Journal of Nepal Agricultural Research Council
Vol. 9:47-60, December 2023
ISSN: 2392-4535 (Print), 2392-4543 (Online)
DOI: https://doi.org/10.3126/jnarc.v9i1.61585

Analysis of technical efficiency and yield gap of potato farmers in Nepal

Surya Prasad Adhikari [1@], Krishna Prasad Timsina[1], Yuga Nath Ghimire[2], Samaya Gairhe[3], Peter R. Brown[4], Renato Villano[5]

[1]Nepal Agricultural Research Council (NARC), National Agricultural Policy Research Centre, Khumaltar, Lalitpur, Nepal;@adhikarisurya56@gmail.com, https://orcid.org/0000-0002-2712-9387;
KPT: krishnatimsina2000@gmail.com; https://orcid.org/0000-0003-4005-7039
[2]Nepal Agricultural Research Council (NARC), Directorate of Planning and coordination;
YN: ynghimire@gmail.com
[3]Nepal Agricultural Research Council (NARC), Monitoring and Evaluation division; SG: samaya43@gmail.com
[4]Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, Australia;
RB: Peter.Brown@csiro.au
[5]UNE Business School, University of New England, Armidale, NSW 2351; RV: rvillan2@une.edu.au

Received: July 15, 2022, Revised: August 02, 2023 Accepted: Sept. 12, 2023
Published : 27 December, 2023.

The authors declare that there is no conflict of interest.

ABSTRACT

The productivity of potato production in Nepal is low compared to neighbouring countries because of a range of production constraints. Potatoes are an important staple crop and commodity for many communities throughout Nepal, thus imperative to improve their performance for the benefit of smallholder producers and consumers. This study aims to identify the technical efficiency and yield gap of potato farmers. Farm-level data from 300 potato farmers randomly selected from three districts of Nepal is used to estimate a stochastic frontier model. The model allows us to estimate the production elasticity coefficients of inputs, determinants of efficiency and technical efficiency of potato farmers. Results showed that among the production variables, seed rate and labour used were positive towards potato production, whereas seed source, extension contact, variety type, and irrigation used were negatively significant factors that influences the technical inefficiency. The mean technical efficiency value of potato farmers was 68%, and there was clear scope to increase potato production by 32% with the better use of available resources. The potential yield gap can be reduced if the adoption of proper agricultural practices such as the use of improved potato varieties with formal seed sources with recommended seed rates along with irrigation application. Such efforts from policymakers and other concerned stakeholders would help improve domestic production and reduce the dependency on potato imports.

Keywords: Coefficient, Determinants, Elasticity, Stochastic

सारांश

छिमेकी देशहरुको तुलनामा नेपालमा आलुको उत्पादकत्व विभिन्न कारणहरुले गर्दा कम छ । आलु नेपालमा धेरै समुदायहरूका लागि एक महत्वपूर्ण बाली हो, त्यसैले साना कृषकहरु र उपभोक्ताहरूको फाइदाको लागि यसको खेति प्रणालीमा सुधार गर्न आवश्यक देखिन्छ। यस अध्ययनको उद्देश्य आलु किसानहरूको प्राविधिक दक्षता र उत्पादनको अन्तर पहिचान गर्ने हो । यसको लागि स्टोकास्टिक फ्रन्टियर मोडेलको प्रयोग गरिएको छ, जसको लागि तीन जिल्लाहरु सुनसरी, बारा र कैलालीबाट ३०० जना आलु कृषकहरु छनौट गरिएको थियो । उक्त मोडेलले आलु उत्पादनको क्षमता वृद्धि गर्ने कारक तत्वहरु र आलु किसानहरूको प्राविधिक दक्षताको मापन गर्दछ । नतिजा अनुसार बीउको दर र आलु खेतीमा प्रयोग भएको श्रम, आलु उत्पादनमा सकारात्मक कारकहरु थिए भने बीउको स्रोत, कृषि प्रसारकहरु संगको सम्पर्क, जातको किसिम, र सिँचाइको प्रयोग प्राविधिक असक्षमतालाई असर गर्ने नकारात्मक महत्वपूर्ण कारकहरू थिए। आलु किसानहरूको औसत प्राविधिक दक्षता ६८% थियो र उपलब्ध स्रोतहरूको राम्रो प्रयोग गरेमा आलु उत्पादन ३२% ले थप वृद्धि गर्ने सकिने देखिन्छ। आलु खेतीमा सिँचाइको प्रयोगको साथै प्रमाणित गरिएको आलुका उन्नत जातहरूको प्रयोग तथा उचित कृषि

अभ्यासहरू अपनाएमा उत्पादकत्वमा हुने अन्तरलाई कम गर्न सकिन्छ। नीति निर्माताहरू र अन्य सरोकारवालाहरूबाट हुने यस्ता प्रयासहरूबाट आलुको उत्पादन वृद्धि गर्न र आयातको निर्भरता कम गर्न मद्दत गर्नेछ।

INTRODUCTION

The potato is a key staple food crop throughout parts of Nepal, particularly in the High hill regions, but it is also a major vegetable crop in the Terai and mid hill regions of Nepal. Nepalese farmers have been cultivating potatoes for over 200 years and it is one of the important crops to address the problem of food insecurity because it can be grown year-round and can be stored for many months. Potato production plays an important role in the economy of Nepal. It accounts for 42.46 % of the total vegetable-cropped area of Nepal providing economic benefits as well as creating employment opportunities for rural farmers. The area under this crop is 198,256 ha with a production of 3,410,829 mt. The national average productivity of potato is 17.20 mt/ha (MoALD 2023).

