Agricultural Technological Change and Technical Efficiency of Crop Production in Ethiopia

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Abstract

Proper utilization of agricultural technology and enhancing the technical efficiency of crop production are key factors for agricultural output growth in Ethiopia. However, the lack of studies that assess the broad set of agricultural technological change and efficiency of multiple crop production together using longitudinal datasets poses major challenges in identifying crop production impediments in Ethiopia. This study explores agricultural technological changes (specifically fertilizer, improved seed, pesticides, irrigation, and extension services) and the factors contributing to technical inefficiency in crop production in Ethiopia. National-level representative longitudinal data sets from 2004/05 to 2018/19 were obtained from the Central Statistics Authority and the Ethiopian Meteorology Agency-(EMA) as data sources in Ethiopia. A panel stochastic frontier model using a true fixed-effect econometrics model was applied to estimate the coefficients of the elasticity production coefficients, identify technical inefficiency factors, and estimate the level of technical efficiency scores for multiple aggregate crops at the national and regional levels. This study assessed the trends in agricultural technology use from 2004/05 to 2018/19 in Ethiopia. In response to the increased utilization of land, labor and inputs such as chemical fertilizer, pesticides, improved seeds and improved practices through expanded extension coverage, the use of irrigation, and the availability of rainfall and temperature, good progress in agricultural production and productivity was observed from 2004/05 to 2018/19. However, there is a less adequate supply of agricultural production input

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technologies and the intensive utilization of irrigation is highly insufficient. Furthermore, the elasticity coefficient estimates with respect to labor, cultivated area, chemical fertilizer, and pesticide have positive and significant effects on crop output, indicating the importance of these inputs. However, the use of capital and local seed had negative and statistically significant impacts on crop output from 2004/05 to 2018/19 in different regions of Ethiopia. The overall technical efficiency value of 73.84% at the national level shows room for further increasing yield using existing technologies by working on inefficiency factors. Additionally, the room for further boosting yield is wide and differs across major regions in Ethiopia. The future crop output growth will be driven by a combination of enhancing the use of agriculture technologies and efficiency of crop production through promoting the use of suitable, reliable and affordable modern agriculture technologies, revitalized agricultural advisory services, mechanization services, providing targeted affordable credit services, land consolidation by cluster farming, deployment of a labor force, and the intensive use of irrigation systems over the coming years.

Keywords: Agriculture technologies, technical inefficiency, Panel stochastic frontier, Ethiopia.

JEL Classification: Q13, Q33, O4, O47

1. Introduction

Agriculture is the most dominant sector and plays a crucial role in the life and livelihood of most Ethiopians, accounting for 32.4% of the country's GDP, 75% of export earnings, 73% of employment opportunities, and 70% of sources of raw materials for agro-processing industries. It also serves as a market for industrial outputs. The country has favorable agro-ecological zones suitable for growing a wide range of temperature and tropical cereals, root crops, oil crops, pulses, fruits and vegetables (NBE, 2022; MOA, 2020). Recognizing this, the Ethiopian government has given attention to and adopted a broad agricultural-led industrial development policy and strategy to guide rural and agricultural development. It has also implemented successive development plans policies, strategies and programs over the last few years to enhance the performance of the agriculture sector and contribute to food security, poverty reduction and the production of exportable agricultural products.

The agriculture sector is considered one of the major sectors driving growth in the current ten-year development plan for the period from 2020/21 to 2029/30. The plan for the agriculture sector focuses on freeing agriculture from rain dependence, increasing the use of agricultural mechanization services; encouraging contract farming, deploying land consolidation through a cluster approach, developing livestock, animal feed and animal health, paying attention to horticulture development including in urban areas (irrigation and urban farming), leveraging private sector participation, providing all-round institutional implementation capacity, and implementing a climate-resilient sustainable agricultural development system. All of these are assumed to help Ethiopia realize its vision of becoming a lower-middle-income country by 2025 and aspire to become an African beacon of prosperity by 2030 (PDC, 2020).

However, agriculture in Ethiopia is characterized by low input-low output, largely based on smallholder producers, low-tech, and rain-fed crop production systems for the majority of farmers. The low technology uptake by the sector has retarded the growth of agricultural productivity, limited the total volume of production and even threatened national food security for decades (Zerssa et al., 2021). The slow pace of transitioning from low to high productivity in agriculture has led to a lack of market-led agriculture to expansion and has seriously challenged the pace towards successful agricultural transformation. Due to over-reliance on rain-fed production by smallholding farmers, the use of traditional subsistence production methods, and the lack of irrigation and modern water management systems, the agriculture sector is still struggling with cycles of drought. The frequent droughts and climate change are not only affecting the rural poor but also posing further challenges to the country's economy (Getachew, 2018 and 2020). Additionally, the sector's poor performance can be attributed to limited private sector investment in recent years (Sisay and Semeneh, 2022). Consequently, a significant number of people are suffering from malnutrition and depend on daily assistance and developmental safety nets.

Previous studies on agricultural technological changes in Ethiopia such as Admassie and Ayele (2010), Aynalem et al. (2018), Shita et al. (2018), Gebru et al. (2021), and Diro et al. (2022) attempted to examine the determinants, challenges and opportunities at the national level. There are also some other micro-level studies that extensively addressed the effect of agricultural technology on welfare outcomes over recent decades in Ethiopia. For example, Bekele et al. (2014) assessed the effect of agricultural technology on food security, Mesele et al. (2022) studied its impact on food consumption expenditure, Wordofa et al. (2021) analyzed its effect on household income, Ayenew et al. (2020) and Araya and Lee (2022) investigated its effect on the welfare of smallholder farmers, Shita et al. (2020) examined its effect on income inequality, and Biru et al. (2020), and Sebsibie et al. (2015) explored its effect on poverty and vulnerability of smallholders in Ethiopia. Further, there are only few empirical studies on efficiency analysis of crops using longitudinal datasets at the national level. These studies were conducted by Bachewe (2009 and 2012) and Bachewe et al., (2011 and 2015), Sisay et al. 2022). On the contrary, there is limited number of studies in Ethiopia that assess the broad set of agricultural technologies change and efficiency of crop production together using longitudinal datasets. Although, there are a few empirical studies such as Abebayehu et al. (2019) and Arega and Manfred (2005) that were conducted using cross-sectional datasets in different parts of the country, which are pertinent for developing policy recommendations for specific study areas. However, these types of studies may provide less assistance in developing strategies and policy implications for improving agricultural production at the national and/or regional levels for multiple cropping systems in Ethiopia. Hence, this study aims to assess the status and performance of a broader set of agricultural technological changes, including technology adoption (such as chemical fertilizers, improved seeds, and pesticides) and recommended agronomic or farm practices (such as the use of irrigation and extension services). The study also aims to estimate the technical efficiency score and its determinants of aggregate crops using longitudinal zone-level data sets from 2004/05 to 2018/19 at the national and regional levels in Ethiopia.

