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Article

Improving Irrigation Water Use Efficiency of Robusta Coffee (*Coffea canephora*) Production in Lam Dong Province, Vietnam

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Abstract: Recent prolonged dry periods and lack of irrigation water have severely affected the productivity of coffee farms' in the Central Highlands of Vietnam. This paper analyzes the efficiency of irrigation water use for Robusta coffee (*Coffea canephora*) in Lam Dong province, Highlands, Vietnam. A Cobb-Douglas production function was used to determine coffee productivity's response to the application of irrigation water and other production factors using data collected from 194 farmers while the Technical Efficiency (TE) and Irrigation Water Use Efficiency (IWUE) were analyzed using a Data Envelopment Analysis (DEA) model. The correlation of different factors to IWUE was determined using the Tobit model. The production function analysis using Cobb-Douglas shows that the volume of irrigation water, amount of working capital, labor and farm size significantly influence coffee productivity. It also shows that indigenous farmers are more efficient in utilizing irrigation water than the (mostly Kinh) migrant farmers. The Tobit result, on the other hand, indicates that farmers' experience, education level, distance of farm to water source, security of access to water source, extension contact and credit access significantly affect IWUE. The study findings further suggest that mitigating water shortages in coffee farms require sub-regional and national policy support such as better access to credit and extension services, training, land management and household-level effort to improve farming practices, through the application of appropriate technologies and traditional knowledge.

Keywords: Data Envelopment Analysis; efficiency; irrigation water; Robusta coffee; Vietnam

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1. Introduction

Vietnam and Brazil both share the status of being the world's top producers of Robusta coffee (*Coffea canephora*). Coffee is the second highest export-earning crop of Vietnam that supports the livelihood of over 2 million people in rural areas. In 2018, the value of coffee exported was USD 3.54 billion, accounting for 2.5% of national GDP [1]. The coffee industry also plays a very important role of reducing the poverty incidence in the rural areas of Vietnam [2, 3]. The majority of Vietnam's coffee area is concentrated in the Central Highland [4] with 95% of Robusta coffee planted mainly in the provinces of Dak Lak, Gia Lai, Kon Tum and Lam Dong [5,6].

Robusta coffee is profitable when produced intensively utilizing large amounts of fertilizer, water and labor [4]. However, in the Central Highlands of Vietnam, irrigation water is scarce given the competing demands from other agriculture crops, industry and households, as well as the poor

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irrigation management [1,7]. About 56.6 to 95% of water used to irrigate the coffee farms come from groundwater reserves [4,5], much of which is wasted due to over-irrigation by farmers [1, 8-10]. In 2016, the amount of water in the West Highland and South-East region was not sufficient to irrigate about 470 hectares of coffee farms during the dry season [11]. According to the West Highlands Agriculture and Forestry Science Institute (2016), only about 72% of the regions' households had sufficient supply of water to irrigate their coffee farms.

To address these irrigation water scarcity [10,12-13], national programs, such as the Vietnam-Netherlands Partnership on Water for Food & Ecosystems (WFE) and the German-Vietnam project—Integrated Water Resources Management Vietnam, Planning and Decision Support, have been implemented to promote sustainable use of water resources for agricultural sector [14]. Through these programs, the levels of water supply and demand and consequent water surpluses or deficits are determined [15]. However, such studies have not been able to provide information on efficiency of water use nor its key determinants. A better understanding of the efficiency of irrigation water use for coffee production is important to improve the productivity of coffee farms as well as efficient water resources management.

There are various indicators of efficiency of irrigation water use. The three most popular indicators used by global scholars are: (i) the ratio of water used to the amount of water supplied for a crop [16-19]; (ii) a ratio of crop productivity to the amount of water applied for a crop [20-22]; and (iii) economic return per unit of water used for crop production [18]. Among the internationally recognized mathematical models used for determining technical efficiency and irrigation water efficiency are the non-radial Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) [18]. A non-radial DEA method allows us to reduce in different proportions the various inputs used in the production system [18]. Non-radial efficiency approach has a higher discriminating power in estimating the efficiencies of production units. These types of models are more effective for evaluating economic and environmental performance. In recent years, therefore, a number of studies [23-29] have used the non-radial DEA approach. While this approach serves as an important tool for identifying economic efficiency in the public sector (gas, water, heat, hospitals, etc.) and the private sector (banking, post, insurance, farms, etc.) [30], it is also widely applied in agricultural sectors [31].

This non-radial DEA measurement technique has never been used to determine the technical efficiency of irrigation water use for Robusta coffee production in Vietnam. The paper aims to calculate Technical Efficiency (TE) and proposes a measure for Irrigation Water Use Efficiency (IWUE) that towards to sustainable water use for Robusta coffee production in Lam Dong province, Central Highlands Vietnam [32].

The paper is organized as follows: Section 2 provides information on the research area, data source and sampling, data analysis and empirical model specification. The main findings are indicated in Section 3 while the discussions and conclusions are presented in the Sections 4 and 5.

2. Materials and methods

2.1. Study area

Lam Dong province is located in the southern part of Central Highlands Vietnam. The province has several fertile high plateaus with a large percentage of the province being forested [15]. In 2017, the total cultivated area in the province was 279,000 ha, of which 160,000 ha was planted with coffee. Since 2010, the total area of coffee plantations has increased by 12,000 ha. By 2020, the total area planted with coffee over 20 years of age, will be 60,000 ha [33].