The productivity of potato in Nepal is below that of neighbouring countries of India and China with 22.56 and 18.76 mt/ha respectively. In 2020, Nepal imported 18,6772 mt of potatoes with a value of US$40,412,000 which has been increasing over the last 10 years (FAOSTAT 2020). Although the annual growth rate of potato productivity was 1.76% per annum in the last 17 years, the gap between potential yield and farm-level production was still very high (Timsina et al 2019). The lower level of production was associated with the poor adoption of agricultural technologies, inefficient use of resources such as land and fertilizer, and lack of research (Adhikari and Bjorndal 2012, Bhattarai et al 2015). There are various technical, environmental, and socioeconomic factors contributing to low potato production in Nepal. To substitute the import of potato, it is necessary to increase production through improvements in potato production efficiency. To increase the efficiency of potato farmers, it is important to know the causes of the inefficient use of resources. Improving efficiency in production allows farmers to increase their output without additional input and changing production technologies resulting in increased productivity (Bravo-Uretra and Pinheiro 1997). In general, resources in the agricultural sector, especially in under-developed countries like Nepal, are being inefficiently utilized (Ahmad et al 2006). Potato productivity and efficiency may be affected by various farm-specific factors such as variety types, amount of fertilizer and seeds, labour use, irrigation condition, farm size, family size, credit accessibility to farmers, technical support, education level of household head, land type, land use pattern, etc. Technical efficiency is the capacity of a farm to produce an optimum quantity of output with the given level of inputs. To increase the productivity of smallholder farmers more efficient use of input is necessary. Several studies have been conducted about potato productivity and the technical inefficiency of potato in developing countries. Amara et al (1999) analyzed the technical efficiency among potato farmers and examined the farmers' attitudes towards technological innovation. Galabada et al. (2014) in Sri Lanka found that there were opportunities in improving resource use efficiency in potato farming. Barasa et al. (2019) in Kenya reported that the mean technical efficiency of potato farmers was estimated at 65%. They found that technical efficiency was positively influenced by the age of the farmer, education years, farming experience, frequency of extension services, and land size, whereas negatively influenced by household size.

Research on the technical efficiency of potato farmers in Nepal is limited, with the majority of the research focused on adoption-related issues. A study conducted in Eastern Hill of Nepal revealed that the improved seed had a positive impact on vegetable production efficiency (Shrestha et al 2015). Enhancing the adoption of improved potato varieties could impact farmers' income, household food, and nutritional security (Gairhe et al 2017). Shrestha et al (2015) found that farm-specific factors such as seed types, credit access, and technical support significantly affected inefficiency in vegetable production. Furthermore, policies need to focus on innovating and adopting improved seed varieties, easy access to credit facilities, technical support, and backstopping farmers. Increasing potato yield and minimizing the yield gap are essential to uplift the economic status of Nepalese farmers. The technical efficiency yield gap is due to crop management inefficiencies in production. The main factors contributing to the technical efficiency yield gap are gaps in knowledge, information and skills such as appropriate use of inputs, combination and timing of inputs (Dijka et al 2020).

The objective of this paper is to provide a detailed analysis of the performance of potato production and the yield gap due to technical inefficiency in Nepal. Thus, this study is important to policymakers as the information can be used to identify major intervention areas to improve productivity. Furthermore, the identification and implementation of appropriate management practices to increase efficiency will result in increasing potato productivity among potato farmers in Nepal.

MATERIAL AND METHODS

The data for this study were obtained from a survey of potato farmers from the Terai region of Nepal, which covered three districts: Jhapa from the eastern, Bara from the central, and Kailali from the western Terai of the country. A multistage random sampling procedure was employed for the selection of respondents. Firstly, three districts from each region were selected based on the highest areas of potato production. Secondly, three pockets in each district were selected based on potato area and variety used to capture the variations within the districts after the consultation with the Agriculture Knowledge Centre and agricultural officials of the local government. Finally,100 households from each district were selected using proportionate random sampling from each pocket. Therefore, a total of 300 households were selected for the study. A questionnaire was restructured according to the feedback from pretesting. The household survey was conducted from February to April 2019.

The questionnaire consisted of 50 questions and took approximately 30 minutes to complete. The questionnaire captured data on the amount of potato production and production-related socioeconomic variables. Information was collected on input-output variables such as labour hours, farm size, fertilizer dose, tillage hours, and seed quantity. Socio-demographic factors such as age, education, access to credit, training received, household size, migration status, variety types, and irrigation application. One focus group discussion was conducted in each pocket. The collected information from three districts was entered in excel and data analysis was conducted using the software Stata (version 16.1). The research area is delineated in **Figure** 1.

