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Technical efficiency and yield gap of smallholder wheat producers in Ethiopia: A Stochastic Frontier Analysis

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Improving technical efficiency of smallholder farmers is one of the options to increase wheat yield in developing countries. This paper assesses technical efficiency, factors for inefficiency and the yield gap due to technical inefficiency in major wheat producing regions of Ethiopia, where the support to agricultural research for development of strategic crops (SARD-SC) wheat project has been implemented using primary data collected from 946 sample households operating 1616 wheat plots. One-step stochastic frontier approach with a Translog production form was used for econometric analysis. The results show that the mean technical efficiency of the overall sample is 0.769 meaning about 23% technical inefficiency in the system implying that the sample wheat producers are producing at a yield gap of 659 kg/ha. Different input variables contribute for wheat yield. It also reveals that education, oxen ownership, credit, soil fertility, using tractor, and using improved seed (in Tigray) were found to improve technical efficiency of wheat producers either for the overall or for some regions. On the contrary, family labor negatively affects efficiency in Oromia and in overall sample, while using improved seed (in Amhara and SNNP), plot distance and crop rotation (in Oromia) had a negative effect on technical efficiency.

Key words: Technical efficiency, wheat, Ethiopia.

INTRODUCTION

Increasing wheat production and productivity could usefully reduce the burden of wheat imports by Ethiopia. To this end, the country has been implementing several research and development strategies. The attention given to improved wheat variety generation and dissemination is one of the attempts made by the government.

According to Ministry of Agriculture (MoA, 2014), 67 and 33 bread and durum wheat varieties, respectively, have been released from different federal and regional agricultural research centers and disseminated for production. As a result, wheat revealed steady growth in production and productivity over recent years even though it did not grow on par with growth of demand. According to the Central Statistical Agency (CSA, 2005, 2015) reports, the domestic production of wheat increased from 2.2 million tons in 2004/2005 to 4.2 million tons ten years later (2014/2015), which is a 91% growth. Similarly, productivity has increased from 1.56 tons/ha in

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2004/2005 to 2.54 tons/ha in 2014/2015, which is a growth of 63%. This swift growth of productivity could largely be attributed to the use of improved technologies of wheat. Within the same period of time the area coverage for wheat has also increased from 1.4 million hectares in 2004/2005 to 1.6 million hectares in 2014/2015, which is a growth of 14%.

Basically, increasing domestic wheat production can be achieved through two options other than increasing area cropped. One is through making more intensive use of inputs and/or technologies while the other is improving the level of efficiency of the wheat producers, given fixed level of inputs at the current available technology so that the producers produce at the frontier to obtain maximum output without using additional input. The former option needs high investment in expensive inputs which is difficult for smallholder farmers, especially if credit is not available on time. In developing countries, resource use is often scanty as farmers are highly constrained with cash to purchase input on one hand and the option of frequently generating new technologies can be rare on the other hand, (Yadav and Sharma, 2015). Another reason which makes this option less probable is that wheat technology adoption is already fairly high in Ethiopia (Chilot et al., 2013) which means the probability of increasing wheat production through wheat technology adoption could not work in areas where the adoption level is at its climax and there is only small room to increase wheat productivity through technology adoption. Different governmental and NGOs are intensively working on dissemination of improved wheat varieties to cover the farmers who have not yet adopted the technology. In order to make its own contribution in bridging-up of wheat supply and demand gaps, the SARD-SC wheat project was launched in Ethiopia in 2013 with four main components, namely, technology generation; technology dissemination and adoption; capacity building; and project management. The project follows the innovation platform (IP) approach in four major wheat producing regions, namely, Tigray, Amhara, Oromia and SNNP regions to bring all stakeholders together to achieve its broad objectives.

While increasing wheat yield through improved technologies is one option, increasing wheat yield by improving efficiency of producers seems the most appropriate strategy in Ethiopia since it does not need additional investment in input use but improving the producers' knowledge to wisely produce at the production frontier with a given technology and limited inputs. The focus of this paper is therefore, unpacking the second option through assessing the efficiency of wheat producers in the IP sites of the project.

Efficiency analysis is one of the important fields of production economics. Economic efficiency is composed of technical efficiency and allocative efficiency. Mathematically, economic efficiency is the product of the two. Technical efficiency is dealing with attaining the maximum attainable level of output for a given level of inputs, under a given technology or it can be seen as producing a given level of output from the minimum amount of inputs for a given technology, given the current range of alternative technologies available for the farmer (Battese and Coelli, 1992; Ellis, 1993; Farrell, 1957; Kalirajan and Shand, 1999). On the other hand, allocative efficiency is the ability of a producer to use the inputs in optimal proportions (Farrell, 1957; Kalirajan and Shand, 1999). Based on the hypothesis of Schultz's (1964) 'poor-but-allocatively efficient' stating that 'small farmers in traditional agricultural settings are reasonably efficient in allocating their resources by responding positively to price incentives', Ethiopian smallholder wheat producers are considered as more or less allocatively efficient. Regardless of the challenges exerted on it from opponents (Shapiro, 1983; Ball and Pounder, 1996; Duflo, 2006; Ray, 2006), the hypothesis has been well accepted by both economists and policy makers over the past half of a century. Therefore, this paper deals with assessing the technical efficiency of wheat producers focusing on four major wheat producing regions of Ethiopia where the SARD-SC wheat project has been implemented.

