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Research Article

Efficiency and Yield Gap Analysis in Potato Production: The Case of Potato Farmers in Central Highlands of Ethiopia

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The study examined efficiency, yield gap and level of responsiveness of output to the factors of production in potato production in central highlands of Ethiopia. The study used household level cross sectional data collected in 2015/16 from 196 sample farmers selected through multistage sampling technique. A stochastic frontier model was employed for the efficiency analysis. The scale coefficient for production function was calculated to be 1.1, indicating a 1% increase in all inputs proportionally increases total production by 1.1%. The mean technical efficiency and actual yield gap of sample households are 62.6% and 15.2 t/ha respectively. Eighty-six percent of the yield variation in potato production is due to technical inefficiency and accounts for 13.07 t/ha yield gap. Therefore, efforts designed to improve efficiency would be more cost effective than introducing new technologies such as developing new varieties as a means of increasing potato production and productivity.

Key Words: *Yield Gap, Efficiency, Production, Productivity, Improved Variety, Ethiopia.*

INTRODUCTION

Potato (*Solanum tuberosum L.*) is the fourth major crop of the world after rice, wheat and maize and is the most consumed food crop world-wide next to wheat and rice (Tewodros et al, 2014). A German immigrant is credited with introducing potato to Ethiopia in 1858 and over decades, farmers in Ethiopia's highlands began cultivating potato as an insurance policy against cereal crop failures (Potato world, 2008).

The International Potato Center (CIP), based in Peru, estimates that Ethiopia may have the highest potential for potato production than any country in Africa, with 70 percent of its 13.5 million hectares of arable land mainly in highland areas is believed to be suitable to potato cultivation (Potato world, 2008). Ethiopia can accommodate growing 3 million hectares of potatoes (Cornell, 2014).

According to the 2013 Global Hunger Index, levels of hunger are still alarming or extremely alarming in 19 countries, including Ethiopia, meaning food security is an urgent issue. Highlands are home to almost 90 percent of Ethiopia's population with 2.4% growth rate (Leonie, 2014). The rapid increase in both human and livestock population has resulted in great pressure on land and has led to decreased holdings of arable land (Million, 2001). Fallow periods for restoring soil fertility have been reduced greatly in the smallholder farming systems and cultivation is expanding to marginal and less fertile areas. Intercropping and crop rotation have become common.

A number of variety trials were conducted by national potato research program in different areas of the country to address problems of different agro-ecologies production constraints. Accordingly, as of 2010, 29 improved potato varieties with high-yielding potential, wide adaptation and resistance/tolerance to diseases and pests have been released (Baye et al., 2013).

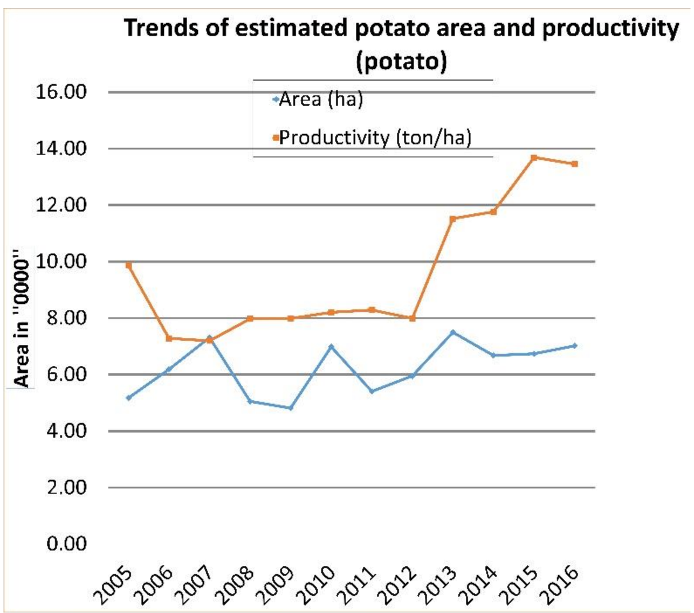
Six improved potato varieties were under production in the study area during the period of 2015/16 cropping season.