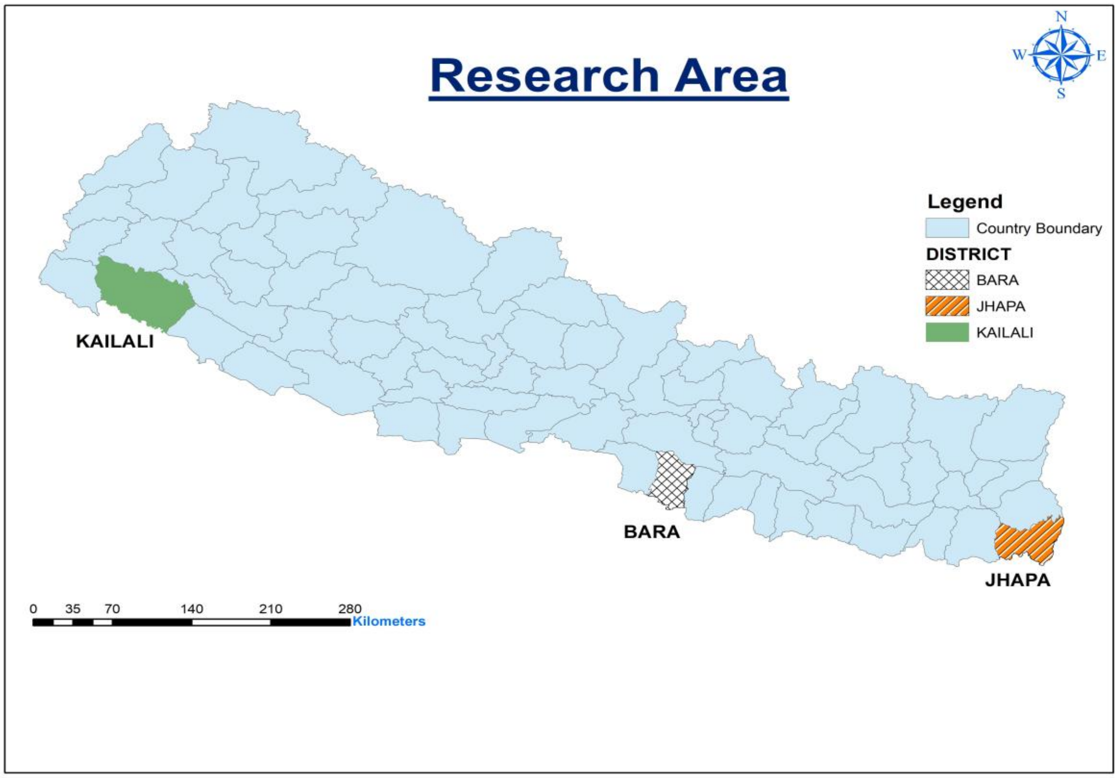

Figure 1. Research Area

Methods of data analysis

Descriptive statistics

Descriptive statistics were used to analyze the survey data using measures of dispersion such as percentage, frequency, and measures of central tendency such as mean, and standard deviation.

Econometric model

The focus of this study was to determine the level of technical efficiency of potato farmers across the Terai region of Nepal. There are two methods to determine technical efficiency: (1) data envelopment analysis (DEA) and (2) stochastic frontier method. The former is a nonparametric approach that developed out of mathematical programming techniques while the latter is a parametric approach that estimates technical efficiency within a stochastic production function model (Chakraborty et al 2002, Coelli et al 2005). The parametric approach considers the production functional form from a priori estimation of the data, while the non-parametric approach uses the data to determine the functional form. The major limitation of the non-parametric approach is that it assumes no sampling error and attributes all deviations from the production frontier to inefficiency (Diagne et al 2013). In this study, stochastic frontier analysis was used in preference to the DEA.

Stochastic production frontier model

The stochastic frontier regression model is a parametric analysis that has been commonly used to estimate technical inefficiency. The stochastic production function frontier shows the most efficient use of inputs to produce the maximum output. This study uses the method of estimating a stochastic frontier production function proposed by Aigner et al (1977), and Meeusen and Van Den Broeck (1977). Kumbhakar et al (1991) extended the stochastic frontier methodology by openly introducing the determinants of technical efficiency into the model. The stochastic frontier production function differs from the traditional production function in that it consists of two error terms. The first error term accounts for technical efficiency and the second for factors such as measurement error in the output variable, the weather, and the combined effects of unobserved inputs. It is a homogeneous function that provides a scale factor enabling one to measure the return to scale and to interpret the elasticity coefficients with relative ease. It is also relatively easy to estimate because in the logarithmic form; it is linear and parsimonious (Beattie and Taylor 1985).

One-step Stochastic Production Frontier

A two-step procedure has commonly been used to estimate the stochastic production frontier. This approach estimates the observation-specific inefficiency measure in the first step and then estimates the effect of the explanatory variables on the inefficiency measures in the second step. The two-step estimation procedure is recognized as biased because the model estimated in the first step is misspecified (Battese and Coelli 1995). Furthermore, Wang and Schmidt (2002) explained that if X (Input variables) and Z (Inefficiency variables) are correlated then the first step of the two-step procedure is biased. Even if they are uncorrelated, ignoring the dependence of the inefficiency on Z will cause the first-step technical efficiency index to be undispersed, so that the results of second-step estimations are likely to be biased downward. Due to the unsatisfactory statistical properties of the two-step estimation, the better approach to incorporating exogenous influence on efficiency is the one-step procedure. Kumbhakar et al (1991) and Reifschneider and Stevenson (1991) proposed a one-step stochastic frontier in which the inefficiency effects are expressed as an explicit function of the vector of firm-specific variables and a random error. Therefore, in this study, all the parameters of the stochastic frontier model and inefficiency function were estimated together with a single maximum likelihood estimation (MLE) procedure.

Functional forms determination

Several functional forms have been developed to measure the relationship between input and output. The most common functional forms are the Cobb–Douglas and transcendental logarithmic (translog) functions. The Cobb–Douglas has been widely used in many empirical studies particularly those related to developing countries for farm efficiency analysis (Bravo-Ureta and Pinheiro 1997). Cobb-Douglas specification provides an adequate representation of agricultural production technology. In this study, we use an empirical Cobb-Douglas frontier production function model with double log form, which can be expressed as:

$$\text{Ln (Yield)} = ß_0 + ß_1 \ln(\text{Total labour in hours}) + ß_2 \ln(\text{Inorganic fertilizer}) + ß_3 \ln(\text{Tillage hours}) + ß_4 \ln(\text{Total seed}) + (V_i - U_i)$$

Where Ln is the natural logarithm, the dependent variable yield is the potato production per hectare (Kg/ha), $ß_0$ –$ß_4$ are the parameters to be estimated. The inputs variables are total labour hours required per hectare, inorganic fertilizer is the amount of Urea, DAP (Diammonium Phosphate), Potash and other micronutrients per hectare (Kg/ha), ploughing constitutes total tillage hours required for one hectare of land, the total seed is the potato seed rate per hectare (kg/ha), V_i is a two-sided random error component beyond the control of the farmer and U_i is a one-sided inefficiency component. In this study, the half-normal distribution is assumed for the asymmetric technical inefficiency parameter.

Estimation of technical efficiency

Following Battese and Coelli (1995), the farm-specific technical efficiency (TE_i) of the i^{th} sample farmer was estimated by using the expectation of U_i conditional on the random variable Єi.

