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Influence of Soil Properties on Technical Efficiency of Paddy Production: Evidence from Malaysia

(Pengaruh ciri-ciri Tanah Terhadap Kecekapan Teknikal Pengeluaran Padi: Bukti dari Malaysia)

Mohd Khairul Hafifi Maidin
Malaysian Agricultural Research and Development Institute
Roslina Kamaruddin
Universiti Utara Malaysia
Shri Dewi Applanaidu
Universiti Utara Malaysia

ABSTRACT

This paper aims to investigate the effects of soil fertility and cation ratios on the efficiency of paddy production. Data envelopment analysis (DEA) was utilized to estimate efficiency, and Tobit regression was used to identify significant factors of inefficiency. The data was collected from 80 respondents in selected Malaysia's major paddy granaries over January to March 2022. The results indicated that the respondents' mean technical efficiency with respect to the constant returns to scale (CRS) and variable returns to scale (VRS) specifications were 60 per cent and 70 per cent, respectively. The results showed that farmers in the study areas may increase yield by 40% without additional inputs. Meanwhile, the inefficiency effects model indicated that experience, soil pH, and (calcium+magnesium)/ potassium ratios significantly affected inefficiency. Thus, it is suggested that any development programmes for the paddy sector should also consider the soil fertility indicators and cation rations besides the farmer's socio-economic factors.

Keywords: Data envelopment analysis; paddy production; socio-economic; soil properties; Tobit regression

ABSTRAK

Kajian ini bertujuan untuk mengkaji kesan kesuburan tanah dan nisbah kation terhadap kecekapan pengeluaran padi. Data envelopment analysis (DEA) digunakan untuk mengira tahap kecekapan, dan regresi Tobit digunakan untuk mengenal pasti faktor ketidakcekapan yang signifikan. Data dikumpul daripada 80 responden di jelapang padi utama Malaysia yang terpilih bagi tempoh Januari hingga Mac 2022. Keputusan kajian menunjukkan bahawa purata kecekapan teknikal responden bagi spesifikasi constant returns to scale (CRS) dan variable returns to scale (VRS) adalah masing-masing adalah 60 peratus dan 70 peratus. Penemuan ini menunjukkan bahawa sawah padi yang dikaji dapat meningkatkan hasil pengeluaran mereka sebanyak kira-kira 40 peratus tanpa memerlukan input tambahan. Sementara itu, model kesan ketidakcekapan menunjukkan bahawa pengalaman, ph tanah dan nisbah kation bagi (kalsium+magnesium)/kalium mempengaruhi ketidakcekapan dengan signifikan. Oleh itu, dicadangkan bahawa sebarang program pembangunan sektor padi perlu mengambil kira petunjuk kesuburan tanah dan nisbah kation tanah disamping faktor sosio-ekonomi petani.

Kata kunci: Data envelopment analysis; pengeluran padi; sosio-ekonomi; ciri-ciri tanah; regresi tobit
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INTRODUCTION

The paddy sector has been Malaysia's most important component of the agricultural development programme. The government has provided various incentives and subsidies to enhance paddy production (Firdaus et al. 2020; Omar et al. 2019). Despite the government's substantial assistance, especially fertiliser subsidies that have led to an increase in fertiliser applied, the outcome is not truly encouraging. The self-sufficiency level (SSL) fluctuated between 62 and 72 per cent from 2011 to 2021, with a level of 65 per cent in 2021, and inevitably 1.1 million metric tonnes of rice were imported. The low SSL resulted from increased rice demand and low production, which averaged 3.7 tonnes per hectare (MAFI 2021).

According to production theory, the relationship between inputs and outputs is expressed on a single production frontier for a given technology, which indicates that increasing inputs will increase output. In practice, however, the theory is not perfectly adhered to as a result of different firm-specific factors that affect the efficiency of input utilisation. This concept relates to technical efficiency, which has been gaining attention among scholars, particularly in Asian countries, since the pioneering work by Farrell (1957). The fact that technical inefficiency is one of the major causes of the low level of paddy yield. Typically, the source of inefficiency has always been associated with farmer socio-economic factors such as age, gender, education, income, and experience (Coelli et al. 2002; Ghee-Thean et al. 2012; Ghee-Thean & Ismail 2013; Kaka et al. 2016; Mailena et al. 2014; Nguyen et al. 2019; Rahman 2009; Tenaye 2020). These socio-economic factors have been prominent in the literature due to the fact that they influence farmers' practises with respect to the application of various inputs via the availability and quality of their knowledge. Besides socio-economic, biophysical environmental factors also substantially affect farming efficiency (Van Passel et al. 2006).