Objectives

(1) To assess the level of technical efficiency of wheat producers,
(2) To assess determinants of inefficiency of wheat producers,
(3) To estimate yield gap due to inefficiency.

METHODOLOGY

The study area

The study was conducted in six districts of support to agricultural research for development of strategic crops (SARD-SC) IP sites selected from four major wheat producing regions of Ethiopia. Two districts each from East Gojjam zone of Amhara region and Bale zone of Oromia region and one district each from South Tigray zone of Tigray region and Gurage zone of SNNP region were purposively selected for the following reasons. First, these districts were selected by each of the regions themselves for the SARD-SC wheat project Innovation Platform (IP) intervention. Second, the districts did not receive enough attention and supports from other development projects to enhance wheat production and productivity. Third, the districts have a high potential of wheat production even though Enemay and Shebel Berenta districts are not as high potential as others. The selected sites represent the African Highlands hub of the SARD-SC wheat project of Ethiopia (Figure 1).

Data collection techniques and target groups

A structured questionnaire was used to collect input and output data from wheat producer households. The comprehensive data

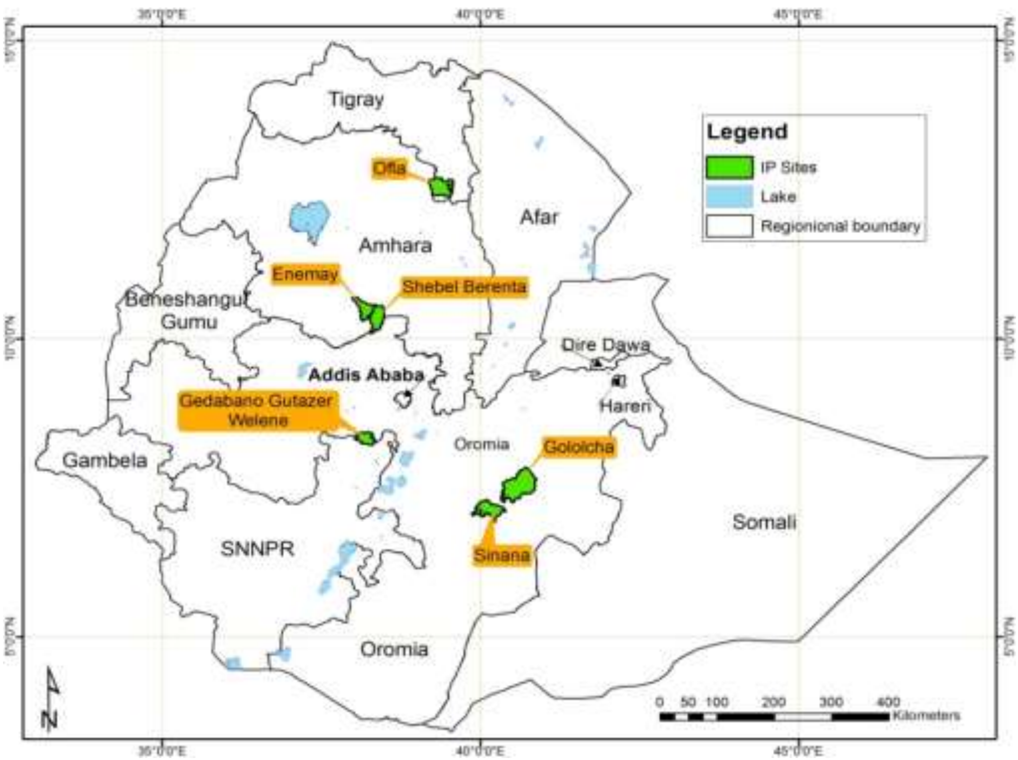

Figure 1. Map of the study area, 2014.

were collected from December 2013 to January 2014 through trained enumerators and supervisors using structured questionnaire. The data collection was implemented using Computer Aided Personal Interview (CAPI) to improve the quality of the data.

Sampling frame and sampling procedure

The sampling frame of the study is the list of wheat producer households in the study districts. Stratified multistage sampling technique was employed to select the required samples of households. First, four wheat growing regions were identified purposively to represent the diverse socio-economic and biophysical environment of wheat producers in Ethiopia. Second, in the stakeholder consultation workshop in each region, six districts which are considered representative of the respective regions were selected based on wheat growing potential, and status of previous wheat research and development interventions. Then, three kebeles from each of the districts were selected based on their level of participation in SARD-SC wheat project. Finally, from the household list available at each kebele, a total of 946 sample households were randomly drawn for interview (Table 1).

Methods of data analysis and synthesis

Information and dataset collected were analyzed and synthesized using different statistical and econometric tools. Descriptive statistics were utilized to analyze the data and summarize the information. An econometric model was also employed for the analysis of wheat producers' technical efficiency and determinants of inefficiency.