$TE_i = \text{Exp} (-U_i)$

$= Y_i/f(X_i\, ß)\exp V_i$

$= Y_i/Y^*$

Where Yi = Observed output

Y^* = Frontier output

If $Y_i = Y^*$

Then, $TE_i = 1$ i.e. 100% efficient

Technical inefficiency model

The determinants of inefficiency were evaluated using the method proposed by Belotti et al (2013) by sfcross command, which estimated socioeconomic determinants of technical inefficiency in a single stage and is expressed as:
Technical inefficiency determinants are as follows.
U_i=ß0+ß1_i (Agesq)+ß2_i (Gender)+ß3_i (Migration)+ß4_i (Education)+ß5_i (Seed source) + ß6_i (Extension contact)+ ß7_i (Credit) + ß8_i (Membership) + ß9_i (Training)+ß10_i (Irrigation)+ ß11_i (Variety types) ß12_i (District Kailali)+ W_i

where U_i is technical inefficiency and W_i is a random error. The subscript i, indicates the i^{th} household in the sample (i=1,……..,300). ß0,………ß12 are the parameters to be estimated. The agesq represents square of years of age of the household head. In the case of gender, 1 implies male farmers and 0 implies female farmers. Migration represents any of the household members who go to other countries, 1 if they go abroad, 0 otherwise; education represents years of schooling for the household head. The seed source represents the source of seed for potato farming 1 if it is formal, 0 otherwise; extension contact represents 1 for farmers who have access to extension agents and 0 otherwise. Farmers who received agricultural credit indicate 1 and 0 for otherwise. The member household in agricultural cooperatives or groups is 1 and 0 otherwise. The training represents training related to potato farming, 1 if participants participated in training activities in the last 5 years and 0 otherwise. Likewise, 1 represents if farmers applied irrigation to potato farming and 0 otherwise, and variety represents potato seed varieties: 1 if the household used Nepalese improved variety seed and 0 if they adopted Indian or local seed varieties. Lastly, 1 indicates if the farmers were from the Kailali district and 0 for Jhapa and Bara districts.

RESULTS

Summary statistics

The variables used in this study are presented in **Table** 1. For the stochastic production function variables, the average total potato output was 12753 kg/ha. The productivity is lower than the national average productivity, which was 17200 kg/ha in 2018 (MoALD 2023). Farmers used an average of 970 hours of labour to produce the potato per hectare, but there was a wide variation from 306 to 2782 hours. Most of the farmers performed potato cultivation activities manually. The average amount of seeds used was about 1690 kg/ha. It is lower than the recommended dose, which is 2000 kg/ha.

Table 1. Descriptive statistics of the variables used in the model (N=300)

Variables	Mean	Std. Dev.	Min	Max
Total potato productivity (kg/ha)	12753	5469	1200	30000
Total labour (hours)	970	370	306	2782
Total inorganic fertilizer (kg/ha)	374.28	272.54	0	1875
Tillage hours (hour/ha)	13.06	6.47	2	33.33
Seed quantity (kg/ha)	1690	656	450	6000
Age of HH (Years)	48.35	11.78	19	78
Gender % (1=Male & 0= Female)	77.33	0.42	0	100
Migration (Yes %)	21.33	0.41	0	100
Education of household head (Years)	6.08	4.22	0	16
Seed source formal (Yes %)	42	0.49	0	100
Extension contact (Yes %)	37	0.48	0	100
Received agricultural credit (Yes%)	33	0.47	0	100

Variables	Mean	Std. Dev.	Min	Max
Membership (Yes %)	72	0.45	0	100
Training (Yes %)	19	.39	0	100
Irrigation used (Yes %)	82	0.39	0	100
Nepalese improved potato varieties (Yes%)	47.33	0.50	0	100
District (1= Kailali & 0=Others)	0.33	0.47	0	100

The average quantity of inorganic fertilizers (DAP, Urea and Potash) used was about 374 kg/ha. Among them, farmers applied DAP 119 kg, Urea 140 kg & Potash 100 kg in one hectare. The recommended dose is 220 kg DAP, 140 kg Urea, and 100 kg Potash in one hectare. Farmers were applying less DAP and Potash than the recommended dose. Almost all of the farmers performed tillage operations by tractor. Farmers used an average of 13 hours for tillage operations to produce potatoes per hectare. To determine factors related to inefficiency, socioeconomic variables were incorporated into the stochastic frontier model. The average age of the household head was 48 years. The household head is a member of the family who has a major role in managing agricultural activities. About one-fifth of the household members migrated to other countries. The average education of the household head was 6 years of schooling. About 42% of farmers obtained certified seeds from a formal source. The certified seed is one that has been produced by a seed producer agency to assure its genetic purity and physical quality with good tag and label, and it's a major factor leading to increased productivity (Mataia et al 2011). Formal sources included government farms, cooperatives, and agrovets, while informal sources consisted of savings and seeds from neighbours and relatives. Likewise, about 37% of farmers have access to contact with government extension personnel. Further, about one-third of the farmers received credit for agricultural purposes. Similarly, about three-quarters of farmers are involved as members of agricultural-related cooperatives and groups. In terms of training, only 19% of farmers received potato-related training. Furthermore, about 82% of farmers used irrigation through pumps and canal irrigation in potato farming. Lastly, in terms of variety, about 47% of farmers used Nepalese improved (NARC released and registered) varieties, while the other farmers used Indian and local varieties. The major Nepalese varieties include Janakdev, Cardinal, and Khumal Red. Indian varieties were Arun Gold, C-40 and Kanpur whereas farmers cultivated Tharu Aalu as a local variety. In the model, we used the Kailali district as a dummy variable.

Hypothesis testing

A generalized likelihood ratio (LR) test was employed to determine which model is better (null hypotheses, **Table** 2) prior to proceeding to the empirical analyses of technical efficiency. We used the LR test based on log-likelihood values for the restricted and unrestricted models. The first null hypothesis tested was the test for the existence of the inefficiency component of the composed error term. This null hypothesis was rejected because the LR- value (102.02) is greater than the critical value (5.41) (d.f. = 1, P < 0.01) (**Table** 2).