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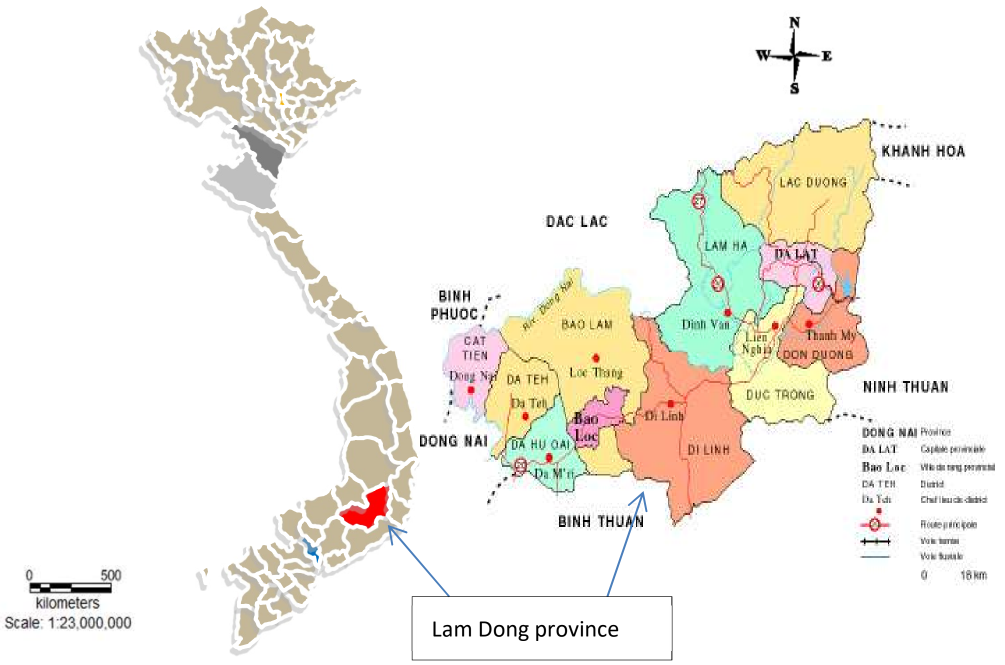

Figure 1. The location of selected Lam Dong province in the Central Highlands, Vietnam (Source: Invest in Vietnam, 2018).

Lam Dong province with its warm tropical climate and distinct dry and rainy seasons influenced by the South Asian monsoon is suitable for coffee production The average rainfall per month of the province was ranged from 130mm to 180mm (1,750mm to 3,150mm a year) in the period of 2002 to 2018. The temperature slightly increased from 18ºC in 2002 to 18.4ºC in 2018 that peaked at 19ºC in 2016. The temperature changes resulted to water resources scarcity for coffee production (Figure 2).

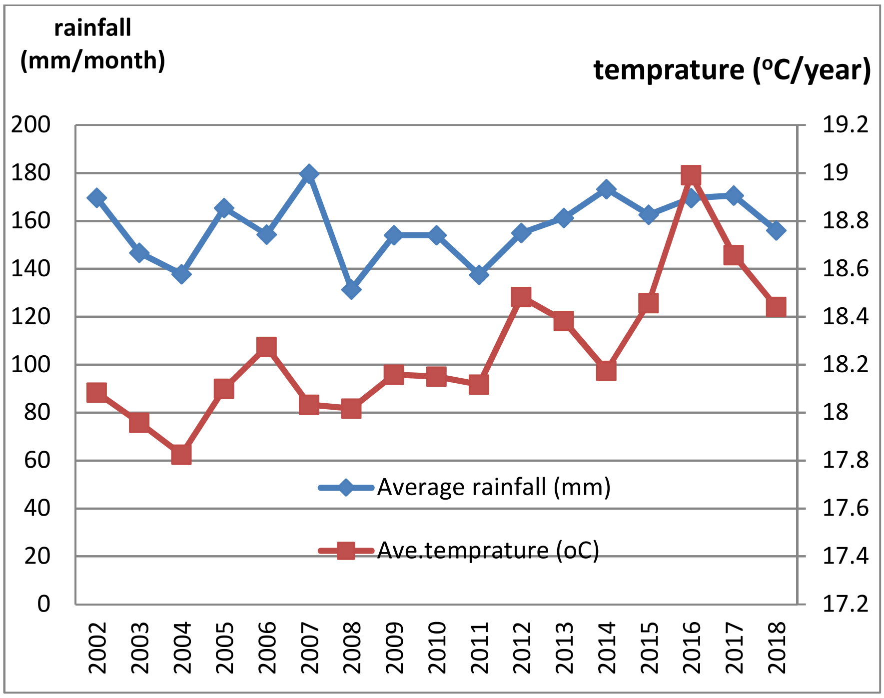

Figure 2. Rainfall and temprature of Lam Dong province from 2002 to 2018
Source: GSO, 2018

