the sugarcane buyer) estimates the crop of a particular sugarcane plantation and offers a specified price. If the farmer accepts the offer, the buyer will harvest the crop. This method of harvesting is called *tebasan.* Production data were not recorded for either *ijon* or *tebasan*; thus, we excluded the data on the crops sold using these methods from the analysis. Then, we further removed the outliers from the data, resulting in a final sample for analysis consisting of 3849 farmers. The variables in this study were categorized into two groups: The first group consists of the variables used in the technical efficiency estimation (coded 1), and the second group contains the variables used to estimate the propensity score in the PSM analysis (coded 2). Table 1 provides descriptive statistics of the variables in the analysis. The average cultivation area for the CSP adopters is higher than that for the nonadopters. However, the nonadopters produced more sugarcane per hectare of land. The difference in productivity might be due to the

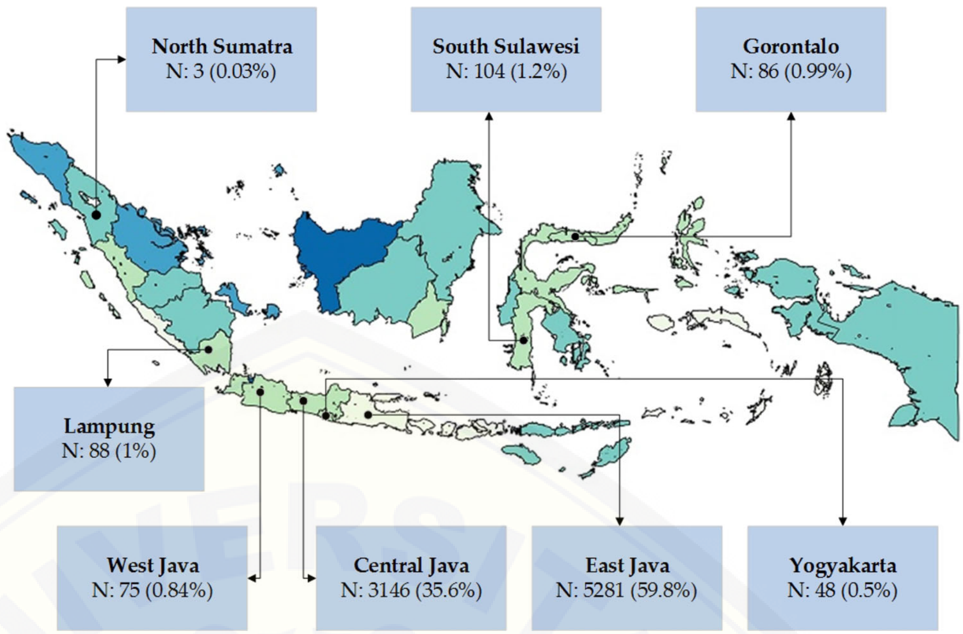

Fig. 1 The distribution of smallholder sugarcane farmer in the 2014 Indonesian Plantation Farm Household Survey

nonadopters using more seed plants than the CSP adopters. The average number of seed plants used by the CSP adopters was 10,118, which was lower than that of the nonadopters, who used 13,419 plants. Additionally, the use of labor by both male and female workers on CSP farms is smaller than that on non-CSP farms. The average labor use on CSP farms is 8.18 for male workers and 3.56 for female workers.

However, on non-CSP farms, the average labor use is 10.29 for male workers and 3.75 for female workers. The CSP and non-CSP farmers have equal household sizes and educational attainments. It seems that both groups (the CSP adopters and nonadopters) have the same characteristics in terms of cultivated land types, land tenure, and livestock-sugarcane farming integration. The percentage of CSP farmers who received government support is higher than that of the non-CSP farmers. This suggests that the farmers might adopt the CSP due to support from the government, usually in the form of free seed plants. The percentages of farmers with access to extension services and who participate in contract farming do not differ significantly between the two groups.

In addition, we conducted an in-depth interview with an officer from the Asosiasi Petani Tebu Rakyat Indonesia (APTRI), i.e., the Association of Indonesian Sugarcane Smallholder Farmers. The APTRI is a nongovernmental organization comprised of smallholder sugarcane farmers in Indonesia. The primary purpose of the APTRI is to improve farmers' bargaining power by acting collectively. The interview was conducted in Jember, East Java.

