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# Technical Efficiency of Irish Potato (*Solanum tuberosum* L.) Production in Molo Sub County, Kenya

**Pauline Nyokabi Kamau[1*], Geoffrey Kingori Gathungu[2] and Rael Nkatha Mwirigi[3]**

*[1]Department of Agricultural Economics, Agribusiness Management and Agricultural Education and Extension, Chuka University, Kenya.*
*[2]Department of Plant Science, Chuka University, Kenya.*
*[3]Department of Business Administration, Chuka University, Kenya.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. Author PNK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author GKG helped in writing the introduction, results and the discussion section. Author RNM also helped in writing the introduction, literature searches, results and conclusion section. All authors read and approved the final manuscript.*

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## ABSTRACT

This study focused on measuring farm level technical efficiency among smallholder Irish potato farmers in Molo Sub County and its determinants. Descriptive research design was applied. Cross-sectional data was collected through multistage sampling from smallholder Irish potato farmers located in Molo Sub County from April to June 2019. A Stochastic frontier approach assuming a Cobb-Douglas production function was adopted to analyze the level of technical efficiency and explain variations in this technical efficiency across farmers and estimation was done by applying the maximum likelihood method. Mean technical efficiency was 70.7%. The statistically significant variables with respect to the farm inputs were land (0.262), seed (0.629), fertilizer (-0.299) and fungicide (0.131) variables respectively. However, fertilizer variable had negative effects on Irish

**Corresponding author: Email: kpauline24@gmail.com;*

potato production. Education (-0.061), gender (-0.262), access to extension services (-0.078) and farmer group (-0.217) variables were significant and influenced technical inefficiency negatively.Increase in smallholder farmers' literacy level, accessibility to extension services and farmer groups may improve Irish potato production technical efficiency. However, gender contribution towards Irish potato production technical efficiency needs a deeper understanding.

*Keywords: Cobb-douglas; Irish potato; Kenya; stochastic frontier model; technical efficiency.*

## 1. INTRODUCTION

As the global population and average income increases so does demand for food [1]. A similar trend is anticipated in the Sub-Saharan Africa (SSA) as the region is expected to take up half of the world population increment by 2050 [2]. Irish potato (*Solanum tuberosum* L.) has been identified as a major crop in the attainment of the Sustainable Development Goal of Zero hunger in SSA [3] hence reducing food insecurity. Irish potato is a crop that provides more food per hectare than other crop staples [4]. With the reduction of arable land due to farm fragmentation, cultivation of Irish potato is suitable to get more food out of the limited arable land. The crop converts seed, land and water into high quality food rich in nutrients. Irish potato has a nutritional value that is much higher than that of maize, beans, soya bean, peas and wheat [5].

Consumer demand for the crop in its more convenient forms such flake, chips and crisps has risen due to escalation of urban dwellers, growing disposable incomes, diet diversification and lifestyle changes that have left many people with less time for cooking [6]. Other uses of the crop include: provision of starch, animal feed and seed tubers [7]. In spite of these significant contributions, production of Irish potato remains unexploited. For instance, in 2017, Africa's production of the crop was 25 million tons of Irish potatoes on 1.9 million hectares, which accounted for 6.4% and 10% of the world production and area harvested respectively [8]. The yield per hectare ranged from 0.7 to 36 tons/ha with a continent average of 13 tons/ha in 2017 [9], which was below Africa's potential of 20 tons/ha [10]. In the same year, Kenya's average yield per hectare was 7.9 tons/ha and it ranks second as Kenya's staple food after maize. On average, 2-3 million tons of the crop with an estimated value of USD.375-468 million are produced annually compared to an average of 40 million bags of maize with an estimated value of USD. 1.12 billion. The unexploited production capacity suggests underutilization of inputs used in the production of this crop thus signaling presence of technical inefficiencies.

Technical efficiency is realized when a specified set of inputs are used to produce a higher level of output or when a particular level of output is obtained from the lower set of inputs given the best production technology available. In general, different farmers having the same inputs produce different levels of output. Variations in output levels can be attributed to variations in levels of technical efficiency. A number of factors are observed to cause the variations in technical efficiency. Such include: education, age, labour, farm location, farm type, intensity of inputs, policy, infrastructure, credit and extension services [11]. These factors can be broadly categorized as farm specific characteristics, demographic, socio-economic, environmental and non-physical and institutional aspects [12].

