Asian Journal of Agriculture and Rural Development
Volume 13, Issue 1 (2023): 1-7.

http://www.aessweb.com/journals/5005

Technology gap ratio decomposition in sugarcane farming in Indonesia

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Article History

Received: 12 September 2022
Revised: 8 December 2022
Accepted: 2 January 2023
Published: 23 January 2023

Keywords

Decomposition
Gap ratio
Sugarcane
Technical efficiency
Indonesia
Meta-frontier DEA.

ABSTRACT

Indonesia's population and income growth have led to a higher demand for raw sugar and its derivative products; for this reason, sugarcane production must be improved, especially in central production areas. However, efforts are constrained by the disparity in resource endowment and technology. This study aimed to analyse technical, technological, and managerial gaps in sugarcane farming in different areas of East Java. The study used primary data collected through a survey during the 2019/2020 sugarcane planting season in Malang, Kediri, and Mojokerto Regencies. A structured questionnaire was used to collect data on inputs and outputs. A meta-frontier data envelopment analysis (meta-DEA) approach was used to measure the technical efficiency of sugarcane farming in each research area. The decomposition using meta-DEA showed that, on average, the meta-technical inefficiency of sugarcane farmers was caused mainly by managerial gaps, as the average managerial gap inefficiency (MGI) was more significant than the technological gap inefficiency (TGI). Malang regency showed the largest TGI and MGI, indicating that sugarcane farmers in Malang regency have lower managerial skills for decision-making and a lower level of production technology compared to the other two regions. Based on the findings of this study, the government should improve technological innovation to mitigate the technology gap that was found in our research location.

Contribution/Originality: This study makes a first attempt to analyse differences in technical efficiency levels and gaps in technological and managerial efficiency in sugarcane farming in three locations in East Java Province using meta-frontier data envelopment analysis (meta-DEA).

DOI: 10.55493/5005.v13i1.4707
ISSN(P): 2304-1455/ ISSN(E): 2224-4433
How to cite: AR, N. H., Asmara, R., & Fahriyah, F. (2023). Technology gap ratio decomposition in sugarcane farming in Indonesia. *Asian Journal of Agriculture and Rural Development*, *13*(1), 1–7. 10.55493/5005.v13i1.4707

1. INTRODUCTION

In the last decades, agricultural intensification has boosted productivity to meet the increasing global demand for agricultural products. However, this effort has not yet generated maximum results (Dong et al., 2016). Many agricultural production activities in developing countries are inefficient due to managerial incompetence, low levels of technological innovation, and lack of government support (Ullah, Silalertruksa, Pongpat, & Gheewala, 2019). Therefore, special efforts need to be made to increase the agricultural sector's contribution to the national economy.

In Indonesia, sugarcane is a strategic commodity for the national economy. It has high forward and backward linkages and plays an essential role in the value chain. Lin and Chen (2015) asserted that an essential role of sugarcane is as a raw material for granulated sugar, which Indonesian customers purchase for direct consumption or the food and beverage industry. Additionally, the industry absorbs labour through sugar factories and sugarcane farming in rural areas. The 2019 industry labour data shows that 74% of workers in the industry, 995 thousand workers, were sugarcane farmers, and the remaining 26% worked in the sugar production process (Ngadi & Nagata, 2022).

According to the Food and Agriculture Organization of the United Nations (FAO) (2018), between 2014 and 2018, the average sugarcane production in Indonesia experienced a slowdown of 5.14%, with an average production of 23.6 million tons and an average harvested area of 442 thousand hectares. Likewise, the growth rate of the sugarcane harvested area declined by 2.39% annually. This decline between 2014 and 2018 was caused by a 6.91% decrease in the number of smallholder plantations (Widyasari, Putra, Ranomahera, & Puspitasari, 2022). Sugarcane productivity fluctuates every year, with an average annual productivity of 53.45 tons per hectare. The highest productivity was recorded in 2015, with 55.61 tons per hectare. In line with the declining growth rate in production and harvested area, the average productivity growth rate also slowed by 2.76%.