Table 1: Potato varieties under production in 2015/16 cropping season

No.	Variety	Suitable altitude (m)	Yield (t/ha)		Year of release
			Research Management (RM)	Farmer Management (FM)	
1	Belete	1600-2800	47.2	28-33.8	2009
2	Gudene	1600-2800	29	21	2006
3	Guassa	2000-2800	24.4-33	22-25	2002
4	Digemegn	1600-2800	30-37	25.7	2002
5	Jalene	1600-2800	40.3	29.10	2002
6	Tolicha	1600-3000	23.8	20.2	1993

In Ethiopia the number of potato holders with potato is very small (1.38) million potato farmers in 2015/16: it is estimated that there were about 23% of all root crop producers. By 2015/16, the area cropped with potato is very small which is 70,131 ha. The cultivated area had grown by 36% when compared to 2004/05. The production has increased from 509,716 tons in 2004/05 to 943,233 tons in 2015/16 with 85% production volume increment. In the last 12 years, potato productivity has progressed by 36.4% from 9.86 to 13.45 tons/ha (CSA, 2004/05, 2015/16). (Graph 1).

Nevertheless, the current area cropped with potato is very small and the national average yields are still far below attainable yields and production does not meet the demand because of low productivity.



Graph 1: *Trends of estimated potato yields from 2004/05 to 2015/16.*

In Ethiopia, potato production could fill the gap in food supply during the months of July to August before the grain crops are being harvested (Gebremedhin et al., 2013). Potato is a smallholder cash crop and remains a key component in the livelihood system of most farmers, contributing to food security as a direct food source especially during hunger season. Potato produces more food per unit area of land, compared to many other crops. It can provide a cheap but nutritionally rich staple food, contributing protein (low in amount, but high in biological value), vitamin C, zinc, and iron (CIP, 2012). Potato produce 54% more protein per unit of land area than wheat and 78% more than rice (Stevenson et al., 2001).

Potato is short cycle crops (3 to 4 months), and thus well suited to the double cropping seasons particularly the rain-fed system (Nteranya et al., 2015). Potato has a high potential for addressing food insecurity due to its potentially high productivity per unit area about 40 t/ha (FAO, 2008). Potato offers employment opportunities to all those involved in potato value chain from production to consumption. Potato is a suitable crop for places where land is limited and labor is abundant by reducing pressure on land resulted from intercropping and crop rotation by restoring soil fertility.

Yield gaps are the difference between yield potential and actual yields over a given spatial or temporal scale (Lobell et al., 2009; Ittersum et al., 2013). There are different types of potential yields, which give rise to three distinct types of yield gaps. The first type of yield gap is the difference between theoretical crop potential and experiment station yield which is a base for scientists to conceive and breed improved varieties. The second type of yield gap results from the difference between experiment station yield and potential farm yield due mainly to environmental conditions and the technologies available at research stations that are nonreplicable at the farm level. Finally, the third type of yield gap is the difference between potential farm yield and actual farm yield. This gap results mainly from management practices, such as low input usage and lack of improved seed and can be cost-effectively narrowed (FAO, 2015).

Agricultural food demand is expected to increase by 50% in 2050 (Tilman et al., 2011). Business as usual will not meet projected global food demand in the coming years due to various factors. Three broad options to face the global food demand (Licker et al., 2010): Expand the area of croplands at the expense of other ecosystems; Increase the yields on the existing croplands (closing the yield gaps) and Reallocate current agricultural production to more productive uses.

Productivity can change due to differences in production technology, differences in the efficiency of the production process and differences in the environment in which production takes place. One of the main reasons for low productivity in agriculture all over the world, including Ethiopia is the inability of farmers to fully exploit the available technologies, resulting in lower efficiencies of production.

This study examines the difference between potential farm yield and actual farm yield and determines to what extent the production could be increased and what potato growers in study district is losing and/or could achieve if all other factors are controlled.

MATERIALS AND METHODS

The study site

Wolmera is one of the districts in central highlands of Ethiopia. The district is about 29 km away from the capital city of Addis Ababa along the Ambo rode. The area ranges in elevation from 2,000 to 3,000 masl. The mean monthly temperature of the district ranges from 10.8º C to 15.4º C with an average annual rainfall of 1,054 mm. (World Potato Atlas, 2009). The district has a total population of 100,439 of which 50,281 (50.1%) are males and 95.3% of the population has been living in the rural areas (CSA, 2013). The district is located in the vicinity of Holetta Agricultural Research Centre (HARC).

Sampling techniques

Multi stage sampling techniques was used. The district was selected purposively because potato is the major potato growing/production area (World Potato Atlas, 2009; Hirpa et al., 2010). Wolmera is a source of potatoes for Addis Ababa and other urban markets. In the district six kebeles were selected purposively. The choice of kebeles for the survey was done on the basis of area coverage under potato production, number of potato holders, larger potato production experience and their importance in production supply to the market.