The second null hypothesis tested was a test for appropriate functional form; Cobb-Douglas versus Translog production functional form. The calculated LR test value (-70.93) is lower than the critical value of Chi-square (29.92 at d.f. = 15, P < 0.05) (**Table** 2). This implies that the Cobb-Douglas functional form was preferred to estimate the technical efficiency of the potato farmers. The same results are obtained while testing the third null hypothesis evaluated between half-normal and truncated normal distributions (**Table** 2). The null hypothesis is accepted, therefore, we used a half-normal distribution in the stochastic production frontier model.

Table 2. Summary of the test of hypothesis

S.N	Null hypothesis	Degree of freedom	LR-value	X^2 value	Decision
1.	H_0= Technical inefficiency does not exist H_1= Presence of technical inefficiency	1	102.02	5.41	Reject
2.	H_0= Appropriate production functional form is Cobb-Douglas H_1= Appropriate production functional form is Translog	15	-70.93	29.92	Accept
3.	H_0= The inefficiency effect follows a half normal distribution H_1= The inefficiency effect follows a truncated normal distribution	2	4.72	8.27	Accept

Empirical results

Explanatory variables and inefficiency variables selected for estimation were checked for the multicollinearity problem using the Variance Inflation Factor (VIF) before the estimation of the stochastic frontier production function model was conducted. A value of VIF above 10 is considered serious multicollinearity (Gujarati 2006), but in our result, none of the variables' VIF values exceed 2; the average VIF value found in the case of explanatory variables were 1.08 and 1.07 for inefficiency variables.

A Cobb-Douglas production function was estimated using half-normal stochastic production methods. All input variables and dependent variables were log-transformed, and the coefficient represents elasticity. The value of gamma (γ) was 0.79, which is the ratio of the variance of the inefficiency component to the total error term. It indicates that about 79% of the variation in the output of potato farmers was due to technical efficiencies. Likewise, the ratio of the standard deviation of u to that of v (λ) is greater than 1, and it is statistically different from 0, which confirms a good fit of the error term. Additionally, the value sum of the parameters estimated from Cobb Douglas production associated with all the inputs is 0.81, which indicates a decreasing return to scale. This implies that a 1% increase in all production input variables leads to a 0.81% increase in potato production.

Among the production variables, seed quantity and labour use were significant and had a positive and significant effect on potato production. Seed quantity was significant ($P<0.01$), indicating that a 1% increase in seed quantity increases potato production by 0.48%. Similarly, labour quantity was positive ($P<0.01$), indicating that a 1% increase in labour quantity increases the potato output by 0.18%.

Table 3. Input elasticity and socio-economic determinants of inefficiency

Variable	Coefficient	Standard error	p-value
lnLabour	0.175^{***}	0.066	0.008
lnTotal inorganic fertilizer	-0.001	0.009	0.911
lnTillagehours	0.062	0.042	0.138
lnSeed	0.481^{***}	0.074	0.000
Constant	4.883^{***}	0.693	0.000
	Inefficiency component		
Agesq	-0.000	0.000	0.397
Gender	0.002	0.287	0.995
Education of household head	-0.028	0.027	0.291
Seed source	-0.449^{*}	0.255	0.078
Training	0.470	0.316	0.137

Variable	Coefficient	Standard error	p-value
Membership	-0.133	0.273	0.625
Migration	-0.233	0.284	0.413
Extension contact	-0.468*	0.284	0.099
Agricultural credit	-0.269	0.255	0.292
Irrigation used	-1.065***	0.303	0.000
Potato variety	-0.635**	0.302	0.035
District_Kailali	-0.698**	0.337	0.038
Constant	0.872	0.540	0.106
Other statistics			
σ_u	0.525		
σ_V	0.254		
Gamma (γ)	0.79		
Lambda (λ)	2.06		
Log likelihood	-146.02		
Return to scale	0.81		
Number of observations	300		
Wald chi^2 (6)	54.50		

*Note: *P < 0.1, **P < 0.05, ***P < 0.00*

The inefficiency factors presented in **Table** 3 relate to the farmers' socioeconomic characteristics. Among the 12 variables used in the inefficiency components, five variables such as seed source, extension contacts, variety type, irrigation use and district variables, significantly influenced technical inefficiency. Farmers who purchased seed from formal sources had a negative effect on technical inefficiency. Likewise, extension service negatively influences the technical efficiency of potato production at a 10% level of significance. Similarly, the dummy variable use of improved potato varieties had a negative effect on technical inefficiency (P<0.01). Furthermore, the coefficient of irrigation availability was negative (P<0.01), meaning that when other factors are held constant, farmers who irrigated at least once for potato farming are more technically efficient than others who did not apply irrigation. Lastly, farmers from the Kailali district had a greater negative influence on the technical inefficiency of potato production than farmers from the Jhapa and Bara districts.

Level of Technical Efficiency of Potato Farmers

Table 4 shows the summary and distribution of the technical efficiency of potato farmers in the Terai region of Nepal. We found a mean technical efficiency score of about 0.68 (± 0.17 sd; range = 0.08 to 0.92). Most farmers (58%) have a TE value of >70%, with about a quarter of the farmers with a TE value of <60%.