Indonesia must intensify its sugarcane production to meet the demands of a growing population that is earning increasingly higher incomes. The Organization for Economic Co-operation and Development (OECD) (2020) reported that the average sugar consumption in Indonesia between 2016 and 2020 was 7 million tons, while the average sugar production was only 2.2 million tons. Since domestic production could not meet domestic demand, imports made up the deficit of 4.7 million tons. An alternative would be to achieve production efficiency in sugar factories and sugarcane farming, especially in sugarcane production centres.

East Java Province is one of Indonesia's production centres. Based on data collected by Artikanur, Widiatmaka, Setiawan, and Marimin (2022), the regencies with the largest harvested area, production, and productivity are Kediri, Malang, and Mojokerto. However, these areas have different productivity and production levels due to differences in the availability of natural resources (resource endowment) and technological infrastructure. This disparity can be influenced by capabilities, cultural characteristics, facilities and infrastructure, and climate. O'Donnell, Rao, and Battese (2008) asserted that gaps could include the use of different sets of technologies, the availability of human and financial resources (e.g., the type of machine, workforce size and quality, and access to foreign exchange), natural resources (e.g., soil quality, climate, energy), and other physical, social, and economic environments where production takes place. Previous research by Francis, Samuel, and Samuel (2020) found that sugarcane farming in developing countries had not yet reached optimum efficiency, presumably due to the ratoon farming system practised by most farmers and the use of local seeds. Carrer, de Souza Filho, Vinholis, and Mozambani (2022) argued that sugarcane farming could still be optimised to achieve full efficiency, especially in countries with high agricultural potential. In Indonesia, research on sugarcane farming has also found technical inefficiencies. For example, Yusuf, Jamhari, and Irham (2020) revealed that sugarcane farming in East Java, whether employing the plant cane or the ratoon cane system, was still technically inefficient. Widyawati (2020) showed that sugarcane farming with the plant cane system was more technically efficient than the ratoon cane system. Meanwhile, Ambetsa, Samuel, and Samuel (2020) and Ali and Jan (2017) discovered that fertilisers, seeds, and labour were the factors that most affected the production and technical efficiency of sugarcane farming.

Extensive research has been conducted on sugarcane farming efficiency, covering different developing countries; however, these studies have only measured the technical efficiency of sugarcane farming (Carrer et al., 2022; Francis et al., 2020), compared efficiency levels based on cultivation techniques (Widyawati, 2020), and identified the factors affecting technical efficiency levels (Ali & Jan, 2017; Ambetsa et al., 2020). To date, little research on sugarcane farming has simultaneously examined technical efficiency levels and gaps in technological inefficiency (GTI) and managerial inefficiency (GMI), especially in Indonesia. Therefore, this study analysed the differences in technical efficiency levels and the gaps in technological and managerial inefficiency in sugarcane farming in three locations in East Java Province using meta-frontier data envelopment analysis (meta-DEA).

2. RESEARCH METHODS

2.1. Research Data

The sample of farmers in this study was recruited using multi-stage sampling from the selected sugarcane production centres in East Java Province, which contributed 80% of the national sugarcane production. The selected production centres in East Java were Kediri, Malang, and Mojokerto Regencies, based on their high production quantity, harvested land areas, and productivity levels. One district was selected from each regency. Then, four central villages were selected from each district. The number of farmers recruited as the sample of this study was 148. The primary data were collected using a survey during the 2019/2020 sugarcane planting season.

2.2. Data Analysis

The efficiency analysis in this research was limited to technical efficiency. In the meta-DEA method, the efficiency measurement does not calculate the average value but the relative efficiency of using production inputs. The input variables were land area, sugarcane seeds, N fertiliser, P fertiliser, K fertiliser, S fertiliser, pesticides, and labour. Meanwhile, the study's output variable was sugarcane production. The DEA efficiency approach is non-parametric. Ramanathan (2003) stated that in the DEA model, multiple inputs and outputs are aggregated linearly using weighting. The input used by a farmer is thus the linear sum of the weights of all the inputs used and can be formulated as in Equations 1, 2, and 3.