2. Methods

Data types and sources: The study employed mainly secondary data obtained from the Central Statistics Authority (CSA) of Ethiopia covering the period from 2004/05 to 2018/19. The dataset included all rural areas of the country except for the non-sedentary population, and provided detailed information on agriculture, such as total crop area, crop production volume, and the use of agricultural technologies such as chemical fertilizer, improved seed, pesticides, extension services, and irrigation (CSA, 2004/05 to 2018/19).

In order to select the sample, a two-stage sampling technique using a combination of stratified and cluster sample designs was implemented in the rural parts of the country. The Annual Agricultural Sample Survey covered the entire rural parts of the country. Census Enumeration Areas (EAs) were taken to be the primary sampling units and the secondary sampling units were agricultural households. EAs from each stratum were selected systematically using the probability proportional to size sampling technique, with size being the number of agricultural households selected based on the Ethiopian population and housing census cartographic frame. Using the fresh list of households prepared at the beginning of the survey, 20 agricultural households within each sample EA were selected using systematic random sampling technique. Each EA was further classified into three agro-ecologies namely “kolla”, “Dega” and “Weyna Dega” for Tigray, Amhara, Oromiya and SNNPs regions. A total of 2,371 EAs (85.66%) in 52 zones throughout the regions were included in the study. The sample survey was conducted based on 20 agricultural households selected from each EA. A total of 47,420 agricultural households were covered by the survey. The raw datasets of the Agricultural Sample Survey were obtained from the Central Statistics Authority (CSA) of Ethiopia.

The dataset covered detailed agricultural information on cereals, pulses and oilseeds, as well as the most grown vegetables, root crops (including tuber crops), and fruits. However, it does not include spices, herbs, Enset, coffee, sugarcane, cotton and other medicinal and essential oil products (CSA, 2004/05 to 2018/19). Additionally, the study also utilized meteorological datasets, such as rainfall, minimum and maximum, temperatures, corresponding to each year and crop growing period obtained from the Ethiopian Meteorology Agency (EMA). The Agricultural Sample Survey datasets of CSA for each EAs were merged with the meteorology datasets by estimating the average meteorological datasets of the Meher season. The Meher season is the main crop growing period in Ethiopia, which is linked to the long rainy season from June to September. It accounts for 95.5 percent of the total annual production (CSA, 2004/05 to 2018/19). A total of 47,420 agricultural households were included in 2,371 EAs Agriculture Sample Survey datasets, which were then combined again into the 52 zones across the country. These datasets were then merged with meteorological data for all periods. The analysis is carried out at the zone-level using panel datasets that cover a time period from 2004/05 to 2018/19.

Methods of data analysis

In order to analyze agricultural technological change and farm practices (chemical fertilizers, improved seed, pesticides, irrigation, extension services) simple descriptive statistics were applied. Meanwhile, stochastic frontier panel using the True Random Effects (TRE) econometrics model was applied to estimate the coefficients of the production function, as well as the level of technical inefficiency and its factors.

The TRE model of Green's uses nationally representative longitudinal panel data set from 2004/2005 to 2018/2019, both at the national level and separately for the Amhara, Oromia, South Nation Nationality and People (SNNP), and Tigray regions of Ethiopia. In contrast to the Random Effect (RE) model of Battese and Coelli (1992), the TRE model captures time-varying technical inefficiency resulting from time-invariant unobserved firm heterogeneity which is inherent in farming (Green 2005 a, b). The Cobb-Douglas production function is specified in log-linear form using zone-level longitudinal crop output and inputs data. The True-Fixed Effect model has been specified for us:

$$lnY_{it} = (\alpha + \theta_i) + lnf(x_{it}; \beta) + v_{it} - \mu_{it} \qquad \textbf{(1)}$$

$$v_{it} \sim N(0, \delta_v^2), \theta_{it} \sim N(0, \delta_\theta^2), \mu_{it} \sim N(0, \mu_\mu^2), \epsilon_{it} = v_{it} - \mu_{it} \qquad \textbf{(2)}$$

Where lnY_{it} is the logarithm of output for farm household in period from 2004/5 to 2018/19 of aggregate crops (cereals, pulse, oilseeds, vegetables, and root crops in kg) for zone i and at time t, where i ϵ (1, 2, 3, ….52) in period t ϵ (2004/5 to 2018/19); x_{it} is the matrix of logarithm of production inputs (such as land in hectare, labor in number of holders, capital (number of livestock used for plowing the land) in oxen days, fertilizer in kilogram, improved seed in kilogram, local seed in kilogram, and pesticides in liter) for zone i and at time t, where i ϵ (1, 2, 3, ….52) in period t ϵ (2004/5 to 2018/19); v_{it} is a random error that is normally distributed with mean zero and variance of δ_v^2; $\mu_{it}$is a non-negative inefficiency term that changes over time; the term θ_i is random term that is time-invariant and normally distributed with mean zero and variance of δ_θ^2 accounts unobserved firm heterogeneity; ϵ_{it} is composite error term; and α is a common intercept for all the production units; β are technology parameters to be estimated.

Based on the above Cobb-Douglas production function in logarithmic specification, a one-step procedure was applied to identify determinants of technical inefficiency in which estimated simultaneously along with production function (Green 2005 a, b), TE of zone i is defined as:

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

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.

$$\mu_{it} = \varphi_0 + lnf(x_{it}; \varphi) + \delta_{it} \qquad \textbf{(4)}$$

Where υ_{it} are technical inefficiency effects in the stochastic frontier model that are assumed to be independently but not identically distributed, φ is vector of variables which influence technical efficiencies (irrigation in hectare, agriculture extension service coverage in hectare, average temperature in degrees Celsius (centigrade), and amount of precipitation of rainfall during Meher cropping seasons measured using a rain gauge, and agro-ecologies (measured as dummy variables; 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_{μ}^{2}, consistent with the assumption of the inefficiency terms being distributed as truncated normal distribution.