Table 4. Distribution of technical efficiency of potato farmers in Nepal

Efficiency level	Frequency	Percent (%)
Less than 0.5	45	15.00
0.51-0.6	35	11.66
0.61-0.7	46	15.33
0.71-0.8	80	26.66
0.81-0.9	89	29.66
0.91-1.0	5	1.66
Total	**300**	**100**
Mean	0.68	
Standard deviation	0.17	
Minimum	0.08	
Maximum	0.92	

Estimates of potato yield gap due to inefficiency

The yield gap is defined as the difference between technically efficient production and actual production in farmers' fields. Therefore, the yield gap is the amount that represents a lower yield due to technical inefficiency. From the stochastic model, the TE of the ith household is estimated to be:

TEi=Yi/Yi*

Yi*=Yi/TEi

where TEi is the technical efficiency of the ith sample household in potato production;

Yi= Actual/observed yield of the ith sample household in potato production

Yi* = Frontier/ potential output of the ith sample household in potato production

The estimated potential yield of potato for each sample household in potato production is presented in **Table** 5. The observed yield was 12,753 kg/ha and the computed mean potential yield was 17,998 kg/ha. It was noticed that the mean yield gap was 5,246 kg/ha at 68% mean technical efficiency, indicating that surveyed households were producing 5,246 kg/ha less potato than their potential yield.

Table 5. Potato yield gap due to technical inefficiency

Variable	Mean	Min	Max	Std. Dev.
Actual yield (Kg/ha)	12753	1200	30000	5469
TE estimates	0.684	0.089	0.922	0.169
Potential/frontier yield (Kg/ha)	17998	8196	34243	4616
Yield gap/loss (Kg/ha)	5246	2131	21187	2499

DISCUSSION

Production variables seed and labour used contributed significantly positive towards potato productivity, whereas, in the inefficiency model, seed source, extension contact, variety type and irrigation influenced significantly negative to the technical inefficiency.

The stochastic frontier model estimated that the seed rate had a positive effect on potato productivity. Farmers applied a low seed rate compared to recommendations. The higher seed rate increases the plant population density and yield (Ahmad et al 2006). A study conducted by Bajracharya and Sapkota (2017) also reported that farmers were unaware of the recommended seed rates and used a lower rate of seed in the Baglung district of Nepal. However, the result is contradicted by Wassihun et al (2019), who mentioned that a higher than recommended seed rate may result in low potato production due to high competition for nutrients. Furthermore, labour used in potato farming also positively influenced potato production. Potato farming is labour-intensive and farmers rely heavily on manual labour. The high labour demands are required for better weeding, fertilizer and pesticide application. Similarly, more labour is also required for land preparation, planting, and harvesting processes. Therefore, households with higher labour demand not only performed their cultural activities very well but also increased their level of technical efficiency. The result is consistent with Dube et al (2018) in Ethiopia, where the amount of seed, area of the plot and labour were positive and significant input variables in potato production.

In the inefficiency model, we found that the seed source was negative toward technical inefficiency. Farmers who purchased potato-certified seeds from a formal channel such as agrovets, government farms and cooperatives were more efficient than those who used their own seed and obtained it from neighbours and relatives. A study conducted by Villano et al (2015) in the Philippines found that the adoption of certified seeds had a positively significant impact on efficiency in rice farming. The impact of extension personnel visits had significant and negative towards technical inefficiency. This result is consistent with the finding of Mango et al. (2015) and Solis et al (2009) who found that access to extension contacts can increase technical efficiency. Andaregie & Astatkie (2020) and Dube et al (2018) also reported that potato farmers with close contact with extension agents improve technical efficiency.

The cultivation of improved varieties had a significant and negative impact on technical inefficiency. In Nepal, farmers are cultivating Nepalese improved, Indian, and local potato varieties. Up until now, the Nepal Agricultural Research Council (NARC) has released eleven and registered five potato varieties. These varieties have a large yield potential, and the adoption of these varieties can greatly enhance national potato production (Kafle and Shah 2012). Moreover, improved varieties have high yield potential and diffusion of these technologies can greatly enhance national potato production (Tufa et al 2015). Farmers who adopted NARC-released and registered potato varieties were more efficient than farmers who adopted Indian or local potato varieties. However, the dominance of old varieties exists in the field (Gairhe et al 2023). In Nepal, the lack of improved quality seed was the most important problem in potato production (Subedi et al 2019). Most of the farmers that used Indian and local varieties used ware potatoes as a seed because those varieties did not have any formal seed chain. Andaregie & Astatkie (2020) and Wassihum et al (2019) also found that potato farming with improved varieties was more efficient compared to using local varieties. Furthermore, similar findings showed that the use of improved varieties and technical efficiency were positively correlated (Jwanya et al 2014, Deressa et al 2017).

The irrigation dummy variable had a significant and negative effect on the technical inefficiency that farmers who applied irrigation water to their counterparts. In Nepal, potatoes are cultivated in both irrigated and rainfed conditions. Irrigation has an important role as they are very sensitive to water stress during tuber initiation and tuber bulking stages, which have an adverse effect on potato productivity (Foti et al 1995, Ierna and Mauromicale 2012). Mardani and Salarpour (2015) stated that irrigation improvement along with a proper application of fertilizers, pesticides, and machinery could have a significant role in the efficiency of potato production. Andaregie & Astatkie (2020) and Alam et al (2012) found that irrigation application had a positive and significant impact on the technical efficiency of potato production in Ethiopia and Pakistan respectively.

Lastly, the average level of technical efficiency of potato farmers in the study area (68%) implies that potato farmers have an opportunity to improve their productivity by 32% with existing technologies and resources if inefficiency factors are addressed. The finding is consistent with the result obtained by Tiruneh et al (2017), they found that the technical efficiency of potato farmers was 68% in irrigated condition. However, Andaregie & Astatkie (2020), and Wassihun et al (2019) reported technical efficiency of potato farmers in Ethiopia was 75% and 46% respectively.