$$Aggregated\ Input = \sum_{i=1}^{I} u_i x_i \quad (1)$$

$$Aggregated\ Output = \sum_{j=1}^{J} v_j y_j \quad (2)$$

$$Efficiency = \frac{\sum_{j=1}^{J} v_j y_j}{\sum_{i=1}^{I} u_i x_i} \quad (3)$$

The model was estimated using the Data Envelopment Analysis Program (DEAP) version 2.1. The meta-frontier function obtained from the DEA approach was carried out using Equation 4.

$$Max_{\Phi_{it}\lambda_{it}}\ \Phi_{it}$$

Subject to

$$-\Phi_{it} b_{it} + B_{it}\lambda_{it} \geq 0$$
$$a_{it} - A_{it}\lambda_{it} \geq 0;$$
$$\lambda_{it} \geq 0 \quad (4)$$

Where:

b_{it} is vector M X 1 sum of outputs from the i[th] decision-making unit (DMU) in period t, a_{it} is vector N X 1 sum of inputs from the i[th] UKE in period t, B_{it} is vector M X L sum of outputs from total UKE (L = the total number of UKE), A_{it} is vector N X L sum of inputs from the total UKE, λ_{it} is a weighting vector, and Φ_{it} is a scalar.

This study used the DEA approach, with meta-frontier analysis carried out for three research sites. All three had different characteristics, which were identified using the meta-frontier analysis. If we assume that the input vector is X and the output is y, then the set of technologies that the producer has in their production is expressed as Equation 5:

$$T = \{(X, y): X \geq 0, y \geq 0\} \quad (5)$$

Related to the set of meta-technology, namely the use of inputs and the results (outputs), the representation of the output set in meta-frontier technology is expressed as Equation 6:

$$P(X) = \{y: (X, y)\ \epsilon\ T\} \quad (6)$$

The transformation of production inputs into outputs in the set of technologies will result in the highest production frontier or limit. If there are factors that affect production, including differences in location characteristics, the achievement of production efficiency in the meta-frontier analysis by region will be different. The lower the efficiency of a group compared to other groups, the lower the efficiency value will be in the meta-frontier. The following equation relates to the distance between the meta frontier and the achievement of producers (sugarcane farmers) in this study.

$$D(X, y) = inf_\theta\ \{\theta > 0; (X)\ \epsilon\ P(X)\} \quad (7)$$

The production distance in Equation 7 (D(X,y)) states that the input set used by the producer will produce maximum output in the observation $((X, y)_i)$ and can be considered technically efficient in the meta-frontier if and only if D(X,y) = 1. This means that, when there is no distance, the ratio of the output achievement to the frontier is the same (D (X, y) is equal to 1).

If K indicates the region, then the technology set in that particular region is as in Equation 8.

$$T^K = \{(X, y): X \geq 0, y \geq 0\} \quad (8)$$

Meanwhile, the technology and related outputs and the production distance per area in question are as in Equations 9 and 10, respectively.

$$P^K(X) = \{y: (X, y)\ \epsilon\ T^K\} \quad (9)$$

$$D^K(X, y) = inf_\theta\ \{\theta > 0; (X)\ \epsilon\ P^K(X)\} \quad (10)$$

Suppose group technical efficiency (GTE) and technical meta efficiency (TME) denote the technical efficiency of the meta frontier, and (meta-TE) denotes technical efficiency in each region (group frontier) or region-TE (Figure 1). In that case, the results of the analysis in the group frontier and meta-frontier will produce a technology gap ratio (TGR) or meta-technology ratio (MTR), respectively. Each is represented in Equation 11.

$$0 < MTR = \frac{MEE}{GEE} \leq 1 \quad (11)$$

If the MTR is close to 1, the technological heterogeneity is lower, and the frontier group will be closer to the meta frontier and vice versa (Chiu, Liou, Wu, & Fang, 2012).

