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Analysis of technical efficiency of irrigated tomato production in North Gondar Zone of Amhara Regional State, Ethiopia

Tigabu Dagnew Koye[1] · **Abebe Dagnew Koye[1]** · **Taye Melese Mekie[1]**

Abstract

Ethiopia is a country with a total population of more than 110 million, of which about 80% of the total population is engaged in subsistence farming in rural areas. Although the agricultural sector plays a great role in the Ethiopian economy, it is characterized by low productivity due to technological and socioeconomic factors. Improving smallholder irrigated tomato production, and productivity would contribute to enhancing food security and alleviating poverty. Therefore, this study was investigated to fill this gap to analyze the technical efficiency of irrigated tomato production and its determinant factors in North Gondar Zone, Amhara Regional State, Ethiopia. Primary data were collected from 160 farmers selected using a multistage sampling procedure and analyzed using descriptive statistics, a parametric stochastic frontier production function model. The stochastic frontier and Cobb–Douglas functional form with a one-step approach were employed to analyze efficiency and factors affecting efficiency in irrigated tomato production. The estimated gamma parameters indicated that 0.69% of the total variation in tomato output was due to technical inefficiency. The means technical efficiency was found 60%, and about 6480.19 kg of tomato output per hectare was lost due to inefficiency factors implying there is a room for improvement in technical efficiency by 40% with the present technology. The Stochastic Production Frontier (SPF) result revealed that plot size at 1% and UREA at 10% probability level significantly influenced tomato production. The socio-economic variables that exercised an important role for variations in technical efficiency positively were the level of education, TLU, fair water distribution service and water in the morning, and in contrast watering frequency, marketing training, and credit were found to increase inefficiency significantly among farm households. To get better farmers' efficiency in the production of irrigated tomatoes continuous marketing training should be established and strengthening the available farmers training center (FTC) to improve farm productivity. The government and any concerned bodies should be built irrigation canals and other alternatives to reduce watering frequency. There should be a timely and sufficient supply of UREA to improve farmers' efficiency in the production of tomatoes.

Extended author information available on the last page of the article

Abbreviations
CC	Contingency coefficient
C–D	Cobb–Douglas
CSA	Central Statistical Authority
DAP	Di Ammonium Phosphate
Ha	Hectare
Kg	Kilogram
LH_0	Log-likelihood ratio of the null hypothesis
LH_1	Log-likelihood ratio of alternative hypothesis
Ln	Natural logarithm
LR	Log-likelihood ratio
MDE	Man Day Equivalent
MLE	Maximum likelihood estimator
NBE	National Bank of Ethiopia
NGOs	Non-Governmental Organizations
ODE	Oxen Day Equivalent
OLS	Ordinary least square
SPF	Stochastic production frontier
TE	Technical efficiency
TLU	Tropical Livestock Unit
VIF	Variance inflation factor

1 Background of the study

Sub-Saharan Africa (SSA) reports for about 13% (950 million people) of the global population (UN 2015). This is anticipated to increase to 2.1 billion people by the year 2050 (OECD 2018). Majority (75%) of the residents in this region are small scale farmers with farms ranging from 0.2 to 3 hectares (ha) (Nyamwamu 2016). The anticipated population rise implies growing demand for sufficient food and better living standards especially in rural areas. Conversely, agricultural production, the main source of food for smallholders in developing countries has declined and remains below the global optimal levels (Najjuma et al. 2016). This shows a need to promote agriculture and ensure population growth keeps pace with food production and income generation Chepng'etich, Nyamwaro, Bett and Kizito (2015: cited in Mbogo Mwangi 2020).

Ethiopia is a country with a total population of more than 110 million, of which about 80% of the total population is engaged in subsistence farming in rural areas (CSA 2017). Poverty and food insecurity are still prevalent problems in Ethiopia. The causes of food insecurity are various such as extreme weather conditions, environmental degradation, population pressure, and policy drawbacks. The economy

of the country highly depends on agriculture; a sector that has persistently played a leading part in employment provision, poverty alleviation, food availability, and export earnings. According to the National Bank of Ethiopia (NBE 2018), agriculture contributes to more than 33.3% of the gross domestic product (GDP) and 68% of employment opportunities. Thus, it is the reason why that policy action in Ethiopia is largely based on influencing the dynamism of the agricultural sector.

Although the agricultural sector plays a great role in the Ethiopian economy, it is characterized by low productivity due to technological and socioeconomic factors. Mostly the farmers with the same resources are producing different per hectare output, because of management inefficiency inputs, limited use of modern agricultural technologies, traditional farming techniques, weak supportive and infrastructural service delivery such as extension, credit, marketing, road, and poor agricultural policies (Abate et al. 2019). To transform the situation, the Ethiopian government has designed a Growth and Transformation Plan (GTP-I) and (GTP-II) in the 5 years (2011–2015) and (2016–2021) respectively. The center of the plan was enhancing smallholder farmers' agricultural productivity (Davis et al. 2012). According to Asfaw et al. (2010), one of the basic strategies of the Ethiopian government in improving agricultural productivity is to adopt new technologies and use modern inputs. However, without removing inefficiency in the utilization of agricultural inputs, trying to adopt new technology may not bring an expected result.

Ethiopia has a comparative advantage in producing different types of horticultural crops due to its favorable climate, proximity to European and Middle East markets, and relatively cheap labor force (Anonymous 2012). It produces different types of vegetable crops under rain-fed and irrigation systems (Alemayehu et al. 2010; Ambecha et al. 2012; Anonymous 2010; Quintin et al. 2013). One crop that is produced is tomato which is rich in vitamins, minerals, and antioxidants (Srinivasan 2010). It is also rich in essential amino acids, sugars, dietary fibers vitamin B and C, iron, and phosphorus (Ambecha et al. 2012). It is produced at all scales (Anonymous 2010). Commercial tomato production has expanded along with national agricultural policies and strategies which favor high-value cash crops (Quintin et al. 2013). Despite the emphasis given to the subsector Ethiopian tomato growers are challenged by inconsistent production and low yields (Ambecha et al. 2012). There is a need to examine the low productivity of tomatoes.

One strategy to increase production is an expansion of irrigation to promote the production of high-value crops (Quintin et al. 2013). Maximizing the level of production may be achieved by compromising for high labor costs and incurring other higher factors of production. Efficient utilization and the proper mix of production factors that could improve the current level of production, with a given level of inputs, are not receiving sufficient attention.

Improving smallholder irrigated tomato production, and productivity would contribute to enhancing food security and alleviating poverty (Ambecha et al. 2012). Agricultural productivity mainly depends on how factors are properly combined and efficiently used. Hassan et al. (2010) reported that efficiency in agricultural production is critical and for the optimum level of production to be achieved, resources must be available and used efficiently. Smallholder farmers, who have scarce agricultural resources, need to improve production efficiency.