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Coffee is not only a key cash crop of Vietnam but also the Lam Dong province that account for 23% of total national land area allocated to coffee production. In Lam Dong, coffee production generates the highest gross output in comparison to other crops such as rice, tea and cashew (Figure 3). However, coffee production is severely constrained by the lack of irrigation water, especially during the dry months when the level of groundwater drops significantly. Currently, the main water supply source for coffee is surface water (80%) while the remaining 20% is sourced from groundwater. Currently, extended irrigation is the usual method of distributing irrigation water in the province's coffee-growing areas. Notwithstanding, only about 40 to 50% of coffee area is serviced by irrigation systems while the rest use ground water for irrigation [33]. During the dry season of November 2013 to April 2014 for example, the amount of coffee produced from about 3,600 ha of planted area was reduced by 20%, while agricultural crop production from 36,200 ha dropped by 5% due to the shortage of irrigation water. Inefficient use of water resources also further put coffee sector in vulnerable development. Based on the studies of West Highlands Agriculture and Forestry Science Institute, the standard volume of water requirement for coffee ranges from 650 to 800 m^3/ha. Currently, however, about 72% of coffee households in the province irrigate twice the standard water requirement for coffee (ex: 1,200 to 1,500m^3/ha) that not only increase input costs but also contribution to a depletion of water resources. Only a few areas utilize other irrigation system such as furrow irrigation that would conserve water. Both surface and ground water have become so polluted from intensive agricultural production that it has affected coffee productivity [33].

Lam Dong province has suffered from drought since 2010, with the majority of the coffee area (78%) using surface water (water from lakes and ponds) and the rest utilizing groundwater [34]. The majority of coffee farmers in Lam Dong continue to use the overflow irrigation method, using pumps to harvest water from rivers and lakes. Together they comprise approximately 71.51% of coffee area in Lam Dong province [35]. The 6,530 ha planted to coffee in this area is suffering from severe water shortages that may partly be attributed to weak management of water resources.

2.2. Data Collection and Sampling

A simple random sampling method was employed to selected coffee farmer respondents for the survey. The sample size for farmers was calculated based on [36].

$$n_0 = \frac{Z^2 pq}{e^2} \quad (1)$$

Where: n_0 is the sample size; Z^2 is the abscissa of the normal curve that cuts off an area α at the tails $(1 - \alpha)$ that equals the desired confidence level, (e.g., 95%); e is the desired level of precision (sampling error); p is the estimated proportion of an attribute that is present in the population; and q is 1 - p. The value for Z refers to the area under the normal curve found in statistical tables.

Then, the finite population correction for proportions method to adjust n_0 achieved from equation (1) is as follows:

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}} \quad (2)$$

Where: n is the sample size after adjustment and N is the population size of Robusta coffee households in Lam Dong province, Vietnam.

Based on the equation (2), a total of 194 coffee households were selected to gather primary data in 2016/2017 crop seasons in the province through face–to-face interviewing using household questionnaires. The questionnaire information includes general information of household heads, family members and labors, coffee production output, input costs, irrigation system, etc. The coffee household heads were randomly selected from the list of coffee household production in each district. Three focus group discussions also were organized in the province with the participation of

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40 coffee farmers that aimed to identify the coffee irrigation practices of coffee farmers as well as the challenging of coffee production.

2.3. Empirical Models

2.3.1. Data Envelopment Analysis (DEA)

The level of efficiency may be determined by estimating the production function from the sample data, using either the parametric (SFA) or non-parametric DEA methods [37]. The main advantage of the SFA approach is that the frontier is stochastic and allows the effects of noise to be separated from the effects of inefficiency. However, it needs prior specification of the functional form of the production function and the distribution of the one-sided error term [38]. The non-parametric DEA approach on the other hand can avoid these limitations but assigns all deviations to inefficiencies, therefore becoming likely to be sensitive to outliers [39]. The deterministic DEA does not impose any assumption about functional form hence it is less prone to miss-specification [40]. The DEA is a linear programming-based technique for evaluating the relative efficiency of Decision-Making Units (DMUs) and is used to construct a piecewise frontier of the data. Terms like DMU are used to emphasize that the interest is centered on decision-making by not-for-profit entities, rather than more customary firms and industries [41]. The best way to introduce DEA is via ratio form of all outputs to all inputs for each farm/DMUs. The optimal weight may be derived by specifying the mathematical programming problem.

2.3.2. DEA approach of IWUE

In this study, the IWUE is defined as the ratio of effective water use to the water applied to the crop [16, 42]. The standard radial is not appropriate for measuring the individual efficiency of inputs used, as it measures the equal contribution of each input to productive efficiency [43]. Therefore, it can be calculated via the sub-vector technical method for each individual input. Individual efficiency is a non-radial notion of input efficiency measure that allows for a differential reduction of the inputs applied. A non-radial contraction of the sub-vector input only, holding all other inputs and outputs constant [44-47], is demonstrated in Figure 3.

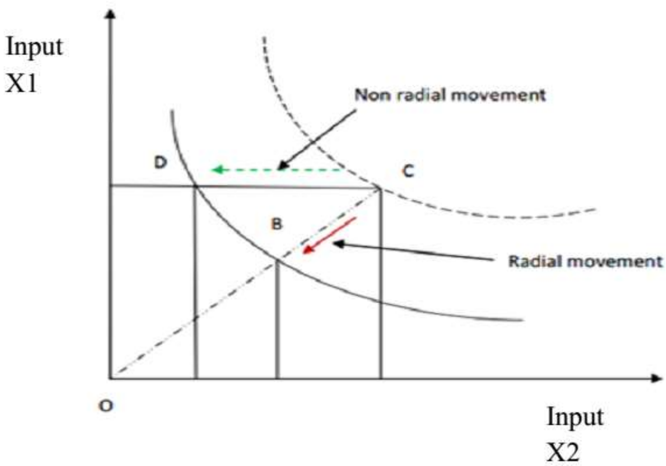

Figure 3. Input oriented water use efficiency. Source: Adapted from [47].

