Yield Gaps and Technical Inefficiency Factors for Major Cereal Crops in Ethiopia: Panel Stochastic Frontier Approach

Sisay Debebe[1], Endale Gebre[2], and Tadesse Kuma[3]

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Abstract

Enhancing the productivity of major cereal crops by narrowing the yield gap between achieved and potential is intrinsically linked with the improvement of the technical inefficiency of crop production. The study aims to explore yield gaps and technical inefficiency factors for major cereals (maize, wheat, tef, sorghum, and barley) using longitudinal data sets from 2007/2008 to 2020/2021 and agricultural field survey data sets from the Central Statistics Authority and other official data sources in Ethiopia. A panel stochastic frontier approach using a true fixed-effect model was applied to estimate the elasticity coefficients of production, determinants of technical inefficiency, and their scores. The result shows productivity of the major cereals steadily increasing over the last fifteen years, with a higher rate of increase from 2013/2014 onwards, particularly for maize. However, the yield increase recorded for all major crops in 2020/2021 was below average compared to achievable yield levels recorded. The elasticity coefficients estimates with respect to cultivated area, area covered with local seed, labor, chemical fertilizer, and pesticide spray had a positive and significant effect on the crop outputs, indicating the importance of these inputs to enhancing production and productivity. However, capital and local seed had significant negative effects on sorghum and maize outputs; while use of chemical fertilizer for maize output only. The level of technical efficiency (TE) of farming improved with an increase in irrigated areas,

[1] Crossponding author: sisay.debebe@aau.edu.et. College of Business and Economics, Department of Economics, Addis Ababa University, Addis Ababa, Ethiopia
[2] kedissoe@msu.edu. College of Agriculture and Natural Resources, Department of Agricultural, Food, and Resource Economics, Michigan State University, Michigan, USA
[3] kwtadesse@yahoo.com. Agriculture & Rural Development Policy Research Center, Policy Study Institute, Addis Ababa, Ethiopia

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Conflict of interest
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extension service cover, amount of rainfall, and in some agroecologies. However, TE declined in moisture-sufficient agroecology for wheat and barley. Further, a mean TE score of 82.66% for maize, 85.04% for sorghum, 60.77% for wheat, 52.65% for barley, and 88.62% for teff output indicates the existence of various levels of inefficiencies. The study recommends narrowing productivity gaps for the major cereals through improving the supply and utilization of agricultural inputs, expanding irrigation, improving access to better technology; strengthening the extension system; and strengthening the agriculture-supporting research system.

Key words: Major cereal crops, yield gap, technical inefficiency, panel stochastic frontier, true fixed effect model, Ethiopia.
JEL Classification: Q18

1. Introduction

The agriculture sector has been decisive in directing the overall path of the economy through its significant contribution to food security and serving as a source of foreign exchange with a share of 76% of merchandise exports and covering over 70% of raw material sources for domestic agro-processing industries. It also employs 65% of the labor force, provides livelihood for about 84% of the population, and contributed 32.7% of the total nation's GDP in 2019/20 (NBE, 2020). Although the Ethiopian government recognizes these facts, formulating proper strategic plans and policies is dependent on very close analysis of the characteristics and dynamics of the growth and factors affecting its performance across time.

Given its contributions to the national economy, the agriculture sector is considered as one of the major sectors driving inclusive, sustainable economic growth in the government's Ten-Year Development Plan (TYDP) to be implemented from the 2021 to 2030 periods. The plan lays out strategies for enhancing agricultural production and productivity, which include converting unutilized arable land, modernizing production systems, improving uptake of technology, expanding use of irrigation, mechanization, improving institutional support, and resilience to climate change. All these strategies are assumed to help Ethiopia realize its vision of becoming an African beacon of prosperity by 2030 (NPC, 2020).