According to the literature review, there have been various empirical studies conducted to measure technical efficiency in Ethiopia. Some of the studies conducted on horticultural crops earlier are: Wassihun et al. (2019) on Analysis of technical efficiency of potato production in Chinga district, Amhara regional state; Abate et al. (2019) on Technical efficiency of smallholder farmers in red pepper production in North Gondar Zone; Weldegiorgis et al. (2018) on Resources use efficiency of irrigated tomato production of smallholder farmers in Hintalo Wajerat district of the South-Eastern Zone of Tigray region in Northern Ethiopia; Dube et al. (2018) on Technical efficiency and profitability of potato production by smallholder farmers in Bale Zone of Ethiopia; Tiruneh et al. (2017) on Technical efficiency determinants of potato production in Welmera district, Oromia. Even though several studies have been conducted on the technical efficiency of crops including tomatoes in Ethiopia, the technical efficiency of irrigated tomato farming is still inappreciable, and very little is known whether smallholder irrigated tomato producers are efficient or not in North Gondar Zone. Moreover, all those findings might not apply to the case of tomato production in the North Gondar Zone due to the diverse agro-ecological zone, differences in the product produced, and differences in technology adoption. Moreover, as to the best of the author's knowledge and belief, there were no similar studies undertaken in the study area. Therefore, this study was investigated to fill this gap to analyze the technical efficiency of irrigated tomato production and its determinant factors in North Gondar Zone, Amhara Regional State, Ethiopia.

2 Research methodology

2.1 Description of the study area

The study was conducted in North Gondar Zone, Amhara National Regional State, Ethiopia. The Zone is located in the northwestern part of the country between 11 and 13 North latitudes and 35 and 35 East longitudes and 738 km. far from Addis Ababa. The zonal capital is Gondar city with an average elevation of 2133 m above sea level. The zone is dominated by the agricultural sector, which employs about 90% of the working force. North Gondar is bordered on the south by Lake Tana, West Gojjam, Agew Awi, and the Benishangul-Gumuz Region, on the west by Sudan, on the north by the Tigray Region, on the east by Wag Hemra, and on the southeast by South Gondar. The weather conditions of the total area of the Administrative Zone are 50,970 km^2. This zone has a total population of 2,921,470 (2,457,645 rural and 463,825 urban) of which 1,481,726 are men and 1,439,744 are women. The population density is 54.11 persons per km^2. The study was conducted in Gondar Zuria, Dembia, and Takusa Woredas. These Woredas are characterized by Dega and Woiyna Dega and there are mixed farming systems. The crop production systems are characterized by rain-fed and irrigation. According to the Zone agriculture department, farmers used irrigation mainly for vegetable production such as onion, tomato, cabbage, pepper, potato, etc., and very often cereal such as maize and

the like. Among these, onion and tomato take the lion's share in terms of irrigated land allocated and volume of production Abate et al. (2019).

2.2 Sample size and sampling method

To select sample respondents multi-stage sampling technique was used. In the first stage, out of the total woredas of the North Gondar Zone, three Woredas namely Takusa, Dembia, and Gondar Zura were selected purposively based on their' tomato production potentials. In the second stage from the selected Woreda, Chemera, Chanikia, and Mekonta from Takusa; Abrjeha and Sufankara from Dembia; Sendeba and Ambober from Gondar Zuria; were purposively selected due to the high production potential. Finally, 160 tomato farmers were selected randomly based on proportionally to the number of irrigated tomato-producing farmers.

2.3 Data type, sources, and method of data collection

Both primary and secondary data were employed. Primary data was collected through personal and face-to-face interviews using a semi-structured and pre-tested interview schedule that was filled up by recruited and trained enumerators under the close supervision of the researchers whereas secondary data was obtained from various sources such as reports of the bureau of agriculture at different levels, NGOs, CSA, Woreda administrative office, previous research findings, Internet and other published and unpublished materials, which was relevant to the study.

2.4 Methods of data analysis

2.4.1 Descriptive statistics

To get some insight into the characteristics of the sampled farm households, descriptive statistics were used. Descriptive statistical analysis was employed to analyze the survey data using measures of dispersion such as percentage, frequency, and measures of central tendency such as mean and standard deviation.

2.4.2 Econometrics analysis

Technical efficiency is the practice of using available resources in the best combination to maximize output by Battese and Coelli (1995). Measuring the technical efficiency of smallholder tomato farmers involved for the estimation of a Stochastic Frontier Production Function. The stochastic frontier production function was independently proposed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). It is defined by:

$$Y_i = f(X_i; \beta)\exp(V_i - \mu_i) \quad i = 1, 2, 3, \dots, 160 \tag{1}$$

where Y_i, is the scalar output of the ith farm, Xi is a vector of inputs of the ith farm and β is a vector of parameters to be estimated. The first error component v_i is assumed to be independently and identically distributed and symmetric. This error term represents the random effects, measurement errors, omitted explanatory variables, and statistical noise. The second error component, $\mu_i \geq 0$ is expected to capture the inefficiency of the irrigated tomato farm and it is assumed to be independently and identically distributed with mean, μ, and variance, σ_μ^2. The technical efficiency for the ith farm, defined by the ratio of observed production to the corresponding frontier production associated with no technical inefficiency, is expressed by:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(X_i;\beta)\exp(v_i - \mu_i)}{f(X_i;\beta)\exp(v_i)} = \exp(-\mu_i) \tag{2}$$

The yield gap defined as the difference between technically full efficient output and observed output. Therefore, the yield gap is the amount that represents fewer yields due to technical inefficiency. From the Stochastic model defined in Eq. (2), then, solving for Y_i^*, the potential output of each household is represented as:

$$Y_i^* = \frac{Y_i}{TE_i} = f(X_i;\beta)\exp(v_i) \tag{3}$$

where TE_i = technical efficiency of the ith sample household in tomato production, Y_i^* = The frontier/potential output of the ith sample household in tomato production, and Y_i = The actual/observed output of the ith sample household in tomato production.

A technical efficiency score of 1 indicates a perfectly efficient firm, while lower scores indicate lower efficiencies. The prediction of the technical efficiencies is based on the conditional expectation, given the composed random error $(v_i - \mu_i)$, which is to be evaluated at the maximum likelihood estimates of the parameters of the model by Battese and Coelli (1995).

The estimates for all parameters of the stochastic frontier and inefficiency effect model were estimated in a single stage by using the Maximum Likelihood (ML) method with the help of the computer software package FRONTIER 4.1 (Coelli 1996).