Mathematically, the input-oriented model for estimating IWUE can be written as shown in equation (3) [45, 48-49] using the notion of the proposed sub-vector efficiency. The technical sub-vector efficiency for variable input k irrigation water is calculated for each firm's i by solving the following linear programming problem:

$$\theta^t = min_{\theta,\lambda}\theta$$

Subject to: (3)

$$\sum_{j=1}^{n} \lambda_j \, y_{m,j} \geq y_{m,i}$$

$$\sum_{j=1}^{n} \lambda_j \, x_{k-t,j} \leq x_{k-t,i}$$

$$\sum_{j=1}^{n} \lambda_j \, x_{t,j} \leq \theta^t x_{t,i}$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0$$

Where, θ^t is the input sub-vector technical efficiency score for input t for each DMU. The measure θ^t represents the maximum reduction of variable input t holding outputs and all remaining inputs (*n-t*) constant. The θ^t can have a value between 0 and 1, where a value of 1 indicates that the observation is a best performer located on the production frontier and has no reduction potential on irrigation water. Any value of θ smaller than 1, however, indicates water use inefficiency, i.e. that excessive irrigation water is being used. On the other hand, λj is a vector of n elements, representing the influence of each DMU in determining the efficiency of the DMU; x_t is the sub-vector of the inputs contracted for the production of outputs; x_{k-t} is the vector of all other inputs. The term $\sum_{j=1}^{n} \lambda_j \, y_{m,j}$ is the weighted sum of outputs of all DMUs, which must be superior or equal to the output of DMUi ($x_{t,i}$, $y_{t,i}$).

The DEA analysis was run on EXCEL-PC. The outputs of the DEA linear programming problem in model (3) were technical efficiencies and IWUEs.

2.3.3. Regression Models

Two regression models, the Cobb-Douglas production function and Tobit regression model, were used in this study. While the Cobb-Douglas function was applied to explain the response of Robusta coffee productivity to the level of irrigation water used and other production factors, the Tobit model was used to identify factors that affect IWUE.

The Cobb-Douglas Production Function

The Cobb-Douglas production function that was used to determine coffee productivity's response to the production factors, has been widely applied in several economic studies. The Cobb-Douglas production function models that incorporate the production rate, labor inputs, equipment/capital inputs and technology efficiency in a very sophisticated form, can be used to explain various types of production activity [50]. One advantage of the Cobb-Douglas production function is that the regression coefficients immediately give the elasticity of production, independent of measurement units for the respective inputs;

The Cobb-Douglas function is expressed as follows:

$$\text{Productivity} = A^{*}\text{Water}^{\beta 1} * \text{Labor}^{\beta 2} * \text{Farm size}^{\beta 3} * \text{Capital}^{\beta 4} * e^{\varepsilon} \quad 4$$

Through a log-linear transformation [51], equation (4) is transformed to equation (5):

$$\text{Ln}Y_i = \text{Ln}A + \beta 1\text{Ln(Water)} + \beta_2\text{ln(Labor)} + \beta_3\text{Ln(Farm size)} + \beta_4\text{Ln(Capital)} + \varepsilon \quad (5)$$

Where: Y is the dependent variable (gross output of Robusta coffee in (kg/ha); The independent or explanatory variables are the quantity of irrigation, labor, farm size, and capital; β_0 is the regression constant; β_1 through β_5 are the regression coefficients for independent variables; and **ε** is the error term.

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Tobit regression model

This study adopted a two-stage DEA analysis, wherein IWUE is estimated by DEA in the first stage, before the resulting efficiency estimates are regressed on certain environmental and socio-economic variables in a second stage, using the Tobit model [52]. Tobit regression is an alternative method to ordinary least squares regression (OLS), employed when the dependent variable is bounded from below or above, or both, either by being censored or by being a corner solution. Censoring is said to occur when the independent variables are observable for the entire sample, but the dependent variable is known only if a certain criterion, defined in terms of its value, is met [53].

The Tobit model supposes that there is a latent unobservable variable IWUE. This variable depends linearly on x_i via a parameter vector (β). The observable variable IWUE is defined as being equal to the latent variable whenever the latent variable is above zero [54]. The following Tobit model can be considered:

$$IWUE^{*} = \sum_{k}^{K} \beta_k x_k + u_k, \quad IWUE = \begin{cases} IWUE^{*} \; if \; 0 < IWUE^{*} < 1 \\ 0 \; if \; IWUE^{*} \leq 0 \\ 1 \; if \; IWUE^{*} \geq 1 \end{cases} \qquad (6)$$

Where IWUE is the DEA sub-vector efficiency index for farm k, IWUE is a true but unobservable efficiency score, β is a row vector of unknown parameters, x_k is a vector of factors that are hypothesized to be correlated with irrigation water use efficiency scores, and u_k is an independently distributed error term assumed to be normally distributed with zero mean and constant variance δ2.

The Tobit model analyses farm-specific factors to assess their influence on the sub-vector efficiencies for water. The IWUE score determined via DEA was used as dependent variable while age of trees, distance from the source of irrigated water to farm, ownership of the irrigation system, household head's education, extension contact, access to credit, farmer's irrigation experience, water source, and location of farm were used as explanatory variables [52]. The expected relationship between dependent variables (*irrigation water use efficiency*) and independent variables is shown in Table 1.

Table 1. Definition and expected result of variable used in the Tobit model.