Cereals account 65 percent of the total share of agricultural GDP and are a major source of staple food crops in the country. It leads in area planted and volume of production of grain crops (cereals, pulses, and oilseeds). During the 2020/2021 cropping season, cereals were cultivated on 10.5 million ha of land, producing 30 million tons. This represented 81.19% and 88.36% of the total area and production for all grains, respectively (CSA, 2021). Among cereals, maize, teff, wheat, barley, and sorghum are important in terms of household-level consumption and dominate the smallholder farming system in Ethiopia (Alemayehu et al., 2011; Sisay et al., 2015; Fisseha et al., 2022). In 2020/2021, the maize accounted for 34.95% (2.53 million ha), wheat 19.14% (1.9 million ha), teff 18.24% (2.93 million ha), sorghum14.96% (1.68 million ha), and barley 7.74% (0.93 million ha). In terms of productivity in 2020/21, maize national average was 41.8 ha-1, wheat (30.5 ha-1), sorghum (26.9 ha-1), barely (25.5 ha-1), and teff 18.8 ha-1. Despite the importance of these crops and efforts, the productivity of some is below-average compared to the African average (Anderson and Kay, 2010; Mann and Warner, 2015; Banchayehu et al., 2019). Previous studies on efficiency and productivity attested to poor infrastructure, inefficient marketing systems, inefficient production methods, and inaccessibility and poor use of agricultural inputs such as improved seeds, fertilizers, and agrochemicals as the main factors contributing to inefficiency and limiting crop productivity in Ethiopia (Arega and Rashid, 2005; Yu and Nin-Pratt, 2014; Sisay et al., 2015; and Yu et al., 2011). Understanding the levels of technical efficiency of crop and its determinants contributes to the optimization of limited available resources, and opportunities for minimizing the yield gaps. In addition, according to previous empirical studies such as Alemayehu (2009), Alemayehu et al (2013), and Sisay et al (2015), crop output growth in Ethiopia has primarily been due to land expansion as compared to yield growth. Despite high yield growth rates, yield levels for most crops remain rather low and have shown signs of slowing down recently. A key question is, therefore, whether the country can sustain productivity increases to achieve further agricultural transformation in the face of declining additional cultivable land and the recent decline in productivity changes.

Extensive empirical studies on TE analyses of specific crops in different parts of the country were carried out using cross-sectional data sets applying either parametric or non-parametric analytical approaches to estimate the level of TE and its determinants (Arega and Rashid, 2005; Endrias et al., 2010; Sisay et al., 2015; Abate et al., 2019; Assefa et al., 2019; Moges, 2019; Adugna et al., 2019). A parametric approach estimates the level of TE score using Stochastic Frontier

Analysis (SFA), while Data Envelopment Analysis (DEA) applies a non-parametric approach by applying either single or two-stage procedures for identifying determinants (Coelli et al., 2005). On the contrary, there are only a few empirical studies that were carried out on technical inefficiency analysis using longitudinal data sets employing single stage SFA in Ethiopia, such as Bachewe (2009) used 19942004 periods, Merie et al (2018) used 1998/1999 to 2013/2014, and Anbes (2020) used 1994-2009 periods. Tenaye (2020) observed various farm practices of smallholders, including farm size, labor, oxen, precipitation, and other inputs such as seed, fertilizer, type of farm implement, soil fertility, and financial status, can contribute to time-varying inefficiency effects. However, there are practically no specific national representative studies that take into account relatively long period data sets in Ethiopia. The use of such types of panel data sets in single stage estimation technique has the advantage of separating technical inefficiency and unobserved heterogeneity in which the error term becomes time-invariant in panel stochastic frontier analysis (Kumbhakar, 1990; Battese and Coelli, 1992; Schmidt and Sickles, 1984; Greene, 2005a and b). Furthermore, the study aids to overcoming the underlying production rigidities, thereby assisting farmers in transforming the farming system, filling knowledge gaps, and directing future necessary policy intervention in Ethiopia. Hence, this study was carried out using the parametric approach of panel stochastic frontier analysis employing true-fixed effect using national level longitudinal data from 2007/2008 to 2020/2021. The study aimed to assess the trends of production and productivity and analyze the yield gaps and factors influencing technical inefficiency of production for the five major cereal crops in Ethiopia.

2. Methodology

Data types and sources: the study employed mainly annual agricultural field survey raw data in Meher crop season outputs obtained from the Central Statistics Authority (CSA) of Ethiopia covering the period from 2007/2008 to 2020/2021. The Meher season, which runs from from June to September, is Ethiopia’s main crop-growing season accounting for 95.5 percent of total annual production. A total of 2,371 enumeration areas were included across the country, and the data were summarized for 51 crop growing zones before being merged with meteorological data with the same data reference for all periods. This dataset covered the entire rural parts of the country except for the non-sedentary population (three zones of Afar and six zones of Somali regions) and detailed agriculture information on total crop area, the volume of crop production, and yield of major crops (maize, barley, wheat, sorghum, and teff) in Ethiopia was obtained from the CSA 2006/2007 to 2010/2021 data set. Other relevant meteorological data sets (rainfall, minimum and maximum temperatures) corresponding to each year and crop growing period are obtained from the Ethiopian Meteorology Agency (EMA). Besides, secondary data was collected from the Ministry of Agriculture (MoA) of Ethiopia.