Specification of the Stochastic Frontier Production and Translog Model

Based on Aigner et al. (1977), Battese and Corra (1977), Battese and Coelli (1995), Bravo-Ureta and Evenson (1994) and Meeusen and Broeck (1977), the Translog stochastic production function of wheat producing sample households aimed to analyze both the production frontier and determinants of inefficiency simultaneously can be specified as:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{6} \beta_{jk} \ln X_{ij} + \sum_{j<k=1}^{6} \beta_{jk} \ln X_{ij} \ln X_{ik} + (V_i - U_i) \quad (1)$$

where ln = stands for the natural logarithm; Y_i = the amount of wheat production in Kg of the i^{th} plot of the farmer; i= stands for the i^{th} wheat plot of the sample household; $\beta_0,..,\beta_{jk}$ = vectors of unknown parameters to be estimated in the SFPF; X_{ij} = represents the j^{th} farm input variables used for wheat produced on i^{th} plot in such a way that: X_1= is the size of plot of land allocated for wheat in hectares;

X_2 =is the amount of expense in agrochemicals (inorganic fertilizer, herbicides, pesticide and fungicides) in Ethiopian Birr; X_3 =is the amount of wheat seed used (in kg) on the plot of land; X_4 =is oxen labor in oxen days (one oxen day=eight hours of ploughing); X_5 =is human labor in man days (one man day=eight working hours); X_6 =is the amount of expense in tractor hiring in Ethiopian Birr;

$\ln X_{ij} \ln X_{ik}$ are squares (second order) and interaction terms of the input variables; V_i = a symmetrical two sided random-error assumed to be independently and identically distributed with zero

Table 1. Distribution of sample sizes by IP districts and region.

Region	Zone	District of IP sites	Sample size
Tigray	South Tigray	Ofla	128
SNNP	Gurage	Gedebano-Gutazer-Wolene	100
Amhara	East Gojjam	Enemay	218
		Shebel Berenta	189
Oromia	Bale	Sinana	166
		Gololcha	145
Total			946

means N $(0, \sigma_v^2)$ associated with random factors beyond the control of the farmer (like: measurement errors, weather, diseases); U_i=the one-sided ($U_i \geq 0$) inefficiency component assumed to be independently distributed such that U_i follows a truncated (at zero) normal distribution N$\left(\mu_i, \sigma_u^2\right)$.

It is assumed that the two error components (U_i and V_i) are independent of each other.

The technical inefficiency effect, U_i is defined as:

$$U_i = \delta_0 + \sum_{j=1}^{15} \delta_j Z_{ij} + W_i \qquad (2)$$

where $\delta_0, .. \delta_j$ are parameters to be estimated that assumed to affect inefficiency; Z_{ij} are factors determining the inefficiency of wheat producers and specified as: Z_1= is a dummy variable for sex of a household head (1=male and 0=female); Z_2 =is a continuous variable to represent the age of household head in completed years; Z_3 =is a continuous variable of education level of household head in completed school years; Z_4 =is a continuous variable stands for a labour force in man equivalent; Z_5 =is a dummy variable for ownership of at least a pair of oxen (1=Yes, 0=No); Z_6 =is a dummy variable for access to extension service (1=Yes, 0=No); Z_7 =is a dummy variable for access to credit (1=Yes, 0=No); Z_8 =is a continuous variable stands for the number of wheat plots operated by a household; Z_9 =is a dummy variable for the use of improved seed (1=Yes, 0=No); Z_{10} =is a continuous variable for an area allocated to wheat (in ha); Z_{11} =is plot distance from homestead of farmers (in minutes of walk); Z_{12} =is a dummy variable for fertility level of plot (1=fertile and 0=otherwise); Z_{13} =is a dummy variable for crop rotation practice (1=Yes 0=No); Z_{14} =is a dummy variable for soil and water conservation practice (1=Yes 0=No); Z_{15} =is a dummy variable for tractor use to plough wheat plot (1=Yes, 0=No); The frontier production function is estimated from a sample of observed yield of each farm that is operating at the best practice farm to indicate the maximum potential output for a given set of inputs, X_i which is expressed as:

$$Y^* = f(X_i; \beta).\exp(V_i) \qquad (3)$$

Equation 3 is an output produced with full efficiency and each farm's performance is then compared with the estimated frontier. Estimating this frontier is served to estimate the level of technical efficiency (TE) of each observation that is given as:

$$TE = \frac{Y_i}{Y_i^*} = \frac{f(X_i; \beta).\exp(V_i - U_i)}{f(X_i; \beta).\exp(V_i)} = \exp(-U_i) \qquad (4)$$

where exp (−U_i) takes values between zero and one and is inversely related to the level of the technical inefficiency effect. The parameters of the stochastic frontier production function (SFPF) model and determinants of inefficiency were estimated by the method of maximum likelihood.

For the model proposed in Equation 1, Battese and Corra (1977) proposed the log Likelihood (LL) function assuming that the distribution of technical inefficiency effect has a half normal. According to these authors, the LL function model can be specified as:

$$\ln \ell = -\frac{N}{2}\left(\ln\left(\frac{\pi}{2}\right) + \ln \sigma_s^2\right) + \sum_{i=1}^{N} \ln\left[1 - \Phi\left(\frac{\varepsilon_i \sqrt{\gamma}}{\sigma_s^2}\sqrt{\frac{\gamma}{1-\gamma}}\right)\right] - \frac{1}{2\sigma_s^2}\sum_{i=1}^{N} \varepsilon_i^2 \qquad (5)$$

where $\varepsilon_i = \ln X_i \beta - \delta_k \ln Z_{ik}$ is the residual of Equation 1; N is the number of observations (number of wheat plots in our case); Φ (.) is the standard normal distribution; $\sigma_s^2 = \sigma_v^2 + \sigma_u^2$ are variance parameters; $\gamma = \sigma_u^2 / \sigma_s^2$ is a variance parameter having a value of zero to one and it measures the technical inefficiency.