Independent variable	Expected result
Age of trees (years)	Negative
Distance from the source of irrigated water to farm (m)	Negative
Ownership of irrigation system	Positive
Education level (dummy variable)	Positive
Farmer's irrigation experience (years)	Positive
Extension contact (dummy variable)	Positive
Access to credit (dummy variable)	Positive

3. Results

3.1. Characteristics of coffee farmers

The average land area of Kinh and indigenous coffee farmers in the selected study sites is 2.3 hectares per household. Of the 194 respondents interviewed, 139 were of Kinh origin and the rest were indigenous to the area. Most of the Kinh people migrated from other provinces, even from the north of Vietnam, following the government's migration policy in the 1970s and 1980s [55].

A comparison of the socio-economic characteristics of the Kinh and indigenous farmers in the study sites shows that most Kinh farmers are better educated with secondary education compared to

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indigenous farmers who only have elementary education (Table 2). The indigenous farmers have larger coffee areas and more experienced in coffee cultivation than Kinh farmers. There was not much difference however in farm size and experience in coffee production between the two groups. The amount of irrigation water used by indigenous farmers (4,766.8 m^3) was higher than that used by Kinh farmers (4,719.6 m^3), there was no significant difference between two groups. The working capital variable includes the cost of hired labor for land preparation, weeding, transplanting, harvesting, application of fertilizers, pesticides, and costs of other inputs such as pesticides and fertilizers. There was significant difference in working capital used between Kinh and Indigenous groups. It can be explained that the Kinh farmers were hired more labor than the Indigenous farmers. They also used more fertilizers (NPK) than that used by Indigenous farmers. However, the productivity of the Robusta coffee farms of indigenous farmers and those of Kinh farmers was not significant difference.

Table 2. Summary statistics of Robusta coffee farmers in Lam Dong province, Vietnam, 2017.

	Kinh group		Indigenous group		All	
Variables	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**
Age of HH head (years)	44.0*	11.0	42.0*	12.0	44.0	12.0
Education level	3.0*	0.7	2.0*	0.8	2.6	0.8
Household size (people)	5.0*	1.4	6.0*	2.2	5.0	1.7
Experience (years)	18.9	6.1	20.7	6.9	19.4	6.4
Farm size (hectares)	2.2	1.3	2.3	1.3	2.3	1.3
Irrigation water (m^3)	4,719.6	3,321.2	4,766.8	3,167.7	4,733.0	3270.3
Family labor (man-days/ha)	66	43	78	60	69	49
Working capital (1000 VND/ha)	55,353.7*	40,801.2	46,465.2*	30,007.2	52,833.7	38,140.1
Coffee output (Kg)	5,864.4	3,487.6	5,051.1	2,857.3	5,633.8	3,334.2

Note: * indicates difference between means of two groups is statistically significant at 95% confidence level in paired t-test; S.D: Standard Deviation.

3.2. The response of Robusta coffee productivity to the level of irrigation water used

The Cobb-Douglas coffee production function was used to analyze the influence of the explanatory variables, namely, quantity of irrigation water (m^3), farm size (hectares), labor (man-days) and capital (VND) on coffee productivity. These explanatory variables were selected based on previous study of [31, 50] and the estimated pairwise correlation coefficients ($r > 0.6$). Other factors such as fertilizers and pesticides were excluded because of the low value of their pairwise correlation cofficients and the presence of many outliers. Similarly, exogenous factors, such as weather conditions and government policy, were excluded in this model because farmers have no influence on these factors [56]. In addition, the variables were tested for multicollinearity and heteroscedasticity problems in the empirical model. The Park's test was used to determine heteroscedasticity issues. Results indicated that homoscedastic errors were not rejected in all cases, indicating no serious heteroscedasticity issues.

Table 3. OLS regression results for coffee production function, Lam Dong province, Vietnam, 2017.

Independent Variable	Coefficient	Std. Err	T-value	P-value
Log constant	4.581*	0.690	6.63	0.059
Log capital	0.072***	0.038	1.90	0.005
Log labor	0.175***	0.062	2.84	0.001

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Log water	0.163***	0.047	3.50	0.000
Log farm size	0.536***	0.063	8.56	0.000
R- square				0.792
Adjusted R-square				0.788
F (4, 189)				180.24
Prob > F				0.0000
Root MSE				0.2928

Note: ***, ** and * are significant at 1%, 5% and 10% probability level, respectively. NS is not significant at 10% probability level.

The OLS regression results indicated that the four independent variables (quantity of water, labor, farm size and working capital) were statistically significant and had a positive influence on the level of Robusta coffee output. The adjusted R-square value was 78.8%. This means that 78.8% of the change in the Robusta coffee output was explained by the changes in the quantity of irrigation water, labor, capital and farm size (Table 3).

Our findings show that a 1% increase in irrigation water results in a 0.163% increase in coffee output [57,58]. Similarly, an equivalent increase in capital, labor and farm size increases coffee output by 0.072%, 0.175% and 0.536%, respectively. This means that coffee output is most responsive to the size of farm, and least responsive to amount of capital. The low output response to water and capital might suggest that water use in the study area is below productive potential.

The sum of all production elasticities of inputs (regression coefficients) in the Cobb-Douglas production model is 0.946. An elasticity less than 1 indicates decreasing return to scale, that is a less than proportionate increase in output of coffee, given a certain level of input. This suggests that investments in new technologies would be a better alternative for increasing productivity, rather than increasing the quantity of inputs applied.