Panel stochastic frontier model specification: Following Pitt and Lee (1981), whose pioneer work of longitudinal data and sub-sequent modifications made by Schmidt and Sickles (1984), Battese and Coelli (1988), and Cornwell et al. (1990), extended the parametric approach of stochastic frontier analysis using cross-sectional data for panel data.

Assume the production frontier specified for panel data:

$$\mathrm{Y_{it}} = \mathrm{f(X_{it})_{\tau_{it}}\varepsilon_{it}} \qquad \textbf{(1)}$$

where Yit is crop output for zone i and at time t, where i $\in (1,2,3 \ldots .52)$ and $\mathrm{t} \in (2006/07 \ldots 2020/21)$ and Xit are production inputs and other factors associated with zone i at time t. τit is the TE measure, with 0 < τit < 1, and εit constitutes the stochastic nature of the frontier.

The Cobb-Douglas production function in loglinear form is specified using zone level longitudinal crop output and input data. The panel stochastic frontier model estimates the technical change of production, which is captured by time dummies from 2006/07 to 2020/21 and time-varying technical inefficiency factors.

The model has specified us;

$$\begin{aligned}&\mathrm{LnOutpu_{it}} = \beta_{0t} + \beta_{1t}\ln(\mathrm{land}) + \beta_{2t}\ln(\mathrm{labor}) + \beta_{3t}\ln(\mathrm{Capital}) + \\ &\beta_{4t}\ln(\mathrm{Fertilizer}) + \beta_{5t}\ln(\mathrm{lmproved\ seed}) + \beta_{6t}\ln(\mathrm{lacal\ seed}) + \\ &\beta_{7t}\ln(\mathrm{Pesticides}) + \sum_{t=2006/07}^{2020/21}\beta_t\,\mathrm{Year} + v_{it} + \mu_{it} \qquad \textbf{(2)}\end{aligned}$$

Where "LnOutputit" it is the natural logarithms of total crop output in zone i and at time t. All inputs variables (land, labor, capital, fertilizer, improved seed, local seed, and pesticides) and the associated parameters from β_{1t} to β_{7t} are factors of production in zone i at time t, respectively. While $v_{it} - \upsilon_{it}$ are idiosyncratic and inefficiency error term of zone i at time period t, respectively. Moreover, υ_{it} and v_{it} are assumed to be independent of each other and independent and identically distributed across observations.

Based on the above Cobb-Douglas production function in logarithmic specification, TE of zone i is defined as:

$$\tau_{it} = e^{\mu_{it}} \quad \textbf{(3)}$$

is ranked a $\mu_{N,t} \leq \ldots \leq \mu_{2,t} \leq \mu_{1,t}$ Zone N produces with maximum TE of the total sampled zone's.

$$\mu_{it} = \varphi_0 + \varphi_1(\text{Irrigation}) + \varphi_2(\text{Agriculture extension}) + \varphi_3(\text{Temperature}) + \varphi_3\ (\text{Rainfall}) + \varphi_3(\text{agroecologies}) + \delta_{it} \quad \textbf{(4)}$$

Where υ_{it} are technical inefficiency effects in the stochastic frontier model that are assumed to be independently but not identically distributed, φ_i is vector of variables which influence technical efficiencies (irrigation in hectare, agriculture extension service coverage in hectare, average temperature and rainfall during Meher cropping seasons, and agroecologies which include moisture sufficient highlands, moisture sufficient midlands, and drought prone highlands, and δ_{it} is a random variable distributed as a truncated normal distribution with zero mean and variance σ^2_{μ}, consistent with the assumption of the inefficiency terms being distributed as truncated normal distribution.

Empirical studies applied two analytical approaches for analyzing the determinants of technical inefficiency. The first approach is a two-stage estimation procedure in which the first TE scores are estimated and then, the efficiency score is taken as the dependent variable and is then, regressed on explanatory variables using separate econometrics models. This procedure has been criticized due to the difficulty of separating inefficiency from unobserved exogenous factors and hence provides biased results (Wang and Schmidt, 2002; Belotti et al., 2013).

In response to these, Battese and Coelli (1992), Kumbhakar (1990), Greene (2005a and b), and Schmidt and Sickles (1984) developed a single-stage procedure for addressing the shortcoming using simultaneous estimation techniques. In this study, true fixed effect model of Greene's was selected because the farming system encounters unmeasured exogenous factors which are inherent in agriculture (unobserved firm heterogeneity). Besides, the model also treats observed firm heterogeneity angles (Oumer et al., 2022). The use of such a model not only helped to disentangle inefficiency factors from unobserved heterogeneity, but also segregates time-invariant heterogeneity from time-varying inefficiency in panel data sets (Greene, 2005a and b).