The MTR also provides information about the differences in DMU technology in various groups in the meta frontier. This also means that factors outside of the technical aspects of input and output impact inefficiency. For instance, site-specific characteristics are considered factors that influence inefficiency. Chiu et al. (2012) promoted the method of decomposing DMU inefficiency in meta-frontier analysis. This decomposition of inefficiency in the meta frontier leads to a distinction between managerial inefficiency (GMI) and technological gap inefficiency (TGI). These are formulated as in Equation 12 and 13, respectively:

TGI = GEE (1-MTR) (12)

GMI = (1-GEE) (13)

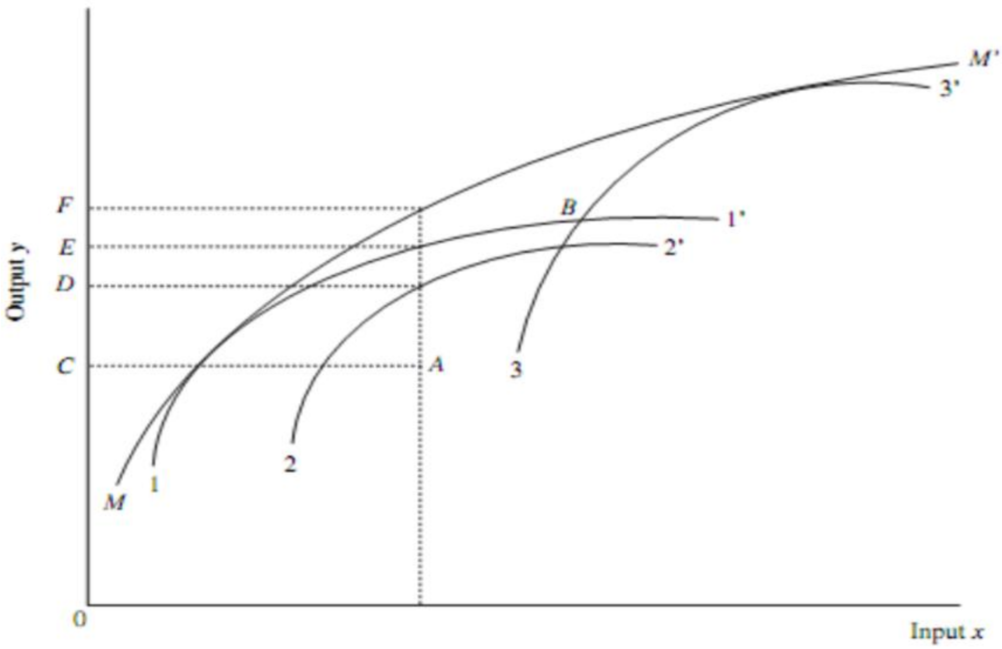

Figure 1. Meta-frontier and group frontier.

Note: * = Final point of *i* curve.
Source: O'Donnell et al. (2008).

TGI provides information related to the level of inefficiency of DMU in its group and efficiency in its meta-frontier. The closer the DMU is to the meta-frontier, the smaller the TGI value. The farther the efficiency of the DMU in the group from the efficiency of the group environmental efficiency (GEE) if higher than the meta-frontier environmental efficiency (MEE), the more inefficient the DMU is.

GMI is a decomposition of managerial-related inefficiency. This is an inefficiency in a specific group frontier, which indicates the ability to achieve lower input productivity than it should be able to achieve in that group. This is caused by a lack of managerial skills or failure in production at the DMU.

Finally, the last measure, the aggregation of managerial failure and technology gap, is referred to as environmental inefficiency (managerial and technology inefficiency = MTI). It is formulated as follows:

$$MTI = TGI+GMI \tag{14}$$

Where MTI is environmental inefficiency, TGI is technology inefficiency, and GMI is managerial inefficiency.

3. RESULTS AND DISCUSSION

3.1. Descriptive Statistics

This section discusses the descriptive statistics of the variables used in this study, including the measurements, mean values and standard deviations. Table 1 shows that the average sugarcane yield produced by farmers was 940 kg per season, with an average total area of 1.06 ha. The inputs used included fertilisers, pesticides, and labour. The four types of fertilisers used by sugarcane farmers were N fertiliser with an average value of 261.6 kg per season, P fertiliser with an average value of 89.9 kg per season, K fertiliser with an average of 89.7 kg per season, and S fertiliser with an average of 131 kg per season. Meanwhile, farmers' average use of pesticides was 10.19 kg per season, and the average labour was 555.49 working days per season.