The biophysical environment influences the input-output interaction in agricultural production, particularly in the paddy sector, which is highly location-dependent (Beza et al. 2017; Van Ittersum et al. 2013). It refers to the environmental characteristics, specifically the chemical and physical production environment, in which crop production takes place. It is suggested that when particular production practises are implemented in different biophysical environments, the yield may vary due to the crop's response to each environment. The chemical and physical environment may affect the potential crop yield or the optimal input level necessary to attain a specific crop yield. It implies that a biophysical environment with superior settings for plant growth has a higher potential yield or requires fewer inputs (high input efficiency) for a given production level than inferior environments (Van Ittersum & Rabbinge 1997).

Two main biophysical environmental factors may influence efficiency: weather and soil properties (Silva et al. 2017). Weather variables such as rainfall and temperature are regarded as truly exogenous, whereas soil properties are considered quasi-fixed in nature (Rahman & Hasan 2008; Sherlund et al. 2002). Thus, soil properties are relatively more relevant to farmers because their components can be improved to some extent through appropriate inputs and sound agricultural practises. Soil differs widely from location to location, determined mainly by its properties. Soil properties affect a plant's ability to absorb water and extract nutrients. The important components of soil properties are cation exchange capacity (CEC) and pH, generally known as soil fertility indicators. These properties regulate chemical activities in the soil system (Othman et al. 2012). Aside from soil pH and CEC, soil cation ratios of potassium (K), magnesium (Mg), and calcium (Ca) may also influence farming efficiency (Kasno et al. 2021; Nguyen et al. 2017).

Many frontier efficiency studies (Mareth et al. 2019; Rahim et al. 2020) overlook the soil properties factors that are extensively emphasised in agronomy and production ecology studies of crop growth models. Thus, the paper is intended to assess the influence of soil fertility indicators and cation ratios on the technical efficiency of paddy production, in addition to the typical determinants of socio-economic factors. This approach facilitates a thorough understanding of the factors contributing to technical inefficiency. The study examines the effects of soil fertility indicators and cation ratios on technical efficiency for several reasons. Soil pH, CEC, and cation ratios are regarded as important components of soil. They determine the plant's access to soil nutrients. Furthermore, they exert an influence on the soil holding capacity of water and nutrients (Fernández & Hoeft 2009). Hence, these soil components greatly influence the efficiency of input utilisation. The study employed DEA to estimate efficiency using CRS and VRS specifications and Tobit regression to identify inefficiency determinants. The analyses revealed that the mean technical efficiency was 60%. Several socioeconomic and soil properties components have significant effects on inefficiency.

The empirical findings in this study, which primarily concern the components of soil properties, are expected to contribute to the body of knowledge since soil cation ratios, in particular, are novel variables that have been overlooked in previous efficiency studies. Knowledge of the effects of soil fertility components and soil cation ratios on technical efficiency is crucial for a better understanding of the plant's response to supplied input. Among the technical efficiency studies that have addressed soil properties are Mishra et al. (2018), Nowak et al. (2015) and Tenaye (2020)such as Ethiopia. This study assesses the level and determinants of technical efficiency of smallholder farmers using the true fixed effects (TFE However, these studies failed to account for the influence of soil cation ratios on technical efficiency. In addition, this paper is anticipated to make a significant contribution towards enhancing resource-use efficiency in agriculture. This research provides valuable insights for farmers and policymakers by identifying the key factors that influence efficiency. This knowledge will enable the development of effective strategies to enhance efficiency and ultimately lead to increased paddy production.

LITERATURE REVIEW

Given a certain level of technology, some farms can produce efficiently, whereas others are relatively inefficient. Farms' relative efficiency in the industry has become a topic of interest in agricultural economics, as reducing the gap between sub-optimal and the most efficient farms on the frontier would contribute to productivity growth (Coelli et al. 2005). Several factors may cause this divergence, but the primary explanatory variables that influence farm efficiency are farmers' socio-economic factors. Farmer's socio-economic factors influence farmers' decisions on the inputs and agricultural practises used, which contribute to disparities in technical efficiency. The farmers' socio-economic factors are frequently associated with variables such as age, education, farm size, non-farm income, and experience.