Estimation of Farm Technical Efficiency

The technical efficiency (TE) of sugarcane cultivation was analyzed using the stochastic frontier production (SFP) model. The SFP measures the actual output compared to the maximum potential output given the input used and technological combinations. The SFP has become the benchmark for productivity analysis. We used the translog functional form of the *Cobb–Douglas* model to estimate the SFP. The *Cobb–Douglas* production function has commonly been used to estimate the agricultural production function. Equation 1 provides the mathematical expression of the production model.

$$\ln Y_i = \alpha_0 + \sum_{j=1}^{n} \alpha_j \ln\left(X_{ij}\right) + e_i \ldots i = 1, 2, \ldots, n \quad (1)$$

where Y_i denotes the sugarcane production of the ith farmer, X_{ij} is a vector of farm inputs, α_0 represents the regression constant, α_j is the coefficient of the input, which is estimated in the model, and e_i is the model error term. The model also underwent a classical assumption test to ensure a linear relationship, multivariate normality, homoscedasticity, and no multicollinearity. The TE is then calculated using the following formula:

$$\mathrm{TE}_i = \exp(-E[u_i|\varepsilon_i]) \quad i = 1, 2, \ldots 3. \quad (2)$$

Impact of CSP Adoption on the Productivity and Efficiency of Sugarcane Farming

We estimated the average treatment effect (ATT) of CSP adoption on sugarcane productivity and technical efficiency using PSM. We define productivity as the amount of

Table 1 Descriptive statistics of variables

Code	Variable	CSP			Non-CSP		
		Mean	S.D.	Freq.[a]	Mean	S.D.	Freq.
	Productivity (ton/ha)	70.63	11.00		71.71	6.73	
1	Production (ton)	44.36	8.43		42.67	10.06	
1	Land (ha)	.70	.83		.59	.79	
1	Seed plants	10,118	19,193		13,419	26,694	
1	Fertilizer (kg)	1539	2123.89		1355.22	2099.37	
1	Male labor (number of men)	8.18	8.78		10.29	9.8	
1	Female labor (number of women)	3.56	4.74		3.75	5.15	
2	Household size[b]	4	0		4	0	
2	Years of education (years)	6	0		6	0	
2	Land type						
	Lowland			167 (23)			1014 (32)
	Not lowland			531 (77)			2137 (68)
2	Land tenure						
	Owner/operator			613 (87)			2500 (79)
	Land renter			71 (10)			399 (12)
	Sharecropper			14 (3)			252 (9)
2	Livestock farming						
	Integrated			67 (9)			428 (13)
	Not integrated			631 (91)			2723 (87)
2	Government support						
	Recipient			254 (36)			1465 (46)
	Nonrecipient			444 (64)			1686 (54)
2	Agricultural extension						
	Access			170 (24)			449 (14)
	No access			528 (76)			2702 (86)
2	Contract farming						
	Participation			424 (60)			1365 (43)
	No participation			274 (40)			1786 (57)
	Sample size (n)			698			3151

The figure in parentheses is the percentage of the farmers in each group

[a]For the categorical variables, the value represents the number of farmers for each category in each group

[b]Household size is the number of household members (including farmers) in a particular farm household

sugarcane produced in each hectare of land (tons/ha), and the TE from the SFP analysis was used for the second outcome variable. The ATT can be defined as the difference between the expected values of the outcome variables of the control group and the treated group. The ATT can be expressed as follows:

$$\begin{aligned} \mathrm{ATT} &= E\left(y_{1j} - y_{oj} \middle| D_j = 1\right) \\ &= E\left(y_{1j} \middle| D_j = 1\right) - E\left(y_{0j} \middle| D_j = 0\right) \end{aligned} \quad (3)$$

where $E(\bullet)$ denotes an expectation operator, y_{1j} is the outcome variable (productivity and TE) for farmer j who adopts the CSP and y_{0j} is the outcome variable for those who did not adopt the CSP.