3. Result and Discussions

This section begins with an assessment of agricultural technological changes, followed by an assessment of the inefficiency of crop production and its determinants over a long period.

3.1. Agricultural Technological Changes

Following the definition of technology adoption by Rogers (1962) and Feder et al. (1985), agricultural technology adoption refers to the use of agricultural technologies such as improved seeds, fertilizers and pesticides. Meanwhile, the use of recommended agronomic or farm practices, such as irrigation and extension services for crop production, helps farmers with the adoption of agricultural technology. In this study, an agricultural technological change refers to the uses of agricultural technologies, recommended agronomic practices and the technical efficiency of production in agriculture. Agricultural technological change might refer to the replacement of traditional varieties with improved cultivars and the increased use of chemical fertilizers pesticides, often aided by better agronomic practices through improved irrigation and agricultural extension services.

Improved seeds

A greater number of improved varieties have been developed and released in Ethiopia in the period since 2004/05-2018/19 than at any other time. Improved variety release has been particularly dynamic for maize, barley and wheat. Table 1 shows using CSA statistics, how the share of farmers that reported using improved seeds in the cereal domain has increased over the last decade.

One of the most successful dissemination of improved seed technologies can be seen in maize production, where the adoptions of improved seeds have grown fourfold from 12% to close to 40%. The participation of private seed sector in hybrid technology is relatively very high. However, the above-mentioned rate based on the CSA mostly underestimates the actual use of improved seeds at the national level. This has been recently documented through a DNA fingerprinting-based study by Moti et al. (2020). The CSA survey methods do not sufficiently capture whether farmers are or were re-using (recycling) improved seeds in subsequent generations. Improved seed adoption monitored through DNA fingerprinting in wheat and maize in Ethiopia indicated that a higher proportion of farmers use improved varieties and the proportion of the area covered with improved seeds is much higher than what the CSA data shows (Moti et al., 2020). DNA fingerprinting analysis showed a much wider adoption in wheat, ranging from 61-73% in sampled areas (Moti et al., 2020). The result shows that apart from wheat, the improvement and dissemination of released varieties of indigenous cereals like teff is remarkably higher than what is shown in Table 1.

Table 1: Proportion of improved seed applying farm holders (%)

Crop	2004/05	2009/10	2013/14	2016/17	2017/18
Barley	0.8	1.2	0.8	1.4	1.5
Maize	11.6	15.7	27.6	34.0	36.9
Sorghum	0.9	1.8	0.4	0.4	1.3
Tef	1.0	2.4	4.6	4.3	2.0
Wheat	4.5	4.1	7.7	1.5	4.6
Cereals	10.1	11.3	21.5	27.3	23.7

Source: CSA, Agricultural Sample Surveys, 2004/05-2018/19

While the overall adoption rates of varieties are low in most crops, there have been significant improvements in maize, wheat, and teff over the last decade. The share of cereal producers using improved varieties increased from 10 percent of cereal producers in 2004/5 to 24 percent in 2017/18 (Table 1). This increase seems to be driven primarily by the rapid adoption of improved seeds in maize, wheat, and teff with the private sector playing a role, such as Corteva (Pioneer Seed) in maize.

Consequently, the use of improved seed appears to be higher than what has been previously reported by CSA or other sources in Ethiopia.