Minimizing Equation 5 with respect to $\beta, \sigma_s^2, \delta$ and solving their partial derivation simultaneously results in the maximum likelihood estimates of $\beta, \sigma_s^2, \delta$. Moreover, γ parameter is used to test the existence of inefficiency which is expressed as the percentage of the variation in output due to technical inefficiency. Similarly, the generalized likelihood ratio test which is given as:

$$LR = -2\left[\ln(H_0) / L(H_1)\right] \sim \chi(n)^2 \qquad (6)$$

is used to test whether the conventional average production function adequately represent the data or not, where: $L(H_0)$ is the likelihood value for the restricted estimate, $L(H_1)$ is the likelihood value for the unrestricted estimate, and n is the number of restrictions imposed by the null hypothesis.

RESULTS AND DISCUSSION

Descriptive analysis of wheat producers technical efficiency

Descriptive results of technical efficiency are shown in Table 2. The result shows that there is a variation in technical efficiency of wheat producers among the IP sites with a smallest and largest mean technical efficiency of 0.682 (68.2%) and 0.837 (83.7%) in Gurage zone of the SNNP IP site and Bale zone of Oromia IP sites, respectively. The overall technical efficiency of the whole sample is 76.9% implying that about 23% of the potential wheat yield is lost due to technical inefficiency in the study area. Within an IP sites, the minimum technical efficiency is as low as 9.7% (in Amhara IP site), while the maximum technical efficiency of the same is as high as 91.9%. Therefore, besides adopting improved wheat varieties, raising the technical efficiency of wheat producers can play a great role in increasing wheat yield. Improving technical efficiency of wheat producers is important to make them produce an optimum yield that can be produced with the current level of production technology and without additional input. This may be possible by arranging experience sharing and formal and informal education and improving access to better agricultural services on time.

Ranges of technical efficiency

Table 3 shows ranges of technical efficiency of wheat producing farmers in percent. The result shows that 25% of the overall sample falls in a technical efficiency range of more than or equal to 85% efficient, while 13% of the wheat producers fall in 50% or less technically efficient group. However, there is variation among the IP sites in terms of ranges of technical efficiency proportion. In SNNP IP site where the mean technical efficiency is the lowest (0.682), wheat producers whose technical efficiency is less than or equal to 50% is the highest (25%) as compared to other IP sites while the opposite is true in Oromia IP (4%) site where the mean technical efficiency is the highest (0.837). The level of technical efficiency is directly related to the average wheat productivity in the respective IP sites. Therefore, raising the proportion of farmers with high technical efficiency would have a great impact on increasing wheat production without incurring additional cost of production but adopting the practice of best performing farmers in the study area. This could be in effect through arranging frequent training and experience sharing mechanisms.

Yield gap due to technical inefficiency

The average yield gap between the potential and the actual yield is shown in Table 4. The result indicated that there is a maximum yield gap of 845 kg/ha in Tigray and a minimum yield gap of 527 kg/ha in Amhara with an average yield gap of 659 kg/ha for the overall sample households. The result implies that there is a large yield gap that could be captured by raising the level of technical efficiency of wheat producers in the study area. This in turn helps the country to be more self-sufficient in wheat from domestic production.

Econometric analysis of wheat producers' technical efficiency

The maximum likelihood estimates of the parameters of the stochastic frontier production and inefficiency model are estimated using Stata software computer program version 13. Before analyzing the parameter estimates and factors that determine the inefficiency of the wheat producers, the validity of the model used for the analysis was investigated using appropriate tests of hypotheses. The results of the tests of hypotheses are shown in Table 5. Testing of the hypotheses that the Translog SFPF can be reduced to Cobb-Douglas and the null hypothesis that technical inefficiency is not influenced by any variable included in the model were conducted using the log likelihood-ratio (LR) statistics using a formula: $LR = -2 \ln [L(H_0) / L(H_1)]$, where $L(H_0)$ and $L(H_1)$ represent the values of the log likelihood function under the specifications of the null and alternative hypotheses, respectively. The LR test statistic is given by an asymptotic chi-square distribution with degrees of freedom equal to the difference between the number of parameters in the unrestricted and restricted models. Another hypothesis that technical inefficiency effects are not in the model was tested using the t-statistic.

The LR test results indicated that the null hypothesis that states the Translog production function can be reduced to Cobb-Douglas (the null hypothesis that second order and the interaction terms in the Translog functions are not different from zero) was rejected at 5% level of significance. Hence, the Translog SFPF is more suitable to the wheat producers' survey data in the study areas (Table 5). Similarly, the null hypothesis states that there is no inefficiency (technical inefficiency effects are not in the model) among wheat producers ($\gamma=0$) was also rejected as ($\gamma=0.59$) was statistically significant at 5% level of significance implying that the existence of inefficiency in the model and hence the traditional average response function was not an adequate representation of the data. Another hypothesis that states there were no factors that contribute for technical inefficiency ($\delta_1= \delta_2= \delta_3=,\ldots= \delta_{15}= 0$) was also rejected at 5% level of significance implying that one or more variables jointly affect the technical inefficiency of wheat producers and hence important to include them in the inefficiency model.

Table 2. Descriptive result of technical efficiency of wheat producers in SARD-SC wheat project IP site in 2012/2013.

IP site	Observation	Mean	Std. Dev	Minimum	Maximum
Tigray	128	0.73	0.13	0.28	0.92
SNNP	100	0.68	0.22	0.12	0.97
Amhara	407	0.75	0.12	0.10	0.92
Oromia	311	0.84	0.12	0.14	0.95
Average	946	0.77	0.13	0.14	0.94

Table 3. Ranges of frequency of technical efficiency of wheat producers in SARD-SC project IP sites in 2012/2013 (% of farmers fall in different categories of technical efficiency).