The stochastic frontier Cobb Douglas production function used for the measurement of technical efficiency is as follows

$$\ln Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \varepsilon_i \tag{4}$$

where ln =Natural logarithm; Y_i = Tomato output (kg/ha); β_0=constant term; β_i =regression coefficient of the ith variable; X_1= Oxen used (oxen-days/ha); X_2= labour used (man-days/ha); X_3=amount of UREA used (kg/ha); X_4=amount of DAP used (kg/ha); X_5= amount of tomato SEEDLING used (kg/ha); X_6= PLOT size used for tomato production (ha); ε_i = error term and defined as $(v_i - \mu_i)$.

v_i= random effects (measurement errors, omitted explanatory variables) assumed to be independent of μ_i, identically and normally distributed with zero mean and constant variance σ_v^2.

μ_i = non-negative random error variables which are assumed to account for technical inefficiency in tomato farmers.

μ_i is the technical inefficiency effects that are assumed to be independent of v_i such that μ_i is the non-negative truncation (at zero) of the normal distribution with mean μ_i and Variance δ^2, the inefficiency model is defined by

$$\mu_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \delta_5 Z_{5i} + \delta_6 Z_{6i} + \delta_7 Z_{7i} + \delta_8 Z_{8i} + \delta_9 Z_{9i} + \delta_{10} Z_{10i}$$
$$+ \delta_{11} Z_{11i} + \delta_{12} Z_{12} + \delta_{13} Z_{13i} + \delta_{14} Z_{14i} + \delta_{15} Z_{15i} + \delta_{16} Z_{16i}$$

(5)

where: μ_i = technical inefficiency; δ_i = inefficiency parameter of the ith variable; Z_1 = AGE (years); Z_2 = level of Education (EDUC) (Grades); Z_3 = Family size (FMS) (number); Z_4 = total number of livestock holding (TLU); Z_5 = Frequency of extension contact (EXTNF) (number); Z_6 = Irrigation cooperative (COOP) (1 for members, 0 for not members); Z_7 = Irrigation water users' association service (IWUAS) (1 for yes, 0 for no); Z_8 = Fair water distribution service (FWTRD) (1 for yes, 0 for no); Z_9 = Watering at morning (WTRMRNG) (1 for preferred, 0 not preferred); Z_{10} = Watering at noon (WTRNOON) (1 for preferred, 0 not preferred); Z_{11} = Watering at evening (WTREVNG) (1 for preferred, 0 not preferred); Z_{12} = Watering at night (WTRNGHT) (1 for preferred, 0 not preferred); Z_{13} = Watering frequency (WTRF) (per 15 days) (number); Z_{14} = Training on production (TRNGP) (1 for yes, 0 for no); Z_{15} = Training on marketing (TRNGM) (1 for yes, 0 for no), and Z_{16} = Credit access (CREDIT) (1 for yes, 0 for no).

3 Result and discussion

3.1 Socioeconomic characteristics of the sample households

The mean age of 41 years implies that the tomato farmers in the study area are within the active working group. The family size for the sample household, on average, was found to be 5.59 with a standard deviation of 1.95. Large family size together with small farmland size and the poor production method, it is difficult for the farmer to sustain his/her family. On the other side, large family size is the source of labor for subsistence farming practice in developing countries like Ethiopia. The educational level of the household head, on average, was 2 with a standard deviation of 1.25 years of schooling. In terms of TLU, the average livestock holding per household head was found to be 7.21 with a standard deviation of 3.89. Regarding credit users, 65% and 35% were noncredit and credit users, respectively. This implies that during the irrigation movement more than 50% of farmers were noncredit users. Training enhances the skill of farm management and the technical ability of the farmers. As shown in Table 1, about 27.50% and 7.50% of the sample households have received training on tomato production and marketing, respectively. In both cases above 30% of the sample, households did not receive training. This indicates that training might have an impact on the technical efficiency differentials among the household heads. Compare to watering at noon, evening, and night; most

Table 1 The socioeconomic characteristics of the sample households. *Source*: Computed from Field Survey Data, 2015/16

Characteristic	Number	Percent
CREDIT		
Yes	56	35
No	104	65
Training in marketing (TRNGM)		
Yes	12	7.50
No	148	92.50
Training in production (TRNGP)		
Yes	44	27.50
No	116	72.50
Watering at night (WTRNGHT)		
Yes	42	26.25
No	118	73.75
Watering at evening (WTREVNG)		
Yes	57	35.63
No	103	64.37
Watering at noon (WTRNOON)		
Yes	10	6.25
No	150	97.75
Watering at morning (WTRMRNG)		
Yes	124	77.50
No	36	22.50
Fairwater distribution service (FWTRD)		
Yes	16	10
No	144	90
Irrigation water users association service (IWUAS)		
Yes	84	52.50
No	76	47.50
Cooperative (COOP)		
Yes	45	28.13
No	115	71.87

Watering frequency (per 15 days) (WTRF)	Number	Percent
Two times	51	31.88
Three times	80	50
Four times	29	18.12
Total	160	100

Characteristics	Unit	Mean	Std. Dev
EDUC	Years	2	1.25
AGE	Years	41.28	9.19
FMS	Numbers	5.59	1.95
Total livestock unit	TLU	7.21	3.89

Table 1 (continued)

Characteristics	Unit	Mean	Std. Dev
EXTNF	Numbers	1.87	1.83

of the farmers have been preferred watering in the morning (77.50%) because soil evaporation is lower early in the morning than later in the day. Irrigation cooperatives in the study areas were established to solve individual problems in the group. The survey results showed that about 28.13% of the sample households were irrigation cooperative members while 71.87% of them were not irrigation cooperative members. Additionally, about 52.50% of the sample households reported that they established and organized an irrigation water users association service (IWUAS) though it was not properly implemented. Among those services, 10% of them had access to the service of equitable water allocation which is a fair water distribution service. In terms of watering frequency 31.88%, 50%, and 18.12% of the sample households irrigate (water) their tomato plot two times, three times, and four times per 15 days, respectively. The result implies that the most frequent watering per 15 days was three times (Table 1).

The average tomato output was 8540.31 kg per ha with a standard deviation of 5404.45 kg per ha. Household labor in man-hours recorded a mean of 170.47 man-hours. The high number of man-hours of household labor could be an indication that most of the tomato farmers rely heavily on the labor provided by household members to undertake their activities. This was not surprising because household members are involved in almost all activities of the tomato production process. Besides, the average oxen power used for plowing for tomato production was 20.16 oxen days per ha with a standard deviation of 16.31 oxen days. Moreover, another essential input was seedling, in which the average seeding rate was 4.66 kg per ha with a standard deviation of 5.35 per ha. The mean plot size was 0.37 ha. This probably implies that tomato farmers in the study area are predominantly smallholder farmers. Fertilizer usage in tomato production in the study area can be said to be demanding low both DAP and urea. The continuous cropping on the same pieces of land implied loss of soil fertility and the need for intensive fertilizer usage (Table 2).