However, the same farmer cannot adopt and not adopt the CSP simultaneously on the same plot of land. Thus, the ATT was estimated using PSM by making conditional independence and overlapping assumptions. The estimation of the ATT by PSM follows the formula in Eq. 4.

$$\mathrm{ATT}^{\mathrm{PSM}} = E\left(y_{1j} \middle| D_j = 1, p(x_{ij})\right) - E\left(y_{0j} \middle| D_j = 0, p(x_{ij})\right) \quad (4)$$

The PSM estimates the probability of a farmer being a CSP adopter, given the observable characteristics x_{ij}. We

Table 2 The estimates of the Cobb–Douglass and stochastic production frontier models

Variable	First trial			Second trial			Third trial		
	β	S.E.	*t* value	β	S.E.	*t* value	β	S.E.	*t* value
Land ($\ln X_1$)	.701***	.008	84.38	.701***	.718	84.51	.829***	.010	82.86
Seed plant ($\ln X_2$)	.033***	.004	8.09	.033***	.053	8.09	.013***	.004	2.88
Shade trees ($\ln X_3$)	− .002^{ns}	.065	− .02	–			–		
Fertilizer ($\ln X_4$)	.167***	.007	24.89	.167***	.197	24.90	.105***	.008	.12
Growth stimulator ($\ln X_5$)	− .005^{ns}	.008	− .54	–			–		
Pesticide ($\ln X_6$)	.047***	.007	7.13	.047***	.042	7.16	–		
Male labor ($\ln X_7$)	.028***	.008	3.48	.028***	.023	3.47	.023***	.008	2.78
Female labor ($\ln X_8$)	.015**	.007	2.13	.015**	.014	2.17	.005^{ns}	.007	.63
Constant	− 1.521***	.050	− 30.30	− 1.519***	.050	− 30.34	− 2.00***	.810	− 35.49
Cobb–Douglass									
R^2	.84			.84			.83		
F value	3303.039***			4405.494***			3929.280***		
SFP									
Gamma (γ)	.36			.35			.56		
Log-likelihood	− .33			− .33			− .18		
Mean efficiency	–			–			.76		

***Significant at 1%, **significant at 5%, *significant at 10%, ^{ns}not significant

used a kernel matching algorithm to check the robustness of our results. We used STATA software to perform the PSM analysis.

Results and Discussions

Recent Conditions on the Adoption of Certified Sugarcane Seed Plant

The in-depth interview with the APTRI officer showed that farmers initially obtained CSPs from the government through the Indonesian Sugar Research Institute (P3GI) in 2012. There were three types of CSPs distributed by the P3GI: the BZ, BL, and HW varieties. Of the three sugarcane varieties, BZ is planted the earliest, BL is planted second, and HW is planted last. The farmers indicated that the CSPs improve sugarcane productivity. However, the improvement is optimized only through good sugarcane farming practices. This is in line with the findings of this study, which demonstrated that under similar farming practices, the difference in yield between CSP and non-CSP farmers does not differ significantly. The next subsection explains this finding. Currently, farmers obtain CSPs from multiple sources. State-owned sugar enterprises provide CSPs in a limited amount. Hence, the farmers obtain the CSPs commercially.

The Technical Efficiency of Sugarcane Farming in Indonesia

The estimation process of the SFP analysis, which requires three trials before resulting in accurate estimation results, is summarized in Table 2. In the first trial, the model consisted of eight variables and had 5037 observations. The first trial obtained a robust estimation of the Cobb–Douglass production function (CDPF) and passed tests of the classical assumptions. There are two variables that have a statistically nonsignificant effect: shade trees and plant growth stimulators. However, the SFP estimation produced statistically nonsignificant results, which are shown by the γ value and the log-likelihood ratio test. Thus, the analysis proceeded to the second trial and excluded the shade trees and plant growth stimulator variables. The second trial consisted of 6 variables with an equal number of observations to that of the first trial. The second CDPF estimation produced a robust result, and all of the input variables had a statistically significant effect at the 5% level. However, the second trial still yielded a weak estimation for the SFP. We suspected that this was due to the outliers in the model. Accordingly, we removed the outliers from the data and obtained the final data, which consisted of 3849 observations. Additionally, we removed the pesticide variable since it had a value of zero for all the observations. The third trial produced a robust estimation for both the CDPF and SFP.