IP site	<50% efficient	50%-74.9% efficient	75%-84.9% efficient	>=85% efficient
Tigray	6	41	39	13
SNNP	25	21	21	33
Amhara	5	31	47	18
Oromia	4	9	24	63
Overall	13	31	31	25

Table 4. Average yield gap due to technical inefficiency of wheat producers in SARD-SC IP sites in 2012/2013.

S/N	Variable	Tigray	SNNP	Amhara	Oromia	Overall
1	Actual yield (kg/ha)	2239	1560	1589	3175	2195
2	Mean technical efficiency	0.726	0.682	0.751	0.837	0.769
3	Potential yield (kg/ha) (1/2)	3084	2287	2116	3793	2854
4	Yield gap (kg/ha) (3-1)	845	727	527	618	659

Table 5. Result of hypotheses tests for some important assumptions.

Hypothesis	H_0	LR test or t-calculated	Critical value: χ^2 or t	Df	Decision
Testing the null hypothesis that the translog Stochastic Frontier Production Function (SFPF) can be reduced to a Cobb-Douglas SFPF	H0; βij= 0	386.88	32.67	21	Reject H_0
The null hypothesis that technical inefficiency is not influenced by any variable included in the model	H0: δ0=δ1=…= δ15=0	127.41	25	15	Reject H_0
The null hypothesis that technical inefficiency effects are not in the model (all farmers are efficient)	H0: γ = 0	19	6.31	1	Reject H_0

Parameter estimates

Table 6 shows the coefficients of the maximum likelihood estimates of the parameters in the Translog stochastic frontier for each IP sites of the wheat producers of the SARD-SC project. The result shows that different production inputs contribute to wheat yield in different IP sites. The coefficient of land (in hectares) was positive and significant at 5% in Oromia and not significant in all other IP sites. The result implies that increasing land allocated for wheat production would increase wheat output in Oromia. This result has been supported by the

Table 6. Coefficients of the maximum likelihood estimate of the Translog stochastic frontier production function by IP sites.

Variable	Tigray	Amhara	Oromia	SNNP	Overall
Constant	-3.430	6.706	3.214	19.087	3.849**
lnland	-6.434	2.412	0.210**	9.697	0.067
lnagrochemicals	-0.047	-0.029	0.428	2.585	-0.075
lnseed	0.314	-0.070	0.609	-1.245	0.368
lnoxen	7.399**	-1.095	0.337	-1.300	0.110
lnlabor	-0.531	0.414	-0.324	-9.519***	0.229
lntractor	-	-	-0.076	-	0.251***
lnlandsquare	-1.325*	0.469	0.058	1.614	0.001
lnagrochemsquare	0.014**	0.013***	0.006**	-0.091	0.004**
lnseedsquare	0.241	-0.044	0.007	0.043	-0.020
lnoxensquare	-1.027*	0.291	-0.013	0.517	0.022*
lnlaborsquare	0.200**	-0.070	0.010	0.087	0.062***
lntractorsquare	-	-	0.045***	-	0.042***
Lnland*lnAgchemical	0.005	-0.013	0.087**	0.521	-0.018
Lnland*lnseed	0.305	-0.077	-0.064	-0.151	0.032
Lnland*lnoxen	2.574**	-0.723	-0.012	-1.035	0.014
Lnland*lnlabor	-0.405	0.051	0.026	-2.417***	0.003
Lnland*lntractor	-	-	-0.019	-	0.026**
lnAgrochemical*lnseed	0.075**	0.012	-0.097**	-0.169	0.024*
lnAgrochemical*lnoxen	-0.014	0.007	0.011	-0.172	0.008
lnAgrochemical*lnlabor	-0.065***	-0.019	0.008	0.134	-0.014
lnAgrochemical*lntractor	-	-	0.005	-	-0.002
Lnseed*lnoxen	-0.461	-0.060	-0.054	-0.816	0.058
Lnseed*lnlabor	-0.341**	0.174	0.048	1.130***	-0.060
Lnseed*lntractor	-	-	-0.009	-	-0.050***
Lnoxen*lnlabor	0.258	-0.100	0.008	0.930	-0.067***
Lnoxen*lntractor	-	-	-0.022	-	-0.044***
Lnlabor*lntractor	-	-	0.006	-	0.011**
σ^2_u =	0.127571	0.099745	0.039335	0.196338	0.133405
$\sigma^2 = \sigma^2_v + \sigma^2_u$	0.219634	0.232344	0.104349	0.233956	0.224986
$\lambda = \sigma_u / \sigma^v$ =	1.177153	0.867314	0.777838	2.284577	1.206936
$\gamma = [\lambda^2 / (\lambda^2 + 1)]$	0.580834	0.4293	0.37696	0.83921	0.592949

*, ** and *** means significant at 10, 5 and 1% level of significance, respectively.

findings of Yami et al. (2013). This might be due to the fact that tractors are widely employed in Bale zone of the Oromia IP site and using tractors is efficient in larger plot size than smaller ones leading to amalgamating plots of land would have a positive effect on wheat output.