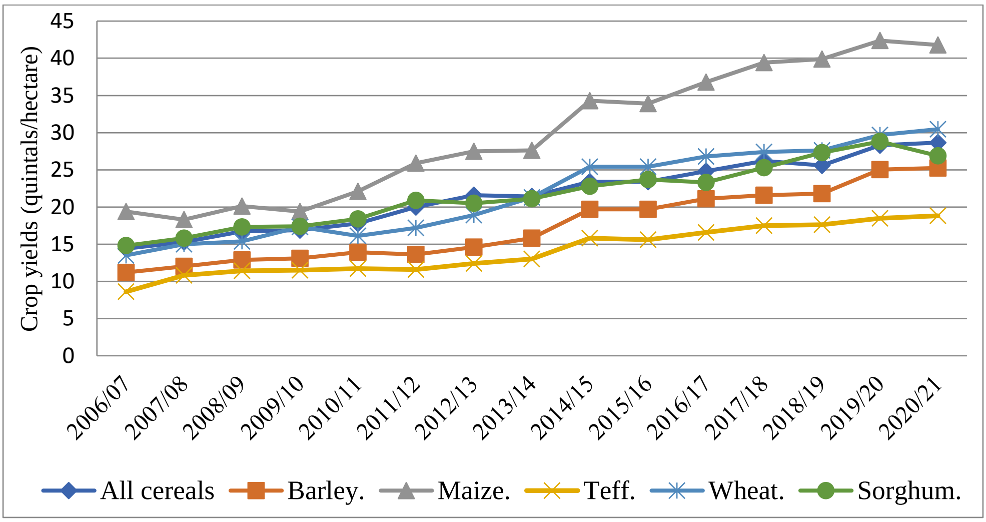
3. Results and discussions

3.1 Descriptive statistics results

3.1.1 Major cereal crops productivity trends

The period from 2007/2008 to 2020/2021 was also marked by rapid growth in crop yields (growth defined as the ratio of the value of output to the area cultivated). Figure 1 reports crop yields for the period 2006/2007 to 2020/21. Yield levels of all cereals almost doubled from 14.4 q ha-1 in 2006/2007 to 28.66 at the end of the period. Similarly, yield levels of the five important major cereal crops (maize, teff, wheat, barley, and sorghum) in 2020/2021 were more than double the yield levels in 2006/2007, with the exception of sorghum and maize in 2020/2021. Figure 1 clearly shows that the major cereal crops' productivity has steadily increased over the last fifteen years. A higher rate of 36 increase was observed for maize between 2013/2014 and 2020/2021, which shows the system has been more successful in transforming maize productivity compared with other crops (See also Annex Table 1).

Figure 1: Trends of major cereal crops



Source: Authors' computation using CSA annual reports (CSA Volume I: 2006/2007-2020/2021).

3.1. 2 Yield gap analysis results

Table 2 shows the estimation of the yield gap between the actual yields at the farmer's level and potential yields from research field trials based on reports of the Ethiopian Agricultural Research Council Secretariat (EARCS) as well as from MoA variety registry profiles. The result shows the yield increase recorded for all major crops in 2020/2021 is lower than the average achievable yield levels, indicating widespread poor new technology adoption due to weak technology availability, poor extension, poor agronomy practices, and inefficiencies in crop production (Sisay et al., 2015; Banchayehu et al., 2019). Accordingly, the average yield gap that is, the difference between actual and achievable yield is 72.87% for major cereal crops. The actual average yield is estimated at 28.64 q ha-1 while the potential yield from on-station trials is 50.4 q ha-1 which shows a considerable yield gap across the major crops. The potential yield from on-station trials is only occasionally attained at some farmers' fields, and the yield gap remains rampant. It is a potential space for pushing productivity levels further through effective technology intervention, training, and technology package scaling out. Attainment of high yield potential requires accelerated rates of genetic gain in yield-related traits and more technological inputs such as fertilizer, improved seeds, extension, and optimum management operations. Current genetic progress requires advanced techniques and increased understanding of morpho-physiological processes (such as enhanced radiation-use-efficiency, deeper root systems, optimized structural stem dray matter, increased fruiting efficacy/enhanced grain production, etc) to exploit traits either directly in breeding or through the development of high-level science-backed research such as molecular breeding, genomics, genome-editing, and fast track technology multiplication.

Table 2: Actual versus achievable yields in 2020/21

Major cereal crops	Actual yield (Q/ha)	Achievable Yield (Q/ha)	Yield gap (%)
Teff	18.82	32	70.03
Wheat	30.46	60	96.98
Maize	41.79	80	91.43
Barely	25.25	35	38.61
Sorghum	26.9	45	67.29
Average	28.64	50.40	72.87

Source: Estimated based on EARCS Technology level assessment report.