In collaboration with expertise of office of agriculture in the district sampling frame prepared with up to date data. Finally, total samples of 196 potato-producing households from the six kebeles proportional to the size were selected by using systematic random sampling techniques.

Sample Size Determination

The sample size of potato producers was computed according to the formula developed by Statistics Canada (2010): that is a step-by-step approach where, first an initial sample size is calculated and then it is adjusted for the population, design effect and the response rate.

Initial sample size

$$n_1 = \frac{z^2 \hat{p}\left(1-\hat{p}\right)}{e^2}$$

Where, z= is desired level of confidence, P hat = is precision of an estimated proportion, and e = is required margin of error.

Sample size adjusted for the size of the population (where for small and medium)

$$n_2 = n_1 \frac{N}{N+n_1}$$

Where, N = is the target population

Sample size adjusted for the design effect (complexity of the survey):

$$n_3 = d_{effect} * n_2$$

Final Sample size adjusted for the response rate(r).

$$n = \frac{n_3}{r}$$

Data Type and Sources

Data was obtained from both primary and secondary sources using appropriate data collection instruments. Primary data was collected from 2015/16 cropping season using personally administered structured questionnaires. Secondary data was gathered from country's statistical report, crop variety register, annual reports, etc.

Methods of Data Analysis

A Parametric Stochastic Frontier Production Function was used to assess technical efficiency of potato producers in the study area. A Cobb-Douglas frontier production function which has self-dual characteristics was used to derive efficiency scores and elasticities of production inputs for the potato producers. The model was ruined by frontier 4.1c program and STATA 13 statistical packages. The maximum likelihood estimates (MLE) of the Cobb-Douglas based stochastic production function parameter is obtained from the summation of the coefficients of the estimated inputs (elasticities). The estimated coefficient of the regression equation indicates the elasticities of production for different inputs.

Following Coelli et al. (1998), Susan et al. (2014) and Mohiuddin M, et al. (2007), the elasticity of output (E_i) with respect to the i^{th} input measures the responsiveness of output to a 1% change in the i^{th} input (X_i) was computed from the following Equation:

For Cobb-Douglas production function defined over N inputs,

$Y = Ax_i^{\beta_1} x_2^{\beta_2} ... x_N^{\beta_N}$, the output elasticities are E_n.

$E_{(n_i)} = \frac{\partial Y / Y}{\partial X_i / X_i}$ Where, Y=yield of potato and X_i = different variable of inputs (i=1, 2, 3…N)

The returns to scale analysis can serve as a measure of total factor productivity. The measure of returns to scale, RTS representing the percentage change in output due to a proportional change in use of all inputs, is estimated as the sum of output elasticities for all inputs.

The double log form of the Cobb-Douglas production function model proved to be a superior alternative on theoretical and econometric grounds. The specific Cobb-Douglas production model estimated is given by:

$$Y_i = \beta_0 * \prod_{i=1}^{6} X_i^{\beta_i} * e^{(v_i - u_i)} \quad \text{------------------------ (2)}$$

By transforming it into double log-linear form;

$$\ln Y_i = \ln \beta_o + \beta_i \sum_{i=1}^{6} \ln X_i + (v_i - u_i) \quad \text{------------------ (3)}$$

Where, Y_i - represents potato output and X_i - represents potato production inputs by i^{th} farmer. Whereas β_0 & β_i - are the regression parameters to be estimated and ln - is natural logarithm. The term $v_i - u_i$ is a composed error term where v_i represents randomness (or statistical noise) and u_i represents technical inefficiency

From the error term component ($v_i - u_i$), v_i is a two sided ($-\infty < v < \infty$) normally distributed random error ($v \sim N[0, \sigma^2 v]$) that represents the stochastic effects outside the farmer's control. (example weather, natural disasters etc), measurement errors, & other statistical noise while U_i is a one-sided ($u_i \geq 0$) efficiency component which is independent of v_i and is normally distributed with zero mean and a constant variance ($\sigma^2 u$) allowing the actual production fall below the frontier but without attributing all short falls in output from the frontier as inefficiency.