Age, farm size and non-farm income can have both positive and negative effects on a farmer's technical efficiency. Age may have a positive relationship due to the fact that older farmers have a wealth of experience and are thus able to deal with various production settings efficiently. In contrast, older farmers may have a tendency to be more conservative and less willing to change or accept new technology, thereby retaining traditional production techniques and becoming less efficient (Sapkota & Joshi 2021; Tipi et al. 2009). Meanwhile, the argument for a positive relationship between farm size and technical efficiency is that larger farms offer greater flexibility in terms of resource utilisation. On the other hand, the negative effect of farm size on technical efficiency is due to the fact that larger firms would have less timeliness in performing particular field operations (Haryanto et al. 2016; Nan et al. 2022; Nowak et al. 2015; Tenaye 2020). Non-farm income has a positive effect on technical efficiency if the additional income earned from non-farm activities enables farmers to hire or purchase productive farm inputs (Andaregie & Astatkie 2020; Lagiso et al. 2020). Meanwhile, having non-farm income could reduce labour force and time spent on the farm, resulting in less attention paid to quality farming operation and management, which may harm the technical efficiency (Lagiso et al. 2020; Tipi et al. 2009).

The subsequent variables, namely education and experience, are frequently observed and identified as factors that have positive effects on the technical efficiency of farmers. Education is widely known as the most effective means of acquiring knowledge and enhancing farmers' capacity to improve their skills (Ali et al. 2022; Ogunmodede & Awotide 2020). Farmers with a higher level of education have better managerial skills that enable them to use information effectively for timely decisions regarding the available production alternatives. Consequently, they can efficiently utilize their production inputs (Khan & Ali 2013; Solís et al. 2009; Tenaye 2020). Meanwhile, experienced farmers have a wealth of practical knowledge and skills that can be applied to selecting the most suitable alternative farm technologies over time (Gbigbi 2021; Sapkota & Joshi 2021). The main focus of this study is to examine the impact of soil properties on technical efficiency. Therefore, the study merely incorporated key socio-economic variables, namely education and experience, which revealed as important determinants with a discernible influence on technical efficiency {Formatting Citation}c.

Agriculture production, mainly paddy, is a complicated process. Production efficiency is influenced not only by farmers' socio-economic factors but also by biophysical environment factors, particularly soil properties. The soil properties vary from field to field, affecting resource utilisation efficiency and crop yield (Rabbinge 1993; Van Ittersum & Rabbinge 1997; Yanai et al. 2001). The key components of soil properties include soil Ph, CEC, and soil cation ratios of K, Mg, and Ca that may affect farming efficiency. The production frontier study has been expanded in a number of ways in which researchers consider the effect of various factors on estimating efficiency or examining factors influencing inefficiency. Paddy crops are one of the most important subjects that take place globally (Bravo-Ureta et al. 2007). Similar research has also been conducted in Malaysia, where rice serves as a staple food. The mean estimated technical efficiency of paddy production in multiple studies conducted across various Malaysian paddy granaries varied between 51.7 per cent and 90.1 per cent (Ghee-Thean & Ismail 2013; Rahim et al. 2020; Zaibidi et al. 2018). Assessing the technical efficiency is an essential procedure for evaluating the performance of paddy production.

On top of that, the identification of factors that contribute to technical inefficiency is a pivotal component of this research endeavour. A number of studies (Ali et al. 2022; Perera et al. 2021) have demonstrated the relationship between technical efficiency and socio-economic characteristics. Education and experience are recognized as socio-economic factors that exert significant effects on the efficiency of Malaysian farmers, thereby playing a crucial role in improving their productivity (Ghee-Thean et al. 2012; Ghee-Thean & Ismail 2013; Kaka et al. 2016; Mailena et al. 2014).

Aside from socio-economic factors, it is worth mentioning that there have been few research considering soil properties in inefficiency effects functions, one of which was conducted by Mishra et al. (2018). The authors investigated the impact of various factors, including soil fertility variables, on the inefficiency of paddy farms. The soil fertility data was based on the farmers' perceptions of their plots. Average and high soil fertility was found to be negatively associated with inefficiency. The findings indicate that farmers with more fertile soil perform significantly better than those with less fertile soil. Similarly, Shi-chao et al. (2016) discovered that land quality negatively affected technical inefficiency. The land quality index was measured as a weighted average of several physical and chemical soil properties of paddy fields. The factors include slope, elevation, the presence of land terracing, irrigation, effective soil depth, surface soil texture, soil organic matter, and soil pH. Similar conclusions were drawn by Nowak et al. (2015) on the influence of soil quality on the technical efficiency of European agriculture, as well as by Tenaye (2020) on the influence of land quality on the technical efficiency of Ethiopian agriculture. However, the effect of individual soil fertility components, including pH and CEC, as well as soil cation ratios of K, Ca, and Mg, on technical inefficiency is relatively unknown, even though these elements influence the absorption of nutrients by plants. Hence, this paper aims to estimate the technical efficiency level and investigate the effect of soil fertility indicators and cation ratios on inefficiency.