Table 1. Descriptive statistics.

Variable	Measurement	Mean	Std. dev.
Production	Sugarcane production in quintals per season	940.007	755.858
Area	Total harvested area in hectares	1.066	0.851
N fertiliser	Total N fertiliser input in kg	261.626	189.067
P fertiliser	Total P fertiliser input in kg	89.983	68.964
K fertiliser	Total K fertiliser input in kg	89.780	69.075
S fertiliser	Total S fertiliser input in kg	131.253	97.841
Pesticide	Total pesticide input in litres	10.194	9.449
Labour	Labour in working days	555.497	867.749

3.2. Analysis of Technical Efficiency and Technological, Managerial, and Environmental Gaps Between Sugarcane Production Areas

The technical efficiency in the research areas varies because each location has different input capabilities to produce different outputs. If each research location is analysed separately, the value of technical efficiency cannot be compared regionally because each region has different technologies (Syafrial, Rahman, & Retnoningsih, 2021) and environments, specifically, resources and climatic conditions (Rahman et al., 2022b; Rahman, Huang, Toiba, & Efani, 2022a). The efficiency value does not capture the different technical efficiency levels between regions caused by differences in the production inputs' environment (resources and technology). Therefore, a meta-analysis is needed to compare technical efficiency between regions. Table 2 shows the distribution of the technical efficiency comparison between the research locations against the meta at various efficiency levels. Table 3 shows the average value of regional/group technical efficiency (GTE), technical meta efficiency (TME), and the technology gap ratio (TGR) in the three research locations.

Table 2. Distribution of comparative technical efficiency between research sites.

TE value	Kediri		Malang		Mojokerto	
	Number	(%)	Number	(%)	Number	(%)
1,000	7	38.88	6	33.3	5	27.77
0.836-0.999	11	61.11	1	5.55	6	33.33
0.677-0.835	18	39.13	12	26.08	16	34.78
0.518-0.676	10	20	20	40	20	40
0.359-0.517	2	12.5	11	68.75	3	18.75
Average	0.783		0.654		0.720	
Standard deviation	0.151		0.170		0.155	

Efficiency patterns among sugarcane production centres were analysed using meta-DEA. The results of the analysis involving 148 respondent farmers showed that the average value of the meta-technical efficiency in the three regions was 0.719. This shows that, on average, farmers could reduce their inputs by up to 28.1% without compromising the output. Dlamini, Rugambisa, Masuku, and Belete (2010) also stated that the sugarcane farmers they observed tended to use inputs excessively. Based on the meta-technical efficiency value, 18 individuals or 11.3% of sugarcane farmers were fully efficient, seven (38.88%) from Kediri Regency, six (33.33%) from Malang Regency, and five (27.77%) from Mojokerto Regency. Fully efficient farmers could become peers or trailblazers for other farmers who have not achieved full efficiency. Most of the sugarcane farmers with low technical efficiency scored between 0.359 to 0.999, which indicates a potential to reduce production inputs by up to 43.1%.

Table 3. Averages and standard deviations of meta-technical efficiency, region technical efficiency, and the technology gap ratio.

Location		TE region	TE meta	TGR
Average	Kediri	0.860	0.783	0.954
	Malang	0.767	0.654	0.848
	Mojokerto	0.814	0.720	0.886
Std. dev.	Kediri	0.152	0.151	0.043
	Malang	0.152	0.170	0.086
	Mojokerto	0.153	0.155	0.089

The data presented in Table 3 indicate the average value of meta-technical efficiency (meta-TE) in the three research locations. Kediri Regency shows the highest technical efficiency compared to the other two regions, while Malang Regency shows the lowest technical efficiency. On average, Kediri farmers' technical efficiency is lower than the regional or regional-group level.

This is because the meta-technical efficiency analysis used data from all samples across the regions. Farmers with the best technical efficiency at the meta-level could be peers for other farmers, while efficiency at the group level only shows the best technical efficiency at the group level.