3.2 Panel stochastic frontier model results

This section briefly discusses the results of the parameter estimate of the panel stochastic frontier using a Cobb-Douglas production function in the true fixed-effect model. In the second sub-section, the results of factors affecting technical inefficiency and efficiency scores for the period from 2006/07 to 2020/2021 are presented.

The result of the parameter estimates of the panel stochastic frontier using a Cobb-Douglas production function in the true fixed-effect model is given in Table 3. Labor is among the factors that make the largest contribution to changes in the output of all major cereal crops except for sorghum and barley from 2006/2007 to 2020/2021. Labor is significant in all cereal crops except for wheat. The elasticity of output with respect to labor has positively and significantly influenced the respective outputs at an estimated elasticity value of 1.60 for maize, 0.24 for sorghum, 0.21 for barley, and 2.00 for teff crops. Labor did not affect the output of the wheat crop from 2006/2007 to 2020/2021. Further, the result implies that the contribution of labor was most important in teff followed by maize but slightly less so in sorghum and barely crops.

The elasticity of output with respect to the cultivated area is about 0.29 for sorghum and 0.26 for barley, which has positively and significantly affected output at 5 and 1 percent statistical significance levels in their respective orders.

The elasticity of output with respect to the number of livestock (oxen power) used to plough land, which is a proxy for capital, is positively and significantly influencing the respective output change at an estimated value of equal to 0.12 percent for wheat, barley, and teff crops. Such an effect is associated with the number of times the traditional oxen-power used to plough the crop land has benefited crop output, which tends to be the case in areas with lower soil fertility levels. The result shows that the contribution of the number of livestock used to plow land was almost equally important in wheat, barley, and teff and less so in sorghum. Whereas oxen power has a negative and significant influence on sorghum crop output at 1% significance levels. The negative significant effect is associated with the overuse of traditional oxen-power due to repeated ploughings with little or no tread off in crop output (Temesgen et al., 2008, 2009). Several studies (Battese and Coelli, 1995; Kumbhakar and Heshmati, 1995; Villano et al., 2015) in developing countries have reported similar negative elasticity effects of oxen power for agricultural production due possibly to overuse of the input.

The elasticity of output with respect to chemical fertilizer was about 0.07 for sorghum and 0.11 for wheat, which has positively and significantly affected output at the 1 percent level of significance. While it negatively and significantly influences the output of maize and teff crops at 1% significance levels. The plausible reason for the negative result of chemical fertilizer on output might be the inappropriate utilization of chemical fertilizer as most farmers applied less than the recommended amount for maize and less responsiveness of fertilizer for teff crops. On the other hand, the estimated elasticity of improved seed is positively and statistically significant with an elasticity value of 0.07 for wheat from 2006/2007 to 2020/2021, which indicates less contribution to changes in the output of most major cereal crops except wheat.

The elasticity of output with respect to local seed is negatively and significantly influenced with a value of 0.61 for maize and 0.84 for teff crops. However, it positively affected output in sorghum, wheat, and barley crops with an elasticity value of 0.02, 0.14, and 0.16 from 2006/2007 to 2020/2021. Moreover, the estimated elasticity of pesticide is positively and statistically significant with an elasticity value of 0.10 for barley, 0.07 for sorghum, and 0.09 for barely output, while it negatively and significantly influenced the output of the wheat crop with an elasticity of 0.20.

Estimates of time with production year using true fixed effect model results compare the aggregate production level of each period as a base category in 2006/2007. The estimated level of aggregate production was positively and statistically significant in all years, which indicates better performance of crop production while in 2015/2016 it was negatively and statistically significant, showing less performance of production for most of the major cereals output except for barely. Similarly, the level of aggregate production estimates for the maize, sorghum, wheat, and teff crops in 2016/2017 were not statistically significant, with the exception of the negative statistically significant aggregate production of the barley crop which indicates less performant aggregate production compared to the production in 2015/2016. The result might be due to the decline in area under crops in the fiscal year 2015/2016 due to the El-Nino induced drought that severely affected large parts of the crop producing areas of the country. This also had a magnitude effect on the following year despite improvements in the weather conditions, as many pockets of the low land areas had not been getting adequate rain for consecutive years. Farmers' ability to use more input and improved technologies was threatened due to the extensive El-Nino drought of 2015/2016. Moreover, the study by Ethiopian Economics Association (EEA) (2017) reports that the agriculture sector has been hit hard by the El-Nino effect in 2015/2016 and, to a lesser extent, in 2016/2017 than in any other years during the study period. As a result, food insecurity has increased and many farm households dependent on agriculture have become indebted and dependent on external assistance.