There are four variables in the final model with statistically significant coefficients: land, seed plant, fertilizer,

Table 3 Estimates of technical efficiency of sugarcane farmers

Estimates of technical efficiency	Total number of farmers	CSP adopters	Nonadopters of the CSP
> 50.00%	71 (1.8)	9 (1.2)	62 (1.9)
50.00–70.00%	427 (11)	33 (4.7)	394 (12.5)
70.01–80.00%	1952 (50.7)	354 (50.7)	1598 (50.7)
80.01–90.00%	1364 (35.4)	292 (41.8)	1072 (34)
> 90.00%	35 (.9)	10 (1.4)	25 (.7)
Mean	.7675	.7831	.7641
Maximum	.961	.955	.961
Minimum	.071	.071	.149
Sample size (n)	3849	698	3151

and male labor. All four variables are statistically significant at the 1% level. Female labor was found to have a statistically nonsignificant effect at the 10% level. The coefficients of the input variables also represent the partial elasticities of production for the sample mean. For example, the coefficient of land is .829. Thus, it can be interpreted that a 1% increase in the cultivation area will result in a .829% increase in sugarcane production, assuming the other inputs are kept constant. The analogous interpretation can be used to interpret the coefficients of the other variables. An analysis of sugarcane technical efficiency in East Java using a sample of 132 farmers found a significant effect of land (β: 1.061) and fertilizer (β: .03) (Susilowati and Tinaprilla 2012). Using the SFP approach to estimate farm efficiency, a similar result was found for Lao PDR; significant effects were found for cultivation area (β: .961) and hired labor (β: .032) (Supaporn 2015). A different result was found in India, where an SFP analysis yielded negative and statistically significant effects of planting material/seed (β: − .567) and human labor (β: − .109), but the Indian case has an elasticity of scale of .454, indicating a decreasing return to scale condition (Murali and Puthira Prathap 2017).

The sum of coefficients represents the elasticity of scale (EoS). The sum of coefficients is .97, which means that the Indonesian sugarcane farmers are operating in the optimal region of constant return to scale. Similar results were found in the study in East Java (EoS: 1.09) (Susilowati and Tinaprilla 2012). However, this result is different from the Lao PDR case, in which the sugarcane farmers are operating at an increasing return to scale (EoS: 1.31) (Supaporn 2015), and the Indian case, in which the farmers are operating at a decreasing return to scale (EoS: .454) (Murali and Puthira Prathap 2017). However, the average technical efficiency of the Indonesian sugarcane farmers is only 76%. This means that, on average, an Indonesian sugarcane farmer produces only 76% of the maximum production potential. This is far below the mean efficiency of the Indian sugarcane farmers (88%), almost identical to that of the sugarcane farmers in Lao PDR (74%), and higher than that of the sugarcane farmers in East Java (67%). However, the study of PTPN X cultivation, which was conducted in East Java, produced a mean efficiency of 93% for plant cane and 89% for ratoon cane (Setyawati and Wibowo 2019).[1] In all of the cases, the high TE was associated with the use of high-quality planting materials. Moreover, the use of ratoon cane in the PTPN X cultivation and East Java cases was the cause of the low TE. Table 3 shows the distribution of the TE estimates for the CSP adopters and nonadopters a and the pooled estimates.

The distribution of the TE estimates demonstrated that the majority of the farmers are operating at the 70% efficiency level. However, grouping the farmers into CSP adopters and nonadopters revealed an interesting comparison. The proportion of farmers who operate below the 70% level is higher in the latter group, with a total of 14.4%, compared to 5.9% in the former group. Moreover, the proportion of farmers who operate at the 70.01–80.00% efficiency level is nearly equal. However, the proportion differs significantly at the > 80% efficiency level; 43.2% of the CSP adopters operate at this level, while only 34.7% of the nonadopters belong to this level. However, this figure is not adequate to provide a robust comparison. Thus, a propensity score analysis was conducted and will be explained in the discussion.

The Impact of CSP Adoption on Farm Productivity and Efficiency

The estimation of the ATT of CSP adoption using PSM begins with the estimation of a logistic regression model (LRM) of CSP adoption. There are eight variables in the

[1] The result demonstrates that the use of a small sample size to assess technical efficiency is open to biased estimates.

Table 4 Estimates of logistic regression model

Variable	β	S.E.	Sig.
Household size	.049	.020	.013**
Years of education (years)	.046	.010	.000***
Land type	− .422	.100	.000***
Land tenure	− .568	.096	.000***
Livestock farming integration	− .325	.143	.023**
Recipient of government support	− .404	.090	.000***
Access to agricultural extension	.460	.107	.000***
Participation in contract farming	.639	.089	.000***
Constant	− 1.385	.161	.000***
Omnibus tests of model coefficients	207.162***		
Hosmer and Lemeshow test	12.244***		
Pseudo R^2	.086		