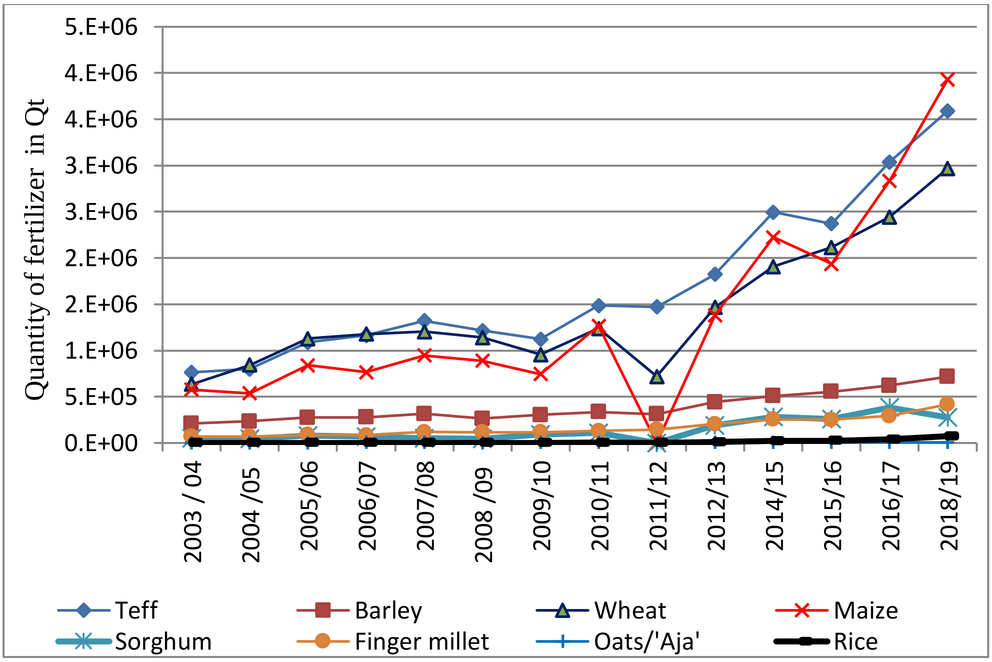
Chemical fertilizers

Soil fertility is among the key constraints of agricultural productivity in Ethiopia due to severe soil degradation caused by natural and man-made factors. As a result, the use of chemical fertilizer has become increasingly critical in order to maintain production. Therefore, chemical fertilizer has gained growing importance as one of the major agricultural inputs that help farmers increase their land productivity. In the highlands, where fertility depletion is particularly high in farmlands due to reduced organic matter, low nutrient content and degraded soil structure resulting from intensive and continuous cultivation for centuries, the situation is in degraded, deforested land, leading to further aggravated soil and nutrient losses. This calls for a more programmatic, science-based fertilizer input intervention program. However, most smallholder farmers in the highland still use lower rates of chemical fertilizer compared to rates even in sub-Saharan Africa. Urea and DAP (Di-Ammonium Phosphate) are the dominant fertilizer sources used in Ethiopia, based on some experimental results in the past (Tilahun et al., 2022). However, the use of nitrogen (N) and phosphorous (P) has not changed over decades despite considerable changes in soil conditions in the highland areas across the country. The agricultural crop area planted with cereals and applied with fertilizer has grown from 2.7 to 7.8 million hectares from 2004/2005 to 2018/2019, a nearly three-fold growth in fifteen years in cereal production. This figure for multiple crops shows a growth from 4.6 to 9.6 million hectares (CSA report, 2018/19). The declining soil fertility and increasing need for chemical fertilizer might be a clear indication of growing sustainability challenges in the near future that need to be taken into account.

The use of chemical fertilizers like potassium, sulfur and zinc has shown a considerable response in different parts of the country (MoA, 2020). This has triggered a national-scale use of blended fertilizer to supply deficient nutrients based on soil fertility mapping done by the same institutions. Fertilizers help to increase yield and product quality but require prior knowledge of soil nutrient information. The increase in crop productivity observed in the country is believed to have been positively impacted by the increased use of chemical fertilizer, in conjunction with improved seed, and increased pesticide use (Robe and Sisay 2021).

As a land-augmenting input, intensive use of fertilizer is supposed to substitute for land as a capital input that smallholders do not have in abundance, by increasing yields per hectare. Therefore, it also provides an option for declining farm sizes in the highland areas of the country. Farmers combine land with labor, seed, fertilizer, and other inputs to produce food and other commodities. Therefore, fertilizers and seeds are important means towards the intensification of production, and smallholders appear to use both more intensively than large-scale farmers (Gebeyanesh et al., 2021).

Figure 1: Trends in quantity of fertilizer use (in quintals) for specific Cereals (from 2003/2004-2018/2019)



Due partly to the attention given to cereal production to achieve food security in Ethiopia, most fertilizer use has been focused on cereals (Sisay et al. 2022; Endale et al., 2023). According to the CSA repot in 2004/05, 2.1 million holders (46 percent) growing cereals used fertilizer, and this number increased to 5.5 million holders (76 percent) in 2013/2014. The cereal area applied with fertilizer nearly doubled during the same period from 2.7 to 5.2 million hectares or increased from 36 to 53 percent of the total cereal area. In 2014/2015 about 82 percent of smallholders applied fertilizer and showed a decline thereafter until 2017/2018. Fertilizer use on other crops has also shown significant increases over the same period. The intensity of fertilizer uses in cereals has also increased from 92 kg/ha in 2003/04 to 122kg/ha in 2013/14.

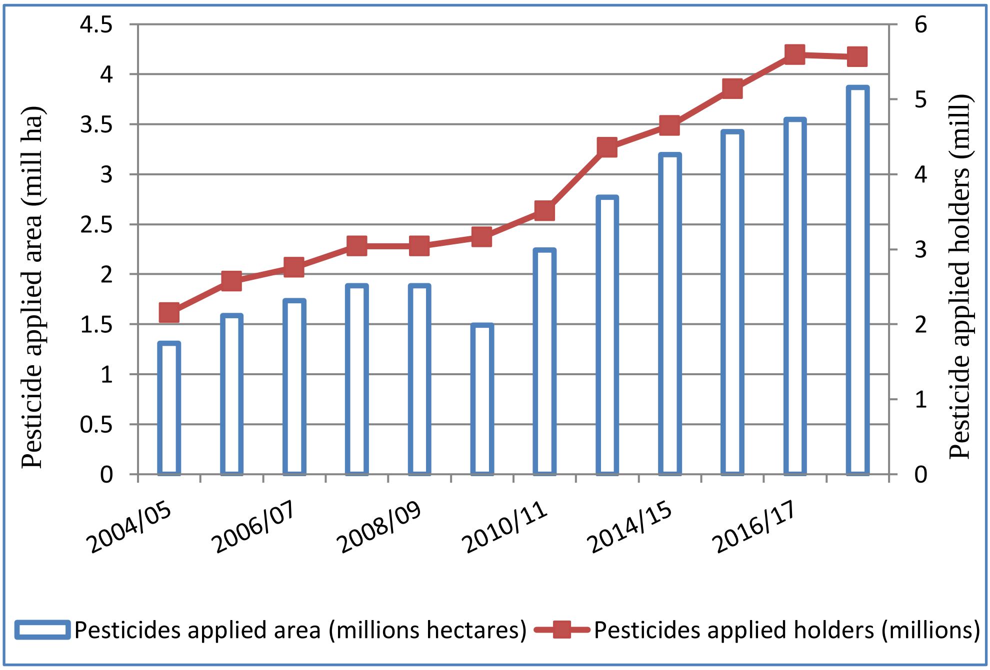
For wheat, maize and tef, fertilizer use has dramatically increased since 2011/2012 while for sorghum, rice and finger millet the increment is far lower (Figure 1). Grain price, crop response to added fertilizer and lower acreage in the case of millet are some of the factors affecting the wider use of fertilizer.

Pesticides

In areas where crop damages caused by pests and weeds are high and difficult to counteract by human labor, the application of pesticides is indispensable. According to CSA data, there has been a considerable increase in the number of farmers who have applied pesticides over time (Figure 2). In 2004/2005, 13 percent of the crop area was exposed to pesticides and this number rose to 24 percent in 2016/2017. Particularly, the proportion of the total area on which pesticides were applied grew rapidly during 2009/10 - 2016/17. A slight decline in the imported pesticide volume was observed in 2018/2019 compared to the previous year.