The average technical efficiency of sugarcane farmers in Kediri Regency in terms of meta (MEE) is higher than in the other two regions, at 0.783, with an average regional technical efficiency (GEE) of 0.860. This shows that in the meta between the three research locations, there is still a 21.77% potential to achieve optimal production, and inter-regionally this potential is 14%. The decomposition of the meta-TE in Kediri Regency is indicated by the TGR value, which is the ratio between MEE and GEE. It has an average of 0.945 with a standard deviation of 0.051. With a TGR value close to 1, Kediri Regency has the lowest TGR and meta compared to the other two regions (meta 4.6%).

Sugarcane farming carried out by farmers in Mojokerto Regency shows an EEC value of 0.720 and an MEE of 0.814. This shows that in the meta between the three research locations, there is still potential to achieve optimal production by reducing inputs by 28% and inter-regionally by 18.6%. The average TGR value of sugarcane farming in Mojokerto Regency is 0.886, with a standard deviation of 0.092.

This shows that there is still an inefficiency in sugarcane farming technology as its meta is 0.114 or 11.4%. Meanwhile, the average achievement of meta-technical efficiency of sugarcane farming in Malang Regency was lower than in Kediri and Mojokerto Regencies, at 0.654. The average TGR value of sugarcane farming in Malang Regency against its meta was 0.844, with a standard deviation of 0.051, indicating an inefficiency of sugarcane farming technology of 0.156 or 15.6%.

Table 41. The values of technology gap inefficiency (TGI), gap managerial inefficiency (GMI), and managerial and technology inefficiency (MTI) in the three research locations.

Regency	TGI		GMI		MTI	
	Average	Std. dev.	Average	Std. dev.	Average	Std. dev.
Kediri	0.038	0.037	0.179	0.152	0.217	0.151
Malang	0.113	0.073	0.233	0.152	0.346	0.170
Mojokerto	0.093	0.082	0.186	0.152	0.280	0.154
Total	0.082	0.075	0.200	0.153	0.282	0.166

Further meta-DEA analysis was conducted to examine the environmental inefficiency of each region (Table 4). This was accomplished by decomposing the group technology gap to its meta (TGI) and the managerial gap between regions to its meta (GMI). As such, environmental inefficiency is also referred to as managerial and technology gap inefficiency (MTI). TGI is meta-technical inefficiency stemming from the use of resource technology, while GMI is a meta-technical inefficiency stemming from managerial skills.

The analysis results show that the average technical inefficiency of sugarcane farming between regions is primarily due to managerial skills, which is indicated by the average GMI value of 0.200, which is greater than the average TGI value of 0.082. Ullah et al. (2019) stated that a higher GMI value indicates regional performance variability. This suggests that farmers do not manage resources efficiently and/or they do not benefit from the services offered by sugar factories and the government.

Malang Regency's average TGI value against its meta is higher (0.113) than those of Kediri Regency (0.038) and Mojokerto Regency (0.093). This indicates that the average sugarcane production efficiency in Malang Regency is the lowest compared to the other two regions. A possible explanation is that most Malang Regency sugarcane farmers do not regularly replace sugarcane plants every three to four years for rejuvenation. Unlike farmers in Kediri and Mojokerto, they are also more open to the development of new varieties, so their technological gap is smaller. In sugarcane cultivation, especially with the ratoon system in the third cycle onwards, sugarcane productivity will decrease because the soil starts to harden, the tillers' diameter becomes smaller, and the sugarcane plants are more prone to dying (Balittas, 2015). Also, most sugarcane farmers in Kediri and Mojokerto regencies used agricultural mechanisation in their farming activities, such as ploughs, tillage at first planting, and root breaking in ratoon cultivation. They did so to reduce labour costs and improve time efficiency.

The managerial gap value (GMI) in Malang Regency is also the highest at 0.233. Sugarcane farmers in Malang Regency have lower managerial and decision-making skills regarding input allocation and the rejuvenation of sugarcane plants that are more than four years old. On average, the sugarcane farmers in Malang Regency have the lowest level of formal education. Also, as they have more experience in sugarcane farming compared to the farmers in the other two regencies, they prefer to use familiar technologies that they have used for a long time rather than adopting new technologies with more potential.