Table 2 Summary statistics of variables for stochastic production function analysis. *Source*: Computed from Field Survey Data, 2015/16

Variables	Number	Mean	Std. Dev
Output (kg/Ha)	160	8540.31	5404.45
PLOT (Ha)	160	0.37	0.31
MDE (Man-day/Ha)	160	170.47	202.61
SEEDLING (kg/Ha)	160	4.66	5.35
DAP (kg/Ha)	160	138.79	144.71
UREA (kg/Ha)	160	102.33	133
ODE (oxen-day/Ha)	160	20.16	16.31

3.2 Econometrics analysis

In this study, individual farmers' technical efficiency in irrigated tomato production was estimated. Before the estimation of stochastic technical efficiency frontier, continuous variables selected for estimation were checked for the problem of multicollinearity using Variance Inflation Factor (VIF). A value of VIF more than 10 is usually considered an indicator of serious multicollinearity (Gujarati 2006) (see Appendix Tables 8 and 9). Regarding the categorical variables, contingency coefficient (CC), which is a chi-square ($\chi 2$) based measure of association, was employed to check for the presence of multicollinearity. A contingency coefficient value of 0.75 and above (*i.e* ≥ 0.75) indicates the existence of a stronger relationship between the variables. By looking at the contents of the table, it can be concluded that there is no problem of association among the variables as the respective coefficients are very low (see Appendix Table 10).

The first null hypothesis tested is, the test for the existence of the inefficiency component of the composed error term of the Stochastic Frontier Model. This is made to decide whether the traditional average production function (OLS) best fits the data set as compared to the stochastic frontier model (SFM) selected for this study. The generalized log-likelihood ratio (LR) statistics, defined by equation $\left\{ LR = -2\left[\ln L\left(H_0\right) - \ln L\left(H_1\right)\right]\right\}$ was used to test the validity of the stochastic frontier production function over the ordinary least squares model. $LR = -2 * (-156.79 + 128.93) = 55.72$. This value exceeds the critical $x^2(5\%, 1)$ value of 3.84 at 5% level of significance in Table 3. Thus, the null hypothesis was not accepted indicating that the stochastic frontier production function was an adequate representation of the data, given the corresponding ordinary least squares production function. Hence, the stochastic frontier approach best fits the data under consideration.

The second null hypothesis tested was, the test for the selection of the appropriate functional form for the data; Cobb–Douglas versus Translog production function the decision to select the functional form depends on the calculated (generalized) likelihood ratio. To select the appropriate specification, both Cobb–Douglas and Translog functional forms were estimated ($LR = -2 * (-128.93 + 113.82) = 30.22$). The calculated Log-likelihood Ratio (LR) is equal to 30.22 and the critical value of x^2 at 21 degrees of freedom and 5% significance level is 32.67 in Table 3. Thus, the null hypothesis that all coefficients of the interaction terms in the Translog specification are equal to zero was accepted. This implies that the Cobb–Douglas functional form adequately represents the data under consideration. Hence, the Cobb–Douglas functional

Table 3 Summary of the test of hypothesis. *Source*: Computed from Field Survey Data, 2015/16

Null hypothesis	Degree of freedom	LR	x^2 value	Decision
$H_0 : \gamma = 0$	1	55.72	3.84	Not accepted
$H_0 : \beta_7 = \cdots = \beta_{27} = 0$	21	30.22	32.67	Accepted
$H_0 : \delta_0 = \cdots = \delta_{16}$	16	50.92	26.30	Not accepted

At 5% significance level

form was used to estimate the technical efficiency of the sample households in the study area.

The third null hypothesis explored is that farm-level technical inefficiencies are not affected by the farm and farmer-specific variables included in the inefficiency model i.e. $H_0 : \delta_0 = \delta_1 = \cdots = \delta_{16} = 0$. The inefficiency effect was calculated using the value of the Log-Likelihood function under the stochastic production function model and the full frontier model: $\{LR = -2[-154.39 + 128.93 = 50.92]\}$. The calculated LR value of 50.92 was greater than the critical value of 26.30 at 16 degrees of freedom, this shows that the null hypothesis that explanatory variables are simultaneously equal to zero was not accepted at 5% significance level. Hence, these variables simultaneously explain the sources of efficiency differences among the sample households.

3.2.1 Estimation of Cobb–Douglas's production function

The maximum likelihood (ML) estimates of the parameter of the stochastic frontier Cobb–Douglas production function results are presented in Table 4. The standard ordinary least squares (OLS) estimate is also presented for comparison. The sigma $(\sigma^2 = 0.47)$ is statistically significant at 1% level of probability, indicating a good fit and correctness of the specified distributional assumption of the composite error term. The technical efficiency analysis of tomato production revealed that there was a presence of technical inefficiency effects in tomato production in the study area as confirmed by the gamma value of 0.69 which was significant at 1% level. The gamma (γ) (which is the ratio of the variance of the inefficiency component to

Table 4 MLE of the parameters of the Cobb–Douglas stochastic production Frontier Function for tomato producers. *Source*: Computed from Field Survey Data, 2015/16

Variable	Parameter	Ordinary least squares		Maximum likelihood estimate	
		Coefficient	t-ratio	Coefficient	t-ratio
Intercept	β_0	6.59	24.06**	7.53	20.98***
LnODE	β_1	0.14	0.96	0.04	0.33
LnMDE	β_2	0.01	0.17	0.02	0.27
LnUREA	β_3	0.11	1.51	0.15	1.89*
LnDAP	β_4	0.007	0.09	−0.11	−1.45
LnSEEDLING	β_5	−0.03	−0.21	−0.03	−0.21
LnPLOT	β_6	1.69	5.31**	1.98	7.50***
Inefficiency effect model					
Sigma-squared	σ^2			0.47	4.84***
Gamma	γ			0.69	6.78***
LL		−156.79		−128.93	
LR				55.72	
Return to scale				2.13	
Total sample size	N	160		160	

*** and* represents significance at 1% and 10% probability levels, respectively

the total error term) value of 0.69 implies that about 69% variation in the output of tomato farmers was due to differences in their technical efficiencies (the total variation in output is due to the existence of production inefficiency). By implication, about 31% of the variation in output among producers is due to random factors such as unfavorable weather, the effect of pests and diseases, errors in data collection, and the like. The (γ) parameter is very important because it shows the relative magnitude of the inefficiency variance associated with the frontier model which assumes that there is no room for inefficiency in the model. The estimated elasticity of mean output means concerning urea and plot size were 0.15 and 1.98, respectively. These coefficients represent the percentage change in the dependent variables as a result of percentage change in the independent variables (Table 4).