Figure 2: Area under pesticide application and total number of holders applied (in millions)

There was a two-fold increase in pesticide application in multiple crops as shown in Table 2. However, the increase in pulses, oilseeds and horticultural crops was more dramatic than in cereals. The commercial nature of these crops has been



very encouraging for farmers to intensify inputs to maximize yield per unit area. Nevertheless, the intensity of research is more focused on cereals and the development of production packages for these groups of crops is rather low in comparison. This has slowed down production intensification and growth in productivity over the period. The area where pesticides were applied for the above groups grew from 26,000 hectares (7%) in 2004/05 to 352,936 hectares (42%) of the total holder area in 2018/2019, representing greater than 13-fold increase. However, compared to the total holder area under these crops, the amount pesticide applied shows the low level of input being used in Ethiopia.

Table 2: Area growth under pesticide application of the 2004/05 and 2018/19

Groups of Commodities	Total holder area (ha)		Area (ha) under pesticides		Proportion (%) of the total	
	2004/05	2018/19	2004/05	2018/19	2004/05	2018/19
Multiple crops	10,887,953	14,966,916	1,312,290	3,870,302	12.05	25.86
Cereals	7,633,802	10,358,891	1,278,139	3,440,647	16.74	33.21
Pulses	1,349,116	1,618,095	10,268	241,718	0.76	14.94
Oilseeds	824,430	745,191	8,757	71,370	1.06	9.58
Vegetables	94,334	240,464	2,188	*	2.32	
Root crops	156,205	229,627	4,735	39,848	3.03	17.35

Source: Computed based on CSA annual reports (2004/05–20118/19)

Irrigation

The use of irrigation is very important for a farming system that is fully dependent on less reliable rain every year. Ethiopia's failure to sustain food security in the past many decades seems to be its strategic failure to develop its irrigation sector. Irrigated areas did not grow significantly in the study period and cereals have been the least benefiting sector. Given the frequent El Niño-caused droughts, which make Ethiopia's agriculture vulnerable to these various shocks and often make it a highly risky business for millions of smallholders, investment in and development of knowledge-based irrigation use is becoming extremely compelling in Ethiopia (Mekonen, 2021). The country has rich unexploited water resources that can be tapped for this purpose.

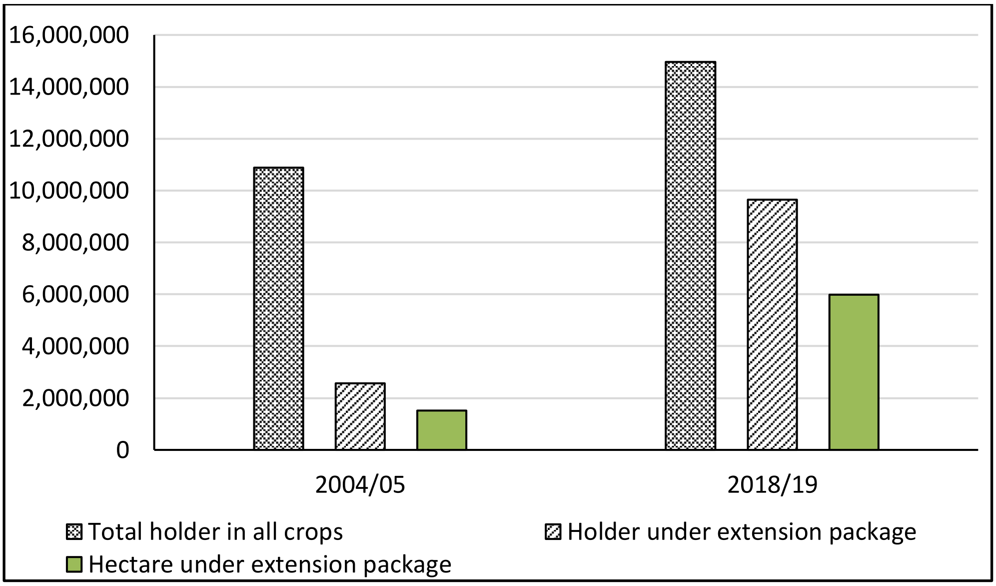
Future agricultural growth is impossible to comprehend without judicious development and more intensive use of irrigation systems. It needs to pay special attention to expanding irrigation development and continuously improving its use to ensure sustainable and rapid agricultural growth. Several big rivers that originate from the highlands cross the terrain and lowland plains and flow and cross the borders without use. Ethiopia's total potential irrigable area is estimated to be around 3.7 to 4.2 million hectares (Awulachew et al. 2007). However, some estimates show quite a higher value i.e. up to 40 million hectares if slopes up to 30 percent are irrigated using modern systems. The country has developed only about 4% of its traditional potential estimate (of 3.7 million ha). Even the performance of the existing irrigation schemes is on average 30% below their design estimation. This indicates that both inadequate irrigation infrastructure and operational problems are major features of the Small-Scale Irrigation Development (SSID) in the country. Because of such a low level of irrigated agriculture development, Ethiopia could not maximize the benefits for its sustainable development.

Irrigation schemes developed with good planning are expected to be fully operational and impactful. In the country many irrigation systems have been built in the past and more are currently being developed. Although it is difficult to obtain precise data, most of the developed systems do not meet the required quality of service. Evidence from the survey indicates that irrigated farms, which are supposed to be in service, have only been able to cultivate a fraction of the expected irrigable land. For example, in the Awash basin, about 741 irrigation schemes are cultivating an average of 79% of their total irrigable land. Among the factors causing the underperformance are, damage to the irrigation systems (42.5%), a low level of river flow and use water shortages due to use by farmers in the upper course of the river (24%). ; Both problems contribute to the underperformance (28%) and for unknown reasons (13%) (PSI, 2019). According to a survey of 75 irrigation schemes in the Oromia region, 65% are able to cultivate their land using the irrigation water.

Agricultural extension

Since 1992, the GoE has made significant investments in an agricultural extension system that focuses on providing of advisory and training services through frontline development agents (DAs). As a result, Ethiopia has achieved one of the highest DA-to-farmer ratios in the world, estimated at approximately 1 DA for every 476 farmers or 21 DAs per 10,000 farmers. This ratio is significantly higher than in other countries such as China, Indonesia, and Tanzania, where the ratio is 16, 6, and 4, respectively (PSI, 2019).