It could not be determined based on the results of the OLS econometric model prove whether resources were being efficiently utilized or not. The results only reveal the functional relationship between the factors of production and output, with the assumption that all respondent farms were fully efficient [39], which is not true in all cases. It is therefore necessary to complement this analysis with a technical efficiency analysis. Likewise, given the insufficiency amont of water that could be provice for coffee production in Lam Dong province and its effect on coffee productivity, as shown by the regression analysis in this section, it is also necessary to analyse irrigation water use efficiency using DEA analysis. The next section presents results for irrigation water use efficiency.

3.3. The DEA results - TE and IWUE scores

The overall TE and IWUE scores, given CRS and VRS in the sample and the two groups of Kinh and indigenous farmers, are summarized in Tables 4 and 5, respectively. The TE scores for all coffee farmer respondents ranged from 30% to 100% with an average of 72% for the VRS DEA model while for the CRS DEA model, the TE scores ranged from 21% to 100% with an average of 66%. These results revealed that inputs for coffee production were not being efficiently utilized. The current level of coffee output could still be attained even if the amount of inputs used is reduced by 28% and 34% based on the VRS and CRS, respectively. The difference between the VRS and CRS measurements indicates that coffee farmers are not operating efficiently. The scale efficiency of 0.92 indicates that by operating at an optimal scale, the amount of inputs used of Robusta coffee farms in the study area could be reduced by as much as 8.0%.

Table 4 also provides a comparison of TE between Kinh and indigenous farmer groups. Results show that indigenous farmers produce more efficiently than Kinh farmers, under both VRS and CRS in the DEA model (81% vs. 76% in VRS, and 75% vs. 67% in CRS). The results seem somewhat surprising given that Kinh farmers are more educated, better trained and have better access to market information than indigenous farmers. This result however is consistent with the findings of [30] on the efficiency of coffee farming in Vietnam's Central Highlands. The reason is that farmers of

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Kinh origin, most of whom migrated from northern Vietnam in the 1980s, have less experience in coffee cultivation (18.9 vs. 20.7 years), smaller farm sizes (2.2 vs. 2.3 ha) and fewer family labor (66 vs 78 man-days/ha) than indigenous farmers. Note that family labor is expected to be more efficient than hired labor due to the moral hazard problem.

Table 4. Frequency distribution of Technical Efficiency of Robusta coffee production by group in Lam Dong, Vietnam, 2017.

Efficiency (%)	TE					
	VRS			CRS		
	Kinh group	Indigenous group	All	Kinh group	Indigenous group	All
Summary Statistics						
Mean	0.76	0.81	0.72	0.67	0.75	0.66
Minimum	0.31	0.30	0.24	0.21	0.29	0.21
Maximum	1.00	1.00	1.00	1.00	1.00	1.00
Std. Dev	0.18	0.19	0.19	0.18	0.19	0.18
Efficiency Interval						
100	23 (17)	17 (31)	21 (11)	9 (6)	9 (16)	16 (8)
90-100	14 (10)	9 (16)	24 (12)	9 (6)	6 (11.5)	10 (5)
80-90	27 (19)	4 (7)	24 (12)	15 (11)	11 (20)	17 (9)
70-80	16 (12)	8 (15)	31 (16)	20 (14)	6 (11.5)	31 (15)
60-70	28 (20)	9 (16)	32 (16)	34 (25)	9 (16)	40 (21)
50-60	23 (16)	6 (11)	44 (23)	35 (25)	9 (16)	48 (25)
40-50	4 (3)	1 (2)	11 (6)	11 (8)	4 (7)	21 (11)
30-40	4 (3)	0 (0)	6 (3)	6 (4)	0 (0)	8 (4)
<30	0 (0)	1 (2)	1 (1)	1 (1)	1 (2)	3 (2)
Total	139 (100)	55 (100)	194 (100)	139 (100)	55 (100)	194 (100)

Note: Figures in parenthesis are percentage of column totals .

Table 5 also shows that the average IWUE scores for the DEA frontiers for all respondents are much lower than TE scores at 52% for VRS and 39% for CRS. The results also show that variability for the estimated IWUE given the VRS assumption at 13% to 100% is less than that under the CRS assumption, at 12% to 100%. These results imply that the level of productivity of Robusta coffee could still be maintained even if the amount of irrigation water used is reduced by 48% and 61% under VRS and CRS, respectively, ceteris paribus. Results also show that under VRS, the score for irrigation water use efficiency (IWUE) of 108 coffee farms is below 50%, between 50-80% for 45 farms and just 41 farms score over 80%. These results indicate that the majority of farms could achieve significant savings in water use if their irrigation systems are improved. Table 5 also shows differences in IWUE scores between the Kinh and indigenous farmer groups. Similar to the results for TE, the average IWUE scores show that the indigenous farmer group produces more efficiently than the Kinh group, under both the VRS and CRS DEA models (69% vs. 54% under VRS, and 52% vs. 40% under CRS, respectively).

The scale efficiency equal to 0.75 suggests that the amount of water used for the Robusta coffee farms in Lam Dong province could be reduced by as much as 25% if utilized optimally. The estimated scale efficiency for Kinh and indigenous farmer groups were 0.74 and 0.75, respectively. This means that by operating at optimal scale, input use could be reduced by as much as 26% and 25% for the Kinh and indigenous farmer groups, respectively. In other words, farmers in both groups could be advised to increase their scale of operation to an optimal level. The efficiency level for the two groups differ under the VRS assumption. Results show that about 11% of the Kinh group and 25% of the indigenous farmer group were on the frontier (100% efficiency) (Figure 4).