Literature on technical efficiency of potato farming remains scarce as few studies have been carried out in Kenya. Information on technical efficiency of the crop in Molo Sub County is lacking as there is a limitation of similar studies for this crop in this area. Available studies have been done by [13] on technical efficiency in resource use: evidence from smallholder Irish potato farmers in Nyandarua North District and [14] on technical efficiency and its determinants on Irish potato farming among smallholder farmers in Trans-Nzoia. Therefore, to narrow down the knowledge gap, this study sought to analyze the technical efficiency among the smallholder Irish potato farmers in Molo Sub County. The specific objectives were to measure the technical efficiency of smallholder Irish potato farmers in the sub county and investigate the effect of some socio-demographic and institutional characteristics of the farmers on the level of technical efficiency. The study findings provide useful understanding on Irish potato production to farmers and policy makers and identify appropriate policy measures that will help towards boosting and sustaining Irish potato production.

## 2. METHODOLOGY

### 2.1 Study Area

The study was conducted in Molo Sub County which ranks as second largest Irish potato producing area in Kenya. It is approximately 478.79 $Km^2$ with a population of 156,732 persons [15]. The Sub County is located along Mau forest running on Mau escarpment with four wards: Mariashoni, Elburgon, Turi and Molo (Fig. 1).

The Sub County is situated at 0.25° South latitude, 35.73° East longitude and 2534 meters above sea level. The area climate is categorized as warm and temperate with average temperatures at 14.1°C and average rainfall of 1131 millimetres. The average farm size for food crops is less than a hectare per household. The main economic activities in the area include maize, pyrethrum, Irish potato and barley farming and dairy and sheep rearing [16]. The Sub County hosts the Irish potato seed multiplication project aimed at enhancing availability of certified seed for better yields.

### 2.2 Sample Procedure and Size

A multi-stage sampling technique was adopted in selecting the respondents. In the 1st stage, four wards in Molo Sub County were purposively selected. Then from each ward, sub-locations were listed and randomly selected. In the next stage, villages from the selected sub-locations were listed selected randomly. Lastly, a list of smallholder Irish potato farmers from the selected villages was obtained with the support of the local administrative leaders and ministry of agriculture extension officers from which the respondents were randomly selected. The sample size was computed according to the formula developed by [17]:

$$n = \frac{N}{1+N(e)^2} = \frac{6450}{1+6450(0.05)^2} = 377$$

where,

n= desired sample size
N=population size
e = sampling error

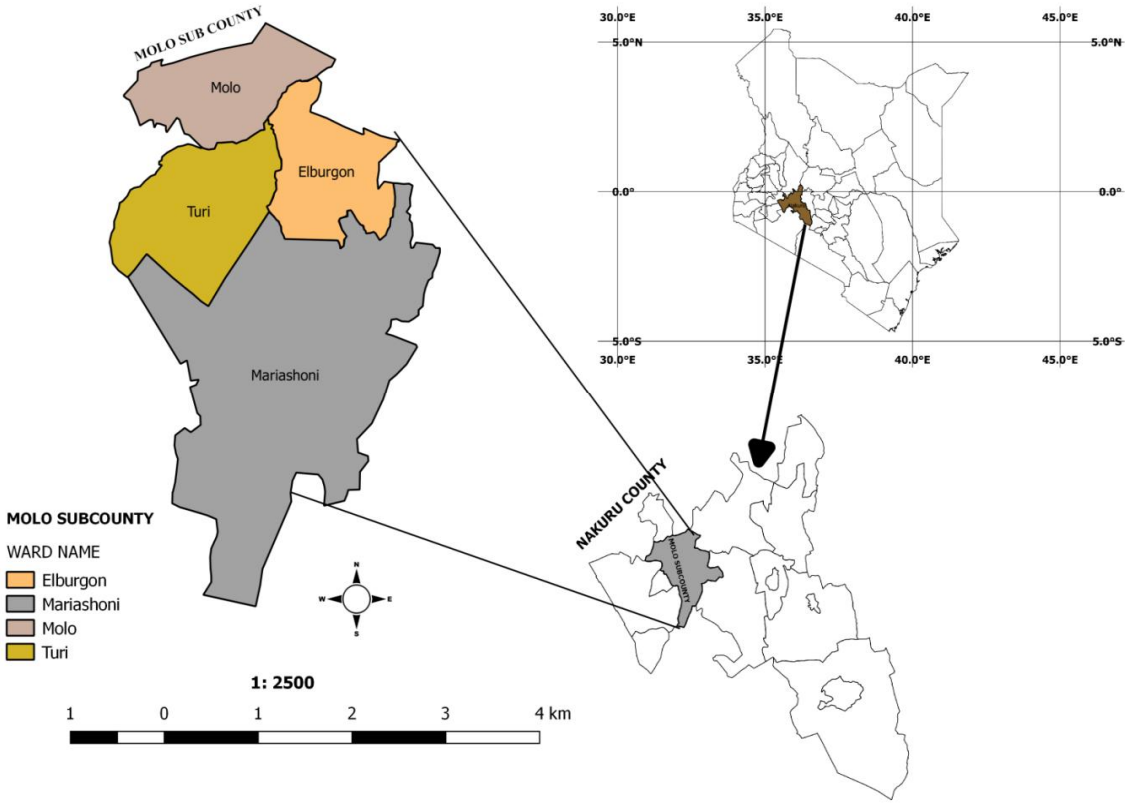


**Fig. 1. Molo Sub County Map (Kiptoo et al., 2017)**

The study assumed 95% confidence (5% sampling error) to obtain a sample size of 377 smallholder Irish potato farmers in the Molo Sub County.

## 2.3 Data Collection

A well-structured survey questionnaire that was pretested for validity and reliability was used to collect data from April to June 2019. The questionnaire captured data on fertilizer in kg, seed in kg, fungicides in liters, labor in man days per hectare and farm size in hectares for the previous planting season. Socio-demographic data was collected on variables such as education level, gender, household size and faming experience of the smallholder Irish potato farmer. Data on institutional factors included access to extension services, farmer group/association and credit variables. Data was collected, coded, entered and edited with 17 respondents being dropped for being outliers. Data analysis was done using STATA version 14.

## 2.4 Model Estimation

Measurement of the physical relationship between inputs and output can be done using several functional forms. Common functional forms are the Cobb-Douglas and trans-log production functions and both have advantages and disadvantages. Therefore, no production functional form can be said to be superior. However, hypothesis testing using the generalized likelihood ratio test can be done to identify a production function that is suitable for available data. Stochastic frontier analysis technique was applied in estimating the production function as it captures deviations of observations made due to random shocks and inefficiency. A stochastic frontier production model can be specified as follows:

$$Y_i = f(X_i, \beta_i) + \varepsilon_i \quad (1)$$

where, $Y_i$ represents Irish potato output in kilograms, $X_i$ represents the vector of farm inputs used in Irish potato production, $\beta_i$ denotes a vector of farm inputs coefficients to be estimated, $\varepsilon_i$ is a composite error term $(v_i - u_i)$, *i* is the *i* th farmer in the sample (1, 2,…..N)

Deviation of output from the frontier as a result of socio-demographic and institutional factors was represented by the non- negative random variable $u_i$ expressed as:

$$u_i = Z_i\beta_i \quad (2)$$

where, $Z_i$ denotes a vector of farmers' socioeconomic and institutional factors, $\beta_i$ denotes a vector of coefficients to be estimated. Technical efficiency of the individual sampled farmers can be expressed as a ratio between the observed Irish potato production to the potential or frontier Irish potato production, given the available technology. Hence, technical efficiency level can be expressed as:

$$TE = \frac{Y_i}{Y^*} = \frac{\exp(\beta X_i + V_i - U_i)}{\exp(\beta X_i + V_i)} = \exp(-U_i) \quad (3)$$

where, $Y_i$ represents observed Irish potato production level , $Y^*$represents predicted Irish potato production level. Technical efficiency takes a value ranging from zero to one indicating the level of technical efficiency for a farmer (Battese and Coelli, 1995). A value of one denotes that a farmer is completely technically efficient. For this study, Cobb-Douglas functional form was considered and was expressed as:

$$\ln Y_i = \beta_0 + \beta_1 \ln land + \beta_2 \ln seed + \beta_3 \ln fertiliser + \beta_4 \ln labour + \beta_5 \ln fungicide + v_i - u_i \quad (4)$$

where, $Y_i$ is the production of the i-th farmer, $\beta_0$ is the intercept term, $\beta_{1-5}$ represents regression coefficients of the farm input variables ,ln represents natural logarithm, $v_i$ is a random variable which is assumed to be identically and independent, $u_i$ is the non-negative random variable assumed to account for technical inefficiency in Irish potato production. The model specification used to specify technical inefficiency effects was specified as:

$$u_i = \delta_0 + \delta_1 z_1 + \delta_2 z_2 + \delta_3 z_3 + \delta_4 z_4 + \delta_5 z_5 + \delta_6 z_6 + \delta_7 z_7 + e_i \quad (5)$$

where, $z_1$ represents education level, $z_2$ represents gender, $z_3$ represents household size, $z_4$ represents farming experience, $z_5$ represents access to extension service, $z_6$ represents access to farmer group, $z_7$ represents access to credit, $u_i$ represents inefficiency model, $e_i$ represents error term, $\delta_0$ represents intercept term, $\delta_{1-7}$ represents regression coefficient of the socio-demographic and institutional variables.

The functional relationship between the farm specific factors and inefficiency effects were simultaneously estimated through the maximum likelihood method in a one-step approach

proposed by Battese and Coelli (1995) which allows for the estimation of the variable and variance parameters ( $\partial^2 = \partial u^2 + \partial v^2$ , $\gamma = \partial u^2/(\partial^2)$). In the one-step approach a model is correctly specified by considering the relationship between the exogenous variables and technical efficiency in estimating the input parameters and technical inefficiency model. Simultaneous estimation of the input parameters and technical inefficiency can be expressed as an explicit function of specific factors using the one-step approach [18]. The alternative, a two-step approach, has been criticized for its inconsistent assumptions regarding the factors that have an influence on technical efficiency. This approach tends to underestimate determinants of technical efficiency [19,20].

## 3. RESULTS AND DISCUSSION

### 3.1 Descriptive Statistics of Respondents

Characteristics of the sampled farms in Molo Sub County are provided in Table 1. The average farm size was 2 hectares with the sampled Irish potato farmers' allocating an average of 0.28 hectares to Irish potato production. The average amount of seed used per hectare was 912 kgs with a deviation of 84.5 kgs suggesting there is a sizeable room for the smallholder Irish potato farmers to increase the average Irish potato produce in the study area. The average amount of fertiliser applied in the production of Irish potato was 93.8 kgs per hectare during the last planting season with a standard deviation of 0.024 kgs. All the sampled respondents were found to apply chemical fertiliser on their Irish potato crop. On average, the sampled farmers applied 1.34 liters of fungicide per hectare. The surveyed households employed an average of 7 man-days of labour per hectare in Irish potato production. Labour comprised of both hired and family labour mainly used in farm operations such as ploughing, planting, weeding and fungicide application. The average yield was 2,699.389 kgs with 20 kgs as the minimum yield and 9,000 kgs as the maximum yield per hectare.The mean age of the farmers was 38 years; while the mean household heads' farming experience were 4 years and 11 years of formal education.

Only 71.11% of the total sample of farmers had access to extension services while 27.78% belonged to a farmers' group/association. The sampled households that accessed credit represented only 18.06% of the sample. With respect to gender, about 56.67% of the respondents were males.

**Table 1. Farm inputs and Irish potato production (N =360)**

| Variable | Mean | SD | Min | Max |
|---|---|---|---|---|
| Land (ha) | 2.229 | 1.403 | 0.25 | 6 |
| Plot size(ha) | 0.28 | 0.211 | 0.125 | 4 |
| Seed (kg/ha) | 912.036 | 84.514 | 50 | 4800 |
| Fertilizer (kg/ha) | 93.8 | 0.024 | 25 | 118 |
| Fungicide (liters/ha) | 1.340 | 1.129 | 0.08 | 6.4 |
| Labour (man-days/ha) | 7.344 | 1.129 | 4 | 22 |
| Age | 38.461 | 5.180 | 19 | 77 |
| Education | 10.813 | 2.328 | 2 | 16 |
| Household size | 5.611 | 1.794 | 1 | 16 |
| Farming experience | 4.431 | 1.218 | 1 | 10 |
| **Characteristics** | | | **Frequency** | **Percent** |
| **Access to extension services** | | | | |
| Yes | | | 256 | 71.11 |
| No | | | 104 | 28.89 |
| **Access to farmer group/association** | | | | |
| Yes | | | 100 | 27.78 |
| No | | | 260 | 72.22 |
| **Access to credit** | | | | |
| Yes | | | 65 | 18.06 |
| No | | | 295 | 81.94 |
| **Gender** | | | | |
| Male | | | 204 | 56.67 |
| Female | | | 156 | 43.33 |