RESEARCH METHODOLOGY

The primary data was collected from January to March 2022 through face-to-face interviews with 80 respondents in the Kemubu Agricultural Development Authority (KADA) and Integrated Agriculture Development Area (IADA) Barat Laut Selangor granaries. This study's total sample size is based on the widely accepted Data Envelopment Analysis (DEA) convention that requires the number of respondents to exceed three times the sum of inputs and outputs, 80 > 3 (4+1) (Raab & Lichty 2002). The sample size for each granary is 38 for KADA and 42 for IADA BLS. These granaries are among Malaysia's major paddy producers. KADA is located on the east coast of the Malaysian peninsula, while IADA BLS is located on the west. Respondents were randomly selected from the sub-units of granaries that involved in soil profiling. Meanwhile, a set of structured questionnaires were used as a data collection tool. The interviews addressed several aspects of socio-economic factors, input usage, paddy yield, and agricultural practises. In the meantime, secondary data was extracted from reports published by various agencies, including the Department of Agriculture (DOA), the Ministry of Agriculture and Food Industries (MAFI), and both granaries.

The study of technical efficiency centres primarily on two methods: stochastic frontier analysis (SFA) and data envelope analysis (DEA). The study employed the DEA method due to its advantages, which allow for a simple computation of the production frontier without requiring any distributional assumptions regarding efficiency and without the need to know the algebraic form of the relationship between inputs and outputs (Coelli et al., 2005; Hjalmarsson et al. 1996). The DEA approach a two-stage analysis in which DEA was used to estimate the efficiency level in the first step, and two-limit Tobit regression was used to investigate the significant determinants of inefficiency in the second step. The combination of DEA and Tobit regression serves as a complementary approach for estimating the level of technical efficiency and its underlying factors. The Tobit regression can account for truncated data corresponding to an inefficiency score between zero and one obtained in the DEA estimates (Coelli et al. 2005). It is the more predominant method, as many researchers adopted it in the second step (Coelli et al. 2002; Ghee-Thean & Ismail 2013; Linn & Maenhout 2019; McDonald 2009; Nowak et al. 2015; Sun & Li 2021; Thiam et al. 2001; Tipi et al. 2009).

DEA is a mathematical programming method. It is widely used in assessing technical efficiency in various production processes because it is simple and flexible since it does not require functional form specification (Jalilov et al. 2019). In addition, the DEA technique permits the use of constant returns to scale (CRS) and variable returns to scale (VRS) specifications. In the meantime, the study adopted an output orientation since it is consistent with the study's objective, which is to increase paddy production by improving farmers' technical efficiency. The CRS DEA specification asserts that all paddy fields operate at optimal scale. In the output-oriented CRS specification, the estimation of technical efficiency is expressed as follows:

$$\begin{aligned} &\max_{\theta,\lambda}\theta, \\ &\text{st} \quad -\theta y_i + Y\lambda \geq 0, \\ &\qquad x_i - X\lambda \geq 0, \\ &\qquad \lambda \geq 0, \end{aligned} \tag{1}$$

Nevertheless, if the decision-making unit (DMU) is not operating at its optimal scale, it could result in scale efficiency (SE). Financial constraints and imperfect competition are among the factors that can prevent a company from operating at an optimal scale (Coelli et al. 2005). Alternatively, the VRS specification precludes these SE effects (Banker et al. 1984). VRS specifications can be easily generated through altering CRS linear programming by inserting the convexity constraint: $N1'\lambda = 1$ to equation 1, resulting in:

$$\begin{aligned} &\max_{\theta,\lambda}\theta, \\ &\text{st} \quad -\theta y_i + Y\lambda \geq 0, \\ &\qquad x_i - X\lambda \geq 0, \\ &\qquad N1'\lambda = 1 \\ &\qquad \lambda \geq 0, \end{aligned} \tag{2}$$

Where

θ	= the efficiency score for the ith paddy farmer;
y_i	= yield of ith paddy farmer;
Y	= yield data set for all paddy farmers;
x_i	= quantity input used by the ith paddy farmer;
X	= input data for all paddy farmers;
λ	= N×1 vector of constants; and
N1	= N×1 vector of ones.

Adding the convexity constraint $N1'\lambda = 1$ permits the comparison of an inefficient farmer to other farmers of comparable size. This approach creates a convex hull instead of the conical hull of the CRS, resulting in efficiency scores equal to or greater than the CRS specification (Coelli et al. 2005).