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In sum, the DEA results for TE and IWUE scores indicated that for many Robusta coffee farmers in Lam Dong province, the key inputs especially irrigation water, could be reduced without affecting the levels of production.

Table 5. Frequency distribution of Irrigated Water Use Efficiency in Lam Dong province, Vietnam, 2017.

Efficiency (%)	IWUE					
	VRS			CRS		
	Kinh group	Indigenous group	All	Kinh group	Indigenous group	All
Summary statistics						
Mean	0.54	0.69	0.52	0.40	0.52	0.39
Minimum	0.14	0.11	0.13	0.10	0.10	0.12
Maximum	1.00	1.00	1.00	1.00	1.00	1.00
Std.Dev	0.29	0.30	0.28	0.24	0.27	0.24
Efficiency Interval						
100	15 (11)	14 (25)	17 (9)	5 (4)	6 (11)	9 (5)
90-100	14 (10)	7 (13)	15 (8)	7 (5)	3 (5)	6 (3)
80-90	8 (6)	5 (9)	9 (5)	1 (0)	0 (0)	2 (1)
70-80	3 (2)	1 (2)	11 (6)	4 (3)	3 (5)	5 (3)
60-70	8 (6)	4 (7)	10 (5)	6 (4)	8 (15)	8 (4)
50-60	18 (13)	6 (11)	24 (12)	10 (7)	6 (11)	13 (7)
40-50	14 (11)	4 (7)	24 (12)	16 (12)	7 (13)	24 (12)
30-40	21 (15)	9 (16)	32 (16)	28 (20)	8 (15)	37 (19)
<30	38 (27)	5 (9)	52 (27)	62 (45)	14 (25)	90 (46)
Total	139 (100)	55 (100)	194 (100)	139 (100)	55 (100)	194 (100)

Note: Figures in parenthesis are percentage of column totals.

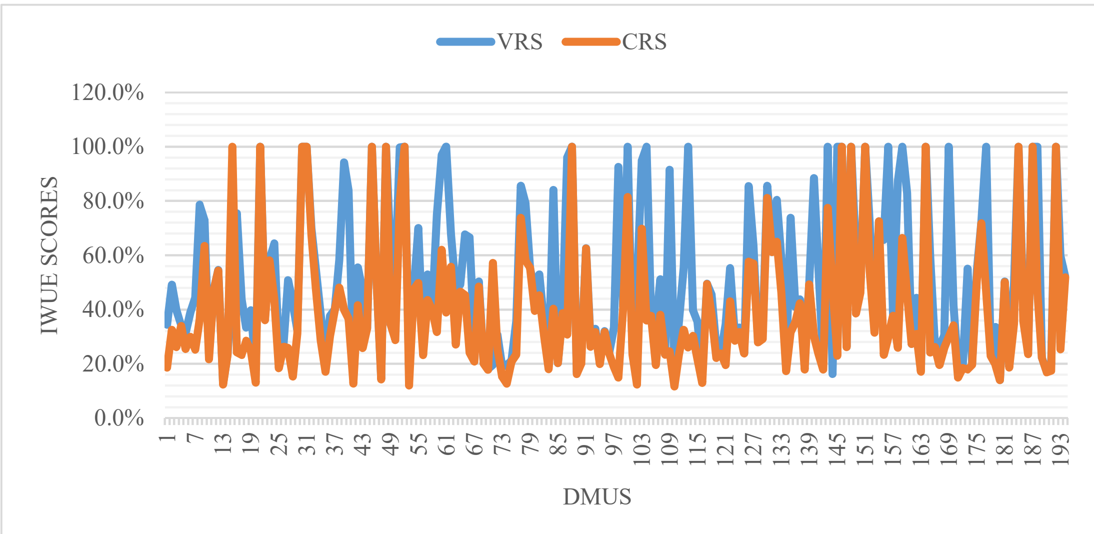

Figure 4. IWUE under VRS and CRS.

3.4. Tobit model results

The Tobit model was used to identify the main factors affecting IWUE. The model was estimated using STATA software version 14.0 to determine the maximum likelihood estimates of seven parameters, namely: age of coffee tree, distance from the source of water, ownership of irrigation system, farmer's education level, farmer's irrigation experience, extension contact and access to credit. The IWUE scores of decision-making units (DMUs) assuming a VRS, were used because they were deemed more suitable as an efficiency measure. The results of the Tobit model estimation are shown in Table 6.

Six out of seven explanatory variables were found to be significant determinants of IWUE. These variables included the distance from water source to farm (DIS), farmer's experience in co8ffee cultivation (EXP), contact to extension services (EXT), and access to credit (CRE) that were statistically significant at the 5% level. Ownership of irrigated water source (OWN), and farmers' education level (EDU) were statistically significant at the 1% level. The age of coffee plants (AGE) was not significant. The marginal effects of the explanatory variables on IWUE showed that contact with extension services and credit access had the greatest influence on IWUE, with 0.123% and 0.122% in IWUE for 1 unit of extension contact or credit access, respectively. This indicates that an increase in contact with extension services or access to credit would encourage or enhance the capacity of farmers to apply additional inputs at the proper time.

Table 6. Results of Tobit model of factors affecting IWUE in Robusta coffee production in Lam Dong province, Vietnam, 2017.