*Source: Own computation*

### 3.2 Stochastic Frontier Parameter Estimates

Table 2 displays the results of the simultaneously estimated stochastic frontier and the inefficiency model obtained through the maximum likelihood method. A generalised likelihood test for functional specification reveals that at 5 percent level of significance, the computed log-likelihood ratio statistic (-17.957) is lower than the [21] critical values. This implies that the null hypothesis for a Cobb-Douglas production function specification against an alternative hypothesis for a translog specification is accepted. The available data was therefore adequately represented by a Cobb-Douglas production function. Lambda ( $\lambda$ ) provides information on whether stochastic inefficiencies are present in the model. At 5 percent level of significance, null hypothesis for no stochastic inefficiencies was rejected implying that deviations from the benchmark frontier were not only as a result of random shocks but also due to inefficiency.

**Table 2. Stochastic frontier model parameter estimates**

| Variable | Coefficient | SE | Z | P-value | 95% Confidence interval | |
|---|---|---|---|---|---|---|
| Constant | 2.387 | 0.265 | 9.00 | 0.000 | 1.867 | 2.907 |
| lnland | 0.262*** | 0.091 | 2.87 | 0.004 | 0.083 | 0.441 |
| lnseed | 0.629*** | 0.096 | 6.55 | 0.000 | 0.440 | 0.817 |
| lnlabour | 0.089 | 0.006 | 1.52 | 0.129 | -0.026 | 0.205 |
| lnfertiliser | -0.299*** | 0.066 | -4.50 | 0.000 | -0.430 | -0.169 |
| lnfungicide | 0.131*** | 0.037 | 3.52 | 0.000 | 4.299 | 6.693 |
| **Inefficiency effect model** | | | | | | |
| Constant | 0.633 | 0.016 | 3.87 | 0.000 | 0.313 | 0.953 |
| Education | -0.061*** | 0.001 | -4.08 | 0.000 | -0.090 | -0.317 |
| Gender | -0.262** | 0.001 | 2.24 | 0.025 | 0.033 | 0.491 |
| Family size | 0.022 | 0.002 | 1.47 | 0.141 | -0.007 | 0.520 |
| Farming experience | 0.100 | 0.002 | 0.62 | 0.532 | -0.021 | 0.041 |
| Extension services | -0.078** | 0.009 | 0.82 | 0.041 | -0.109 | 0.266 |
| Farmer group | -0.217** | 0.010 | -2.07 | 0.038 | -0.421 | -0.012 |
| Credit | -0.074 | 0.010 | -0.75 | 0.454 | -0.267 | 0.119 |
| Sigma u | 0.8662*** | | | 0.000 | | |
| Sigma v | 0.2094*** | | | 0.000 | | |
| $\lambda$ | 4.1366*** | | | 0.000 | | |
| Prob>chi2 | 0.000 | | | | | |
| Log likelihood | -17.957 | | | | | |
| N | 360 | | | | | |

**, ** and *** Represents level of significance at 10%, 5% and 1%*
*Source: own computation*

**Table 3. Distribution of technical efficiency scores of the sampled respondents**

| Efficiency range levels | Frequency | Percentage (%) |
|---|---|---|
| 0.21-0.30 | 5 | 1 |
| 0.31-0.40 | 6 | 2 |
| 0.41-0.50 | 47 | 13 |
| 0.51-0.60 | 35 | 10 |
| 0.61-0.70 | 87 | 24 |
| 0.71-0.80 | 52 | 14 |
| 0.81-0.90 | 80 | 22 |
| 0.91-1.00 | 48 | 14 |
| Total observations | 360 | 100 |
| Mean Technical efficiency | 0.71 | |
| Minimum Technical efficiency | 0.21 | |
| Maximum Technical efficiency | 0.96 | |

*Source: Own computation*

Estimated elasticity of the mean Irish potato production with respect to; land, seed, labor, fertiliser and fungicide were 0.262, 0.629, 0.089, -0.299 and 0.131 respectively. Summation of the output elasticity gives 0.812 implying decreasing returns. Education, gender, extension services and farmer group variables were statistically significant at five percent level of significance. Education and access to extension had positive and significant effect on technical efficiency of smallholder farmers. The coefficient for membership to a farmer's group was significant and negative. The distribution of individual farm specific technical efficiency levels for the sampled Irish potato farmers is shown in Table 3.