***Significant at 1%, **significant at 5%, *significant at 10%

Table 5 Estimated impact of certified seed plant adoption on sugarcane farming

Variable	CSP	Non-CSP	ATT	S.E.	*t*-stat
Productivity (ton/ha)	88.24	82.94	5.29	2.81	1.89
Technical efficiency (%)	78.31	76.44	1.86	.33	5.52
Cultivation area (ha)	.74	.66	.08	.04	2.02
Seed (plants)	10,118	14,397	− 4279	925	− 4.62
Labor (workers)	11.45	15.86	− 4.41	.5	− 8.72

The values presented are the average values after matching

A kernel matching algorithm was used

LRM, which consisted of both farm and household characteristics (Table 1). Table 4 shows the estimation results of the LRM; the results were then used for the estimation of the propensity score for each farmer. The propensity scores fall in the common support area, ranging between 0 and 1. Thus, each respondent has a positive probability of adopting certified seed plants. A balance test was conducted on the mean differences, and we found no covariates that are significantly different between the adopters and nonadopters of the CSP. This suggests that the matching algorithm produces a relevant group for comparison.

Table 5 shows the ATT estimates of the adopters and nonadopters of the CSP on the productivity and efficiency of Indonesian sugarcane farmers. We employed a kernel matching algorithm to estimate the ATT scores. Additionally, we estimated the difference in the input use of the CSP and non-CSP adopters. The result shows that the productivity and technical efficiency of the CSP adopters is higher than that of the nonadopters. Adoption of the CSP produces relatively high sugarcane productivity (2.8 tons/ha). Additionally, the technical efficiency of the CSP adopters is 1.9% higher than that of the nonadopters. The total labor use is significantly higher on the farms that did not adopt the CSP. The average labor use on the CSP and non-CSP farms after matching are 11.45 and 15.86 workers, respectively. The ATT estimate for labor is − 4.41, indicating that, on average, the CSP adopters use 4.41 less labor than the nonadopters. A similar result is also found for seed plant use, for which the ATT estimate is − 4279. Finally, the ATT estimate for cultivation area is .08 ha. This indicates that, on average, the CSP adopters cultivated .08 ha more land than did the nonadopters. This suggests that the labor and crop density for each hectare of cultivation area are lower on the CSP farms.

The results of the PSM analysis demonstrate that the adoption of the CSP increases the land productivity of smallholder sugarcane farmers in Indonesia. The improvements resulting from the CSP can be achieved; although, on average, the CSP adopters have lower labor use and crop density than those of the nonadopters. This result provides crucial insight into the effort to increase sugar production in Indonesia. The introduction of CSPs has been shown to be an effective method to increase sugarcane production. Additionally, it confirms that the policy to arrange sugarcane varieties is appropriate for the current conditions in Indonesia (Ardana et al. 2016). Furthermore, considering the positive partial elasticity of land, labor, and seed plants, further improvements can be made by increasing the intensity of labor on the CSP farms. Currently, the rate of CSP adoption is only 18.13%. Thus, the government should increase the availability and accessibility of CSPs to farmers. In addition to the high cost of crop renewal, the unavailability of CSPs is one of the reasons for the lack of renewal of sugarcane plantations (Toharisman and Triantarti 2016; Bello-Bello et al. 2018).

The adoption of CSPs also improves the technical efficiency of sugarcane cultivation in Indonesia. However, CSP adoption only results in a 1.86% improvement, and the average efficiency of the CSP adopters is only 78.31%. These figures suggest that the use of CSPs only slightly increases the efficiency of the farms. This is not surprising since one of the primary problems in Indonesian sugarcane farming is the poor farming practices of sugarcane farmers (Yunitasari et al. 2015). Improving farming practices would maximize the yield potential of the CSPs. Additionally, incentivizing farmers to improve sugarcane quality by a quality-based pricing mechanism would drive farmers to adopt better farming practices (Bantacut 2010). Furthermore, mitigating the impact of climate change (CC) would prevent a dramatic loss in sugarcane production. CC causes severe drought and floods in Indonesia, leading to a significant loss of agricultural production, especially in Java, where the majority of the sugarcane plantations are located (Rondhi et al. 2019). Other primary threats of agricultural production in Java are farmland conversion, in which the majority of farmland is converted to nonagricultural uses, and the development of urban areas, which decreases land quality (Rondhi et al. 2018). Mitigating the impact of CC and farmland conversion is crucial to improve the efficiency of sugarcane cultivation since the SFP analysis demonstrates that 44% of farmer inefficiency is beyond the farmers' control.[2]

Conclusion

This study evaluated the impact of certified seed plant adoption on the productivity and efficiency of sugarcane cultivation in Indonesia. The analysis revealed that CSP adoption significantly improves productivity and farm efficiency by 5.29 tons/ha and 1.86%, respectively. Although CSP adoption has a positive effect, the magnitude of improvement is quite small, indicating the need to improve farming practices to realize the maximum yield potential of the CSPs.