4. CONCLUSION

Based on the results of the meta-DEA analysis, the average technical efficiency in the three regions in East Java against its meta (MEE) is 0.719. Kediri Regency shows the highest value at 0.783, Mojokerto Regency scored 0.720, and Malang Regency 0.654. In terms of the average GEE value in each region, Kediri Regency also had the highest value at 0.860, followed by Mojokerto Regency at 0.814 and Malang Regency at 0.767. The TGR value in Kediri Regency was the highest at 0.954, meaning that it had the lowest gap, followed by Mojokerto Regency.

The decomposition results from the meta-DEA analysis show that, on average, the meta-technical inefficiency originates from managerial gaps, as indicated by the fact that the average value of GMI was greater than that of TGI. The managerial gap in this study refers to decision-making on cultivation systems, input allocation, sale systems, and the adoption of the latest technological innovations, such as new varieties and the selection of fertilisers according to land needs. This gap must be minimised to achieve technical efficiency. The largest managerial gap (GMI) was in Malang Regency at 0.233. This shows that the managerial skills of sugarcane farmers in Malang Regency are relatively lower than in the other two regions.

Concerning the three research areas' technical efficiency, as measured using meta-DEA, the average meta-technical efficiency in Malang Regency was the lowest, meaning that production was low. Therefore, farmers need to familiarise themselves with alternative production technologies to minimise production costs and input prices without compromising productivity.

The results of the decomposition of technical efficiency using meta-DEA show that the technology gap between production areas is not too high. However, the technological gap between regions can be corrected if farmers practising ratoon system cultivation rejuvenate their plants to improve plant and soil quality for the upcoming planting season. Rejuvenation of plant quality can be done by rotating the sugarcane plantations with seasonal crops that suit the existing land conditions and using organic matter to regenerate the organic content in the soil.

The managerial gap is the primary source of meta-technical inefficiency between regions. Farmers need to receive continuous professional development, support, and training from sugar factories, as well as the government and related agencies. Most sugarcane farmers lack innovation, initiative, and motivation to achieve high levels of productivity and yield. Incentives could motivate farmers to reduce managerial failure.

Funding: This research is supported by Brawijaya University (Grant number: 2335/UN10.F04/PN/2020).
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.

REFERENCES

Ali, A., & Jan, A. U. (2017). Analysis of technical efficiency of sugarcane crop in Khyber Pakhtunkhwa: A stochastic frontier approach. *Sarhad Journal of Agriculture, 33*(1), 69-79. https://doi.org/10.17582/journal.sja/2017.33.1.69.79

Ambetsa, F. L., Samuel, C. M., & Samuel, N. N. (2020). Technical efficiency and its determinants in sugarcane production among smallholder sugarcane farmers in Malava sub-county, Kenya. *African Journal of Agricultural Research, 15*(3), 351-360. https://doi.org/10.5897/ajar2020.14703

Artikanur, S. D., Widiatmaka, W., Setiawan, Y., & Marimin, M. (2022). Predicting sugar balance as the impact of land-use/land-cover change dynamics in a sugarcane producing Regency in East Java, Indonesia. *Frontiers in Environmental Science, 10*, 76. https://doi.org/10.3389/fenvs.2022.787207

Balittas. (2015). Leaflet for caring for ratoon sugarcane in dry land [internet]. Ministry of Agriculture. Retrieved from: http://balittas.litbang.pertanian.go.id/index.php/id/publikasi/leaflet/alat-dan-mesin/58-berita/1831-teknologi-budidaya-tebu-rawat-ratun-dukung-peningkatan-produktivitas-hablur. [Accessed january 2021].