CONCLUSION

This paper determines the technical efficiency level of potato farmers and its determinants in Nepal. Moreover, it also estimates the yield gap of potato farmers due to technical inefficiency. The empirical analysis was carried out by employing half-normal stochastic frontier analysis. Results showed that among the four main factors of production (seed, labour, fertilizer and tillage hours), seed and labour were the major factors associated with potato production. The significant determinants of technical inefficiency variables include the use of the certified seed, extension contact, adoption of improved varieties and irrigation. Farmers who purchased certified seeds from the formal channel have a higher level of technical efficiency than those who used their own uncertified seeds. Likewise, farmers who had close contact with extension agents were more efficient than farmers who had fewer extension contacts. Similarly, the adoption of NARC-released improved varieties was also positively related to the technical efficiency of potato farmers. Farmers who adopted NARC-released improved potato varieties (Janakdev, Cardinal, Khumal Red, etc.) have a higher level of technical efficiency than those farmers who adopted Indian (Arun Gold, Kanpure, C-40) or local varieties (Tharualu). Farmers who applied irrigation in potato farming were more technically efficient than those in rainfed conditions.

The yield gap (5246 kg/ha) can be improved through the improvement of inefficiency factors. For increasing efficiency, the extension agents should play a significant role in promoting certified seeds of newly released improved varieties along with providing technical support on potato seed rate and irrigation application.

ACKNOWLEDGEMENTS

We thank all colleagues who helped to collect the data during the survey. We are grateful to the farmers in the Jhapa, Bara and Kailali districts of Nepal who gave their valuable information and time to complete this research.

REFERENCES

Adhikari CB and T Bjorndal. 2012. Analyses of technical efficiency using SDF and DEA models: evidence from Nepalese agriculture. Applied Economics, **44** (25):3297-3308. **DOI**: https://doi.org/10.1080/00036846.2011.572856

Alam A, H Kobayashi, T Matsuda, A Ishida, I Matsumura and M Esham. 2012. Stochastic frontier approach to measure the technical efficiency of two irrigation systems in Gilgit district, Gilgit-Baltistan region of Pakistan. Journal of Food, Agriculture and Environment. **10**:543–550.

Andaregie A and T Astatkie. 2020. Determinants of technical efficiency of potato farmers and effects of constraints on potato production in Northen Ethiopia. Experimental Agriculture. **56**:699-709. **DOI**: https://doi.org/10.1017/S0014479720000253

Ahmad B and BK Abedullah. 2006. Technical efficiency and its determinants in potato production, evidence from Punjab, Pakistan. Lahore J Econ. **11**(2):1–22.

Aigner D, CAA Lovell and P Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. Journal of Economics. **6** (1):21–37.

Amara N, N Traorr, R Landry and R Romain. 1999. Technical efficiency and farmers' attitudes toward technological innovation: The case of the potato farmers in Quebec. Canadian Journal of Agricultural Economics. **47**:31-43.

Bajracharya M and M Sapkota. 2017. Profitability and productivity of potato (Solanumtuberosum) in Baglung district, Nepal. Agriculture & Food Security. **6**(47): 1-8.

Barasa AW, PO Odwori, J Barasa and S Ochieng. 2019. Technical efficiency and its determinants on Irish Potato farming among small holder farmers in Trans-Nzoia County-Kenya. International Journal of Research and Innovation in Social Science. **5**(3):235-238.

Battese GE and TJ Coelli. 1995. A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data. Empirical Economics. **20**(2):325–332.

Beattie BR and CR Taylor. 1985. The Economics of Production. Montana State University, John Wiley & Sons, New York, USA.

Belotti F, S Daidone, G Ilardi and V Atella. 2013. Stochastic frontier analysis using Stata. The Stata Journal. **13**(4):719-758.

Bravo-Ureta BE and AE Pinheiro. 1997. Technical, economic and allocative efficiency in peasant farming: evidence from the Dominican Republic Dev Econ. **34**:48–67.

Bhattarai B, R Beilin and R Ford. 2015. Gender, agrobiodiversity, and climate change: a study of adaptation practices in the Nepal Himalayas. World Dev. **70**:122–132.

Chakraborty C, SK Mishra and PN Johnson. 2002. Cotton farmer's technical efficiency: Stochastic and non stochastic production function approaches. Agric. Resour. Econ. Rev **31**: 211-220.

Coelli TJ, DSP Rao, CJ O'Donnell and GE Battese. 2005. An Introduction to efficiency and productivity analysis 2nd edition. Springer US. **DOI**: https://doi.org/10.1007/b136381

Deressa B, D Garoma, CS Reddy and B Alemu. 2017. Analysis of technical efficiency of potato (Solanumtuberosum) production: in the case of Welmera Districts, Oromia Regional State, Ethiopia. International Journal of Basic and Applied Science. **7**:43–56.

Diagne M, M Demont, P Seck and A Diaw. 2013. Self-sufficiency policy and irrigated rice productivity in the Senegal River Valley. Food Security **5**: 55-68. **DOI**: https://doi.org/10.1007/s12571-012-0229-5

Dijk MV, T Morley, MV Loon, P Reidsma, K Tesfaye and MK Ittersum. 2020. Reducing the maize yield gap in Ethiopia: Decomposition and policy simulation. Agricultural Systems. **183**: 1-11. **DOI**: https://doi.org/10.1016/j.agsy.2020.102828

Dube AK, B Ozkan, A Ayele, D Idahe and A Aliye. 2018. Technical efficiency and profitability of potato production by smallholder farmers: The case of Dinsho District, Bale Zone of Ethiopia. Journal of Development and Agricultural Economics. **10**(7): 225-235

Farrel M. 1957. The measurement of production efficiency. Journal of the Royal Statistical Society. **120**(3):253-290.

Food and Agriculture Organization of the United Nations. 2020. FAOSTAT statistical database. [Rome]: FAO

Foti S, G Mauromicale and A Ierna. 1995. Influence of irrigation regimes on growth and yield of potato cv. Spunta. Potato Research. **38**:307–318.