Plot size: At the 1% level of significance, the elasticity of tomato production to plot size is positive. Plot size appeared as the single most important factor of production with an elasticity of 1.98. This suggests that an increase in 1% in tomato plot size can lead to an increase of 1.98% in total tomato production. It is the first important input that determines tomato output. Thus, plot size is crucial to increase technical efficiency in tomato production in the study areas. The result agrees with the study of Chefebo et al. (2019/20), Shettima et al. (2015), and Aboki et al. (2014) (Table 4).

The coefficient of the rate of UREA fertilizer is statistically significant at 10% significance level and carries an expected positive sign. This implies a 1% increase in the rate of UREA fertilizer until the recommended rate; tomato output will increase by 0.15%. The result agrees with the study of Abdulkadir (2015), and Degefa et al. (2020).

According to Eatwell (1987) if the sum of all partial elasticity is equal to one then there are constant returns to scale; less one (though not less than 0), then there are decreasing returns to scale, and more than one there are increasing returns to scale. The coefficient parameters of the summation of the partial elasticity of all inputs which had a significant effect was 2.13 showed that tomato production in the study areas was operated at increasing returns to scale. The increasing returns to scale shows that when an equiproportional increase in factor inputs results in a greater than proportional increase in output. A value of > 1 return to scale indicates tomato farmers were producing in increasing return to scale. Therefore, an increase in all production inputs by 1% will increase tomato output by greater than 1%.

3.2.2 Determinants of technical efficiency

After estimating technical inefficiency variables by using the single-stage estimation approach of the stochastic frontier model, the significant factors of technical efficiency of tomato producers are as follows (Table 5):

Level of education The education level of farmers had a negative relation with technical inefficiency and was significant at 5% significance level. The result illustrated that farmers with more years of formal schooling were more efficient than their counterparts. As farmers become educated she/he has awareness of how to maximize their tomato output with the given limited inputs. Education enhances the acquisition and utilization of information on improved technology by the farmers. Generally, more educated farmers were able to perceive, interpret and respond to

Table 5 Maximum likelihood estimates of factors affecting technical inefficiency source. *Source*: Computed from Field Survey Data, 2015/16

Variables	Parameter	Coefficient	t-ratio
Intercept	δ_0	− 0.058	− 0.06
AGE	δ_1	0.021	1.44
EDUC	δ_2	− 0.484	− 2.55**
FMS	δ_3	0.060	0.83
TLU	δ_4	− 0.106	− 2.13**
EXTNF	δ_5	− 0.024	− 0.269
COOP	δ_6	0.353	1.147
IWUAS	δ_7	− 0.117	− 0.319
FWTRD	δ_8	− 4.216	− 1.89*
WTRMRNG	δ_9	− 0.907	− 2.74***
WTRNOON	δ_{10}	− 0.031	− 0.123
WTREVNG	δ_{11}	0.064	0.225
WTRNGHT	δ_{12}	0.196	0.645
WTRF	δ_{13}	0.389	2.33**
TRNGP	δ_{14}	0.072	0.223
TRNGM	δ_{15}	0.795	1.67*
CREDIT	δ_{16}	0.468	1.76*
Log-likelihood function		− 128.93	

***, ** and * represents significance at 1%, 5%, and 10% probability levels, respectively

new information and adopt improved technologies such as fertilizers, pesticides, and planting materials much faster than the uneducated farmers. The result agrees with the studies of (Usman and Bakari 2013; Jwanya et al. 2014; Ojo et al. 2009).

TLU The estimated coefficient associated with livestock holding (TLU) is positive and statistically significant at 5% probability level. Households who have more livestock holding may not have difficulties purchasing inputs like seed, fertilizer, and the like, and also oxen ownership is among the livestock units considered which help farmers in land preparation and sowing. More livestock ownership also supplies more organic fertilizer to cultivate irrigated tomatoes. Thus, an increase in livestock holding increases the technical efficiency of tomato production. The result agrees with the study of Abate et al. (2022).

Watering in the morning It positively affects tomato production and is statistically significant at 1% probability level. The reason is that soil evaporation is lower early in the morning than later in the day. While evaporation is also low at night, fungal diseases may develop, particularly when overhead systems that wet leaves are used. Tomato plants are sensitive to water stress and show a high correlation between evaporation and crop yield (Birhanu and Tilahun 2010). Since wind is usually milder in the morning, less water is wasted during morning irrigations than later in the day, as well.

Watering frequency It negatively affects tomato production and is statistically significant at 5% probability level. Due to the shortage of water farmers have been used in the shift. As a result, during the production of tomatoes, the number of water supplies at the right time in the right amount was not enough. Therefore, tomato output should be raised in irrigation farming practices mostly depending on the timely and adequate application of irrigation water needed for tomato growth, in addition, it is vital to determine the growth period when plants are most susceptible to water deficit to generate the highest output per unit area.

Farmers' training related to marketing It negatively affects the level of technical efficiency at 10% statistical level of significance. The reason is that extension agents and other concerned bodies like NGOs mainly focus on training related to production activities rather than marketing. A few days of training has been given for the producer related to marketing per year for instance market information related to input and output price, value addition, spreading sales, and forward contracting. This implies that within a short day of training farmers might not easily understand the benefit of training related to marketing. During data, collection farmers said that after production, marketing access or linkage is the main problem, and they should not get continuous training related to marketing, and the district marketing department did not solve their problems by creating market linkages on potential marketing areas like Gondar town and Gende wuha town.

The fair water distribution service (FWTRD) has a statistically significant effect on tomato production at a 10% probability level. The amount of water distributed for irrigation has been diminishing; local societies handle the irrigation water according to their traditions. Due to the fact that all farmers were treated equally for their farming efforts and that they had been used in shifts over a period of 15 days, a distributive principle should be a guarantee for the farmers. The dispute over irrigation water in society has thus, typically, been resolved.

At a 10% probability level, credit access significantly and positively influences technical inefficiency. This indicates that farmers in the study areas who have access to credit are less technically efficient than their counterparts who do not. If production credit is used on the farm, it is expected that this will result in higher levels of output; however, if the credit is not accessed promptly, it may, more often than not, lead to misapplication of funds or may not be used properly. In microfinance institutions, the interest rate is also high in addition to the credit availability. As a result, the farm will not receive the intended outcomes of such cash. On the other hand, if the credit is used for consumption, it is unlikely to result in a rise in technical efficiency. This outcome is consistent with the finding reported by Abate et al (2019).