Carrer, M. J., de Souza Filho, H. M., Vinholis, M. d. M. B., & Mozambani, C. I. (2022). Precision agriculture adoption and technical efficiency: An analysis of sugarcane farms in Brazil. *Technological Forecasting and Social Change, 177*, 121510. https://doi.org/10.1016/j.techfore.2022.121510

Chiu, C.-R., Liou, J.-L., Wu, P.-I., & Fang, C.-L. (2012). Decomposition of the environmental inefficiency of the meta-frontier with undesirable output. *Energy Economics, 34*(5), 1392-1399. https://doi.org/10.1016/j.eneco.2012.06.003

Dlamini, S., Rugambisa, J., Masuku, M., & Belete, A. (2010). Technical efficiency of the small scale sugarcane farmers in Swaziland: A case study of Vuvulane and Big bend farmers. *African Journal of Agricultural Research, 5*(9), 935-940.

Dong, F., Mitchell, P. D., Knuteson, D., Wyman, J., Bussan, A. J., & Conley, S. (2016). Assessing sustainability and improvements in US Midwestern soybean production systems using a PCA–DEA approach. *Renewable Agriculture and Food Systems, 31*(6), 524-539.

Food and Agriculture Organization of The United Nation (FAO). (2018). *Sugarcane crop publication of the world*. Rome: FAO.

Francis, L. A., Samuel, C. M., & Samuel, N. N. (2020). Technical efficiency and its determinants in sugarcane production among smallholder sugarcane farmers in Malava sub-county, Kenya. *African Journal of Agricultural Research, 15*(3), 351-360.

Lin, B.-J., & Chen, W.-H. (2015). Sugarcane bagasse pyrolysis in a carbon dioxide atmosphere with conventional and microwave-assisted heating. *Frontiers in Energy Research, 3*, 4. https://doi.org/10.3389/fenrg.2015.00004

Ngadi, N., & Nagata, J. (2022). Oil palm land use change and rice sustainability in South Sumatra, Indonesia. *Land, 11*(5), 669. https://doi.org/10.3390/land11050669

O'Donnell, C. J., Rao, D. S., & Battese, G. E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empirical Economics, 34*(2), 231-255. https://doi.org/10.1007/s00181-007-0119-4

Organization for Economic of Co-operation and Development (OECD). (2020). OECD-FAO agricutural outlook 2018-2027: Sugar. Retrieved from: https://stats.oecd.org/Index.aspx?DataSetCode=HIGH_AGLINK_2018. [Accessed 05 October 2022].

Rahman, M. S., Andriatmoko, N. D., Saeri, M., Subagio, H., Malik, A., Triastono, J., & Yusuf, Y. (2022b). Climate disasters and subjective well-being among urban and rural residents in Indonesia. *Sustainability, 14*(6), 3383. https://doi.org/10.3390/su14063383

Rahman, M. S., Huang, W.-C., Toiba, H., & Efani, A. (2022a). Does adaptation to climate change promote household food security? Insights from Indonesian fishermen. *International Journal of Sustainable Development & World Ecology*, 1-14.

Ramanathan, R. (2003). *An introduction to data envelopment analysis: A tool for performance measurement*. New Delhi: Sage Publication.

Syafrial, T. H., Rahman, M. S., & Retnoningsih, D. (2021). The effects of improved Cassava variety adoption on farmers' technical efficiency in Indonesia. *Asian Journal of Agriculture and Rural Development, 11*(4), 269-278.

Ullah, A., Silalertruksa, T., Pongpat, P., & Gheewala, S. H. (2019). Efficiency analysis of sugarcane production systems in Thailand using data envelopment analysis. *Journal of Cleaner Production, 238*, 117877. https://doi.org/10.1016/j.jclepro.2019.117877

Widyasari, W. B., Putra, L. K., Ranomahera, M. R. R., & Puspitasari, A. R. (2022). Historical notes, germplasm development, and molecular approaches to support sugarcane breeding program in Indonesia. *Sugar Tech, 24*(1), 30-47. https://doi.org/10.1007/s12355-021-01069-0

Widyawati, W. (2020). Technical efficiency analysis of sugar cane production in East Java. *Habitat, 31*(2), 95-101.

Yusuf, M. T., Jamhari, J., & Irham, I. (2020). Technical efficiency of state-owned sugarcane production in East Java. *Agro Economy, 31*(1), 1-15. https://doi.org/10.22146/ae.50004