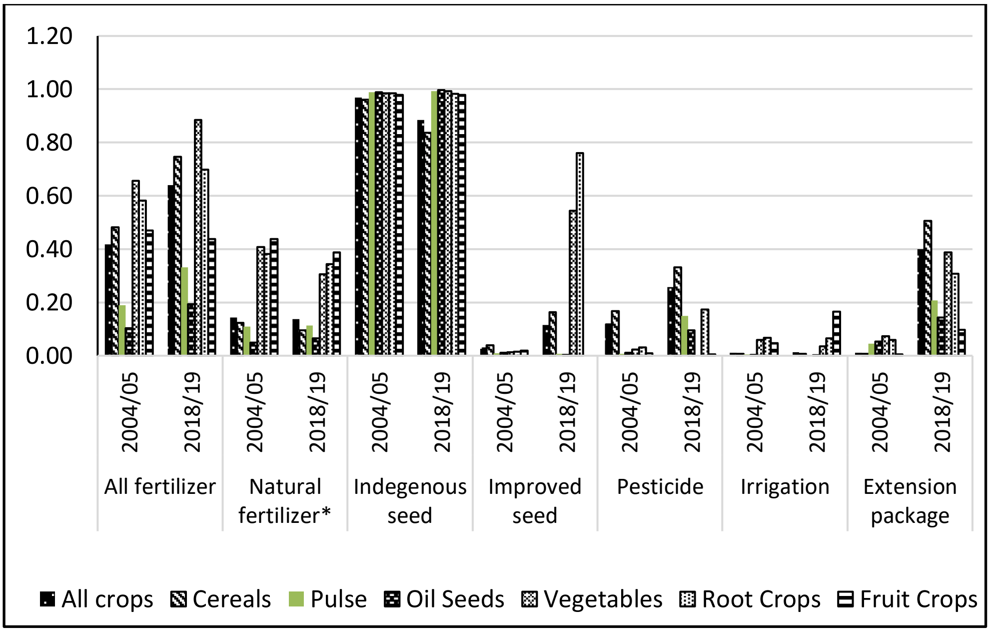
Figure 3: Area covered through the public extension system (package), 2004/2005 and 2018/2019



Source: CSA data (CSA, 2005b–2018/2019).

CSA data allow us to track changes in the number of farmers with access to extension advice. Figure 3 clearly confirms the increasing presence of extension agents over the last decade. The number of smallholders who reported using different crop extension packages quadrupled from 2.6 million in 2004/2005 to 9.6 million in 2018/2019, an average growth of 18.4 percent each year from 24.0 percent of all smallholders to 65 percent. In the same period, the cultivated areas covered by the extension package program increased from 1.5 million hectares in 2004/2005 to 5.98 million hectares in 2018/2019. Figure 4 shows further detailed dynamics of changes that took place in the crop sector. Among the different package components, the least change observed was in irrigation application, which showed no improvement at all except in root crops from about 5 percent in 2004/2005 to 17 percent in 2018/2019. On the other hand, a huge increase was recorded in comparison for improved seed use in 2018/2019 from 4 percent to 16 percent on average for multiple crops. Highest increment was recorded in root (74 %) and fruit crops (54%) from one and two percent respectively. Fertilizer use has increased from 48 percent in 2004/2005 to 64 percent in 2018/2019.

Figure 4: Progress of various recommended agronomic practices covered (hectares), 2004/2005 and 2018/2019



For wheat, maize and teff, fertilizer use has dramatically increased since 2011/2012 while for sorghum, rice and finger millet the increment is far lower (Figure 1). Grain price, crop response to added fertilizer and lower acreage in the case of millet are some of the factors that might contribute to the wider utilization of fertilizer.

3.2. Efficiency Analysis of Crop Across Regions

In the first part, the stochastic frontier is estimated using a Panel fixed-effect model with zone-level data from 2004/2005 to 2018/2019. In the subsequent section, the results of parametric stochastic frontier analysis of aggregate crops across regions are presented focusing on determinants of inefficiencies, and technical efficiency score.

Parameter estimates of the Stochastic Frontier Panel True-Fixed Effect Model applying a Cobb-Douglas production function is given in Table 3. The results indicate that growth in the size of cultivated land and labor are among the factors that make the largest contribution to changes in output at the national level. Land is significant in all specifications except in the Tigray region. The elasticity of output with respect to the cultivated area is about 0.28 at the national level. The contribution of the cultivated area was most important in SNNP (0.43), slightly less so in Oromia (0.26), and the Amhara region (0.21). Similarly, the elasticity of output with respect to labor is about 0.41 at the national level. Labor's contribution was most important in Tigray (0.78) and SNNP (0.51), and slightly less so in the Oromia region (0.06). Labor did not affect output in Amhara. Moreover, the estimated elasticity of labor at the national level from 2004/2005 to 2018/2019 in the aggregate production function indicates that a one percent increase in the labor force and cultivated land accounted for 0.41 percent and 0.28 percent increase in agricultural output growth, respectively. Both results are statistically significant at a one present significance level.

The elasticity of output with respect to chemical fertilizer is about 0.02 at the national level, which is the third largest estimate next to land. While the use of chemical fertilizer positively and significantly influences the total output in all regions at a 1% significance level, but negatively and significantly affects the total output at a 5 % statistical significance level in the SNNP region. The elasticity of chemical fertilizer is positive and relatively higher in Oromia (0.64) and relatively lower importance in both Tigray (0.20) and Amhara (0.19) regions. While it negatively contributed to the SNNP region with an elasticity value of 0.04. The plausible explanation for the negative results in SNNP might be due to the problem related to the untimely distribution of fertilizer to the farmer and/or less responsiveness of land to fertilizer in the region. Moreover, the estimated elasticity of chemical fertilizer in the aggregate production function result implies that one percent increase area covered by chemical fertilizer was accounted by 0.02 percent increase in output growth at the national level from 2004/2005 to 2018/2019 and the result is statistically significant at five present significance levels.