In Ofla district of the Tigray IP site, the coefficient of oxen (in oxen days) was found to increase wheat yield positively and significantly at 5%. However, the coefficient of the second order of oxen is negative and the level of significance falls from 5 to 10% although the coefficient of the second order of the overall sample is positive and significant. The result implies that increasing the oxen power would increase wheat yield up to some level and increasing oxen power beyond that level will decrease wheat productivity. The coefficient of the interaction between oxen and wheat land was also positive and significant showing that expanding wheat land as far as oxen are available to cultivate land would have a positive contribution to wheat yield in Tigray IP site. Therefore, ensuring the ownership of a pair of oxen in areas where cultivation is mainly operated by oxen would have a positive effect on wheat yield.

The coefficient of labor (in man days) was found to have an inverse relationship to wheat yield in SNNP IP site and not significant at other IP sites. Similarly, the interaction effect of labor with wheat land was also negative and significant at 1% in the same IP site. On the contrary, the interaction effect of labor with wheat seed was found to have a positive effect on wheat yield in SNNP IP site. In this IP site therefore, increasing labor force for wheat production and expanding wheat area without using appropriate wheat seed penalizes the farmers in wheat production.

The result of the estimate shows that the coefficient of the second order of labor in Tigray IP site as well as the overall sample (probably due to Tigray IP site) was positive and significant at 5% showing that increasing labor force in wheat production activities such as plowing, weeding, harvesting and threshing would increase wheat yield in the Tigray IP site. This is because almost all activities including weeding are conducted using human labor in Ofla district of Tigray IP site.

The overall sample result shows that the coefficient of expense on tractor/combine harvester and the coefficient of the second order of the overall sample as well as Oromia IP site were positive and significant at 1% each suggesting that an increase in investment in hiring more tractor and combine harvester for wheat production would increase the wheat output. This is mostly related to timely conducting land preparation and sowing at appropriate sowing date and harvesting at minimum post-harvest loss that otherwise reduce wheat output. Therefore, in areas where topography is suitable for tractor/combine harvester, increasing the access to such machines at appropriate time has to be ensured. One of the options to ensure this is by pursuing farmers' cooperatives to own and rent tractors, as it is difficult and costly to own tractors at individual level. Currently, the use of tractor and combine harvester is practiced only in Oromia IP site.

The coefficient of the second order of expense on agrochemical inputs (inorganic fertilizer, herbicides, pesticides and fungicides) was found to contribute positively and significantly to wheat yield in all IP sites except SNNP IP site as well as the overall sample. Therefore, higher investment in agrochemical inputs would contribute to wheat yield in Tigray, Amhara and Oromia IP sites of the SARD-SC wheat project.

The estimation result shows that the coefficient of the second order of expense on hiring tractor and combine harvester was found to contribute positively and significantly to wheat yield in Oromia IP site. Therefore, there is a need of improving access to machinery to increase wheat yield in Bale zone. Similarly, the coefficient of interaction between wheat area and expenses on tractor/combine harvester was positive and significant at 5% level of significance indicating that expansion of wheat land as far as tractor is available would increase wheat production. This is an expected result as these two inputs have a complementary relationship. The result therefore implies that, by keeping other factors constant, increasing both land allocated for wheat and expenses to hire tractor increases the wheat yield. Hence, ensuring the sustainable access to tractors is again important for increased wheat production, especially in areas where suitable for cultivation by tractor.

The coefficient of the interaction between wheat area and expense on agrochemical costs on wheat plots was significant and positive in Bale zone of the Oromia IP site implying that expanding wheat area needs to simultaneously invest in agrochemicals (fertilizer and crop protection chemicals) to increase wheat yield in wheat belt areas such as in Bale zone.

Another important result of the estimate is that the coefficient of interaction between agro-chemical costs (cost of inorganic fertilizer and crop protection chemicals like herbicide, pesticide and fungicide) and wheat seed was positive in both Tigray IP site and the overall sample and statistically significant at 5 and 10%, respectively while it was negative and significant at 5% in the Oromia IP site. The positive result is expected as these two inputs are usually recommended as a package during variety release and hence have a complementary nature. That is, inorganic fertilizer is a key input in wheat production by providing important nutrients required for crop production. Similarly, crop protection agrochemicals such as herbicides are very important to control weeds on time while pesticides and fungicides are important to control diseases. The result further implies that, other factors held constant, an increase in both wheat seed and investment in agro-chemical expenses, increases the wheat productivity in the study area. However, it should be noted that application of these agrochemicals may not increase wheat productivity beyond some limit. Nevertheless, the contrary result in Oromia IP site may be due to the fact that farmers of Oromia IP site are using high seed rates and using additional seed rate would likely penalize farmers in reducing wheat yield.

The coefficients of the interaction between expenses on agrochemical inputs (fertilizer in the case of Ofla district) and labor and interaction between quantity of wheat seed and labor were both negative and significant at 1 and 5%, respectively in Ofla district of the Tigray IP site showing that there is no apparent substitution nature between these inputs.

The result of the maximum likelihood estimates demonstrated that the coefficient of the interaction between wheat seed and expenses on tractor/combine harvester was significant at 1% level of significance but negative in sign in the overall sample. This might be due to the fact that tractors are used only in Bale zones where average seed rate is about 185 kg/ha and this is higher than the recommended rate for most of the wheat varieties released so far, and using seed beyond this maximum level would penalize the yield even if tractors are employed for wheat production. The result hence implies that increasing seed rate of wheat plots cultivated by tractor would result in decrease in wheat yield in these areas, which means double penalty by incurring additional unnecessary cost of wheat seed and loss of wheat yield due to low performance in plant stand caused by inappropriate seed rate. Therefore, there should be some sort of awareness creation on appropriate seed rates.