Variables	Coefficient	Std. Dev	T-value	P-value
Intercept	-0.155^{NS}	0.116	-1.34	0.183
Age of coffee plant (AGE)	0.002^{NS}	0.28	0.85	0.395
Distance to water source (DIS)	-0.00009**	0.00003	-2.56	0.011
Ownership of irrigation system (OWN)	0.060***	0.019	3.11	0.002
Education level (EDU)	0.066***	0.025	2.66	0.008
Experience (EXP)	0.007**	0.003	2.31	0.022
Extension contact (EXT)	0.123**	0.043	2.89	0.004
Access to credit (CRE)	0.122**	0.041	2.94	0.004
Number of observations				194
LR chi2 (7)				59.38
Prob>chi2				0.0000
Pseudo R2				0.3912

Note: ***, **, * refers to significance at 1%, 5% and 10% level, respectively. NS refers to non-significant.

4. Discussion

The availability of water for irrigation is very dependent on the amount of available water [59]. It is necessary therefore to use irrigation water more efficiently since most of the Robusta coffee farms in Lam Dong use an overflow method of irrigation for their coffee plants. According to [60], the productivity of coffee is very sensitive to the availability of sufficient amounts of water especially during the fruiting period when seeds are produced. A period of water stress therefore seems to be mandatory for normal flower bud development. The period from January to April is very critical in the production cycle of coffee [1] when water should be available for the crop to ensure a good yield [61]. This direct relationship between irrigation water supply and productivity of Robusta coffee has been observed in Lam Dong province. This finding is consistent with [5] who also found that the high productivity of coffee in Vietnam cannot be sustained without sufficient supply of irrigation water. Our findings show that in Lam Dong province, the productivity of most coffee farms has not reached it full potential despite the availability of capital. This can be attributed to the lack of water from poor water management especially during the period of flower bud growth as well as non application of proper cultural practices. The group discussions with coffee farmers also revealed that ninety-five (95) percent of coffee respondents used the overflow irrigation water method for their coffee plants. These results suggest that farmers should be informed and encouraged to follow irrigation and input application schedules.

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Sustainable farming is more cost-effective and profitable than conventional farming, despite the insignificant difference in production efficiency [62]. The fact that coffee farmers in Lam Dong are small-scale and the indigenous farmer groups used water more efficiently than Kinh farmers (who have better access to school, education level and credits) is consistent with discussions of [30]. This tells us that experience in coffee production and knowledge play a crucial role in coffee production. A combination of indigenous technical knowledge, good irrigation water management, and replacment of unproductive coffee varieties with better yielding varieties would enhance the sustainable development of Vietnam's coffee industry.

Results of the regression analysis using DEA shows that the mean technical efficiency of irrigation water use was 72% for the VRS DEA model and 66% for the CRS DEA model (Table 3) and that with the current level of available resources and technology, coffee production can potentially increase by 28% and 34%, respectively. The average irrigation water use efficiencies (IWUE) were 52% for VRS and 39% for CRS, implying that the amount of irrigation water used may be reduced by 48% and 61% under VRS and CRS, respectively, without reducing coffee productivity.

Information on the different factors affecting IWUE would be useful in determining the appropriate interventions that can be used to improve the water irrigation systems of farmers. Factors such as distance from water source to farm, farmers' experience, contact to extension services and access to credit, and famers education level have significant effects on IWUE. Improving the level of education and farming knowledge as well as accessibility to credit and extension services could all positively affect the efficiency of irrigation water use for more sustainable coffee farming. These results are consistent with the findings of [63, 64].

5. Conclusions and policy recommendations

Improving allocation and technical efficiency of coffee farmers is fundamental to increasing farm-level total factor productivity, returns to coffee farmers and stabilizing the region's underling agro-ecology. The analysis of the factors affecting technical efficiency of coffee farmers in the study areas shows that irrigation water has a very significant effect on coffee productivity. The findings show however that coffee farmers in Lam Dong province are very inefficient in utilizing irrigation water. Local farmers in fact can reduce the amount of irrigation water used by 25% without reducing the productivity of Robusta coffee. The results of the study also show that indigenous Robusta coffee farmers are more efficient in using irrigation water than Kinh farmers. Increasing farmers' educational levels, providing them with regular contact to extension personnel and regular training, would provide farmers with sufficient information on the efficient utilization of irrigation water resources. Similarly, access to credit would enhance farmers' capacity to acess and apply farm inputs. Distance from or access to a water source is also an important factor affecting IWUE. Farmers who are near or have access to water resources have higher IWUE scores. Although farmers in Lam Dong province felt the need to install water wells to meet their irrigation water requirements, they were constrained by the high investment costs. This means that financial and technical support from the government will be critical in improving IWUE.

The possible technical and institutional interventions to address the issues faced by farmers and improve their IWUE included: 1) intensify the provision of extension services, i.e. training on good agriculture practice (GAP) such as the judicious application of production inputs, pruning and irrigation techniques, water and soil management, fertilizer and pesticide usage, etc..; 2) promote better collaboration among stakeholders (institutions, governmental extension departments and farmer associations) to implement coffee farming experiments and best management practices; 3) increase access to credit, with favorable interest rates for coffee farmers. This may help farmers to overcome financial constraints, resulting in an increase in TE and IWUE; and 4) encourage farmers to apply water-saving irrigation technologies (sprinklers and drip irrigation) and farming practices through application tools (cellphones, computers, internet, etc.).

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