Table 3: Panel Stochastic frontier using True Fixed Effect Model result, major cereal crops- 2006 to 2021

Variables	Maize		Sorghum		Wheat		Barley		Teff	
	Coef.	St.E	Coef.	St. E	Coef.	St. E	Coef.	St. E	Coef.	St. E
Land	0.12	0.123	0.29**	0.152	0.24	0.361	0.26*	0.674	-0.01	0.142
Labor	1.60*	0.194	0.24***	0.098	0.22	0.158	0.21**	0.092	2.00*	0.117
Capital	0.19	0.080	-0.13*	0.019	0.12*	0.018	0.12*	0.145	0.12*	0.015
Fertilizer	-0.11*	0.017	0.07*	0.014	0.11*	0.026	0.11*	0.014	-0.15*	0.026
Imp. seed	0.00	0.156	-0.02	0.013	0.07*	0.018	0.02	0.090	-0.01	0.010
Local seed	-0.61*	0.312	0.22*	0.046	0.14*	0.139	0.16**	0.070	-0.84*	0.096
Pesticides	0.10*	0.008	0.07*	0.011	-0.20*	0.016	0.09*	0.009	0.03*	0.011
Year										
2007/08	0.53*	0.124	0.95*	0.137	0.68*	0.111	0.83*	0.111	).29***	0.011
2008/09	0.60*	0.121	1.00*	0.137	0.92*	0.124	1.00*	0.115	0.31*	0.115
2009/10	0.58*	0.139	1.03*	0.125	0.80*	0.109	0.81*	0.110	0.50*	0.117
2010/11	0.96*	0.147	0.88*	0.119	0.91*	0.117	0.83*	0.111	0.74*	0.111
2011/12	0.31**	0.131	1.33*	0.144	1.19*	0.344	0.68*	0.117	1.75*	0.191
2012/13	0.77*	0.143	1.07*	0.118	0.86*	0.108	0.92*	0.108	0.52*	0.106
2013/14	0.80*	0.122	0.97*	0.116	1.01*	0.109	0.94*	0.108	0.56*	0.102
2014/15	0.73*	0.132	0.85*	0.126	0.90*	0.114	0.87*	0.110	0.47*	0.170
2015/16	-1.84*	0.159	-1.30*	0.116	-1.40*	0.111	0.81*	0.011	-128*	0.155
2016/17	1.76	?	-0.13	0.167	-2.94	0.212	-0.37*	0.143	-0.26	0.170
2017/18	0.70*	0.126	0.95*	0.115	1.12*	0.280	0.94*	0.106	0.34*	0.103
2018/19	0.63*	0.133	1.13*	0.113	1.28*	0.302	1.07*	0.113	0.39*	0.104
2019/20	0.75*	0.121	1.42*	0.136	1.24*	0.299	1.27*	0.113	0.52*	0.121
2020/21	1.01*	0.152	1.42*	0.119	1.62*	0.361	1.22*	0.111	0.63*	0.108
Sigma_u	4.35*	0.582	4.00*	0.627	4.24*	1.573	2.82*	0.964	5.05*	0.706
Sigma_v	0.37**	0.190	0.18*	0.012	0.12*	0.014	0.16*	0.011	0.35*	0.028
Lambda	11.66*	0.718	22.76*	0.626	34.20*	1.571	21.89	0.611	14.62*	0.705
# Observation	729		724		728		730		726	
Wald chi2	1.64*		8966.93*		8338.25*		1338.45*		23931.89*	

Note: *, ** and *** represents statistically significant at 1%, 5% and 10% levels, respectively.

Source: Computed based on national data accessed from CSA for the period 2006/2007- 2020/2021

The parameter estimates of the inefficiency using single-stage estimation in the panel stochastic frontier true fixed-effect model result are given in Table 4. The result implies that technical inefficiency declines with an increase in irrigated areas for all major cereal crops. Similarly, the technical inefficiency declined with the proportion of area cultivated supported with agriculture extension services, with an estimated coefficient value of 3.8 for maize, 1.93 for sorghum, 1.53 for wheat, 1.51 for barley, and 6.13 for teff cereal crops from 2006/2007 to 2020/2021. Moreover, the technical inefficiency declines with an increase in the availability of adequate rainfall during Meher cropping seasons, with an estimated coefficient of 0.03 for sorghum, 0.02 for wheat, 0.03 for barley, and 0.11 for teff crops from 2006/07 to 2020/2021.