Another interesting result of the estimate is that the coefficient of interaction between oxen labor (in oxen days) and human labor (in man days) was significant at 1% level of significance carrying negative sign in the overall sample. This is due to the fact that there is a fixed proportion relationship (one person to a pair of oxen) for land cultivation and some additional labor for planting and fertilizer application only during the planting time. A combination of these two inputs below or above the optimum would result in lower labor productivity and hence lower yield per hectare.

The coefficient of interaction between oxen labor (in oxen days) and expenses on tractor/combine harvester was significant at 1% level of significance but with negative sign in the overall sample. The result implies that using oxen labor in combination with tractor is not economical in wheat production in places where there is access for tractors for wheat production. That is, using tractor increases wheat productivity as stated earlier when used solely but the yield decreases if tractor is used in combination with oxen. It is a usual practice of Bale zone wheat producers that using tractor for the first time and using oxen for the second and third time to cultivate (level) their lands. However, this result suggests that using tractor is more advisable than oxen in these areas.

Finally, the results of the estimation shows that the coefficient of interaction between human labor (in man days) and tractor was positive and significant at 5% level of significance for the overall sample data implying the supplementary relationship between these two inputs. This is true especially as human labor is used where tractors cannot be used for some activities such as weeding that are usually implemented by human labor.

The value of gamma (γ) for each region of the SARD-SC wheat IP site was statistically significant at 1 to 5% level of significance and varies from region to region with a lowest and highest values at Oromia (0.38) and SNNP(0.84), while the value of the overall sample is 0.59. The value of gamma of each region imply that about 58, 43, 38, 84 and 59% of the yield variation from optimum production frontier in wheat production was due to farm specific technical inefficiency in Tigray, Amhara, Oromia, SNNP IP sites and for the overall sample, respectively while the rest 42, 57, 62, 16 and 41% of the respective IP sites and the overall sample result was due to external factors that are out of farmers' control that include diseases and other environmental factors (such as erratic rainfall) or due to measurement errors. The low value of the gamma in Oromia IP site implies that more of the yield variation was due to external factor (diseases outbreak observed in the area during the study period). The result therefore, suggests that there is a room to increase wheat productivity by improving the technical efficiency of wheat producers without adding any additional input in the study area by expanding the best practices of well-performing farmers using experience sharing and training mechanisms.

Determinants of technical inefficiency of wheat producers

Table 7 shows the coefficients of estimates of factors determine technical inefficiency of wheat producers in the study area. As expected, the overall sample result shows that education level of the household head (in number of grade completed) significantly influenced wheat producers technical inefficiency negatively at 1% of significance level implying that education reduces inefficiency or improves efficiency of wheat producers. Therefore, arranging education opportunities like adult education would improve technical efficiency of farmers. Previous findings (Ahmad et al., 2002; Hassan and Ahmad, 2005; Kaur et al., 2010; Sekhon et al., 2010; Wassie, 2014; Yami et al., 2013, Wudineh and Endrias, 2016) are in line with this finding.

The result of the overall sample and the Oromia IP site indicates that labor (in man days) found to affect wheat producers technical inefficiency positively and significantly at 10% level of significance each indicating that the amount of labor force beyond the required level decreases labor productivity and hence wheat output per labor force. This result has been supported by the findings of Kaur et al. (2010).

Another important result is that ownership of at least a pair of oxen significantly and negatively influenced technical inefficiency of wheat producers at 1% level of significance for the overall sample. This is an expected result especially in areas where most of farmers depend on oxen and the ownership of a pair of oxen enables farmers to plough their plot timely and at the recommended sowing date. In most areas, oxen are used for wheat production not only for ploughing but also for threshing. Therefore, policies that enable farmers to own such kind of productive assets using different methods such as arranging oxen purchase credit would have a positive effect in reducing farmers' inefficiency or enhancing their efficiency so that they can produce wheat at a maximum possible frontier using the same level of resource that they are currently using.

Access to credit in Tigray IP site was found to have a significant and negative effect on technical inefficiency or positively contributes to farmers' efficiency of wheat production as expected. The explanation for this result is that availability of credit enables farmers to purchase inputs and plant wheat within appropriate sowing dates that can positively contributes to wheat yield. This result is consistent with the finding of Ahmad et al. (2002).

As expected adoption of improved wheat variety was found to improve the efficiency of wheat producers in Ofla district of the Tigray IP site. This result has been supported by the finding of Wassie (2014). However, contrary to our expectation, adoption of improved seed negatively contributes to farmers efficiency in Amhara and SNNP region IP sites. One possible reason for the contradiction in Amhara and SNNP IP sites is that

Table 7. Coefficients for factors affecting technical inefficiency of wheat producers in SARD-SC study area disaggregated by IP sites.