The efficiency scores of paddy farms were estimated using both CRS and VRS specifications. Analysing both

CRS and VRS specifications allows for scale efficiencies (SE) estimations. If there is a difference in the CRS and VRS TE scores for a particular firm, then this indicates that the firm has scale inefficiency. According to Coelli et al. (2005), the farmer may be technically efficient yet working at a suboptimal scale, which may be too small or too large. Farmers can increase their efficiency by changing the scale of their operations. Measuring both CRS and VRS provides more conclusive results, which allow to distinguish between scale inefficiency and „pure" technical inefficiency (ie. VRS TE). Given its advantages, a number of studies have adopted both CRS and VRS specification, including Li et al. (2018), Linn & Maenhout (2019) and Nguyen et al. (2018). The model deals with similar dependent and independent variables with four inputs and one output. The following are the variables:

y = paddy yield
$\chi 1$ = land
$\chi 2$ = seed
$\chi 3$ = fertilizer
$\chi 4$ = pesticide

The study employed four main inputs of paddy production: land, seeds, fertiliser, and pesticide. The dependent variable in this study was the paddy yield. The land was measured in hectares, seeds, and fertiliser in kilogrammes, pesticides in Malaysian Ringgit (RM), and paddy yield in tonnes.

It is important to acknowledge that the farmer may be technically efficient yet working at a suboptimal scale, which may be too small or too large. Farmers can increase their efficiency by changing the scale of their operations. Scale efficiencies (SE) can be estimated by analysing the CRS and VRS specifications. The SE may be determined using the following formula (Coelli et al. 2005):

$$SE = \frac{TE_{CRS}}{TE_{VRS}} \tag{3}$$

In the second stage, soil properties and socio-economic factors were analysed using two-limit Tobit regression to determine the significant determinants of inefficiency. Though the OLS is also widely used, the Tobit regression is more appropriate from a methodological standpoint because it accounts for truncated data (Bravo-Ureta et al. 2007; Coelli et al. 2005). Tobit regression is a valuable technique because it can accommodate the distribution characteristics of technical efficiency scores bounded by zero and one (Coelli et al. 2002; Thiam et al. 2001; Tipi et al. 2009). As stated by McDonald (2009), a general Tobit regression model can be defined as follows:

$$\begin{aligned} & y_i^* = x_i\beta + \varepsilon_i \\ & y_i = 1 \text{ if } y_i^* \geq 1 \\ & y_i = y_i^* \text{ if } 0 < y_i^* < 1 \\ & y_i = 0 \text{ if } y_i^* \leq 0 \end{aligned} \tag{4}$$

Where
y_i^* = a latent variable;
x_i = independent variables;
β = estimated parameter coefficients;
$\varepsilon_i \sim N(0, \sigma^2)$ = the error term; and
y_i = the DEA score.

The inefficiency effects model encompassed the analysis of six variables. These variables consisted of two socio-economic factors, namely farmers' experience and education, as well as four soil properties factors, specifically soil pH, CEC, Ca:Mg ratio, and (Ca+Mg)/K ratio. The study classified the independent variables of Ca:Mg and (Ca+Mg)/K into three categories based on the literature's suggested cation ratio and data suitability. In terms of socio-economic factors, the study employed length of involvement in paddy farming and length of formal education. It was anticipated that both socioeconomic factors would have a negative relationship with inefficiency, with an increase in education and experience decreasing inefficiency (Ali et al., 2022; Andaregie & Astatkie, 2020). Moreover, it was expected that soils with a pH of 5.5 or higher would have a lower inefficiency than those with a pH below 5.5 (Van Dijk et al., 2017; Husson, 2013). CEC, another indicator of soil fertility, was predicted to have a negative relationship with inefficiency; increasing CEC would reduce inefficiency. This association was made based on research by Zou et al. (2017), who found that CEC had a positive relationship with paddy productivity. For the cation ratio variables, Ca:Mg of the first group, with a value less than two, was predicted to have a higher inefficiency than those of the second and third groups. The justification for this predicted relationship was based on arguments from the studies of Nguyen et al. (2016), and Phillips (2015), which suggested that plant was productive when the Ca:Mg ratio greater than two. Lastly, it was expected that ratios of (Ca+Mg)/k less than 15 would have a lower inefficiency than ratios greater than 15. This ratio was determined based on the argument of Hodges (2010) and Phillips (2015) regarding the optimal ratio of Ca, Mg, and K in crop production, where it appeared that a ratio greater than 15 was detrimental to plant productivity.