The sampled farmers have different levels of technical efficiency ranging from 0.21 to 0.96 with an average score of 0.71. Half of the farms have a score of 0.71 or more.

### 3.3 Discussion

Land, seeds, fertilizer and fungicide variables were statistically significant in Irish potato production. When more land is brought under Irish potato production the yield gap will be reduced. This finding is similar with results of [13]. Irish potato seeds are a basic input for Irish potato production and use of quality seeds enhances productivity per unit area of land, however, caution should be taken not to apply more than the recommended amount of seeds. This finding is similar with [14]. Fungicide application on the other hand also positively affected Irish potato output similar to what was reported by [13,12]. Fertilizer had an unexpected sign but statistically affected Irish potato production in the study area. Increase in fertilizer affected Irish potato production negatively. This may be due to application of Diammonium phosphate (DAP) for long periods which has been associated with increased soil acidity. Probably the acidity problem is further aggravated by the fact that the soils in highland areas are obtained from acidic volcanic rocks and have been highly leached by high rainfall. This may cause nutrient imbalance in the soil that negatively affects potato yields. This finding contradicts [14,22] who reported that fertilizer (DAP) contributed positively towards Irish potato production.

For the technical inefficiency model a negative coefficient implied that as the independent variable increased, there was an increase in technical efficiency levels. Education variable had a negative coefficient indicating that education had a positive effect on technical efficiency. This suggested that increasing the number of years of schooling would increase technical efficiency in Irish potato production. The reason behind this observation probably was education sharpens farmers' skills and their ability to perceive technology use. Similar findings were observed in other studies [23,24, 25,26]. The negative coefficient on the gender variable implied that male farmers were more technical efficient than their female counterparts. Men and women carry out different functions in a household; do not have equal decision making power and access to agricultural production resources as per cultural practices. This may affect their contribution towards Irish potato production technical efficiency. A similar finding was reported by [27].

Farmers who accessed extension services were technically efficient than those who did not. Extension workers do provide information, guiding and motivation services to farmers about available farming technologies. Similar results were reported by [28]. Access to farmer group/ association was found to have negative and significant effect on technical inefficiency of Irish potato production. This was probably as a result of the group members having a platform where they obtained production information and farm inputs easily. Consistent findings were reported by [26,28]. Results on technical efficiency show that the farmers' level of technical efficiency ranged from 0.21 to 0.96 and the mean technical efficiency score was 70.7 percent implying that Irish potato smallholder farmers in Molo have the potential to increase their production by an average of 29.3 percent. Increase in technical efficiency may help the sample farmers reduce their costs of production and consequently increase gross margin of Irish potato producers.

## 4. CONCLUSION AND RECCOMENDA-TIONS

This study focused on measuring farm level technical efficiency among smallholder Irish potato farmers in Molo Sub County and its determinants by applying a descriptive research design. Cross-sectional data was collected through multistage sampling from smallholder Irish potato farmers located in Molo Sub County from April to June 2019. A Stochastic frontier approach assuming a Cobb-Douglas production function was adopted to analyze the level of

technical efficiency and explain variations in this technical efficiency across farmers and estimation was done by applying the maximum likelihood method

The mean technical efficiency score was found to be 70.7 percent, which indicated that there is 29.3 percent room to increase Irish potato production with the existing levels of farm inputs. The study concluded that land allocated to potato farming was the most responsive in increasing the yield. Hence, bringing more land under potato farming may be considered and more importantly use of quality seeds may increase productivity per unit of land. Fertilizer had negative effects on Irish potato production and this raised questions on the soil fertility issues. Therefore, this study recommends that soil testing may be considered as a basis for fertiliser application scheme.

Education, gender, access to extension services and farmer group/association variables influenced technical efficiency positively. Smallholder farmers with high level of education had high Irish potato production technical efficiency level. Therefore, farmers with high literacy level had high Irish potato production technical efficiency. Male Irish potato farmers were more technically efficient than their female counterparts suggesting that their productive potentials differ. Hence, a deeper understanding of gender contribution towards Irish potato production technical efficiency may help in effective allocation of farm inputs. Access to farmer groups and extension services by smallholder Irish potato farmer were key factors that increased technical efficiency. Policy makers may focus on increasing smallholder farmers' accessibility to extension services and encourage them to form or join existing groups in order to boost farmers' education and information on production. Accessibility to extension services by Irish potato farmers proved to be critical in improving potato production hence government should enhance accessibility to these services.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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