The estimated coefficients of agro-ecological dummies imply that technical inefficiency declines within high moisture-availability with an estimated coefficient of 8.98 for maize and 13.21 for teff. However, it increased, with an estimated coefficient value of 4.4 for wheat and 2.88 for barley crops. The possible reason is that the level of moisture sufficiency in agroecology was not as useful for wheat and barley crops as it was for maize and wheat. Technical inefficiency declines within the moisture-sufficient midland with an estimated coefficient of 2.90 for sorghum crops and 3.77 for barley crops. Crops like tef suffer from end-of-season stress due to traditional late sowing related to seed size and agronomy, which exposes the crop to stress from insufficient moisture during the grain filling period as well as the common practice of sowing tef in moisture deficit areas and poor soils. Similarly, technical inefficiency declined in drought-prone highland areas with an estimated coefficient of 0.08 for the wheat crop from 2006/2007 to 2020/2021.

Table 4: Panel Stochastic frontier using True Fixed Effect inefficiency factors, 2006 to 2021

Variables	Maize		Sorghum		Wheat		Barley		Teff	
	Coef.	St.E	Coef.	St. E	Coef.	St. E	Coef.	St. E	Coef.	St. E
Irrigation	-3.35**	1.707	-3.08*	0.641	-2.47*	0.782	-2.11*	0.539	-1.92**	1.026
Extension	-3.80*	0.721	-1.93*	0.256	-1.53*	0.383	-1.51*	0.194	-6.13*	1.551
Rain fall	-0.03	0.217	-0.03*	0.010	-0.02***	0.011	-0.03**	0.011	-0.11*	0.040
Temperature	0.15	0.110	0.04	0.047	-0.03	0.057	0.02	0.037	0.06	0.133
Agroecology										
Agro. 02	-8.98*	2.247	1.42	1.378	4.40*	1.658	2.88**	1.291	-13.21*	4.697
Agro.03	4.12		-2.90**	1.406	-1.23	1.655	-3.77*	1.429	-0.27*	3.577
Agro.04	2.86		-0.63	1.12	-0.08***	1.312	-0.32	1.091	2.29	3.508
_Cons	0.74	3.436	1.78*	1.573	0.815	1.569	1.31	1.383	3.45	4.449
T*echnical Efficiency scores*										
Mean (%)	82.66		85.04		60.77		52.65		88.62	
St.dev.	2.007		1.762		1.507		1.319		2.138	

Note: *, ** and *** represents statistically significant at 1%, 5% and 10% levels, respectively.

Agro. 02: Moisture sufficient highland; Agro. 03: Moisture sufficient midland; Agro. 04: Drought prone highland

Source: Computed based on national data accessed from CSA and EMA for the period 2006/2007- 2020/2021

Table 4 also explains the panel stochastic frontier true fixed-effect model result on TE scores for major cereal crops. The result implies that an overall national average level of TE from 2006/2007 to 2020/2021 was 85.79%, where the overall level of TE of major cereal crops including teff (88.62%), sorghum (85.04%), maize (82.66%), wheat (60.77%), for barely (52.65%), for and for which shows more variation in the level of inefficiency of crops from 2006/07 to 2020/21 periods in Ethiopia. This implies that crop output can be increased by approximately 45.36% for barley, 16.42% for maize, 17.08% for sorghum, 10.4% for teff, and 38.03% for wheat without the use of additional inputs or the application of modern agricultural technologies.

4. Conclusion and Recommendations

This study assessed the trends of production and productivity and analyzed the yield gaps and factors influencing technical inefficiency of production using panel data from 2007/2008 to 2019/2020 for the five major cereal crops, maize, wheat, tef, sorghum, and barley in Ethiopia. Using agricultural field survey and meteorology data sets for each major cereal crop, a panel stochastic frontier approach with a true fixed-effect model employing the Cobb-Douglas production function was used to estimate the elasticity coefficient. Moreover, the level of TE score and its determinants were estimated using a single-stage procedure and disentangled inefficiency factors from unobserved heterogeneity.

The result of descriptive statistics shows the productivity of the major cereal crops steadily increasing over the last fifteen years, with a higher rate of increase from 2013/2014 onwards for maize, which shows the agriculture input supply and extension system is more effective for maize compared to others. However, the yield increase recorded for all major crops in 2020/2021 is below average and has shown signs of slowing down recently compared to achievable yield levels. Minimization of the yield gap requires accelerated rates of genetic gain in yield-related traits and sustainable use of more and better inputs in the years to come. Factors that contribute to inefficiencies and widening yield gaps include pushing production of crops to marginal growing conditions (soil, temperature and moisture), weak input supply, poor agronomy practices, weak extension system, and inefficiency in crop production.