3.2.3 Technical efficiency analysis

The maximum likelihood estimates of the Cobb–Douglas stochastic production function coefficients, which are presented in Table 6, are used to predict the technical efficiencies of the sample individual firms. The results of efficiency analysis revealed that the technical efficiency of the smallholder tomato household varied from a minimum of 11% to a maximum of 95% with a mean of 60%. In other words, on average

Table 6 Frequency distribution of technical efficiency of irrigated tomato producers. *Source*: Computed from Field Survey Data, 2015/16

TE level	Frequency	Percentage
0.10–0.20	9	5.63
0.20–0.30	6	3.75
0.30–0.40	21	13.13
0.40–0.50	19	11.87
0.50–0.60	19	11.87
0.60–0.70	25	15.62
0.70–0.80	20	12.5
0.80–0.90	29	18.13
0.90–1	12	7.5
Total	160	100
Mean	0.60	
Minimum	0.11	
Maximum	0.95	

smallholder tomato producer households in the study area incur a 40% loss in output due to technical inefficiency. This implies that on average output can be increased by at least 40% while utilizing existing resources and technology if inefficiency factors are fully addressed or more precisely, on average, the output can be expanded by as much as 40% if appropriate measures are taken to improve technical efficiency. The wide variation in technical efficiency estimates is an indication that farmers are still using their resources inefficiently in the production process and there still exist opportunities for improving on their current level of technical efficiency. This result suggests that a few households were not utilizing their production resources efficiently, indicating that they were not obtaining maximum output from their given quantity of inputs.

To give a better indication of the distribution of the technical efficiency, a frequency distribution of the predicted technical efficiency is presented in Table 6. The frequencies of occurrence of the predicted technical efficiency in the decile range indicate that the highest number of farmers have technical efficiency between 0.60–0.70 and 0.80–0.90, representing about 15.62% and 18.13% of the respondents, respectively. The findings also reveal that there is a huge gap between the least technically efficient and the most technically efficient farmers in the study area.

3.2.4 Yield gap due to technical inefficiency

Based on Eq. 3 and using the values of the actual tomato output obtained and the predicted technical efficiency indices, the potential tomato output was estimated for each sample household in tomato production on a hectare basis. The mean result is presented in Table 7 below.

It was observed that the mean technical inefficiency was 60% which caused a 6480.19 kg/ha yield gap of tomato on the average with a mean value of the actual output and the potential output of 8540.31 kg/ha and 15,072.20 kg/ha, respectively. This shows that the sample households in the study area were producing on average 6480.19 kg/ha lower tomato output than their potential yield.

Table 7 Tomato yield gap due to technical inefficiency. *Source*: Computed from Field Survey Data, 2015/16

Variable	Min	Max	Mean	Std. Dev
Actual yield (kg/ha)	788	24,000	8540.31	5404.45
TE estimates	0.11	0.95	0.60	0.22
Potential/frontier yield (kg/ha)	1739.11	28,974.43	15,072.20	8114.31
Yield gap/loss (kg/ha)	283.10	21,434.43	6480.19	5623.23

The mean levels of both the actual and potential output during the production year were 8540.31 kg/ha and 15,072.20 kg/ha, with the standard error of 5404.45 and 8114.31, respectively. Figure 1 illustrates that under the existing practices there is room to increase tomato output following the best-practiced farms in the study area.

4 Conclusion and recommendations

The traditional average response function is not an adequate representation of the production frontier. The significant proportion of the residual variation in the SPF is due to technical inefficiency. This implies that there is room for improvement through better technical efficiency. The estimated Cobb–Douglas stochastic production frontier shows that there is considerable inefficiency among plots in irrigated tomato production. And this may also be true in other crops. The mean efficiency level of 0.60 indicates that production can be increased by 40%. There is also a considerable difference in their efficiency level among plots. Hence if inputs are used to their maximum potential, there will be considerable gain from improvement in technical efficiency. Out of six input variables, two input variables which are UREA and plot size statistically significant in the frontier model, and positively affected irrigated tomato production. The positive coefficient of these parameters indicates that increased use of these
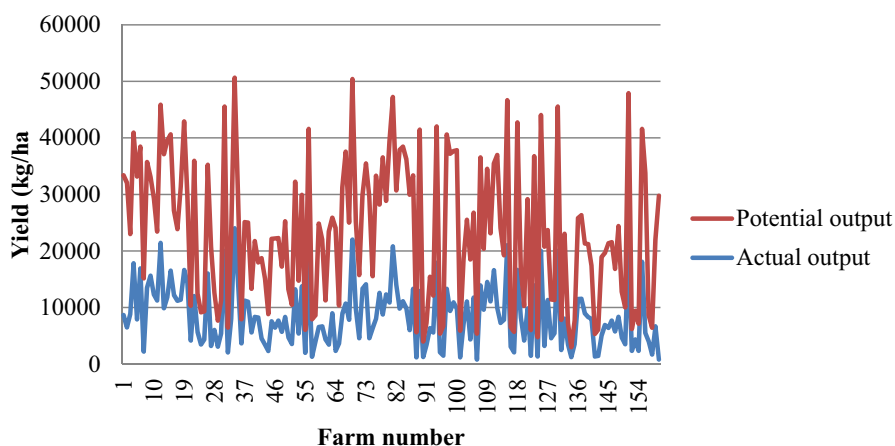
Fig. 1 Comparison of the actual and the potential level of yield. *Source*: Computed from Field Survey Data, 2015/16

inputs will increase the production level to a greater extent. The estimated SPF model together with the inefficiency parameters shows that the level of education, TLU, fair water distribution service and water in the morning were influenced inefficiency negatively whereas watering frequency, training in marketing and credit increased the level of technical inefficiency. Based on the findings, the following recommendations are forwarded: There should be a timely and sufficient supply of UREA to improve farmers' efficiency in the production of tomatoes. Continuous marketing training should be established and strengthening of the available farmers' training center (FTC) to improve farm productivity. In the study area farmers have been used traditional irrigation systems. The government and any concerned bodies should be built irrigation canals and other alternatives to reduce watering frequency. Livestock should be encouraged to purchase new agricultural technologies like improved seed and fertilizer. Education has a positive effect on technical efficiency. The government should be designed appropriate policies to provide adequate and effective basic educational opportunities for farmers in the study area, particularly for integrated adult education. Smallholder farmers should be receive credit from microfinance institutions at the appropriate time, in the proper amount, and at a reasonable interest rate. In addition to microfinance organizations, the banking sector should be open to the public and offer chances for the agricultural sector, especially for smallholder farmers.