RESULTS AND DISCUSSIONS

Four inputs and one output were included in the analysis for estimating technical efficiency. The variables exhibited a mean value of 3.59 hectares for land size, 635.01 kilogrammes for seeds, 779.32 kilogrammes for fertiliser, and MYR 2420.94 for pesticides. In the meantime, given the farmers' average acreage 3.59 hectares, the farmers' mean total paddy yield was 14.84 tonnes. The details, including the unit, mean, standard deviation, minimum and maximum quantity or value for each variable, are depicted in Table 1.

TABLE 1. Summary of inputs and output

Variable	Unit	Mean	Std. dev.	Min	Max
Output					
Total Yield	Tonne	14.84	14.52	1.4	62.5
Inputs					
Land	Ha	3.59	2.93	0.4	12.14
Seeds	Kg	635.01	598.89	50	2400
Fertiliser	Kg	779.32	684.03	97	2884.5
Pesticide	Value (MYR)	2420.94	2228.87	247.5	9699

The result of farmers‘ technical efficiency was categorised into seven groups. The largest percentage of farmers fell to the group with an efficiency of less than 50 per cent, followed by farmers with efficiencies ranging from 60 - 69 per cent for CRS (18.8 per cent) and 70 - 79 per cent for VRS (18.8 per cent). The mean technical efficiency of farmers for the CRS and VRS specifications was 60 per cent and 70 per cent, respectively. The findings showed that farmers may potentially raise their crop yield by almost 40% without additional inputs. Paddy farmers with lower levels of efficiency produce less output relative to their efficient counterparts, given utilising similar quantities of inputs. The implications of these scenarios would result in the wastage of resources and a decrease in national paddy production and productivity.

Furthermore, the result indicated a slight difference between CRS and VRS, implying that the scale effect had less influence on inefficiency. It is reflected in the high scale efficiency, which was 86 per cent, indicating that most respondents operate at or near optimal production scale. Accordingly, the main sources of inefficiency may be attributed to farmers‘ socio-economic and soil properties. In the meantime, the variation in efficiency level across samples, as measured by standard deviation, was slightly greater for the VRS specification with 0.24 per cent than for the CRS specification with 0.21 per cent.

The distribution of the technical efficiency for the CRS and VRS specifications is depicted in Table 2.

TABLE 2. Distribution of technical efficiency for CRS, VRS and scale

Technical efficiency distribution	CRS TE		VRS TE		Scale	
	Frequency	Per cent	Frequency	Per cent	Frequency	Per cent
< 0.50	25	31.3	20	25.0	0	0
0.50 - 0.59	13	16.3	8	10.0	0	0
0.60 - 0.69	15	18.8	7	8.8	3	3.8
0.70 - 0.79	14	17.5	15	18.8	19	23.8
0.80 - 0.89	7	8.8	8	10.0	29	36.3
0.90 - 0.99	1	1.3	10	12.5	19	23.8
1.00	5	6.3	12	15.0	10	12.5
Mean efficiency	0.60		0.70		0.86	
Standard deviation	0.21		0.24		0.09	

In the inefficiency effects model, the two-limit Tobit model was used to regress six socio-economic and soil properties variables against the efficiency score obtained from the DEA analysis. The average value for each variable was found to be 18.33 years of experience, 9.82 years of formal education, 4.99 for pH, 27 cmol(+)/kg for CEC, 2.69 for Ca:Mg ratio and 13.87 for (Ca+Mg)/K ratio. The details relating to these variables is presented in Table 3. Moreover, based on the classification of pH, Ca:Mg and (Ca+Mg)/K ratios, as shown in Table 4, it was observed that more than 80% of the farmers‘ plots had pH levels below 5.5, while only 17.5% of the plots had a pH level of 5.5 or higher. It‘s worth noting that none of the farmer‘s plots had a pH level above 6, so the study only divided the model into two groups, those with pH levels below 5.5 and above 5.5.

Meanwhile, more than 40 per cent of the farmers‘ plots fell into the first Ca:Mg ratio group, below 2. The percentage was slightly lower for the second and third groups, with 32.5 per cent and 21.25 per cent, respectively. Conversely, the (Ca+Mg)/K ratio was evenly distributed throughout all three groups, with the second group somewhat higher at 36.25 per cent compared to the first and third groups at 32.5 per cent and 31.25 per cent, respectively.