Following Khan and Saeed (2011) and Bealu et al. (2013) the stochastic frontier production functions model will be specified as follows:

$$Y_i = f(X_i; \alpha_i) + \varepsilon_i \quad \text{for } i = 1, 2, \ldots, n \quad \text{------- (4)}$$

Whereby Y_i is the output of farmer i, X_i are the input variables, α_i are production coefficients and ε is the error term that is composed of two elements, that is: $\varepsilon_i = v_i - u_i$

RESULTS AND DISCUSSION

Descriptive Results

Total samples of 196 potato-producing households were selected. From sampled respondents 86.2% were male headed households. Farmer’s experience in potato activities were ranged from 1 to 30 years (6.3 years, on average). In terms of age, most of the sampled households were relatively old with an average age of 40 years. Most of the sampled household heads had low levels of education. The average number of years in formal education is 5 years, which is primary education. Seventeen percent of the household heads not attended any formal school at all. About 52.5% of the total sampled households had at least 6 persons in the household.

The results of this study show that 73% of the farmers in the study area do not receive off-farm income. This indicates that majority of the farmers depend on farm activities for income generation. Ninety six percent of the households had assets value falling below Ethiopian Birr 800,000.00. Average livestock holding per household in the study area was 8.7 TLU (Tropical Livestock Unit).
The average land holding per household in the study area was 2.4 ha. Ninety percent of the cultivated area in the study area reported better quality soil with 37.8% and 52% for highly and moderately fertile soil respectively. The operated area under contracted land (either cash rented, sharecropped, gifted or borrowed) were observed to be 51.2 percent substantially larger than the average size of owner-operated land.

Empirical Results

Partial Elasticity and Returns -to- Scale

The maximum likelihood estimates (MLE) of the Cobb-Douglas based stochastic production function was specified to determine the possible relationships between the production of potato and inputs used. Estimated values of the coefficients and related statistics of the Cobb-Douglas production function for the sample farmers producing potato are presented in Table 2.

Table 2: Regression results of stochastic frontier production function

Input Variables	*Coefficient*	*Standard error*	*Z*
plot area	0.214***	0.056	3.80
seed	0.190***	0.044	4.27
Fertilizer	0.148***	0.042	3.53
Chemical	0.077***	0.019	3.90
oxen days	0.239***	0.082	2.91
labor	0.196***	0.057	3.41
_cons	5.788	0.422	13.69
sigma_v	0.271	0.045	
sigma_u	0.682	0.074	
$sigma^2$	0.539	0.086	
lambda (λ)	2.512	0.111	
gamma (γ)	0.863		
Number of obs = 196 Wald chi2(6) = 132.49			
Prob > chi2 = 0.0000 Log likelihood = -133.83			
Log likelihood-ratio test of sigma_u=0:			
chibar2(01) = 11.77 Prob>=chibar2 = 0.000			

*Note: ***Significant at 1%*

The scale coefficient was calculated to be 1.07, indicating a percent increase in all inputs proportionally will increase the total production by 1.07%. Potato production in the study area was in the stage I of the production surface.

Stage I is the stage of increasing return-to scale, where the increase in output is more than proportional to the increase in input. This implies that there is potential for potato producers to continue to expand their production.

The important parameter of log-likelihood in the half-normal model is λ which $\lambda=\sigma_u/\sigma_v$. If the value of λ is equal to 0 there are no technical inefficiency effects and all deviations from frontier are due to noise. The estimated value of λ=2.5125 is significantly different from 0 and the null hypothesis that there are no inefficiency effects is rejected at 1% significance level.

Technical Efficiency

Frontier version 4.1c computer program was used to estimate technical efficiency (TE). The results of the efficiency scores indicate that there were wide ranges of differences in TE among potato producing farmers. The mean TE of sample households during the survey period was 62.6%. The TE among the households ranges from 0% to 92.8%, with standard deviation of 0.1771.

TE scores showed that the majority (more than 54%) of the sample households had TE score of greater than 60% (Table 3). But there were also some households whose TE levels were below 25%. Households in this group have a room to enhance their potato production at least by 67.8%. Out of the total sample households, only 0.51% had TE greater than 90%. This implies that about 99.5% of the households can increase their production by 10%. Moreover, 50% of the sample households can increase their production at least by 28.5%.

Table: 3. Efficiency Level Distribution of TE scores

Efficiency Category	***TE***	
	Freq.	***Percentage***
0.00 < E ≤ 0.25	21	10.71
0.25 < E ≤ 0.50	44	22.45
0.50 < E ≤ 0.75	76	38.78
0.75 < E ≤ 1.00	55	28.06
Total	196	100
Mean TE	62.6	
Minimum TE	0.0	
Maximum TE	92.8	

Results indicate that potato farmers are 62.6 percent technically efficient, implying significant potential in potato production that can be developed. By shifting the average farmer to the production frontier, the average yield would increase by 15.7 tons per hectare and to the production potential by 17.8 tons per hectare using the available resources.