Acknowledgements We wish to acknowledge the Institute for Research and Community Service (LP2M) of University Jember for supporting this study. Also, we wish to acknowledge the helpful cooperation from the officials of Association of Indonesian Sugarcane Smallholder Farmers who were interviewed in this study. We are grateful for two anonymous reviewers for their constructive and encouraging comments which significantly improved the manuscript. Finally, all errors are ours.

Author Contributions All authors contributed equally to the study.

Funding This research was funded by *Lembaga Penelitian dan Pengadian kepada Masyarakat* (The Institute for Research and Community Service) University of Jember, Number: 1394/UN25.3.1/LT/2019.

Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Code Availability The coding of the data is available from the corresponding author upon reasonable request.

Compliance with Ethical Standards

Conflict of interest The authors declare no conflict of interest.

References

Abdelmageed, Kishk, Xu hong Chang, De mei Wang, Yan jie Wang, Yu shuang Yang, Guang cai Zhao, and Zhi qiang Tao. 2019. Evolution of varieties and development of production technology in Egypt wheat: A review. *Journal of Integrative Agriculture* 18: 483–495.

Abdul-Rahaman, Awal, and A. Abdulai. 2018. Do farmer groups impact on farm yield and efficiency of smallholder farmers? Evidence from rice farmers in northern Ghana. *Food Policy* 81: 95–105.

Ardana, I.Ketut, Soetopo Deciyanto, and Syafarudin. 2016. Cropping pattern arrangement of sugarcane varieties, an important strategy in increasing national sugar production. *Perspektif* 15: 124–133.

Arouna, A., J.C. Lokossou, M.C.S. Wopereis, S. Bruce-Oliver, and H. Roy-Macauley. 2017. Contribution of improved rice varieties to poverty reduction and food security in sub-Saharan Africa. *Global Food Security* 14: 54–60.

Bantacut, Tajahuddin. 2010. Swasembada Gula: Prospek dan Strategi Pencapaiannya. *Pangan* 19: 245–256.

Bello-Bello, Jericó J., Maurilio Mendoza-Mexicano, and Juan A. Pérez-Sato. 2018. In Vitro Propagation of Sugarcane for Certified Seed Propagation of Sugarcane for Certified Seed Production. In *Sugarcane: Technology and Research*, ed. Alexandre De Oliveira, 101–112. London: IntechOpen Limited.

Chandio, Abbas Ali, and Jiang Yuansheng. 2018. Determinants of adoption of improved rice varieties in Northern Sindh, Pakistan. *Rice Science* 25: 103–110.

Chaovanapoonphol, Yaovarate, and Wirasak Somyana. 2018. Production efficiency of maize farmers under contract farming in

[2] The gamma value of the SFP is .56, indicating that farmers contribute only 56% to farm inefficiency (Table 2).

Laos PDR. *Kasetsart Journal of Social Sciences*. https://doi.org/10.1016/j.kjss.2018.06.006.

Directorate General of Plantations. 2013. *Peningkatan Produksi, Produktivitas dan Mutu Tanaman Semusim: Pedoman Teknis Pengembangan Tanaman Tebu (Improving the Production, Productivity and Quality of Seasonal Crop: Technical Guidance on The Improvement of Sugarcane)*. Jakarta.

Fahriyah, Nuhfil Hanani, Djoko Koestiono, and Syafrial. 2018. Analisis Efisiensi Teknis Usahatani Tebu Lahan Sawah dan Lahan Kering dengan Pendekatan Data Envelopment Analysis (DEA). *Jurnal Ekonomi Pertanian dan Agribisnis (JEPA)* 2: 77–83.

Huy, Hoang Trieu, and Trung Thanh Nguyen. 2019. Cropland rental market and farm technical efficiency in rural Vietnam. *Land Use Policy* 81: 408–423.

Koirala, Krishna H., Ashok Mishra, and Samarendu Mohanty. 2016. Impact of land ownership on productivity and efficiency of rice farmers: The case of the Philippines. *Land Use Policy* 50: 371–378.