TABLE 3. Summary of socio-economic and soil properties factors

Variable	Unit	Mean	Std. dev.	Min	Max
Experience	year	18.33	13.25	1	60
Education	year	9.82	2.75	0	17
PH	pH level	4.99	0.46	4	5.94
CEC	cmol(+)/kg	27	9.27	11.9	85.1
Ca:Mg	ratio	2.69	1.59	0.71	5.94
(Ca+Mg)/K	ratio	13.87	5.76	0.66	26.04

TABLE 4. Distribution of the cation ratios of the farmers‘ plot

	pH		Ca:Mg		(Ca+Mg)/K	
Classification	Level	Per cent	Ratio	Per cent	Ratio	Per cent
1	0 – 5.4	82.5	0 – 1.9	46.25	0 – 10.9	32.5
2	5.5 - max	17.5	2 – 3.9	32.5	11 – 14.9	36.25
3	-	-	4 – max	21.25	15 – max	31.25

The results of the inefficiency effects model revealed that a few socio-economic and soil properties variables, such as experience, soil pH, and (Ca+Mg)/K ratios, significantly affected efficiency, as shown in Table 5. The experience variable has a negative sign, indicating that the farmer‘s experience contributed to the low inefficiency. Experienced farmers have likely dealt with a variety of production environments and possess the requisite know-how that comes with time spent farming to adapt to various environment settings (Ali et al. 2022; Vortia et al. 2021; Wongnaa & Awunyo-Vitor 2018). It enables them to operate the farms in a proper way, wisely allocating resources at the optimal timing with the appropriate inputs. It accords with the findings of Tenaye (2020), Linn & Maenhout (2019), and Kaka et al. (2016), which demonstrated a similar relationship between experience and inefficiency. However, another socio-economic variable, education, appeared to be non-significant to the farmers‘ inefficiency, similar to the findings of Ghee-Thean & Ismail (2013), Ghee-Thean et al. (2012), and Coelli et al. (2002).

As for soil properties, a soil pH of 5.5 and above appeared negatively significant to inefficiency. It implies that plots with pH levels of 5.5 and above will command a lower inefficiency than those with below 5.5. The majority of the plots had acidic soil problems, with more than 80% of the areas having low pH levels, with the highest being 5.94. It is in line with Sung et al. (2017), who found that Malaysian soil is dominated by the ultisol and oxisol orders, which are acidic in nature and have a pH range between 4 and 5. Thus, this finding is crucial because many areas have low soil pH, and increasing soil pH to a level of 5.5 or higher is required to improve paddy production efficiency.

Another soil fertility variable, CEC, was insignificant to inefficiency. Similarly, the Ca:Mg ratio appeared insignificant across all three groups. There was a paucity of evidence associating the Ca:Mg ratio with inefficiency. Nonetheless, (Ca+Mg)/K exhibited a significant effect on inefficiency. The (Ca+Mg)/K ratio in the third group, higher than 15, would command a higher inefficiency than the first and second groups. However, there was a non-significant difference between the first and second groups. This implies that a higher Ca+Mg to K ratio above than 15 may inhibit the absorption of certain nutrients, including K, hence indirectly reducing the input usage efficiency, as highlighted by Biswas et al. (2019), Dobermann et al. (1996) and Nguyen et al. (2017). According to the distribution of (Ca+Mg)/K in the studied areas, more than 30 percent of farmer plots had an inappropriate ratio of greater than 15. Thus, maintaining the optimal ratio of (Ca+Mg)/K has a significant impact on farming efficiency and paddy production.

Several soil properties have been shown to significantly impact the efficiency of paddy farming. Therefore, enhancing these soil variables under optimal conditions is crucial, as it directly affects the ability of plants to absorb water and extract specific nutrients. The soil's pH plays a significant role in influencing chemical reactions and regulating the chemical forms of specific minerals. It may result in an excess or shortage of particular soil nutrients (Fernández & Hoeft 2009). Meanwhile, K, Mg, and Ca highly interfere with each other in the process of absorption by a plant, and an excess of one nutrient may cause a deficiency of other nutrients (Ding et al. 2006; Nguyen et al. 2017). Plants require ideal soil conditions that promotes optimal plant growth and enables them to reach their potential attainable paddy yield.

In general, variations in agricultural practises resulting from socio-economic differences between farmers may influence soil properties. However, this will not occur in the short term because the time coefficient of agricultural practises is way smaller than that of the production environment (Van Ittersum & Rabbinge 1997). In addition, most farmers were unconcerned with the ideal soil properties for optimal plant growth due to a lack of understanding of soil status and awareness of proper soil management.