Yield Gap Analysis

The farmers in the district grow a wide range of potato varieties. Table 4 shows that there were six different potato varieties identified among sampled farmers. Most farmers in this area grow improved varieties obtained from Holeta Agricultural Research Center (HARC). Mean yield per ha for each variety was computed to determine which variety was the most productive among the farmers. According to the findings most of the farmers (95.9%) grew the Gudene variety which yielded 12.5 t/ha. This variety was prevalent in all the six kebeles focused in the study.

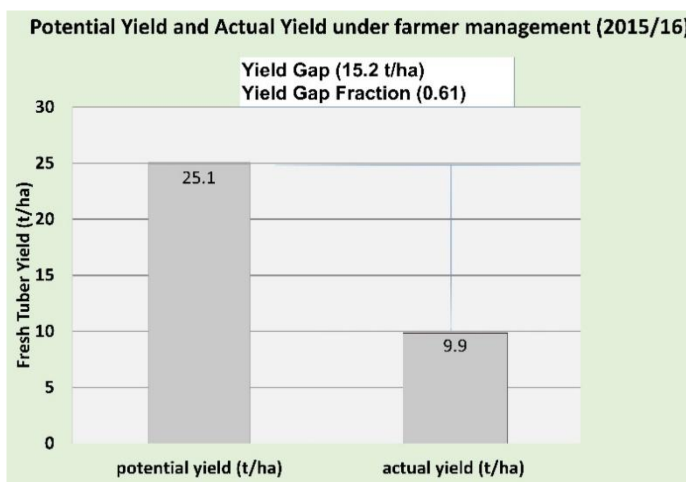
The second most commonly grown variety was the Belete variety, which was developed and released in 2009 by the national research program and was found among 9.2% of the sampled potato farmers. This variety also gave an average yield of 11 t/ha.

Table 4: Yield potential and yield gap

Potato Variety	Potential Yield (t/ha)	Actual Yield (t/ha)	Yield Gap (t/ha)
	FM	FM	FM
Tolicha	20.2	7	13.2
Guassa	22-25	5.8	17.7
Digemegn	25.7	11.7	14
Jalene	29.10	11.5	17.6
Gudene	21	12.5	8.5
Belete	28-33.8	11	19.9

FM - farmer management

The current average farmers' yields are too low, less than 10 t/ha (9.9 t/ha) for materials with a potential to achieve 25.1 t/ha. The actual yield gap was large in all potato variety, and ranged between 8.5 t/ha and 19.9 t/ha of mean actual yields. At a district level, the mean actual yield gap was 15.2 t/ha from yield potential suggesting ample room to increase yields.



Graph 2: *Yield gap in potato*

Productivity and Efficiency

The results of Maximum Likelihood estimates of variance parameters explain that variance parameter gamma (γ) is the ratio of variance of farm specific technical efficiency to the total variance of output and has a value between zero and one. Results of gamma in (table 2) shows;

$$\gamma = \frac{\sigma_u^{\ 2}}{\sigma_u^{\ 2} + \sigma_v^{\ 2}}$$

γ has value of (0.86) which shows that out of total variation in potato production 86 percent variation is due to technical inefficiency u_i (accounted for 13.07 t/ha yield gap) while remaining 14 percent is due to the uncertainty v_i which is expected especially in the case of agriculture where uncertainty is assumed to be the main source of variation (accounted for 2.13 t/ha yield gap). This implies that the stochastic production frontier is significantly different from the deterministic frontier, which does not include a random error.

CONCLUSION AND RECOMMENDATION

A lot of research and development efforts made on high yielding potato varieties in Ethiopia. National average yields are still far below attainable yields. At a district level, the mean actual yield gap was 15.2 t/ha from yield potential suggesting ample room for improvement. Output growth is not only determined by technological innovations alone but also by efficiency with which available technologies are used.

The study observed that efficiency of potato farmers varied due to the presence of inefficiency effects in potato production. Farmers are not making efficient use of the existing technology in the district. Eighty six percent variation in potato production is due to technical inefficiency and accounted for 13.1 t/ha yield gap. Finally, if the level of efficiency is increased by 30.2% and if all other factors are controlled there is an opportunity for the average farmers in the study area to increase their productivity by 13.1 t/ha using the available resources.

Therefore, efforts designed to improve efficiency would be more cost effective than introducing new technologies as a means of increasing potato productivity.

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