Kurniawan, Ahmad Yousuf. 2012. Faktor-Faktor Yang Mempengaruhi Efisiensi Teknis Pada Usahatani Padi Lahan Pasang Surut Di Kecamatan Anjir Muara Kabupaten Barito Kuala Kalimantan Selatan. *Jurnal Agribisnis Perdesaan* 02: 35–52.

Murali, P., and D. Puthira Prathap. 2017. Technical efficiency of sugarcane farms: An econometric analysis. *Sugar Tech* 19: 109–116.

Nguyen, Trung Thanh, Truong Lam Do, Priyanka Parvathi, Ada Wossink, and Ulrike Grote. 2018. Farm production efficiency and natural forest extraction: Evidence from Cambodia. *Land Use Policy* 71: 480–493.

Patnaik, J.R., S.N. Singh, Debasis Sarangi, and P.K. Nayak. 2017. Assessing potentiality of bud chip technology on sugarcane productivity, profitability and sustainability in real farming situations under south east coastal plain zone of Odisha, India. *Sugar Tech* 19: 373–377.

Rondhi, M., P.A. Pratiwi, V.T. Handini, A.F. Sunartomo, and S.A. Budiman. 2018. Agricultural land conversion, land economic value, and sustainable agriculture: A case study in East Java, Indonesia. *Land*. https://doi.org/10.3390/land7040148.

Rondhi, Mohammad, Ahmad Fatikhul Khasan, Yasuhiro Mori, and Takumi Kondo. 2019. Assessing the role of the perceived impact of climate change on national adaptation policy: The case of rice farming in Indonesia. *Land*. https://doi.org/10.3390/land8050081.

Setyawati, Intan Kartika, and Rudi Wibowo. 2019. Technical efficiency of plant cane and ratoon cane production (case study of PT. Perkebunan Nusantara X). *Jurnal Sosial Ekonomi Pertanian* 12: 80–88.

Singh, Priyanka, S.K. Pathak, M.M. Singh, V. Mishra, and B.L. Sharma. 2017. Impact of high sugar early maturing varieties for sustainable sugar production in subtropical India. *Sugar Tech* 19: 368–372.

Singh, Priyanka, S.N. Singh, Ajay K. Tiwari, Sanjeev Kumar Pathak, Anil K. Singh, Sangeeta Srivastava, and Narendra Mohan. 2019. Integration of sugarcane production technologies for enhanced cane and sugar productivity targeting to increase farmers' income: Strategies and prospects. *3 Biotech* 9: 1–15.

Sub-Directorate of Plantation Crop Statistics. 2016. *Indonesian Plantations Farm Household Survey 2014*. Jakarta.

Supaporn, Poungchompu. 2015. Determinants of technical efficiency of sugarcane production among small holder farmers in Lao PDR. *American Journal of Applied Sciences* 12: 644–649.

Susilowati, Sri Hery, and Netti Tinaprilla. 2012. Analisis efisiensi usaha tani tebu di Jawa Timur. *Jurnal Littri* 18: 162–172.

Toharisman, Aris, and Triantarti. 2016. An overview of sugar sector in Indonesia. *Sugar Tech* 18: 636–641.

Toharisman, Aris, Triantarti, and Muhammad Fadhil Hasan. 2013. Rise and Fall of the Indonesian Sugar Industry. In *Proceedings of International Society of Sugarcane Technologists*, ed. D. M. Hogarth, 28:1992–2000. Sao Paulo, Brazil: Sociedade dos Técnicos Açucareiros e Alcooleiros do Brasil (STAB) and The XXVIIIth ISSCT Organising Committee.

Yadav, Ranjeet Singh, Vivek Singh, Sumita Pal, Sunita Kumari Meena, Vijay Singh Meena, Birinchi Kumar Sarma, Harikesh Bahadur Singh, and Amitava Rakshit. 2018. Seed bio-priming of baby corn emerged as a viable strategy for reducing mineral fertilizer use and increasing productivity. *Scientia Horticulturae* 241: 93–99.

Yunitasari, Duwi, Dedi Budiman Hakim, Bambang Juanda, and Rita Nurmalina. 2015. Achieving national sugar self-sufficiency: A policy model to increase sugar production and boost sugar cane farmer's income. *Jurnal Ekonomi & Kebijakan publikakan publik* 6: 1–15.