TABLE 5. Tobit regression of technical inefficiency effects model

Inefficiency	Coefficient	Std. err.	p-value
Experience	-0.005**	0.002	0.036
Education	-0.014	0.011	0.216
CEC	0.001	0.003	0.777
PH			
5.5 - max	-0.212**	0.084	0.014
Ca:Mg			
2 – 3.9	-0.092	0.074	0.220
4 – max	0.020	0.084	0.810
(Ca+Mg)/K			
11 – 14.9	0.071	0.075	0.349
15 – max	0.238 ***	0.081	0.005

*, ** and *** indicate significance at the 10%, 5% and 1% level

CONCLUSIONS

The influence of soil properties on technical efficiency was frequently overlooked in the previous study. Thus, this paper examined the effect of soil fertility indicators and cation rations on the technical inefficiency of paddy production in order to provide a thorough understanding of the underlying causes of inefficiency. The mean technical efficiency measured by the CRS and VRS specifications was 60% and 70% respectively. The results indicate a prospect of improving paddy yield by approximately 40 per cent with the existing technological level and without additional inputs. It is suggested that relevant authorities should pay more attention to inefficient farmers by closely monitoring and guiding them to improve their efficiency. The guidance covers all significant aspects pertaining to both socio-economic and soil characteristics factors.

Several socio-economic and soil properties factors significantly affect the inefficiency, including farmer's experience, soil pH and (Ca+Mg)/K ratios. Farmer's experience was found to contribute to the low inefficiency. It is undeniably important for efficiency, as experienced farmers have more exposure and tacit knowledge than less-experienced farmers. Letting young farmers learn through their own experience is the norm, but gaining the necessary knowledge will take a long time. As the findings indicate that experience significantly impacts productivity, it is highly encouraged that sharing sessions or mentoring programmes between experienced and new farmers be promoted, as this would expedite the learning process.

Meanwhile, soil pH levels below 5.5 reduce efficiency; thus, a lower pH level is a major concern that must be addressed. A considerable portion of the farmer's plot was acidic, with a mean pH of 4.99 and more than 80% with a pH less than 5.5, and the maximum pH was 5.94. The study suggests that concrete measures, particularly regular soil liming and soil testing, are required to ensure the soil is in ideal pH conditions greater than 5.5.

Lastly, the study's findings revealed that a higher Ca+Mg/K ratio above 15 lowers efficiency. It is recommended that a relevant authority should monitor the Ca+Mg/K ratio, as the interplay between these elements significantly affects technical inefficiency. Ensuring adequate levels of K as a primary macronutrient and maintaining a desirable ratio with Ca and Mg below 15 is of utmost importance.

In general, farmers' efficiency is influenced not just by socio-economic factors but also by soil properties. It is recommended that any development programs for the paddy sector should take into account not only the socio-economic factors of farmers but also the soil fertility indicators and cation ratios. Given its importance to the efficiency of farmers, it is proposed that soil properties, in particular pH and cation balance, be constantly monitored and corrective measures made to ensure that all paddy plots are in optimal conditions. In addition, farmers particularly for young farmers should be educated on soil properties to at least understand the soil status of their plots, the ideal ratios of the main soil parameters, and the basic techniques for improving soil conditions. The intervention holds promise for enhancing national paddy production, as optimising key soil components enables plants to utilize provided inputs effectively, leading to improved paddy productivity.

Particular components of soil properties have a significant impact on the efficiency of paddy farming. This important finding provides stakeholders with valuable insights into the required measures that need to be implemented in order to enhance efficiency and potentially increase paddy production. However, it is important to note that the overall performance of paddy production efficiency may also be influenced by other soil conditions, such as soil physical condition (including soil elevation) and water management practises (such as irrigation systems), which are not addressed in the scope of this research paper. Therefore, it is advisable for future studies to examine the influence of soil physical conditions and water management practises on the efficiency of paddy cultivation.

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Mohd Khairul Hafifi Maidin*
Strategic Planning & Innovation Management Centre
Malaysian Agricultural Research and Development Institute
43400 Serdang, Selangor, MALAYSIA.
E-mail: khairulhafifi@mardi.gov.my

Roslina Kamaruddin
School of Economics, Finance and Banking
Universiti Utara Malaysia
06010 UUM Sintok, Kedah, MALAYSIA.
E-mail: roslina_k@uum.edu.my

Shri Dewi Applanaidu
School of Economics, Finance and Banking
Universiti Utara Malaysia
06010 UUM Sintok, Kedah, MALAYSIA.
E-mail: dewi@uum.edu.my

* Corresponding author