Appendix

See Tables 8, 9, 10, and 11.

Table 8 VIF of the explanatory variables of the stochastic frontier production function model. *Source*: Computed from Field Survey Data, 2015/16

Variables	VIF	$1/\text{VIF}$
LnUREA	2.94	0.34
LnPLOT	2.66	0.38
LnDAP	2.59	0.39
LnODE	2.41	0.41
LnMDE	2.37	0.42
LnSEEDLING	1.57	0.64
Mean VIF	2.42	

Table 9 VIF for the continuous variables used in technical inefficiency model (n = 160). *Source*: Computed from Field Survey Data, 2015/16

Variables	VIF	1/VIF
AGE	1.52	0.65
FMS	1.51	0.66
EDUC	1.28	0.78
TLU	1.24	0.81
WTRF	1.20	0.83
EXTNF	1.05	0.95
Mean VIF	1.30	

Table 10 Contingency coefficients for hypothesized discrete explanatory variables (n = 160). *Source:* Computed from Field Survey Data, 2015/16

	COOP	IWUAS	FWTRD	WTRMRNG	WTRNOON	WTREVNG	WTRNGHT	TRNGP	TRNGM	CREDIT
COOP	1	0.355	0.069	0.004	0.047	0.028	0.296	0.287	0.033	0.220
IWUAS		1	0.302	0.151	0.166	0.054	0.455	0.031	0.081	0.016
FWTRD			1	0.119	0.086	0.100	0.177	0.166	0.355	0.104
WTRMRNG				1	0.108	0.473	0.049	0.130	0.074	0.203
WTRNOON					1	0.084	0.152	0.157	0.073	0.134
WTREVNG						1	0.029	0.107	0.014	0.263
WTRNGHT							1	0.174	0.046	0.267
TRNGP								1	0.335	0.157
TRNGM									1	0.186
CREDIT										1

Table 11 MLE of parameters of trans-log stochastic production Frontier function for tomato producers. *Source*: Computed from Field Survey Data, 2015/16

Variables	Coefficient	Standard-error	t-ratio
Constant	4.39	0.61	7.20***
LnODE	1.82	0.38	4.81***
LnMDE	0.13	0.25	0.54
LnUREA	3.65	0.09	40.09***
LnDAP	− 3.38	0.51	− 6.65***
LnSEEDLING	3.85	0.64	6.06***
LnPLOT	7.07	0.89	7.95***
$LnODE^2$	− 0.51	0.33	− 1.55
$LnMDE^2$	0.06	0.05	1.18
$LnUREA^2$	0.17	0.02	6.97***
$LnDAP^2$	− 0.03	0.05	− 0.63
$LnSEEDLING^2$	− 0.29	0.14	− 2.03**
$LnPLOT^2$	− 0.71	0.87	− 0.81
LnODE*LnMDE	− 0.08	0.16	− 0.48
LnODE*LnUREA	− 0.61	0.18	− 3.29***
LnODE*LnDAP	0.92	0.08	11.38***
LnODE*LnSEEDLING	− 1.68	0.24	− 6.97***
LnODE*LnPLOT	0.37	0.79	0.47
LnMDE*LnUREA	− 1.02	0.04	− 23.02***
LnMDE*LnDAP	0.97	0.10	9.29***
LnMDE*LnSEEDLING	0.08	0.13	0.64
LnMDE*LnPLOT	− 1.40	0.47	− 2.99***
LnUREA*LnDAP	− 0.24	0.05	− 4.93***
LnUREA*LnSEEDLING	− 1.043	0.19	− 5.35***
LnUREA*LnPLOT	3.91	0.39	10.04***
LnDAP*LnSEEDLING	0.73	0.23	3.21***
LnDAP*LnPLOT	− 3.59	0.26	− 13.98***
lnSEEDLING*LnPLOT	− 0.29	0.71	− 0.41
Variance parameters			
Sigma-squared (σ^2)	0.90	0.05	16.97***
Gamma (γ)	0.99	0.002	659.88***
Log-likelihood function	− 113.82		
Total sample size	160		

***, ** and * represents significance at 1%, 5%, and 10% probability levels, respectively

Declarations

Competing interests The authors declare that they have no competing interests.

References

Abate, T.M., Dessie, A.B., Mekie, T.M.: Technical efficiency of smallholder farmers in red pepper production in North Gondar zone Amhara Regional State, Ethiopia. J. Econ. Struct. **8**(1), 18 (2019). https://doi.org/10.1186/s40008019-0150-6

Abate, T.M., Dessie, A.B., Adane, B.T., et al.: Analysis of resource use efficiency for white cumin production among smallholder farmers empirical evidence from Northwestern Ethiopia: a stochastic frontier approach. Lett. Spat. Resour. Sci. (2022). https://doi.org/10.1007/s12076-022-00299-4

Abdulkadir, K.O.: An evaluation of the efficiency of onion producing farmers in irrigated agriculture: empirical evidence from Kobo district, Amhara region, Ethiopia. Int. J. Agric. Ext. Rural Dev. **2**(5), 116–124 (2015)

Aboki, E., Umaru, I.I., Mshelia, S.I., Luka, P.: Resource use efficiency of irrigated tomato production in northern part of Taraba State, Nigeria. Int. J. Agric. Innov. Res. **3**(2), 512–515 (2014)

Aigner, D.J., Lovell, C.A.K., Schmidt, P.: Formulation and estimation of stochastic production function models. J. Econom. **6**(1), 21–37 (1977)

Alemayehu, N., Hoekstra, D., Berhe, K., Jaleta, M.: Irrigated vegetable promotion and expansion: the case of Ada'a District, Oromia Region, Ethiopia: improving the productivity and market success of Ethiopian farmers: case study report. International Livestock Research Institute, Addis Ababa, Ethiopia (2010). http://cgspace.cgiar.org/handle/10568/1422

Ambecha, O.G., Paul, S., Emana, B.: Tomato production in Ethiopia: constraints and opportunities. The resilience of agricultural systems against crises. Tropentag, 19–21 September, Göttingen-Kassel, Witzenhausen, Germany (2012)

Anonymous: Investment opportunity profile for the production of fruits and vegetables in Ethiopia. Ethiopian Investment Agency, Addis Ababa (2012)

Anonymous: United Nations Food and Agriculture Organization, Rome (2010). http://faostat.fao.org/default.aspx?lange

Asfaw, S., Shiferaw, B., Simtowe, F., Muricho, G., Abate, T., Ferede, S.: Socio-economic assessment of legume production, farmer technology choice, market linkages, institutions and poverty in rural ethiopia: institutions, markets, policy and impacts research report no. 3. Field Crop Res. **36**(2), 103–111 (2010)