Variable	Tigray	Amhara	Oromia	SNNP	Overall
Constant	-0.165	-3.309***	-2.931**	-16.485	-2.545***
Sex of head (1=Male; 0=Female)	-0.602	0.497	-0.984	6.683	-0.197
Age of HH head in years	-0.017	0.007	0.011	0.033	0.005
Education of HH head	-0.087	-0.008	-0.045	0.010	-0.072***
Labor in man equivalent	0.213	-0.051	0.175*	-0.034	0.095*
pair of or more oxen (1=Yes, 0=No)	0.089	-0.130	-0.051	0.186	-0.441***
Access to extension (1=Yes, 0=No)	-0.860	0.405	0.382	4.848	0.273
Access to credit (1=Yes, 0=No)	-0.778*	-0.040	0.182	-0.242	-0.106
Number of wheat plots	0.048	-0.069	0.018	0.078	0.047
improved seed (1=Yes, 0=No)	-0.824**	0.449*	0.383	1.971***	0.052
Area allocated to wheat (ha)	3.576	0.093	-0.322	1.433	0.312
Plot distance (minutes of walk)	0.003	0.011**	0.014***	-0.017	0.007***
Soil fertility level (1=fertile; 0=not)	-0.479	0.061	-0.885***	0.005	-0.188
Crop rotation (1=Yes and 0=No)	0.291	0.159	0.476*	-0.623	0.403***
SWC (1=Yes and 0=No)	-0.044	0.062	-	0.428	0.086
Tractor used (1=Yes , 0=No)	-	-	-1.70***	-	-1.761***
Number of observations	331	559	617	109	1616
Wald chi2	543.89	420.99	1665.04	294.30	6460.49
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000
Log likelihood	-197.96	-372.855	-170.845	-54.7644	-981.541

*, ** and *** means significant at 10, 5 and 1% level of significance, respectively. SWC: Soil and water conservation practice.

adoption of improved wheat varieties is less in both IP sites as compared to other IP sites and farmers may not be aware of some important agronomic practices such as sowing dates of newly introduced wheat varieties.

The result also demonstrates that plot distance (in walking minutes from homestead of the wheat producers) significantly and positively influenced the technical inefficiency of wheat producers of the overall sample, Amhara and Oromia IP sites at 1, 5 and 1%, respectively, indicating that nearer plots can be efficiently operated as compared to farther plots. This is an expected result as far plots require additional time to travel before actually starting the operation. The finding of Ahmad et al. (2002) is also consistent with this result.

The estimation result indicates that planting wheat on fertile soils was found to significantly improve the technical efficiency (reduces technical inefficiency) of wheat producers in Bale zone of Oromia IP site. This is an expected result as fertile soil rewards more to farmers and initiated to perform farm activities with a great motive.

Another variable that significantly influenced the technical inefficiency of wheat producers is the crop rotation practice both for the overall sample and for the Oromia IP site. The result shows that a plot on which crop rotation was practiced was positively related to technical inefficiency of wheat producers in the study area. This might be because not only crop rotation but also appropriate (usually pulses) crop rotation is more important for farmers to be technically efficient in wheat production. Therefore, besides availing improved wheat variety choice, providing appropriate alternative crop used for crop rotation would contribute to wheat production efficiency in the study area.

As expected, using tractors for cultivating wheat plots and combine harvester for harvesting and threshing influenced the technical inefficiency of wheat producers negatively and significantly at 1% level of significance in Oromia IP site (also for the overall sample due to Oromia IP site). Using tractors for land preparation and combine harvesters for harvesting and threshing enables to perform agricultural activities in a timely manner and hence increase technical efficiency of wheat producers. Therefore, arranging for easy access to tractors where there is no problem of land topography for tractors would have a positive effect on improving wheat farmers' technical efficiency and hence increases wheat yield in the study area.

Conclusion

The results indicated that the technical efficiency of wheat producers is about 77% for the overall sample but varies from IP site to IP site. The result shows that the average yield gap due to technical inefficiency of farmers ranges from 527 kg/ha (in Amhara IP site) to 845 kg/ha (in Tigray IP site) with a yield gap of 659 kg/ha for the overall sample indicating domestic wheat production could be significantly increased only by improving farmers practices with the current amount of resource they are using. The Gamma (γ) value of the overall sample is 0.59 implying 59% of the variation in wheat yield is due to the existence of technical inefficiency in the system while the rest 41% is due to the external factors out of control of the farmers.

The results indicate that expanding land would result in increasing wheat yield in Oromia but decreasing yield in Tigray in its second order. Similarly, using more oxen labor would increase wheat yield to some limit in Tigray and then decreases. However, in its second order, the yield increment continues for the overall sample. Using more labor alone as well as with an interaction with land would lead to decrease in wheat yield in SNNP while it resulted in continuously increasing wheat yield in Tigray and in the overall sample. Additional expenses on tractor use in the overall sample and its second order increases wheat yield for the overall sample and both for Oromia and overall sample, respectively while its interaction effect with land also increases wheat yield in the overall sample. The result also indicates that the coefficient of the second order of agrochemical cost increases yield in all IP sites as well as in the overall sample except SNNP IP site where it is not significant. The result shows that the interaction effect of land and agrochemicals (fertilizer, crop protection chemicals); and oxen would result in increasing wheat yield in Oromia and Tigray IP sites, respectively while the interaction effect between agrochemicals and seed increases yield in Tigray as well as in the overall sample but decreases wheat yield in Oromia. The interaction effect between agrochemicals and labor; and seed and labor decrease wheat yield in Tigray while the interaction effect between seed and labor decreases yield in SNNP. The interaction effects between seed and tractor, oxen and human labor, oxen and tractor all found to decrease wheat yield while the interaction effect between labor and tractor increases yield of the overall sample.

As a factor of inefficiency, result indicates, education, oxen ownership, credit, soil fertility, using tractor, and using improved seed (in Tigray) were found to improve technical efficiency of wheat producers either for the overall or for some regions. On the other hand, family labor (in man equivalent) negatively affect efficiency in Oromia and overall sample using improved seed (in Amhara and SNNP), plot distance and crop rotation (Oromia) were found to negatively affect technical efficiency.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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