Table 3: Stochastic Frontier using true-fixed panel model result for multiple crops, across regions- 2004-2019

Variables in log	**National**		**Amhara**		**Oromia**		**SNNP**		**Tigray**	
	Coef.	**St.E**	**Coef.**	**St. E**	**Coef.**	**St. E**	**Coef.**	**St. E**	**Coef.**	**St. E**
Land	0.28*	0.025	0.21*	0.064	0.26*	0.041	0.43*	0.050	0.12	0.087
Labor	1.41*	0.040	0.19	0.200	1.06*	0.819	1.51*	0.064	0.78*	0.158
Capital	-0.03*	0.021	0.21	0.211	0.04	0.024	-0.19*	0.047	0.47**	0.276
Fertilizer	0.02**	0.010	0.19*	0.267	0.64*	0.178	-0.04**	0.017	0.20*	0.031
Imp. seed	-0.02***	0.009	-0.02	0.018	0.01	0.015	-0.02	0.016	0.03	0.024
Local seed	-0.12*	0.011	0.12*	0.025	-0.08*	0.018	-0.21*	0.022	-0.09**	0.043
Pesticides	0.02*	0.007	0.08*	0.016	0.01	0.017	-0.02**	0.012	0.04**	0.021
Constant	0.18	0.046	-4.86***	2.696	3.06	7.55	3.58*	0.132	6.34*	0.829
Sigma_u	14.59*	2.084	0.09	0.119	4.91**	2.316	5.20*	0.396	23.86**	9.889
Sigma_v	1.09*	0.025	1.54*	0.053	1.18*	0.48	0.91*	0.050	0.71*	0.061
Lambada	13.34*	2.086	40.06	0.117	4.15***	2.315	6.59*	0.408	33.66*	9.890
# Observation	3642		750		1230		1287		375	
Wald chi2	4257.67*		644.35*		583.75*		3316.25*		521.49*	

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

Source: CSA, 2004/05 to 2018/19

The elasticity of output with respect to the area covered by pesticide is positive 0.02 at the national level, which is the third larger estimate with equal value to chemical fertilizer. While the area covered by pesticide positively and significantly influences the output change in Amhara and Tigray regions. However, it negatively affects and significantly output change in the SNNP region with an elasticity value of 0.02 from 2004/2005 to 2018/2019. The elasticity of pesticide is positive in Amhara (0.08) and Tigray (0.04) regions. Meanwhile, it has a negative effect in the SNNP region (0.02) which might be due to the unaffordable higher price, untimely distribution of pesticide, and less responsiveness of land to pesticide in the region. Moreover, the estimated elasticity of pesticide in the aggregate production function result implies that a one percent increase in the area covered by pesticide accounted for a 0.02 percent increase in output growth at the national level from 2004/2005 to 2018/2019, and the result is statistically significant at a one percent significance level.

The elasticity of output with respect to capital which is proxied by the number of livestock used to plow the land is about 0.03 at the national-level from 2004/2005 to 2018/2019. The effect of change in the number of livestock used to plow land has a negative and statistically significant effect on output at the national level (0.03) and in the SNNP region (0.19) from 2004/2005 to 2018/2019. However, it has a positive and significant effect on the output in the Tigray region (0.47). The negative result might indicate that there is less contribution from draft cattle to the plowing power and hence seems a less tendency to use tractors and other divisible technologies from 2004/05 to 2018/2019. The elasticity of output with respect to the area covered by improved seed is negative and statistically significant with a value of 0.02 at the national level. Similarly, the elasticity of output with respect to the area covered by local seed is negative at National, SNNP, Tigray, and Oromia regions with elasticity values of 0.12, 0.21, 0.09, and 0.08, respectively. However, it has a positive effect with an elasticity value of 0.12 in the Amhara region from 2004/05 to 2018/19. The negative results might be due to problems related to timely supply, low utilization of recommended packages as most farmers use improved varieties by mixing with local varieties, and untimely distribution of improved seed in the regions.

Determinants of inefficiency factors across regions

Parameter estimates of the inefficiency of an equation using the single-stage estimation technique in Cobb-Douglas production function estimated by the Stochastic Frontier Panel-Fixed Effect model result is given in Table 4. The result implies that inefficiency declines with an increase in irrigated areas with an estimated coefficient of 6.85 and 0.19 both at the national and Amhara region from 2004/2005 to 2018/2019, respectively. However, the proportion of area curved by irrigation does not affect technical efficiency in other regions. Besides, none of the inefficiency factors used in the equation for Tigray explains technical inefficiency. Similarly, with an estimated coefficient of 7.39, inefficiency declined with the proportion of area cultivated using the Ministry of Agriculture's recommended agricultural extension services at the national level from 2004/2005 to 2018/2019. This result was also found in SNNP with an estimated coefficient of 1.05 implying that efficiency improved with more users of agricultural advisory services. Similarly, the inefficiency declines with an increase in the average temperature during Mehir cropping seasons with an estimated coefficient of 1.38 at the national level and 0.21 in SNNP from 2004/2005 to 2018/2019. Moreover, the finding further attested the availabilities of adequate rainfall during Mehir cropping season's decreases inefficiency with an estimated coefficient of 0.42 at national and with a value of 0.06 in the SNNP region from 2004/2005 to 2018/2019. Besides, none of the inefficiency factors associated with various agro-ecologies used in the equation affected technical inefficiency variation both at the national level and in all regions from 2004/2005 to 2018/2019.

The result in Table 4 shows that the overall level of Technical Efficiency (TE) for multiple crops is 73.84%. For Amhara, it is 78.42%, for Oromia, it is 79.64%, for SNNP, it is 63.34%, and for Tigray, it is 61.84%. These figures indicate the existence of substantial levels of inefficiencies from 2004/05 to 2018/19. The results suggest that there is potential for further increasing the output level without the need for additional inputs or the use of modern agricultural technologies by addressing the inefficiency factors.

Table 4: Stochastic Frontier using true-fixed panel model inefficiency factors for multiple crops, 2004-2019.