The results of a true-fixed panel model indicate that the elasticity of output with respect to cultivated area has a positive and significant effect on sorghum and barley outputs. Similarly, the elasticity of output with respect to employed labor has a positive and significant effect on maize, sorghum, barley, and teff outputs. The results also showed that the elasticity of output with respect to the use of improved seed has a positive and significant effect on wheat output. With the exception of maize and teff outputs, the elasticity of output with respect to the use of chemical fertilizer has a positive and significant effect on sorghum, wheat, and barley outputs. The elasticity of output with respect to capital has a positive effect on wheat and barley outputs, while it negatively affects sorghum output. The elasticity of output with respect to local seed has a positive effect on sorghum, wheat, and barley outputs, while it negatively affects maize output. The elasticity of output with respect to the use of pesticides has a positive effect on maize, sorghum, and barley outputs, while it negatively affects wheat output.

The results of technical inefficiency of farming using single-stage estimation show that TE improved with the increase of irrigated area for maize, sorghum, wheat, barley, and teff outputs. TE improved with the improvement of the use of agricultural extension packages or with improvement in agricultural extension services for all major cereal outputs. Similarly, it increased due to the increment of rainfall during the Meher cropping season for maize and teff outputs but declined for wheat and barley outputs. Moreover, as compared with other agro-ecology areas, the TE of sorghum output improved in moisture-sufficient area, and for sorghum, barley, and teff outputs in moisture-sufficient midlands, and only wheat outputs in drought-prone highlands areas of the country.

The average TE was 85.79% of the overall level TE of major cereal crops, suggesting the current level of output could be increased by an average of 14.21 % of all major cereal crops without additional use of inputs or modern agricultural technologies injected but only by working on inefficiency factors.

Looking ahead, no crop area expansion will be possible except in the irrigable lowlands. Instead, increases in production of a crop will need to be driven by increases in productivity, or else be expected to come at the expense of production of other crops. With climate change, such factors as drought, global warming, and disease pressure are expected to strongly challenge yield increases in many crops. The role of agricultural R andD in innovate approaches with new technologies and production techniques will continue to be increasingly important on crop production. Therefore, narrowing the productivity gaps through various interventions will have a determinant effect in crop output efficiency and growth in Ethiopia:

- Increasing supply and proper utilization of agriculture production inputs; the wise use of limited land (consolidation of land), deployment of the labor force, strengthening the existing agricultural extension service providers in such a way that addresses the needs of crop types, and providing targeted affordable credit service for dissemination and proper utilization of productivity-enhancing agricultural technologies such as improved seed, chemical fertilizer, and pesticides.

- Expanding irrigated areas including small scale irrigation schemes and rectifying the shortage of rainfall by allocating an adequate public budget for the construction of irrigation schemes,
- Strengthening the existing agricultural extension service providers in such a way that address the specific needs of crops types by providing short and long-term training, upgrading educational qualification, and providing non-overlapping and congruent responsibilities to extension workers. This also includes broadening the knowledge base to bring a paradigm shift in agri-water use and improve irrigation agronomy for various crops and agroecology.
- Strengthening the research system with advanced methods and facilities is extremely mandatory to take research to the next higher and challenging yield levels that require the application of advanced science and technology (e.g. biotechnology) and more innovative approaches as it becomes tougher going upwards for higher TE to provide the necessary backstopping for the future more productive and responsive agriculture.

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AnnexTable 1: Crop yields (quintals/ha)

Crops	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	% growth/ year
Cereals	14.4	15.3	16.7	16.9	17.8	20.0	21.6	21.4	23.4	23.4	24.8	26.2	25.6	28.32	28.66	7.26
Barley	11.2	12.0	12.9	13.1	13.9	13.6	14.6	15.8	19.7	19.7	21.1	21.6	21.8	25.01	25.25	8.12
Maize	19.4	18.3	20.1	19.4	22.1	25.9	27.5	27.6	34.3	33.9	36.8	39.4	39.9	42.37	41.79	8.78
Teff	8.6	10.8	11.4	11.5	11.7	11.6	12.4	13.0	15.8	15.6	16.6	17.5	17.6	18.50	18.82	8.38
Wheat	13.5	15.0	15.4	17.3	16.1	17.2	18.9	21.3	25.4	25.4	26.8	27.4	27.6	29.70	30.46	9.56
Sorghum	14.8	15.8	17.3	17.4	18.4	20.9	20.5	21.1	22.8	23.7	23.3	25.3	27.3	28.80	26.90	7.09