Gairhe S, D Gauchan and KP Timsina. 2017. Adoption of improved potato varieties in Nepal. Journal of Nepal Agriculture Research Council. **31**: 38–44. **DOI:** https://doi.org/10.3126/jnarc. v3i1.17274

Gairhe S, KP Timsina, YN Ghimire, SP Adhikari, D Gauchan, KP Upadhyay, BP Prasai and P Bhattarai. 2023. Does potato seed system working effectively in Nepal? Nepal Agriculture Research Journal. **15**(1): 1-19. **DOI:** https://doi.org/10.3126/narj.v15i1.51015

Galabada JK, HU Warnakulasooriya, KS Karunagoda and THCS Perera. 2014. Level of protection and competitiveness of the potato sector, Sri Lanka. Annals of the Sri Lanka Department of Agriculture. **16**:169-181

Gujarati DN. 2006. Basic econometrics, 4th edn. Tata Mc Graw-Hill, New Delhi

Ierna A and G Mauromicale. 2012. Tuber yield and irrigation water productivity in early potatoes as affected by irrigation regime. Agric. Water Manage. **115**:276–284

Ierna A, G Pandino, S Lombardo and G Mauromicale G. 2011. Tuber yield, water and fertilizer productivity in early potato as affected by a combination of irrigation and fertilization. Agric. Water Manage. **101**:35-41.

Jwanya BA, NC Dawang, IM Mashat and BS Gojing. 2014. Technical efficiency of rain-fed Irish potato farmers in Plateau State,Nigeria: a stochastic frontier approach. Developing Country Studies. **22**(4):34-39.

Kafle B and P Shah. 2012. Adoption of improved potato varieties in Nepal: A case of Bara district. J Agri Sci. **7**: 14-22.

Khanal U, C Wilson, S Shankar, VN Hoang and B Lee. 2018. Farm performance analysis: Technical efficiencies and technology gaps of Nepalese farmers in different agro-ecological regions. Land Use Policy. **76**: 645-653. **DOI:** https://doi.org/10.1016/j.landusepol.2018.02.045

Kumbhakar SC, S Ghosh and J McGuckin. 1991. A generalized production frontier approach for estimating determinants of inefficiency in U.S. Dairy Farms. Journal of Business & Economic Statistics. **9**(3): 279-286

Levy D, WK Coleman and RE Veilleux. 2013. Adaptation of Potato to Water Shortage: Irrigation Management and Enhancement of Tolerance to Drought and Salinity. American Journal of Potato Research. **90**:186-206. **DOI**: https://doi.org/10.1007/s12230-012-9291-y

Mardani M and M Salarpour M. 2015. Measuring technical efficiency of potato production in Iran using robust data envelopment analysis. Information Processing in Agriculture. **2**: 6-14.

Mataia A, N Jamora, P Moya, S Francisco and D Dawe. 2011. Sources of decade rice yield growth in the Philippines. Philippine Journal of Crop Science. **36**: 20–29.

MoALD. 2019. Statistical Information on Nepalese Agriculture. Ministry of Agricultural and Livestock Development. Monitoring, evaluation and statistics division, Singhdurbar, Kathmandu.

Meeusen W and JVD Broeck. 1977. Efficiency estimation from Cobb–Douglas production functions with composed error. International Economic Review. **18** (2):435-444.

Panta S, UP Sigdel and GD Awasthi. 2019. Adoption of recommended production practices of a cardinal variety of potato among potato growing farmers in Dadeldhura. ACTA Scientific Agriculture. **3**(2): 144-148.

Prasanna R and N Lakmali. 2016. Estimating technical efficiency among smallholder potato producers in Welimada, Srilanka. Srilanka Journal of Economic Research. **4**(1): 59-74.

Reifschneider D and R Stevenson. 1991. Systematic departures from the frontier: a framework for the analysis of firm inefficiency. International Economic Review. **32**(3):715-723.

Sharif NR and A Dar. 1996. An empirical study of the patterns and sources of technical efficiency in traditional and HYV rice cultivation in Bangladesh. Journal of Development Studies. **32**: 612-629.

Shrestha RB, WC Huang and R Ghimire. 2014. Production Efficiency of Smallholder Vegetable Farms in Ilam District, Eastern Hill, Nepal. American- Eurasian Journal of Agriculture & Environment Science. **14**(2): 150-154.

Subedi S, YN Ghimire, S Gautam, HK Poudel and J Shrestha J. 2019. Economics of potato (Solanumtuberosum L.) production in Terai region of Nepal. Archives of Agriculture and Environmental Science. **4**(1):57-62. **DOI:** https://dx.doi.org/10.26832/24566632.2019.040109

Timsina KP, S Gairhe, YN Ghimire, HK Poudel, D Devkota, S Subedi and SP Adhikari. 2019. Returns to Potato Research Investment in Nepal. Journal of Agriculture and Natural Resources. **2**(1):1-13. **DOI**: https://doi.org/10.3126/janr.v2i1.26002

Tiruneh GW, A Chindi and G Woldegiorgis. 2017. Technical efficiency determinants of potato production: A study of rain-fed and irrigated smallholder farmers in Welmera district, Oromia, Ethiopia. Journal of Development and Agricultural Economics. **9**(8): 271-273. **DOI**: https://doi.org/10.5897/JDAE2016.0794

Tufa AH, MPM Gielen-Meuwissen, WJM Lommen, A Tsegaye, PC Struik and AGJM Lansink. 2015. Least-cost seed potato production in Ethiopia. Potato Research. **58**(3):277-300.

Villano R, BB Ureta, D Solis and E Fleming. 2014. Modern rice technologies and productivity in the Philippines: disentangling technology from managerial gaps. Journal of Agricultural Economics. **66**(1): 129-154. **DOI**: https://doi.org/10.1111/1477-9552.12081

Wan HJ and P Schmidt. 2002. One-step and two-step estimation of the effects ofexogenous variables on technical efficiency levels. J. Prod. Anal. **18** (2):129–144.

Wassihun AN, TD Koye and AD Koye. 2019. Analysis of technical efficiency of potato (Solanumtuberosum L.) production in Chilga District, Amhara National Regional State, Ethiopia. Economic Structures. **8**(34):1-18. **DOI**: https://doi.org/10.1186/s40008-019-0166-y

||-------|||-------||