Battese, G.E., Coelli, T.J.: A model of technical inefficiency effect on stochastic frontier production for panel data. Empir. Econ. **20**, 325–345 (1995)

Birhanu, K., Tilahun, K.: Fruit yield and quality of drip-irrigated tomato under deficit irrigation. Afr. J. Food Agric. Nutr. Dev. **10**(2), 2139–2151 (2010)

Chefebo, D.E., Tefera, G.E., Tafa, B.E.: Analysis of technical efficiency and its potential determinants among smallholder tomato farmers in Siltie Zone, Southern Ethiopia (2019/20)

Coelli T.J.: A guide to FRONTIER version 4.1: a computer program for frontier production and cost function estimation, CEPA Working Paper 96/07, University of New England, Armidale (1996)

CSA (Central Statistical Agency): Agricultural Sample Survey Report on Area and Production of Crops. Statical Bulletin 586, April 2018, Addis Ababa (2017)

Davis, K., Nkonya, E., Kato, E., Mekonnen, D.A., Odendo, M., Miiro, R., Nkuba, J.: Impact of farmer field schools on agricultural productivity and poverty in East Africa. World Dev. **40**(2), 402–413 (2012)

Degefa, K., Biru, G., Abebe, G.: Economic efficiency of smallholder farmers in tomato production in BakoTibe District, Oromia Region, Ethiopia. J. Agric. Sci. Food Res. **11**, 273 (2020). https://doi.org/10.35248/2593-9173.20.11.273

Dube, A.K., Ozkan, B., Ayele, A., Idahe, D., Aliye, A.: Technical efficiency and profitability of potato production by smallholder farmers: the case of Dinsho District, Bale Zone of Ethiopia. J. Dev. Agric. Econ. **10**(July), 225–235 (2018). https://doi.org/10.5897/JDAE2017.0890

Eatwell, J.: Returns to scale. In: Durlauf, S., Blume, L.E. (eds.) The New Palgrave: A Dictionary of Economics, vol. 4, pp. 165–166. Palgrave Macmillan, London (1987)

Gujarati, D.: N: Basic Econometrics, 4th edn. Tata McGraw-Hill, New Delhi (2006)

Hassan, Y., Ala, A.L., Kyiogwom, U.B.: Comparative analysis of resource use efficiency in maize production involving local and improved varieties in Zamfara State, Nigeria. J. Agric. Environ. **6**, 17–24 (2010)

Jwanya, B.A., Dawang, N.C., Mashat, I.M., Gojing, B.S.: Technical efficiency of rain-fed Irish potato farmers in Plateau State, Nigeria: a stochastic frontier approach. Dev. Ctry. Stud. **4**(22), 40–47 (2014)

Mbogo Mwangi, T.: Technical efficiency, profitability and market diversity among smallholder tomato farmers in Kirinyaga County. M.Sc. thesis presented in the University Of Embu (2020)

Meeusen, W., Van den Broeck, J.: Efficiency estimation from Cobb–Douglas production functions with composed error. Int. Econ. Rev. **18**(2), 435–444 (1977)

Najjuma, E., Kavoi, M.M., Mbeche, R.M.: Assessment of technical efficiency of open field tomato production in Kiambu County, Kenya (Stochastic Frontier Approach). JAGST **17**(2), 21–37 (2016)

NBE (National Bank of Ethiopia): Annual Report for 2018/19. National Bank of Ethiopia, Addis Ababa (2018)

Nyamwamu, R.O.: Implications of human-wildlife conflict on food security among smallholder agropastoralists: a case of smallholder maize (*Zea mays*) farmers in Laikipia County, Kenya. World J. Agric. Res. **4**(2), 43–48 (2016)

Organisation for Economic Co-operation and Development (OECD): Agricultural outlook 2018–2027. OECD Publishing (2018)

Ojo, M.A., Mohammed, U.S., Adeniji, B., Ojo, A.O.: Profitability and technical efficiency in irrigated onion production under Middle Rima Valley Irrigation Project in Goronyo, Sokoto State Nigeria. Cont. J. Agric. .ence **3**, 7–14 (2009)

Quintin, G., Abu, T., Teddy, T.: Tomato production in Ethiopia is challenged by the pest. Report Number 1305, Global Agriculture Information Network, Addis Ababa, Ethiopia (2013)

Shettima, B.G., Amaza, P.S., Iheanacho, A.C.: Analysis of technical efficiency of irrigated vegetable production in Borno State, Nigeria. J. Agric. Econ. Environ. Soc. Sci. **1**(1), 88–97 (2015)

Srinivasan, R.: Safer tomato production methods: a field guide for soil fertility and pest management, Publication No. 10:740. Asian Vegetable Research and Development Center, Shanhua, Taiwan (2010)

Tiruneh, W.G., Chindi, A., Woldegiorgis, G.: Technical efficiency determinants of potato production: a study of rain-fed and irrigated smallholder farmers in Welmera district, Oromia, Ethiopia. J. Dev. Agric. Econ. **9**(8), 217–223 (2017). https://doi.org/10.5897/JDAE2016.0794

United Nations (UN): Transforming our world: the 2030 agenda for sustainable development (2015)

Usman, J., Bakari, U.M.: Productıvıty analysis of dry season tomato (*Lycopersicon esculentum* Mill.) production in Adamawa State, Nıgerıa. ARPN; J. Sci. Technol. **3**(5), 2225–7217 (2013)

Wassihun, A.N., Koye, T.D., Koye, A.D.: Analysis of technical efficiency of potato (*Solanum tuberosum* L.) production in Chilga District, Amhara National Regional State, Ethiopia. J. Econ. Struct. **8**(1), 34 (2019). https://doi.org/10.1186/s40008-019-0166-y

Weldegiorgis, L.G., Mezgebo, G.K., Gebremariam, H.G., Kahsay, Z.A.: Resources use efficiency of irrigated tomato production of small-scale farmers. Int. J. Veg. Sci. **24**(5), 456–465 (2018). https://doi.org/10.1080/19315260.2018.1438552

Authors and Affiliations

Tigabu Dagnew Koye[1] [iD] **· Abebe Dagnew Koye[1] · Taye Melese Mekie[1]**

✉ Tigabu Dagnew Koye
    tigabu567@gmail.com

    Abebe Dagnew Koye
    adagnew268@gmail.com

    Taye Melese Mekie
    tayemelese20@gmail.com

[1]   Department of Agricultural Economics, College of Agriculture and Environmental Sciences,
      University of Gondar, Gondar, Ethiopia