Variables	National		Amhara		Oromia		SNNP		Tigray	
	Coef.	**St.E**	**Coef.**	**St. E**	**Coef.**	**St. E**	**Coef.**	**St. E**	**Coef.**	**St. E**
Irrigation	-6.85**	2.715	-0.19**	0.087	-2.21	1.929	0.24	0.395	5.82	9.396
Extension	-7.39*	2.435	0.04	0.045	-1.371	1.212	-1.05*	0.299	-26.83	23.30
Rain fall	0.42*	0.134	0.0001	0.002	0.047	0.048	0.06*	0.016	1.02	0.997
Temp.	-1.38*	0.510	-0.0001	0.003	-0.252	0.311	-0.21*	0.065	-0.46	0.785
Agro.02	-16.20	29.54	0.66	-	-10.09	9.042	-198.94	329.03	-	-
Agro.03	10.35	27.56	-	-	3.67	12.52	2.72	4.07	-	-
Agro.04	42.40	30.48	-		-	-	-		-192.11	242.86
_Cons	-147.08*	51.015	-0.69*	0.171	-3.06	7.549	-20.21	5.171	-124.57	227.75
TE	0.7384		0.7842		0.7964		0.6334		0.6184	

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

Agro.02 – moisture sufficient highlands, Agro.03- moisture sufficient midlands & Agro.04- drought prone highlands

Source: CSA, 2004/05 to 2018/19

4. Conclusion and Policy Implications

This study assessed the trends of agricultural technological change in the form of chemical fertilizer, improved seed, pesticides, irrigation, extension services, and analyzed the factors influencing technical inefficiency of crop production using panel data from 2004/2005 to 2018/2019 in Ethiopia. Panel stochastic frontier using a true fixed-effect econometrics model employing Cobb-Douglas production function was applied to estimate the elasticity coefficients of production, determinants of technical inefficiency, and their scores using national-level agricultural field survey and meteorology data sets in four major-crop producing regions of Ethiopia.

In response to increased utilization of land, labor and inputs such as chemical fertilizer, pesticides and improved seeds, as well as improved practices through expanded extension coverage, good progress in agricultural production was observed from 2004/05 to 2018/19. However, agricultural technological change through agricultural investment has not been well coordinated and the institutional support system to appraise commercial farmers and ensure sustainability was nearly lacking. Besides, the adequate supply of agricultural production input technologies (such as good quality seeds and chemical fertilizer) and their timely distribution in different regions, as well as intensive use of irrigation and extension services, have contributed to lower productivity over the last years. The desired changes in the use of improved technologies and farm practices need to be critically viewed from a sustainability point of view in order to maintain the increasing productivity trend of farm lands in the most exploited part of agricultural lands in the country.

The results of the true-fixed panel econometrics model imply that the elasticity of output with respect to cultivated area, labor, area covered by chemical fertilizer and pesticides has a positive and statistically significant effect on crop output. This indicates the importance of these inputs in crop production. However, the elasticity of output with respect to capital (proxied by the number of livestock used to plow the land) and local seed has a negative and statistically significant effect on crop output at the national level from 2004/05 to 2018/19. Similarly, the result of disaggregation of the national data across regions implies that the elasticity of all inputs with respect to crop output is different in the Amhara, Oromia, SNNPR, and Tigray regions. The important policy implication of this finding is that policies aimed at enhancing agricultural crop output at the national and regional levels should be specific in order to enhance the proper utilization of production input resources. This can be done through, the wise use of limited land, deployment of the labor force, and providing targeted affordable credit service for adopting technologies that facilitate divisible farming at the national and Tigray region levels. It is also important to strengthen the dissemination of improved seeds, as the local seed is often used in combination with improved seed, which hinders the proper utilization of improved seed both at the national and Oromia, SNNP and Tigray regions. Additionally, the use of pesticide and soil deficient chemical fertilizer input utilization should be particularly addressed at SNNP region.

The overall technical efficiency of crop output value at the national level shows that there is room for further increase using existing technologies and addressing inefficiency factors. Furthermore, there is significant potential to boost yield, with TE values ranging between 62% and 80% across different regions. Technical efficiency has been observed to improve with the expansion of irrigated areas and the implementation of agriculture extension packages or services. However, it can decline due to insufficient rainfall and higher temperatures during cropping seasons.

The future expansion of crop areas in the highlands is already severely limited and boosting crop production will only be driven by a combination of both enhancing the use of agricultural technological change and efficiency of crop production. The use of suitable, reliable and affordable modern agriculture technologies such as more intensive use of improved varieties and high-quality seeds replacing traditional varieties and optimizing crop management through aggressive promotion of packages for fertilizers with better and efficient water management and irrigation is required. Besides, the providing revitalized agricultural extension and advisory services and mechanization services. In this regard, the role of agricultural Research and Development (R&D) and innovative systems and advanced sciences for faster information generation, retrieval, and analysis will be critically important. Research skills and facilities that use and integrate state-of-the-art technologies are becoming increasingly important for the development of superior varieties (in terms of yield and quality) and promotion of hybrid technologies in future agricultural development in Ethiopia.

Policy that aims to enhance agricultural crop output at national and regional levels should be specific to enhance the proper utilization of production input resources. This can be done through, the wise use of limited land through cluster farming (land consolidation) and expansion of mechanization service, deployment of labor force, and providing targeted affordable credit service for adopting production technologies at national and Tigray region. It is also important to strengthen the dissemination of improved seed since the local seed is applied in combination with improved seed that hinders the proper utilization of improved seed both at national and Oromia, SNNP and Tigray regions. Additionally, the use of pesticide and soil deficient chemical fertilizer inputs should be particularly addressed at SNNP region.

The results of determinants of technical inefficiency show that technical efficiency improved with the increase in irrigated area and improvements in the agriculture extension package or agriculture extension services. It also improved with an increase of the average temperature during Mehir cropping seasons. However, technical efficiency declines due to a lack of adequate rainfall during Mehir cropping seasons at the national level. Similarly, the regional disaggregated model also yielded similar results in Amhara and SNNP regions. The key policy implication therefore is that expanding irrigated areas and rectifying the shortage of rainfall by allocating an adequate public budget for the construction of irrigation schemes, strengthening the existing agricultural extension service provision through providing short and long-term training, upgrading education, and providing non-overlapping and congruent responsibilities to extension workers.

Abbreviations

CSA: Central Statistical Authority; DAP: Di-Ammonium Phosphate; EMA Ethiopian Meteorology

Agency: GDP: Growth Domestic Project; MOA: Ministry of Agriculture; NBE: National Bank of Ethiopia; PDC: Plan Development Commission; PSI: Policy Study Institute; RE: Random Effect; SNNP: South Nation Nationality and People; SSID: Small-Scale Irrigation Development; TRE True Random Effects.

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